EXPERIMENTAL VALIDATION OF THE EFFECTIVENESS OF AUTOMATED OMA FOR STRUCTURAL HEALTH MONITORING OF EXISTING BRIDGES IN SEISMIC AREAS

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ABSTRACT

Bridges play an important role to ensure the efficiency of the transportation network and prompt rescue in the case of an emergency. However, most of the existing bridges have been designed and built according to outdated codes. Post-earthquake surveys have remarked the significant impact of strong seismic events on the road network. Structural Health Monitoring (SHM) systems can support the prompt assessment of bridges after seismic events. However, this has always been challenging due to the need of analyzing large amount of data. Effective vibration-based damage detection requires accurate modal parameter estimates automatically obtained from the analysis of the operational response of the monitored structure. However, earthquake shaking can also cause saturation of sensors aimed at resolving the ambient vibration response only, thus affecting the reliability of monitoring. The present paper aims at evaluating, against real data, the effectiveness of automated Operational Modal Analysis (OMA) for vibration-based SHM of existing bridges in earthquake prone areas. Shaking table tests have been carried on a 1:3 scale single span bridge representative of existing highway bridges built in the 60’s in Italy. The dynamic properties of the structure in operational conditions have been estimated first. Seismic input has been applied afterwards, and the structural response has been analyzed for damage detection. Results show that hidden damage can be identified on a remote basis, thus demonstrating the interesting applicative perspectives of automated OMA for fast health assessment of existing bridges in the early earthquake aftershock. The resilience to earthquake shaking of the SHM system has been also assessed, showing that a reliable modal-based monitoring before and after the earthquake by means of automated OMA is possible even in the presence of a measurement chain not specifically designed to resolve the strong motion response.

Keywords: modal tracking, structural health monitoring, earthquake
INTRODUCTION

Reinforced concrete (RC) bridges represent a majority of the Italian stock. However, most of them have been designed and built according to outdated codes. Thus, effective seismic protection of these structures is fundamental, not only because of the possible consequences of a collapse in terms of life losses, but also because they ensure the efficiency of the transportation network and prompt rescue in the case of an emergency. The experimental identification of the modal properties of full-scale structures represents an effective approach to gain knowledge about their dynamic and seismic behavior [1, 2], in particular when it is combined with shaking table tests. Moreover, modal-based damage detection is a promising technique for near real-time health assessment of structures in earthquake prone areas [3, 4]. In this perspective, advanced SHM techniques can be addressed as innovative measures of seismic protection and performance assessment.

Starting from real measurements collected during a large experimental campaign based on shaking table tests, the present study investigates the effectiveness of modal-based SHM of existing bridges in earthquake prone areas. The experimental tests allowed assessing the damage detection performance of the monitoring system, and its resilience to large earthquake shaking.

EXPERIMENTAL PROGRAM

A number of dynamic tests have been carried out on a scaled (1:3) bridge model (Fig. 1) of a RC single span bridge (more details can be found elsewhere [5]). The bridge model was tested under different configurations: (i) with roller and cylindrical hinge, and (ii) with friction pendulum isolators. A number of asynchronous shakings, at increasing PGA, were applied. Similar PGA scalings were considered for the as-built and the isolated bridge for performance comparison. The health assessment of the structure was carried out by comparing the modal properties, estimated from ambient vibrations, before and after the shakings and with turned off shake tables. Output-only modal identification was based on data collected by a measurement system replicating a typical vibration-based SHM system installed on existing bridges. The accelerometers installed on the superstructure (Fig. 1) had the following characteristics: ±0.25 g full scale range, 40 V/g sensitivity, 140 dB dynamic range; ±4 g full scale range and 2.5 V/g sensitivity characterized the additional four accelerometers. The data acquisition system had the following main features: 16 bit ADC and on-board anti-aliasing filter. A sampling frequency of 100 Hz was adopted.

An innovative automated OMA algorithm, called ARES (acronym for Automated modal paRameter Extraction System) [6], has been applied to process ambient vibration data. The algorithm is based on the combination of different OMA techniques in order to make easier the analysis and interpretation of the stabilization diagram.

 Modal parameter tracking for damage detection

Modal parameter tracking results for the retrofitted configuration are shown in Fig. 2. No drops in the natural frequency sequences can be observed, confirming that no damage occurred as a result of shaking when the structure was equipped with friction pendulum isolators. These results indirectly confirm the effectiveness of the retrofitting intervention, since it preserved the structure from earthquake-induced damage. Modal parameter tracking results for the as-built configuration of the bridge are shown in Fig. 3. Clear drops in the natural frequency sequences can be observed, confirming the occurrence of damage as a result of the applied shakings.

Resilience of the SHM system to large earthquake shaking

The accuracy of modal parameter estimates strongly affects the effectiveness of damage detection methods, in particular at low damage level. Sensor saturation due to high amplitude vibrations can negatively affect the accuracy of the estimates and, as a consequence, the reliability of damage detection. Thus, resilience of the measurement chain is critical to ensure the adequacy of a modal-based SHM system for applications in earthquake prone areas.
In order to assess the reliability of vibration measurements right after a strong shaking, the traces of two PSD matrices, computed from measurements carried out right before and right after a shake table test able to saturate the sensors, have been compared (Fig. 4). Measurements refer to the last test on the as-built bridge, with shake tables on and still. The disturbance due to the testing equipment prevented a reliable identification of the modal parameters of the bridge when the shake tables were on. However, Fig. 4 clearly shows that the two datasets share common frequency content, with dominant frequency components given by the operation of the testing equipment. This result confirms that the vibration-based monitoring system installed on the structure was able to provide reliable measurements even right after a strong shaking causing saturation of the sensors devoted to resolve the ambient vibration response of the bridge.
3. CONCLUSIONS

The effectiveness of automated modal parameter monitoring for vibration-based SHM of existing bridges in earthquake prone areas has been assessed against real data. Shake table tests of a bridge model characterized by different support conditions (simply supported, with friction pendulum isolators) have been carried out. The obtained results have confirmed the potentialities of SHM systems in remotely detecting damage. The collected results have also shown that, even in the presence of a measurement chain not specifically designed to resolve high amplitude vibrations, a reliable monitoring of the modal properties before and after an earthquake by means of automated OMA techniques can be accomplished.

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