NCDOT SHRP2 R06A Feasibility Study for Nondestructive Evaluation of Bridge Decks

FINAL REPORT

FEBRUARY 5, 2018

BDI
RAW DATA. REFINED RESULTS.

Contents

Executive Summary

In December of 2017 and January of 2018 BDI performed nondestructive testing of three (3) select bridge decks Davie County, NC as part of a two-phase nondestructive evaluation (NDE) of the structures. The testing methods included ground penetrating radar (GPR), infrared thermography (IR), high-resolution video (HRV), BDI's deck acoustic response system, SounDAR, chloride ion penetration, and rebound hammer testing. Utilizing jointly developed proprietary data analysis software, BDI and Infrasense performed the analysis of the data. Conclusions include:

1. GPR results indicate that 17.4%, 14.4%, and 3.6% of Structures 290007, 290014, and 290018, respectively, have a high probability of deterioration at the rebar level.
2. IR results indicate that 5.2%, 4.6%, and 2.0% of Structures 290007, 290014, and 290018, respectively, are delaminated.
3. Sounding results indicate that 21.1%, 14.4%, and 4.4% of Structures 290007, 290014, and 290018, respectively, have indications of horizontal cracking.
4. Chloride ion penetration results indicate that Structures 290007, 290014, and 290018 had maximum chlorides concentrations of 4.01, 7.57, and 7.14 lbs./CY, respectively, with 33%, 75%, and 67%, respectively, having concentrations over 2.0 lbs./CY.
5. Rebound hammer results indicate the following:
    a. Structure 290007:
        i. $f'c$ < 3,000 psi – 13% (551 ft^2)
        ii. $f'c$ < 4,000 psi – 22% (932 ft^2)
        iii. $f'c$ < 5,000 psi – 34% (1441 ft^2)
        iv. $f'c$ > 5,000 psi – 31% (1314 ft^2)
    b. Structure 290014:
        i. $f'c$ < 3,000 psi – 0% (0 ft^2)
        ii. $f'c$ < 4,000 psi – 6% (498 ft^2)
        iii. $f'c$ < 5,000 psi – 27% (2240 ft^2)
        iv. $f'c$ > 5,000 psi – 67% (5538 ft^2)
    c. Structure 290018:
        i. $f'c$ < 3,000 psi – 1% (134 ft^2)
        ii. $f'c$ < 4,000 psi – 5% (672 ft^2)
        iii. $f'c$ < 5,000 psi – 35% (4706 ft^2)
        iv. $f'c$ > 5,000 psi – 59% (7933 ft^2)

Introduction and Background

The Strategic Highway Research Program (SHRP) 2 R06A study identified multiple methods of nondestructive evaluation (NDE) for use on bridge decks. Additionally, the SHRP2 program developed an Implementation Assistance Program (IAP) and under round 7 of the IAP funding, the North Carolina Department of Transportation (NCDOT) was awarded funding to perform a feasibility study of NDE on bridge decks. As such, NCDOT identified three bridge decks to test utilizing NDE. The three (3) bridges are identified in Table 1.

Table 1 – Bridge Identified for Study

Bridge ID	Feature On	Feature Over	County	Length (ft)	Width (ft)	Deck Area (sf)
290007	SR 1147	South Yadkin River	Davie	163	26	4238
290014	SR 1147	I-40	Davie	244	34	8296
290018	US 64	I-40	Davie	249	54	13446

With that objective, BDI was secured to perform a 2-Phase NDE of the bridges. Phase I consisted of high-speed scanning surveys including infrared thermography (IR), ground penetrating radar (GPR), and high-resolution video (HRV) to quantify and map concrete deterioration, delamination, patching, spalling, and concrete. The Phase II validation testing included acoustic testing of the deck utilizing manual chain drag and BDI's deck acoustic response (SounDAR) system, chloride penetration testing, and rebound hammer testing to determine compressive strength. While acoustic testing was not specifically requested by NCDOT, BDI has found that this type of data provides results with which state DOTs are familiar.

Testing and Analysis Activities

OVERVIEW

On December 4, 2017 and January 3-5, 2018 BDI performed Phase I and II testing on the bridges, respectively. BDI's partner, Infrasense, performed Phase I testing including GPR, IR, and HRV testing and BDI performed Phase II testing including manual chain drag, SounDAR, chloride ion penetration testing, and rebound hammer testing. Utilizing jointly developed proprietary data analysis software, BDI and Infrasense performed the analysis of all collected data.

GROUND PENETRATING RADAR (GPR)

The GPR surveys were carried out in accordance with ASTM D 6087-08 using twin air-coupled 2GHz horn antennas suspended above the bridge surface (Figure 1). The GPR data was collected in a series of lines spaced 3 feet transversely across the width of each deck at a speed of approximately 55 mph. All decks required multiple lines of data, each representing a cross sectional slice of the deck at a particular offset. Using a distance measurement instrument (DMI), a rotary encoder, distance data is continuously recorded into each GPR record, so that each GPR data scan has an associated distance.

Ground penetrating radar operates by transmitting short pulses of electromagnetic energy into an elastic material using an antenna attached to a survey vehicle. These pulses are reflected to the antenna with an arrival time and amplitude that is related to the location and nature of dielectric discontinuities in the material (air/asphalt or asphalt/concrete, reinforcing steel, etc.). The reflected energy is captured and may be displayed on an oscilloscope to form a series of pulses that are referred to as the radar signal. The signal contains a record of the properties and thicknesses of the layers within the structural member. By combining each sampled signal from the survey vehicle into a single image, features within the structural member can be identified.

The GPR analysis is carried out with GSSI's commercial software Radan 7, along with proprietary software, using the following steps:

(1) Identification of the beginning and the end of the deck in each radar file, and check of the radar distance measurement against the known length and other features within the deck;

(2) Identification of features (top rebar, bottom of deck) that appear as dielectric discontinuities in the GPR data (see example data, Figures 2-4);

(3) Setup of the analysis for all the passes for a given deck, computation of concrete dielectric constant, rebar depth, and amplitude at the rebar-level.

Structural concrete deterioration can be inferred from changes in the dielectric properties and attenuation of the GPR signal in concrete. The dielectric constant is a measure of density, chloride and moisture content, and large variations in the dielectric constant can indicate concrete degradation.

A vacuum theoretically has a dielectric permittivity of 0 and would allow a complete transfer of these waves, and a perfect conductor would have an infinite dielectric permittivity and cause a perfect reflection of the waves. Air and steel act similarly to these cases, respectively, and thus, GPR can be used to identify steel reinforcement in structural concrete elements. Additionally, as the corrosion process occurs and iron oxide is formed, the dielectric properties of the material changes and the attenuation of the GPR signal is affected. The attenuation (loss of signal strength) of the radar signal, as measured from the top rebar reflection and/or the bottom of the deck, is used as a measure of concrete delamination. This is because contaminated and delaminated concrete will cause the GPR signal to dissipate and lose strength as it travels through the deck and reflects from the rebar and the bottom.

Figures 2-4 present examples of GPR data used for mapping rebar-depth, evidence of moisture at the rebar-level, and deterioration. Figure 2 is a sample of GPR data showing reasonably consistent rebar reflections that appear to shift in depth between two adjacent spans. Figure 3 provides a sample of GPR data showing an area of relatively high amplitude rebar reflections, which are indicative of moisture. The moisture interpretation is based on the amplitude of the GPR signal at the rebar level, so the moisture may exist at any depth between the surface and the rebar. The moisture is defined as the highest amplitude GPR reflections, which typically indicate the presence of moisture. The potential for moisture designation is based on subjective analysis of the data set. Regions that correlate to higher amplitude GPR reflections, but are not at the highest amplitude, are considered to have the potential for moisture content. Similarly, Figure 4 presents areas with a lower amplitude GPR reflections. These areas are indicative of possible deterioration of the rebar level and subsequent degradation of the bridge deck. Once these areas are identified, an amplitude range is established with thresholds for moisture presence and potential for degradation. The data is then analyzed and presented in the form of contour plots (Figure 5).

Table 2 presents the probable deterioration measured with GPR. Appendix A-C provide detailed GPR results for bridges 290007, 290014, and 290018, respectively, including the rebar cover maps.

Figure 1 - GPR Survey Equipment

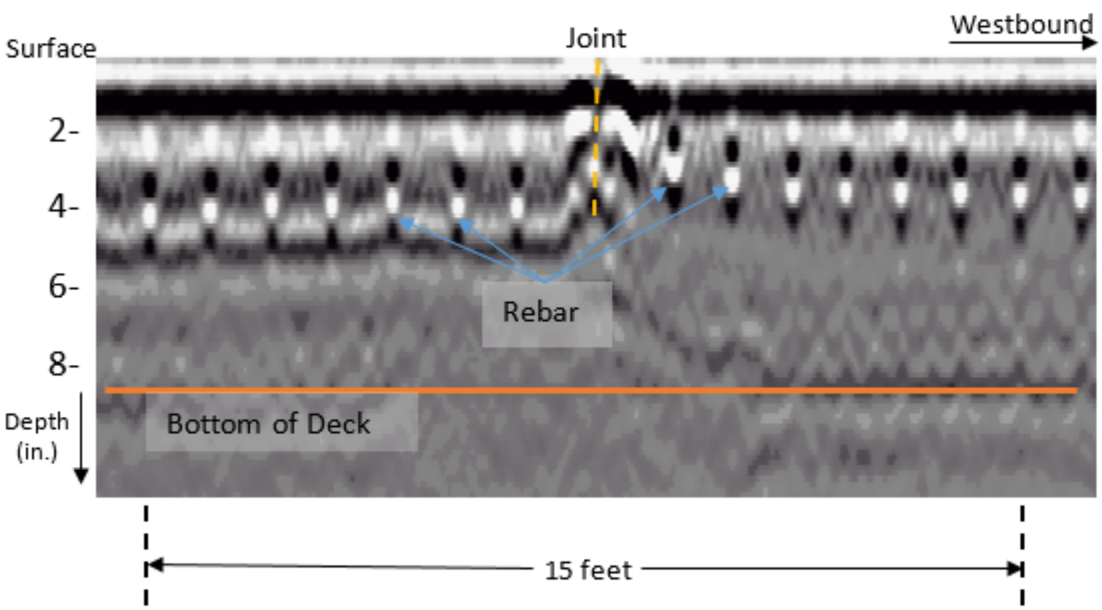


Figure 2 - Sample GPR Data Showing Consistent Rebar Reflections and Varying Depths

