Full-Scale Laboratory Validation of Vibration-Based Damage Assessment using Stochastic Subspace Identification and Particle Swarm Model Updating

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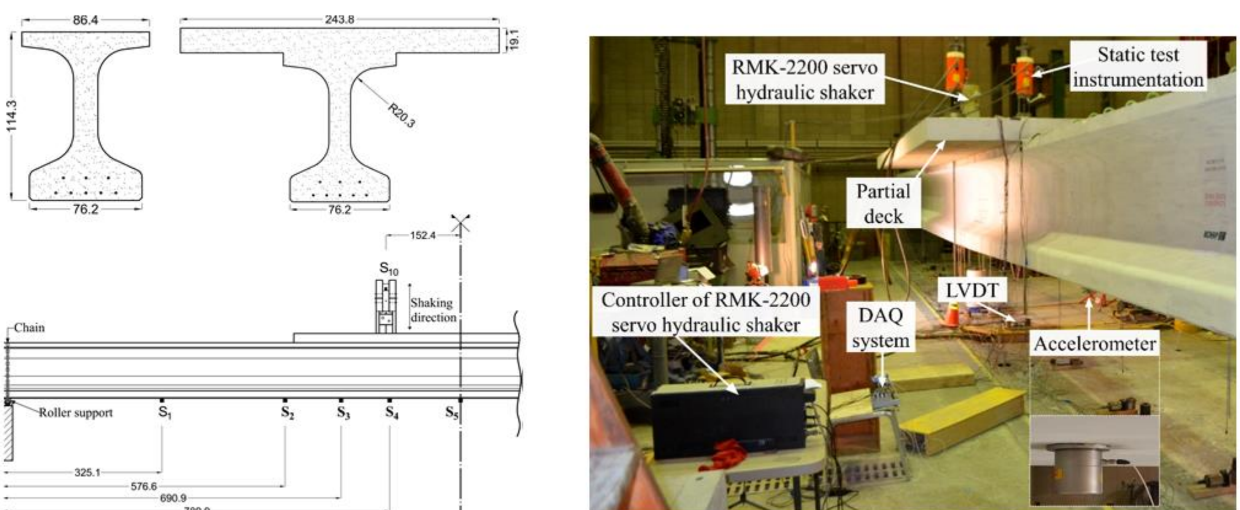
ABSTRACT: Vibration-based damage localization and quantification was conducted on a full-scale pre-stressed concrete beam supporting a partial deck. The algorithm consisted of extracting modal properties from a network of accelerometers using stochastic subspace identification, and updating a physical representation to match these properties using particular swam optimization.

Test Structure and Measured Data

Full-scale laboratory validation [1] was performed on a full-scale pre-stressed girder supporting a partial deck. The girder is a standard pre-stressed bulb-tee type C girder designed by the Iowa Department of Transportation. It has a depth of 1.14 m (45 in), spans 18.3 m (60 ft), and its partial deck is extending symmetrically about mid-span over a length of 6.80 m (22.3 ft). Figure 1a shows the cross-sectional dimensions of both the girder and composite sections. The is a 41.36 MPa (6 ksi) concrete with eight 1.52 mm (0.6 in.) low relaxation tendons applying a total prestressing force of 1513.73 kN (340.3 kips). The deck was casted in-place using a 27.60 MPa (4 ksi) concrete.

The test was excited using an RMK-2200 servo hydraulic shaker applying a white noise excitation over 80 sec that generated a response acceleration ranging between 50-150 mg. The response of the structure was collected using nine accelerometers mounted to the bottom surface of the girder, and one additional accelerometer was mounted to the top of the actuator. Two different types of Seismic ICP® uniaxial piezoelectric accelerometers were used for this experiment: five model 393C, and four model 393B04 from PCB. Figure 1a (bottom) shows the location of the shaker and sensors. Figures 1b is a picture of the experimental configuration.



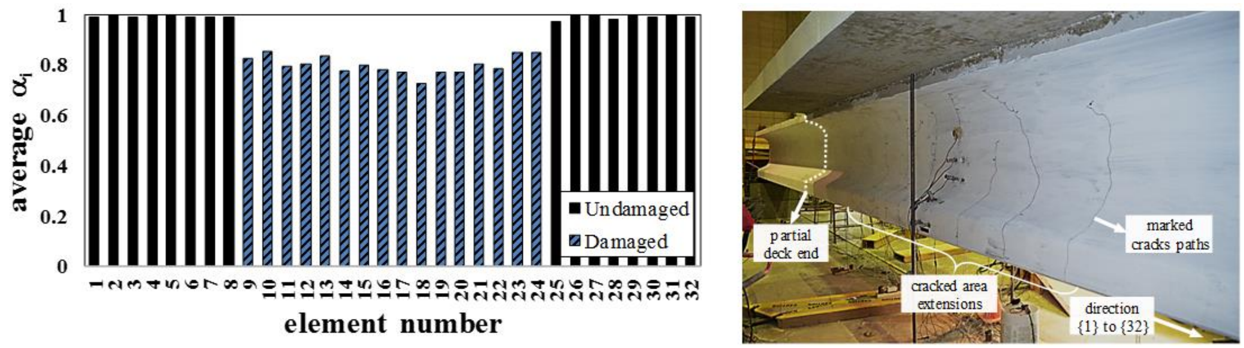
(a) (b)

Figure 1. (a) Cross-sectional dimensions of girder (top) and composite (bottom) sections showing location of accelerometers (dimensions in mm); and (b) picture of experimental configuration.

SHM Methodology and Results

The structural health monitoring (SHM) method consisted of extracting modal information, including modal frequencies and shapes, using the stochastic subspace identification (SSID) algorithm described in Ref. [2]. Subsequently, a reduced order stiffness matrix was reconstructed based on the system equivalent reduction expansion process (SEREP). Lastly, a finite element model (FEM) was constructed and updated using particle swarm optimization (PSO) to match the extracted reduced order stiffness matrix and extracted modal properties.

Fig. 2 shows a typical result extracted from Ref. [1]. Fig. 2(a) is a plot of the extracted average damage index α per sections of the beam separated in element numbers. Elements 9-24 correspond to location of the composite section where cracks where visually observable, shown in Fig. 2(b). Results from the algorithm were validated against the beam's secant stiffness (see Ref. [1]) that exhibited a good match.



(a) (b)

Figure 2. (a) damage index α versus girder element number; and (b) picture of cracked specimen.

Lessons Learned

Results from the full-scale laboratory investigation showed the promise of the SHM methodology at conducting damage localization and quantification using a network of accelerometers. While only a brief summary of results are here discussed, the methodology was capable of extracting different levels of damages: "no damage", "approach to yielding", and "yielding". A difficulty in the exercise was the validation of the quantification of damage beyond numerical demonstrations. During the test, LVTDs were used to monitor the absolute displacements of the beam, and we were able to validate some results through the comparison of experimental-based and model-based deflections shapes. We were also able to validate against the secant stiffness of the beam. Further experiments were recently conducted on two full-scale concrete beams linked by a concrete deck. The experiment is discussed in Ref. [3], and the above-mentioned SHM methodology will soon be applied to experimental data, this time fusing data from both strain gauges and accelerometers.

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