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WIND INDUCED VIBRATIONS ON CABLE STAYED BRIDGES

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Abstract - *Cable-stayed bridges are preferred these days as they provide much greater stiffness than the suspension bridge and deformations of the deck under live loads are reduced. A cable stayed bridge has one or more pylons, from which cables support the deck of the bridge. A distinctive feature of the bridge are the cables which run directly from tower to deck, normally forming a fan like pattern or a series of parallel line. This is in contrast to modern suspension bridge, where the cables supporting the deck are suspended vertically from the main cable, anchored at both end of the bridge and running between the towers. The cable stayed bridges are used for spans shorter than suspension bridges and longer than cantilever bridges. Cable-stayed bridges under wind loading exhibit dynamic characteristics that depend on the aero elastic forces and coupling among vibration modes. This paper will focus on the parametric investigation on the different wind induced vibrations and therefore the response of cable stayed bridges under wind load.*

Key Words: Cable-stayed Bridge, Wind effects, Vibration

1 INTRODUCTION

The past two or three decades has found the wide application of Cable-stayed bridges in different parts of the world. Varied and victorious long span application of cable-stayed bridges has been realized just recently, with the initiation of high-strength steel and FRP materials, evolution of advanced welding techniques, different deck shapes, and the advancement in structural analysis. The diversity in shapes and forms of cable-stayed bridges fascinate even the most demanding designers, architects as well as the common people. Engineers are finding them both innovating and challenging. Cable-stayed bridges are considered as one of the most engaging recent development in the stream of bridge engineering. Increased application of these bridges among bridge engineers are often attributed to its appealing aesthetics, full and economical utilization of structural elements, augmented stiffness over long span suspension bridges, efficient and quicker mode of construction and also the comparatively tiny size of their substructure.

Cable-stayed bridges are perfect for spans shorter than suspension bridges and longer than cantilever bridges. The span length lies in range where a cantilever bridge would be really heavy and suspension bridge will not be practical because using large amount of cables for a shorter span bridge will be uneconomical.

The main objective of this paper is to review the various wind effects and the different vibrations which are induced due to the wind on cable-stayed bridges. Cable-stayed bridges being more flexible, a proper wind study is inevitable.

2 NEED FOR WIND ANALYSIS

Wind produces 3 different effects on any structure. They are static, dynamic and aerodynamic. The response on effect of load depends on the type of structure. The dynamic and aerodynamic effects should be analysed in addition to the static effect when a structure responds to wind load. Slender and flexible structural members are effected by wind along and across the direction of action of wind.

Cable-stayed bridges have very low inherent damping and they are very flexible. They are usually subjected to various dynamic loads such as vehicular loads, wind loads and seismic loads. The structural and geometric properties of cable-stayed bridges are complex. One of the notable features of this bridge is the non-linearity of the material and geometry. In addition to those, the precise nature of excitation and mechanism underlying the vibration development still stay to be absolutely understood.

3 TYPES OF WIND INDUCED VIBRATIONS

The cables of a Cable-stayed bridge are made by winding together strands or wires of materials like steel or fibre-reinforced polymers (FRP). They are popular because of their lightness, flexibility and low damping characteristics. They are excited easily and can oscillate severely when subjected to wind. Cable vibrations are generated depending on different factors and phenomena. The cable vibrations are coupled with vibration of the bridge deck and pylon towers. So it is the vibration occurring on the cables which primarily induces vibration on the other structural members of the bridge. The different wind induced vibrations are the following.

3.1 Aerodynamic Galloping

Galloping due to wind effect means the wave like motion of elongated bodies which are not aerodynamic in shape (bluff bodies). In the case of a cable-stayed bridge the bluff body is usually the bridge deck. So aerodynamic galloping is the oscillation of bridge deck when acted upon by wind. It is a low frequency situation and therefore does not create an adverse effect usually.

3.2 Wake Galloping

Wake galloping is the vibration of the bridge deck induced due to the wake effect formed between cables. When wind is acted on two cables which are spaced close to each other, a force or wake effect is developed between the cables. Under the action of this force the cables tend to rotate in opposite directions which induces torsional oscillations. This vibration is transmitted to the bridge deck which in turn causes galloping effect on the deck.

3.3 Buffeting

Buffeting is the sudden instability occurred due to shock wave oscillations or air flow separation created when two objects strike each other. Sudden impact of a seismic load or dynamic load leads cables to strike one another. This sudden shock induces vibration on the whole structure. Buffeting is a high frequency phenomena.