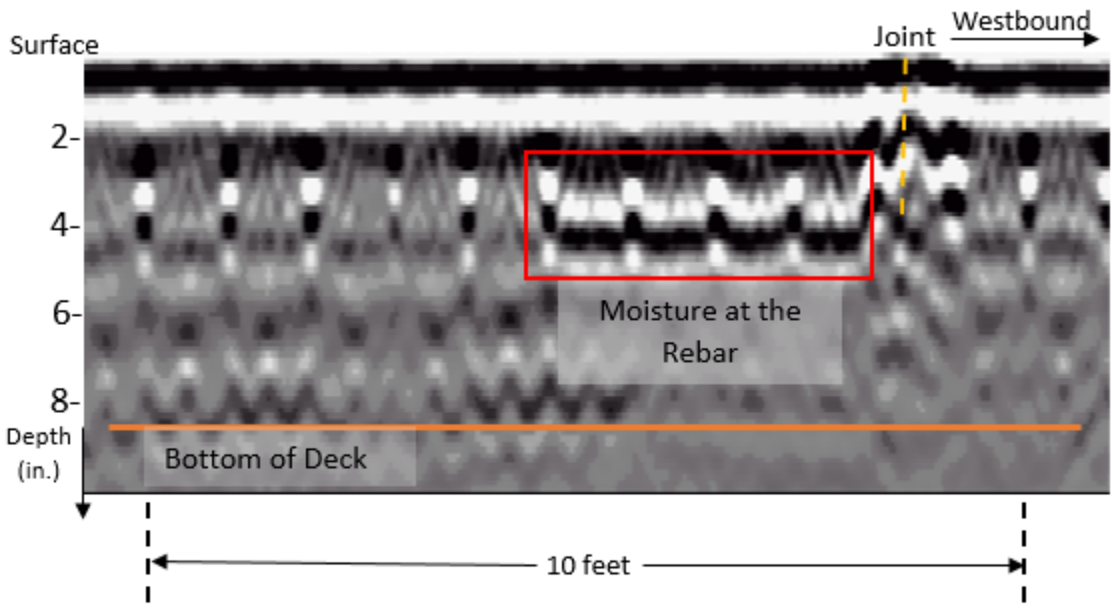


Figure 3 - Sample GPR Data Showing Evidence of Moisture at the Bottom of the Overlay

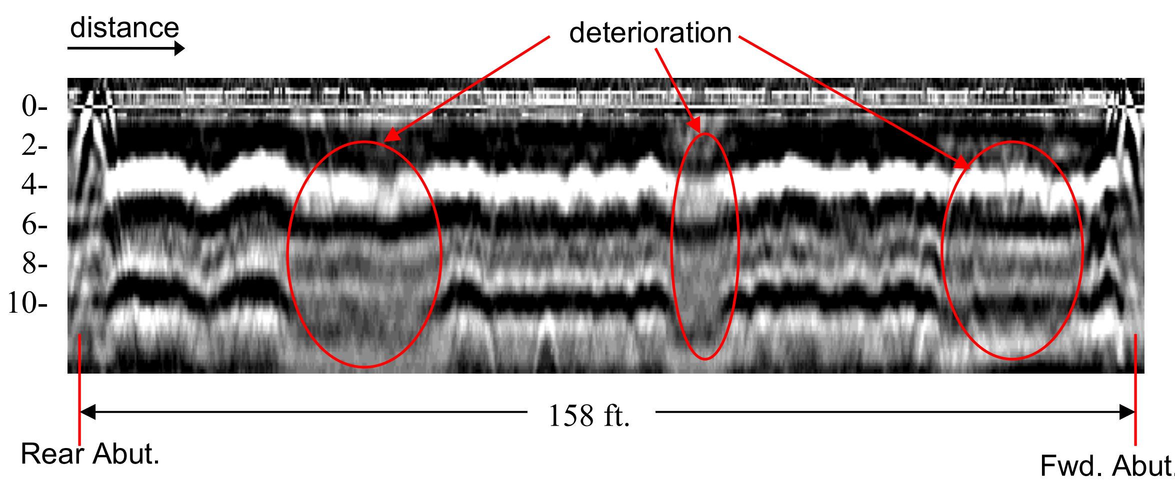


Figure 4 – Sample GPR Bridge Data with Probable Areas of Deterioration

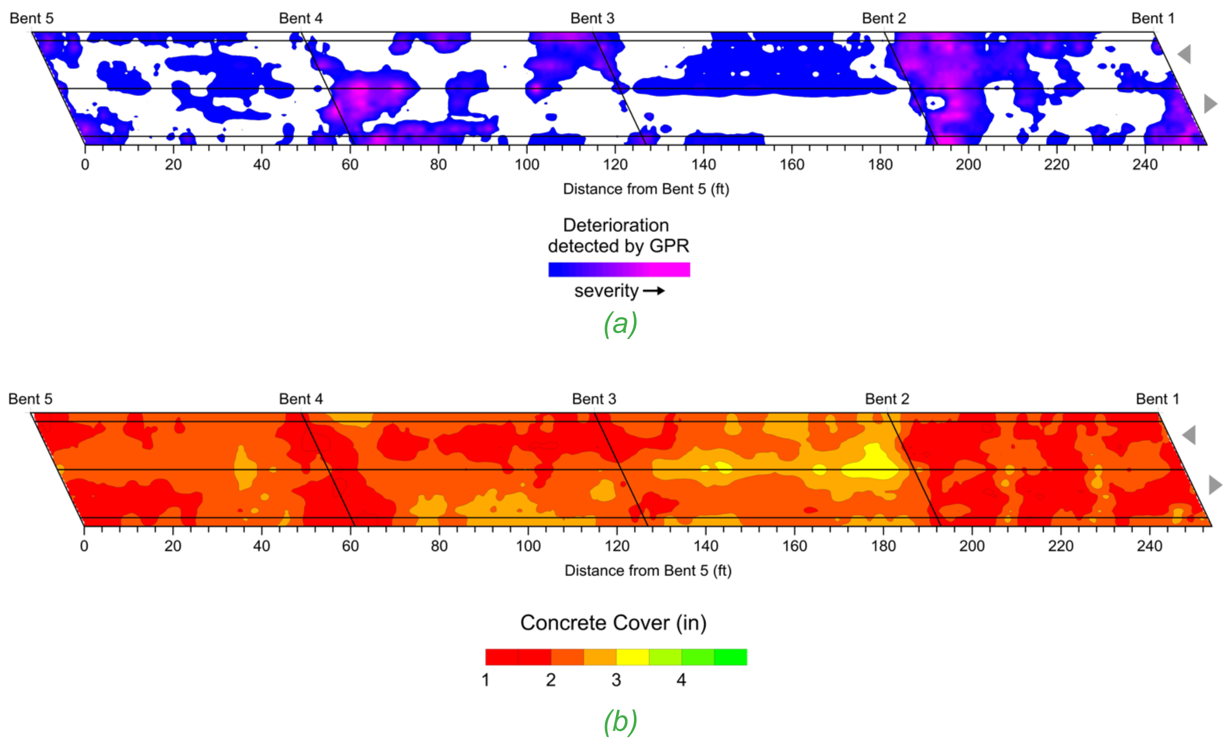


Figure 5 – Sample GPR Bridge Results Identifying Deteriorated Areas (a) and Rebar Cover (b)

Table 2 – GPR Results

Bridge ID	Deck Area (sf)	GPR Deterioration (%)
290007	4238	17.4
290014	8296	14.4
290018	13446	3.6

INFRARED THERMOGRAPHY (IR) AND HIGH-RESOLUTION VIDEO (HRV)

The infrared thermography survey was carried out in accordance with ASTM D 4788 – 03 (2013) using a 640 x 480 pixel FLIR Systems Model A655sc infrared camera and a Sony – Alpha a 74K resolution video camera, both mounted to an elevated platform on top of the survey vehicle and operated remotely from within the vehicle (Figure 6).
The infrared and video data were collected in a series of passes across each deck, moving at approximately 55 mph. The survey required multiple passes along each deck. Each pass covers a deck width of 12 to 15 feet. The cameras are connected to the DMI and set to record an image for every foot of travel.

The infrared data is reviewed simultaneously with HRV data to differentiate delaminated areas from surface features (discoloration, oil stains, sand and rust deposits, etc.) that appear in the infrared, but are unrelated to subsurface conditions. Delaminations typically appear as white blotchy areas on the IR image. These are "hot spots" where the surface temperatures are higher due to the thermal barrier produced by the delaminations. Surface staining /

discoloration can also produce “hotspots" unrelated to subsurface conditions. The darker the color of the deck surface, the higher the emissivity and corresponding surface temperature.

