EVALUATIONS OF MULTIPLE NON-DESTRUCTIVE TECHNIQUES ON TOP AND BOTTOM SURFACES OF A REINFORCED CONCRETE BRIDGE DECK

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Abstract

This study is intended to assess the integrity of a reinforced concrete bridge deck at the Missouri S&T campus using non-destructive testing (NDT) methods performed at top and bottom surfaces of the bridge deck. These utilized methods are named ground generating radar (GPR), impact echo (IE), and ultrasonic surface waves (USW). GPR was applied using 1.6 GHz and 2.5 GHz antennas to transmit and receive electromagnetic radio waves at embedded concrete reinforcement or distinct contacts between solid and loose concrete materials with different dielectric properties. Due to significant variations of the apparent depth to top of the embedded reinforcing steel bars, it was difficult to interpret the GPR results for the bridge deck assessment. Therefore, GPR results are often calibrated in application with ground truth data from either borehole tests or other non-destructive methods, such as IE and USW. IE and USW are based on the reflection of the acoustic waves at discontinuity (e.g., delamination). Both IE and USW data were acquired using portable seismic property analyzer (PSPA) device. USW is used to measure the variations of Young's modulus of concrete deck and IE is used to measure depth to possible embedded defects in concrete deck. Eventually, USW and IE results were used as an indicative of the concrete quality of the bridge deck. An approximately 10 x 9 ft. sections were surveyed at the top and the bottom surfaces of the bridge deck in order to evaluate and correlate the three NDTs results for the bridge deck assessment.

1. Introduction

Bridges are continuously aging and deteriorating with time passing due to multiple physical, chemical and bacterial deterioration processes which may develop and cause problems in form of spalling, reinforcement corrosion, concrete leaching, cracking, etc. as shown in (Figure 1). The effective and reliable bridge assessment is required to keep the integrity and serviceability of bridges and essential to reduce the cost involved in repairing and replacing deteriorated bridges.

Therefore, NDTs are commonly used in bridge evaluations and can provide a rapid and cost-effective bridge assessment [1]. For instance, the repairing and replacing cost of the deteriorated U.S. highway bridges was estimated by the FHWA at approximately $100 billion [2-3]. Therefore, understanding the deterioration process is necessary to select the appropriate non-destructive techniques for bridge deck assessment [2-5].

