Exploration of Ultrasound for the Evaluation and Preservation of Structures

Final Report
January 2021

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-757)
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16. Abstract

Recent developments in nondestructive testing technology have opened the door for innovative inspection methods for infrastructure. One such technology is ultrasound evaluation, specifically in the form of linear arrays. The objective of this project was to explore the potential ability of an ultrasound evaluation device called MIRA to assess the condition of a bridge's superstructure. To achieve this goal, MIRA was deployed at two bridges with two different sets of objectives. On the first bridge, two concrete overlays had previously been applied, and the bridge was soon to be overlaid for the third time. The second bridge was constructed using concrete box girders, and the condition of the post-tensioning ducts was of interest. For each bridge, multiple test sections were evaluated. Based on the test results, the following conclusions were made:

- When the overlay on the concrete deck was in good condition, MIRA could effectively detect the location and relative size of the rebar in the top layer.
- MIRA scans could not clearly distinguish between the bottom surface of the deck and the bottom layer reinforcement at about 575 mm below the surface.
- When cracks were present in the overlay, MIRA was able to detect these defects. However, since the substrate deck condition of one of the bridges was unknown during this project, the damage seen in the MIRA scans could not be field verified.
- MIRA performed well in detecting voids in post-tensioning ducts.

This project hoped to capture the actual condition of the substrate of the first bridge via field evaluation during overlay placement. Unfortunately, due to delays in the letting of that work, the actual condition was not able to be captured within the timeframe of this project. As such, future research is recommended on an experimental basis to quantitatively evaluate MIRA's performance related to validating the condition of the substrate.

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EXECUTIVE SUMMARY

Recent developments in nondestructive testing technology have opened the door for innovative inspection methods for infrastructure. One such technology is ultrasound evaluation, specifically in the form of linear arrays. The objective of this project was to explore the potential ability of an ultrasound evaluation device called MIRA to assess the condition of a bridge's superstructure. To achieve this goal, MIRA was deployed at two bridges with two different sets of objectives. On the first bridge, two concrete overlays had previously been applied, and the bridge was soon to be overlaid for the third time. The second bridge was constructed using concrete box girders, and the condition of the post-tensioning ducts was of interest. For each bridge, multiple test sections were evaluated. Based on the test results, the following conclusions were made:

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- MIRA performed well in detecting voids in post-tensioning ducts.

This project hoped to capture the actual condition of the substrate of the first bridge via field evaluation during overlay placement. Unfortunately, due to delays in the letting of that work, the actual condition was not able to be captured within the timeframe of this project. As such, future research is recommended on an experimental basis to quantitatively evaluate MIRA's performance related to validating the condition of the substrate.

CHAPTER 1. INTRODUCTION

1.1 Background and Problem Statement

As infrastructure ages, inspections and repairs are required to ensure public safety. However, the structural monitoring of bridges and other structures presents difficulties, primarily because not all parts of the structures are visible and inspection methods can be imprecise. Nondestructive testing (NDT) of bridges in particular has been a part of inspection and preservation planning for decades, with the most common nondestructive methods being chain dragging and hammer sounding. These methods are successful in detecting near-surface delamination but can be subjective based upon the experience of the inspector. In addition, these methods are not able to detect reinforcement degradation, have limited applicability when overlays are present, and lack precision.

Many other nondestructive testing technologies have been used to detect damage in concrete structures. These technologies, which include impact echo, ultrasonic pulse velocity, ground penetrating radar (GPR), and nonlinear acoustic methods, among others, have inherent limitations that have prevented their widespread implementation. These limitations include sensitivity to moisture conditions, the need for extensive access to the structure, limited effectiveness when inspecting structures with complex geometries, and shallow penetration depths. These limitations are especially problematic when the technologies are used to inspect bridges and structures.

Technology that allows for conditions below the surface to be inspected, both visually and quantitatively, would be advantageous for inspection methodologies and preservation planning. MIRA, an ultrasonic linear array device that employs dry point contact transducers, has many capabilities that make it a viable candidate for achieving these goals. Ultrasonic linear array technology is promising due to its large penetration depth, high accuracy due to overlapping measurement acquisition, ability to characterize structures regardless of moisture conditions, and ability to obtain data when access is only available from one side of a structure.

While it is unrealistic to think that MIRA can achieve all objectives of nondestructive testing, this technology can likely be deployed successfully to improve the accuracy and coverage of structural inspections. This project aimed to explore multiple applications of MIRA to identify promising inspection capabilities.

1.2 Objective

The goal of this project was to explore the use of MIRA in the field of bridge condition evaluation with an emphasis on inspecting the internal conditions of bridge superstructures. The specific objectives of this research were as follows:

- Detection of the location and relative size of rebar in the deck underneath an overlay
- Detection of internal cracking in the deck underneath an overlay

- Detection of voids in post-tensioning ducts

1.3 Research Plan

The research plan consisted of four main tasks, as follows:

1. Establishment of a Technical Advisory Committee (TAC)
2. Field Deployment of MIRA
3. Data Analysis
4. Reporting

The research team met with the project's TAC to review the project scope and work plan. The purpose of this meeting was to discuss and clarify the scope of work and provide an opportunity for the TAC to offer direction and input regarding field applications that are of interest to the Iowa Department of Transportation (DOT) Bridges and Structures Bureau. The details of the field testing activities and data analysis are documented in this report.

CHAPTER 2. LITERATURE REVIEW

As concrete structures and pavements age, timely repairs and inspections are required to ensure public safety. One maintenance issue for concrete structures is the need for effective and timely assessments to produce an optimum repair plan. Various NDT methods have been used to assess the condition of concrete structures. Commonly used NDT methods include impact echo, GPR, electrical resistivity, and ultrasonic pulse velocity. Additionally, a newer and more advanced technology called MIRA, an ultrasonic linear array device that employs dry point contact transducers, has many capabilities that make it a viable candidate for NDT. While these methods have been used successfully for different NDT applications, each method has its own advantages and limitations. Limitations include the need for extensive access to the structure, sensitivity to moisture conditions, the time required to conduct testing, and shallow penetration depths. Given these limitations, inspectors often lack inspection tools that offer an efficient and quick analysis.

This chapter presents the results of a literature search conducted to review past uses for each NDT method listed above. The advantages and disadvantages of each method are discussed and compared.

2.1 Impact Echo

Impact echo is a method based on the use of impact-generated stress waves that penetrate through concrete. These stress waves can determine flaws within the concrete, such as delamination, voids, honeycombing, and the degradation of reinforcement and grouted tendon ducts, and can be used to measure the thickness of concrete slabs. Table 1 lists the capabilities, advantages, and limitations of the impact echo method.

Table 1. Capabilities, advantages, and limitations of impact echo

Capabilities	Advantages	Limitations
• Detects the thickness of a concrete structure • Detects delamination, cold joints, honeycombing, overlay debonding, voids, and the condition of grouted tendon ducts	• Instant results • Accurate • Works well on concrete slabs or bridge decks	• Expert interpretation required • Influenced by presence of reinforcement • Can only be applied reliably to plate-like structures • Time consuming
Lim and Honggang 2013, Rehman et al. 2016	Lim and Honggang 2013, Rehman et al. 2016	Freeseman 2016, Lim and Honggang 2013

2.2 Ground Penetrating Radar

GPR deploys high-energy electromagnetic waves into a concrete structure to assess its properties. The main principle behind GPR is that a transducer transmits a pulse and then receives the partially reflected pulse. The energy and travel time of the pulse can be used to conduct measurements. A typical GPR device is shown in Figure 1.

Escalante 2019

Figure 1. Ground penetrating radar device

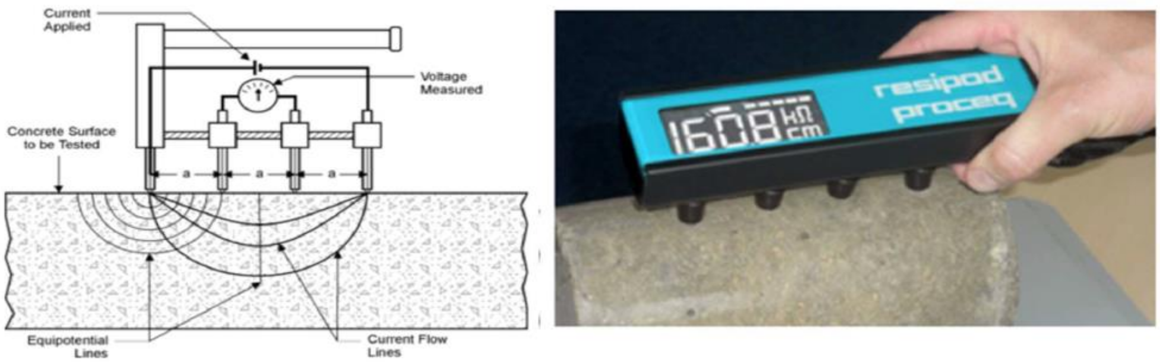
Table 2 lists the capabilities, advantages, and limitations of GPR.

