# Bridge Deck Scanning for Condition Assessment of Bare Concrete and Asphalt Overlaid Decks

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## ABSTRACT

This paper presents technologies used for condition assessment of bare concrete decks and asphalt overlaid decks. The study was funded by the NCHRP-IDEA program. The objective of the research and development was to develop a faster, more accurate technology to determine internal conditions of bridge decks. A Bridge Deck Scanner (BDS) prototype with a pair of transducer wheels was originally developed. Later the BDS system was expanded as part of a SHRP 2 R06 (D) research project for asphalt pavement delamination (NCAT study at Auburn University) so that up to three pairs of transducer wheels could be added to the system for more rapid testing. The BDS system can be set to perform either Impact Echo Scanning on all wheels for condition assessment of bare concrete decks or simultaneously perform Impact Echo Scanning and Spectral Analysis of Surface Waves Scanning for condition assessment of concrete decks underneath overlays such as asphalt. In this paper, two case studies are presented (one from a bare concrete deck and one from an asphalt overlaid deck) in which comparison/ground-truthing techniques (sounding, coring, hydro-blasting, etc.) were employed along with BDS results.

## INTRODUCTION

Corrosion of reinforcement leading to concrete deck delamination is a major maintenance repair/replacement cost for state DOT's across the country. Accurate mapping of top and bottom delamination is needed to guide repair/replacement decisions. The inspection of concrete bridge decks typically includes a delamination survey (with chain dragging for acoustic sounding that detects top rebar delamination only). Employing innovative scanning NDE systems can improve delamination mapping accuracy, reduce inspection time, and provide additional information regarding possible bottom delaminations as well as the internal concrete conditions such as freeze-thaw and alkali-silica reaction cracking damage. In addition, sophisticated NDE systems can be employed in instances in which traditional chain dragging techniques have not been effective, such as areas with deeper delamination or on asphalt overlaid concrete bridge decks.

A research project titled "Vehicle-Mounted Bridge Deck Scanner" funded by the NCHRP-IDEA program is summarized herein. This research project focused on the development of rapid inspection techniques by adapting well known NDE test methods into rolling/scanning equipment. The equipment then allowed for rapid testing to provide: (1) top and bottom delamination mapping; (2) internal conditions / deterioration mapping; and (3) thickness profiling. Since development of the system, multiple bridge decks of varying type and condition have been evaluated from bare concrete decks to asphalt overlaid decks. Two case studies (one on a bare concrete deck and one on an asphalt overlaid deck) with actual destructive correlations are presented herein.

## BRIDGE DECK SCANNER

The Bridge Deck Scanner (BDS) was recently developed by the research team at Olson Engineering as part of research funded by the National Cooperative Highways Research Program – Innovations Deserving Exploratory Analysis program (1). The current BDS system consists of up to three sets of two identical transducer wheels. Figure 1 shows a transducer wheel assembly. The transducer wheel was designed to include six impact echo piezoceramic displacement transducers at 6 inch (152.4 mm) spacings, resulting in a wheel circumference of 3 feet (0.91 meter) or a diameter of approximately 11.5 inches (279.4 mm). The 6 inch (152.4 mm) transducer spacing was selected to provide relatively close measurement intervals consistent with a high data resolution bridge deck survey. Six displacement transducer elements were incorporated into the wheel. The six transducers were spring mounted with rubber isolators and captured with a thin urethane tire approximately 2.5 inch (63.5 mm) wide that is replaceable. The thin urethane tire was added as a dust cover to prevent dirt from entering the sensor housing and more importantly to increase sensor contact area and coupling. The transducer wheel design of the BDS uses a solenoid impactor to impart energy into the concrete and create high amplitude signals which are easily measured. The urethane tire, larger impacting solenoids, and overall sensor weight (approximately 25 lbs or 11.3 kilogram), which affects contact pressure, are the primary changes that improved the rough surface performance of the BDS system over previous prototypes. Six solenoids per wheel were used in the design. The solenoids were mounted to the side of the rolling transducer wheel in line with the sensor element, thus ensuring the solenoid height (distance between bridge surface and solenoid) remained constant to improve test consistency.