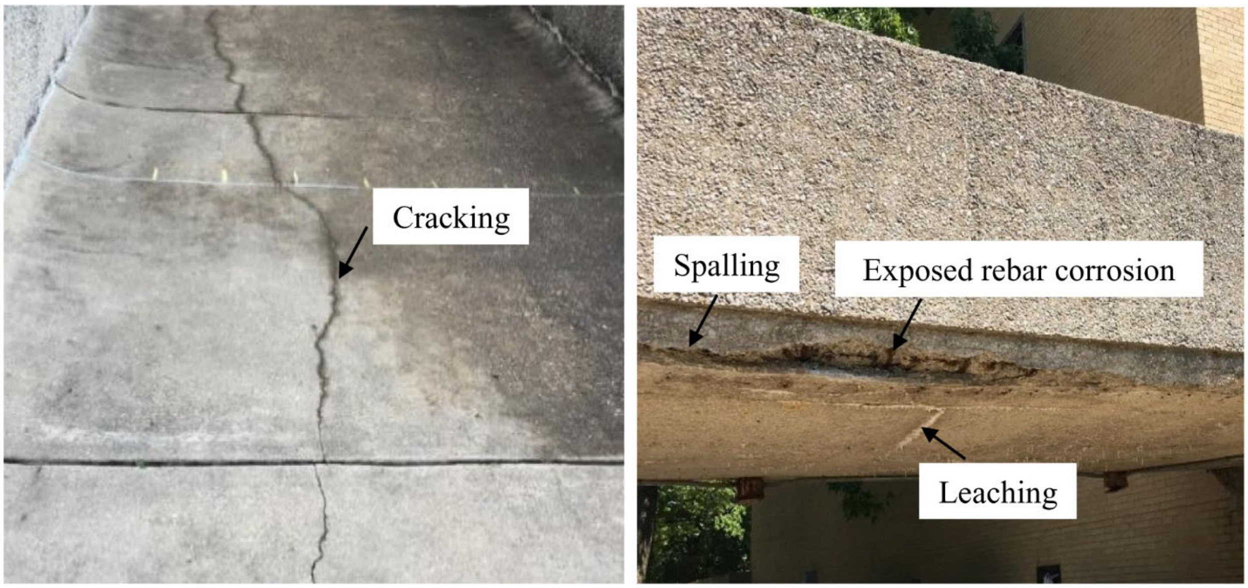

Figure 1: Bridge deck deterioration

GPR is a non-destructive method used widely in bridge evaluations. GPR depends on the transmission and receiving of electromagnetic (EM) waves that propagate through the subsurface materials. The reflected EM signals are recorded and then used to detect some embedded features (e.g. delamination, and rebar corrosion) based on the changes of electrical conductivity and dielectric properties of the subsurface materials [6]. Furthermore, GPR responds to the presence of saline moisture and can be used to determine the relative concrete condition by identifying areas where there is probably a low to a high concrete deterioration has occurred. Based on data interpretation, relative concrete condition is determined as good (no deterioration), fair (moderate deterioration), poor (extensive deterioration) [7-8].

IE and USW are non-destructive methods used widely in bridge evaluations. IE and USW are based on transmitting and receiving acoustic waves propagating through a uniform medium using the device of portable seismic property analyzer (PSPA). USW method is used to measure the variations of Young's modulus of concrete along the bridge deck and IE method is used to measure depth to possible embedded defects in concrete along the bridge deck. Both USW and IE were used to provide information about the concrete quality of the bridge deck [9-10]

An approximately 10 x 9 ft. sections were surveyed using GPR, IE, and USW methods at the top and the bottom surfaces of a 10 in. thick reinforced concrete bridge deck for bridge deck assessment at Missouri S&T campus as shown in (Figure 2). The results of this study can be used to verify the usefulness of using multiple NDTs from the underside (bottom) of the bridge deck, which could reduce the cost and safety concerns associated with surveying at traffic direction. The preliminary results indicated that the bottom surface surveying could be effectively implemented in the bridge deck assessment. However, more of detailed data interpretation is required to provide an in-depth understanding of the quality of deck underside surveys.

Figure 2: Bridge deck location

2. Data acquisition and processing

GPR data were acquired using a GSSI 1.6 and 2.5 GHz antennas. GPR profile spacing was 1 ft. (12 in.) along a predetermined section of 9x10 ft. (108x120 in.) on the top and the bottom surfaces of the 10 in. thick bridge deck as shown in (Figures 3, 5, and 6). Furthermore, USW and IE data were acquired using the PSPA device. PSPA profile spacing was 1 ft. (12 in.) along a same predetermined section of 9x10 ft. (108x120 in.) on top and bottom the bridge deck as shown in (Figures 4, and 5).

GPR data were processed using Radan 7 (by GSSI) and plotted using Surfer 10 (by Golden Software), and USW and IE data were processed using PSPA device and plotted using Surfer 10 (by Golden Software) as shown in (Figures 7, and 8) respectively.