Table 2. Capabilities, advantages, and limitations of ground penetrating radar

Capabilities	Advantages	Limitations
• Detects the thickness of a concrete structure • Locates reinforcement • Estimates concrete properties • Detects concrete flaws and corrosion in the reinforcement	• Fast testing • Most well-known nondestructive test for investigating bridge decks • Accurate	• Data can be difficult to analyze • Influenced by presence of reinforcement • Only 20 in. of penetration in concrete • Affected by high moisture content in concrete • High labor and machine costs
Lim and Honggang 2013, Rehman et al. 2016, Freeseman 2016	Lim and Honggang 2013, Rehman et al. 2016	Lim and Honggang 2013, Rehman et al. 2016, Freeseman 2016

2.3 Electrical Resistivity

In electrical resistivity testing, a device measures how well concrete accommodates the movement of an electric charge. A current is applied between electrodes and is measured. This test can be used to determine moisture content, homogeneity, and corrosion of reinforcement in concrete. Measurement is typically carried out using the Wenner configuration, as shown in Figure 2.



Escalante 2019

Figure 2. Electrical resistivity testing configuration (left) and device (right)

The capabilities, advantages, and limitations of electrical resistivity testing are shown in Table 3.

Table 3. Capabilities, advantages, and limitations of electrical resistivity testing

Capabilities	Advantages	Limitations
• Detects moisture • Surveys can be used to map corrosion activity • Detects regions susceptible to chloride penetration	• Easy to transport • Fast and reliable	• Interpretation is challenging • Surface must be pre-wetted • Results depend on material properties such as porosity, salt content, and moisture content
Rehman et al. 2016	Rehman et al. 2016	Rehman et al. 2016

2.4 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity is a test that determines the condition of concrete by measuring the time it takes for an ultrasonic wave pulse to travel over a path with a known length (Rehman et al. 2016). The test device uses ultrasonic transducers to send and receive impulses. This method requires a good coupling material, such as grease or petroleum jelly. The capabilities, advantages and limitations of ultrasonic pulse velocity testing are shown in Table 4.

Table 4. Capabilities, advantages, and limitations of electrical resistivity device

Capabilities	Advantages	Limitations
• Detects the location of internal defects in concrete • Detects the thickness of a concrete structure	• Well known • Has potential for in-depth testing of selected areas on bridge decks	• Transmission requires access to two opposite sides of a structure • Requires good surface conditions • Time consuming • Requires a liquid coupling material
Lim and Honggang 2013, Rehman et al. 2016		Lim and Honggang 2013, Rehman et al. 2016, Freeseman 2016

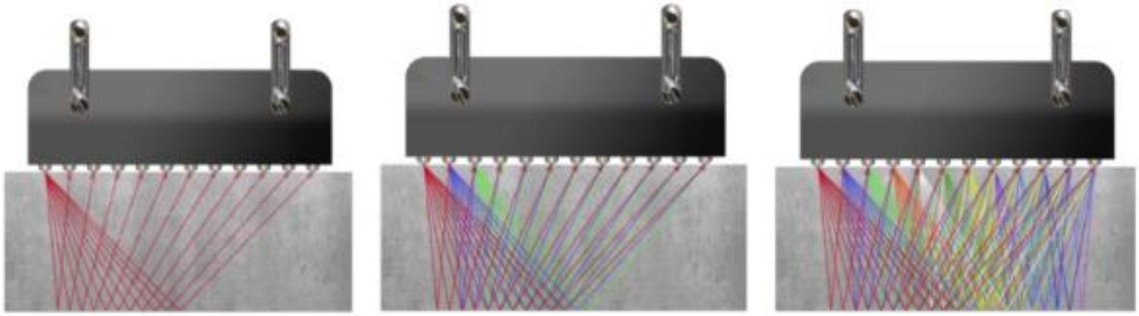
2.5 MIRA

MIRA, shown in Figure 3, is an ultrasonic shear wave device that employs a linear array of 48 dry point contact transducers.

Figure 3. MIRA device deployed in the field

The device uses the ultrasonic pitch-catch method, in which one transducer sends out a stress wave pulse and a second transducer receives the reflected pulse. The shear waves have an adjustable nominal center frequency of 25 to 85 kHz.

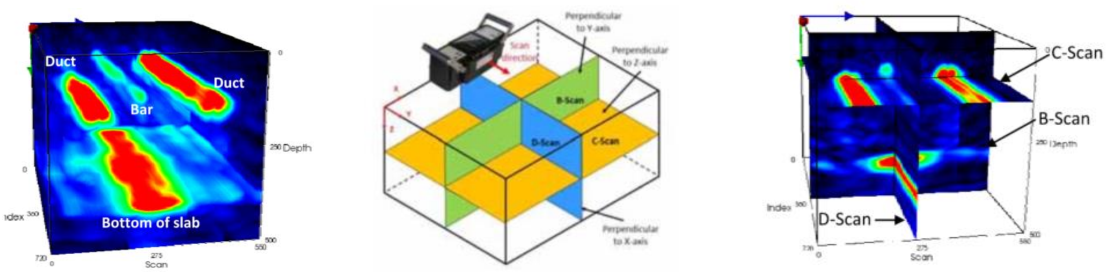
MIRA uses an antenna with a 4 by 12 array of dry point contact transducers. Each pulse gives a unique measurement and provides a two-dimensional (2D) image for analysis. Each set of four transducers interacts with the remaining 11 sets of transducers, resulting in 66 unique transducer pairs (i.e., 1 to 2, 1 to 3, 1 to 4, …8 to 9, 8 to 10, 9 to 10), as shown in Figure 4.



Germann Instruments 2015

Figure 4. MIRA point transducers obtaining 66 unique time measurements

MIRA captures a series of 2D images, and software such as Introview Concrete or Idealviewer assembles them into a three-dimensional (3D) image, as shown in Figure 5.



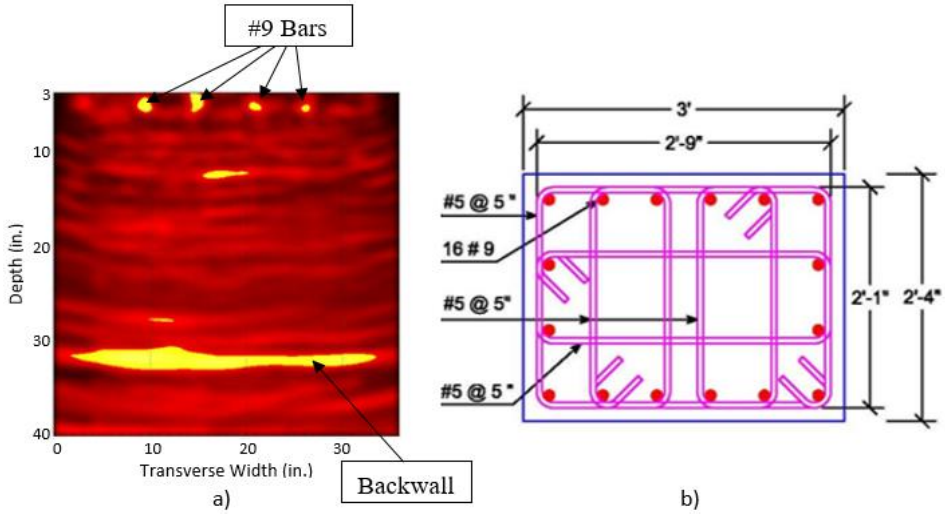
Germann Instruments 2015

Figure 5. MIRA scan configuration

Using a grid method, the inspector can input the location of each scan into the chosen software to carry out an in-depth inspection of an area. Each series of tests provides a B-Scan, D-Scan, C-Scan, and a 3D image. The software can measure to a specific location or adjust the frequency of the measurements.

MIRA is intended to be an inspection tool for concrete infrastructure. The tool is designed to evaluate the integrity of concrete structures, detecting voids, cracks, inclusions, defects, and the thickness of the inspected object. To allow for field testing of heterogeneous materials such as PCC, dry point contact transducers are used, which eliminates the need for manual mechanical impact and time-intensive surface coupling. Moreover, the results are independent of moisture conditions because the device utilizes shear waves.

These benefits make MIRA an attractive tool for quick and effective nondestructive testing of concrete structures and bridges. Much research has been conducted to explore the use of MIRA for evaluating concrete infrastructure. For example, Freeseman et al. (2016) used MIRA to detect the location of rebar in and the thickness of a reinforced concrete column. Figure 6 shows a cross-sectional plan view on the right and a corresponding B-scan image from MIRA on the left.



Freeseman et al. 2016

Figure 6. Comparison of a reconstructed image from MIRA (left) and corresponding cross-sectional plan view (right)

The results shown in Figure 6 demonstrate the ability of MIRA to locate reinforcing steel and determine slab thickness. The advantages, capabilities, and limitations of MIRA are summarized in Table 5.

