

4. Field Testing and Demonstrations

The objective of the field demonstrations of this research was to evaluate the performance of four non-destructive assessment techniques: BVRCS, 3DOBS, passive infrared thermography, and active infrared thermography. These remote sensing methods were used to assess the condition of selected bridge decks, a major element in a bridge that provides protection from the environment to the superstructure and substructure, indicates overall bridge health, and determines when preservation activities should be performed.

Field deployments of the non-destructive testing methods occurred in three phases, one in the fall of 2013 and then again in the spring and summer of 2014. Fall deployments included testing locations at four highway bridges while three bridges were visited in the spring. Emphasis was taken on the evaluation of the 3DOBS high-resolution system to detect spalls and cracking and passive infrared thermography to detect delaminations during fall deployments. The testing results were used as a basis for comparison for the second deployment phase in the spring. The duration between deployment phases was used to evaluate the remote sensing techniques, make upgrades to the existing systems, and conduct additional lab testing.

The second deployment in the spring of 2014 allowed for further evaluation of the 3DOBS low-resolution system and passive infrared thermography conducted at near highway speeds simultaneously. This phase also allowed for implementation and evaluation of the 3DOBS high-resolution system at slower speeds for more refined crack evaluation. Two highway bridges were selected as data collection sites for the 3DOBS systems and passive infrared thermography testing. The demonstration sites are described in detail in the following sections. An additional demonstration site was visited to perform the active infrared thermography in the summer of 2014 for the bottom deck surface evaluation (see Chapter 6).

For comparison and correlation purposes, an MDOT certified bridge inspector was present for the US-131 and Maryland Ave. field tests to establish ground-truth information. The inspector either conducted an assessment of the entire structure or evaluated only specific areas of interest to produce delamination maps, spall maps, and crack maps. Results from the remote sensing tests were compared to inspector's findings and are included below.

4.1 Bridge Selection

To facilitate the testing and evaluation of the remote sensing techniques, several parameters were established during the bridge selection process. The goal of the selection process was to identify three testing locations for the fall data collection phase and an additional three testing locations for the spring phase within the state of Michigan. The selected bridges were deemed acceptable for both traditional health monitoring techniques, performed by MDOT qualified inspectors such as sounding (hammer or chain-dragging), and for the remote sensing systems.

Preliminary selection was based on the NBI rating scale found from the most recent MDOT assessments. Sites with varying levels of deterioration were preferred in order to evaluate the performance of the several non-destructive techniques on bridges with varying deck conditions. Preference was also given to bridges with all structural components composed of a homogeneous material, however, this was not an essential requirement unless the underside of the bridge was being evaluated. In the case of the active infrared thermography deployment, a selection parameter was established to identify a testing location at which all bridge structural components were composed of concrete. Lab testing had not yet revealed the effects of combining bridge components of different materials on this remote sensing technique and such selection parameter was necessary to ensure accuracy while evaluating the testing method.

Once preliminary selections were made, photographs of each bridge were collected using satellite images. The images were then used to further categorize the selected bridges based on access to the bridge components of interest and surrounding industry and transportation facilities influencing traffic patterns. The average daily traffic (ADT) was also used as a selection parameter. Bridges sites with a relatively low ADT were preferred to minimize lane closures and traffic disruptions and to provide a safe working environment for both MDOT inspectors and remote sensing technicians.

Upon further categorization of the testing sites, upcoming bridge inspection dates were also taken into consideration during the selection process. To establish ground-truth information, selecting bridges that underwent a recent biennial inspection was both beneficial and convenient.

4.2 Fall 2013 Field Test Sites

The following bridges were selected for the fall data collection and testing phase of research. Bridge assessments were made using the 3DOBS high-resolution system and passive infrared thermography and the testing data was evaluated based on ground-truth information obtained by MDOT inspectors.

4.2.1 20 Mile Road Bridge

MDOT structure No. 1279 – 20 Mile Road over I-94 was selected as a demonstration site for the 3DOBS high-resolution deployment and passive infrared thermography and is located approximately 4.5 miles east of I-69 near Battle Creek Michigan in Calhoun County. The structure spans both east and west bound I-94. A satellite aerial view of the structure can be seen in Figure 4-1.

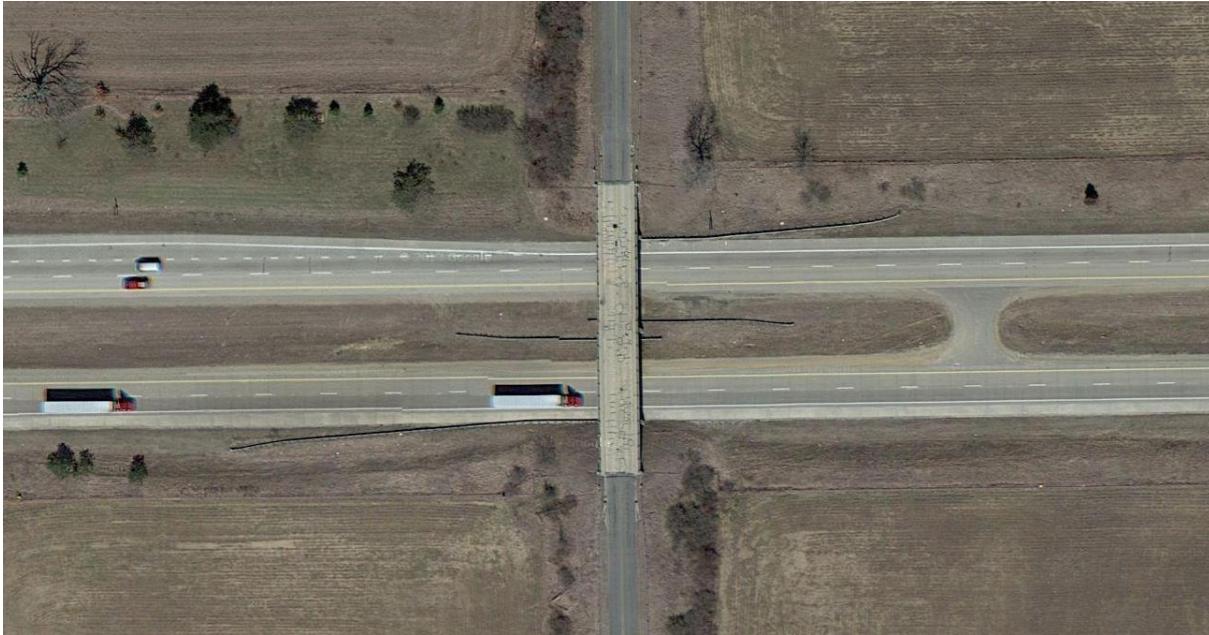


Figure 4-1: 20 Mile Road Bridge over I-94 Located in Calhoun County, Michigan.

