Dynamic testing of a pre-stressed concrete highway bridge using *Martlet* wireless sensing system

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ABSTRACT: This study presents a field test of the *Martlet* wireless sensing system installed at an in-service pre-stressed concrete highway bridge. Four types of sensors are interfaced with *Martlet* in this test, including accelerometers, strain gages, strain transducers and magnetostrictive displacement sensors. The acceleration, strain and displacement responses of the bridge due to traffic and ambient excitations are measured. To obtain the modal properties of the bridge, hammer impact tests are also performed. The results from the field test demonstrate the reliability of the *Martlet* wireless sensing system. In addition, detailed modal properties of the bridge are extracted from the acceleration data collected in the test.

Test Structure and Measured Data

The testbed bridge was built in 2006, located on the highway SR113 over Dry Creek in Bartow County, Georgia, USA. The bridge has two lanes carrying the eastbound traffic. Figure 1 shows the plan and elevation view of the entire bridge. The bridge consists of three skewed spans, 70 feet long each. The continuous reinforced concrete bridge deck is supported by five I-shaped pre-stressed concrete girders, denoted as G1 ~ G5. The girders are spaced 8 feet and 9 inches away from one another, connected by lateral diaphragms and simply supported at the two ends of every span. The east span here is chosen for instrumentation due to its accessibility. Overall, the bridge is in a very good condition. The wireless sensing system used in this test is named *Martlet* [1]. Four types of sensors, including integrated accelerometer, strain gage, strain transducer and magnetostrictive displacement sensor, are interfaced with *Martlet* through corresponding sensor boards (Figure 2). The integrated accelerometer board is used together with a low-cost MEMS accelerometer with on-board signal conditioning that performs mean shifting, low-pass filtering and amplification [2]. The strain gage board is used together with a 90mm strain gage, providing selectable amplification gains and low-pass filtering. The strain transducer board is developed to work together with a Bridge Diagnostics Inc. strain transducer, supplying 3.3V power and on-board signal conditioning. The smart ADC/DAC board is connected with a MTS magnetostrictive linear-position displacement sensor, powering the sensor at 5V and providing programmable amplification gain and on-board low-pass filtering.

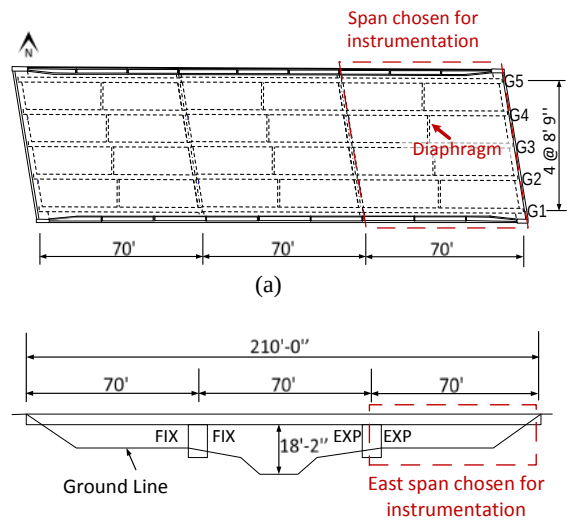
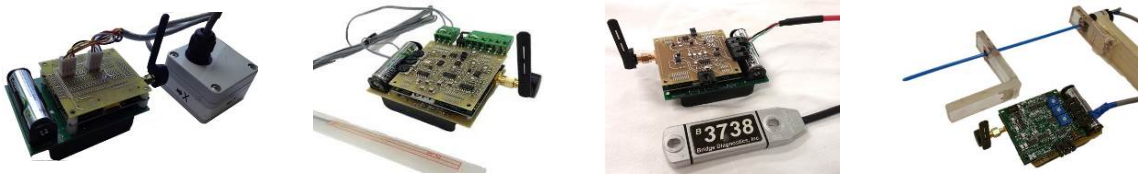


Figure 1. (a) Plan view, (b) Elevation view



(a) (b) (c) (d)

