# Structural Health Monitoring of Bridge Abutments using Imaging Radar and Digital Image Correlation

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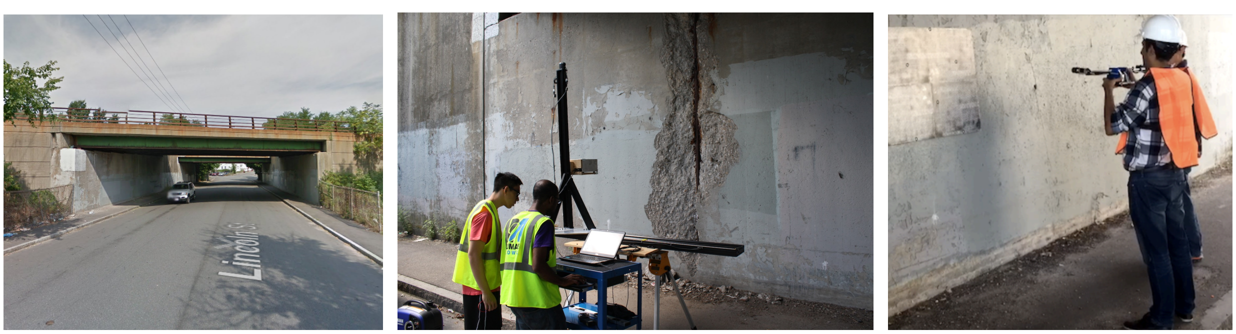
**ABSTRACT:** In this study, a local composite bridge was monitored by portable sensors (an imaging radar sensor and a digital image correlation (DIC) sensor) for surface and subsurface sensing of bridge abutments. The combination of radar (subsurface) and DIC (surface) enables civil engineers to monitor bridge abutments in a multiphysical approach, allowing changes of different nature in bridges to be detected. From our experimental result, locations of subsurface steel rebars are detected by the imaging radar sensor, as well as changes in surface displacement and stress distribution are reconstructed by the DIC sensor.

## Test Structure and Measured Data

A local bridge (L-15-74) in the City of Lowell, MA on the Lowell Connector (U.S. Highway 3) and crossing Lincoln Street was selected for the monitoring effort. Fig. 1 shows the location and a picture of the bridge. As shown in Fig. 1, there are two structures of the bridge; the northbound section and the southbound section. Bridge abutments of both sections were monitored by radar and DIC.



(a) L-15-74 bridge (b) Radar imaging of bridge abutment (c) DIC sensing of bridge abutment

**Fig. 1**. Test structure and radar-DIC sensing

A commercial DIC sensor (Aramis®, Trilion Quality Systems and GOM mbH) was used to monitor long-term displacement and surface distressing of bridge abutment. Fig. 1 (b) shows the data collection scheme of the DIC sensor. In our current measurement scheme using DIC, a stochastic pattern needs to be applied to the surface of interest in order to take a series of photographs are taken by both cameras of the surface at different deformation levels. A custom-built imaging radar sensor (center frequency = 10 GHz, bandwidth = 4 GHz) based on stripmap synthetic aperture radar (SAR) imaging algorithm [1] was developed for locating subsurface steel rebars in bridge abutment. Fig. 1 (c) shows the data collection scheme of the imaging radar sensor. Instrumentation of both sensors can be either portable or hand-held.

## SHM Methodology and Results

Derived from digital shearography, DIC is a three-dimensional technique for static and dynamic inspection of materials and structures [2]. The DIC sensor used in this case study consists of a pair of camera lenses installed on a supporting bar at a fixed distance. Two digital images from same location are simultaneously collected each time, and images collected at different times are compared to determine displacement and stress field distribution. Bridge abutment displacement of the southbound section of the L-15-74 Bridge was monitored on 09/14/12, 10/11/12, 02/05/13 and 04/24/13, from nine photogrammetric targets. Displacement results are shown in Fig. 3.