Constructed in 1960, the bridge is a 4-span cast-in-place tee beam structure with a total length of 227 ft. The bridge has a total width of 31.2 ft with two 11 ft lanes and 3'-3" shoulders. Measured in 1988, the ADT over the structure was determined to be 1500 vehicles per day with 3% being commercial truck traffic (MDOT). Future ADT predictions for 2000 made at the time of measurement estimated a 36% increase in traffic.

During the most recent bridge inspection on August 8th, 2013, the concrete deck surface was assigned a poor condition NBI rating of 4. A photograph of the current deck surface condition can be seen in Figure 4-2. With the main purpose of this deployment being the assessment of the 3DOBS high-resolution system and passive infrared thermography, the bridge deck was the main bridge component of interest. Only the surface of the bridge deck was evaluated for deficiencies, however, particular interest should be taken to spalling on many of the bridge beams that have left reinforcing steel and stirrups exposed. It was recommended that these areas be patched to preserve the integrity of the structure.



Figure 4-2: Deck Surface for 20 Mile Road Bridge.

Testing on 20 Mile bridge corresponded with the inspection of the bridge by MDOT. A sketch of the deck sounding was georeferenced as a GIS shapefile (Figure 4-3). The sounding determined that there was $1,276 \text{ ft}^2$ of delamination with 32 ft^2 of bit patching and scale which corresponded to 24% of the deck surface.

20 Mile Rd. Over I-94, Marshall, Michigan



Figure 4-3: Georeferenced Sketch of the Results of the Deck Sounding Showing the Locations of Delaminations. The Total Area Delaminated is 1,276 ft².

4.2.2 24 Mile Road Bridge

MDOT structure No. 1282 – 24 Mile Road over I-94 is located approximately 9 miles east of I-69 near Albion, Michigan in Calhoun County and was selected as a demonstration site for the 3DOBS high-resolution system and passive infrared thermography deployment.

The bridge was constructed in 1959 and is a 4-span cast-in-place variable depth tee beam structure with a total length of 227 ft. The bridge has a total width of 31.2 ft and with a 24 ft roadway and no shoulder. Figure 4- shows the multiple span structure over I-94. The ADT over the structure was determined to be 160 vehicles per day in the year 1988 with 3% being commercial truck traffic (MDOT). At that time, it was estimated that the future ADT in 2000 was to only increase slightly to 218 vehicles per day.



Figure 4-4: 24 Mile Road Bridge Selected as a Fall 2013 Deployment Site.

The concrete deck surface was assigned a poor condition NBI rating of 4 during the last inspection on August 14th 2013. With the assessment of the 3DOBS high-resolution system and passive infrared thermography being the main purpose of this deployment, the bridge deck was the main bridge component of interest. Only the surface of the bridge deck was evaluated for deficiencies, however, it should be noted that numerous spalls have left reinforcing steel exposed on many of the bridge beams reducing the superstructure to a rating of 5. Patching of these areas was recommended prevent further deterioration and extend the service life of the bridge.

The inspection report indicated various transvers and longitudinal cracks across the deck surface, some of which had been sealed with rubber. Various concrete patches were also present over the structure surface. A main area of interest was noted to be the unsealed longitudinal joint where cracking and scaling have contributed to wetness, exposed reinforcement steel from spalling, corrosion, and delaminations on the underside of the deck. To locate and quantify delaminations, the surface of the bridge deck was sounded on October 15th, 2013 revealing that 14% of the deck area contained these defected areas. Upon completion of the two inspections, recommendations

were made to seal construction joins and perform a shallow overlay to preserve the integrity of the bridge. An aerial image of the bridge deck can be seen in Figure 4-5.

