Journal of Advances in Science and Technology
Vol. 16, Issue No. 1, March-2019, ISSN 2230-9659

A Review on Modal Analysis of a Cable-Stayed Bridge

Vipul Shinde[1]* Dr. J. N. Vyas[2]

[1] Mahakal Institute of Technology and Management

[2] Professor, Department of Civil Engineering, M.I.T.M., Ujjain (MP)

Abstract* – *Cable-stayed bridges with longer spans and slender girder sections are constantly built around the world, pushing their analysis and design to their extremes. Therefore having a good understanding of the structure's behavior is of vital importance. Several methodologies exist when it comes to model the cables of cable-stayed bridges accounting for the cable's sag effect. These methodologies can be classified in two distinct groups. The first is based on polynomial interpolation of the shape and displacement field of the cable such as the methodology of straight bar with equivalent elasticity modulus and the derivation of Isoparametric cable formulation. The second group of methodologies uses analytical functions that define the cable shape under certain load conditions such as the elastic Catenary. There are several applications that require accurate finite element models such as: earthquake or wind simulations, health monitoring and structural control.

Keywords: Cable-Stayed Bridge; Finite Element Method; Modal Analysis; Vibration Characteristics

---------------------------♦-----------------------------

1. INTRODUCTION

Cable-stayed bridges have increased in quality throughout last decades, because of their beauty and highly efficient use of the materials (Karoumi 1999). Cable-stayed bridges with longer spans and slender beam sections are constantly designed, pushing the analysis and style of those structures to its limits. These structures also are exposed to dynamic event like hurricanes, earthquakes, and cable galloping (or excessive vibrations created by lightweight rain wind) the rise in cable spans and also the exposure to those structures to dynamic loads considerably will increase the importance of getting an honest understanding of the dynamic behavior of the structure. as an example, although cable stayed bridges have an inherent sensible seismic performance; these kinds of structures have shown to be damaged by seismic movements like the case of the Gi-Lu Bridge in Taiwan (Chadwell et al. 2002, Chang Jiang et al. 2004). One amongst the challenges found in modeling cable-stayed bridges is their geometrical nonlinear behavior. This behavior in the main comes from 3 sources: cable sag impact, PΔ effect (beam-column effect) and huge displacements effect. During this thesis all 3 sources of nonlinearity are accounted. The sag impact is considered by the cable models; the P-Δ impact is accounted by using stability factors that affect the stiffness of the columns and beams as a relying upon the top moments and axial load (Shantaram G. and Ekhande 1989), and therefore the massive displacements impact is considered by the cables formulations. Though each supply of geometrical nonlinearities are thought-about within the numerical models, these models don't essentially behave because the real structures. this can be due not only to the problem of capturing the nonlinear behavior of the structure however as a result of finite component models are typically developed supported idealizations of actual structures. Therefore, modeling these structures because some challenges to the engineer like the determination of the amount of discretization, determination of support conditions, section and material parameters. so as to work out an honest finite component is important to develop an honest understanding of the behavior of the designed structure and an honest understanding of the finite components offered to model the structure.

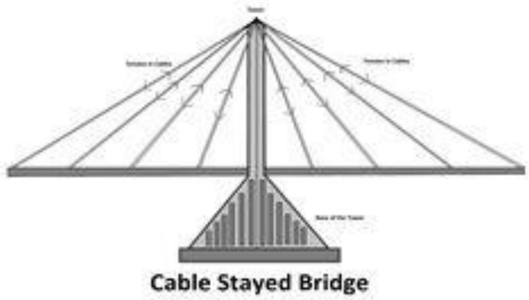

Fig.1 Cable Stayed Bridge

The study of the dynamic behavior of the structure are often accomplished by identifying the dynamic characteristics of the structure (i.e. natural frequencies, mode shapes, damping rations and transfer functions) supported information capture from the bridge. Many strategies are presently offered for modal identification for instance; Ren et al. (2005) known the natural frequencies of the Qingzhou cable-stayed bridge in Fuzhou, China, using the height Peaking technique. Chang et al. (2001) have known the natural frequencies and damping ratios, of the Kap Shui Mun cable-stayed bridge in port, China, using a Peak Peaking technique and an ARMA model. The study of the characteristics of different finite elements can be performed by numerical simulations and by comparing the results of these numerical simulations to data obtained from the real structure.