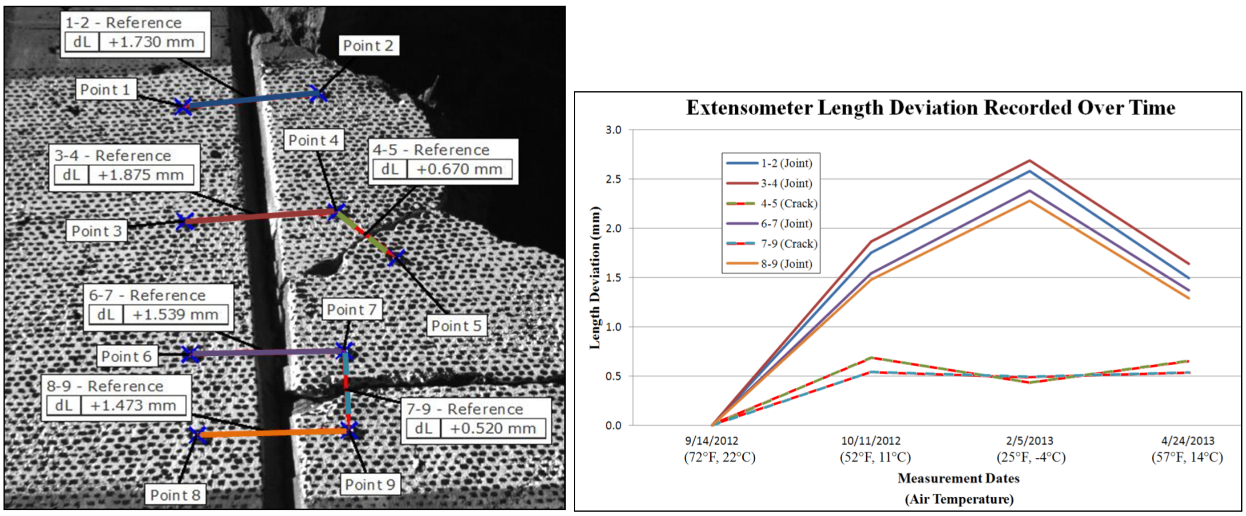
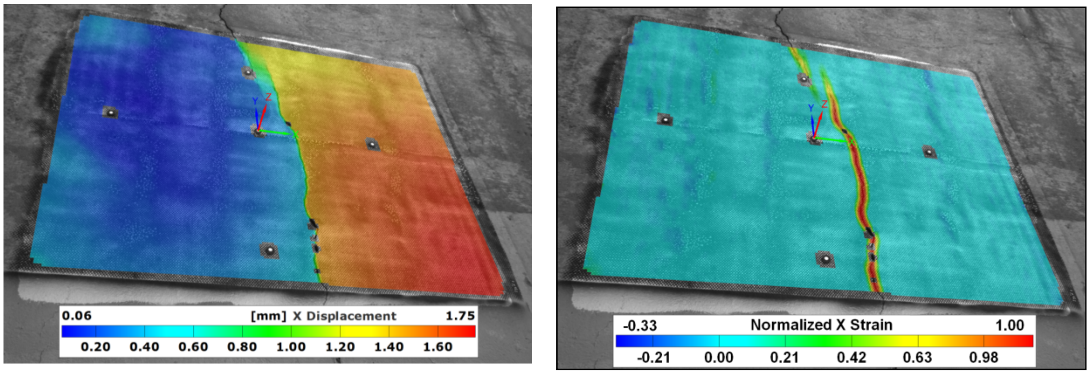



**Fig. 3.** (left) Photograph of bridge abutment with nine photogrammetric targets denoted by blue X's and extensometers between targets indicated by color-coded lines. (right) Length deviation of photogrammetric target extensometers monitoring joint and cracks widths on a bridge abutment.