Figure 3: GPR data acquisition

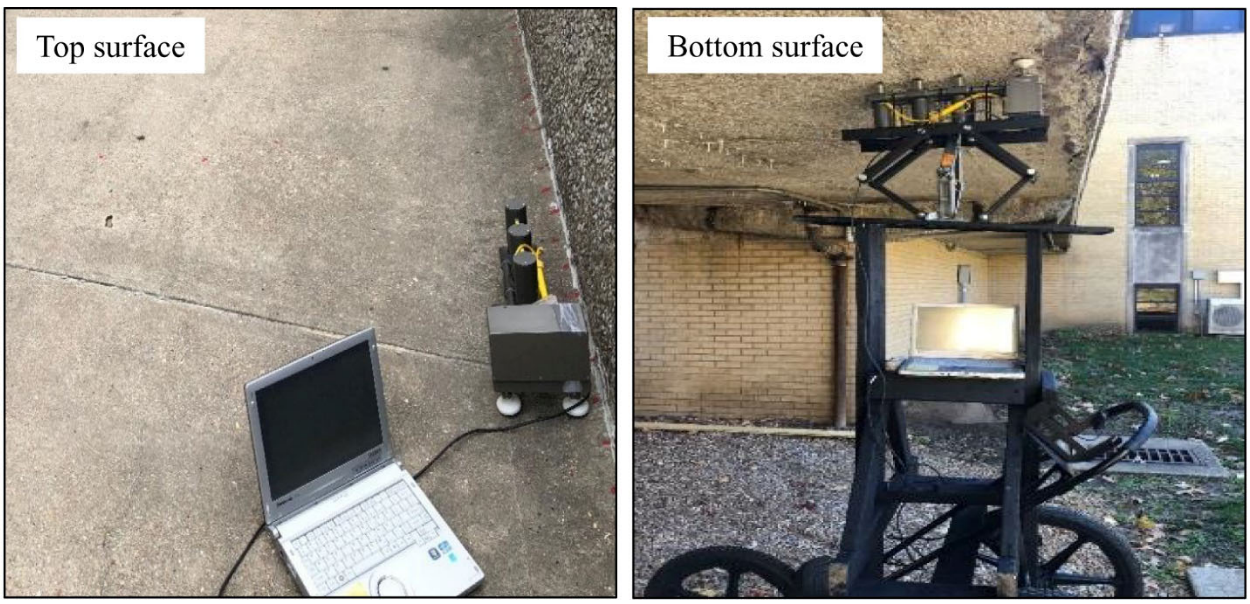

Figure 4: PSPA data acquisition

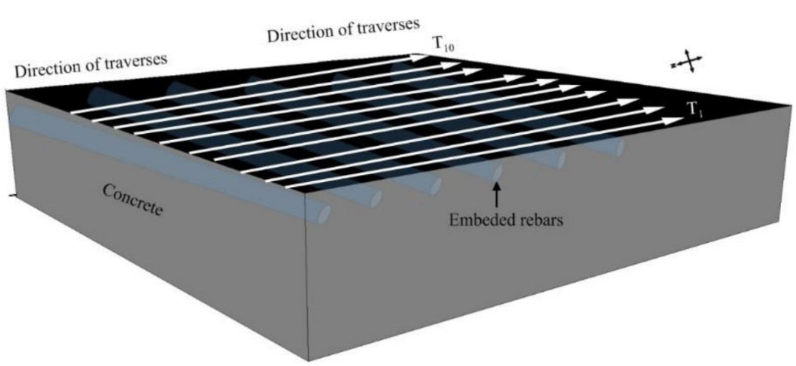

Figure 5: Illustration of GPR and PSPA traverses direction with respect to embedded concrete reinforcements

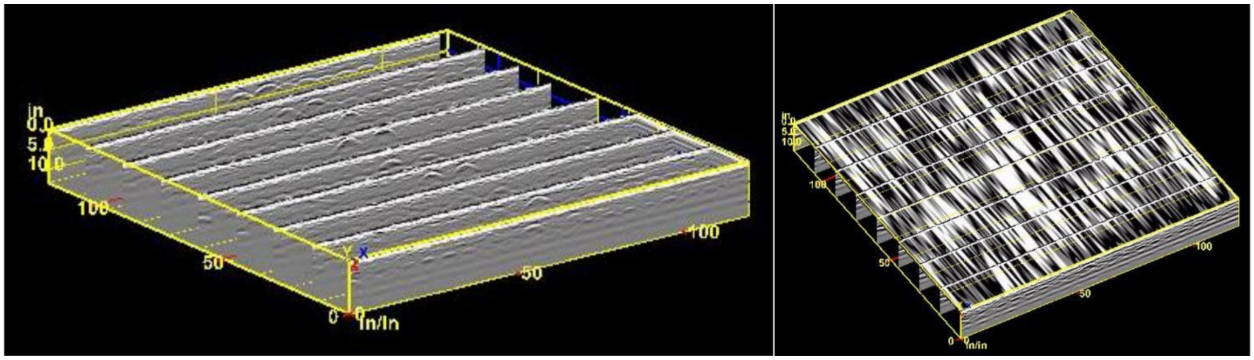

Figure 6: Illustration of GPR parallel profiles (left) and possible detected reinforcements (right) of top surface section using 2.5 GHz frequency antenna