Figure 7 presents an example of a patched area as it appears in a single image of infrared data and in the corresponding visual data. For analyzing this data, proprietary software automates the process of taking horizontal slice from each infrared and visual image and calibrates the image so that an area of 1 foot is captured in the direction of travel. Sequential slices are then automatically stitched together to create a single strip image for each pass of both the infrared and visual data. The strip images for each pass are placed next to those of adjacent passes to produce composite visual and thermal images of the entire deck as presented in Figure 8. While Figure 8 is a compressed example, the final deliverable provided to NCDOT will be of 4K resolution, allowing for the identification and mapping of 1 mm size cracks. Finally, composite images such as those presented in Figure 3 are analyzed to identify delaminations, which are outlined with a cursor. These outlined areas are then quantified and used to create final plan area maps (Figure 9).

Table 3 presents the probable deterioration measured with IR and HRV. Appendix A-C provide detailed IR and HRV results for bridges 290007, 290014, and 290018, respectively.

Figure 6 - Infrared and Video Survey Equipment

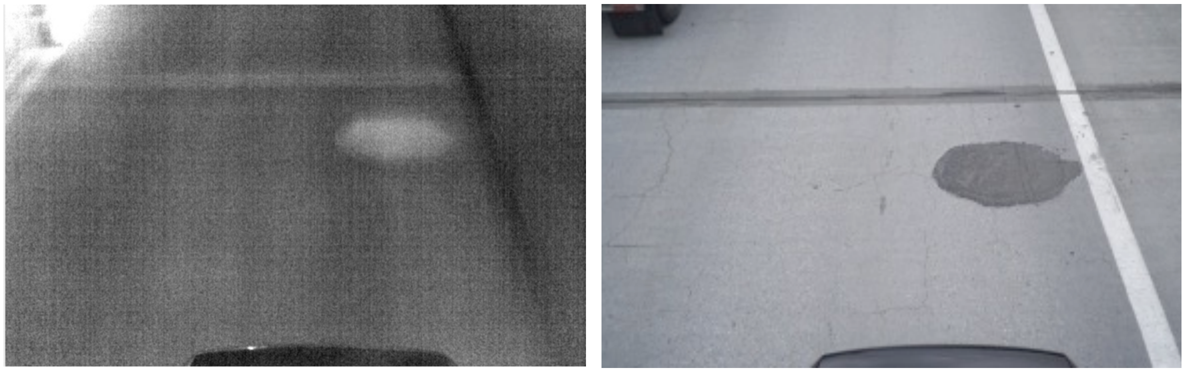
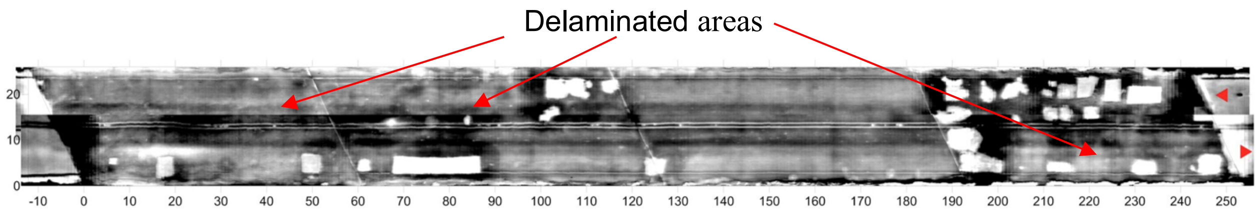
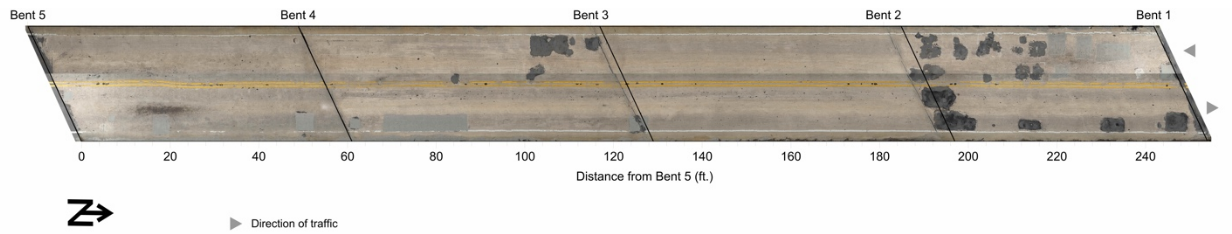


Figure 7 - Sample Infrared and Visual images



(a)



(b)

Figure 8 – Sample Stitched (a) IR and (b) HRV Images

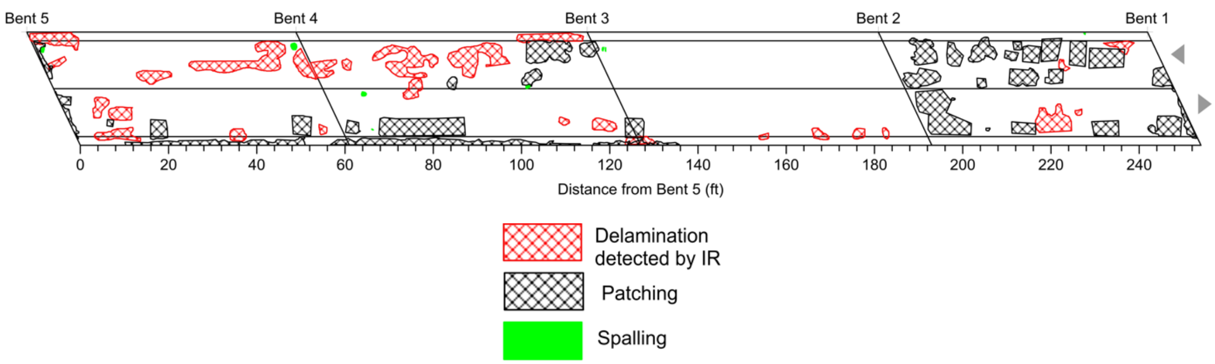


Figure 9 – Sample Finalized Plan Area Map Showing IR Delaminations, Visual Patches, and Spalling

Table 3 – IR and HRV Results

Bridge ID	Deck Area (sf)	IR Delamination (%)	HRV Patching (%)	HRV Spalling (%)
290007	4238	5.2	3.1	0.0
290014	8296	4.6	1.0	0.0
290018	13446	2.0	1.0	0.0

DECK ACOUSTIC RESPONSE (DAR)

Typically, acoustic methods using a low strain, stress wave are used to interrogate the integrity of concrete structures. This includes a variety of methods including traditional methods such as hammer sounding and chain drag as well as nondestructive techniques such as impulse response and impact echo. While the impulse response method utilizes the response of a known impulse, the IE method measures the frequency response induced from the dynamic impact of the structure. Using a small ball peen hammer or steel spheres, the concrete surface is struck and the dynamic response is recorded on a high-speed data acquisition unit. Time domain data is transferred into the frequency domain using a Fast Fourier Transform (FFT), and the frequency domain is analyzed to determine the velocity of the concrete, depth of the slab, location of delaminations, or all three. During this procedure, multiple wave form types are analyzed to determine the location of delaminated areas. Similarly, the human ear detects similar changes in frequency during investigation using hammer sounding and chain drag techniques. Researchers have found that chains of specific type induce a consistent dynamic response from concrete decks, and by recording the response from this dynamic force, the effects of manual chain drag can be automated. Manual chain drag was carried out on the westbound lane of 290007, the southbound lane of 290014, and was not performed on 290018 for safety reasons. This provided a baseline for the DAR calibration.

The deck acoustic response (DAR) method utilizes a combination of these techniques. The device is modular allowing for individual impacts to be made similar to hammer sounding or by dragging chains across the bridge deck in a more traditional chain drag approach (Figure 10). In both instances, the acoustic response is recorded by free field microphones. The microphones record sound and vibration amplitudes as a function of time, and that data is transferred into the frequency domain for analysis. The quantities of delaminations found utilizing the SounDAR system encompasses those areas found with manual chain drag and expands upon them. This is because of the quantitative nature of the device. Rather than depending on the human ear, the device utilizes a trained machine learning algorithm that identifies changes in the acoustic response and identifies them as intact concrete or degraded concrete. In this way, SounDAR provides a more comprehensive determination of the true quantity of delaminations.

Table 4 presents the probable deterioration measured with manual chain drag and SounDAR. It should be noted that areas identified by SounDAR were often larger than that identified with manual chain drag. This can be attributed to the ability of the human ear to quantify differences across a very broad frequency spectrum that also includes frequencies above that which the human ear can detect. Additionally, areas identified with manual chain drag often encompassed multiple smaller areas of delamination identified by chain drag. This can be attributed to the quantifiable nature of recording with a microphone versus the human ear attempting to differentiate a small area between two larger delaminations. Appendix A-C provide detailed sounding results for bridges 290007, 290014, and 290018, respectively.

The advantage of utilizing a quantitative sounding mechanism such as SounDAR is that the human ear cannot distinguish the varying levels across the frequency spectrum of response measured when performing chain drag. In other words, a microphone and computer can provide more accurate results than the human ear. However, the system has its inherent limitations as well. Because data is processed only on a limited spacing, areas of delaminations between the dynamic excitation source may be missed. This weakness can be improved by taking more passes across any one lane of interest, however. Finally, the major strength of this system is it provides similar results to chain drag while being much fast and requiring only a rolling lane closure.