In Fig. 3, the solid lines represent length deviations of extensometers measuring across the joint between the abutment and retaining wall, and the dashed lines represent measurements across cracks. Fig. 3 shows the joint between the abutment and retaining wall opened to a maximum of approximately 2.5mm in February and at last measurement (04/24/13) was approximately 1.5mm wider than the initial joint width measured in September. The opening of the joint is likely caused by thermal contraction of the concrete, not damage. Both cracks have opened approximately 0.5mm and are currently fluctuating around that width. Unlike the joints, the crack widths do not appear to correlate with temperature and therefore could indicate some permanent deformation from damage has occurred. These results show that long term monitoring of relative displacements can be performed using photogrammetric targets.

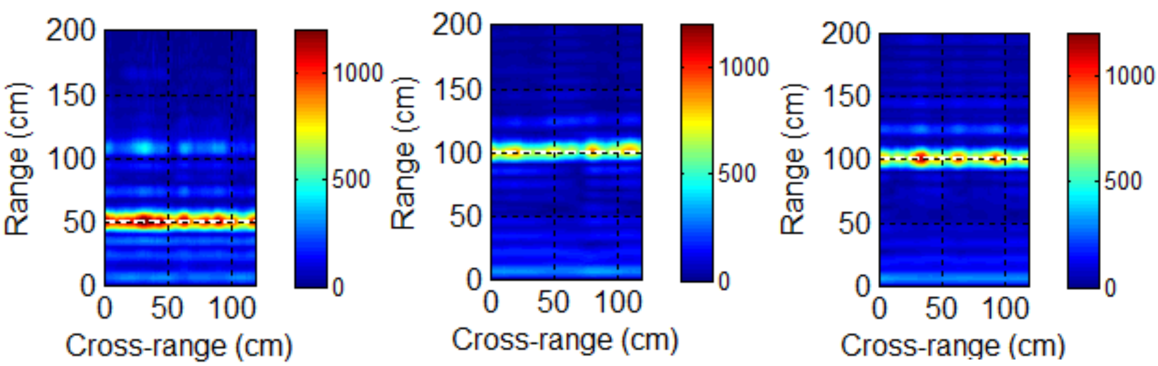
Fig. 4 provides the monitored displacement and normalized stress in the horizontal direction (in-plane). The result indicates the growth of a crack on the bridge abutment.

The imaging radar sensor mainly consists of a horn antenna, a modulator, and a signal amplifier. In-depth information of the test structure was reconstructed by SAR imaging and rendered in the range--cross-range plane. The range axis is the radar line-of-sight direction, while the cross-range axis is the direction the radar sensor travels. Fig. 5 shows in-depth radar images of three locations (1 and 2) at ranges = 0.5m and 1m. In Fig. 5, the part of SAR image on the range axis beyond the target location indicates the subsurface region of the target. For instance, the SAR image beyond range = 0.5m (50cm) in Fig. 5(a) is the subsurface region. A white-dashed line is added to the SAR images in Fig. 5 to indicate the location of bridge abutment surface line. In these SAR images, the amplitude indicates level of electromagnetic reflection from both the surface and subsurface regions. In Fig. 5(a), both surface reflection from concrete and subsurface reflection from steel rebars are present, while in Figs. 5(b) and (c) the subsurface reflection (shown in red scatterers) becomes dominant. Five steel rebars are identified in these SAR images.




(a) Horizontal displacement (b) Horizontal normalized strain

**Fig. 4.** Full-field horizontal displacement and strain of bridge abutment (from 09/13/12 to 02/02/13).




(a) Range = 0.5m (location 1) (b) Range = 1m (location 1) (c) Range = 1m (location 2)

**Fig. 5.** SAR images at different ranges and different locations on the bridge abutment.

## Lessons Learned

1) DIC can be used to monitor surface displacement and distressing; 2) In-situ calibration is important for improving the accuracy of DIC measurement; 3) When using radar images for subsurface sensing, surface reflection (specular return) is inevitable and must be removed; 4) Attenuation patterns of surface reflection (noise) and subsurface reflection (signal) are different and can be used to improve the signal-to-noise ratio in subsurface sensing.

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