2. LITERATURE SURVEY

(Wei, Cheng and Li, 2012) the area FEM model of cable-stayed bridge is established, and modal analysis is distributed for the cable-stayed bridge. The results are used because the basic information of the bridge on numerous complex dynamic response analyses, long-term health monitoring and state assessment. The strategy of the cable- stayed bridge FEM models institution will give a reference for similar structure modelling, and therefore the analysis results will give a helpful reference for different cable-stayed bridges safety style. The bridge tower and therefore the beam are compression members. Once taking into account nonlinear effects, the stiffness of the members can reduce, the deflections are larger and frequencies are reduced. What’s a lot of, buckling might seem. Of these conditions would like take into account. The leads to this paper are supported the initial style FEM model. Therefore, the finite part model must be valid and corrected within the future.

(Cable and Shear, 2019) the symmetrical cable-stayed bridge is analyzed for 6 completely different shapes of pylons on SAP 2000 software for dead and moving live loads. It will be all over from the above study that “H shape” is that the best possible pylon shapes for symmetrical cable-stayed bridges. The bridges with this form showed flexible characteristic having a lesser fundamental that is advantageous. Also, it's been found from the analysis that having varied cable areas in numerous planes is advantageous because it reduces the nonlinear behavior of the deck, conjointly increasing the cable tensile force ensuring efficient utilization of cable strength. Within the boundary conditions, it had been all over that having each hinged conditions is that the additional appropriate one, because it reduces compression in deck thereby reducing nonlinear behavior of the deck. within the unsymmetrical cable-stayed bridges, it will be con- cluded that “H shape” and “inverted Y shape” are additional appropriate.

(Shi and Ran, 2018) the concrete creep calculation model suggested by Chinese, European, american and Japanese codes is combined with the author's previous analysis results, The deflection calculation of a single tower cable stayed bridge with single cable plane and a Extradosed cable-stayed bridge is carried out, and the following conclusions are obtained:

1) In the operation stage, the final deformation value caused by the creep effect of concrete is smaller, which is about 2cm. It can be seen that the later creep part is smaller than that of the same span continuous rigid frame bridge when the camber of the single-tower Extradosed Cable-stayed Bridge with single plane is set up.

2) The deflection caused by creep decreases with the increase of environmental humidity; If the humidity is large, the camber will be smaller, and the camber will be increased when the humidity is small.

3) By comparing the model analysis found that the current standard of 04 Chinese calculated envelope the most value in the middle is not visible, concrete creep effect in the Extradosed cable- stayed bridge is not clear, according to the 04 standard setting camber is the most conservative, the design can be appropriately improved.

4) The calculation difference of each model increases with the decrease of humidity, and the camber of each model is different in the drying environment. Therefore, the more dry area, the more important the choice of concrete creep calculation model.

(Abass, Hammoudi and Mahmood, 2018) this research, a 3D cable-stayed bridge was modeled using Ansys 15.0 software, and an earthquake inserted longitudinally and laterally for beam and link element type cables without damping, with two vertical dampers, and with four inclined dampers using different values of damping coefficient. The results showed that four inclined dampers had a clear effect on the beam element type cables of cable-stayed bridges, and that dampers with damping coefficient 75,000 N.m/s had more effect on bridges those with other damping coefficient values. The response of the deck to earthquakes with and without damping was discussed in terms of three spans. The results showed that the effects of damping systems depended on the type of dampers (damping coefficient value), direction of dampers (vertical or inclined) and the position of dampers (between deck and tower, in anchorage, and in cables). In addition, modelling of the bridge was discussed in terms of the element types of cables. The results showed that dampers have more effect on beam element type cables than link element type cables. These factors have a clear effect on cable-stayed bridges in terms of earthquake damping.