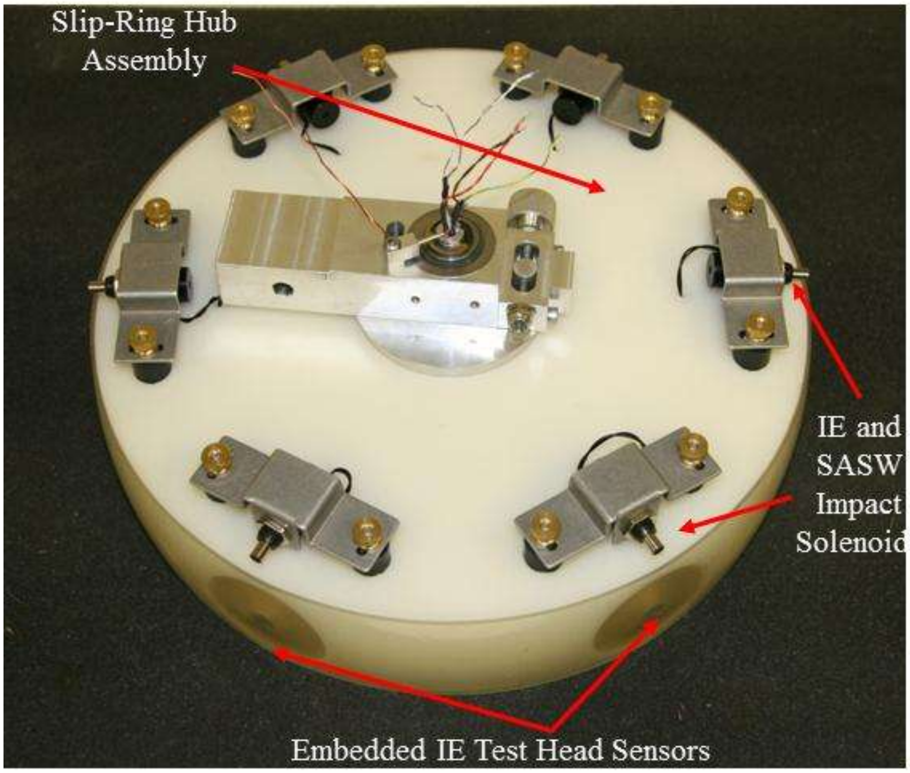


**Figure 1 – Transducer Wheel Assembly**

The two transducer wheels are identical. The BDS system can be equipped with up to three pairs of transducer wheels and can be easily attached to either a vehicle hitch (if all three pairs of transducer wheels are used) as shown in Figure 2 or a scanning cart (if only a pair of transducer wheels are used) as shown in Figure 3. Each set of transducer wheels of the BDS system can perform:

1) Impact Echo tests on both wheels simultaneously in two scan lines (one scan per each wheel) by offsetting the transducer elements (by approximately 3 inches or 76.2 mm) and having the impactors from both wheels turned on. This is a good setup for condition assessment of bare concrete decks if top delaminations and general integrity are the primary concern. Note that the spacing between the two adjacent transducer wheels can be set between 6 inches (0.15 meter) and 2 feet (0.61 meter) depending on the scan resolution desired for the testing.
2) Impact Echo and Spectral Analysis of Surface Waves (SASW) scanning simultaneously by aligning the transducer elements of both transducer wheels. The first transducer wheel (with the impactors on) can be used to perform the Impact Echo test. The second wheel (with the impactors off) can be used as the second transducer to acquire data for the SASW test analysis. Note that both Impact Echo and Spectral Analysis of Surface Waves tests can be performed simultaneously in a single scan. This setup provides additional information for complex situations such as assessment of a concrete deck under an asphalt overlay, which, in past experience, has been problematic for IE testing alone.