Table 5. Capabilities, advantages, and limitations of MIRA

Capabilities	Advantages	Limitations
• Detects discontinuities in concrete, including cracks, delamination, mudballs, and defects • Detects slab thickness • Detects relative size and location of rebar • Evaluates grout condition in tendon ducts	• Transducers do not require a coupling agent • Requires little surface preparation • Easy to transport • Quick on-site results • Maximum view depth in reinforced concrete of 2.5 ft • Works on rough and uneven surfaces	• Not widely used in the industry; lacks training support • May need to be calibrated if multiple layers exist • Difficult to analyze heavily reinforced structures • Unable to detect corrosion • Effective measurement range of flaw locations is 4 to 16 in.
Choi et al. 2016, De La Haza et al. 2013, Escalante 2019, Freeseman 2016, Freeseman et al. 2016, Hoegh et al. 2011, Lim and Honggang 2013	Choi et al. 2016, De La Haza et al. 2013, Escalante 2019, Freeseman 2016, Freeseman et al. 2016, Hoegh et al. 2011, Lim and Honggang 2013	De La Haza et al. 2013, Hoegh et al. 2011, Lim and Honggang 2013, Lin et al. 2018

2.6 Conclusions

Compared to other nondestructive testing equipment, MIRA demonstrates numerous advantages. The device does not require a coupling agent, requires little surface preparation, is easily transportable, provides on-site results, can work on uneven surfaces, and is not affected by moisture conditions. Inspectors and engineers could use the 3D images created by MIRA to effectively identify solutions for repairing a structure. However, MIRA is not well known in the industry, and therefore there is a lack of training for the device. A device such as MIRA has the potential to make an impact on the maintenance of aging infrastructure if its capabilities are better understood and more training is available.

CHAPTER 3. FIELD DEPLOYMENT AND RESULTS

In order to achieve the project objective of exploring the application of MIRA for bridge condition evaluation, two field deployments were conducted on bridges in state of Iowa: Mingo Bridge and Highway 2 Bridge over the Missouri River.

3.1 Mingo Bridge

The objective of deploying MIRA on the Mingo Bridge was to investigate the ability of MIRA to detect cracking and reinforcement in the bridge deck underneath an existing overlay. The reason for choosing the Mingo Bridge is that this bridge has an aging overlay in place, with many cracks observed on the top surface of the deck. This bridge was also slated to be re-overlaid in the near future.

The Mingo Bridge was built in September 1955 over a creek in Mingo, Iowa. The bridge is a 120 ft by 28 ft continuous concrete slab bridge that consists of three spans of 37.25 ft, 45.5 ft, and 37.25 ft in length. The current overlay on the bridge is 1.75 in. thick, as shown in Figure 7.

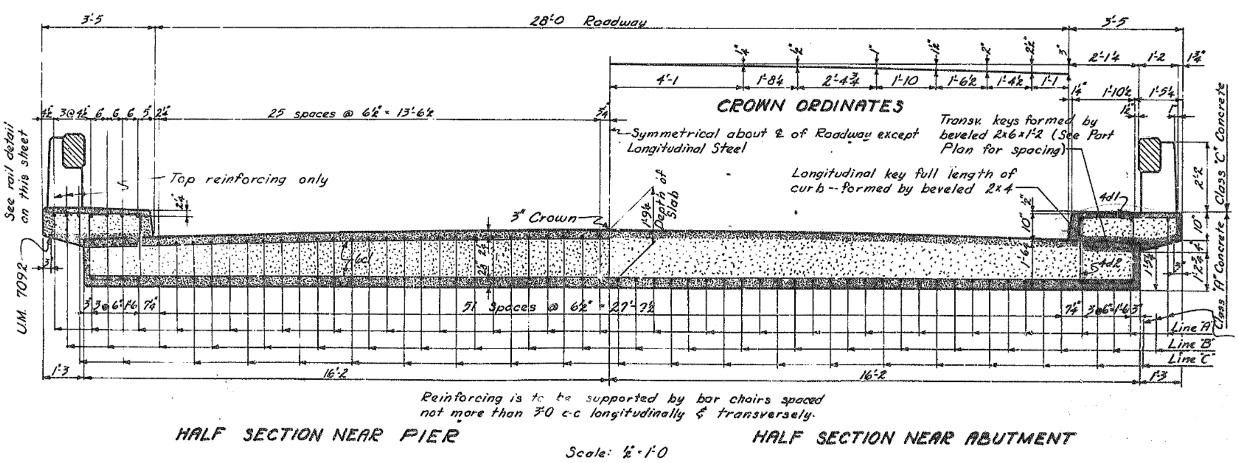


Figure 7. Mingo Bridge cross-section

3.1.1 Field Work Description

On August 29, 2019, the research team gathered data at the Mingo Bridge alongside Iowa DOT staff who were on-site to complete other data collection. The bridge is 28 ft wide with two lanes of traffic, and traffic control was required during data collection. In total, MIRA was deployed at five locations on the bridge, as shown in Figure 8: two on the south lane and three on the north lane.

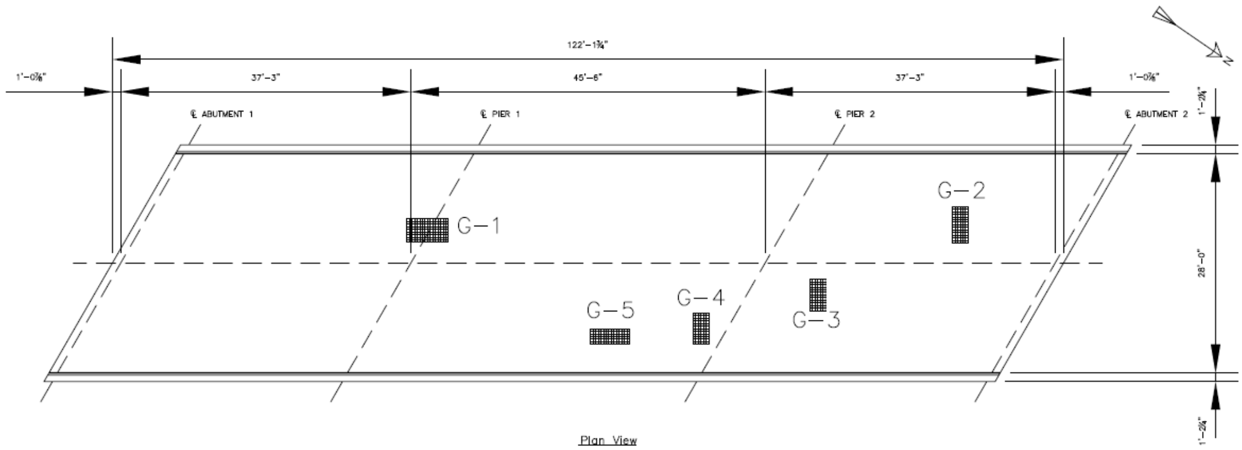


Figure 8. Mingo Bridge layout with testing locations identified

These locations were selected to obtain a wide variety of results, in that two areas with major cracking (G-1 and G-3), two areas with no cracking (G-2 and G-4), and one area with minor cracking (G-5) were selected.

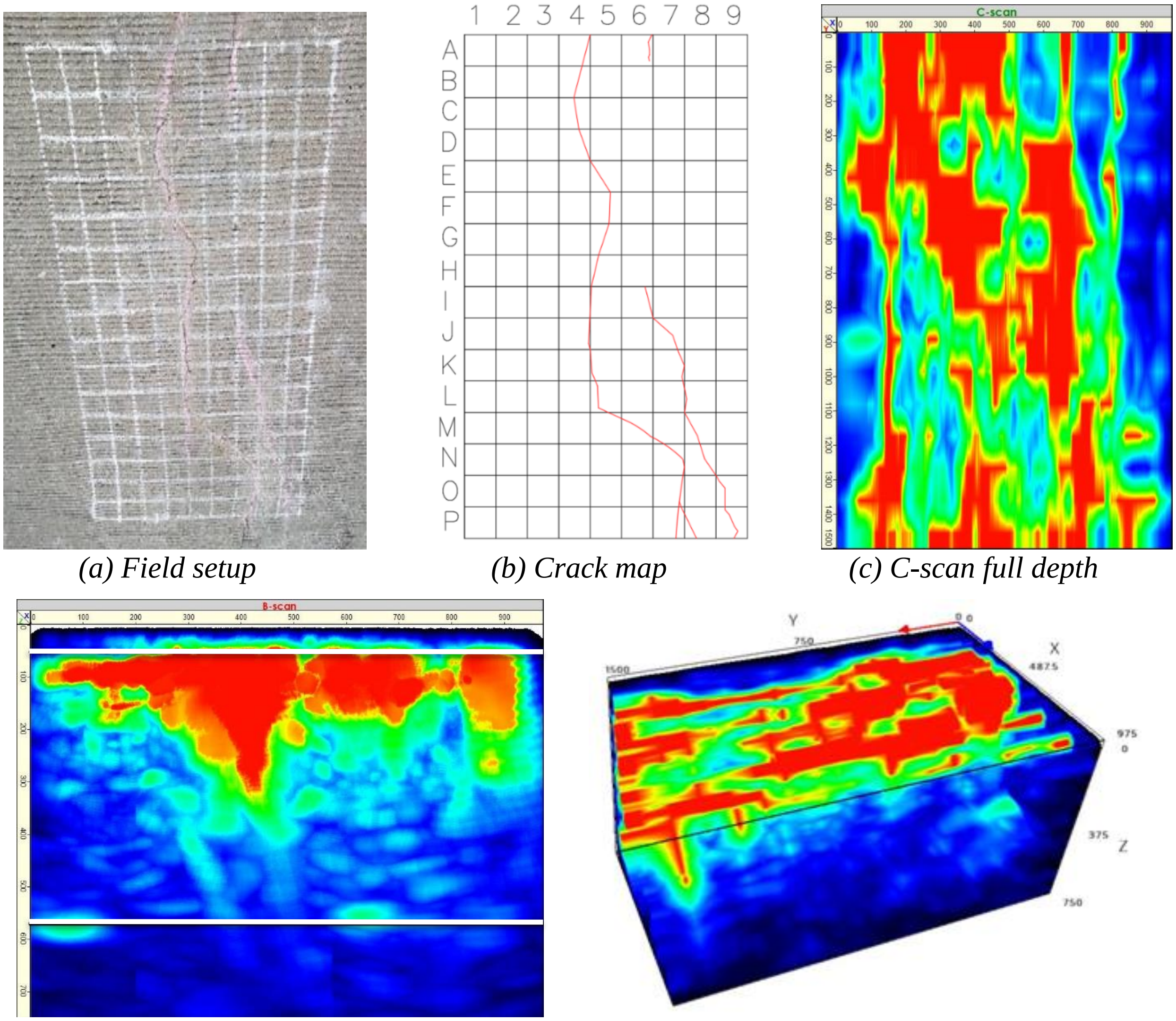
Before testing at each location, a grid was drawn utilizing a tape measure, straight edge, and chalk. The grid was composed of 4 in. by 4 in. squares covering the area of interest and was used to aid in positioning the device to ensure uniform scan spacing and overlap between scans. Scans were conducted from right to left in each row, with the device being moved 4 in. to the right after each scan.

