Ground Penetrating Radar Condition Survey of 7 Bridge Decks in Iowa

FINAL REPORT

Submitted to

Iowa Department of Transportation
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By

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1. Introduction

The overall purpose of this project has been to evaluate the condition of the 7 bridge decks listed in Table 1. The condition of the decks was assessed using a highway-speed 3D-Radar ground penetrating radar (GPR) system. The resulting condition information will be used, in conjunction with actual repair quantities, to assess the capabilities of the 3D-Radar GPR system.

Table 1 – Bridge List

Maint. No.	Feature On	Feature Over	Length (ft)	Width (ft)	Deck Area (sf)
7148.6S018	US-18	Little Floyd River	122	28	3416
5341.2S038	Iowa-38	Sybil Creek	74	30	2220
3572.3S003	Iowa-3	I-35	350	60	21000
4959.4R061	US-61	Maquoketa River	374	30	11220
0417.7S005	Iowa-5	Chariton River	413	30	12390
8684.0S021	Iowa-21	Wolfe Creek	287	30	8610
4915.2S052	US-52	Maquoketa River	714	28	19992

2. Data Collection

The GPR survey was carried out from March 15-17, 2017. The data collection was originally intended to begin on March 13, but due to snow and subfreezing temperatures the data collection was delayed until the weather had improved and the temperatures had risen to above freezing. The temperature range during data collection was 38 to 66 °F. The GPR survey was carried out using a 3D Radar step-frequency array system with a DX1821 antenna mounted to a survey vehicle as shown in Figure 1, travelling at approximately 40 mph. The GPR system is controlled by the GeoScope, which is the data acquisition system operated from within the survey vehicle using a laptop. The laptop is connected to the GeoScope with an Ethernet connection, and the data collection is controlled using a web browser. Also connected to the GeoScope are the wheel-mounted distance encoder and the GPS unit.

The DX1821 antenna specification indicates that it is 1.8 meters wide and has 21 antennas. Since each antenna is spaced 3 inches apart, the effective data collection width of this antenna is 5 feet. Three driving passes were collected in each lane (right, center and left). This provided some overlap but ensured that all areas would be covered. The shoulders of these decks are typically 2-3 feet wide, and due to the close proximity of the equipment to the curb travelling at driving speed, shoulder data within 3 feet of the curb was not collected. Bridge 3572.3S003 has 6 foot shoulders, but the survey width was still limited by snow pileup at the edges.

Data was collected on distance at a rate of 6 scans per foot of travel (per antenna), with distance data obtained from a wheel-mounted encoder. Since the antennas are spaced 3 inches apart, this data rate yields 24 scans per square foot of coverage, or 288 scans per foot per 12-foot lane. A typical highway GPR system will collect 4 scans per foot and 4 lines of data per lane, or 16 scans per foot per lane. Therefore, the 3D Radar system provides far more detail than the conventional highway GPR system.

In addition to the distance-based data collection, high precision GPS data was simultaneously collected so that the data from each pass could be accurately stitched together. Since the data was collected at close to normal driving speed, traffic control was not required.

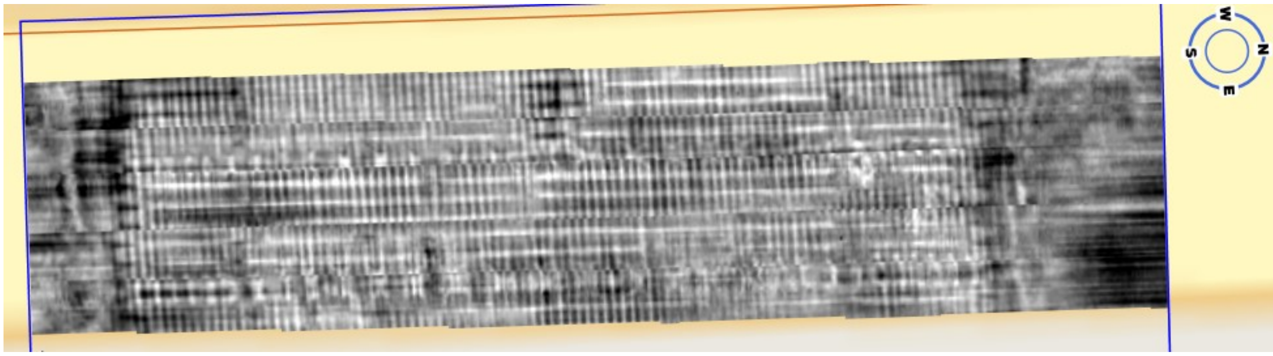
Figure 1 – 3D GPR survey vehicle setup

3. Data Analysis

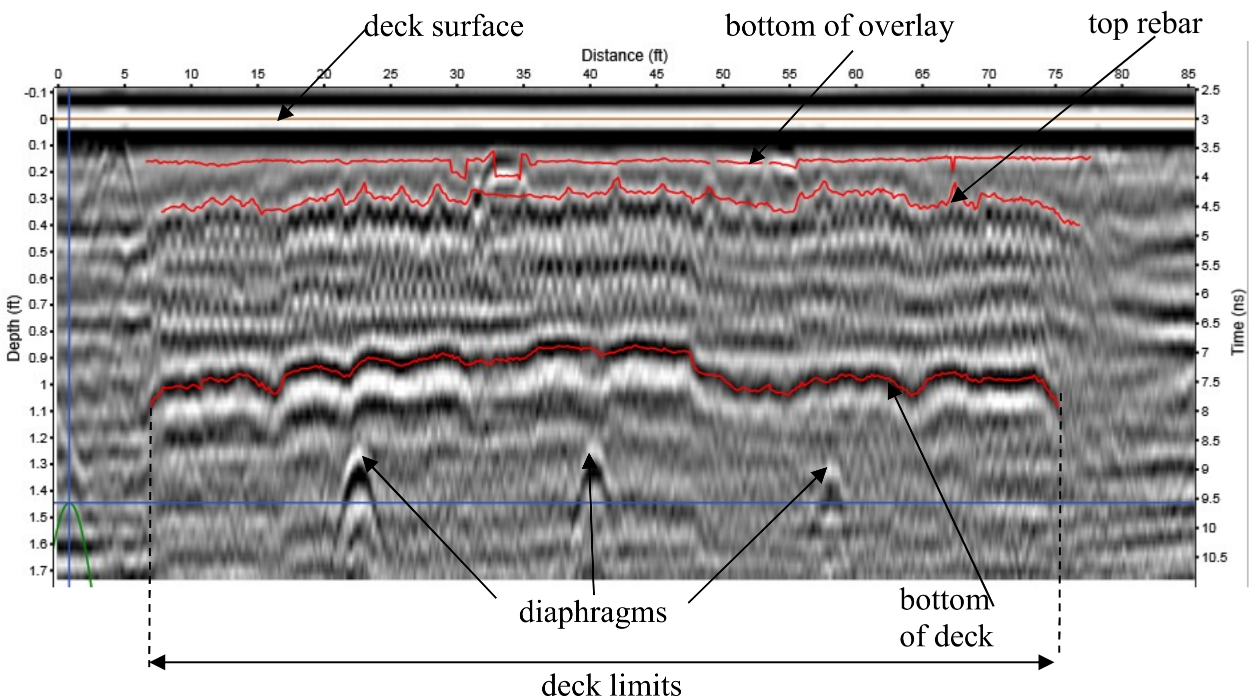
Ground penetrating radar operates by transmitting electromagnetic energy into a material using an antenna attached to a survey vehicle. This energy is reflected back to the antenna with an arrival time and amplitude that is related to the location and nature of dielectric discontinuities in the material (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 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.

Concrete deterioration can be inferred from changes in the attenuation of the GPR signal in concrete. The attenuation is associated with chloride infiltration and corrosion, not directly with delamination. However, since high chloride and corrosion are good indicators of delamination, there is a good correlation between the two.

Data was initially processed using 3D Radar's "Examiner" software. Examiner converts the frequency to time domain data, provides filtering and other processing functions, allows for the "stitching" of parallel data files across the width of the bridge, and enables the user to "pick" the layers of interest in the deck. Figure 2a shows an Examiner "depth slice" view of the data from bridge 5341, and Figure 2b shows the "picking" of the top rebar and bottom of the deck.



(a) Depth slice at 5" showing longitudinal and transverse rebar



(b) Single antenna cross section showing picked layers and features

Figure 2 – Examiner depth slice and cross section for bridge 5341.2S038

Once the data is stitched with Examiner, the data is processed using Infrasense's "ExploreGPR" software to calculate the amplitude of each of the picked layers. These amplitudes are then displayed in a contour plot format. The displayed areas of deck deterioration are based on setting an amplitude threshold below which the deck is considered "deteriorated". The entire analysis process can be summarized as follows:

(1) Import the 3D Radar files into Examiner;

(2) Stitch together of the individual survey passes to form a complete 3D image of the entire deck;

(3) Identify the beginning and the end of the deck, and check of the radar distance measurement against the known length and other features within the deck;

(4) Identify features (top rebar, bottom of deck) that appear as dielectric discontinuities in the GPR data;

(5) Track the detected layers using the Examiner "picking" tool;

(6) Import the stitched data and the tracking data into ExploreGPR, and compute rebar depth, and amplitude at the rebar-level and the bottom deck;

(7) Contour plot the rebar depth;

(8) Combine the top rebar and bottom deck data and display areas where the amplitude is below a specified threshold.

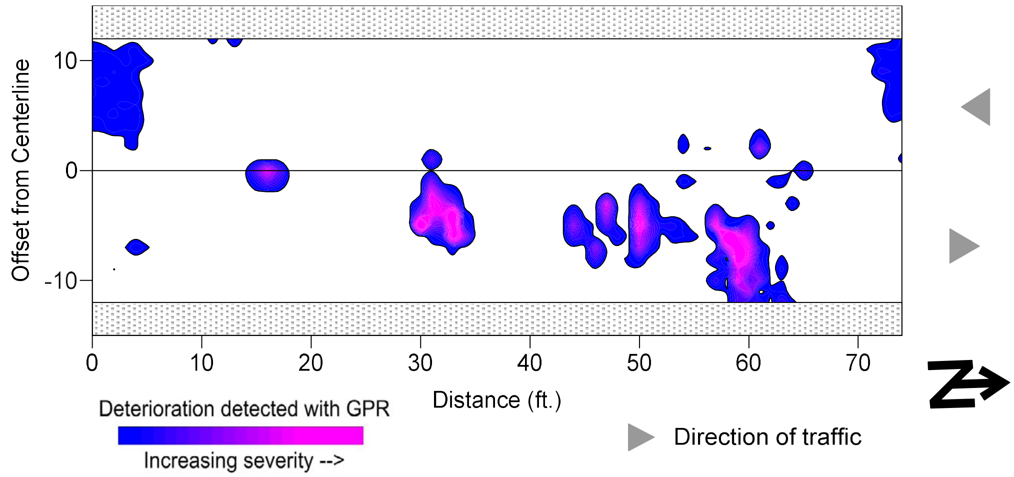
4. Results

The condition and rebar depth maps described above are presented in Attachment A.