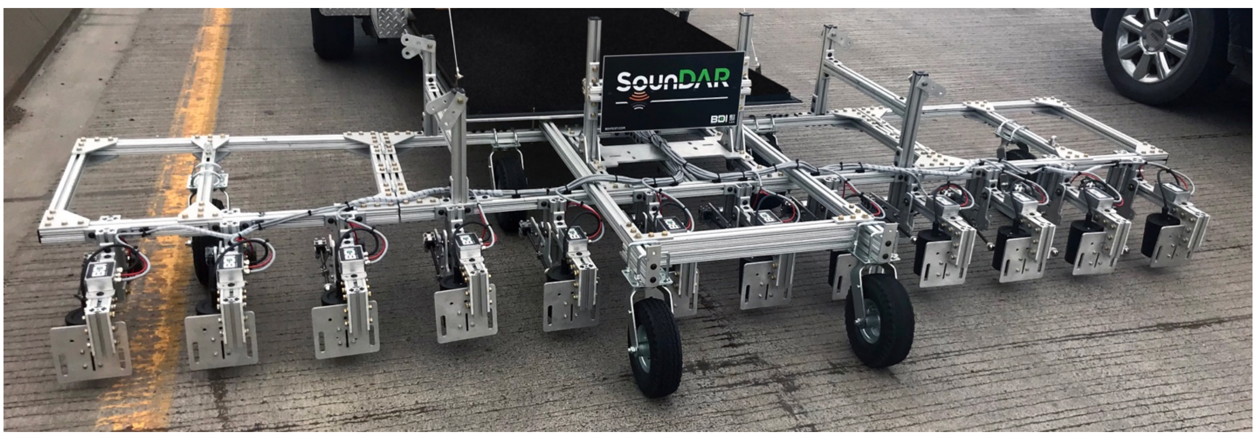


Figure 10 – Deck Acoustic Response (SounDAR) System

Table 4 – Sounding Results

Bridge ID	Deck Area (sf)	Manual Chain Delamination (%)	SounDAR Delamination (%)
290007	4238	7.8	21.1
290014	8296	2.9	14.4
290018	13446	N/A	4.4

RAPID CHLORIDE TESTING (RCT)

The nature of corrosion in structural concrete is an exchange of energy within different sections of the reinforcing steel. When a metal is put into an electrolyte, as when reinforcing steel is embedded into concrete, positive metal ions will resolve (oxidize). This produces a heavy concentration of electrons in the metal lattice and thus a heavy concentration of positive ions at the metal surface (originally a passive layer of protection). However, this concentration of positive ions attracts the negatively charged ions (anions) from the surrounding electrolytic material (in concrete, these negatively charged ions are typically Cl- and SO42- ions) and this forms a half-cell. The areas where there is a larger surplus of negative ions will have a higher probability of corrosion, and current will begin to flow from that area to areas with fewer electrons (this is the formation of a cathode). This is the process of corrosion with regards to steel reinforcement embedded in concrete. Another excellent thing to identify is that the combination of steel and concrete is a viable construction material of proven durability. In the normally alkaline environment, the passive layer that forms on the surface of the reinforcing steel acts as a protective barrier for the reinforcing steel. The mechanism that causes the corrosion in the reinforcing steel is a complex reaction between the protective oxide layer and any ions, typically Cl-, as mentioned above. Essentially, the protective layer, in the presence of chloride ions, is transformed into FE (OH2), or rust. Figure 11 presents a general illustration of this concept.

As the corrosion continues and the reinforcing steel loses cross section, an air void forms between the concrete and the steel (i.e. the bond between the reinforcing steel and the concrete is lost). As this happens, the remaining steel also begins to expand and induces tensile forces into the concrete matrix. Because concrete has a relatively low tensile strength, this causes the concrete to crack. At first, with small levels of steel corrosion and expansion, the cracks are in the form of microcracks within the concrete matrix itself. However, as the corrosion process continues and the reinforcing steel loses more cross section, these cracks coalesce and eventually form horizontal cracks that are parallel to the concrete surface (delaminations). Eventually these delaminations will grow to the surface and cause concrete spalls. Essentially, the rust product formed during the corrosion process occupies a much greater volume than the original steel member, tensile stresses are exerted into the surrounding concrete, and the concrete cracks, delaminates, and given enough time spalls (Figure 12).

As this process of corrosion and eventually spalling occurs, the processes that cause the phenomena can be measured and monitored. A high concentration of ions in a material cause the material to be highly conductive and indicate the presence of a corrosive environment. To measure the concentration of these ions, the rapid chloride test (RCT) method was utilized. The RCT provides the weight of chloride ions by weight of concrete in accordance with AASHTO T 260.

Three (3) powder samples from each bridge deck were obtained by drilling cover concrete in 1” increments. The first 1” was drilled with a 1.5” diameter drill bit, the second inch was drilled with a 1” drill bit, and the third inch was drilled with a ½” drill bit. This technique limited contamination from one sample to the next. Table 3 presents the locations for the powder samples and the corresponding chloride concentrations in units of percentage of weight of concrete. Additionally, the first figure in each of Appendices A-C presents the locations of the cores. Figure 13 presents the distribution of these values as a function of depth.

Sample 2 of bridge 290007 indicates typical behavior for chloride ingress and chloride concentration decreases as a function of depth. However, samples 1 and 3 of bridge 290007 exhibit odd behavior. This contamination correlates with locations where GPR identified high corrosion probability. 33% of the samples taken exceeded 2.0 lbs.CY.

All samples taken from bridge 290014 indicate typical behavior for chloride ingress through concrete. However, 75% of the measurements taken exceed the threshold of 2.0 lbs./CY and correlate with areas identified for probable corrosion.

Samples taken from bridge 290018 mostly indicate typical behavior for chloride ingress through concrete. However, sample 1, taken in an area of high GPR corrosion probability, maintains a higher chloride concentration from 2” – 3”. Additionally, 67% of the measurements taken exceed the threshold of 2.0 lbs./CY and correlate with areas identified for probable corrosion.

In general, all chloride measurements correlate well with GPR, IR, HRV, and SounDAR results and provide the general conclusion that the bridge decks sampled are the subject of chloride induced structural concrete degradation.

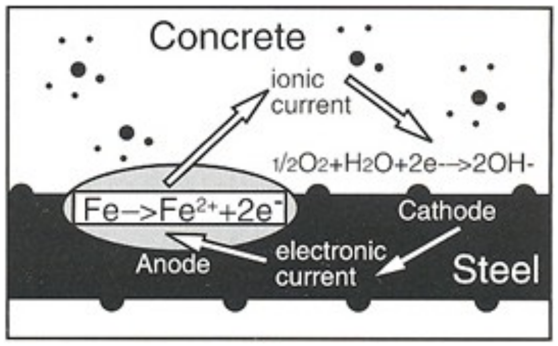


Figure 11 – Process of Corrosion in Structural Concrete.

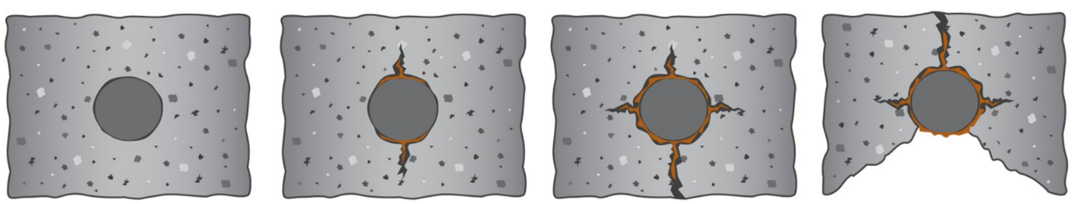
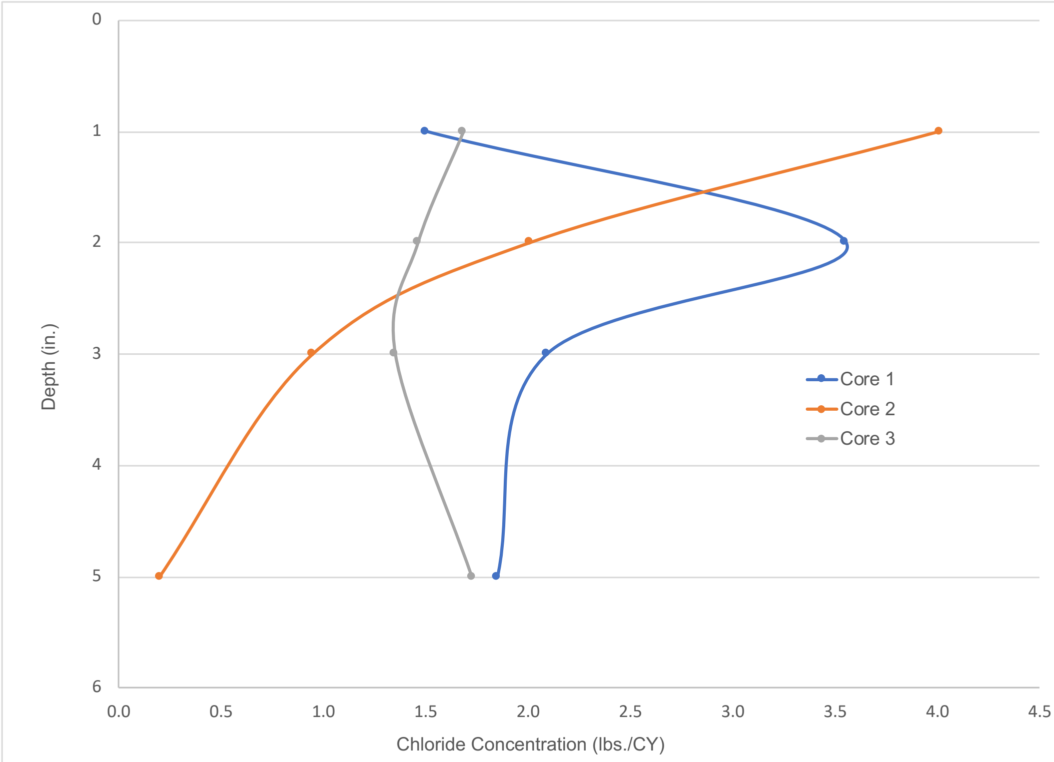


Figure 12 – Corrosion in Structural Concrete Leads to Cracks and Eventual Spalling.

