

Effect of Wind on Cable Stayed Bridges

Osama Maniar¹, Prathamesh Khanwilkar², Sucheta Sable³

¹ Department of Structural Engineering, India, maniarosama@gmail.com

² Department of Structural Engineering, India, prathameshkhanwilkar@yahoo.com

³ Department of Structural Engineering, India, suchetasable17@gmail.com

Abstract: Cable-stayed bridges under wind loading exhibit dynamic behaviours that depend on the aeroelastic forces and coupling among vibration modes. This paper presents a parametric investigation on various types of wind effects on cable stayed bridges. An up-to-date literature review of various types of wind effects followed by control of vibrations in cable stayed bridges.

Key words: Cable-stayed bridges, aerodynamic, buffeting, galloping, vortex-shedding.

INTRODUCTION

Cable stayed bridges have only become an established solution for long span structures over the last 60 years. This recent ascendancy is primarily due to the development of reliable high strength steels for the cables and perhaps more importantly, the advent and widespread use of computers to analyse the complex mathematical models.

Nicholas P. Jones and Robert H. Scanlan (2001) developed multimode flutter and buffeting analysis procedures. They reviewed the current state of the art in long-span bridge wind analysis, focusing the application of the theory to the stability (flutter) and serviceability (buffeting) analyses of a new long-span bridge in North America. This research work seeks to exhibit recent developments in the field to the interested structural/bridge engineer, outline alternative procedures available for assessment of wind effects on cable-supported bridges, and provide an overview of the basic steps in the process of a typical aerodynamic analysis and design.

M. Gu, S.R. Chen, C.C. Chang developed a numerical study on four representative cable-stayed bridges in China is performed to investigate the contribution of the background component to the total buffeting response of cable-stayed bridges. The background component usually contribute around or over 15% to the total response of the first vertical bending mode. Higher natural frequency and damping and lower wind speed will result in larger background component.

Ming Gu, Ruoxue Zhang, Haifan Xiang analysed sectional Jiangyin Bridge deck's models with different dynamic parameters were carried out in the TJ-1 Boundary Layer Wind Tunnel to investigate the effects of parameters of the test model on the flutter derivatives. The flutter derivatives of the plate model and the Jiangyin Bridge model identified in both smooth and turbulent flow conditions using the present method indicate that the effects of turbulence on the flutter derivatives are negligible.

J.Y. Fu, J.R. Wu, A. Xu, Q.S. Li, Y.Q. Xiao measured wind-induced acceleration and wind pressure compared with those obtained from the wind tunnel test to evaluate the accuracy of the model test results. They concluded that the probability density function, power spectral density and mean values of wind-induced response was conducted in this study. It was found that the probability density functions of wind-induced pressures at most pressure transducers are very close to the Gaussian distribution. Also the quasi-static hypothesis was testified by analyzing the measured wind-induced pressure at the windward

side, while the vortex shedding phenomena was found for the wind induced pressure at the sideward side of the building. Slight difference was found for the mean value of wind-induced pressure obtained from field measurements with those from wind tunnel test.

B. N. Sun, Z. G. Wang, J. M. K and Y. Q. Ni proposed a nonlinear dynamic model for the simulation and analysis of a kind of parametrically excited vibration of stay cables. Based on this model, the oscillation mechanism and dynamic response characteristics of this kind of vibration were analyzed through numerical computation. They concluded that in cable-stayed bridges, if the ratio of natural frequencies of cable to bridge deck falls into certain range, serious parametric vibrations of the cables with large amplitude may occur. The beating frequencies relate to tension force of the cable. The larger the static tension force is, the lower the beating frequency

Necessity of Wind Analysis for Cable-Stayed Bridges:

Cable-stayed bridges are subjected to variety of dynamic loads like traffic, wind, pedestrian and seismic loads.

In addition to this the stay cable are very flexible and have very low inherent damping.

Also the geometric and structural properties of these bridges are very complex.

In addition to these the exact nature of excitation and the mechanism underlying some of the vibration phenomenon still remain to be fully understood.

The most important feature of this kind of structure is the non-linearity in geometry and material.

DIFFERENT TYPES OF WIND INDUCED VIBRATION:

Structural Cables are popular due to their High Flexibility, Light Weight and Low Damping Characteristics. They are easily excited and severely oscillate through Dynamic Effects of Wind.

There are many factors and phenomena can generate Cable Vibrations. The cable Vibrations is coupled with the vibrations of the bridge girder and pylons.