3.1.2 Test Results

The test results from all five locations are presented below.

Grid 1

The first test setup was a 64 in. by 36 in. grid, as shown in Figure 9a.



(a) Field setup *(b) Crack map* *(c) C-scan full depth*

(d) B-scan section view of the deck *(e) 3D image*

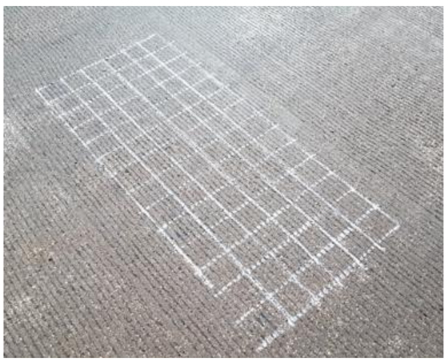
Figure 9. Test setup and results for Grid 1 on Mingo Bridge

This test location was over Pier 1, as shown in Figure 8, and included several cracks in the bridge deck, as shown in Figure 9b. Figure 9c and 9d show the C-scan and B-scan, respectively, and Figure 9e shows the 3D image for the scanned area. The original bridge plans show that rebar is present in the top layer of this test location (see Figure 7). Figure 9e shows that there are rebar-like shapes running along the y-axis. However, the configuration of each rebar is not clear in the scans.

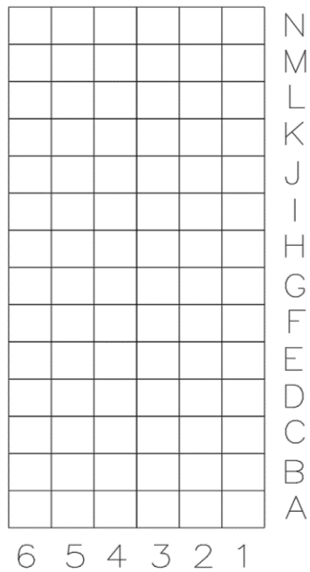
Based on the information in the bridge plans, a white line marks the interface between the overlay and substrate in Figure 9d. The overlay is about 1.75 in. thick. Recall that MIRA's measurement range of the depth of the flaw location is from 2 to 16 in. This indicates that the cracks in the overlay cannot be accurately captured in the scans because the entire thickness of the overlay is within the first 2 in. of the concrete depth. As is evident from this scan, red shading extends from the rebar level to approximately the mid-depth of the slab. This demonstrates that there are defects in the substrate beneath the overlay. The bottom surface of the deck is also marked with a white line in Figure 9d based on information in the bridge plans. However, the scans do not clearly capture this interface.

Grid 2

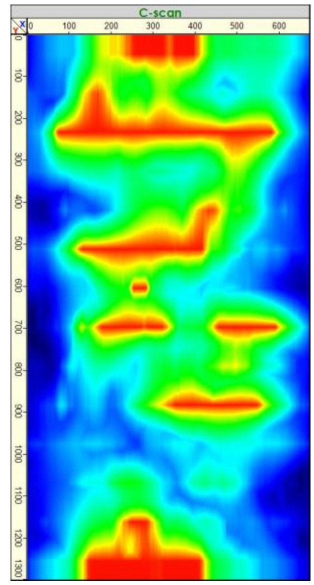
The second test setup was a 56 in. by 24 in. grid that contained no visible cracks in the bridge deck, as shown in Figure 10a and 10b.



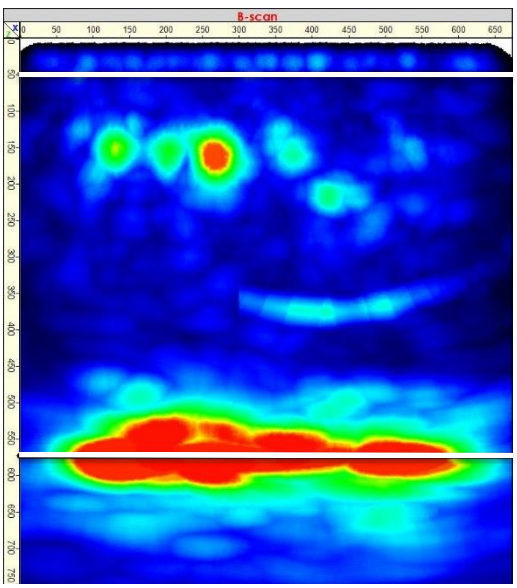
(a) Field setup



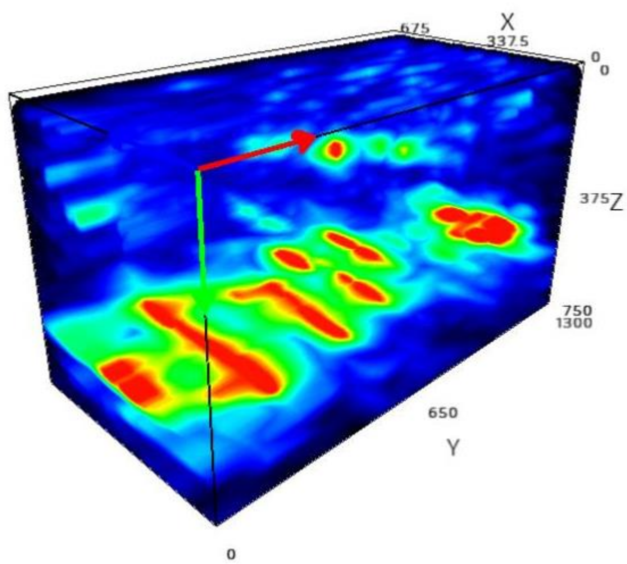
(b) Crack map



(c) C-scan full depth



(d) B-scan section view of the deck



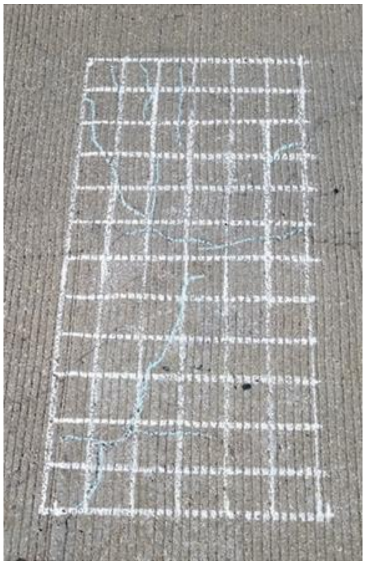
(e) 3D image

Figure 10. Test setup and results for Grid 2 on Mingo Bridge

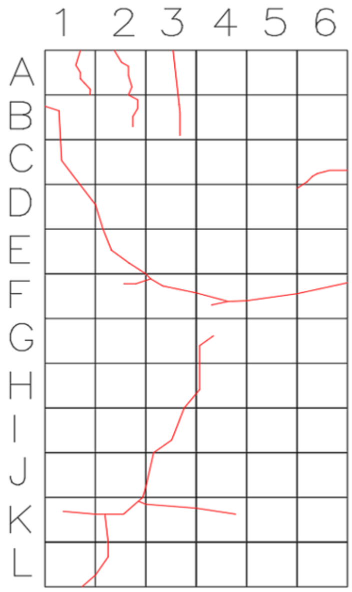
Figure 10c and 10d show the C-scan and B-scan, respectively, and Figure 10e shows the 3D image for the scanned area. Similar to the first location, white lines in Figure 10d mark the interface between the overlay and substrate and between the substrate and the bottom of the deck. It can be seen that the MIRA scans do not show the location of the interface between the overlay and substrate. However, a red area is visible at the bottom the deck. According to the bridge plans, the deck at this location has a depth of 22.5 in. (570 mm). In the MIRA scan, the red area is between 21.7 in. (550 mm) and 22.6 in. (575 mm) deep. In this case, MIRA was able to give a general range of the slab thickness. However, the intensities in the scan do not clearly distinguish between the bottom of the slab and the reinforcement. Additionally, this test was located near the abutment/mid-span, where the bridge plans indicate that no top reinforcement is present (see Figure 7). The scans confirm that no top reinforcement is present. Figure 10d and 10e show a red region located 6 in. (150 mm) below the surface that may indicate the location of a potential defect.