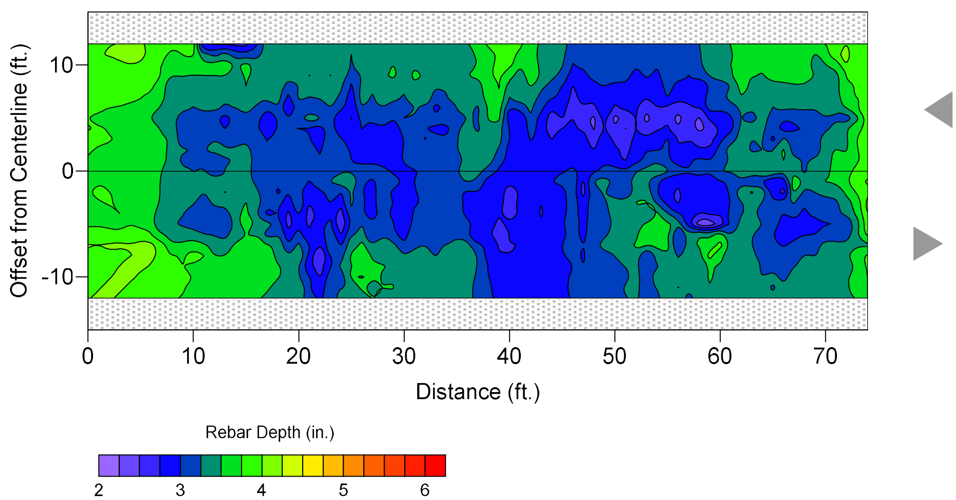
Representative results for bridge 5341.2S038 are shown in Figure 3a and 3b below. Areas shown in Figure 3a are those where the attenuation levels exceed a threshold value, indicating chloride contamination and corrosion. The color scale indicates the degree to which the threshold is exceeded, which represents the severity. Figure 3b shows a contour map of the rebar depth. The blue areas represent rebar cover from 2.5 to 3.25 inches, and the green areas represent rebar cover from 3.5 to 4.25 inches. A summary of deterioration and rebar depth quantities is presented in Table 1 below:

Table 2 – Summary of Quantities

Maint. No.	Feature On	Feature Over	% deteriorated	Avg. rebar depth (in.)
7148.6S018	US-18	Little Floyd River	11.0	3.8
5341.2S038	Iowa-38	Sybil Creek	8.7	3.4
3572.3S003	Iowa-3	I-35	9.4	4.4
4959.4R061	US-61	Maquoketa River	14.8	3.8
0417.7S005	Iowa-5	Chariton River	13.4	3.7
8684.0S021	Iowa-21	Wolfe Creek	3.7	3.5
4915.2S052	US-52	Maquoketa River	11.2	4.2



(a) Concrete deterioration map



(b) Rebar depth contour plot

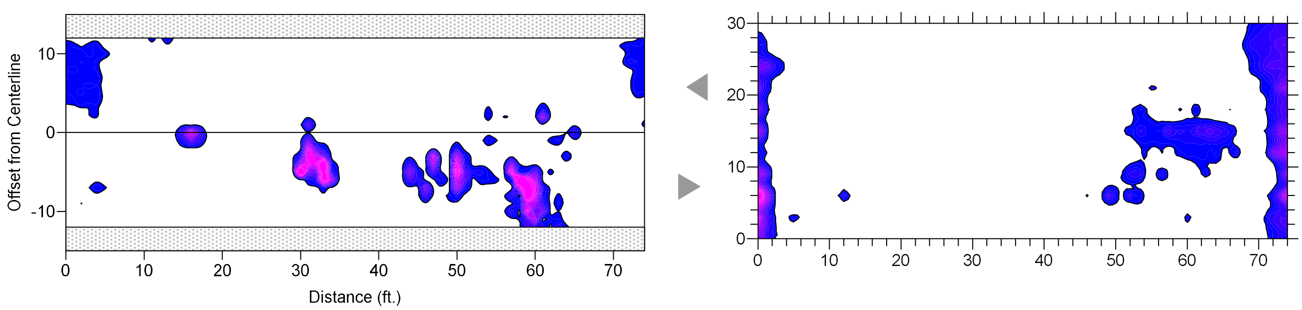
Figure 3 – Sample GPR survey results for bridge 5341.2S038

5. Comparison to Conventional GPR

As part of the evaluation of the 3D Radar system, a comparison study was carried out for three of the seven decks surveyed for this project. The comparison system used was a GSSI SIR 30 system using a pair of 2 GHz horn antennas. The setup of this equipment is shown in Figure 4.

Figure 4 – Conventional GPR horn antenna system for bridge deck surveys

The following decks were surveyed with this system: 5341.2S038; 4915.2S052; and 4959.4R061. The surveys were carried out a driving speed, with data collected at 6 scans per foot longitudinally, and data lines spaced transversely at 3 foot spacing. With this type of collection, a typical lane would have lines of data in the wheelpaths, along the centerline, and along the lane lines. The data was analyzed in a similar fashion as was the 3D Radar data, and the results have been presented as similar plan area plots.



(a) 3D Radar results (b) 2 GHz horn antenna results

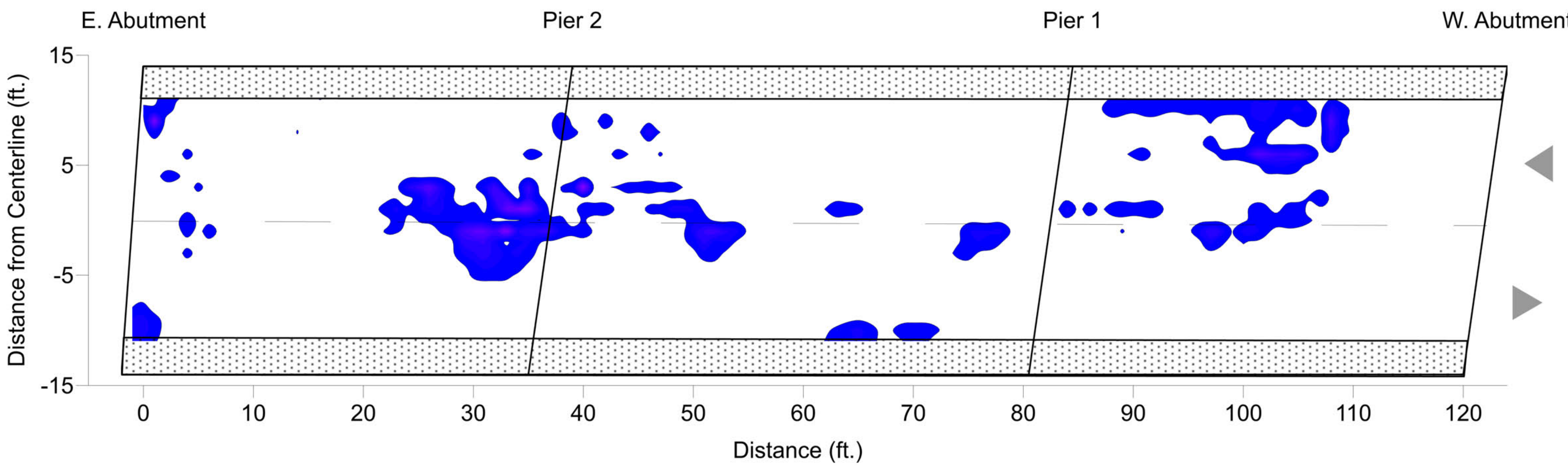
Figure 5 - Bridge 5341.2S038: Comparison of 3D Radar results with conventional system

The results show some differences and some similarities. While the locations of the deterioration in the north (right) span are different, the results do agree that most of the deterioration is in that span. Also, the total quantity of deteriorated concrete is approximately the same. The 3D Radar data appears to show more detail, and does indicate areas of deterioration in the south span that are not identified by the 2 GHz horn system. Also, the mapped 2 GHz horn antenna data is extrapolated out to the curb, even though the antenna offset from the curb was not less than 3 feet. The 3D Radar map, on the other hand, only shows data where the antennas were located.

Attachment B shows the complete set of comparisons for each of the three decks. The results for bridge 4915.2S052 showed similar results to that in Figure 5 – i.e., some differences in detailed locations but some similarities in general areas of deterioration. The results for bridge 4959.4R061 show very little similarity between the two methods. At this point the only way to explain these differences is that the 3D Radar system detects much higher levels of detail and therefore is showing more potential areas of deterioration.