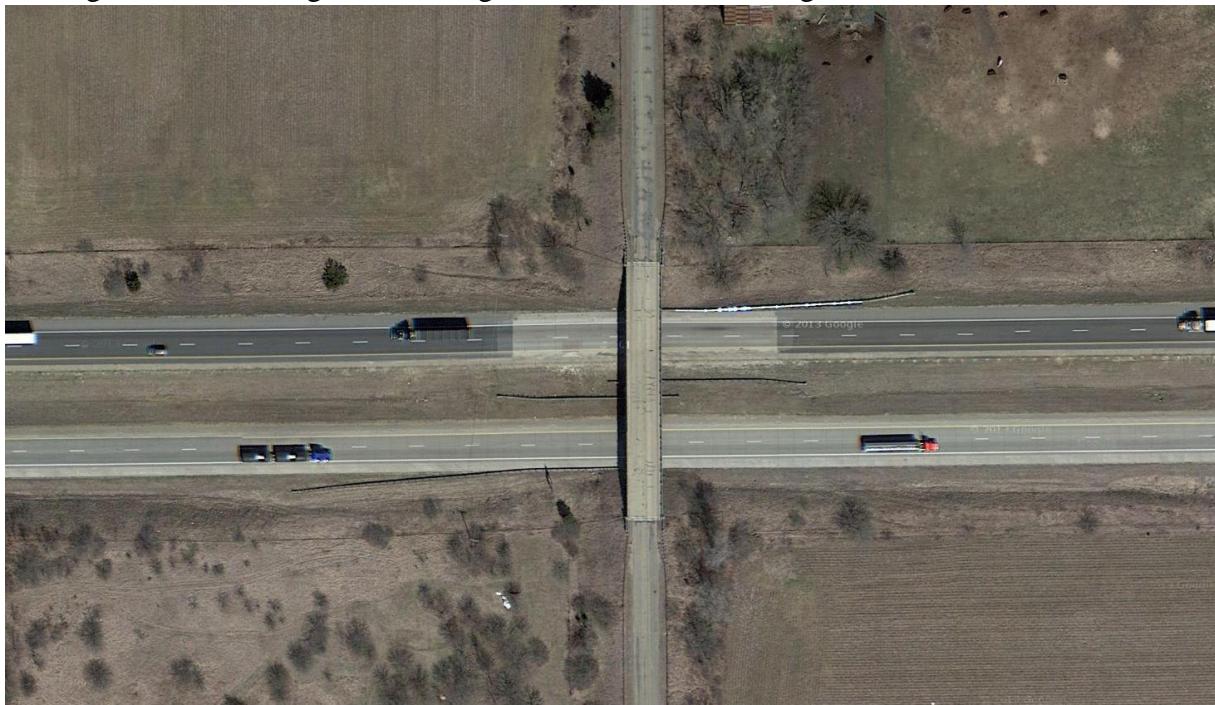


Figure 4-5: Satellite Image of 24 Mile Road Bridge Deck in Calhoun County, Michigan.

Like 20 Mile Road, testing on 24 Mile bridge corresponded with the inspection of the bridge by MDOT. A sketch of the deck sounding was georeferenced as a GIS shapefile (Figure 4-6). The sounding determined that there was 762 ft^2 of delamination with 13 ft^2 of bit patching and scale which corresponded to 14% of the deck surface.



Figure 4-6: Georeferenced Sketch of the Results of the Deck Sounding of 24 Mile Rd Showing the Locations of Delaminations. The Total Area Delaminated is 762 ft²

4.2.3 US-131 NB and SB Bridges

MDOT structures 5002 and 5003 – US-131 over White Creek Ave. are located directly to the east of Cedar Springs Michigan in Kent County and were selected as demonstration sites for the 3DOBS high-resolution and passive infrared thermography deployment. An aerial view of the two structures can be seen in Figure 4-7. Both the north bound (No. 5003) and south bound (No. 5002) bridges of US-131 were inspected for deficiencies. Passive infrared thermal data was also collected by MDOT at these two locations using their agency-owned thermal camera to test the capabilities of their own thermal imaging camera.

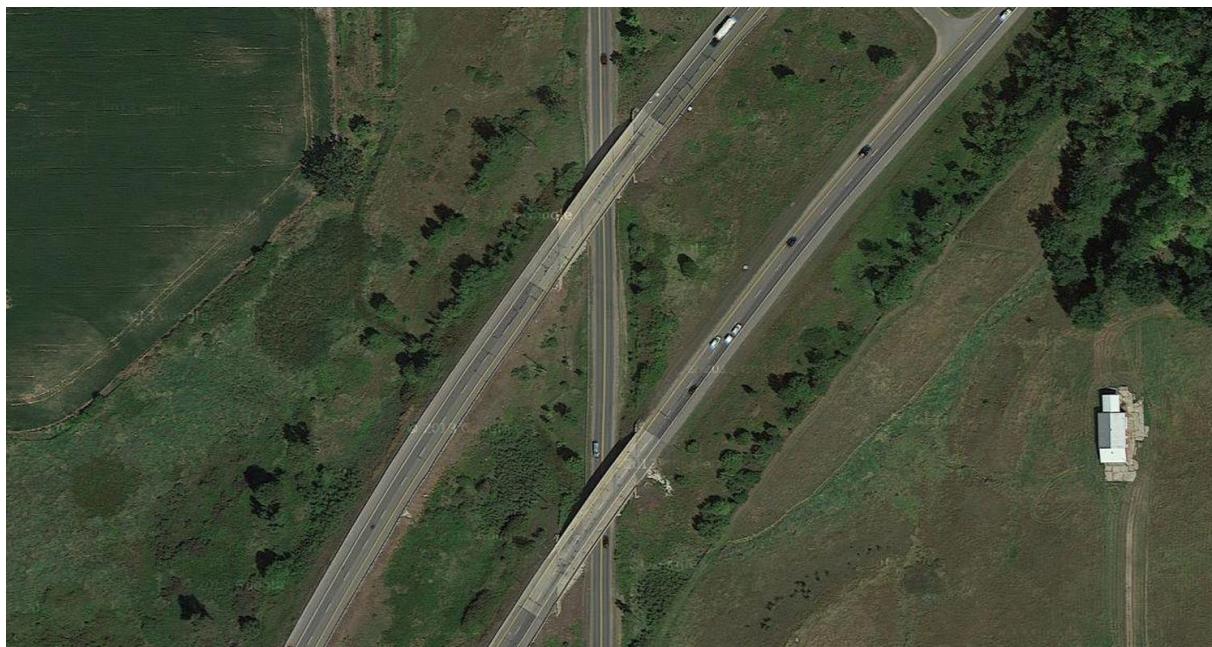


Figure 4-7: North and South Bound US-131 Bridges over White Creek Ave. near Cedar Springs, Michigan.

Both bridges, 5002 and 5003, were constructed in 1971 and are 3-span steel beam bridges. Structure No. 5002 has a total length of 176.8 ft while structure No. 5003 spans a slightly larger distance with a total length of 187 ft. Both of the bridges have a 40'-6" roadway with two 12 ft lanes, a 5'-3" shoulder and an 11'-3" shoulder. In 2007, the ADT over structure No. 5002 and No. 5003 was measured to be 13,760 vehicles per day with 10% being commercial truck traffic (MDOT). It was estimated that the ADT over both structures will reach about 20,000 vehicles per day in the year 2018, a significant increase in traffic volume making bridge improvements and preservation activities increasingly more important.