**Figure 2 – Bridge Deck Scanner Towed behind a Vehicle – 3 pairs of wheels at 2 feet (0.61 meter) apart**

**Figure 3 – BDS System Attached to a Scanning Cart on Asphalt Overlaid Deck – Single Pair of Wheels at 6 inches apart for Combined Impact Echo/Surface Waves Scanning**

## FIRST CASE STUDY: BRIDGE DECK SCANNER USING IMPACT ECHO SCANNING ON A BARE CONCRETE DECK

### Project Background

Olson Engineering was invited by Dr. Nenad Gucunski of Rutgers University to participate in the non-destructive evaluation (NDE) validation testing of bridge decks as a part of Rutger's Strategic Highway Research Program SHRP 2 R06(A) Bridge Deck Validation research project (2). The selected test bridge is located on James Madison Highway – US 15 over Interstate 66 at Haymarket, Virginia. The area of testing measured 84 feet in length and 12 feet in width. The nominal thickness of the bridge deck is 8.5 inches (215.9 mm). An overview of the bridge and the investigated area is presented in Figure 4 below.

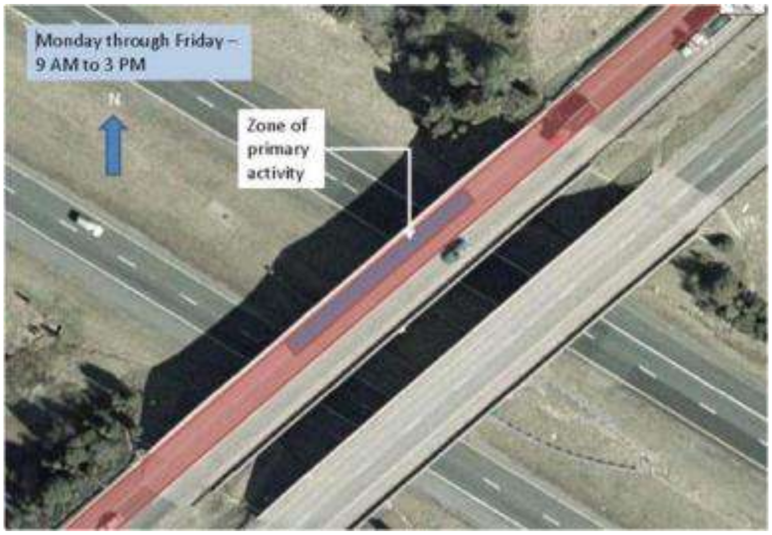


**Figure 4 – Overview of Bridge Deck Validation Test Area for James Madison Highway - US 15 over Route 66 near Haymarket, Virginia**

## Non-Destructive Evaluation Test Methods for Concrete Bridge Deck Delamimnation Detection

The field validation was performed by personnel of Olson Engineering, Inc., in November 2010 with assistance by personnel of IDS from Pisa, Italy in the performance of ground penetrating radar using the Aladdin system which is manufactured by the GeoRadar division of IDS. Non-destructive evaluation test methods performed by the Olson Engineering team included:

1) Impact Echo Scanning (IES) using a recently developed Bridge Deck Scanner (BDS) with a pair of transducer wheels on a 1 feet (304.8 mm) interval across the width of the lane and 0.5 feet (152.4 mm) interval along the length of the lane
2) Ground Penetrating Radar using a GSSI SIR3000 with a 1.6 GHz ground coupled antenna and an IDS Aladdin GPR system with a 2.0 GHz ground coupled bi-polar antenna (test results are not presented in the paper).

The background and theory of Impact Echo (IE) test can be found in many publications (1, 2 and 3). Note that the Impact Echo Scanning technique has been previously used with excellent correlation between the BDS-IE test results and acoustic sounding on other bridges (2).