Attachment A

Deck Condition and Rebar Depth Maps



Concrete Condition Legend

Deterioration

Increasing severity -->

Area not covered by GPR antenna

Orientation

N

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	11
Deck	Conc. Deterioration (s.f)	291
Rebar	Avg.Rebar Depth (in.)	3.7
Rebar		

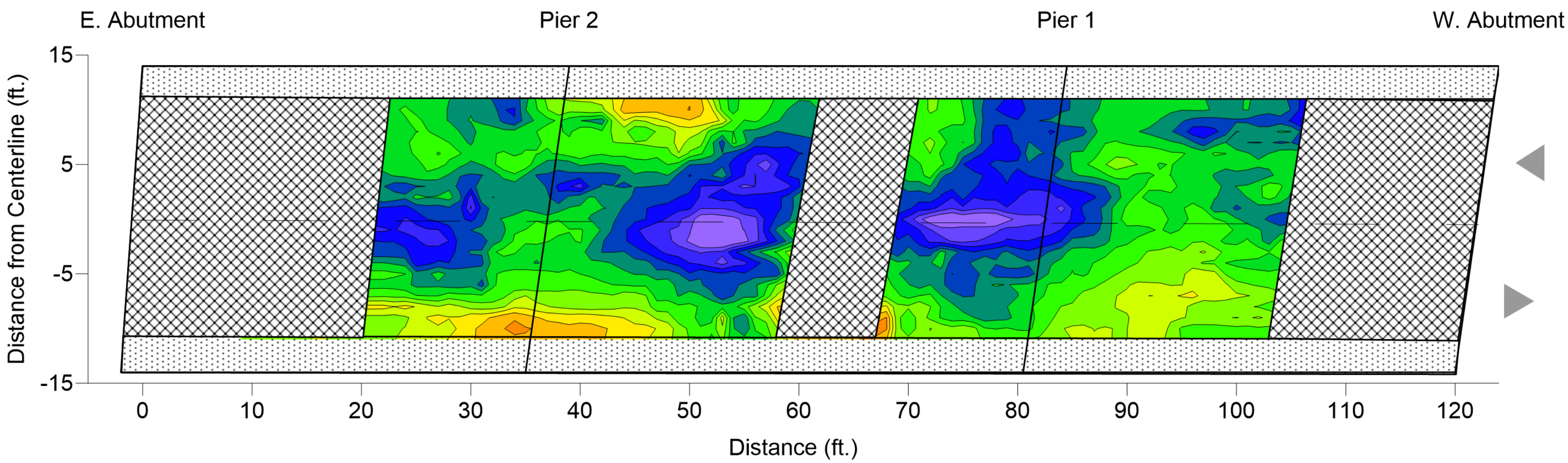
General Information

Bridge ID: 7148.6S018
US-18 over Little Floyd River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

INFRASENSE



Rebar Depth Legend	Orientation	Quantity Summary			General Information
Rebar Depth (in.) 1.5 3 4 5 6	N	Deck	Conc. Deterioration (%)	16	Bridge ID: 7148.6S018 US-18 over Little Floyd River
No Top Rebar Mat		Deck	Conc. Deterioration (s.f)	265	Analyzed by: KS Reviewed by: KM Completed: 6/7/2017
Area not covered by GPR antenna	Direction of traffic	Rebar	Avg.Rebar Depth (in.)	3.8	**Sheet 1 of 1**

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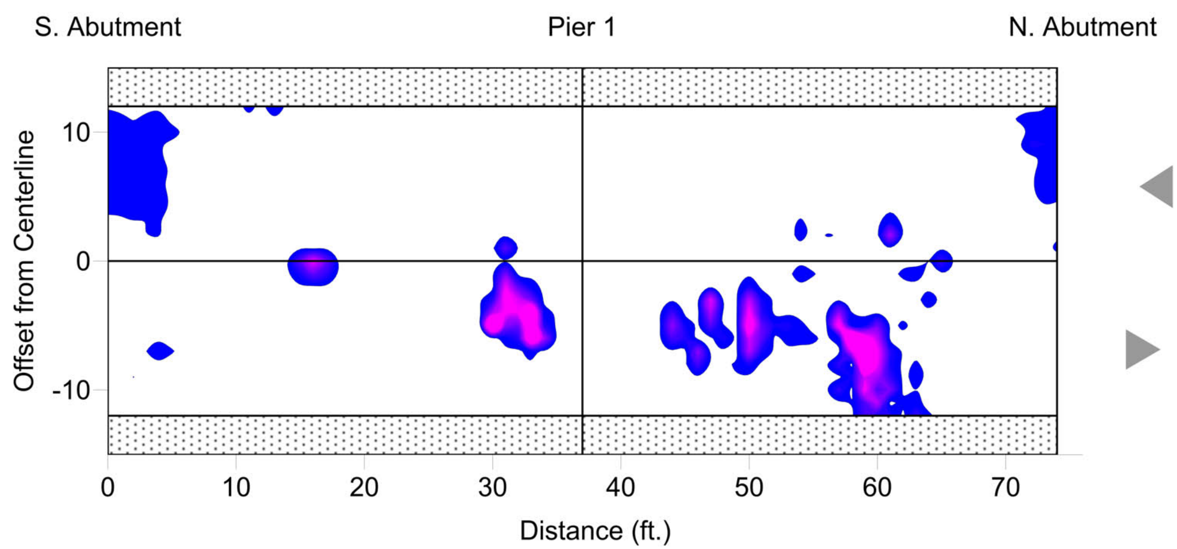

Concrete Condition Legend	Orientation	Quantity Summary			General Information
Deterioration Increasing severity -->		Deck	Conc. Deterioration (%)	8.7	Bridge ID: 5341.2S038 Iowa-38 over Sybil Creek
		Deck	Conc. Deterioration (s.f)	155	Analyzed by: KS Reviewed by: KM Completed: 6/19/2017
Area not covered by GPR antenna	Direction of traffic	Rebar	Avg.Rebar Depth (in.)	3.4	**Sheet 1 of 1**

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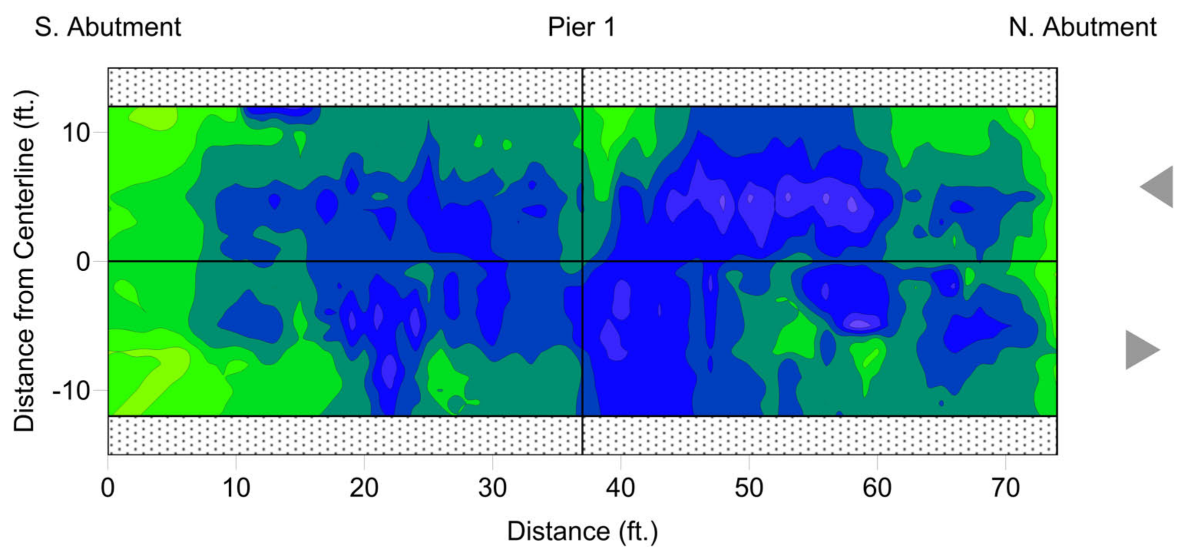

Rebar Depth Legend	Orientation	Quantity Summary	General Information
Rebar Depth (in.) 2 3 4 5 6			Bridge ID: 5341.2S038 Iowa-38 over Sybil Creek
Area not covered by GPR antenna	Direction of traffic		Analyzed by: KS Reviewed by: KM Completed: 6/19/2017
			Sheet 1 of 1

Deck	Conc. Deterioration (%)	8.7
Deck	Conc. Deterioration (s.f)	155
Rebar	Avg.Rebar Depth (in.)	3.4
Rebar		

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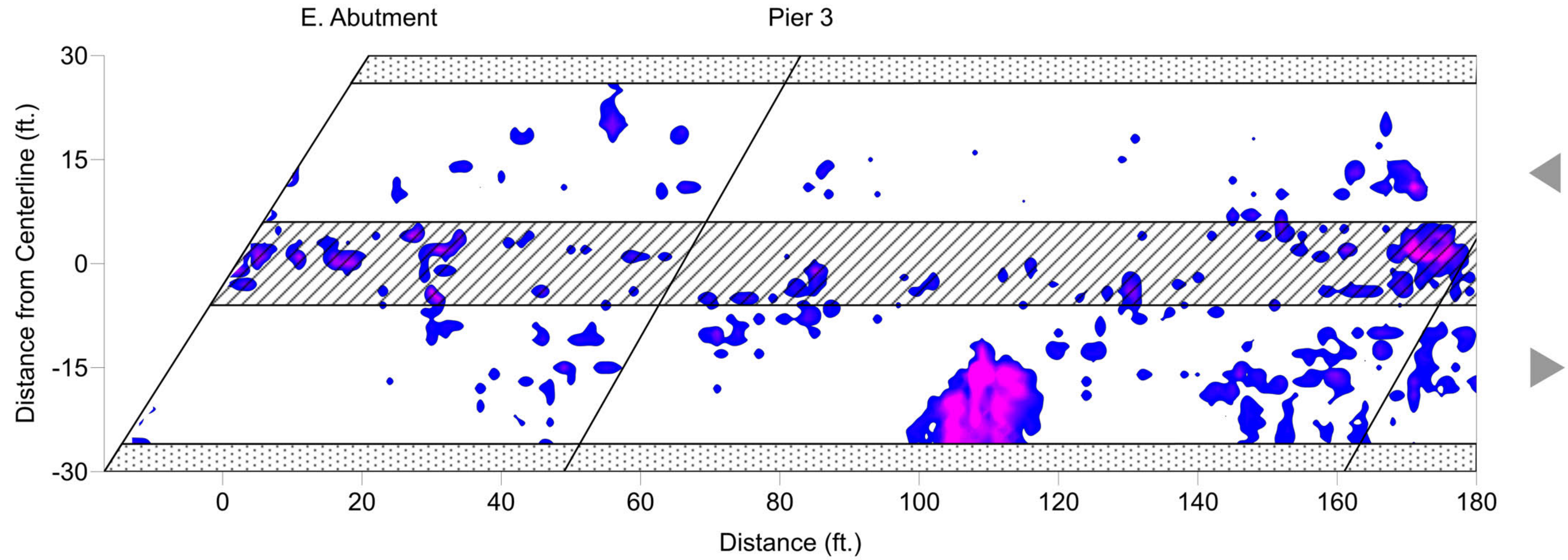
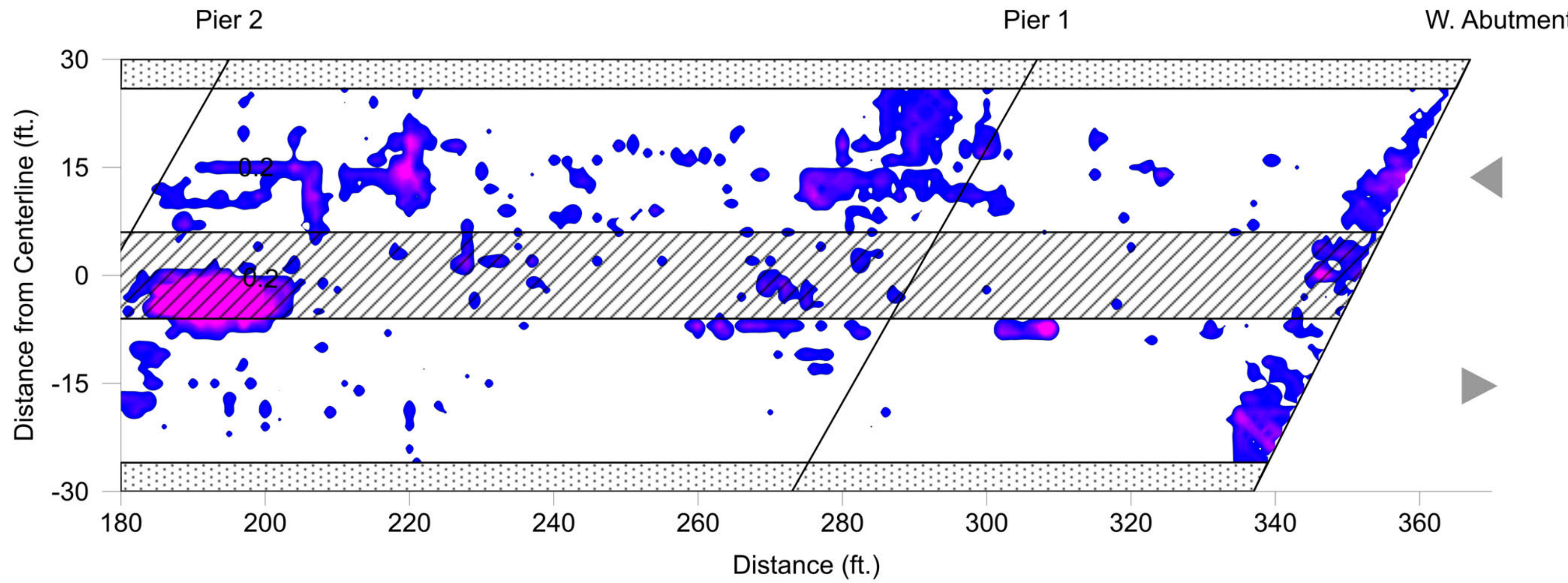