Figure 2. Wireless sensing system (a) integrated accelerometer board, (b) strain gage board, (c) strain transducer board, (d) smart ADC/DAC sensor board with the displacement sensor

In order to capture the bridge vibration and deformation under traffic excitations and to obtain bridge modal properties, a total of 15 integrated accelerometers, 20 strain gages, 2 strain transducers and 4 magnetostrictive displacement sensors are instrumented on the bridge. As shown in Figure 3(a), the accelerometers are instrumented at the bottom of every girder at quarter span and mid-span locations to measure vertical accelerations. The strain gages are installed at the top and bottom of the girders at quarter spans to measure the longitudinal deformation. The two strain transducers are installed at the bottom of the two south girders at mid-spans. The four magnetostrictive displacement sensors are installed at the two ends of the middle girder G3 to measure girder end displacement relative to the pier cap (Figure 3(b)). The east direction here is used as the positive direction.

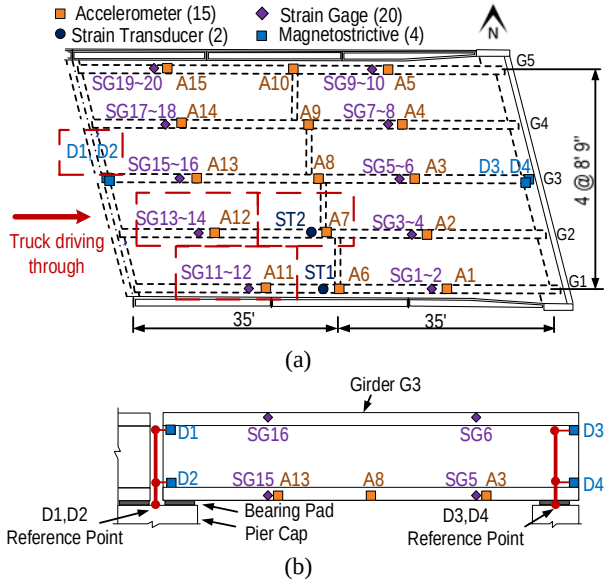


Figure 3. Instrumentation: (a) instrumentation plan, (b) elevation view of girder G3

SHM Methodology and Results

Bridge vibration responses are measured under different traffic excitations. The sampling frequency is set as 100Hz for all sensing channels. Figure 4 shows the comparison of the vibration responses under two truck excitations, including a small truck and an 18-wheeler passing through the bridge, respectively. For each case, larger vertical accelerations occur at the bottom mid-span of girder G2 and G3. The same trend is observed in the tensile strain measurements at the bottom of the girders. The displacement responses measured by sensors D1 and D2 located at the end of girder G3 also indicates a convex bending curvature of the girder under traffic excitation.