There are different types of wind induced vibrations such as:- Aerodynamic Stability such as Galloping, Buffeting, Vortex Shedding, Wake Effect. This type of Vibration is caused by interaction between wind, rivulet and cables. The rivulet motion is coupled with cable vibration in the effective range of mean wind speed.

Aerodynamic (Galloping):

This is a relatively low-frequency oscillatory phenomenon of elongated, bluff bodies acted upon by a wind stream. The natural structural frequency at which the bluff object responds is much lower than the frequency of vortex shedding. It is in this sense that galloping may be considered a low-frequency phenomenon

Wake galloping: It is considered of two cylinders one windward, producing a wake, and one leeward, within that wake separated at a few diameters distance away from each other. In wake galloping the downstream cylinder is subjected to galloping oscillations induced by the turbulent wake of the upstream cylinder. Due to this, the upstream cylinder tends to rotate clockwise and the downstream cylinder, anti-clockwise thus inducing torsional oscillations.

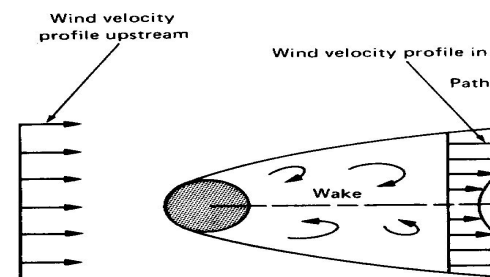


Figure1- Wake galloping

Buffeting:

Buffeting is a high frequency instability, caused by airflow separation or shock wave oscillations from one object striking another. It is caused by a sudden impulse of load increasing. This phenomenon is quite different from vortex-induced vibration.

The relation of 2:1 between the aerodynamic damping coefficients in the along-wind and across-wind direction may contribute to the fact that most vibration problems in cable stayed bridges occur in the plane of the cables. The significant increase of damping at high wind velocities prevents, most

situations, the occurrence of important cable oscillations under buffeting loads.

For along wind Direction, Aerodynamic damping Coefficient can be approximated by –

$$\xi_{aero,kD} = \frac{\rho U D C_D}{2m\omega_k}$$

For across wind Direction, Aerodynamic damping Coefficient can be approximated by –

$$\xi_{aero,kL} = \frac{\rho U D C_D}{4m\omega_k}$$

Vortex Shedding

It is an oscillating flow that takes place when a fluid such as air or water flows past a cylindrical body at certain velocities, depending on the size and shape of the body. In this flow, vortices are created at the back of the body and detach periodically from either side of the body. The fluid flow past the object creates alternating low-pressure vortices on the downstream side of the object. The object will tend to move toward the low-pressure zone.

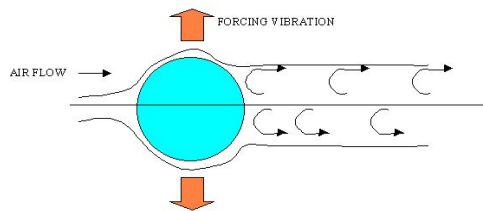


Fig 2: vortex shedding

If the cylindrical structure is not mounted rigidly and the frequency of vortex shedding matches the resonance frequency of the structure, the structure can begin to resonate, vibrating with harmonic oscillations driven by the energy of the flow.

Wake Effect

Wake effect is the term used for all the vibration phenomenon of stays that lie in the wake of other

stays or structural elements. The perturbing element affects the wind flow, creating local turbulent conditions that produce oscillations of the cable.

Wake oscillation cannot be anticipated in the design phase. The most common wake effects are as follows: Resonant buffeting and Vortex resonance

Resonant buffeting

The phenomenon was described by davenport and can occur for bridges with two parallel planes of cables. Accordingly, the wind gusts strike the up-wind and down-wind planes of cables with a time delay of B/U , Being the distance between the two planes of cables and U the mean wind velocity as in Fig. If this delay coincides with half the period T_t associated with torsional deck mode, then resonant effects can be attained.