Concrete Condition Legend

Deterioration

Increasing severity -->

Median Gore Strip

Area not covered by GPR antenna

Orientation

N

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	9
Deck	Conc. Deterioration (s.f)	1475
Rebar	Avg.Rebar Depth (in.)	4.4
Rebar		

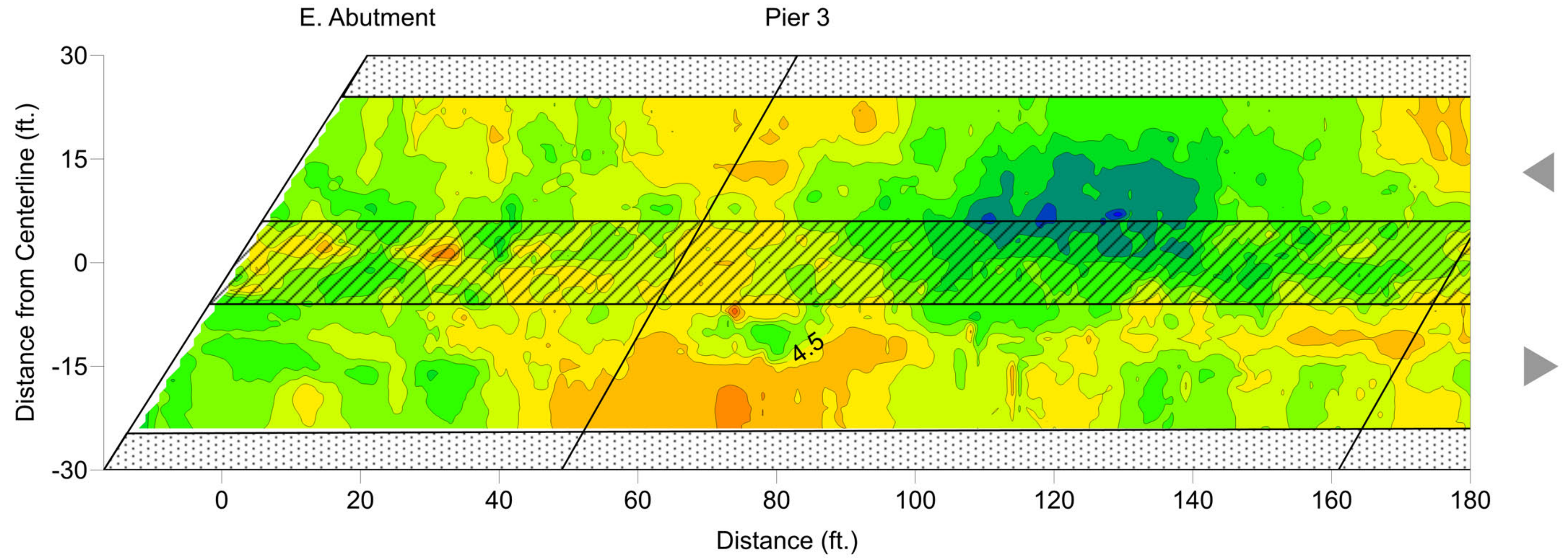
General Information

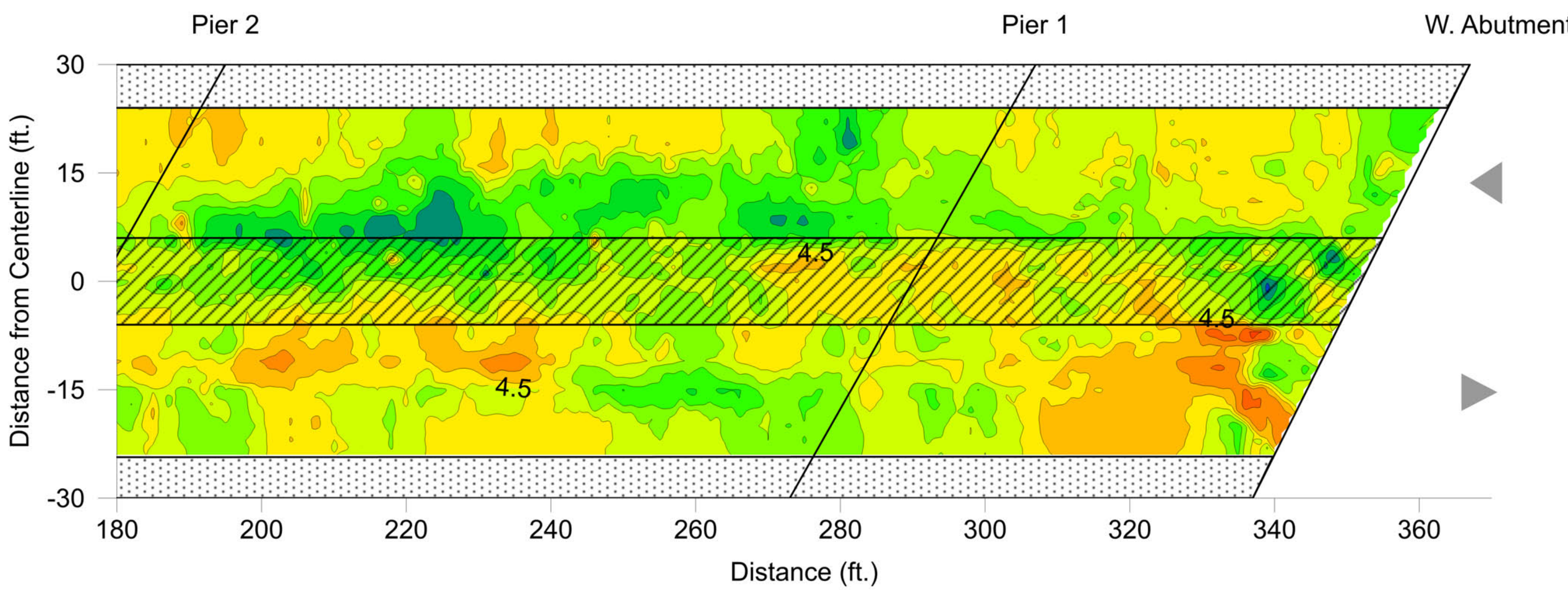
Bridge ID: 3572.3S003
Iowa 3 over I-35

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

INFRASENSE





Rebar Depth Legend

Rebar Depth (in.)

2 3 4 5 6

Median Gore Strip

Area not covered by GPR antenna

Orientation

N

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	9
	Conc. Deterioration (s.f)	1475
Rebar	Avg.Rebar Depth (in.)	4.4