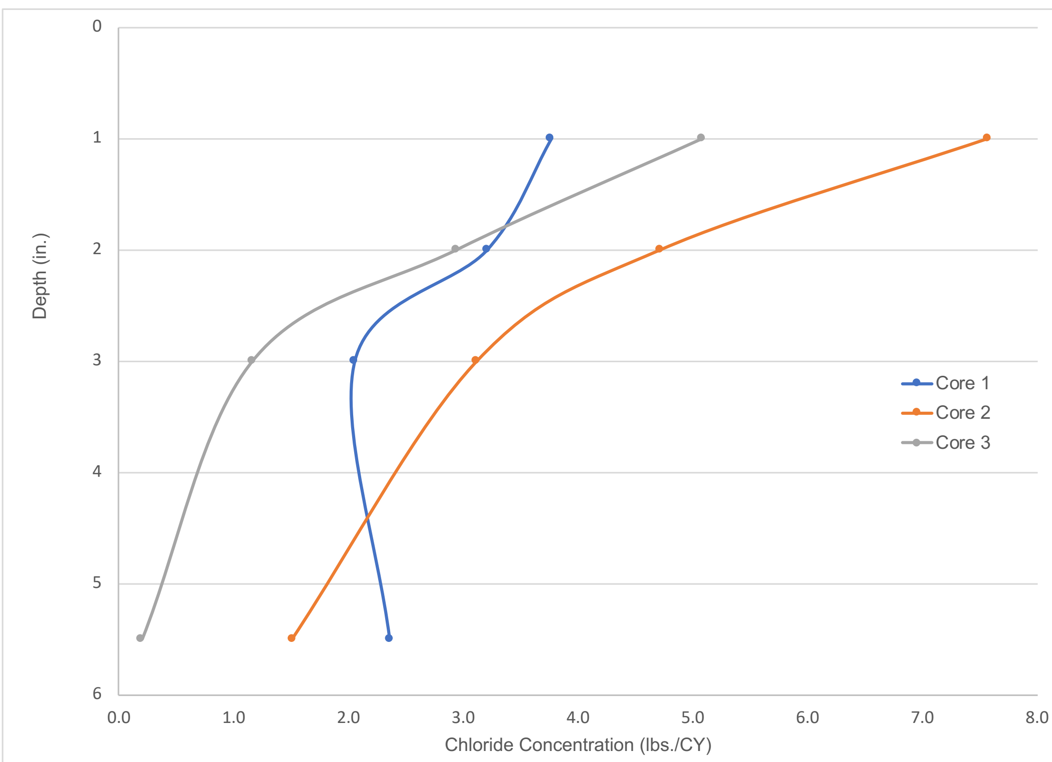
Table 4 – Chloride Ion Penetration Test Results

Bridge	Core	Lane Direction	Distance from Near Shoulder (ft)	Distance from Approach Abutment (ft)	Depth (inches)	%Cl by Weight	lbs/ft^3	Rebar Cover (in)
290007	1	West	5	78	5	0.05	0.068	2.0
					3	0.05	0.077	
					2	0.09	0.132	
					1	0.04	0.056	
	2	East	4	140	5	0.01	0.008	2.5
					3	0.02	0.035	
					2	0.05	0.074	
					1	0.10	0.148	
	3	East	7	50	5	0.04	0.064	3.0
					3	0.03	0.050	
					2	0.04	0.054	
					1	0.04	0.062	
290014	1	South	8	90	5.5	0.06	0.087	2.0
					3	0.05	0.076	
					2	0.08	0.119	
					1	0.09	0.139	
	2	South	9	156	5.5	0.04	0.056	1.5
					3	0.08	0.116	
					2	0.12	0.175	
					1	0.19	0.281	
	3	South	8	168	5.5	0.01	0.008	1.5
					3	0.03	0.043	
					2	0.07	0.109	
					1	0.13	0.188	
290018	1	South	4	248	6	0.01	0.010	1.0
					3	0.07	0.101	
					2	0.07	0.111	
					1	0.13	0.197	
	2	South	10	168	6	0.00	0.005	2.3
					3	0.04	0.059	
					2	0.06	0.096	
					1	0.14	0.206	
	3	South	10	30	6	0.01	0.008	3.0
					3	0.06	0.086	
					2	0.10	0.146	
					1	0.18	0.265	



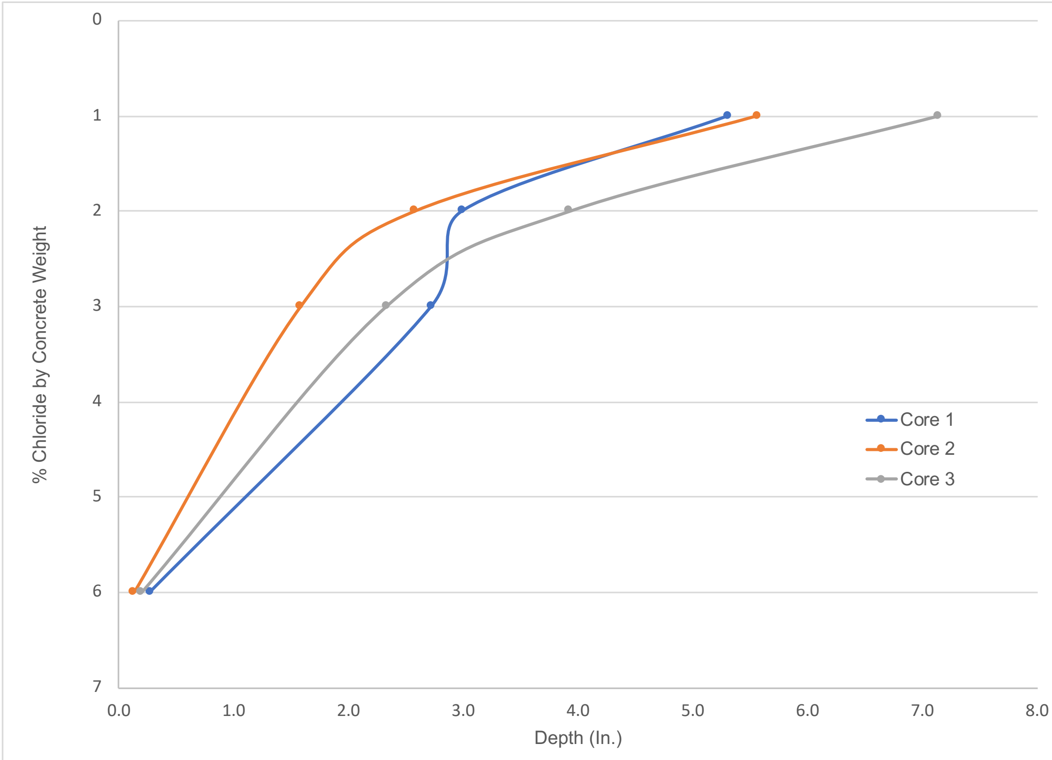
0
1
2
3
4
5
6
Depth (in.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Chloride Concentration (lbs./CY)
Core 1
Core 2
Core 3

(a)



0
1
2
3
4
5
6
Depth (in.)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Chloride Concentration (lbs./CY)
Core 1
Core 2
Core 3

(b)



(c)

Figure 13 – Percentage of Chloride Ion Concentration by Weight of Concrete for Bridge (a) 290007, (b) 290014, and (c) 290018

REBOUND HAMMER STRENGTH TESTING

Rebound hammer strength testing was performed in the middle of each lane on all bridges. Rebound hammer testing was performed with a Proceq Schmidt Hammer; values measured with the rebound hammer were converted to compressive strength in accordance with Figure 14.

Appendix A-C provide detailed rebound hammer test results for bridges 290007, 290014, and 290018, respectively.