Grid 3

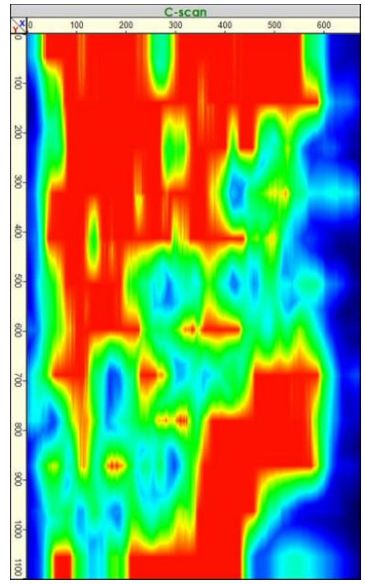
The third setup was a 48 in. by 24 in. grid that included several visible cracks in the bridge deck, as shown in Figure 11a and 11b.



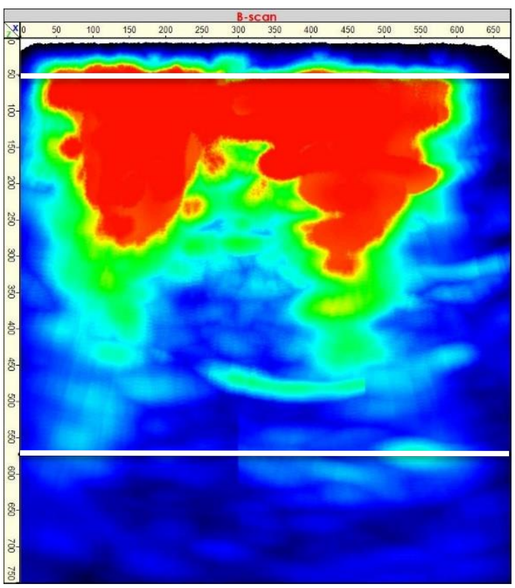
(a) Field setup



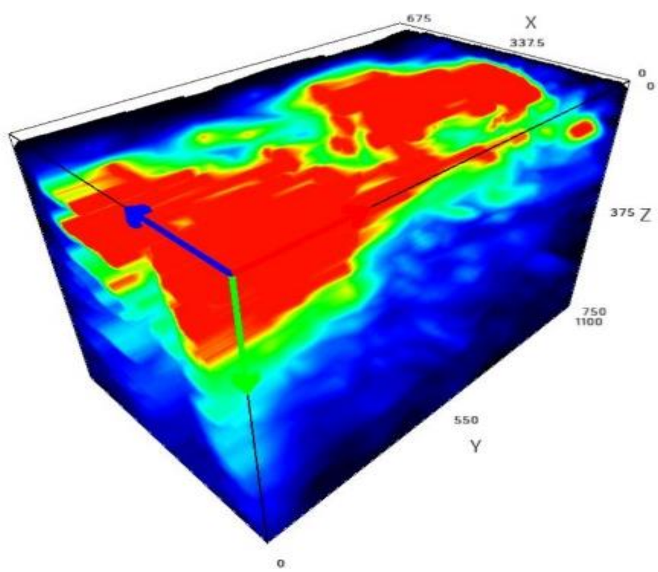
(b) Crack map



(c) C-scan full depth



(d) B-scan section view of the deck



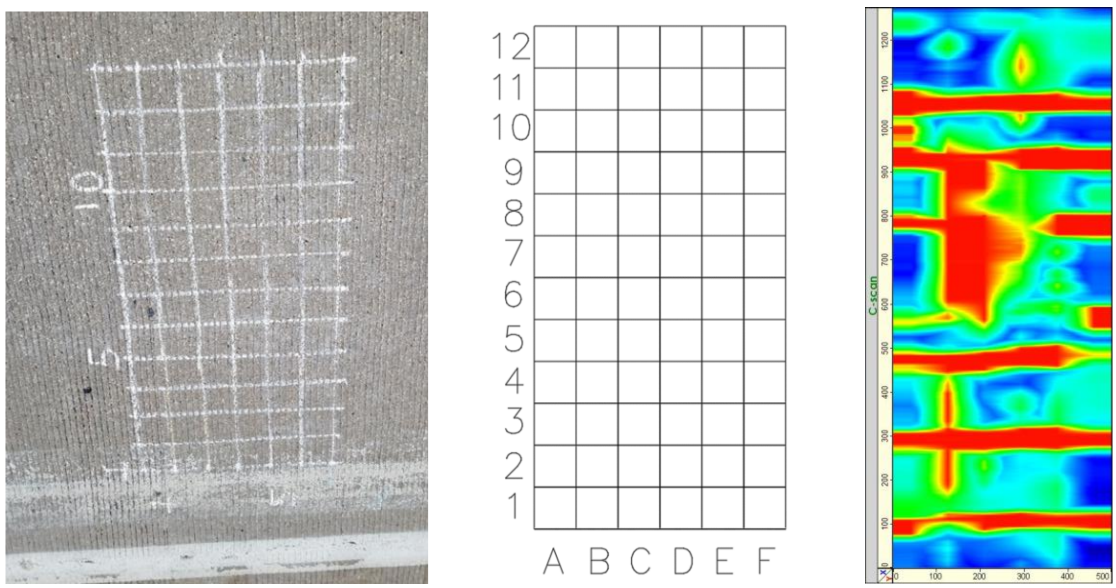
(e) 3D image

Figure 11. Test setup and results for Grid 3 on Mingo Bridge

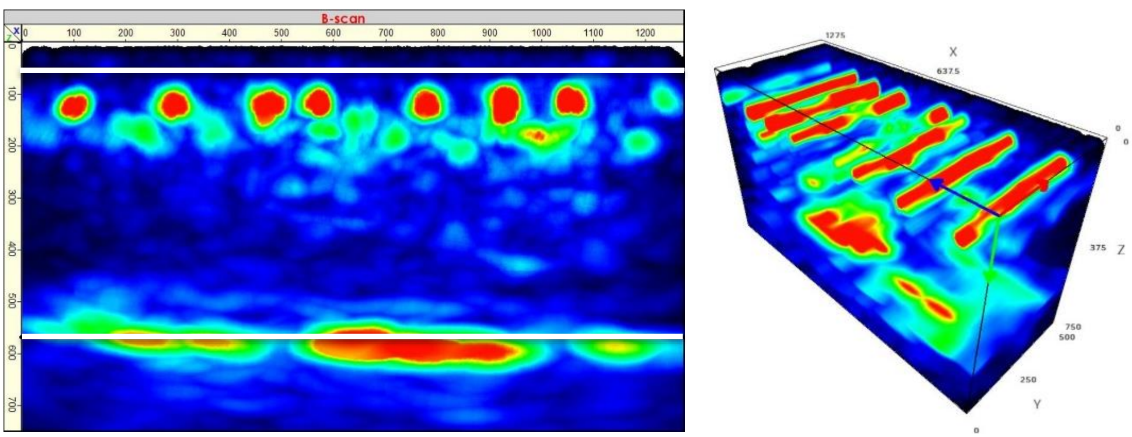
Similar to the scans for Grid 1, the scans for Grid 3 show a large red area at the level of the top rebar that extends down to the mid-depth of the deck, as shown in Figure 11c, 11d, and 11e. Since MIRA detected several defects in the top portion of the bridge deck, the bottom of the slab could not be detected. This low-depth attenuation, or the presence of damage, can be thought of as “noise” that is not allowing the waves to penetrate to the full depth of the deck. As the cases for Grids 1 and 3 illustrate, if significant low-depth damage is present, the depth of the deck cannot be accurately captured in the scans.

Grid 4

The fourth setup was a 48 in. by 24 in. grid that included no visible cracks in the bridge deck, as shown in Figure 12a and 12b.