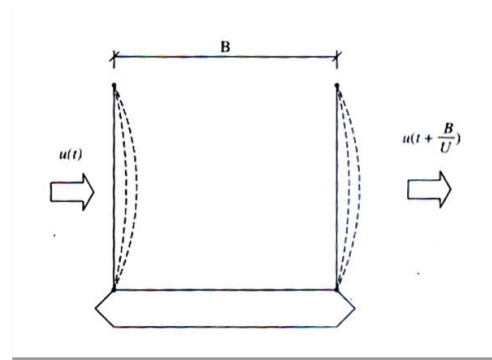


Fig 3: Resonant Buffeting

The critical velocity U_{cr} for the resonant buffeting is then defined by,

$$U_{cr} = \frac{2B}{T_t}$$

Vortex resonance

This phenomenon occurs typically in cable-stayed bridges with two planes of cables. When subjected to oblique winds. Resonant effects may occur for the cables behind the pylon that have a natural frequency f_t close to the shedding frequency. The critical wind velocity for the occurrence of vortex resonance of a cable of frequency f in the wake of a pylon can therefore be evaluated from

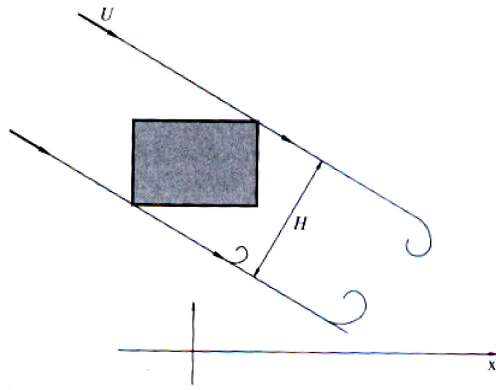


Fig 4: Vortex Resonance

$$U_{cr} = \frac{Hf_k}{St}$$

Where H is the projection of the pylon in the direction transversal to the wind and St is the Strouhal number of the pylon cross section.

Conclusion:

Buffeting has a direct effect on Cables as on other Flexible Structures although this phenomenon increases with wind velocity, they do not appear to be dangerous unless buffeting can produce shock in cross-cables.

In cable-stayed bridges, if the ratio of natural frequencies of cable to bridge deck falls into certain range, serious parametric vibrations of the cables with large amplitude may occur.

The impact of its intensity, the frequency of axial vortex shedding, the possible interaction between vortices along cable axis and in the wake, and the relation between limited-amplitude high-speed vortex excitation and dry inclined cable galloping need to be further investigated.

The analytical and experimental modal analysis provides a comprehensive investigation of the dynamic properties of bridges. The analytical modal analysis through three dimensional finite element modeling gives a detailed description of the physical and modal characteristics of the bridge, while the experimental modal analysis through the field dynamic tests offers a valuable source of information for validating the drawing-based idealized finite element model.

The design predictions of buffeting amplitudes of vertical and torsional modes were reasonable, but these were based on overestimates of the wind turbulence intensity and overestimates of total damping. Further analysis suggests that if the values of turbulence and damping found from site

measurements had been used with the design method, then the actual vertical

References:

- [1] M.S. Troitsky (1988), "Cable-Stayed Bridges – Theory and Design", pp. 17-83.
- [2] Walter Podolny and John B. Scalzi (1986), "Construction and Design of Cable-Stayed Bridges", pp. 1-20.
- [3] Niels J. Gimsin, "Cable Supported Bridges – Concept and Design", pp.23-27.
- [4] B. N. Sun, Z. G. Wang, J. M. K and Y. Q. Ni., "Cable oscillation induced by parametric excitation in Cable-stayed bridges".
- [5] M. S. Pfei and R. C. Batist (1995), "Aerodynamic stability analysis of cable stayed bridges", Journal of Structural Engineering.
- [6] Jin Cheng, Jian-Jing Jiang, Ru-Cheng Xiao, Hai-Fan Xiang (2002), "Advanced aerostatic stability analysis of cable-stayed bridges using finite-element method", Computer and Structure.
- [7] Nicholas P. Jones and Robert H. Scanlan (2001), "Theory and full bridge modeling of wind response of cable supported bridges", Journal of Bridge Engineering, Vol-6, No.6, Nov/Dec 2001.
- [8] Thai Huu-Tai and Kim Seung-Eock (2007), "Triple-girder model for modal analysis of cable-stayed bridges with warping effect", "Standardization of Construction Specifications and Design Criteria based on Performance".
- [9] Gregor P. Wollmann (2001), Journal of Bridge Engineering, Vol. 6, No. 4, July/August 2001, pp. 227-233
- [10] Munenobu Kondoh, Motoi Okuda, Kouji Kawaguchi, Takefumi Yamazaki (2001), Journal of Bridge Engineering, Vol. 6, No. 3, May/June 2001, pp. 176-182

IJSER

IJSER

IJSER