Validation of Wireless Monitoring Technology Densely Instrumented on a Full-Scale Concrete Frame Structure

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ABSTRACT: In this study, a new generation wireless structural health monitoring (SHM) device, named *Martlet*, together with its precursor wireless unit, *Narada*, have been installed on a full-scale two-story, two-bay concrete frame structure for performance validation. The performance of the wireless sensing system is compared with a high-precision cabled sensing system. The results demonstrate that the accuracy of the wireless sensor data is comparable to that of the counterpart cabled system. Using the data collected by the densely deployed wireless and cabled sensors, detailed modal properties of the structure are identified.

Test Structure and Measured Data

The concrete test frames were built at full scale outside the Structural Engineering and Materials Laboratory on Georgia Tech campus (Figure 1). Four identical frames and two strong collapse prevention frames were constructed. The total of six individual frames are separate from each, with a gap between every two neighboring frames. Figure 2 shows the main dimensions of the test frame, which consists of two bays and two stories and was meant to be representative of low-rise reinforced concrete office buildings in the central and eastern United States built in the 1950s-1970s, when non-ductile reinforced concrete frames were built before modern seismic code was used. Frame 1 is an as-built bare frame as the reference structure, while different seismic retrofit measures are applied to the other three frames for seismic research. This report shows results from Frame 1 only. The locations of the two shakers provided by NEES@UCLA are shown in Figure 2. A portable 980 lb-in eccentric mass shaker and a 75-kip hydraulic linear inertial shaker are mounted on the first and the second elevated slab, respectively. As the experiment carries on, the excitation amplitude generated by the linear shaker increases, gradually causing damage to the concrete frame. The eccentric shaker is used for low amplitude sine sweeping.

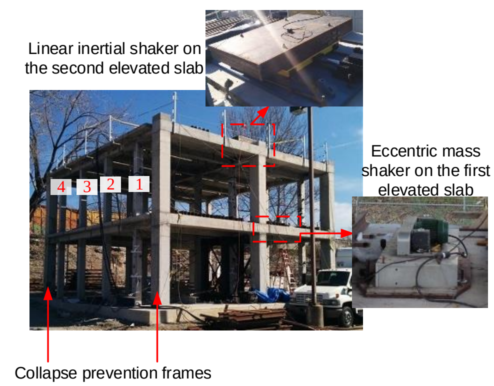


Figure 1. Photo of test frames and two shakers on Frame 1 under test

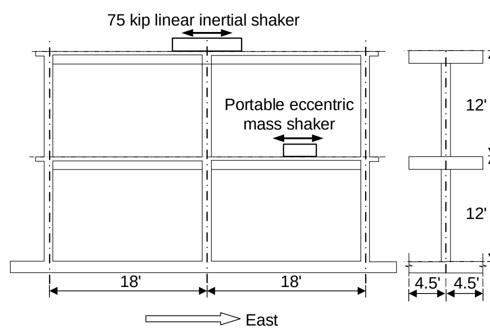
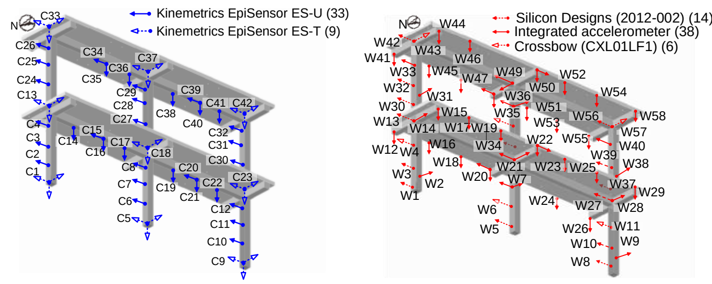


Figure 2. Elevation and side-view drawing

As shown in Figure 3(a), the frame is first installed with 42 Kinemetrics cabled accelerometers (EpiSensor ES-T and ES-U) on columns and girders (60 data acquisition channels in total) to capture the acceleration responses. To increase spatial resolution of the instrumentation, 23 *Narada* and 13 *Martlet* wireless units with overall 66 acceleration channels are interspersed between cabled accelerometers on the columns, girders and slabs (Figure 3(b)). As a result, there are a total of 126 acceleration channels installed on the structure, including both cabled and wireless channels. Details about *Narada* and *Martlet* wireless units can be found in [1-3].

Figure 4 presents the example acceleration time histories recorded at a beam-column joint on the first elevated slab (C13 and W13). The data is collected when the linear shaker operates with a scaled El Centro earthquake record. In this test, the El Centro record is scaled such that the corresponding maximum displacement is 4 inches. The amplification gain and cutoff frequency of the integrated accelerometer node is set to be ×20 and 25 Hz, respectively. A 25 Hz low-pass digital filter has been applied to both the wireless and cabled data sets so that signal in the same frequency range is compared. Figure 4 shows the close-up comparison of acceleration time histories and the corresponding frequency spectra. The data shows that the accuracy of the wireless sensor data is comparable to that of the counterpart cabled system.