## Test Results from the BDS-Impact Echo Scanning

The graphical IES test results from the Bridge Deck Scanner are presented in Figure 5. The thickness results from the IES tests were normalized by the nominal thickness of the tested line. A global normalization could not be applied because the thicknesses of the concrete deck along the C and D Test Lines (5 feet (1.52 meters) and 6 feet (1.83 meters) east of Line A) were thicker than the design thickness of 8.5 inches (215.9 mm). It is assumed that this area was thickened to provide additional bearing support, as this was at a location of one of the supporting steel girders. The plot is a normalized surface thickness tomogram to illustrate the general condition of the tested concrete deck. The majority of the indicated anomalies are predominantly top delaminations (presented in red) based on the IES results. The gray color represents areas in which the normalized thickness results were less than or equal to a value of 1.2, which are indicative of "sound concrete". Yellow represents areas with normalized thickness of 1.2 to 1.7, or areas with incipient concrete delaminations. The quantity of areas with incipient delaminations (plotted in yellow) detected from the BDS was estimated to be 135 sq ft (12.5 sq meter) or 13.5% of the tested deck surface area. Areas with incipient delaminations and delaminations deeper than 3-4 inches or 75 to 100 mm are not likely to be audibly detected by human ears using chain drags for acoustic sounding (very subjective and dependent on chain drag operators). Areas where the normalized thickness is greater than 1.7 are plotted in red, which represents areas with probable top shallow concrete delaminations. These top delaminated areas are likely detectable by human ears using acoustic sounding as a hollow, drummy sound versus a high frequency sound from undamaged, good quality concrete. The quantity of probable delaminations (plotted in red) detected from the BDS was estimated to be 149 sq ft (13.8 sq meter) or 14.6% of the tested deck surface area. The quantity of both probable delaminations and incipient delaminations (plotted in yellow and red) detected from the BDS was estimated to be 285 sq ft (26.5 sq meter) or 28.1% of the tested deck surface area. Approximate data analysis of the IES data was 4 hours and 2 – 4 additional hours were required for the results plotting process.

## Comparisons between the BDS-IES Test Results, Chain Dragging and Cores

For comparison purposes, Rutgers University performed acoustic sounding using chain dragging and hammer sounding to listen to the hollow sounds from shallow top delaminations of the concrete deck. The delamination map from chain drags is presented in Figure 6. In addition, eight cores were taken from the deck. The delamination map from the BDS-IES component agreed well with the visual observations of the eight cores. Photographs of two (of eight) cores are shown in Figure 7. Review of Figure 7 indicates that the test results from the BDS-IES component correctly identified both shallow (Core # 5) and deeper delaminations (Core # 3), where-as chain dragging only correctly identified shallow delaminations (Core # 5 - 2.5 inches or 63.5 mm deep) and failed to identify deeper delamination (Core # 3 – 3.5 inches or 88.9 mm deep).

