18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 356–357
Paper #22

EXPERIMENTAL AND NUMERICAL VERIFICATION OF VORTEX-INDUCED VIBRATION OF HANGERS ON THE FOOTBRIDGE

Sh. Urushadze [*], **M. Pirner** [**], **S. Pospíšil** [***], **R. Král** [****]

Abstract: *The paper deals with vortex-induced oscillations of footbridge hangers at a very low wind speed. The two-spans (2x50m) reinforced concrete structure with the central pylon (25m height) is designed as the harp system of hangers with circular cross-section. The oscillations were observed at the low wind speed and the high double amplitudes has been measured. The wind-excited deformation shape corresponded to the 6th, 7th and 8th natural modes of a hanger. The individual hanger as well as their group were analysed to estimate the dynamic response, possible aeroelastic vibration and special interference or coupling effects. It also includes proposal for the elimination of the extensive vibration. The analysis is complemented by numerical investigation using Computational Fluid Dynamics methods.*

Keywords: ***Footbridge, vortex-induced oscillations, Kármán vortex, fluid dynamics.***

1. Introduction

Long-span footbridges rank among engineering structures with a high social significance. Their architecture design must in general satisfy matters such as attractive look, reliability and weight. These requirements determine the bridge to be sensitive to the wind effects and the assessment against the wind becomes crucial. One of the several wind phenomena occurring on such a type of structures is termed the vortex shedding with consequent vortex induced vibration. This flow-induced excitation originating from the periodic separation of the vortices may arise even at a low wind velocity.

In this paper, the unacceptable vibrations of the bridge hangers were measured and investigated with respect to the pedestrian comfort. The examination includes a frequency analysis of the hangers accompanied by the analysis of the origin of the unstable behaviour. Moreover the numerical simulation of such an aero-elastic system, which provides addition information to discover the problem, was carried out.

2. Bridge description

The suspended three-section bridge with the almost straight deck was examined. The bearing structure consists of pre-fabricated and pre-stressed concrete sections. An A-shaped steel pylon supports the first two sections. The bridge deck core is composed from the steal beams of 800 mm height with the distance between their axes d=3.3 m. The bridge deck is 3.9 m wide.

3. Examination of excessive vibrations using numerical simulation

To identify an origin of the unstable behaviour of the selected hanger and to investigate the possibilities to suppress excessive vibrations, two-dimensional numerical model adapted for solving the fluid-structure interaction has been defined. This method employs three boundary value problems

[*] Ing. Shota Urushadze, CSc.: Institute of Theor. and App. Mechanics Academy of Sciences of the Czech Republic, v.v.i; Prosecká 76, 190 00 Praha 9. Tel.: +420.222363071, Fax.: +420.286884634; E-mail: urushadze@itam.cas.cz.

[**] Prof. Ing. dr.h.c. Miroš Pirner, DrSc.: Institute of Theor. and App. Mechanics Academy of Sciences of the Czech Republic, v.v.i; Prosecká 76, 190 00 Praha 9. Tel.: +420.286882121, Fax.: +420.286884634; E-mail: pirner@itam.cas.cz.

[***] Doc. Ing. Stanislav Pospíšil, PhD.: Institute of Theor. and App. Mechanics Academy of Sciences of the Czech Republic, v.v.i; Prosecká 76, 190 00 Praha 9. Tel.: +420.283880854, Fax.: +420.286884634; E-mail: pospisil@itam.cas.cz.

[****] Ing. Radomil Král, PhD.: Institute of Theor. and App. Mechanics Academy of Sciences of the Czech Republic, v.v.i; Prosecká 76, 190 00 Praha 9. Tel.: +420.286882121, Fax.: +420.286884634; E-mail: kral@itam.cas.cz.

respecting the Newton's fluid, elastodynamic equations and equations of the Lagrangian-Eulerian description of motion. A circular cross-section with adequate dimensions $d = 0.054\,\mathrm{m}$ is free oscillating in vertical and horizontal direction *x* and *y*, respectively, with specific frequencies. Each of the degrees of freedom is proportionally damped with respect to the velocity. Furthermore, it is assumed that the hanger is subjected to the wind action with a constant velocity profile. Due to the primitive variable formulation of the Navier-Stokes equations, no turbulence is given on the inlet boundary. This does not correspond to the experiment, wherein turbulence components are always presented, and therefore certain discrepancy in the results may be expected.
Simulations have been performed with COMSOL^{R} software. This partly-open computation package solves an arbitrary weak-form of integral-differential equations with boundary conditions (Pospíšil et al., 2006). It makes a possible to define the modified Navier-Stokes equations for incompressible fluid, see Tezduyar et al., (1992).

4. Conclusion: proposal on elimination (or reduction) of the hanger vibrations

Hangers 9 and 8 in the footbridge section above the bridge deck vibrate with higher shapes and clearly visible amplitudes under the load of the wind as slow as 1.75 to 2 m/s, if its direction is perpendicular to the footbridge axis.

Vibrations of the cables under the wind load are results from the periodical separation of vortices behind the hanger with circular cross-section (Strouhal vibrations, Kármán vortex path). Theoretical calculation has indicated that:

Vibrations of the cables caused by wind load on the deck can be neglected.

The main cause of the unacceptable effect is the smoothness of the PE pipe surface affecting the flow regime.

The vibrations of the 9th and 8th hangers caused by wind do not pose a threat to the footbridge structure (or cables, deck or pylon), so it would be possible to keep it in the original state.

However, the motion of the cables could lead to the discomfort or fear of some pedestrians and, in the case of a larger amount of people on the footbridge, even panic. Therefore it is necessary to reduce the vibrations to the indistinctive level, or eliminate them.

In this case, there are three possibilities:

- To equip the 9th and 8th hangers with Stockbridge dampers (see Anagnostopoulos, (2002), the dampers there are doubled; in our case, single ones will do).
- Interlocking, by means of an additional cable, the 9th and 8th, perhaps also the 7th, hangers and anchor them into an anchorage "block".
- Changing the flow regime by coarsening the hanger surface through covering with (sticking) grains with diameter up to 5 mm onto the upper half of the circular cross-section.

Acknowledgement

The support of the grants GA CR 103/09/0094, MPO TIP FR-TI3/654 and GA CR P105/10/2159 are gratefully acknowledged. Identification code of research project of the Institute of Theoretical and Applied mechanics is RVO: 68378297.

References

Anagnostopoulos P. (2002), Flow induced vibrations in engineering practice, *WIT press, Southampton*, Boston.

Pospíšil S., Král R., Náprstek J. (2006), Numerical model of nonlinear wind-structure interaction. *In proceedings of CWE2006: JAWE*, 307-311, 2006.

Simiu E., Scanlan R.H., (1996), *Wind Effects on Structures*. John Wiley & Sons, New York, 1996.

Tezduyar T.E., Mittal S., Ray S.E., Shih R. (1992), Incompressible flow computations with stabilised bilinear and linear equal-order-interpolation velocity-pressure elements. *Computer Methods in Applied Mechanics and Engineering*, 95, 221-242.