Although these two bridge structures are in close proximity, their levels of degradation are different which raises questions of construction inspection consistency and construction practices. The concrete deck surface of structure No. 5002 was assigned a fair condition NBI rating of 5 while the deck surface of No. 5003 was in poor condition and rated at a 4. The most

recent inspection for both structures occurred on September 10th 2013. The surface of the bridge deck was of particular interest during this deployment because assessments of the 3DOBS high-resolution system and passive infrared thermography were made. It should be noted however that both structures have considerable amounts of rusting and corrosion over many of the steel beams. In order to preserve the structural integrity of the two bridges, it was recommended that the beams, pins, and hangers be cleaned and painted to extend their service lives.

The inspection report for structure No. 5002 indicated considerable amounts of concrete patches, spalling, and delaminated areas across the deck surface. A photograph of the structure can be seen in Figure 4-8. Several transverse cracks were also apparent over the structure. Expansion joints were missing much of their sealer resulting in some cracking and spalling at the deck surface as well as the bottom surface of the deck.



Figure 4-8: MDOT Structure No. 5002 SB US-131 Bridge Deck.

The inspection report for structure No. 5003 indicated that about 26% of the deck surface area was spalled, bit patched or delaminated and about 15% was patched with concrete. Various degrees of cracking were present over the surface of the structure with some occurring around expansion joints where a majority of the sealer was missing. Spalls and cracks on the underside of the bridge deck have originated near joints where water has migrated through the structure. Figure 4-9 shows the north bound structure.



Figure 4-9: MDOT Structure No. 5003 NB US-131 Bridge Deck.

In the case of both bridges, it has been recommended that sealer be applied to expansion joints where deterioration has occurred. Concrete overlay on both bridge decks was also reported for consideration.

US-131 had significantly more vehicle traffic than the previous two bridges. This meant that lanes had to be closed prior to the collection of data by the MDOT inspectors and 3DOBS high-resolution. A sketch of the deck sounding was georeferenced as a GIS shapefile (Figure 4-10 and Figure 4-11). The MDOT sounding determined that there was $2,072 \text{ ft}^2$ of delamination on the north bound lanes (Figure 4-10) and 759 ft^2 of delaminations on the south bound lanes (Figure 4-11).

Bridge Deck Distress Markings: US 131 Northbound Over White Creek Avenue



Figure 4-10: Georeferenced Sketch of the Results of the Deck Sounding of the North Bound Bridge of US-131 Showing the Locations of Delaminations, Cracking and Spalls.

Bridge Deck Distress Markings: US 131 Southbound Over White Creek Avenue

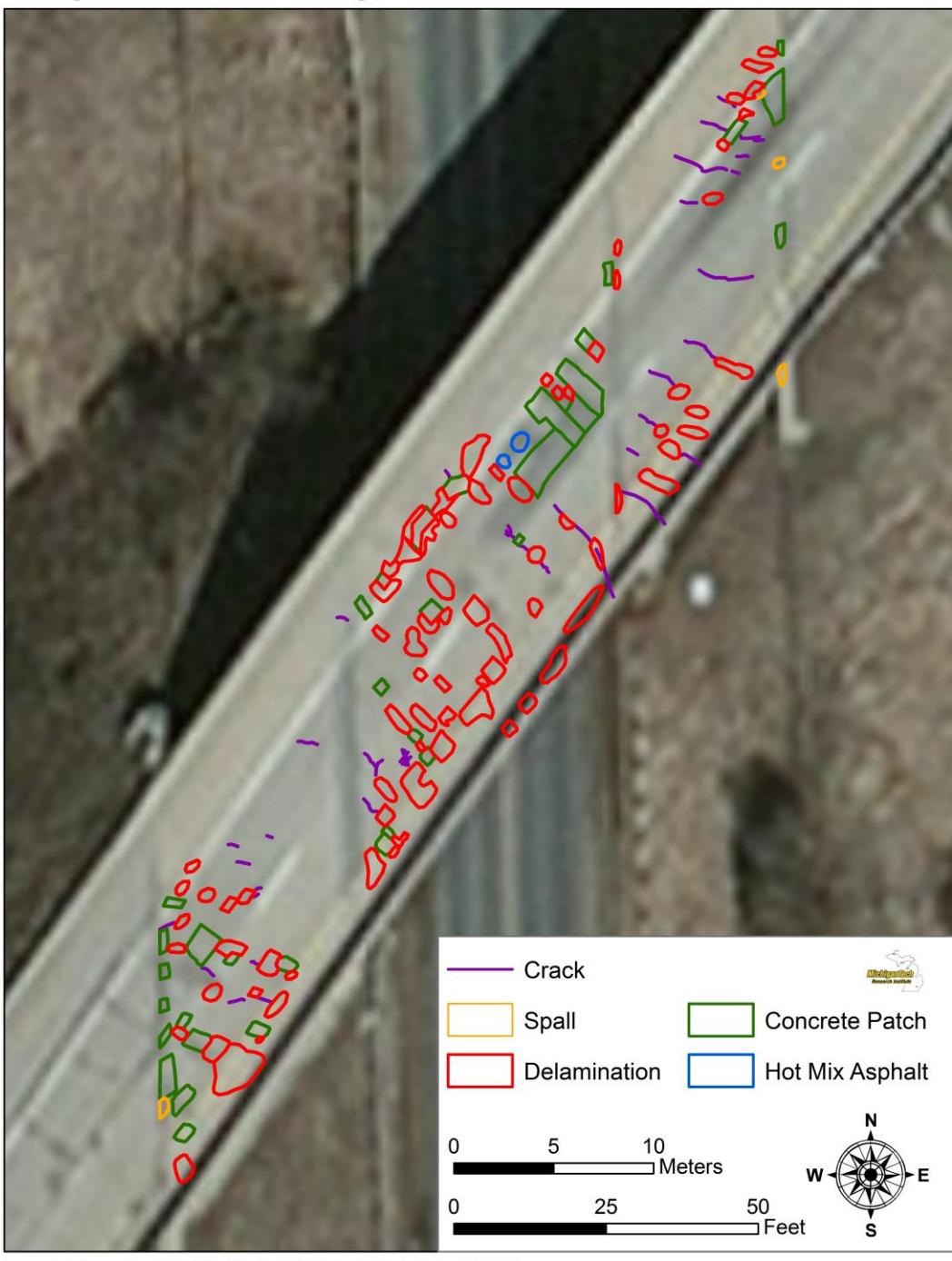


Figure 4-11: Georeferenced Sketch of the Results of the Deck Sounding of the South Bound Bridge of US-131 Showing the Locations of Delaminations, Cracking and Spalls.