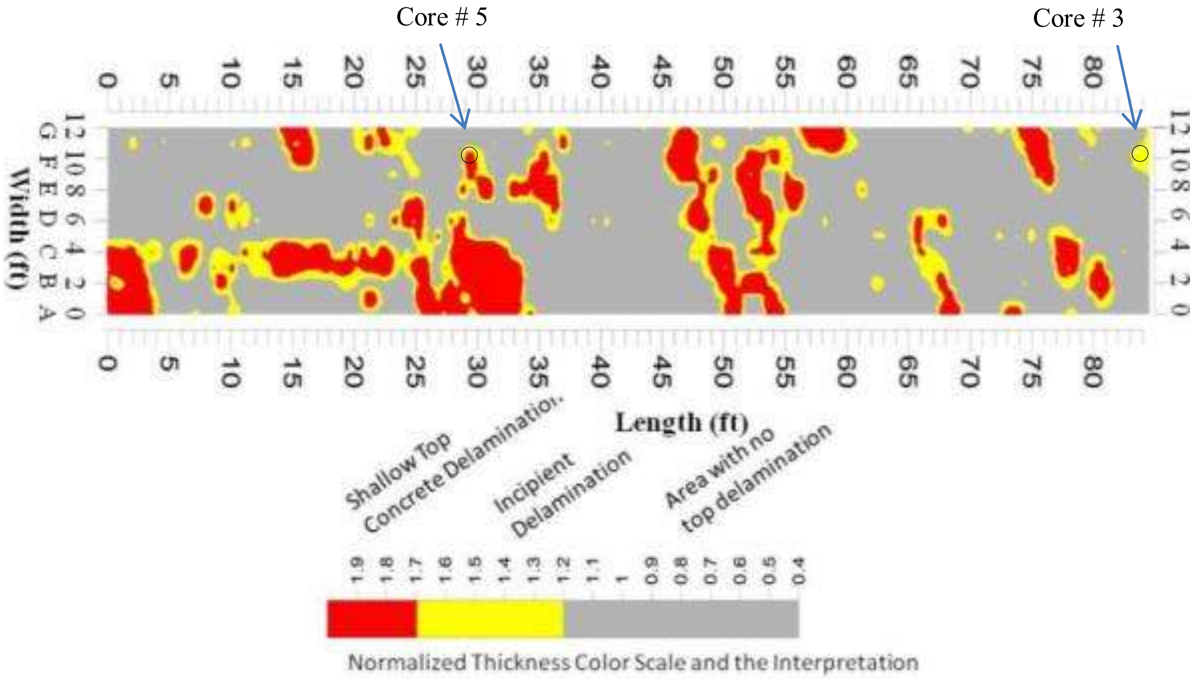


Figure 5 – Top Concrete Delamination Map from the BDS System – Impact Echo Scanning

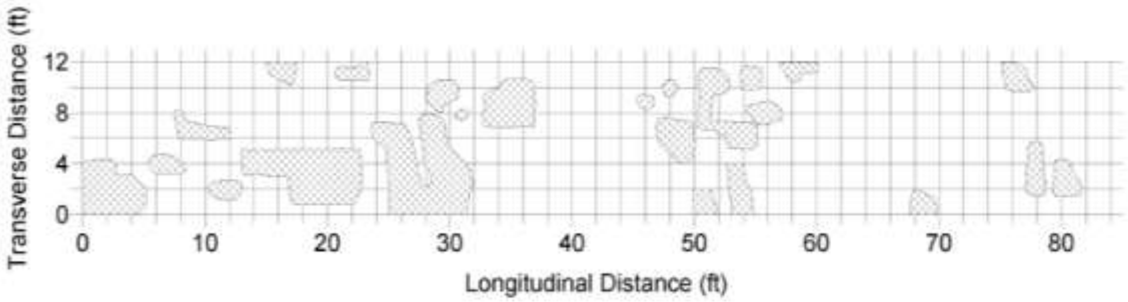


Figure 6 – Top Concrete Delamination Map from Chain Drags

Core # 5 - Delamination Depth at 2.5 inches

Core # 3 - Delamination Depth at 3.5 inches

Figure 7 – Photographs of Cores # 5 and #3 (Courtesy of Rutgers University)

## SECOND CASE STUDY: BRIDGE DECK SCANNER USING SPECTRAL ANALYSIS OF SURFACE WAVES SCANNING ON AN ASPHALT OVERLAID CONCRETE DECK

### Project Background

An internal research project was conducted by the research team at Olson Engineering with support from the Colorado Department of Transportation (CDOT) – Region 6 to evaluate the internal condition of a concrete bridge deck with asphalt overlays, without removing the asphalt. Structure E-17-IE: I-270 eastbound bridge over South Platte River (asphalt covered concrete deck without water-proofing membrane) was selected for this study.

### Non-Destructive Evaluation Test Methods for Asphalt Overlaid Concrete Deck to Detect Concrete Delamimnation

A Bridge Deck Scanner (BDS) system using the Spectral Analysis of Surface Waves (SASW) method was used to assess the bridge deck condition, with scanning conducted through the asphalt. For this setup, the solenoid impactors were turned on for one transducer wheel and off for the second transducer wheel. This setup allows the Impact Echo Scanning and Spectral Analysis of Surface Wave Scanning to be performed simultaneously in a single scan. However, in this case, only SASW data were used in the analysis. The background and theory of the SASW test method can be found in many publications (4 and 5). The SASW scanning was performed on the second span (between Pier 2 and Pier 3) of the bridge between a distance of 4 – 8 feet (1.22 – 2.44 meter) from the left rail on the left lane and shoulder. Each scan line started approximately 11 feet (3.35 meter) from the west joint and ended approximately 2.6 feet (0.79 feet) from the east joint.