(Javanmardi et al., 2018) investigated the seismic performance of an existing steel cable-stayed bridge retro- fitted with LRBs below bi-directional ground motions. the most objective was to find the most adequate seismic retrofit configuration for the cable-stayed bridge to enhance its longitudinal and cross seismic performance. In line with this purpose, a three-dimensional finite component model of the bridge was created and analyzed through the nonlinear time-history analysis to evaluate every retrofitting configuration. The difference within the elevation of the abutments and sources of nonlinearity of the cable-stayed bridge were taken into consideration throughout the analysis. From the numerical analyses, the results of the implementation of the seismic isolation system in every retrofitting case of the cable-stayed bridge LED to the subsequent conclusions:

- The base isolation retrofitting prevented the damage and failure within the tower and prevented the incidence of damage concentration within the cable-stayed bridge. It additionally reduced the trans- mission of seismic forces from the substructure to the structure.

- The base isolation system at the tower base and therefore the deck-tower connection increased the flexibility of the bridge within the longitudinal direction whereas the use of the base isolators at the end supports increased the flexibility of the bridge within the transverse direction, and, hence, decreased the longitudinal and transverse evoked seismic forces, severally.

(Shi and Cheng, 2018) Combining with the engineering example of 2X175m Extra dosed cable-stayed bridge, the simulation analysis of cantilever construction of the bridge is mainly done. The parameter selection, model establishment, construction stage division and operation result analysis of the construction simulation for the. Extra dosed cable-stayed bridge is expounded. The theoretical basis is provided to ensure the linear shape of the bridge. And stress of the bridge, and provide reliable technical guarantee for the safety construction of the bridge.

(Study et al., 2017) an automated OMA algorithm using the SSI-Cov method was presented. Based on the ideas of implementing clustering approaches to automatically clear the stabilization diagram, this algorithm incorporates the concept of MEL as a new criterion for the initial k-means clustering and introduces a novel threshold for the hierarchical clustering process. Accurate and robust modal identification results are obtained when this automated OMA algorithm is applied to a cable-stayed bridge structure. The superiority of the proposed threshold over the old threshold was validated, and it was demon- strated that the new threshold can result in successful modal identification regardless of the system order considered. The method was also proved to provide consistent identification results using nearly one month of data from this bridge. High MAC values (>0.9) were observed between the identified modes from different data sets. The issue of missed identification was extensively investigated, and it was realized that although the excitation level during ambient vibration is insufficient to produce reasonably strong vibration, the estimation process is more likely to fail to extract all of the modes, particularly the higher modes. This automated algorithm is proved to generate results with comparable accuracy to the corresponding results from expertise manual analysis, and it is recommended as an OMA frame- work for testing the full-scale bridge and building structures.

(Mohammed et al., 2017) Non-destructive monitoring technologies are essential method to evaluate bridges structures. The study adopted finite element analysis to assess the dynamic behavior of Penang (I) bridge. The analytical modal analysis was allotted to see 15 frequencies and therefore the associated mode shapes of the structure at dead load state. The results show the dominated modes were lateral and vertical bending modes, in addition to the longitudinal and torsion modes due to natural vibration. From the nature of modes vibration, critical grid points were identified at the bridge members. In corresponding to these grid points locations, sensor placements were proposed accordingly. These locations were at 220.0m, 144.5m, 121.5m, 119.9m grid points at the end side spans; 112.5m grid point at towers areas; 16.0m, 4.0m at main span and 0.0 m middle main span of each side of the bridge. Meanwhile, at the towers member, grid points of 86m, 82.2m, 78.0m at the pylons and 35.6m, 21.6 m at the piers. Finally, the grid points influenced by the vibration were at end side spans cables coded as E12, E11, E10 and M12, M11, M10 at the main spans. Thus, based on the analysis conducted and discussion of the findings above, the study recommends 66 locations of sensors for Penang (I) bridge.