(a) Field setup *(b) Crack map* *(c) C-scan full depth*



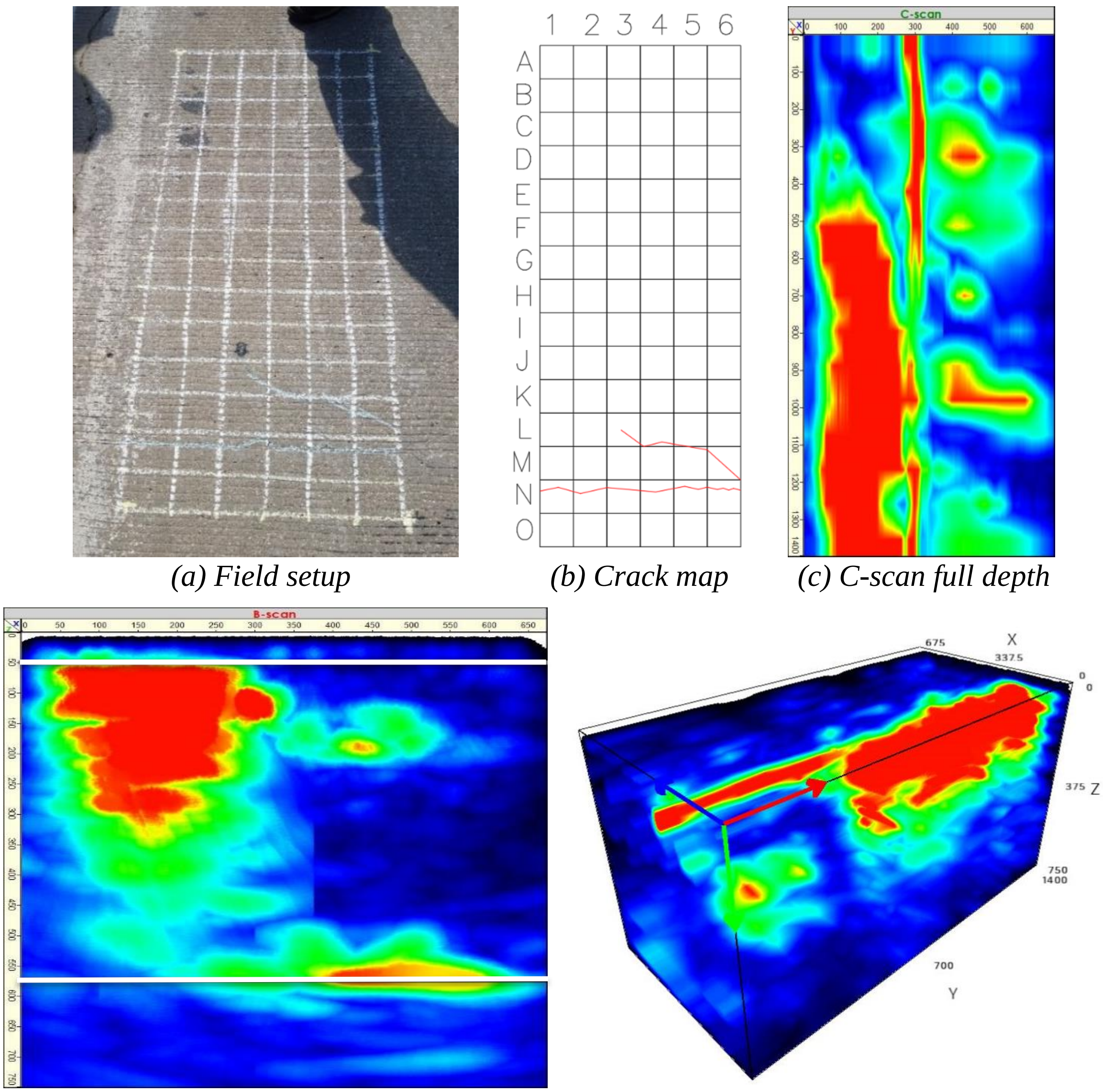
(d) B-scan section view of the deck *(e) 3D image*

Figure 12. Test setup and results for Grid 4 on Mingo Bridge

In this grid, the MIRA scans were able to locate the top layer of reinforcement, as shown in Figure 12c, 12d, and 12e. This grid was located over a pier, and the bridge plans confirm that top reinforcement is present at this location. The plans locate the reinforcement approximately 3.75 in. below the surface, which was confirmed by the MIRA scans. Moreover, the MIRA data show that the diameters of the red areas are around 1.5 in. (38.1 mm). The plans indicate that #11 rebar is located in this area, which has a diameter of 1.41 in. (35.8 mm). This indicates that MIRA has the ability to determine the location and relative size of rebar near the surface when extensive low-depth damage is not present. It is important to note, however, that the size of the area shown in the scan is highly depenedent upon threshold selection and can therefore be misleading. In addition, red shading is visible at a depth that coincides with the bottom of the deck, showing that MIRA can also identify the thickness of the deck when extensive damage is not present. The plans indicate that bottom reinforcement is located in this area, but because the top reinforcement blocked most of the shear waves, the bottom reinforcement could not be clearly scanned.

Grid 5

The fifth setup was a 60 in. by 24 in. grid that included some minor visible cracking on one side of the grid, as shown in Figure 13a and 13b.



(a) Field setup *(b) Crack map* *(c) C-scan full depth*

(d) B-scan section view of the deck *(e) 3D image*

Figure 13. Test setup and results for Grid 5 on Mingo Bridge

As shown in Figure 13c, the scans did show red areas in the bottom left corner of the grid. Figure 13d and 13e indicate that this red area extends from the top to the mid-depth of the deck. According to the bridge plans, no top reinforcement is present in this area. These scans appear to indicate that the damage seen at the surface, i.e., the two cracks, extends through the overlay and into the substrate. These scans could be useful for determining the extent of damage and could thus indicate the level of repair necessary.

3.1.3 Discussion

The results indicate that MIRA is good at detecting the location and relative size of the top layer reinforcement in the deck through a 1.75 in. overlay when the overlay is in good condition (see the results from Grid 2 and Grid 4).

It was also found that although the MIRA scans for Grid 2 and Grid 4 showed a large red area near the bottom of the deck (about 575 mm below the surface), it could not clearly distinguish between the bottom surface of the deck and the bottom layer reinforcement.

However, when the overlay exhibits significant cracking (as in Grid 1 and Grid 3), the scans show a large shaded area that extends from the level of the top rebar to the mid-depth of the deck. At these locations, it is impossible to identify the top and bottom layer reinforcement and the deck thickness.

3.1.4 Validation of Test Results through Field Inspection

Based on the results from a field inspection of the bridge and the MIRA tests described above, a rating factor was given for each location (see Table 6).

Table 6. Field inspection versus MIRA results

Location	Field Inspection	MIRA
Grid 1	5	4
Grid 2	1	1
Grid 3	5	5
Grid 4	1	1
Grid 5	3	4

Each location was rated from 1 to 5, with 1 representing good condition and 5 representing a severely cracked condition.

According to the field inspection, the results of which are shown in Figure 9a and 9b to Figure 13a and 13b, Grids 1 and 3 had the worst cracking and were therefore rated as 5, while Grids 2 and 4 were in the best condition and were rated as 1. Grid 5 had minimal cracking (two visible cracks) and was rated as 3. These ratings are based solely on the external condition observed on the top surface of the bridge deck.

Based on the MIRA scans, the results of which are shown in Figure 9c, 9d, and 9e to Figure 13c, 13d, and 13e, Grid 3 was rated as 5, Grids 2 and 4 were rated as 1, and Grids 1 and 5 were rated as 4.

Although some differences exist in the ratings resulting from the field inspection and the MIRA scans, the results are generally similar. As such, the MIRA scans are able to provide a general assessment of the bridge deck condition. The most promising scenario is that observed for Grid 5, which had minimal visible cracking while the MIRA scans showed that the damage extended further into the depth of the substrate. This situation shows that MIRA is capable of detecting deeper damage that is not yet evident at the surface. This information would be advantageous when determining repair and maintenance needs because the extent of the repairs needed could be more accurately determined using MIRA than by basing the decision solely on the visible condition of the deck.

3.2 Highway 2 Bridge over the Missouri River

The second deployment of MIRA was conducted on the Highway 2 Bridge over the Missouri River connecting Iowa and Nebraska. The objective of this round of MIRA testing was to assess the condition of the post-tensioning ducts in areas where voids had previously been found using an alternate NDT method. This bridge was constructed in 1983 with 12 spans, as shown in Figure 14.

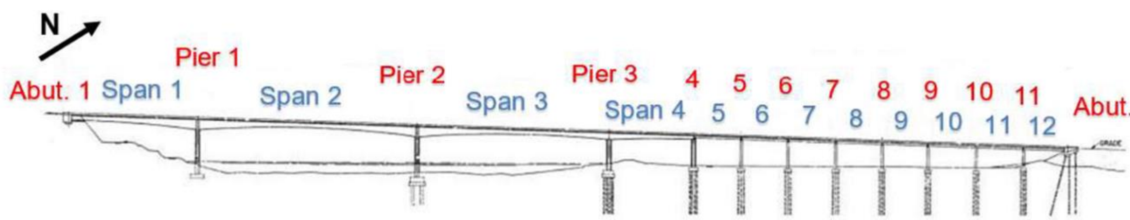


Figure 14. Bridge layout

The four spans on the Iowa side consist of post-tensioned segmented concrete box girders, while the eight spans on the Nebraska side consist of prestressed concrete I girders.

Prior to the acquisition of the MIRA data, Vector Corrosion Services, Inc. (VCS) conducted inspections on the post-tensioned reinforcement to determine whether improper grouting was used or voids existed within the ducts. Ground penetrating radar was used to determine the location of the ducts, and impact echo was used to identify defects in the concrete and the voids within the web tendon ducts. The goal of this testing was to obtain data that could be compared with the results obtained by MIRA.

Areas for testing were determined based on the inspection report provided by VCS. In the report, VCS notes that two large voids were found in the web tendon ducts. The areas of the two voids (over T-30 and T-35) and another random location (T-34) were selected for MIRA scanning. In the field, the tendons had been marked during the previous inspection, allowing the exact areas to be located.

3.2.1 Field Work Description

On October 17, 2019, the research team collected data alongside personnel from the Iowa DOT and the Nebraska DOT (NDOT). Three tests were conducted on the bridge: two on the north web and one on the south web.