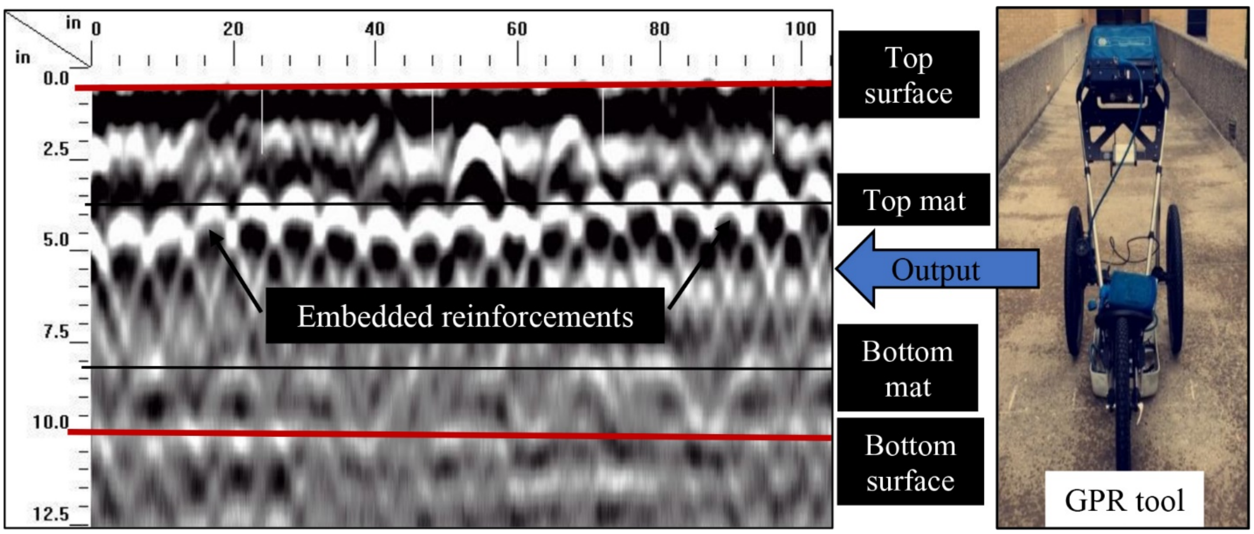

Figure 7: An example of processed GPR output showing embedded concrete reinforcements