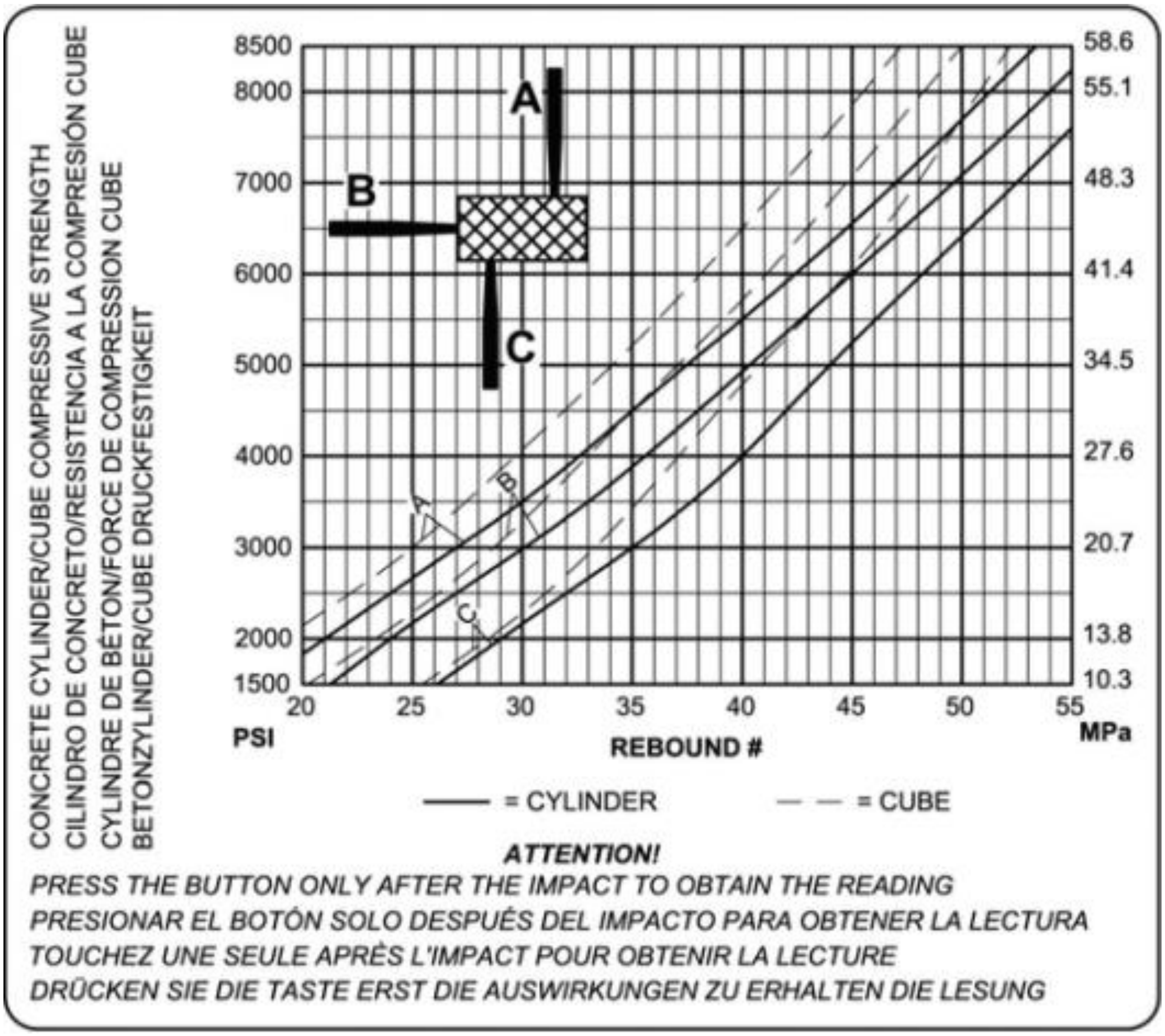


Figure 14 – Rebound Hammer Measurement Conversion Curves

Conclusions and Recommendations

In December of 2017 and January of 2018 BDI performed nondestructive testing of three (3) select bridge decks Davie County, NC as part of a two-phase nondestructive evaluation (NDE) of the structures. The testing methods included ground penetrating radar (GPR), infrared thermography (IR), high-resolution video (HRV), BDI's deck acoustic response system, SounDAR, chloride ion penetration, and rebound hammer testing. Utilizing jointly developed proprietary data analysis software, BDI and Infrasense performed the analysis of the data. Conclusions include:

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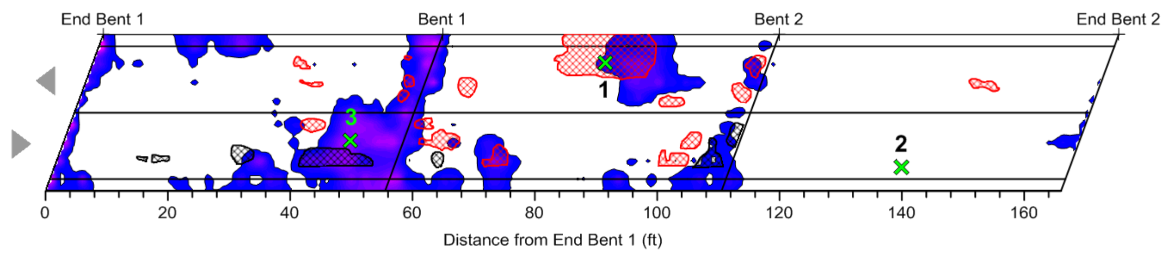
        iii. $f'c$ < 5,000 psi – 35% (4706 ft^2)
        iv. $f'c$ > 5,000 psi – 59% (7933 ft^2)

APPENDIX A – STRUCTURE 290007



Concrete Condition Legend

Deterioration detected by GPR

severity →

*combined quantity accounting for overlap

Delamination detected by IR

Patching

Spalling

Thermal Obstruction

Orientation

N

Direction of traffic

Quantity Summary

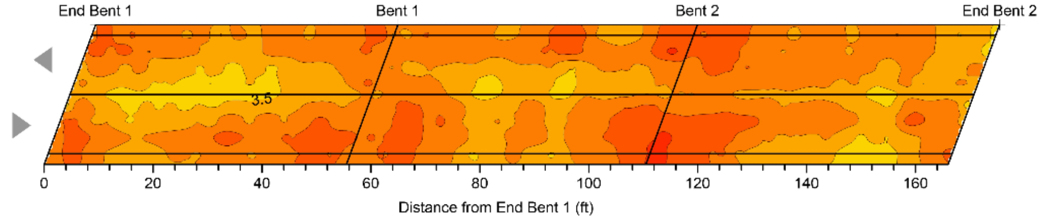
Condition	sq. ft.	%
Delamination (IR)	225	**5.2**
Deterioration (GPR)	749	17.4
Patching	**134**	3.1
Spalling	0	0.0
Combined Defects*	947	**22.0**

General Information

Bridge ID: 290007
SR 1147 over Hunting Creek

Analyzed by: SB
Reviewed by: AC
Completed: 12/14/17

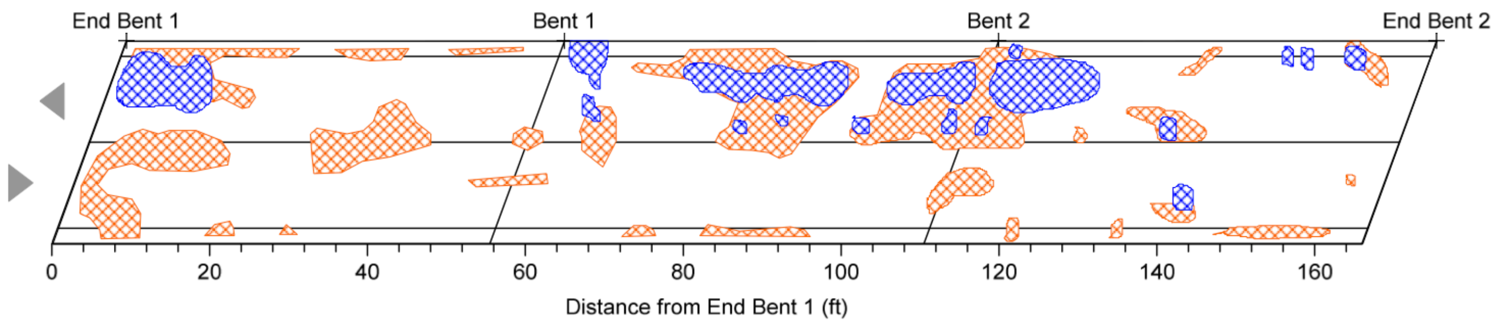
Sheet 1 of 1



Concrete Cover Legend	Orientation	Concrete Cover Statistics		General Information
Concrete Cover (in) 1 2 3 4	N Direction of traffic	Average	2.9 in	Bridge ID: 290007 SR 1147 over Hunting Creek
				Analyzed by: SB Reviewed by: AC Completed: 12/14/17
				Sheet 1 of 1

INFRASENSE

BDI
RAW DATA. REFINED RESULTS.



Concrete Condition Legend

*Manual chain drag was performed only on the West bound lane.

Delamination detected by Chain

Delamination detected by SounDAR

Orientation

N

Direction of traffic

Quantity Summary

Condition	sq. ft.	%
Delamination (Chain)*	331.7	7.8
Deterioration (SounDAR)	892.4	21.1

General Information

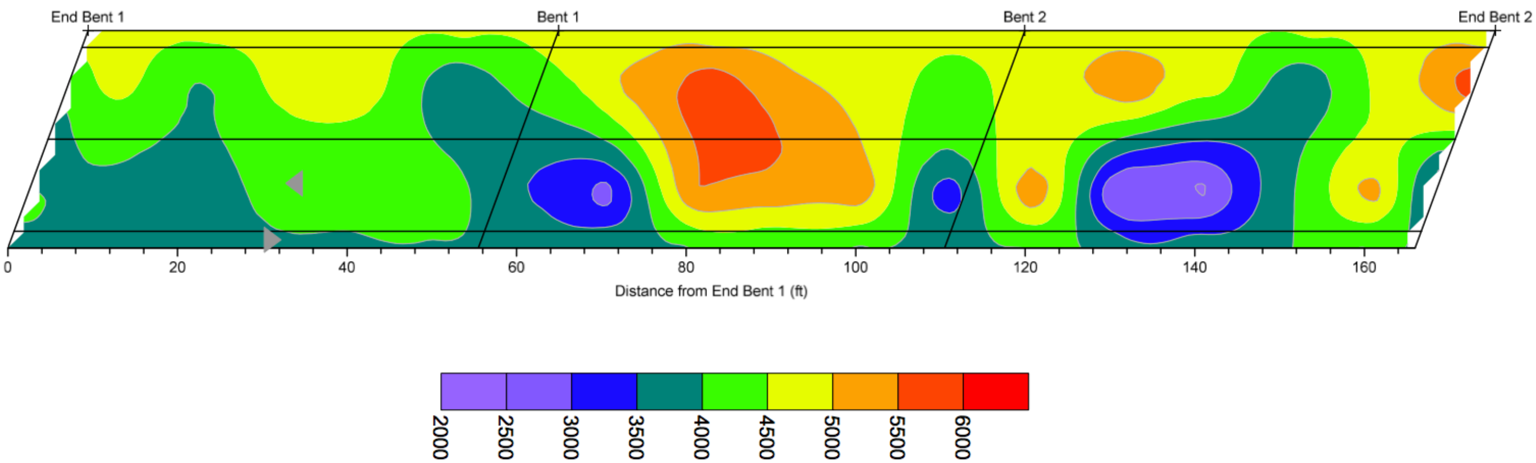
Bridge ID: 290007
SR 1147 over Hunting Creek

Analyzed by: JC
Reviewed by: SB
Completed: 1/22/18

Sheet 1 of 1

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.