### SASW Data Interpretation

Figures 8a – 8d present example SASW test records and the corresponding data interpretations from the asphalt overlaid deck. The plot shows the dispersion curve presenting the surface wave velocity vs wavelength (or depth in the deck). Sound concrete (with no asphalt debonding) yields a high and relatively constant surface wave velocity shown as a flat and horizontal line in a dispersion curve throughout the depth of the bridge deck. A typical example of this case is shown in Figure 8a. Olson Engineering has found that the presence of a sharp drop in the surface wave velocity within the dispersion curve acts as a reliable indication of either potential debonding between the asphalt (and between layers of asphalt pavements) and concrete and/or delamination within the concrete layer. The location (wavelength) of the velocity drop relates to the depth of either the debonding or delamination. This sudden drop of surface wave velocity is then automatically detected by the BDS software to locate the depth of discontinuity (either asphalt debonding or concrete delamination). The depth of the detected discontinuity is then used to determine if discontinuity is in the asphalt layer, between the asphalt and concrete or within the concrete layer. Figure 8b presents a dispersion curve (surface wave velocity vs wavelength) from a location with possible asphalt debonding where a velocity drop is located at a depth of 3.5 inches (88.9 mm) from the surface. Figure 8c presents a dispersion curve from a location with apparently both asphalt debonding and bottom concrete delamination where two velocity drops are detected at 3.2 inches (81.3 mm) and 7.4 inches (187.9 mm) from the surface.

Note that the destructive verification of bottom delamination conditions were not performed due to safety concerns during coring. Figure 8d presents dispersion curves from locations with apparent top concrete delaminations where the depths (wavelengths) of the velocity drops are indicative of the top reinforcement depths.