Similar to the work on the Mingo Bridge, a grid was created over each testing area to aid in the positioning of the MIRA device. The boxes consisted of 4 in. segments that spanned the width of the device and ran perpendicular to the tendon. The testing length varied depending on how large the area in question was. MIRA was deployed twice for each testing layout: once perpendicular to the tendon and once parallel to the tendon.

3.2.2 Test Results

The data collected by MIRA were processed utilizing Introview Concrete to combine the individual scans into one 3D image. The scans were then analyzed by comparing the results to the plan set and the report from VCS.

T-34 and T-35

Two tendons (T-34 and T-35) were located west of Pier 2 (Span 2) in the north web. The two web tendons tested are shown in Figure 15 and Figure 16.

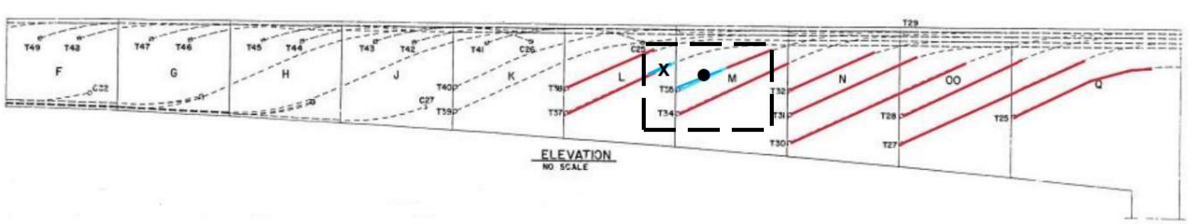


Figure 15. Detailed tendon layout for T-34 and T-35

Figure 16. MIRA testing layout for T-34 and T-35

VCS identified potential defects in T-35 using impact echo. The area of the defects is depicted in Figure 15 by the blue line. Moreover, to confirm that there was, in fact, a void at the identified location, a borescope inspection was conducted at the location shown by the black dot in Figure 15. In the results, a void was indeed identified. The impact echo testing did not identify defects in T-34.

The C-scan, B-scan, and 3D image resulting from MIRA testing are shown in Figure 17, Figure 18, and Figure 19, respectively.

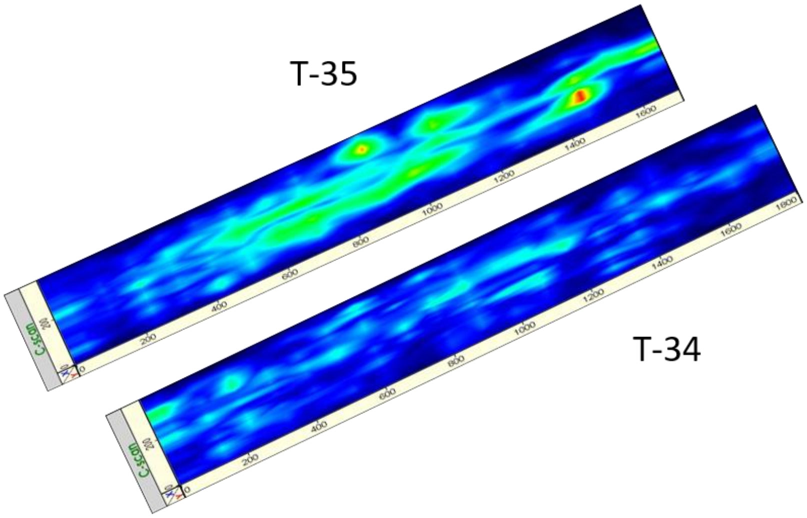


Figure 17. C-scans for T-34 and T-35

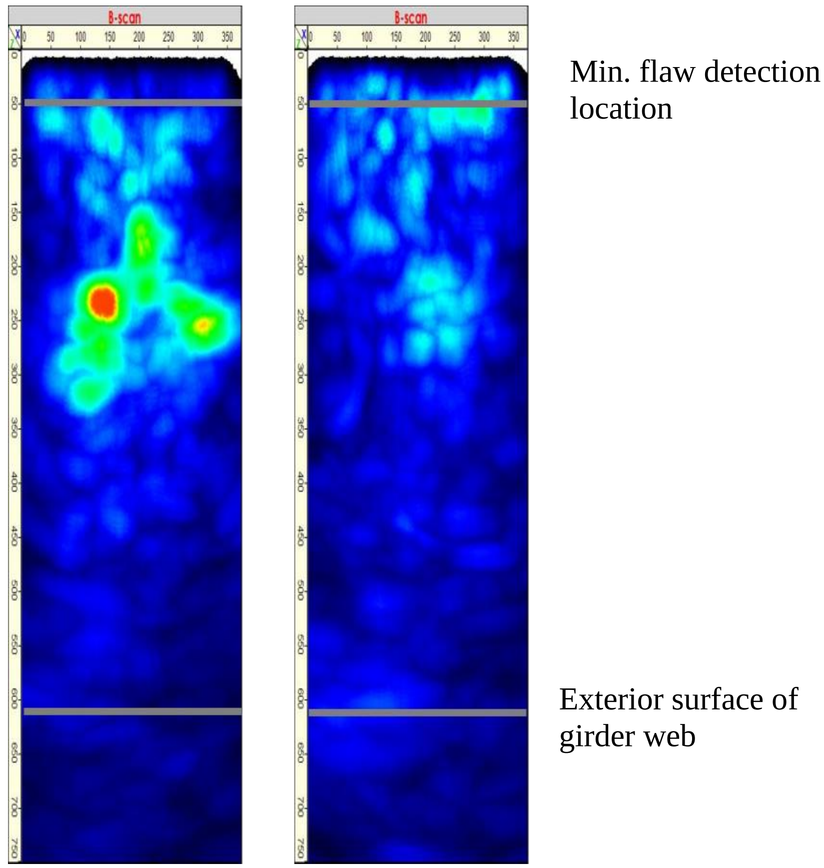


Figure 18. B-scans for T-34 and T-35

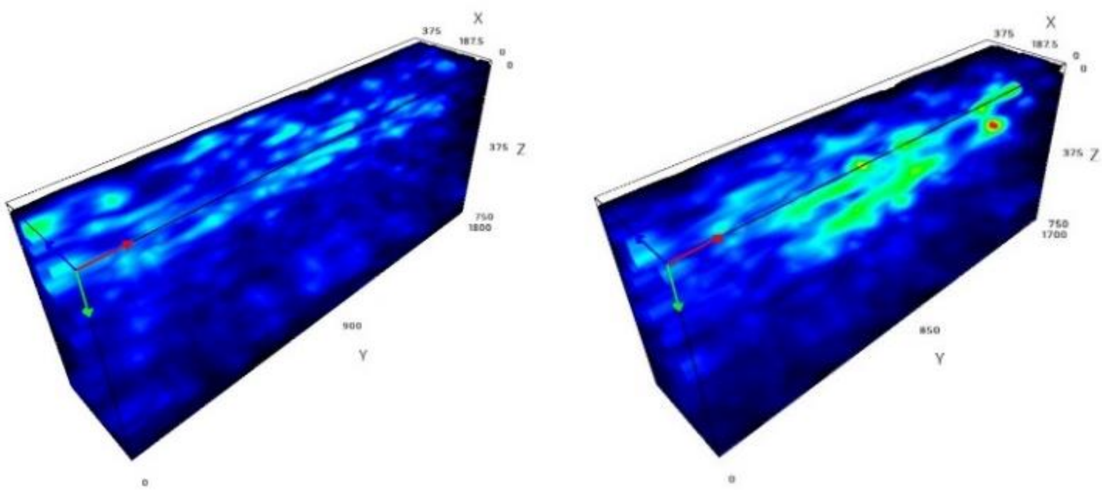


Figure 19. 3D images for T-34 and T-35

All MIRA scans showed a red area corresponding to the ducts for T-35, while no red area was found corresponding to the ducts for T-34. This result shows good agreement with the findings from the VCS inspection report, incating that voids were present in duct T-35.

T-30

One tendon (T-30) west of Pier 2 (Span 2) in the south web was also tested. The web tendon tested is shown in Figure 20 and Figure 21.

