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"TRIPOD" FOOTBRIDGE IN TERNI (ITALY): ON SITE DYNAMIC CHARACTERIZATION AND NUMERICAL INVESTIGATION OF LOCK-IN

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Summary

Benedetti Architects (formerly McDowell+Benedetti) and Manfroni Engineering Workshop were the winners of an international competition for a new 180m footbridge and improved railway station in Terni, Italy.

The structure, named "TRIPOD" due to its particular form, is made entirely of steel and the walking deck is finished with timber.

The bridge slenderness imposed to the designers much precaution to mitigate the oscillations due to both crowd and wind. Due to these precautions, during the design stage, wind tunnel tests were conducted to investigate the aero-elasticity of the structure. TMDs were also designed to account for vertical and lateral movement of the deck. They were placed under the floor at a location where the oscillations are at a maximum. Furthermore, on site dynamic characterization was undertaken to investigate the bridge's oscillations and to compare them with the design assumptions to properly calibrate the TMDs' performance.

Based on the amount of data recorded during construction of this bridge, this paper will investigate and present a model for the physical phenomenon of synchronization related to the oscillations induced on it by the passage of a group of people. Vortex shedding is also analyzed and reproduced by the same model.

Finally it will be shown that both phenomena are almost equivalent and that they can be reproduced in the same way. The base assumption for this paper comes from the theory of complex systems and the non-linear dynamics which underlies these phenomena.

Keywords: dynamics; crowd; lateral vibration; TMD; complex systems; vortex shedding; synchronization

The phenomenon of synchronization (lock-in) is brought back on an analytical matrix formulation with reduced degrees of freedom (MDOF), i.e., a very simple numerical method which can run quickly and reproduce locally the real behavior of the whole system.

The forcing load is then given by the vertical motion induced by man-made stepping. Moreover, as a result of a spontaneous ignition of the horizontal motion due to the proximity of the natural frequencies of movement induced by steps, it also causes horizontal action which tends to quickly synchronize with the motion of the walkway itself.

By virtue of a reciprocal dynamic adaptation between the forcing action and the walkway response, a stationary state of motion is reached which leads the walkway to swing both in vertical and horizontal directions with periods respectively equal and twice the stepping one.

The synchronizing action, unlike the simple resonance phenomenon, occurs with a continuous and positive feed-back that causes an adaptation of the forcing step with the moving walkway. Specifically, the human body shows a higher sensitivity to the horizontal motion as opposed to the vertical one, in that the former causes the loss of equilibrium. In fact, to prevent falling, the human body instinctively tends to spread the legs whilst walking to increase the support base. As a consequence, horizontal pulses are performed on the walkway with intensity proportional to the deceleration component of this motion and to the mass of the crowd.

Likewise vortex shedding grows up from an incident wind blowing on a structure that, due to its shape, gives rise to alternating transversal forces with frequency as per the Strouhal law. Like human induced vibration, along wind forces also have twice the across wind frequency. Moreover by seeing the Strouhal law, it’s clear that the vortex’s frequency is proportional to wind speed and inversely to the structure width.

In virtue of this when the resonant transversal frequency is approached by vortices, the movements of the structure are considerable and the vortices are alternating with the same frequency of the structure, as if in the Strouhal law the width of the structure was increased to take account of the transverse displacement too.

This trick is accounted for in a simple model so as it will drive the general aero elastic behavior toward the well-known “violation” of the Struhal law, namely the lock-in phenomenon.

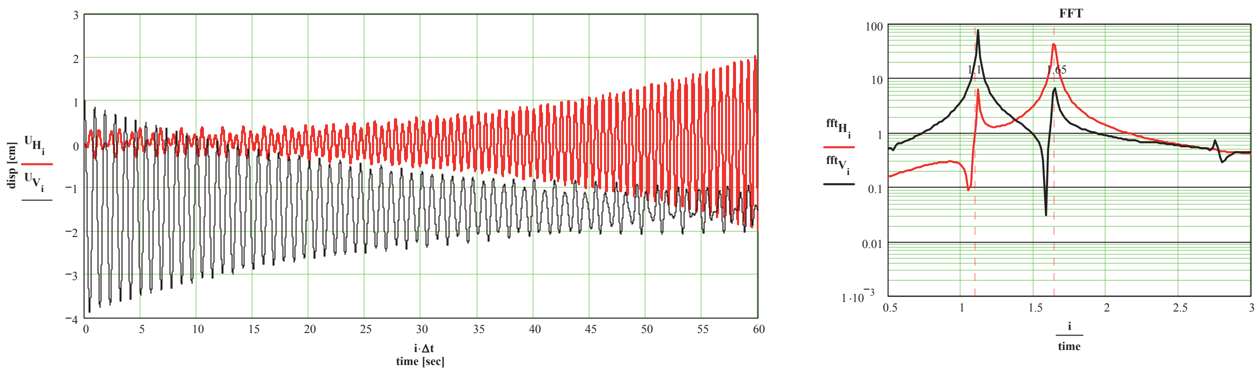

Fig. 1. Time histories and FFT analysis in critical regime of the numerical model for crowd’s action

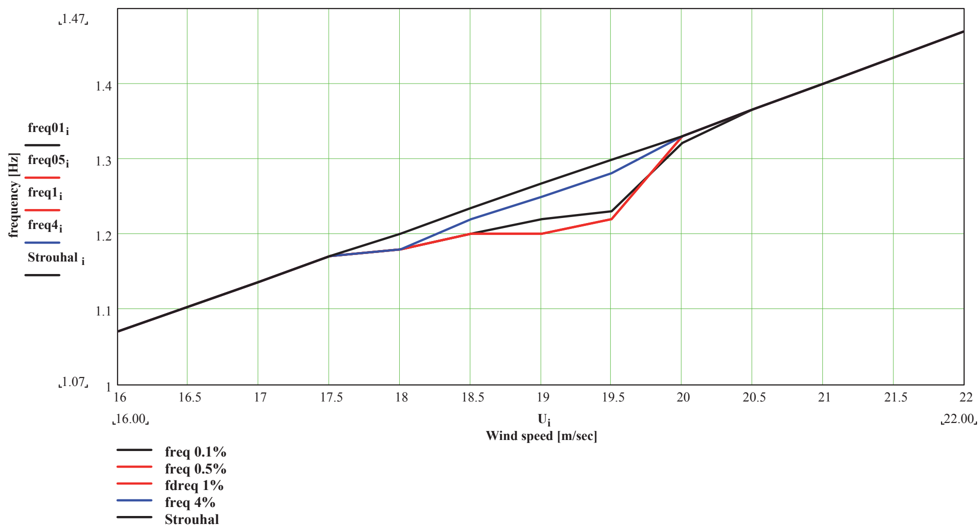

Fig. 2. “Violation” of the Strouhal law during vortex shedding accounted for the numerical model.