(a) Cabled sensing system (b) Wireless sensing system

Figure 3. Accelerometer instrumentation on Frame 1

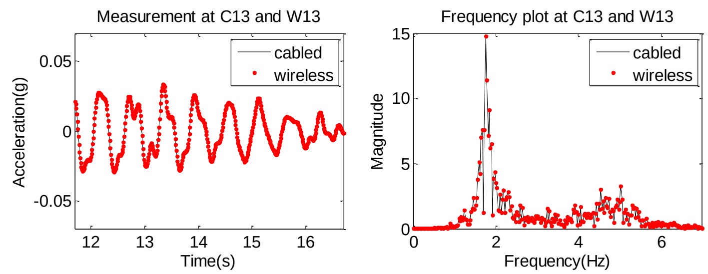


Figure 4. Close-up comparison of acceleration time histories and frequency spectra between cabled and wireless system

SHM Methodology and Results

Using an accelerometer mounted on the moving mass of the shaker, the shaker force record can be estimated as a dynamic input to the structural system. With a known input to the system, frequency response functions (FRFs) can be calculated for all response DOFs instrumented with cabled and wireless accelerometers. The commonly used eigensystem realization algorithm (ERA) is applied to extract the structural modal properties. Because the unidirectional inertial shaker force is along the horizontal in-plane direction, this report focuses on extraction of in-plane mode shapes of the frame.

Three sets of data are analyzed herein when the linear shaker operates with a scaled El Centro record, with the corresponding maximum displacement scaled to 1”, 2” and 4” respectively. The first three in-plane modes are extracted from ERA method. El Centro 1” and 2” results are obtained by using data from the cabled system only (52 channels used). The first mode shape shows all

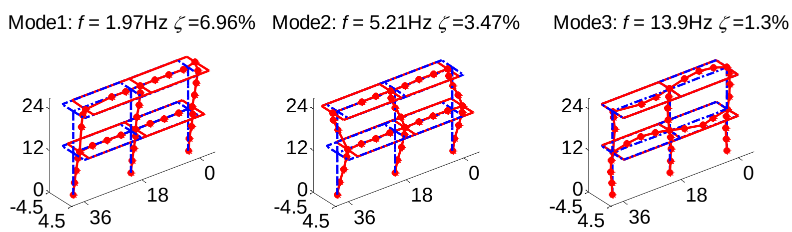


Figure 5. First three identified mode shapes of Frame 1 (El Centro 1”)

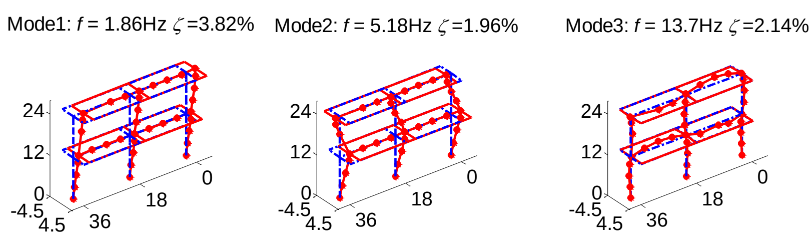


Figure 6. First three identified mode shapes of Frame 1 (El Centro 2”)

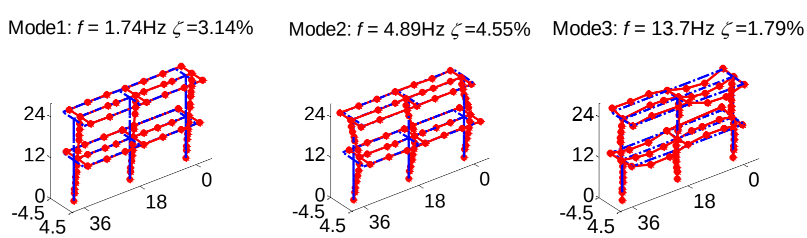


Figure 7. First three in-plane mode shapes of Frame 1 (El Centro 4”)

nodes moving along one direction, which is expected for this frame structure. Figure 6 shows each of the three resonance frequencies found in El Centro 2” decreases with respect to the previous El Centro 1” results. Overall, the three mode shapes are close to those in Figure 5.

Finally, Figure 7 shows modal analysis results from the El Centro 4” test. Both cabled and wireless acceleration data, 95 channels in total, are used. The resonance frequencies of the first and second identified modes decrease further, compared with the El Centro 2” results. With more sensor channels available for modal analysis, more detailed vibration modes can be obtained. This is particularly the case for the third mode, where vertical vibration of the concrete slabs is captured by the wireless accelerometers.

The decrease in resonance frequencies is possibly due to the damage on the structure caused by the shaker excitation, and the difference observed among results from three sets of data can be a promising indicator for locating and assessing the severity of damage on the structure.

Lessons Learned

The performance of a recently-developed wireless sensing unit, *Martlet*, and its precursor wireless unit, *Narada*, have been evaluated during the experiment. The acceleration time histories are compared between wireless and cabled systems, illustrating that the wireless data achieves comparable quality to the cabled data. In addition, modal properties of the structure are successfully obtained by using both the wireless and cabled acceleration data. The decrease in the resonance frequencies of the frame structure may indicate the existence of damage on the structure, and meanwhile, the difference in the mode shapes may help to localize and assess the severity of structural damage. In the future, data collected from more tests at different stages will be analyzed so as to assess the growth of structural damage through the course of experiment. In addition, more vibration modes may be obtained by analyzing structural response data from other shaker excitations.

Acknowledgements

This research is partially sponsored by the National Science Foundation (#CMMI-1041607 and #CMMI-1150700). Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the sponsors.

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