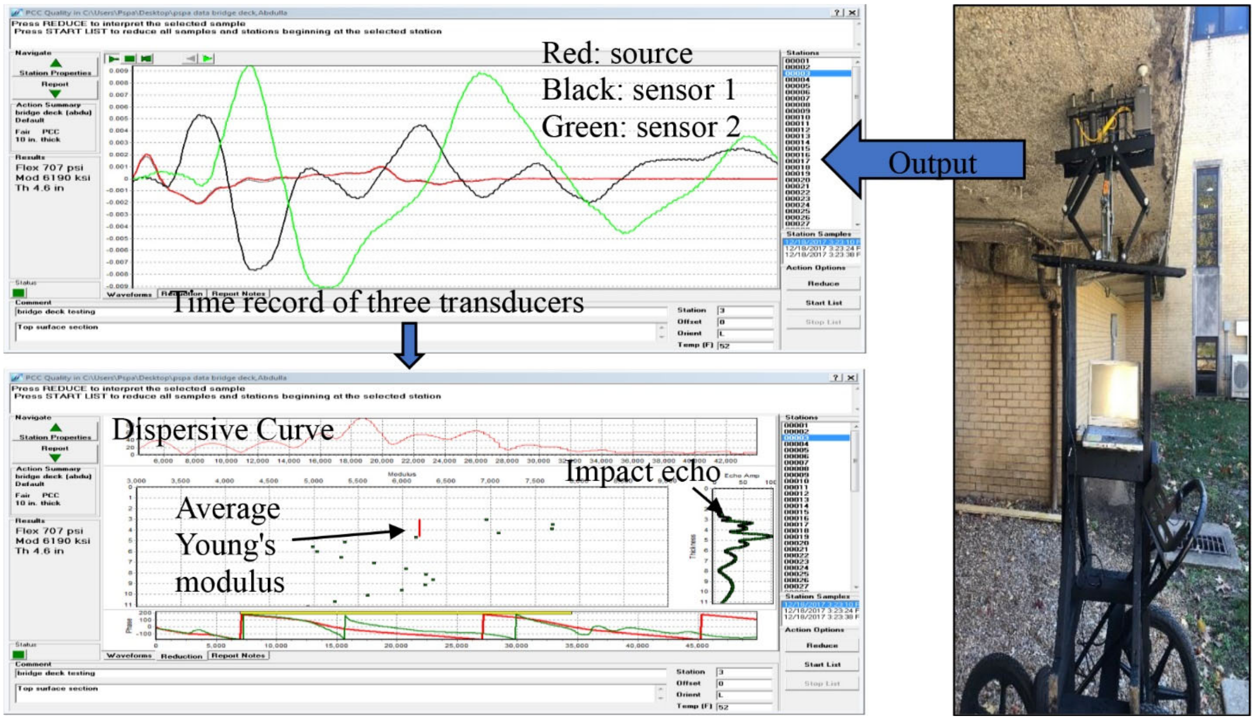

Figure 8: An example of processed PSPA output showing USW and IE results

3. Data interpretation and discussions

The significant inconsistency of the apparent depth to top layer of embedded concrete reinforcements due to possible of irregular construction reinforcement placements or been affected by severe delamination process as shown previously in (Figure 7) makes the GPR data difficult to be interpreted for the bridge deck assessment [11]. This was clearly demonstrated by the uncorrelated amplitude variations maps in particularly at top surface section as shown in (Figure 9). However, the bottom surface section has more consistent of apparent depth to bottom layer of embedded concrete reinforcements and indicated that the center area (dashed black line) has a high probability of deterioration relatively compared to the rest of the section as shown in (Figure 10) and the solid black marked area is the location of visually inspected of exposed reinforcement corrosion area at the bottom surface of the bridge deck.

USW and IE variations maps correlated well at both top and bottom surface sections of the bridge deck. At top section, areas of high deterioration indicated by low range of average Young's modulus (less than 3000 ksi) and high range of depth to defects (2-5 in) as shown in (Figure 11). At the bottom section, areas of high deterioration indicated by low range of average Young's modulus (less than 3000 ksi) and high range of depth to defects (2-4 in) as shown in (Figure 12). Extensive deteriorated area was located approximately at the western part of the bottom section near the exposed reinforcement corrosion area.

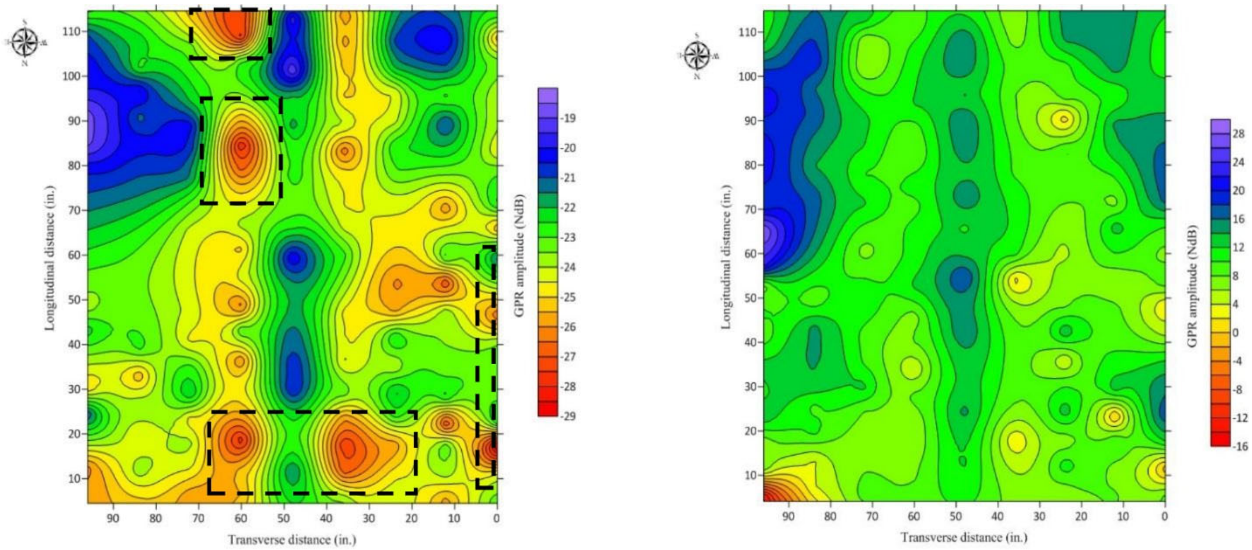

Figure 9: Amplitude variations map using 1.6 GHz (left) and 2.5 GHz (right) frequency (top section)

