STRUCTURAL MONITORING OF A HIGHWAY BRIDGE IN A HIGH-SEISMIC HAZARD URBAN AREA

A. D'Alessandro[1], S. Bongiovanni[2], A. Costanzo[1], A. Di Benedetto[3], A. Figlioli[2], S. Scudero[1], S. Speciale[1], G. Vitale[1]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Nazionale Terremoti, Rome, Italy
[2] Università di Palermo, Dipartimento di Scienze della Terra e del Mare, Palermo, Italy
[3] Università di Palermo, Dipartimento di Matematica e Informatica Palermo, Italy

Introduction. The stress factors acting on the structures can be due to natural or anthropogenic factors: earthquakes atmospheric agents (wind, thermal cycles), vibration due traffic flow, applied loads. All these factors, may lower the resistance properties of the structure therefore the Structural Health Monitoring (SHM) represents a fundamental tool to integrate and support conservation strategies of infrastructures and to preserve their functions. The function which describes the behavior of a structure will be dependent on the structural parameters obtained with the building monitoring. Such parameters may change after an earthquake, or even after extreme phenomena, and the continuous SHM enable to verify if the general parameters of the building have changed as today widely accepted (Calvi *et al.*, 2006 for a complete review).

In the framework of RAFAEL (System for Risk Analysis and Forecast for Critical Infrastructures in the AppenninEs dorsaL Regions) project, the case study as critical infrastructure to monitor is a bridge in Catania (Sicily, Italy). This viaduct is called "San Paolo bridge (Fig. 1); the choice of this structure has several reasons: i) it is the longest viaduct in the highway surrounding the city of Catania and part of the E45 European motorway corridor; ii) the seismic hazard of Catania is among the highest in Italy (expected horizontal peak acceleration up to 0.25 g); iii) the viaduct was built about 35 years ago, when the seismic classification and building codes were different. In this paper, we present the preliminary results of the tests performed for the characterization of the structure and its foundation soil.

Fig. 1 - a: Google Earth view of S. Paolo bridge (the arrows indicated the segment under investigation) and plan view of sensors location for the experiments; b: lateral view (southern flank) of the structure; c: location of the posthole (50 m deep) seismometer and ground-level accelerometer.

Geophysical investigations and bridge experiments. The bridge has a total length of about 378 m and consists of 10 spans. The first and last span have a length of 33.55 m, the remaining have a length of 34 m except for the span between columns 6 and 7 which has a double length of 73 m. The bridge is supported by 9 columns and the monitored span is between the columns 4 and 5 (Fig. 1).

Geophysical investigations have been carried out in order to characterize the soil foundation below the bridge. These investigations would have also suggested the depth of the seismic bedrock, and therefore the depth of the perforation in which install a sensor with the objective to record the ground motion without being altered by the interaction with the bridge.

The seismic tomography was realized under the western half of the bridge (columns 1-6). The resulting 2D profile shows a difference in the thickness of the surface layer between the two ends of the investigated line. It also clearly highlights the foundations in correspondence of the pillars (Fig. 2a). This difference in thickness at the ends of the investigated line was also observed by two 1D profiles obtained from MASW (Fig. 2b, c). Finally, from the microtremor measurements it is possible to observe the presence of two frequency peaks: one of about 1.6 Hz and one of about 4.3 Hz (Fig. 2d).