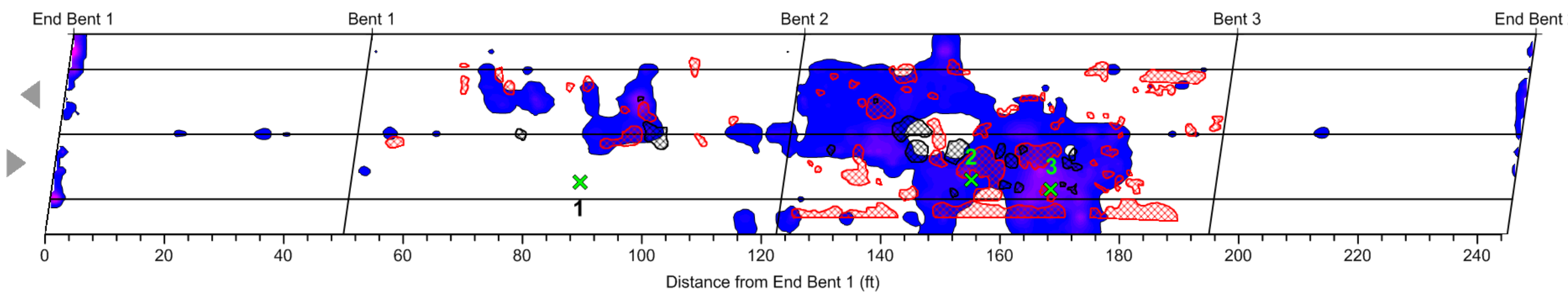
Concrete Condition Legend	Orientation	Quantity Summary		General Information
The Lane was Closed During the Survey Strength values are presented in lbs/sq. in. (psi)	N Direction of traffic	Condition	%	Bridge ID: 290007 SR 1147 over Hunting Creek
		<3000 psi	13	Analyzed by: SB Reviewed by: JC Completed: 1/26/18
		<4000 psi	22	
		<5000 psi	34	
		>5000 psi	31	**Sheet 1 of 1**

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.

APPENDIX B – STRUCTURE 290014

RAW DATA. REFINED RESULTS.



Concrete Condition Legend		
Deterioration detected by GPR severity →		Delamination detected by IR
		Patching
		Spalling
*combined quantity accounting for overlap		Thermal Obstruction

Orientation

Direction of traffic

Condition	sq. ft.	%
Delamination (IR)	396	**4.8**
Deterioration (GPR)	1196	14.4
Patching	**87**	1.0
Spalling	0	0.0
Combined Defects*	1371	**16.5**

General Information

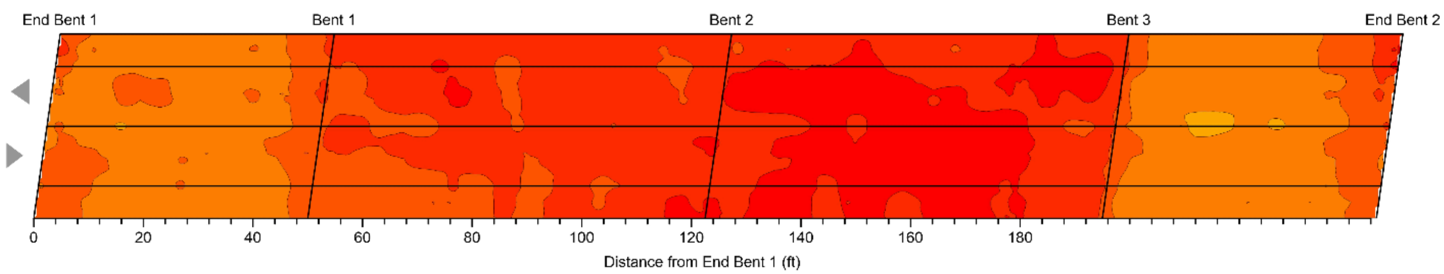
Bridge ID: 290014
SR 1147 over I-40

Analyzed by: SB
Reviewed by: AC
Completed: 12/14/17

Sheet 1 of 1

INFRASENSE

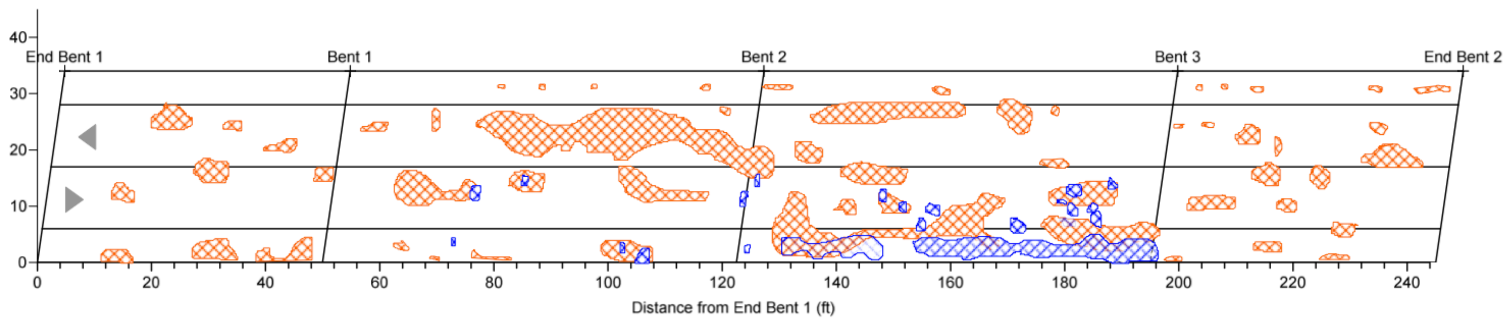
BDI
RAW DATA. REFINED RESULTS.



Concrete Cover Legend	Orientation	Concrete Cover Statistics		General Information
Concrete Cover (in)		Average	2.1 in	Bridge ID: 290014 SR 1147 over I-40
1 2 3 4				Analyzed by: SB Reviewed by: AC Completed: 12/14/17
	Direction of traffic			**Sheet 1 of 1**

INFRASENSE

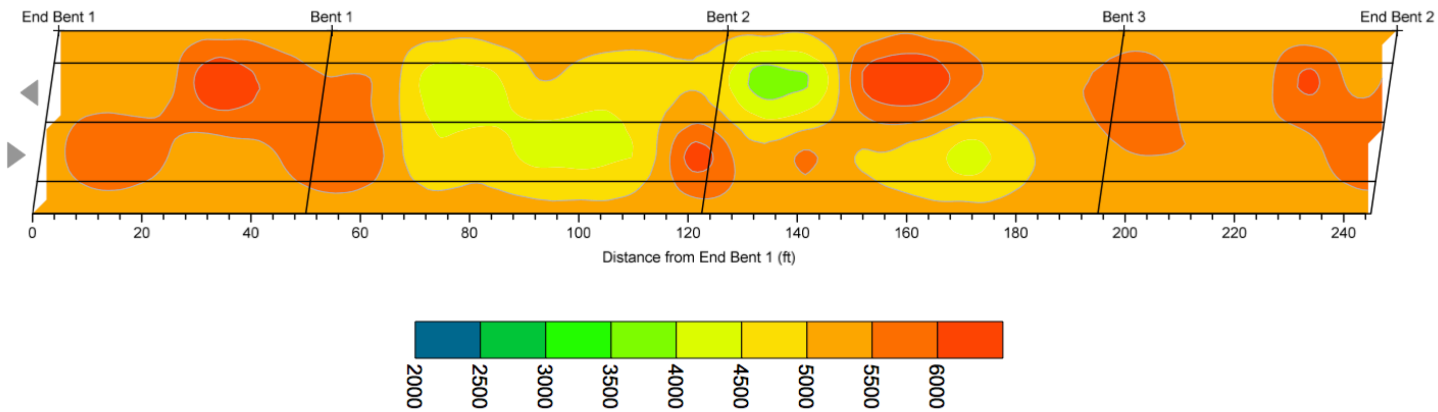
RAW DATA. REFINED RESULTS.



Concrete Condition Legend	Orientation	Quantity Summary			General Information
*Manual chain drag was performed only on the East bound lane.		Condition	sq. ft.	%	Bridge ID: 290014 SR 1147 over I-40
Delamination detected by Chain		Delamination (Chain)*	237	2.9	Analyzed by: JC Reviewed by: SB Completed: 1/22/18
Delamination detected by SounDAR	Direction of traffic	Deterioration (SounDAR)	1197	14.4	Sheet 1 of 1

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.