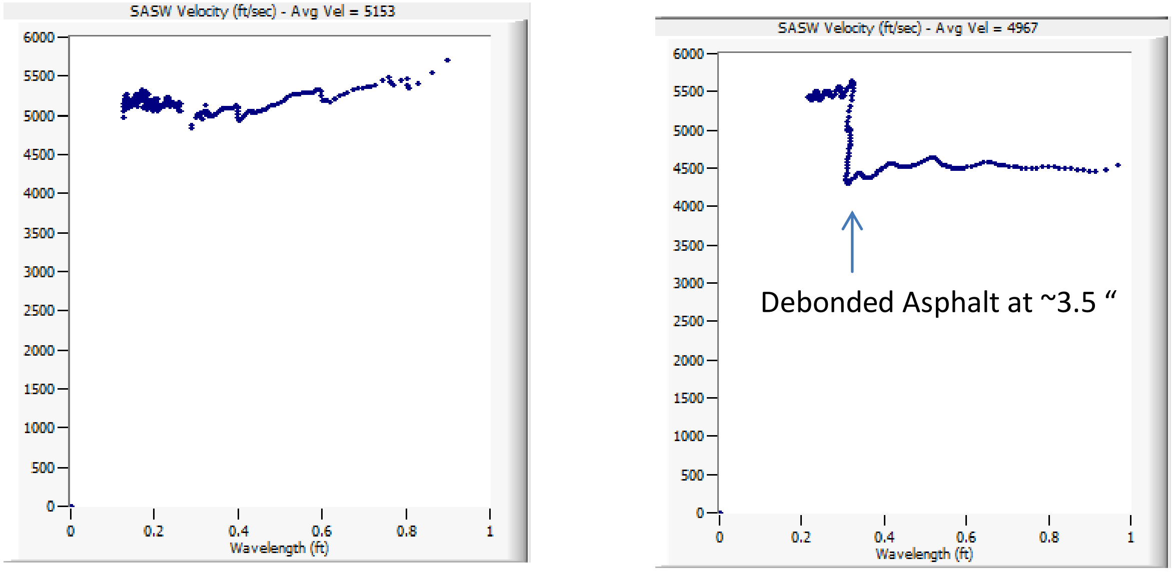


Figure 8a – Sound Concrete Figure 8b- Debonded Asphalt on Sound Concrete

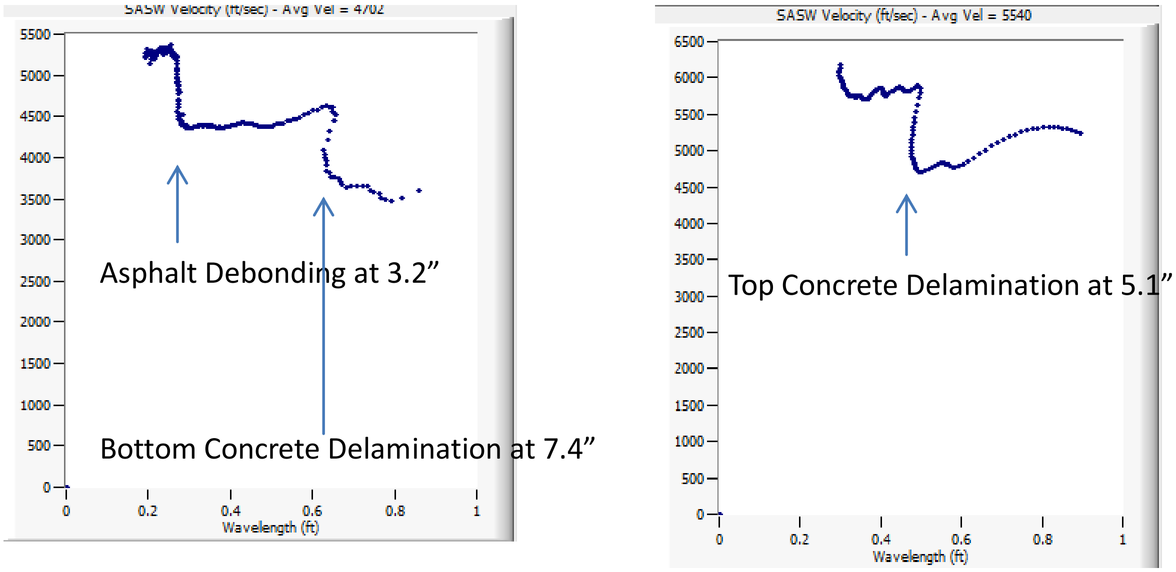


Figure 8c – Debonded Asphalt on Concrete With Bottom Delamination

Figure 8d – Top Concrete Delamination

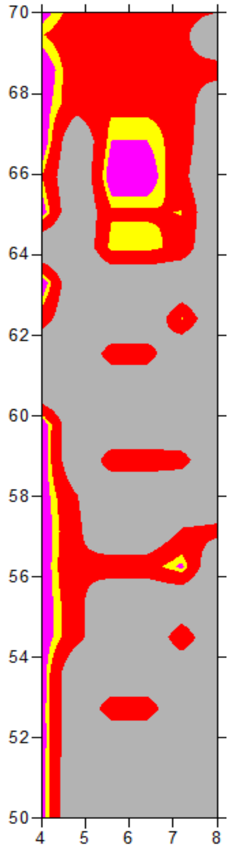
**Figure 8 – SASW Data Interpretation for an Asphalt Overlaid Deck**

## Top Delamination Map from the BDS - SASW Component

A section of test results is presented in Figure 9a. In general for the condition ratings in Figures 9 - 14, each color represents different conditions as follows: “Pink” represents areas with apparent asphalt debonding (0.2-0.33 feet or 61 – 100.6 mm), “Yellow” represents areas with either asphalt debonding or top concrete delamination (0.33-0.41 feet or 100.6 – 125 mm),“Red” represents areas with apparent top steel concrete delamination (0.41-0.55 feet or125 – 167.6 mm) and “Grey” represents sound concrete with no potential top concrete delamination.

## Comparisons between the SASW Test Results and Actual Conditions

After the completion of the initial BDS scanning, the asphalt overlay was removed to expose the concrete and hydro-blasting was performed to remove loose/weak concrete. Due to time limitations of night work, CDOT did not perform chain dragging on the bare deck of this structure after the asphalt was removed. During the hydro-blasting process, approximately 2 – 2.5 inches (50 to 62 mm) of concrete was removed from the entire deck. However, deeper concrete was removed in the areas with weaker, apparently delaminated concrete. Figure 9b shows the concrete condition of this deck (same section where the SASW test results are presented in Figure 9a) after hydro blasting. Note that dashed lines are added to Figure 9b to outline one area in the foreground which is clearly worse than the rest of the deck. The area within the dashed lines compare very well with the top delamination map shown in Figure 9a. Note that additional areas around the 70 foot (21.3 meter) distance mark also appear to have extensive exposed rebar indicative of delamination exposed by hydro-blasting. This also matches well with the SASW scanning results plot (Figure 9a).