3. DESCRIPTION OF CABLE STAYED BRIDGES

Cable stayed bridges are indeterminate structures. The structure behaves as a continual beam elastically supported by the cables, that are connected to at least one or 2 towers. The structural system consists of 3 main structural sub-systems: Stiffening beam, tower, and inclined cables. The interrelation of those elements makes the structural behaviour of cable stayed bridges efficient for long-span structures, additionally to providing an aesthetic pleasant resolution.

The cable-stayed system has become a really effective and economical system throughout the last century. It's principally wont to cover massive spans. The event of this structural system is because of advances in materials, engineering analysis and style, and construction methodology. The structural elements of a cable-stayed system behave within the following manner: The stiffening beam transmits the load to the tower through the cables that are continuously in tension. The stiffening beam is subjected to bending and axial loading. The tower transmits the load to the muse below in the main axial action. The planning of cable-stayed bridges, compared with the traditional bridges, is controlled by the development sequence, and therefore the construction hundreds tend to be the dominant style loading.

3.1 Cable types

Different types of cables are utilized in cable-stayed bridges; their kind and configuration depend upon the method individual wires are assembled. The steel used for the cables is stronger than standard steel. A strand is usually composed of seven wires, helically shaped around a middle wire; the wire diameter is between three and seven millimeter. The strands are closely packed along and usually finite with a helical strand.

Cables are the most necessary parts in cable-stayed bridges; they carry the load from the structure to the tower and to the stay cable anchorages. Additionally to high durability, they have to even have high fatigue resistance and corrosion protection.

Cables are classified in step with the subsequent descriptions:

1. Helically-wound galvanized strands.

   Ultimate Tensile Stress σ_u =670 MPa

   Young Modulus E = 165 000 MPa

2. Parallel wire strands.

   Ultimate Tensile Stress σ_u =1860 MPa

   Young Modulus E = 190 000 MPa

3. Strands of parallel wire cables.

   Ultimate Tensile Stress σ_u =1 600 Mpa

   Young Modulus E = 200 000 MPa

4. Locked coil strands.

   Ultimate Tensile Stress σ_u =1500 MPa

   Young Modulus E = 170 000 MPa

3.2 Deck Types

The most common deck type for these bridges is the orthotropic deck, which consists of longitudinal ribs resting on cross-girders. Orhtotropic decks are a very light, efficient, superstructure solution for long span bridges. Concrete deck systems, steel deck systems and composite deck systems are also widely used in cable-stayed systems. Steel decks are about twenty percent lighter than concrete decks. Concrete decks are more common in multiple stay bridges. The choice of the material is in function of the required stiffness, the method of erection, and the economics. Deck systems are chosen according to the cable layout, the span dimensions, the material utilized, and the special requirements of the bridge. The most common types of deck are shown in figure 2. The qualities required for the deck also depend on the nature of the structure and its service requirements (road or rail bridge). Of the deck types shown in figure 2, the most frequently used deck system is the box section deck because it provides convenient anchorages, and has significant torsional properties. It is common to utilize diagonal bracing and frame-type diaphragms to increase the rigidity of the box section. When selecting a deck, it is also important to consider maintenance and deflections limits.