4.3 Spring and Summer 2014 Demonstration Sites

The following bridges were selected for the spring and summer data collection phases of research. System upgrades for the 3DOBS high-resolution system and passive infrared thermography were implemented, tested, and evaluated. Initial data collection of the 3DOBS low-resolution system at near highways speed and active infrared thermography on the underside of the bridge allowed for the evaluation of these systems in the spring of 2014 at the Maryland Ave. and Freer Rd. bridges. Active thermography was deployed at the Franklin Street Bridge in the summer of 2014.

4.3.1 Maryland Ave. Bridge

MDOT structure No. 4795 – Maryland Avenue over I-196 is located in Kent County approximately 3 miles east of Grand Rapids, Michigan and was selected as one of the two spring demonstration sites for the 3DOBS and passive infrared thermography deployment. The structure spans both east and west bound I-196. A satellite image of the bridge is shown in Figure 4-12.



Figure 4-12: Maryland Ave. Bridge over I-196 Located in Kent County, Michigan

The bridge was constructed in 1963 and is a 4-span prestressed concrete composite structure with a total length spanning 230 ft. The bridge has a total width of 35.1 ft with a 28 ft roadway. In the year 1990, the ADT over the structure was measured to be 6,633 vehicles per day with 3% being commercial truck traffic (MDOT). Future ADT predictions for 2010 revealed an expected 15% increase in traffic to 7,628 vehicles per day.

The concrete deck surface was assigned an NBI rating of 6 during the most recent inspection on May 16th 2012. Figure 4-13 shows a photograph of the bridge deck. Because only 3DOBS and the passive infrared thermography testing methods were implemented on this structure, only the condition of the top deck was of interest. Neither the underside of the deck or the superstructure were tested for deficiencies at this location. However, it should be noted that end repairs have been made to fascia beams to prevent further deterioration and extend the service life of the bridge. Shallow spalls that have exposed reinforcing steel on the east fascia beams but still leaves the superstructure in good condition with a rating of 7.



Figure 4-13: Current Condition of the Maryland Avenue Bridge Deck

The inspection report indicated scattered areas of diagonal cracking on the bridge deck, some of which were associated with delaminations. A majority of the identified cracking occurred at the corners of the structure spans. Minor amounts of spalling have left reinforcing steel exposed on the east deck fascia beams but a total of less than 2% of the deck was reported cracked, spalled, or contained delaminations. A majority of the cracking and spalling was reported to occur at joints other than expansion joints.

The Maryland Ave. bridge was inspection of the bridge by MDOT the same day that the combined system deployed. A sketch of the deck sounding was georeferenced as a GIS shapefile (Figure 4-14). The sounding determined that there was 108 ft² of delamination with 13 ft² of bit patching and scale which corresponded to 14% of the deck surface.