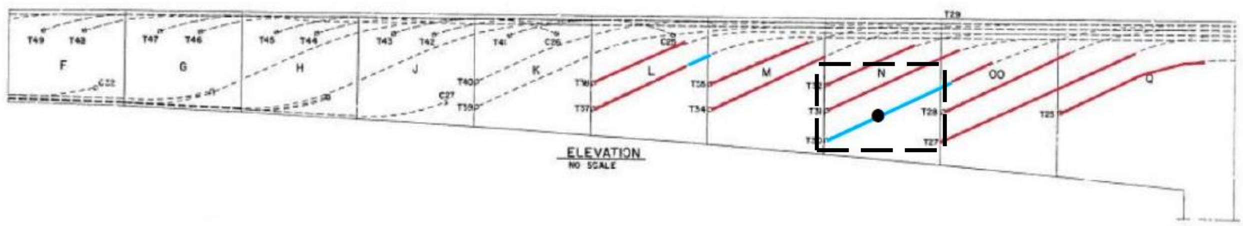


Figure 20. Detailed tendon layout for T-30

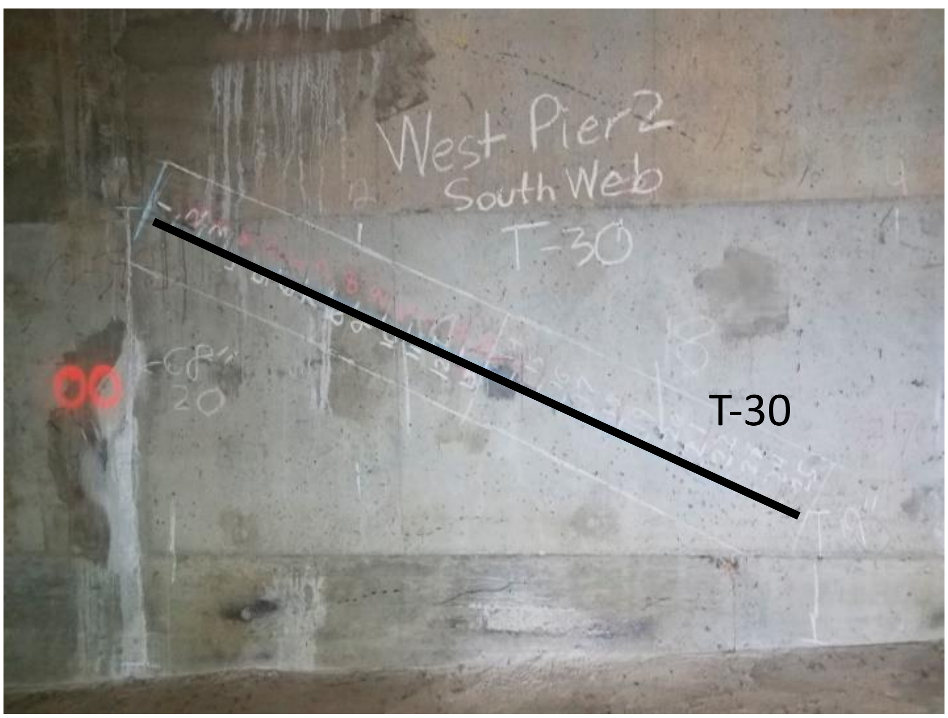


Figure 21. MIRA testing layout for T-30

T-30 was the second void location determined by VCS. Figure 22, Figure 23, and Figure 24 show the C-scan, B-scan, and 3D image for T30, respectively.

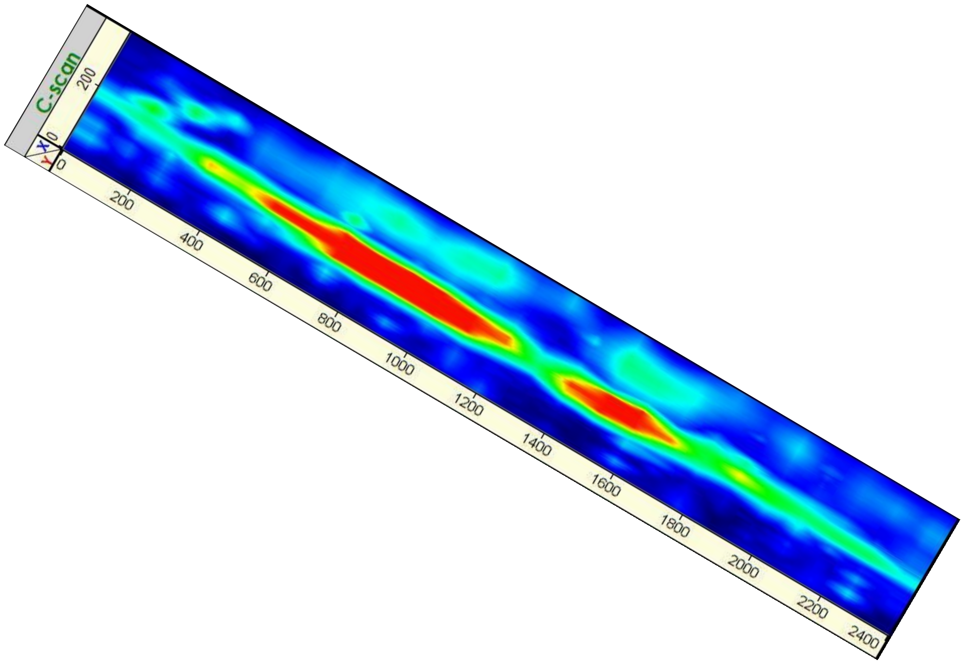


Figure 22. C-scan for T-30

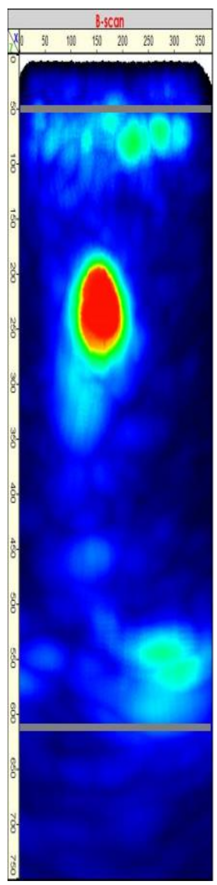


Figure 23. B-scan for T-30

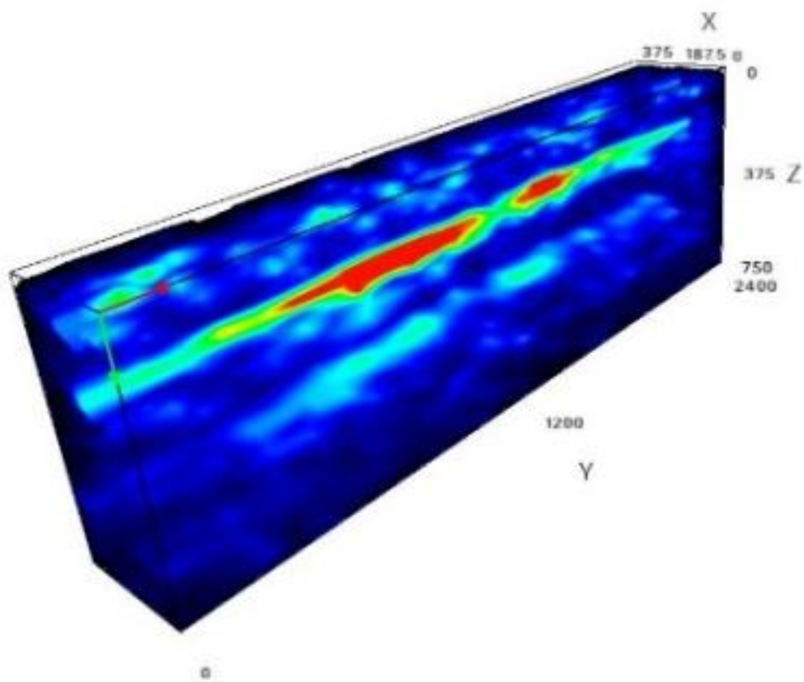


Figure 24. 3D image for T-30

A red area is visible in the MIRA scans and confirms the void in the tendon duct.

CHAPTER 4. SUMMARY, CONCLUSION, AND FUTURE RESEARCH DIRECTION

4.1 Summary and Conclusion

The goal of this project was to explore the potential applications of MIRA for assessing bridge condition. In order to achieve this goal, two bridges in the state of Iowa were selected for the deployment of MIRA at the suggestion of the TAC. Multiple tests were performed on each bridge. The purposes of these tests included, among others, detecting the relative size and location of rebar in the bridge deck, determining the thickness of the deck, evaluating the extent of cracking in the deck substrate, and identifying voids in post-tensioning ducts. The results were validated against field inspection results and/or existing bridge inspection reports.

Based on the results of this research, the following conclusions can be made:

- When the overlay on the concrete deck was in good condition, MIRA could effectively detect the location and relative size of the top layer rebar.
- MIRA scans could not clearly distinguish between the bottom surface of the deck and the bottom layer reinforcement at about 575 mm below the surface.
- When cracks were present in the overlay, MIRA was able to detect these defects. However, since the substrate deck condition on the Mingo Bridge was unknown during this project, the damage seen in the MIRA scans could not be field verified.
- MIRA performed well in detecting voids in post-tensioning ducts.

4.2 Future Research Direction

Although MIRA demonstrated promising capabilities for various bridge condition assessment applications in this project, some limitations were made apparent. For example, when severe cracking is present in an overlay, as seen in Grid 1 and Grid 3 on the Mingo Bridge, MIRA scans show a large area of damage from the level of the top rebar to the mid-depth of the deck. As noted above, it is difficult to determine the precise location of the distress. While the damage shown in the MIRA scans could be due to the damage visible at the overlay level extending into the deck, this could not be verified via field testing because the overlay removal and replacement efforts on the Mingo Bridge were delayed beyond the timeframe of this project. As such, further validation is required to confirm the trends seen in these preliminary efforts.

If confirmation of the damage seen in the MIRA scans performed on the Mingo Bridge is not possible, a parametric experimental study could provide the needed validation. For example, several sample slabs with cast overlays could be prepared in the laboratory with varying levels of cracking present. With the internal condition of the slabs known, a comparison of MIRA scans could quantitatively evaluate the device’s ability to predict internal damage in a deck’s overlay and substrate.

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