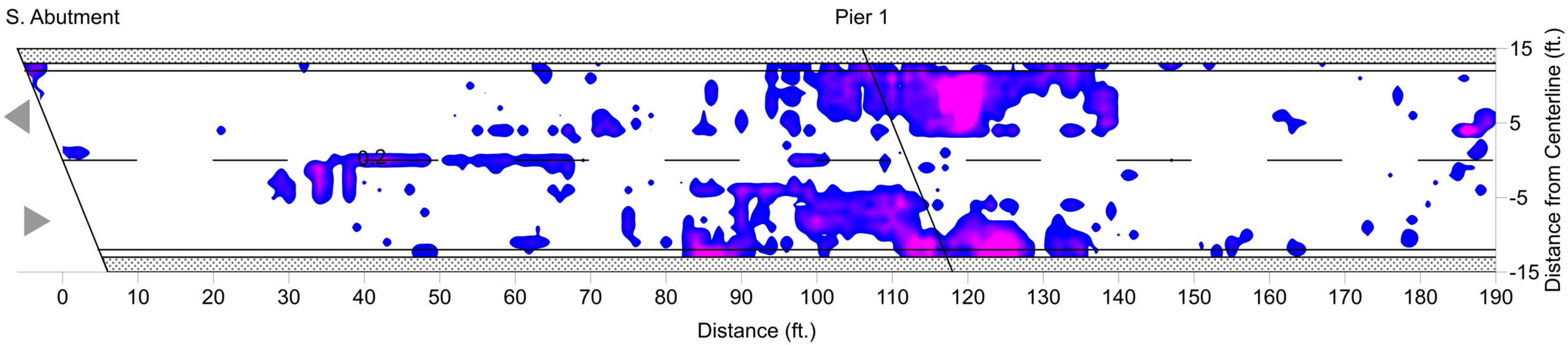
General Information

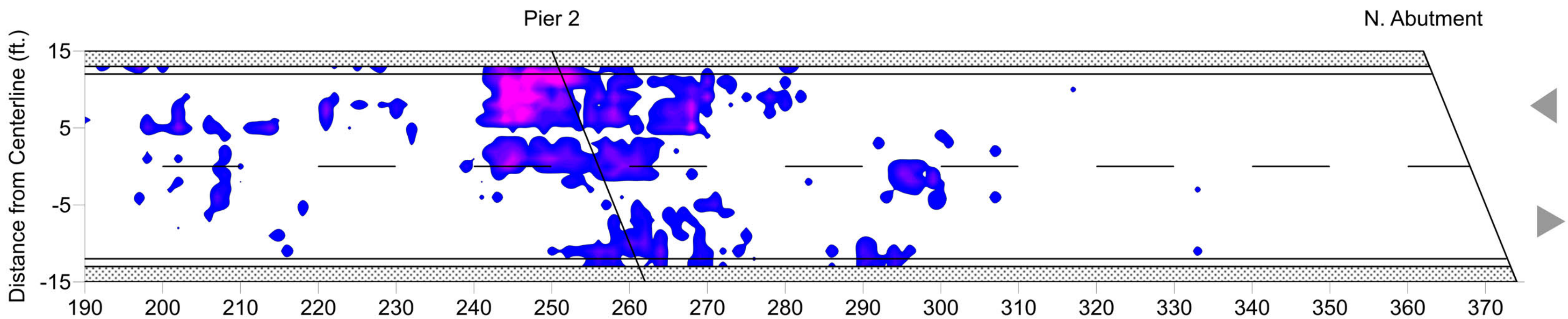
Bridge ID: 3572.3S003
Iowa 3 over I-35

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

INFRASENSE





Concrete Condition Legend	Orientation
Deterioration Increasing severity --> Area not covered by GPR antenna	Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	14.8
	Conc. Deterioration (s.f)	1412
Rebar	Avg.Rebar Depth (in.)	3.8

General Information

Bridge ID: 4959.4R061
US-61 over Maquoketa River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

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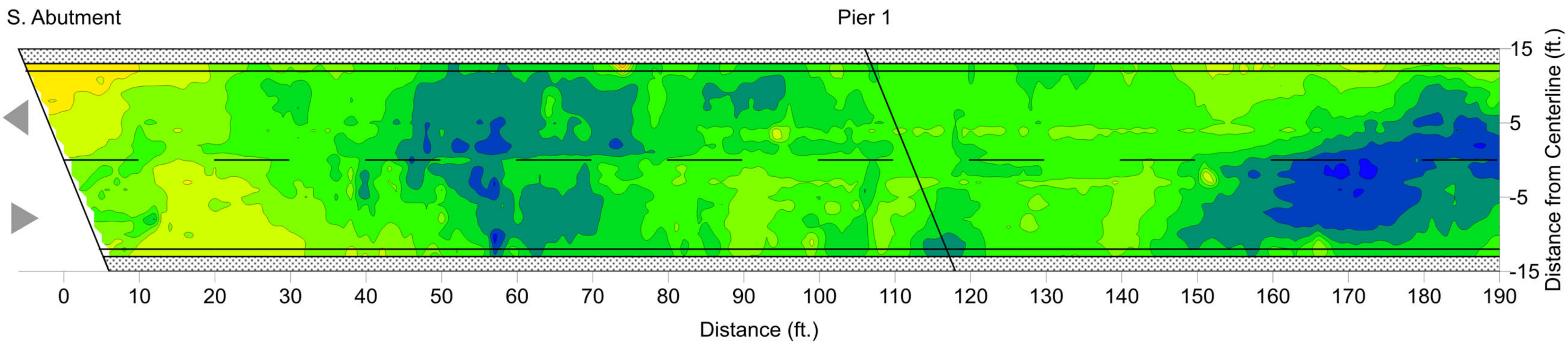

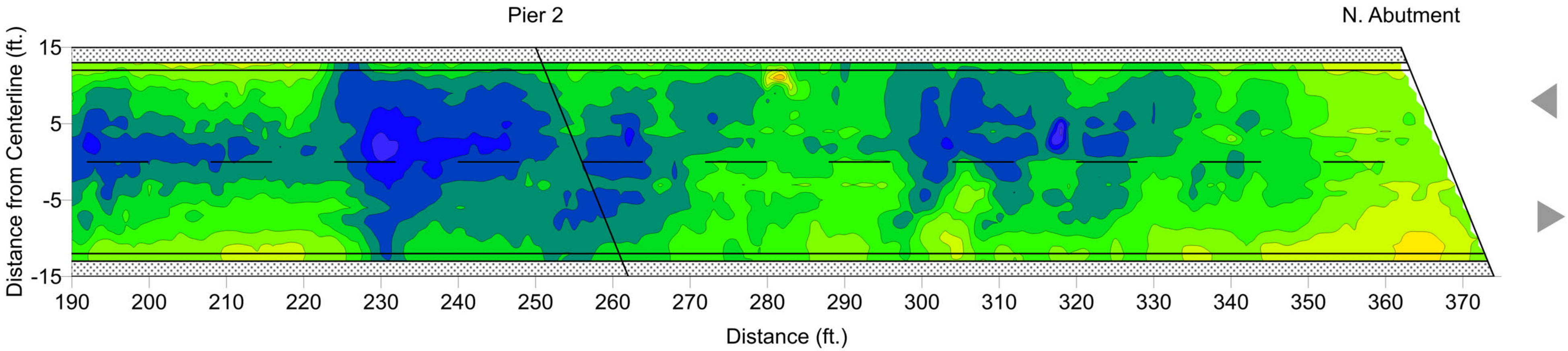

Rebar Depth Legend	Orientation	Quantity Summary			General Information
Rebar Depth (in.) 2 3 4 5 6		Deck	Conc. Deterioration (%)	14.8	Bridge ID: 4959.4R061 US-61 over Maquoketa River
		Deck	Conc. Deterioration (s.f)	1412	Analyzed by: KS Reviewed by: KM Completed: 6/7/2017
		Rebar	Avg.Rebar Depth (in.)	3.8	
Area not covered by GPR antenna	Direction of traffic	Rebar			**Sheet 1 of 1**

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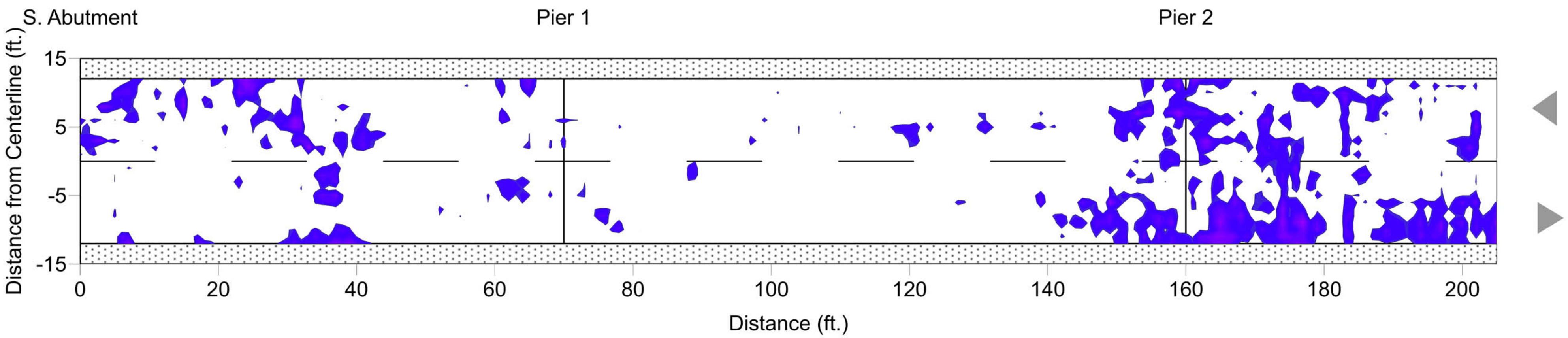
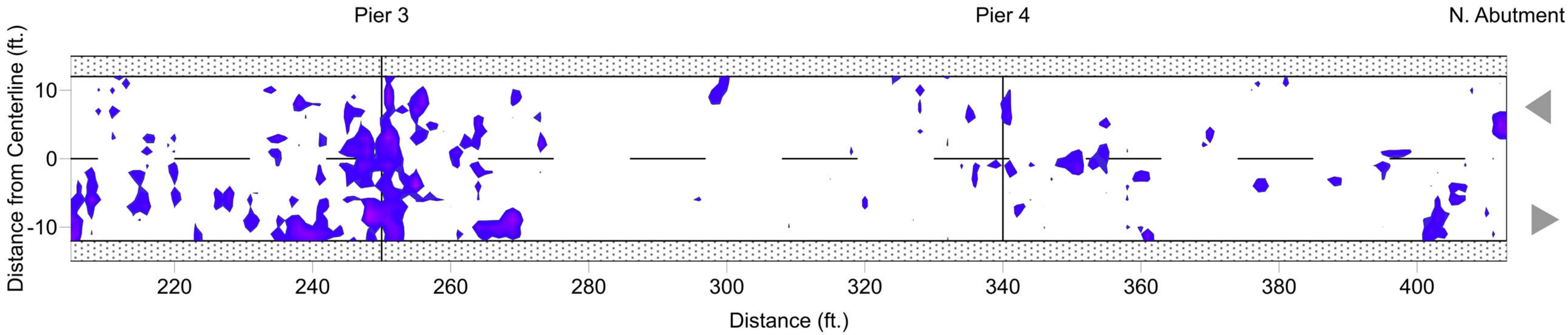