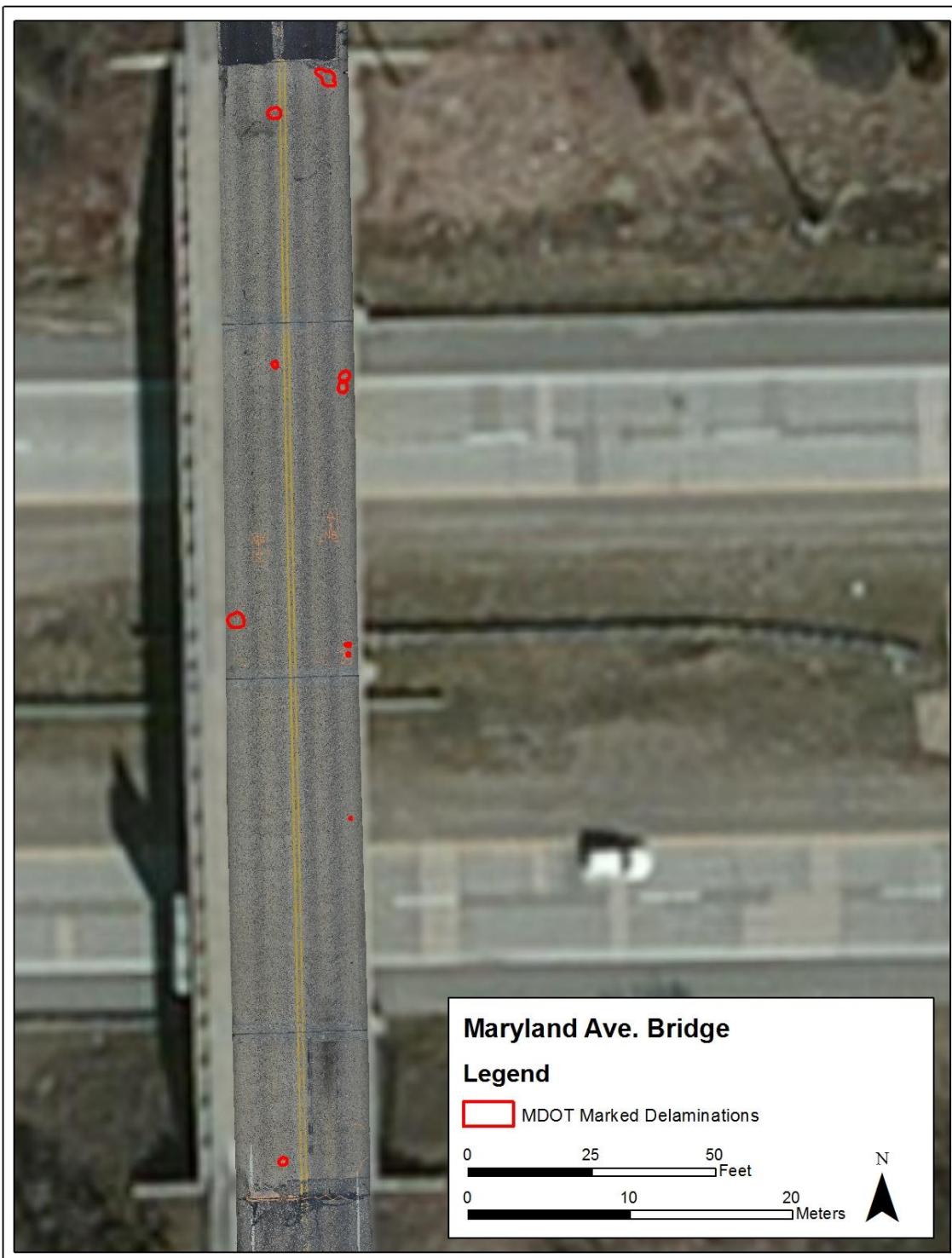


Figure 4-14: Georeferenced Sketch of the Results of the Deck Sounding of Maryland Ave. Showing the Locations of Delaminations.

4.3.2 Freer Rd. Bridge

MDOT structure No. 10940 - Freer Road over I-94 is located in Chelsea, MI approximately one mile east of M-52 and was selected as another spring demonstration site for the 3DOBS systems and passive infrared thermography deployment. The roadway functions as a collector for the area and the bridge structure spans both east and west bound I-94. The structure can be seen in Figure 4-15.

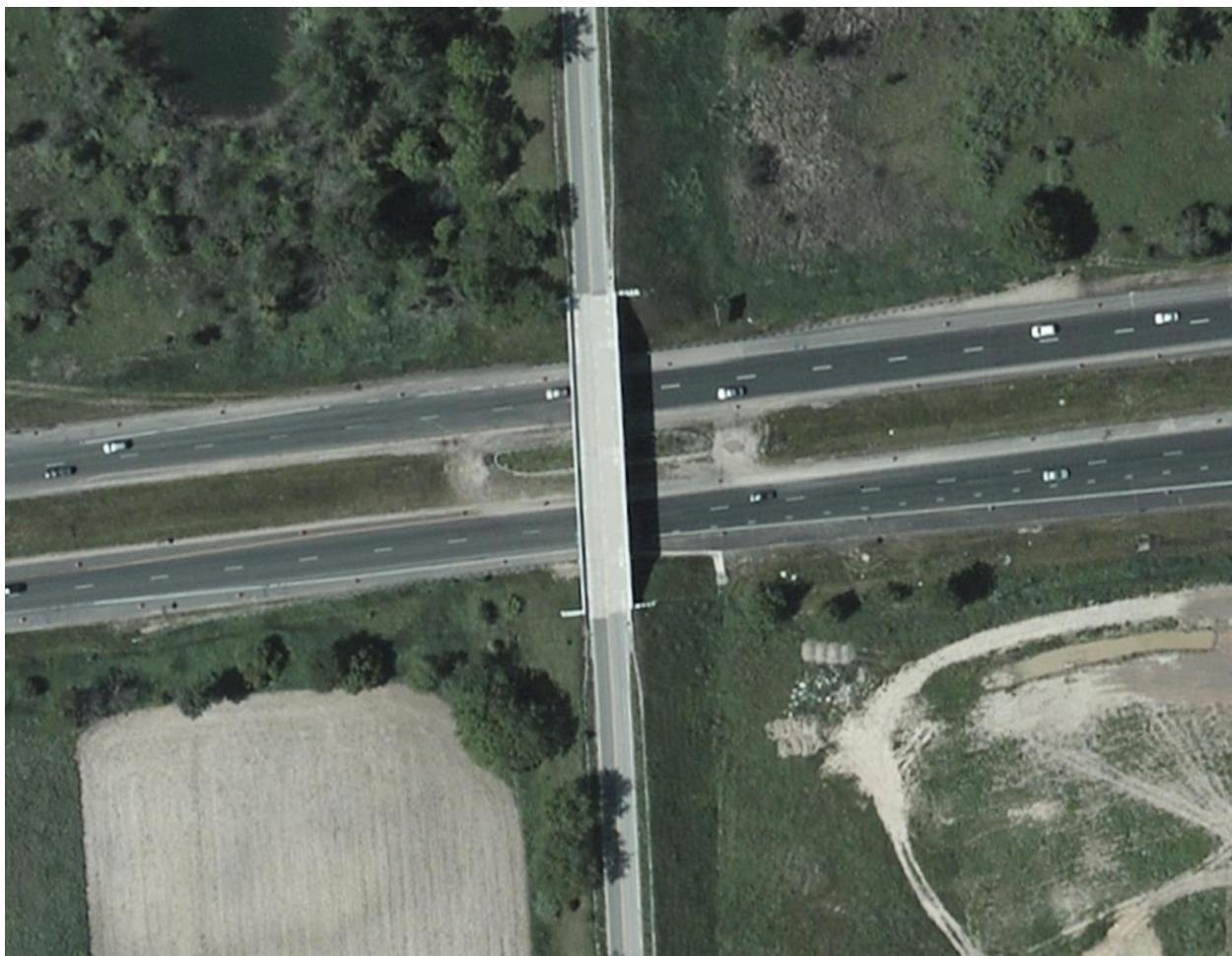


Figure 4-15: Freer Road over I-96 Spring Deployment Location.

Constructed in 1960, the bridge is a 4-span prestressed concrete composite structure with a total length spanning 209 ft. The bridge has a total width of 32.8 ft and has no shoulder. The ADT measured in 1997 over the structure was recorded to be 150 vehicles per day with 3% being commercial truck traffic. ADT predictions for the future year of 2017 reveal only a slight increase in traffic volume at 173 vehicles per day.