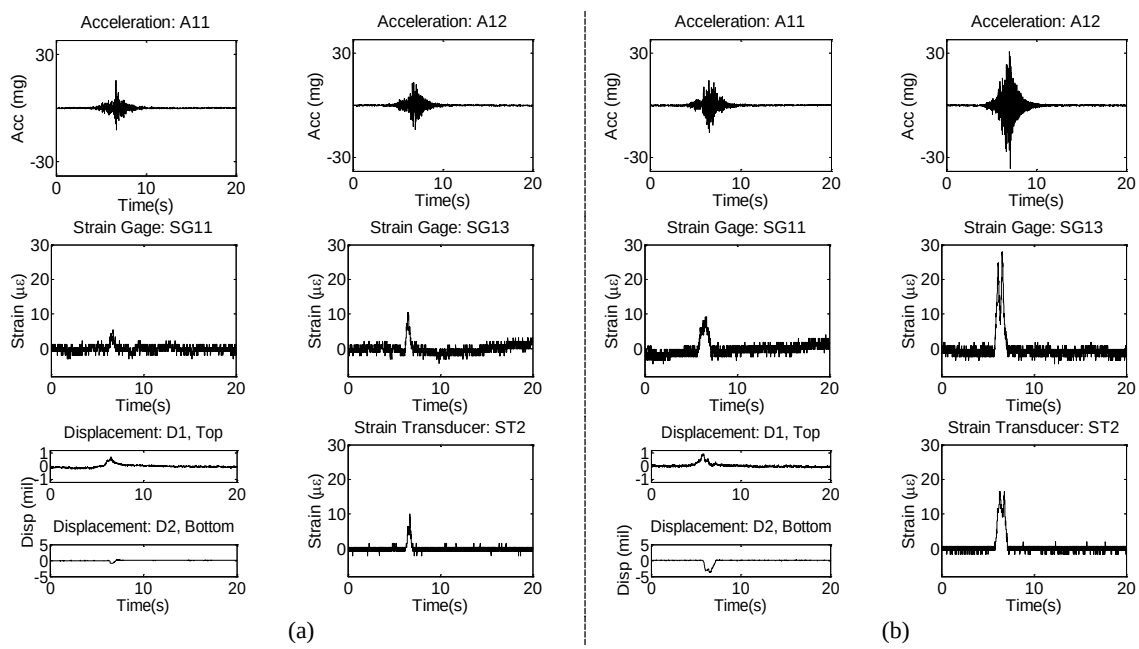


Figure 4. Bridge vibration measurement: (a) small truck, (b) 18-wheeler

Compared to the small truck case, the magnitudes of the bridge responses excited by the 18-wheeler are clearly larger as shown in all the acceleration, strain and displacement measurements. Overall, the vibration

measurements of the bridge under traffic excitation demonstrate the reliability and versatility of the *Martlet* wireless sensing system and its potential ability to detect truck weight.

In order to obtain modal properties of the bridge, an impact hammer is used to generate an excitation on the bridge deck at the mid-span of girder G1. The response is sampled at 1000Hz for 15 seconds. The acceleration responses are analyzed to extract the resonance frequencies, damping ratios and the corresponding mode shapes of the bridge, using eigensystem realization algorithm. The first four modes are obtained (Figure 5). Mode 1 shows all five girders bending in one direction. Mode 2 shows opposite bending motions among girder G1, G2 and G4, G5. Mode 3 shows the opposite bending motions among side girders G1, G5 and middle girders G2, G3, G4. Mode 4 shows the alternating bending motions among girder G1, G2, G4 and G5. All the modes agree well with the typical behavior of a simple supported bridge span.

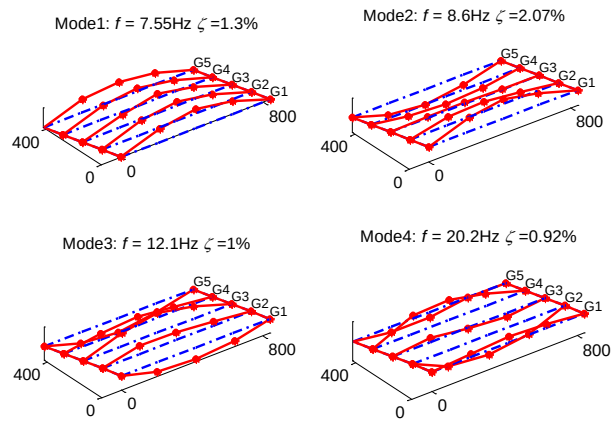


Figure 5. Bridge vibration modes

Lessons Learned

This research presents a field test of the *Martlet* wireless sensing system, interfaced with four types of sensors to capture the bridge responses under various traffic excitations. The responses are measured and compared as a small truck and an 18-wheeler driving through the bridge, respectively. Clear differences in response magnitudes are shown in all four types of sensor measurements. In addition, the acceleration measurement during impact hammer tests are used to obtain bridge modal properties. Overall, the low-cost yet versatile *Martlet* wireless sensing system shows reliable performance during the field test and the potential to be used in various applications. Interested readers are referred to the original conference paper [3] for details.

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