Concrete Condition Legend

Deterioration

Increasing severity -->

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

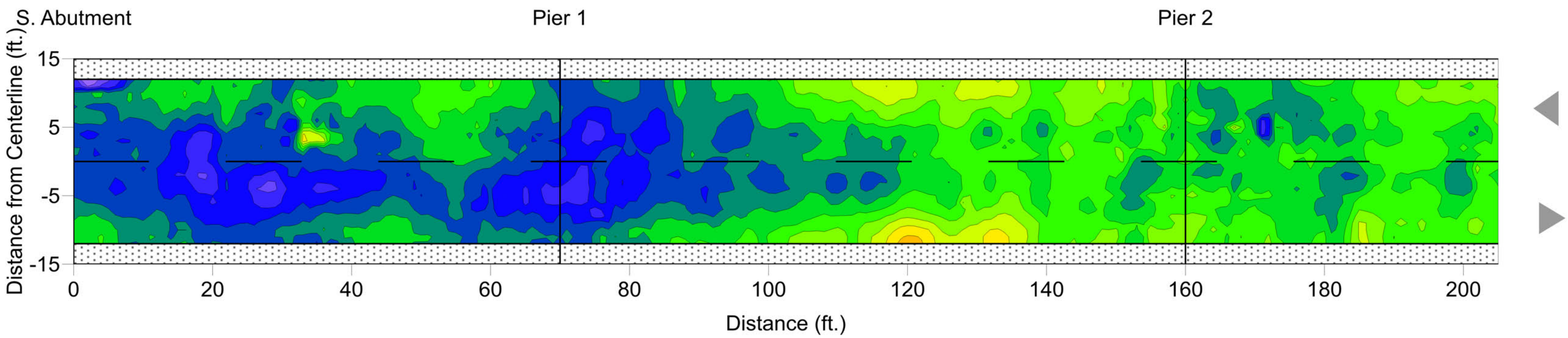
Deck	Conc. Deterioration (%)	13
Deck	Conc. Deterioration (s.f)	1331
Rebar	Avg.Rebar Depth (in.)	3.7
Rebar		

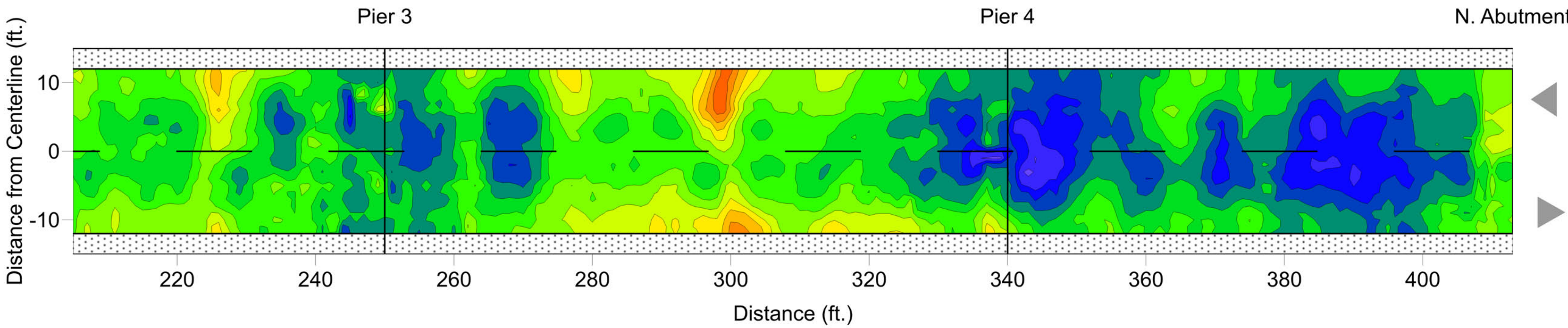
General Information

Bridge ID: 0417.7S005
Iowa - 5 over the Chariton River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1





Rebar Depth Legend

Rebar Depth (in.)

2 3 4 5 6

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	13
	Conc. Deterioration (s.f)	1331
Rebar	Avg.Rebar Depth (in.)	3.7

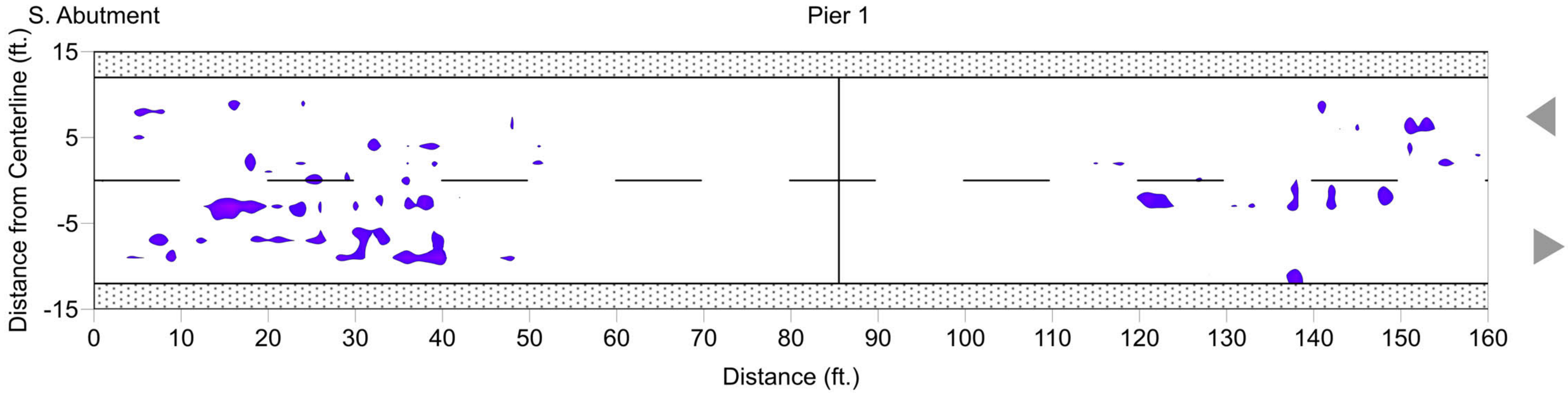
General Information

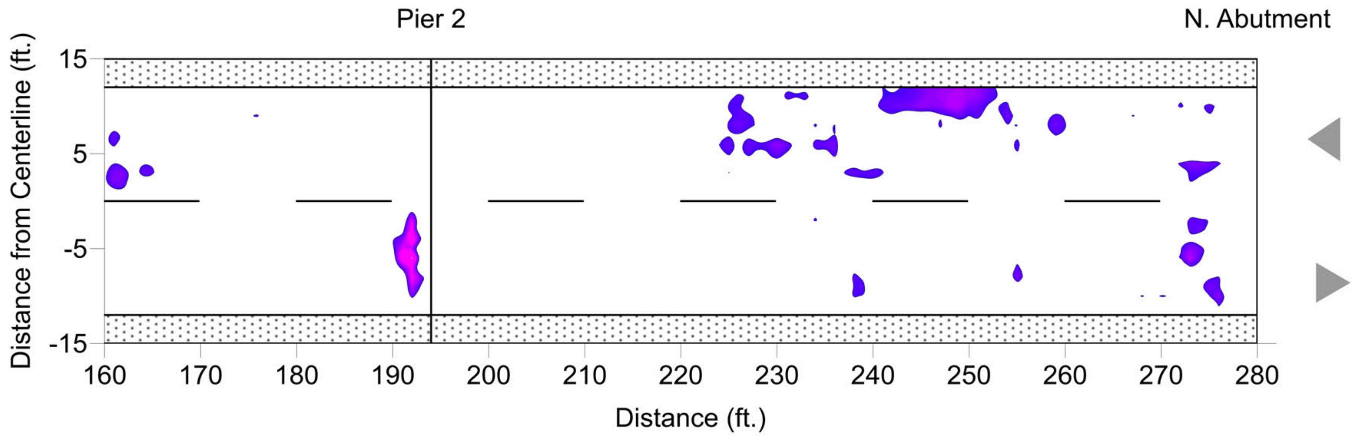
Bridge ID: 0417.7S005
Iowa - 5 over the Chariton River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

INFRASENSE





Concrete Condition Legend

Deterioration

Increasing severity -->

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	3.7
Deck	Conc. Deterioration (s.f)	250
Rebar	Avg.Rebar Depth (in.)	4.2
Rebar		

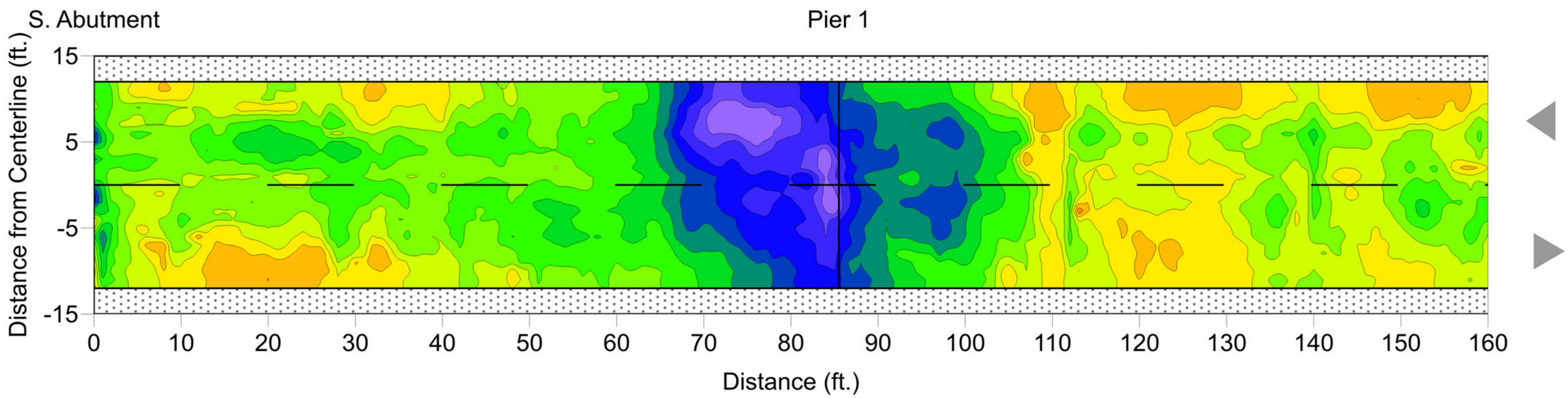
General Information

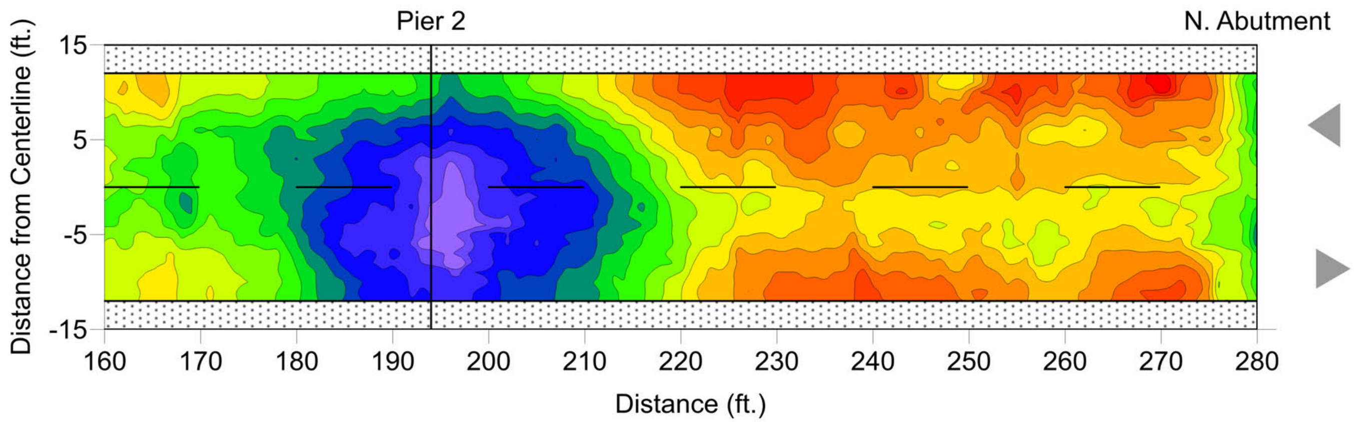
Bridge ID: 8684.0S021
Iowa-21 over Wolfe Creek

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

INFRASENSE





Rebar Depth Legend

Rebar Depth (in.)