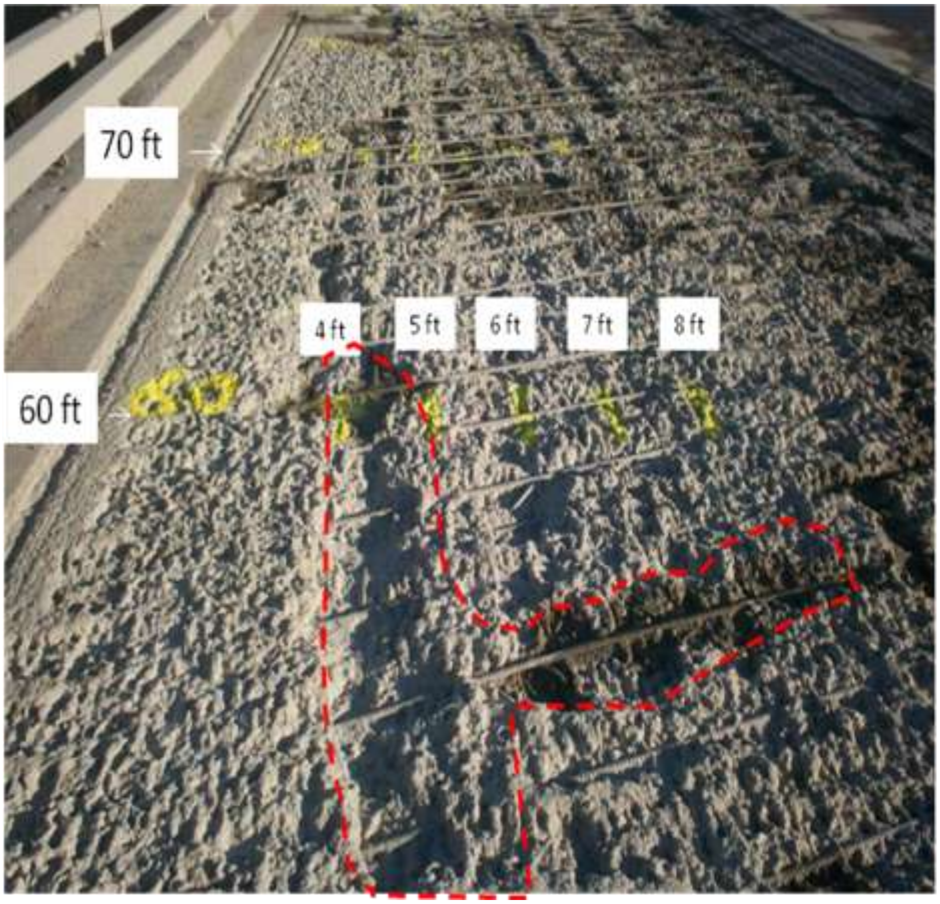


**Figure 9a (left plot) – Top Concrete Delamination Map from the BDS – SASW component**
**Figure 9b (right photograph) – Actual Concrete Condition after Hydro Blasting Process**

## CONCLUSIONS

Funded and internal research have shown the ability of the Bridge Deck Scanner with Impact Echo and Spectral Analysis of Surface Waves technologies to accurately identify top and possibly bottom concrete delaminations and general concrete integrity for bare and asphalt overlaid concrete decks. An important finding was the ability of surface waves to penetrate debonded asphalt and detect underlying corrosion induced top and/or bottom delaminations associated with corrosion of the top and bottom deck reinforcement. Thus, deck repair/replacement decisions can be made with typically a 0.5 to 1 square foot (0.022 to 0.09 square meters) resolution of delamination/damage. The BDS-IE/SASW system is applicable to bare concrete or asphalt overlaid decks.

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