DOI: 10.24904/footbridge2017.09443

WIND TUNNEL TESTS AND FULL-SCALE MEASUREMENTS ON A CABLE-STAYED FOOTBRIDGE

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Summary

The present work presents the experimental results aimed to assess the dynamical characteristics of a cable-stayed footbridge recently built in Terni (Italy). The assessment process involved both wind tunnel and full-scale experimental tests, and relied on the fruitful interaction between designers and academic experimenters. The wind-tunnel study investigated the wind-induced dynamical phenomena possibly affecting the structure. Then, the experimental work focused on assessing the actual dynamic features at prototype scale in order to confirm and/or to update the assumptions used for the design of devices to mitigate the undesired vibrations.

Keywords: cable-stayed footbridges; wind tunnel tests; vortex-induced vibrations; flutter; full-scale measurements; system-identification methods

Lightness and peculiar shapes dictate the aesthetics of modern footbridges. Although these features make footbridges one of the most appealing structural typology in civil engineering, they are often responsible for structural sensitivity to wind and human actions. As for wind effects, the ultimate and serviceability conditions of these structures are assessed by wind-tunnel simulations on scaled models of the entire footbridge and/or parts of it. When countermeasures must be taken to mitigate unwanted dynamical effects on structures, full-scale measurements, are also carried out to determine accurately the natural modal shapes of vibration, which are usually estimated using a preliminary finite element model, and the actual modal damping ratios.

Fig. 1. View of the footbridge (left - Terni, Italy); sectional model in the wind tunnel (right - CRIACIV lab.).

This work encompasses several design phases of a cable-stayed footbridge with a main span of 55 m, recently built in Italy (Fig. 1). Preliminary structural analyses revealed that wind-tunnel tests were needed in order to assess the structural sensitivity to vortex-induced vibrations of the deck and tripod, and flutter of the bridge deck. Thus, an experimental campaign was conducted in the CRIACIV laboratory, Prato (Italy).

Special focus was on the effects of the wind-screen porosity, carrying out a sensitivity study on the dynamical response of the model with two types of porous screens, respectively of ε_1 = 55% and ε_2 = 80%.

The sectional model was rigidly mounted on a static set-up capable to measure the aerodynamic forces of lift, drag and torque by means of two specular load-cell systems positioned at both the ends of the model axis. Aerodynamic force coefficients and Strouhal number ($St = n_s B/U$, were n_s is the vortex-shedding frequency) were estimated in different configurations, varying both porosity and angles of attack.

A double series of experimental tests were performed on the elastically-suspended sectional model of the bridge deck to investigate the proneness to torsional flutter and vortex-induced vibrations.

Full-scale measurements were performed to estimate the actual dynamic properties of the structure in order to have useful information for the proper design of Tuned Mass Dampers (TMDs) to mitigate both aeroelastic and human-induced vibrations of the deck. Records of the structural response in operating conditions (ambient vibrations) were used to estimate natural frequencies, mode shapes and associated damping.

Two approaches were followed. In the former, the experimental data were processed to obtain the time histories of the accelerations referred to the footbridge axis due to longitudinal, torsional, vertical, and lateral vibration components. In the second approach, ambient vibration measurements were considered in their original spatial positions and processed using the Operational Modal Analysis (OMA) technique. Frequency Domain Decomposition (FDD) and Enhanced Frequency Domain Decomposition (EFDD) algorithms were used to identify the natural frequencies and the associated modal shapes and damping.

Measured time histories of the system response due to impulse loading tests were processed through the Modified Unifying Least Squares (MULS) method, which performs a time-domain multi-degrees-of-freedom identification based on the complex modal analysis.

Both approaches provide similar results in terms of frequencies. Nevertheless, the identification of the modal damping coefficients is more difficult and their estimates present a wide range of variability, because some modes of vibration were not sufficiently excited during both ambient and impulsive vibrations to make reliable the damping identification.