1.5 3 4 5 6

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	3.7
Deck	Conc. Deterioration (s.f)	250
Rebar	Avg.Rebar Depth (in.)	4.2
Rebar		

General Information

Bridge ID: 8684.0S021
Iowa-21 over Wolfe Creek

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 1

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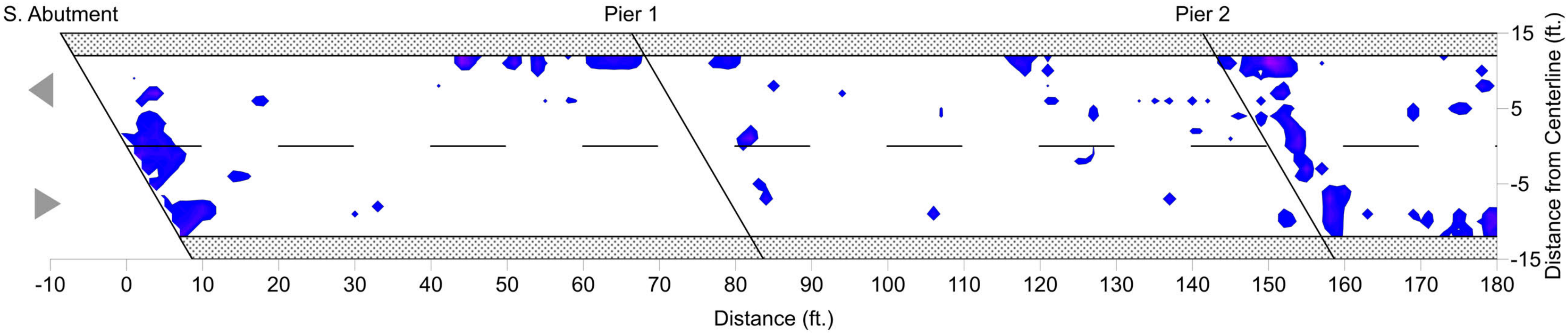
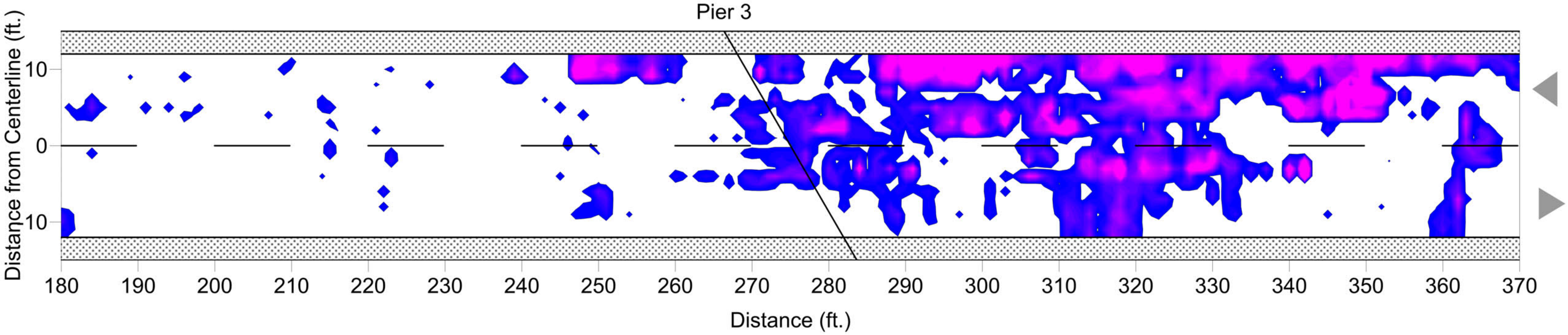




Concrete Condition Legend	Orientation
Deterioration Increasing severity -->	
Area not covered by GPR antenna	Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	11.2
	Conc. Deterioration (s.f)	1924
Rebar	Avg.Rebar Depth (in.)	3.7

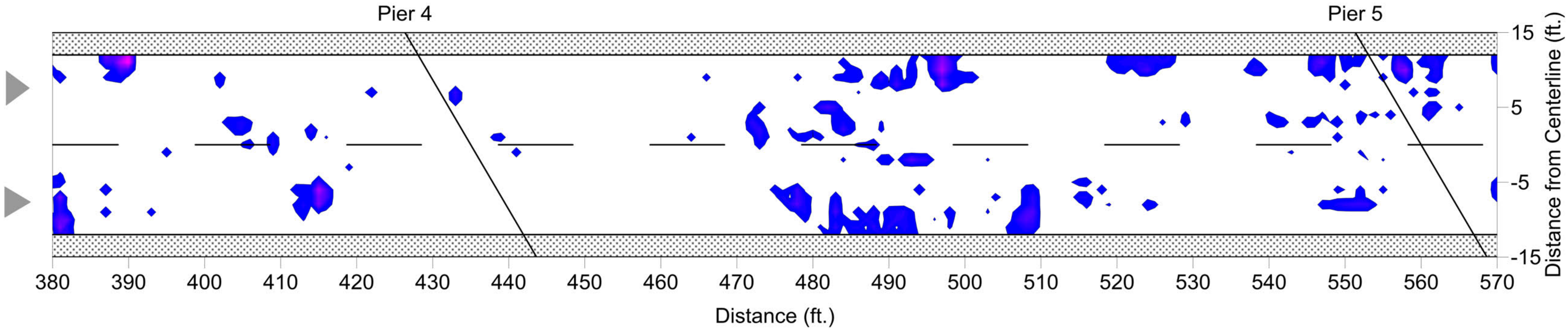
General Information

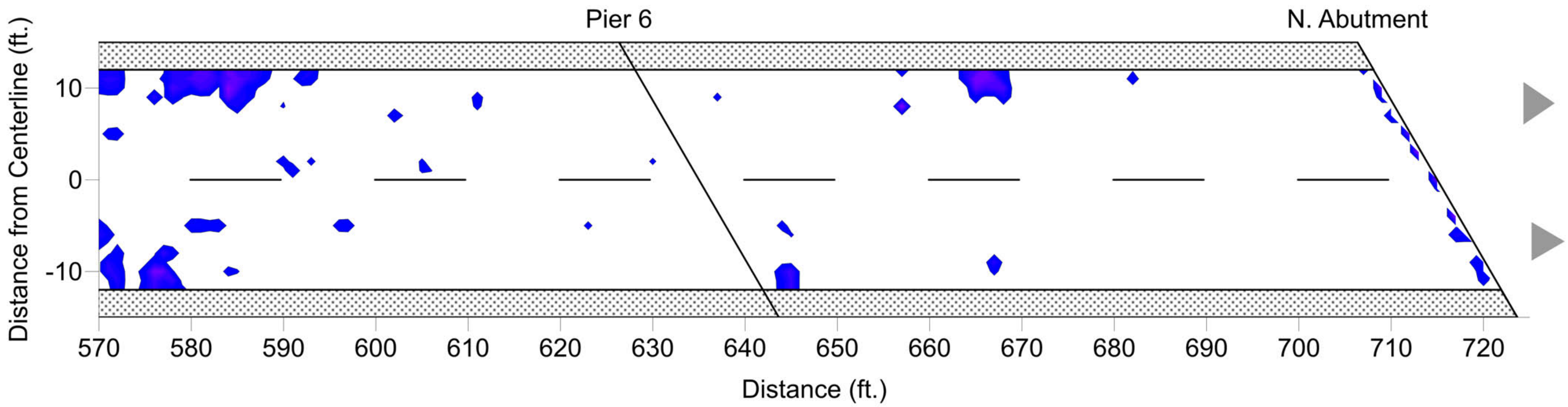
Bridge ID: 4915.2S052
US-52 over Maquoketa River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 2

INFRASENSE





Concrete Condition Legend

Deterioration

Increasing severity -->

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	11.2
Deck	Conc. Deterioration (s.f)	1924
Rebar	Avg.Rebar Depth (in.)	3.7
Rebar		