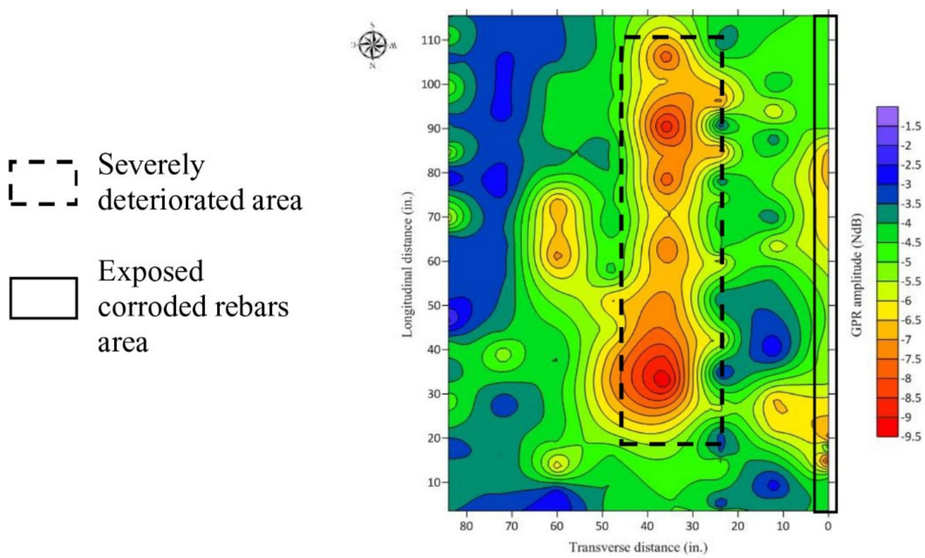

Figure 10: Amplitude variations map using 1.6 GHz (bottom section)

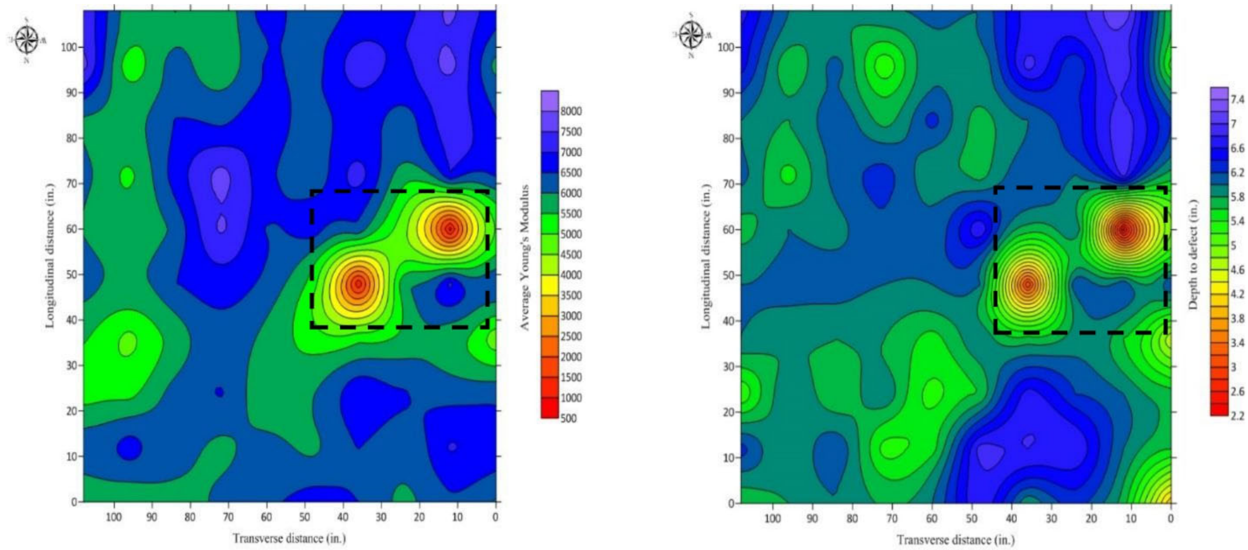

Figure 11: USW (left) and IE (right) variation maps (top section)