3.4 Vortex Shedding

When air flows past a slender and tall body at certain velocities, an oscillation is experienced. This oscillating force is called vortex shedding. In the case of a cable-stayed bridge pylons are prone to experience this effect. When wind flows past the pylon, low pressure vortices are formed on the downstream side of it. This vortex force will be likely to move the pylon from side to side. If the vortex shedding frequency becomes equal to resonance frequency of the structure, the whole structure will vibrate with harmonic oscillations. Vortex shedding is a higher frequency phenomena and it depends mainly on the size and shape of the pylon.

3.5 Fluttering

Fluttering is an unstable vibratory motion of the structure due to the coupling between elastic deformation of the structure and the aerodynamic force acted on it. Fluttering occurs due to the combined effect of bending and torsion. Long span bridges like suspension bridge and cable-stayed bridges are more prone to fluttering because of their large d/t value, d being the depth of structure parallel to wind and t being the least lateral dimension. Fluttering is a major vibratory motion and has even lead the collapse of Tacoma Narrows cable-stayed bridge in 1940.

3.6 Resonant buffeting

Resonant buffeting occurs in bridges with 2 parallel planes of cables. This phenomena happens mainly due to the wake effect formation between the cables. Wind striking the upwind and downwind portions of the cable with a time delay induces the whole cables to move laterally.

4. LITERATURE REVIEW

Various literature reviewed on wind effects on cable-stayed bridges are presented in this section. A number of studies have been performed on analyzing the wind induced vibrations on cable-stayed bridges. A review of literatures is presented in brief, summarizing the work done by different scholars and researchers on studying the wind effects.

Nicholas P Jones, Robert H Scanlan (2001) together developed analysis procedures for buffeting and multimode fluttering. They used state of the art wind analysis techniques to study the buffeting and fluttering effects on a long span cable-stayed bridge in North America. The work intended to show the recent developments in aerodynamic analysis to the upcoming bridge engineers, find out alternative procedures for wind analysis and give an outline of steps in the process of wind analysis.

M Gu, S R Chen, C C Chang (2001) conducted a study on 4 illustrative cable-stayed bridges in China and developed a numerical study to find out the allowance of background component on the buffeting effect on cable stayed bridges. It was found that the background component contributed about fifteen percent to the total response of the first vertical bending mode. Lower wind speed and higher damping and natural frequency will lead to a larger background component.

Ming Gu, Ruoxue Zhang, Haifan Xiang (2001) discussed a method for identifying the flutter derivatives of a bridge deck. A test of the sectional Jiangyin Bridge deck's models with varied dynamic parameters were conducted in a boundary layer wind tunnel to enquire the dynamic the dynamic parameters of the bridge deck model on flutter derivatives. A plate model and a sectional deck model of the bridge was tested to find out the effect of turbulence on flutter derivatives in both smooth and turbulent flow conditions. The obtained results indicated that the flutter derivatives were negligible with the effect of different model parameters and with turbulence.

J Y Fu, J R Wu, A Xu, Q S Li, Y Q Xiao (2003) compared wind tunnel test results with measured values of wind pressure and wind induced acceleration. The study was conducted to assess the precision of model test results. The mean values of wind induced response, power spectral density and the probability density function were considered. They were able to find out that at most pressure transducers the probability density functions of wind induced pressures were close to the Gaussian distribution. Quasi static hypothesis was also testified by analyzing the wind induced pressure at windward side of the structure. Also vortex shedding phenomena was found on sideward side of the structure for the wind induced pressure. There was a slight difference in the wind induced pressure obtained from wind tunnel test and those from field measurements.

B N Sun, Z G Wang, J M Ko, Y Q Ni (2003) presented a nonlinear dynamic model for simulating and analyzing a kind of parametrically exited vibration of the cables. Through numerical computation the dynamic response characteristics and oscillating mechanism was analysed based on the dynamic model created. They concluded that in cable-stayed bridges serious parametric vibration of the cables with large amplitude may occur if the ratio of natural frequencies of the cable to bridge deck falls to certain range. The beating frequency is related to force of tension in the cables. Larger the tension, less will be the beating.

5 SUMMARY AND CONCLUSION

Cable-stayed are the promoted type of long span bridge these days because of its nicer aesthetic appearance, greater stiffness, lesser deformation and economy of materials. Cable-stayed bridges being more flexible, the study of wind effects and wind analysis plays a major role in the design. Wind induced vibrations include high frequency phenomena such as vortex shedding, buffeting, fluttering and low frequency phenomena such as galloping and resonant buffeting. A brief review of several literatures presented shows that the precise nature of excitation and vibration development due to the wind loads still stay to be precisely understood. There is future scope for further study in this area.

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