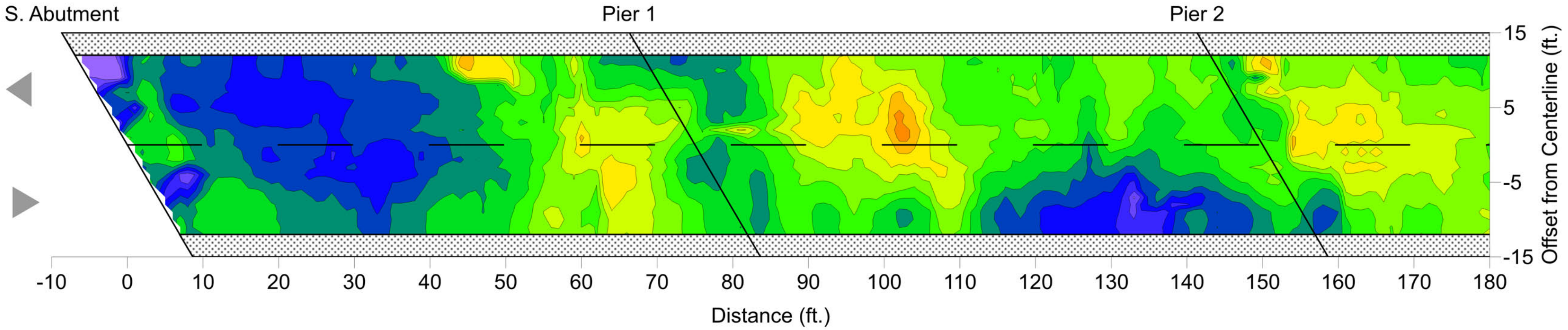
General Information

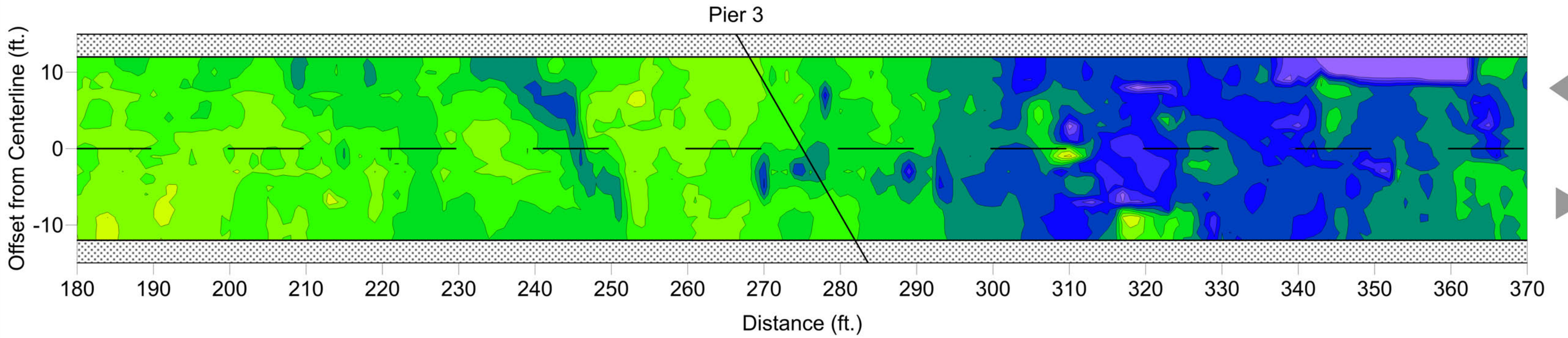
Bridge ID: 4915.2S052
US-52 over Maquoketa River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 2 of 2

INFRASENSE





Rebar Depth Legend

Rebar Depth (in.)

1 3 4 5 6

Area not covered by GPR antenna

Orientation

Direction of traffic

Quantity Summary

Deck	Conc. Deterioration (%)	11.2
Deck	Conc. Deterioration (s.f)	1924
Rebar	Avg.Rebar Depth (in.)	3.7
Rebar		

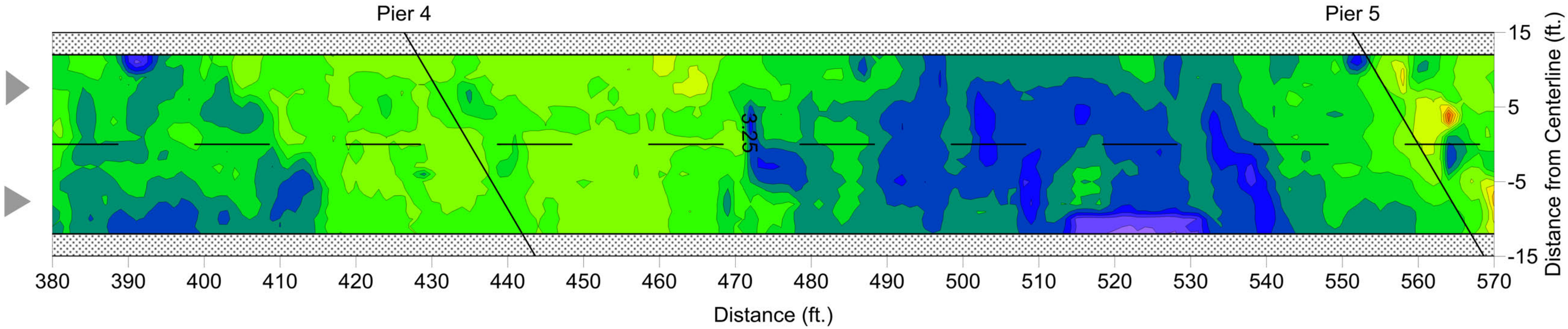
General Information

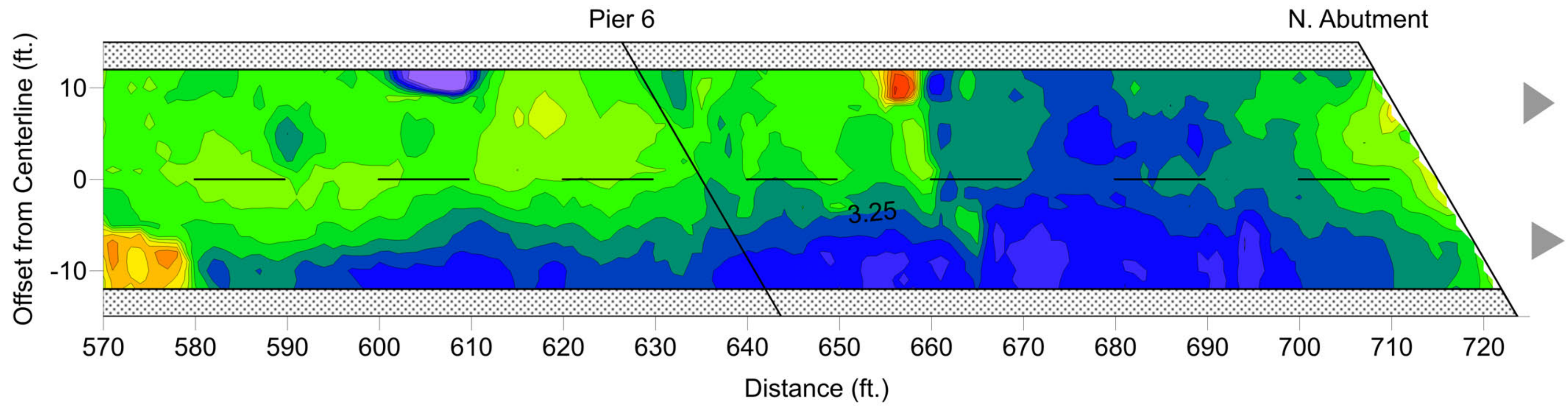
Bridge ID: 4915.2S052
US-52 over Maquoketa River

Analyzed by: KS
Reviewed by: KM
Completed: 6/7/2017

Sheet 1 of 2

INFRASENSE





Rebar Depth Legend	Orientation	Quantity Summary			General Information
Rebar Depth (in.) 1 3 4 5 6		Deck	Conc. Deterioration (%)	11.2	Bridge ID: 4915.2S052 US-52 over Maquoketa River
Area not covered by GPR antenna	Direction of traffic		Conc. Deterioration (s.f)	1924	Analyzed by: KS Reviewed by: KM Completed: 6/7/2017
		Rebar	Avg.Rebar Depth (in.)	3.7	**Sheet 2 of 2**

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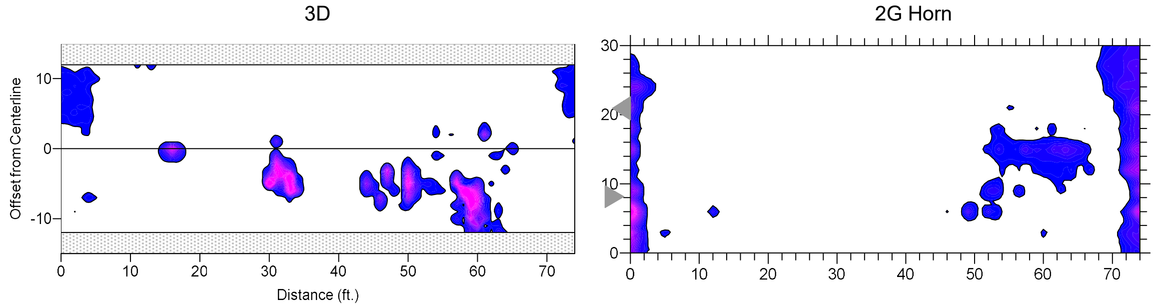
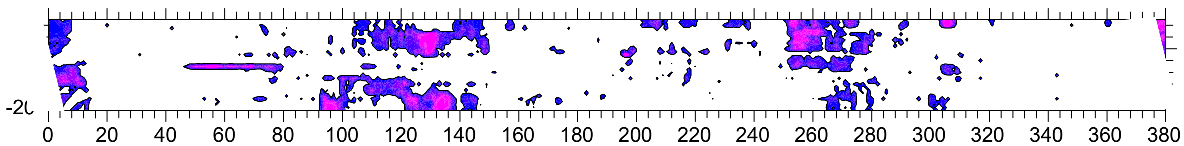
Attachment B

Comparison of 3D Radar Results to 2 GHz Horn Antenna Result

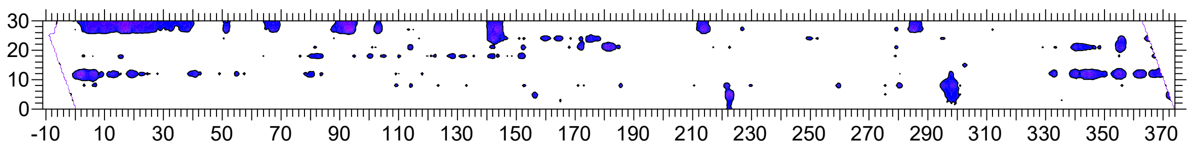
5341



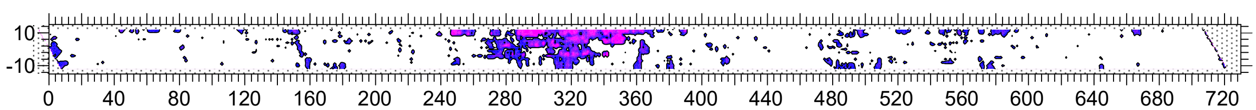
4959 - 3D



4959 - 2G Horn



4915 - 3D



4915 - 2G Horn