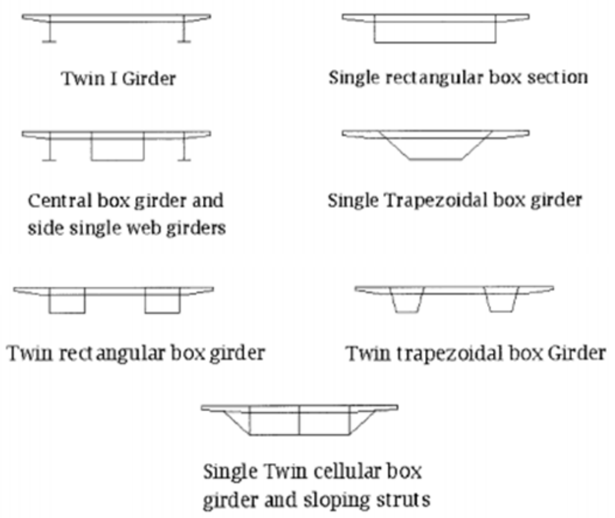

Fig.2 Deck Types

3.3 Tower types

The tower form is especially selected for aesthetic reasons, and is refined based on proportions, materials, and restrictions related to the tower style. A considerable style of tower shapes exists. In general, the form of the tower is governed by the desired height and also the environmental loading conditions, like seismic zones and wind criteria. The towers are classified consistent with the essential forms shown in figure 3.

The towers are subjected to axial forces. so they need to offer resistance to buckling. A additional refined analysis of the tower includes the non-linear P-Delta result. Additionally, the tower strength additionally should be checked under lateral hundreds and second-order effects (non-linearity) made by tension within the cables.

Box-sections are most often used for the towers. They will be made-up out of steel or reinforced or prestressed concrete. Concrete towers are additional common than steel towers as a result of the permit additional freedom of shaping, and are additional economical.

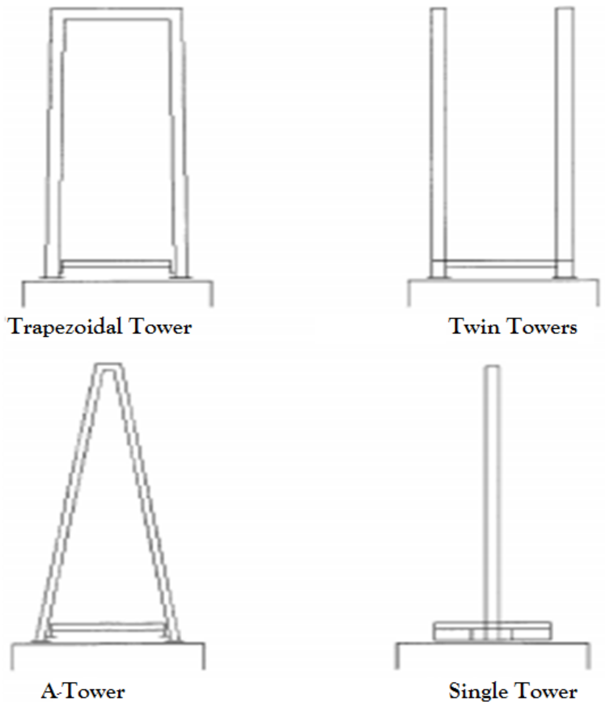

Fig.3 Tower Types

4. FINITE ELEMENT MODELS OF CABLE-STAYED BRIDGES

The supper-structure of cable-stayed bridges are principally designed of 3 structural elements: pylons, deck and cables. Geometrical nonlinearities are necessary to consider within the modeling of cable-stayed bridges because of the structure flexibility and also the use of cables. Cable structures are characterized by a geometrical hardening behavior that affects the curvature of the force displacement curve (Figure 4). That is made by the rise in cable stiffness caused by larger tension because the structure is deformed (Karoumi 1999). This chapter provides the background information about the methodologies used to develop the finite element models used later in this work. This chapter also describes the methods used to compare the dynamic characteristics that result from the different models.