Upon completion of the most recent inspection on June 5th 2012, the deck surface received an NBI fair rating condition of 6 and can be seen in Figure 4-16. Because the active thermography

inspection method was not implemented at this location, neither the underside of the deck or the superstructure were tested for deficiencies. It should be noted that minor repairs have been made to the superstructure beams due to spalling. Repairs were made to the bottom flanges at the beam ends but the structure components remain in good condition.



Figure 4-16: Bridge Deck of Freer Road Bridge.

The inspection report indicated that concrete patches were present in all spans of the structure. The patches were applied to prohibit further deck deterioration and prolong the service life of the bridge. Transverse and map cracking were also reported to be present in all spans of the structure. An estimated 85 ft^2 of delamination was additionally reported throughout the deck surface of the structure.

4.3.3 Franklin Street Bridge

MDOT structure No. 4947 – Franklin Street over US-131 and CSX railroad line is located in Kent County in Grand Rapids Michigan. The structure spans both the north and south bound US-131 traffic as well as the north and south bound CSX railroad lines. This site was selected for the active infrared thermography deployment because of the ease of access to the bottom surface of the deck. Open land access to the underside of the bridge on the east side of the structure allowed testing to be conducted in a safe environment while minimizing disruptions to traffic flow at road crossings. The structure can be seen in Figure 4-17.

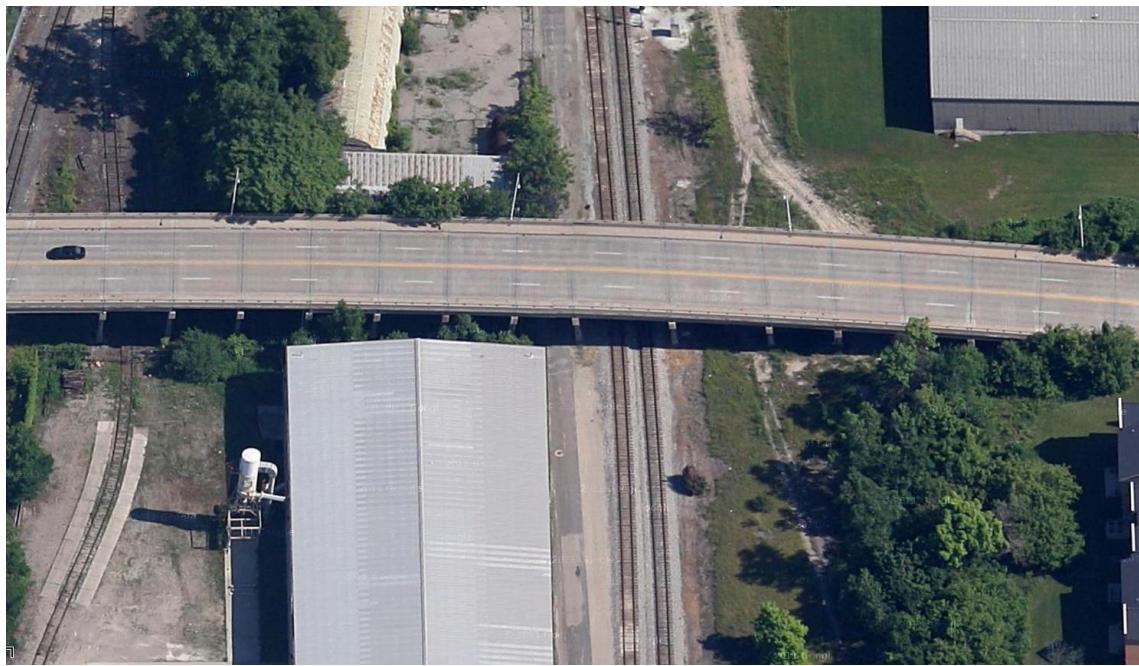


Figure 4-17: East Side of Franklin Street Bridge with Land Access to Underside.

This bridge was constructed in 1960 and is a multiple span structure composed of a combination of both steel and concrete girders. Main spans of the structure over US-131 are composed of steel beams while approach spans were constructed using prestressed concrete beams. The bridge spans a total length of 1,035 ft and is 58.4 ft wide. In the year 2011, the ADT over the structure was measured to be 27,000 vehicles per day with 5% being commercial truck traffic. Figure 4-18 and Figure 4-19 show the east side concrete beam approach structure and condition of the bottom deck surface respectively.



Figure 4-18: Franklin Street Bridge East Side Concrete Beam Approach Structure.



Figure 4-19: Current Condition of Bottom Deck Surface of Franklin Street Bridge.

The bottom concrete deck surface was assigned an NBI fair condition rating of 6 during the last inspection on October 23rd 2012. Because only the active thermography testing method was conducted at this site, the bottom surface of the deck remained the main structural component of interest. It should be noted that seven spans of the structure were replaced while the others were overlaid in 1990.

The inspection report indicated various degrees of deterioration on the bottom deck surface. Replaced deck spans have remained in good condition but other spans contain considerable

amounts of spalling and cracking. In addition, soot buildup from locomotive exhaust was reported directly above the railroad line.

4.4 3DOBS at Near Highway Speed

3DOBS Near Highway Speed System was tested alongside the BridgeGuard thermal camera at both Maryland Ave and Freer Rd bridges. The RED Epic was mounted at the end of the boom next to the thermal camera so that they collect the same section of bridge at the same time (Figure 4-20 and Figure 4-21). The Trimble GPS antenna is also mounted above the two cameras so that is collecting GPS data as closely to the center of the cameras position for accurate image referencing.



Figure 4-20: BridgeGuard Thermal Camera and RED Epic Mounted on Vehicle attached Boom.

Multiple runs were collected at speeds ranging from 25 mph to 45 mph under different lighting conditions to test the RED Epic cameras capabilities and to determine if there are limitations due to lighting that would affect the vehicles speed for collection.



Figure 4-21: Combined 3DOBS and BridgeGuard Collecting Imagery over Maryland Ave. in Grand Rapids.

