Minimum Wind Design Considerations for Long Span Bridges – Case Studies

K. Suresh Kumar, PhD, PEng
Wind Engineering Consultant
RWDI India
Trivandrum, India
suresh.kumar@rwdi.com

Suresh Kumar, born 1966, spent many years as a wind engineering researcher /consultant in India, Canada and Netherlands. He had the privilege to work as a wind consultant on many iconic structures around the world.

Stoyan Stoyanoff, PhD, PEng
Wind Engineering Consultant
RWDI Inc
Bromont, Canada
stoyan.stoyanoff@rwdi.com

Stoyan Stoyanoff, born 1954, received engineering degrees from the Univ. of Sofia, Bulgaria and Kyoto, Japan. He studied over 50 long-span bridges including Tatara, Tacoma Narrows and Messina Strait. Bridges.

Pierre-Olivier Dallaire, ing.
Bridge Consultant
RWDI Inc
Bromont, Canada
pierre-olivier.dallaire@rwdi.com

Pierre-Olivier Dallaire, born 1979, studied in Univ. of Sherbrooke, Canada. He works as a wind engineering consultant for long span bridges and other structures susceptible to wind excitation.

Summary

Bridges are susceptible to wind-induced vibrations, especially when their span is long and with bluff deck sections. Even when the earthquake loading governs the design of a particular bridge, its vulnerability to wind has to be checked for aerodynamic stability confirmation. Wind tunnel tests have been often used for the wind engineering design of bridges. For preliminary studies, computational and analytical simulations are also performed at times. Regardless of the span or complexity of the bridge under consideration, certain studies need to be performed as a minimum to evaluate the wind effects on bridges. This paper focuses on the minimum design considerations for assessing the wind effects on long-span bridges.

Keywords: bridge; design considerations, long span; wind.

1. Introduction

At the start of every long-span bridge project, the site wind characteristics are required for the verification of aerodynamic stability and derivation of design loads. Long term wind records are typically obtained from local airports. In regions of very strong winds such as hurricanes/typhoons, numerical simulations are carried out to extend the existing data base. In instances of complex terrains, either topographical wind tunnel test and/or numerical simulations have to be carried out. Wind climate analysis is then carried out to create statistical models. Once the wind characteristics at the site are known and the initial bridge geometry established, preliminary design wind loads are predicted analytically using buffeting theory. As the design of the bridge evolves, sectional model tests are performed to verify the aerodynamic stability of the completed as well as construction stage configurations. While testing sectional models at lower speeds, amplitudes of the vortex-induced vibrations and onset speeds can also be identified if any. In case of unacceptable wind-induced vibrations are found either in the safety region (at higher return periods) or in the serviceability region (at lower return periods), possible mitigation measures altering the cross-sectional geometry can also be worked out. Once sections with acceptable stability characteristics are found, static force and moment and aeroelastic coefficients are measured through this test and used later in the analytical simulations to determine the structural responses and associated load distributions. This paper focuses on the wind climate study, sectional model tests and buffeting analysis which are to be performed as a minimum to evaluate the wind effects on long-span bridges.

2. Wind Climate Analysis

Wind climate data from nearby airports and other meteorological stations is analyzed to establish the dependence of wind speeds to the period of speed reoccurrences. This process also uncovers the local wind directionality since the alignment of the bridge relative to the preferred strong winds at the site can have a significant impact on the bridge responses. Note that the surface roughness and other structures around the bridge site may modify the local wind turbulence which in turn will affect both stability and loads. Topographical features such as hills and valleys may also contribute to these variations and potentially re-align the wind velocity vector both horizontally and vertically.

https://doi.org/10.2749/222137813808627541
Distributed by structurae

The effects of topography, such as hills, ridges and escarpments, on local wind flows have been previously investigated by many researchers using wind tunnel model studies, full-scale measurements and numerical simulations [1, 2].

3. Sectional Model Test

Sectional model tests have been widely used by the wind engineering consultants to evaluate the wind-induced response of bridges. Sectional model tests are usually carried out at the preliminary design stage in order to assess the aerodynamic stability of a given deck section. If unacceptable instabilities such as flutter or vortex excitation are found, remedial measures in the form of refining the deck cross-section will be investigated. The stability performance of the revised cross-section will be compared to the earlier stage through testing and improved until project criteria are met.

4. Buffeting Analysis

During the design of long span bridges, once the stability of the bridge is confirmed through sectional model tests, design wind loads are required for verification of structural integrity. For derivation of the wind loads acting on a bridge, theoretical buffeting analysis can be conducted [4]. The requited input parameters include static aerodynamic force and moment coefficients, mass and polar moment of inertia, bridge dimensions, modal frequencies and shapes, structural damping and wind turbulence properties. Typical forms of power spectra and co-spectra of turbulence, and representative aerodynamic admittance functions are also applied. Statistical predictions of peak responses are obtained from a solution of the dynamic equations of motion.

An effective solution method (called *3D Buffeting Analysis*) is the direct integration of these basic equations in time domain [5]. The time domain approach generally involves two steps during the analysis: (a) numerical simulation of turbulence velocity histories and wind loads; and (b) evaluation of the structural response due to these loads.

5. Concluding Remarks

This paper describes the minimum design considerations which should be given due consideration while designing long span bridges for wind. Certain minimum studies such as wind climate analysis, sectional model tests and buffeting analysis have to be carried out for all the bridges before final design. Wind climate study will determine the detailed site wind characteristics which are essential for the design of bridges. The study continues with a sectional model test where the stability of the sections needs be confirmed. In case of problems, sections may have to be modified or as an alternative supplementary damping solutions will be sought. Finally, buffeting analysis is carried out to determine the response distributions and derive various load cases for strength design.

6. References

[1] GLANVILLE M.J., and KWOK K.C.S., "Measurements of topographic multipliers and flow separation from a steep escarpment. Part II. Model-scale measurement", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 69-71, 1997, pp. 893-902.

[2] HOLMES J.D., BANKS R.W., and PAEVERE P., "Measurements of topographic multipliers and flow separation from a steep escarpment. Part I. Full scale measurement", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 69-71, 1997, pp. 885-892.

[3] YAKYMYK W., GARBER J., SURESH KUMAR K., HUNTER M.A., and IRWIN P.A., *Topographical Model Study – Anji Khad Arch Bridge – Jammu & Kashmir, India*, RWDI's Final Report 05-1289, 2005.

[4] IRWIN P.A., *Wind Tunnel and Analytical Investigations of the Response of Lions' Gate Bridge to a Turbulent Wind*, National Research Council of Canada, *NAE Report LTR-LA-210*, 1977.

[5] STOYANOFF S., "A unified approach for 3D stability and time domain response analysis with application of quasi-steady theory", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 89, 201, pp. 1591-1606.