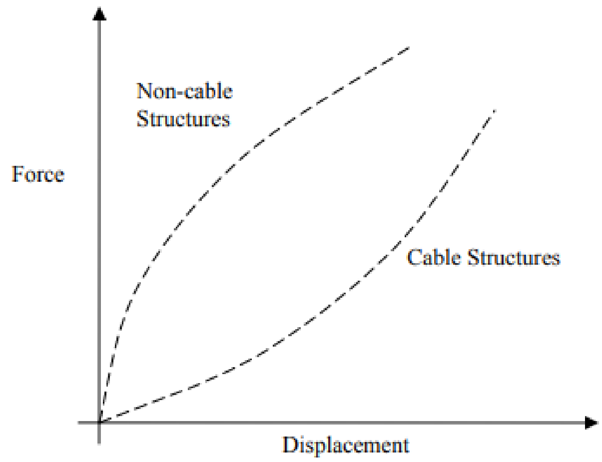

Fig.4 Cable structures nonlinear behavior

5. CONCLUSION

Based on the review study has carried on the research breakthrough to the Modal Analysis of a Cable-stayed Bridge. In this paper various research papers are studied related t to Modal Analysis of a Cable-stayed Bridge. The dynamic characteristics analysis of cable-stayed bridge is the basis of studying cable-stayed bridge dynamic behavior, so the research of natural vibration characteristics is very important. The cable-stayed bridge is a bridge type which is common application today with larger applicable scope of span, and good-looking appearance. After half a century, the technology of cable-stayed bridge got unprecedented development.

REFERENCES

Abass, A. L., Hammoudi, Z. S. and Mahmood, H. A. (2018). 'Seismic Analysis of a Cable-Stayed Bridge Using the Finite Element Seismic Analysis of a Cable-Stayed Bridge Using the Finite Element Method .' doi: 10.1088/1757-899X/433/1/012062.

Argentini, T. Et. al. (2012). 'Modal identification of stays and deck of a cable-stayed bridge', pp. 1031–1044.

Benedettini, F. and Gentile, C. (2008). 'F . E . modelling of a cable-stayed bridge based on operational modal analysis', pp. 0–9.

Cable, Á. D. Á. and Shear, Á. M. Á. (2019). Pylon Shape Analysis of Cable-Stayed. Springer Singapore. doi: 10.1007/978-981-13-0362-3.

Chen, C., Chen, J. and Lin, Y. (2009). 'E XPERIMENTAL M ODAL AND A ERODYNAMIC A NALYSIS OF A L ARGE S

PAN C ABLE -S TAYED B RIDGE', (Chen 2005).

Javanmardi, A. et al. (2018). 'Seismic isolation retrofitting solution for an existing steel cable-stayed bridge', pp. 1–22.

Ko, J. M. et al. (2000). 'MODAL ANALYSIS OF CABLE-STAYED KAP SHUI MUN BRIDGE TAKING CABLE LOCAL VIBRATION INTO CONSIDERATION'.

Liu, M. and Wang, P. (2012). 'Finite Element Analysis of Cable-Stayed Bridges with Appropriate Initial Shapes Under Seismic Excitations Focusing on Deck-Stay Interaction'.

Mohammed, M. I. et. al. (2017). 'Sensor placement based on FE modal analysis : Dynamic characteristic of cable stayed Penang (I) bridge', pp. 145–151.

Morassi, A. et al. (2015) 'Meccanica Ambient vibration testing and structural identification of a cable-stayed bridge'.

Shi, J. and Cheng, Y. (2018). 'Simulation Analysis of Cantilever Construction of Extradosed Cable-Stayed Bridge', (Icectt), pp. 298–303.

Shi, J. and Ran, Z. (2018). 'Effect of Concrete Creep on the displacement of single tower single cable plane Extradosed Cable- stayed Bridge Effect of Concrete Creep on the displacement of single tower single cable plane Extradosed Cable-stayed Bridge'.

Study, C. Et. al. (2017). 'Automated Operational Modal Analysis of a Cable-Stayed', 22(12), pp. 1–16. doi: 10.1061/(ASCE)BE.1943-5592.0001141.

Wei, L., Cheng, H. and Li, J. (2012). 'Modal Analysis of a Cable-stayed Bridge', Procedia Engineering. Elsevier B.V., 31, pp. 481–486. doi: 10.1016/j.proeng.2012.01.1055.

Wu, J. et. al. (2013). 'Finite Element Modal Analysis of the Cable-stayed Bridge', 439, pp. 883–885. doi: 10.4028/www.scientific.net/AMM.438-439.883.

Corresponding Author

Vipul Shinde*

Mahakal Institute of Technology and Management