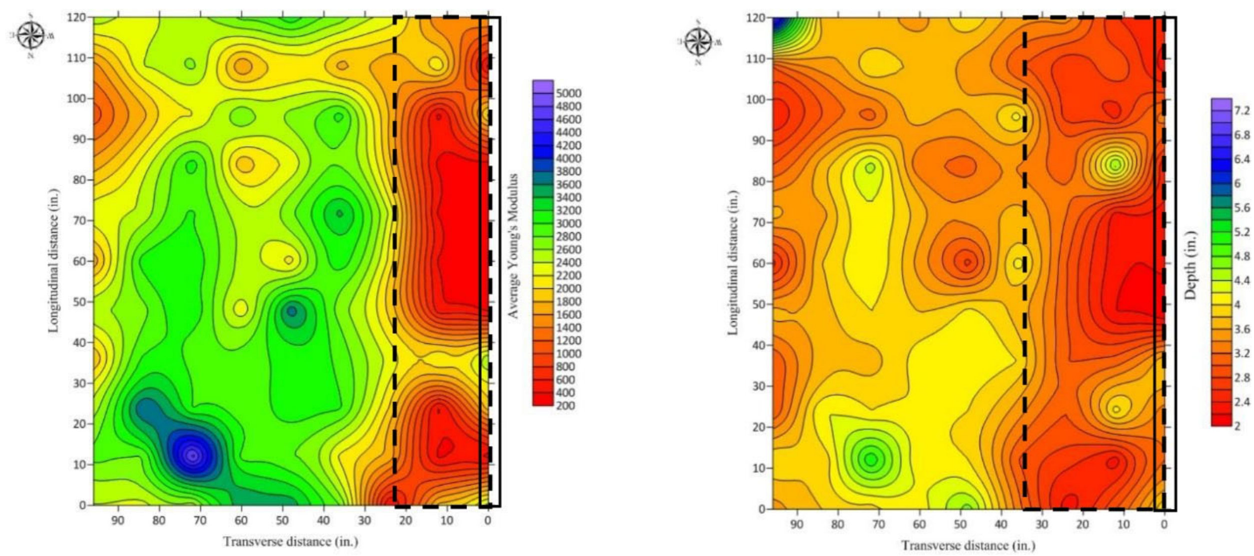

Figure 12: USW (left) and IE (right) variation maps (bottom section)

4. Conclusions

GPR was used to assess the relative concrete condition of the bridge deck. However, due to the significant inconsistent apparent depth of embedded reinforcements, GPR data were difficult to interpret for the overall bridge deck integrity assessment.

USW and IE were used to determine concrete quality of the bridge deck by estimating elastic Young's modulus and depth to embedded defects respectively. Where western part of the bottom section dominated by low average Young's modulus and high depth to defects located close to or adjacent to the exposed corroded rebars area.

References

[1] Gucunski, Nenad, and National Research Council. “Nondestructive testing to identify concrete bridge deck deterioration”. Transportation Research Board, (2013).
[2] Gucunski, Nenad, et al. “Multiple complementary nondestructive evaluation technologies for condition assessment of concrete bridge decks.” Transportation Research Record: Journal of the Transportation Research Board 2201 (2010): 34-44.
[3] El-Safty, A. “Behaviour of RC bridge deck slabs and girders strengthened with CFRP laminates.” Proc., 12th International Conference on Structural Faults and Repair. (2008).
[4] Wamweya, Amos. “Application of ground penetrating radar (GPR) for bridge deck condition assessment: using a 1.5 GHz ground-coupled antenna.” (2009).
[5] Abudayyeh, Osama, et al. "Using non-destructive technologies and methods in bridge management systems.” Journal of Urban Technology 11.1 (2004): 63-76.
[6] Maser, Kenneth R. "Integration of ground penetrating radar and infrared thermography for bridge deck condition evaluation." Proceedings of the NDTCE 9 (2009).
[7] Anderson, Neil, and Evgeniy Torgashov. “Nondestructive Evaluation of MoDOT Bridge Decks–Pilot Study.” (2014).
[8] Anderson, Neil, and Mengxing Li. “Testing and Assessment of Portable Seismic Property Analyzer”. No. NUTC R297. (2014).
[9] Gucunski, Nenad, et al. "Impact echo data from bridge deck testing: Visualization and interpretation." Transportation Research Record 2050.1 (2008): 111-121.
[10] Nazarian, Soheil. In situ determination of elastic moduli of soil deposits and pavement systems by spectral-analysis-of-surface-waves method. Diss. University of Texas at Austin, (1984).
[11] Alhaj, Abdullah. “Bridge deck assessment using visual inspection, ground penetrating radar, portable seismic property analyzer-ultrasonic surface wave, hammer sounding and chain drag.”Master’s thesis, Missouri University of Science and Technology (2018).