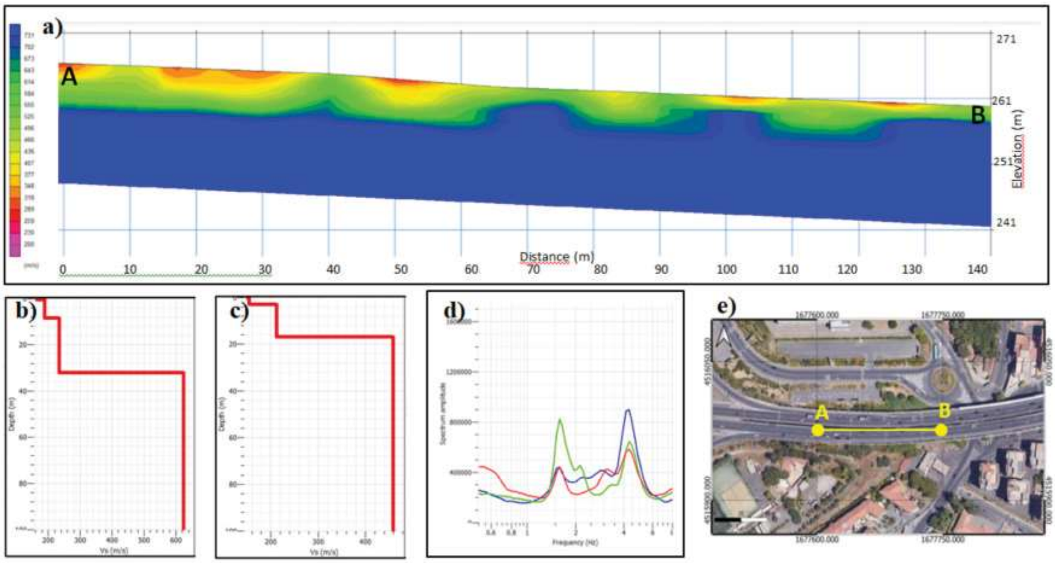

Fig. 2 - Results of geophysical surveys: seismic tomography (a), MASW (b and c), microtremor (d), and their location (e).

The results of the preliminary geophysical investigation suggested to drill the perforation at least 40 m deep. The perforation has been finally drilled down to 51 m and posthole 3-axial seismometer (model Nanometrics Trillium PH 120 s) has been placed its bottom (Fig. 1c) and set at 100 Hz sampling rate. A 3-axial accelerometer (Nanometrics Titan) has been placed at surface, next to the perforation top (Fig. 1c), at sample rate of 200 Hz. This couple of sensors, installed in January 2022, will be maintained installed for a long-term monitoring. In order to calibrate the velocimeter in the well, a velocimeter was installed at ground surface. Both sensors acquired a seismic event that occurred in January 2022. The difference between the surface and down-hole sensor is notable (Fig. 3). While the former is constantly affected by the noise of the morning traffic over the bridge (Fig. 3a), in the latter the waveforms of the event are clearly recognizable (Fig. 3b) even though a notable amount of noise is still present.

In order to characterize the vibrating modes of the bridge, a devoted experiment had been carried out in April 2022. It was a temporary experiment lasting some hours; because the