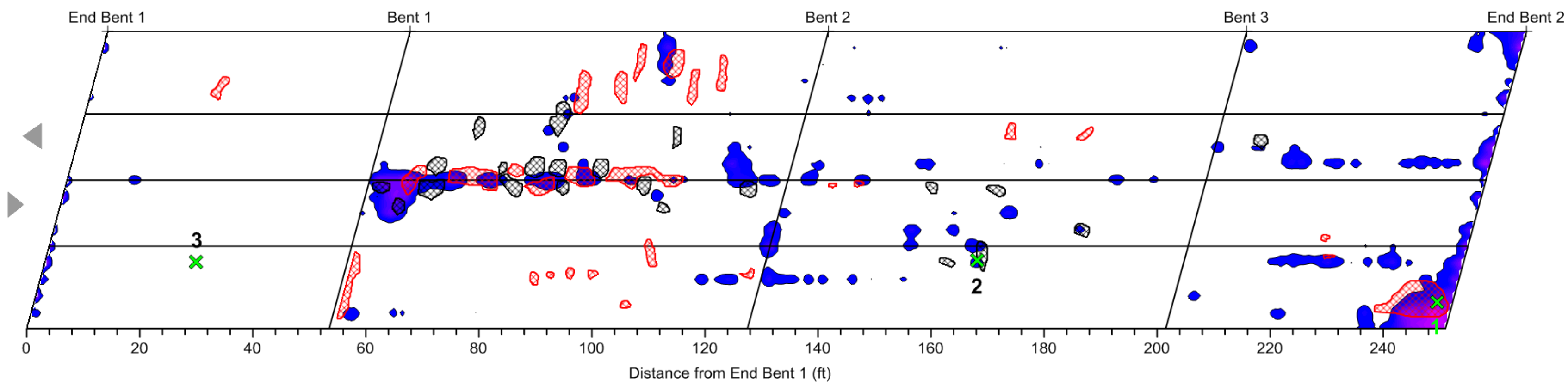


Concrete Condition Legend	Orientation	Quantity Summary		General Information
The Lane was Closed During the Survey Strength values are presented in lbs/(sq. in.) (psi)	Direction of traffic	Condition	%	Bridge ID: 290014 SR 1147 over I-40
		<3000 psi	0	Analyzed by: SB Reviewed by: JC Completed: 1/26/18
		<4000 psi	6	
		<5000 psi	27	**Sheet 1 of 1**
		>5000 psi	67	

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.

APPENDIX C – STRUCTURE 290018



Concrete Condition Legend

Deterioration detected by GPR

severity →

Delamination detected by IR

Patching

Spalling

Thermal Obstruction

*combined quantity accounting for overlap

Orientation

Direction of traffic

Quantity Summary

Condition	sq. ft.	%
Delamination (IR)	269	2.0
Deterioration (GPR)	489	3.6
Patching	**142**	1.0
Spalling	0	0.0
Combined Defects*	758	**5.6**

General Information

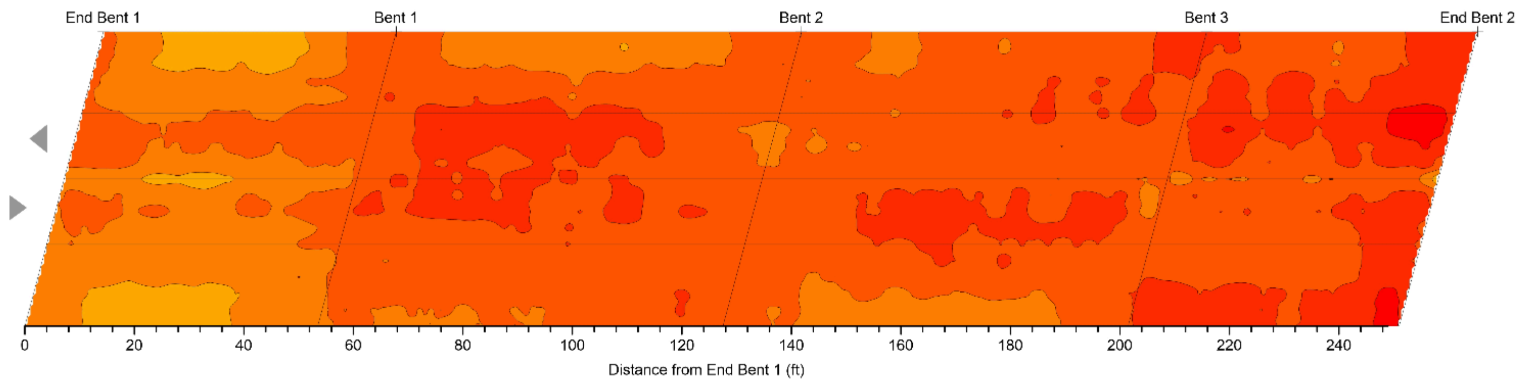
Bridge ID: 290018
SUS 64 over I-40

Analyzed by: SB
Reviewed by: AC
Completed: 12/14/17

Sheet 1 of 1

INFRASENSE

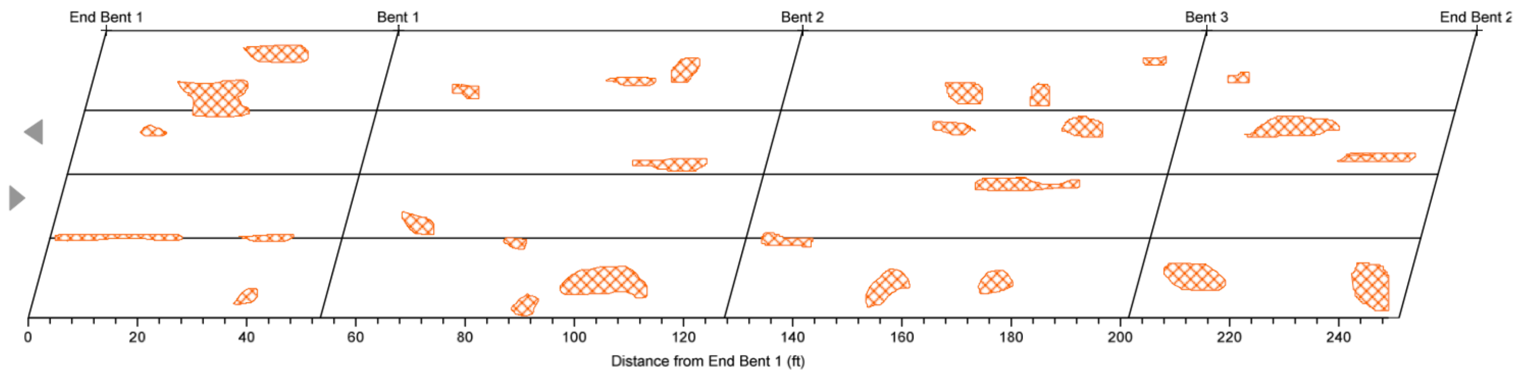
RAW DATA. REFINED RESULTS.



Concrete Cover Legend	Orientation	Concrete Cover Statistics		General Information
Concrete Cover (in) 1 2 3 4	Direction of traffic	Average	2.3 in	Bridge ID: 290018 SUS 64 at I-40
				Analyzed by: SB Reviewed by: AC Completed: 12/14/17
				Sheet 1 of 1

INFRASENSE

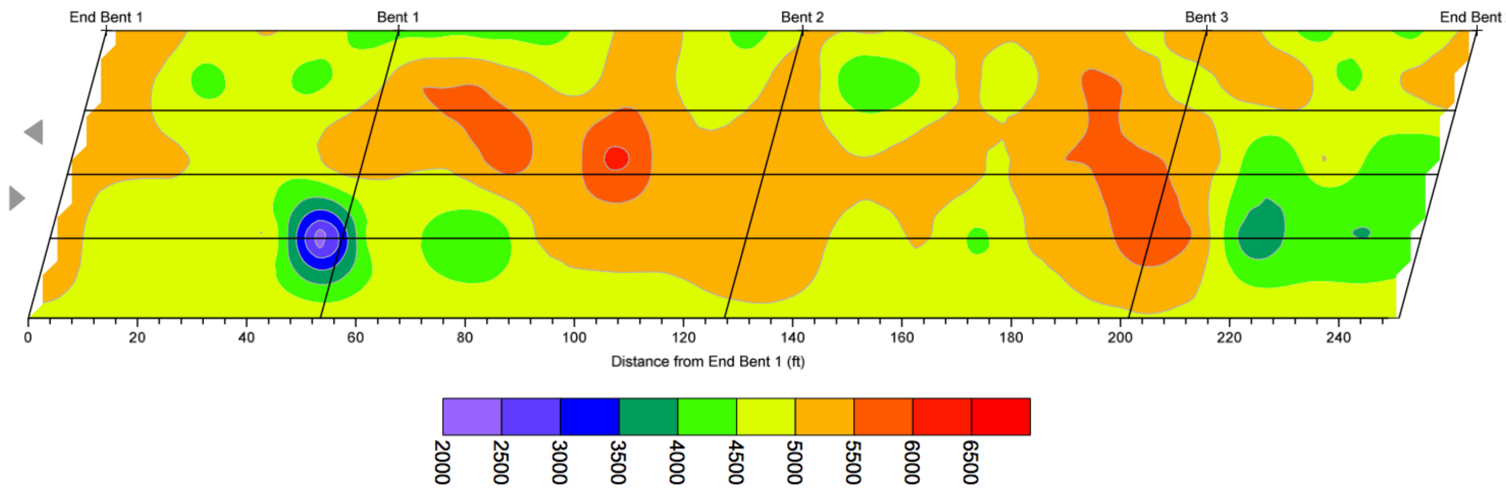
BDI
RAW DATA. REFINED RESULTS.



Concrete Condition Legend	Orientation	Quantity Summary			General Information
*Manual chain drag was not performed due to traffic control restraints.		Condition	sq. ft.	%	Bridge ID: 290018 SUS 64 over I-40
		Delamination (Chain)*	*	*	
		Deterioration (SounDAR)	597.5	4.4	Analyzed by: SB Reviewed by: JC Completed: 1/26/18
Delamination detected by SounDAR	Direction of traffic				**Sheet 1 of 1**

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.



Concrete Condition Legend	Orientation	Quantity Summary		General Information
The Lane was Closed During the Survey Strength values are presented in lbs/sq. in. (psi)	Direction of traffic	Condition	%	Bridge ID: 290018 SUS 64 over I-40
		<3000 psi	1	Analyzed by: SB Reviewed by: JC Completed: 1/26/18
		<4000 psi	5	
		<5000 psi	35	Sheet 1 of 1
		>5000 psi	59	

RAW DATA. REFINED RESULTS.

RAW DATA. REFINED RESULTS.