4.5 3DOBS High Resolution System

The Nikon D800 was also mounted to the BridgeGuard vehicle mount to collect high resolution imagery of the bridge decks. Due to a slower maximum frame rate of only 2 fps, the vehicle was limited to speeds less than 5 mph in order to capture imagery with the necessary overlap needed to produce a 3D model of the bridge deck. However, this slower speed enabled high-resolution crack detection. Figure 4- 22 shows an image that was collected from the Nikon D800 over Maryland Ave in Grand Rapids.

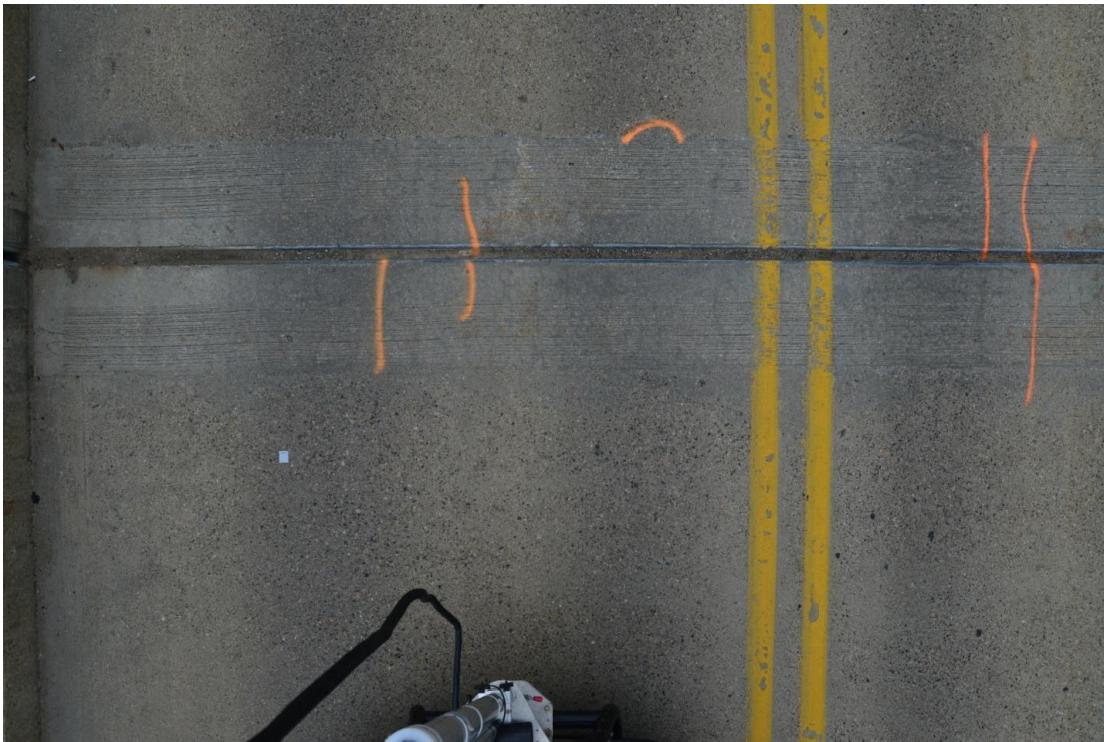


Figure 4-22: Imagery Collected from the Nikon D800 of Maryland Ave.

4.6 BridgeGuard Passive Infrared Thermography

BridgeGuard technicians perform weather studies to determine the theoretical ideal scanning times and durations for the bridge site. Bridge identification data and other pertinent information are entered into the collection program prior to or upon arrival at the site. Field delamination control areas are then selected using the infrared cameras and are verified by sounding with a hammer and documented in the field notes. The control areas are used to confirm when conditions are optimal for scanning.

The data collection is carried out using a vehicle-mounted thermal imaging system and high-definition digital imager to record visible and invisible defect data on the bridge deck top (traffic lanes). The camera equipment is set up and scanning begins. In this particular study with the addition of the Nikon D800, travel speeds were limited to only a few miles per hour. Data was collected one lane at a time until the entire deck had been scanned, and the recorded imagery was saved using proprietary software to a laptop computer. The technicians representing Michigan Tech collected their data at the same time as BridgeGuard.

Prior to leaving the bridge, a QA/QC check was done to ensure the data was of good quality and that the bridge measurements were accurate. After scanning was completed, the data was analyzed with the results imported into a CAD file and defects tabulated in spreadsheet form to allow integration into project plan documents.

4.7 BridgeViewer Remote Camera System (BVRCS)

The BridgeViewer Remote Camera System was deployed on the US-131 bridges near Grand Rapids, 20 Mile and 24 Mile Roads near Marshall. In all the deployments the GoPros were capturing 12.3 MP images at 2 fps. The collection setup for US-131 was different than normal as the cameras were mounted to the roof of the truck rather than the hood (Figure 4-23). This was necessary as the hood was not made of steel and the magnets were not effective. This limited the view of the road in front of the truck with the hood taking up a portion of the image (Figure 4-24). The collects form 20 and 24 Mile Roads had a two camera setup with the cameras mounted to the hood the truck (Figure 4-25).



Figure 4-23: The Collection Setup for US-131 with a Single GoPro Mounted on the Roof of the Collection Vehicle.



Figure 4-24: Example Image Collected from a Single GoPro Mounted to the Roof of the Collection Vehicle.



Figure 4-25: Example Image Captured on 24 Mile Road with a GoPro Mounted on the Hood of the Collection Vehicle.

The GPS for all collects was mounted on the dash of the collection vehicle. Prior to each collect a picture was taken with the GoPro of the GPS screen showing the time (Figure 4-26). This

allowed for the researcher to add the correct time difference between the camera and the GPS within GeoJot+. The image locations are interpolated based on the time adjustment calculated in GeoJot+.



Figure 4-26: Detailed Image Showing the GPS Time in a Photo used to adjust the Time Difference between the Camera and the GPS Unit.