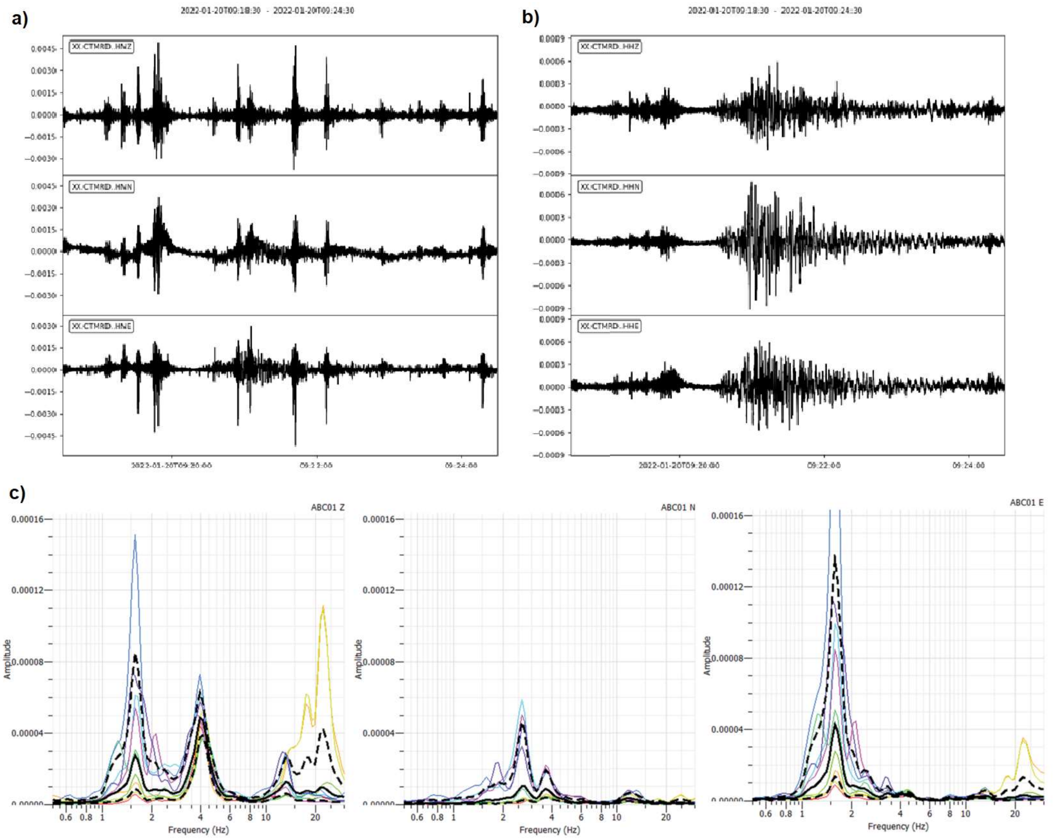

Fig. 3 - Comparison of the waveforms of a Mw 4.3 (20-01-2022 09:19:57) at 166 km recorded at S. Paolo bridge recorded with a Trillium PH 120 s located at ground surface (a) and recorded with an identical sensor placed at 51 m depth (b). Amplitude spectra for the three components of one of the velocimeters placed over the viaduct (c, see text for further information).

sensors were placed directly above the road, it was necessary to close the bridge to traffic. Overall, a set of 6 monitoring sites were placed in both edges of the road segment as reported in Fig. 1a. At each node were employed both a 3-axial velocimeters (Nanometrics Trillium Horizon 20s) and 3-axial accelerometers (Nanometric Titan). All the sensors were aligned in the same direction so that the two horizontal components coincide with the longitudinal and transversal directions of the bridge (Fig. 1a).

The tests consisted in the passage of a fully loaded vehicle at increasing velocity (20 km/h, 50 km/h and 80 km/h); the passage of a fully loaded vehicle, in an almost static way, over an obstacle of increasing thickness (2.5 cm, 5 cm, 9 cm) about 23 m from the column 4; the passage of a fully loaded vehicle at increasing velocity (20 km/h, 50 km/h, 60 km/h) braking at the centre of the span. As an example, we report the amplitude spectra of the signals triggered by the braking truck at 50 km/h speed over the monitored bridge segment (Fig. 3c). The spectra highlight differences between the components either in the frequencies and in the amplitudes which are ascribable to the mode of vibrations of the bridge.

Conclusions. The tests carried out at S. Paolo bridge are of extreme importance. In fact, with reference to road bridges of significant importance, dynamic load tests are mandatory in addition to static ones (NTC 2018). Dynamic monitoring consists in the processing of data detected by control instrumentation in response to dynamic disturbances present on the structure to determine the natural frequencies and the corresponding shapes of the vibrating modes.

Monitoring of vibration frequencies serve as a useful reference for evaluating the degradation in stiffness or strength of the structure, and even for identifying possible damages in the structure, say, due to long-term overloading and impacts by heavy trucks or earthquake shakings (Yangh *et al.*, 2004).

The development of a dynamic monitoring system therefore requires a knowledge of the natural frequencies and the shapes of the vibration modes of the structure and it is possible to obtain it by taking advantage of the vibrations induced by wind and traffic (Magalhães *et al.*, 2008). Among the significant sources of environmental excitation there is also the earthquake that produces a transient stress, the spectrum of which varies from one event to another. The limits of applicability of this excitation are linked to the fact that an earthquake is a sporadic event and can be detected with permanent monitoring systems (Aceti and Bressan, 2014).

The recorded data will allow to determine the natural frequencies and of the relative forms of the modes of vibration for the evaluation the dynamic behavior of the structure and to calculate the response of the structure following any dynamic stress acting on known characteristics such as an earthquake or a dynamic load of exercise.

Acknowledgements. The authors thank Dr. Giuseppe Macaluso and all the other members of ANAS team for support in the activities.

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