NON-DESTRUCTIVE BRIDGE ASSESSMENT TECHNOLOGY BY INFRARED THERMOGRAPHY

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Abstract

After the execution of the surface transportation act 'Moving Ahead for the Progress in the 21st Century Act (MAP-21)' in 2012, it is mandatory that the element level condition states for highway bridges carrying National Highway Systems (NHS) be reported biannually to the federal government. Applying a more efficient method to collect filed data to determine the current state of a bridge can save significant time and lead to cost reduction. This paper describes the results of on-site applications of non-destructive highway bridge inspection methods using high quality digital image and infrared thermography performed in conjunction with the joint research with University of Central Florida.

Introduction

Condition ratings of bridge components in the Federal Highway Administration (FHWA)'s Structure Inventory and Appraisal (SI&A) database are determined by bridge inspectors in the field for bridge deck, superstructure and substructure. This information has been used by bridge owners as a basis for decisions on bridge maintenance, rehabilitation, and replacement. The condition ratings also influence a bridge's Sufficiency Rating (SR), as well as whether the bridge may be classified as "structurally deficient".

However, the determination of bridge condition ratings is generally subjective depending on individual inspectors' knowledge and experience, as well as varying field conditions. For the evaluation and documentation of concrete deterioration (cracks, potholes, delamination, spalls, etc.) and changes over time, the current practice can be lacking in accuracy and completeness, as well as time consuming and costly if road closures are required for the inspection (Fig.1).

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Fig.1: Current Bridge Inspection Practice

Recent advancements in imaging technologies have made their applications practical and possible in more detailed bridge inspections. The technologies can overcome some shortcomings of human subjectivity and are intended to improve and complement, but not to replace, human inspections. The innovative technologies presented herein will be able to make bridge inspections more objective, more consistent, more scientific, and more efficient. The need for utilization of thermography has been advocated especially for detecting subsurface defects using low-cost hand-held infrared cameras by Washer et al. These thermal imaging cameras are intended to be used by the state DOT personnel using while they are conducting their conventional visual inspections and walk-throughs (Washer, et al., 2009). Guideline requirements developed for the effective application of the technology in the field using the hand-held cameras are also described along with application of the technology for the detection of deterioration in a typical highway bridge (Washer, et al., 2010). In this paper, the authors present the integrated use of high-end infrared thermography (IR) and line sensors to obtain bridge deck cracks, defects and delamination at a very rapid and high resolution for structural assessment and decision making (Matsumoto, et al., 2013). The authors present that the integrated system can scan a network of bridge decks from a vehicle at 50 mph (80km/h) (without any lane closure) with excellent detail. In order to validate the effectiveness of the new inspection technologies, a pilot inspection project was conducted through a joint research effort with the University of Central Florida (UCF). The objective of the research project was to investigate the technologies on the selected bridges to objectively characterize these deteriorated bridges with a university-government-industry collaboration, by exploring the use of novel image based technologies in a way that the information generated through these technologies will provide useful data for the inspection and evaluation of civil infrastructure systems.

The pilot Project

On March 8-14, 2014, a condition assessment project was performed at Bridge #770054 (Lake Jessup Bridge) carrying SR417 for the purpose of evaluating the capabilities of the digital imaging and infrared (IR) technology by determining condition states for concrete bridge elements. The total length of the bridge is approximately 1.5 miles (2.4km) (Fig.2). Both north bound and south bound lanes, supported by prestressed I-shaped beams and reinforced concrete deck were scanned and analyzed. In this study, a sophisticated IR camera was used, which is currently used in industry for delamination detection. The Infrared camera (FLIR 5600) has the shutter speed of 1/1400, enabling the bridge deck scanning team to drive 50mph while collecting the high quality IR images for analysis (where the conventional IR inspection uses lower standard IR camera with only 1/125 shutter speed). The uncooled detector which is used in the conventional IR inspection works by the change of resistance, voltage or current when heated by infrared radiation, thus requiring longer exposure time to take the IR image. In this study, raw infrared images were further analyzed based on algorithm developed and tested in Japan on many bridges. The proprietary IR software applied in this project can classify the damage rate into three categories; the classification categories being “Critical” (crack caused by delamination reaches on concrete surface and immediate attention is required), “Caution” (crack exists within 2cm from the concrete surface and close monitoring is recommended) and “Indication” (Currently satisfactory) (see Fig.3). Raw infrared (IR) image data is filtered and rated into three categories by the software to indicate and evaluate the severity of the subsurface defects in concrete structures.

Fig.2 Location of the lake Jessup Bridge

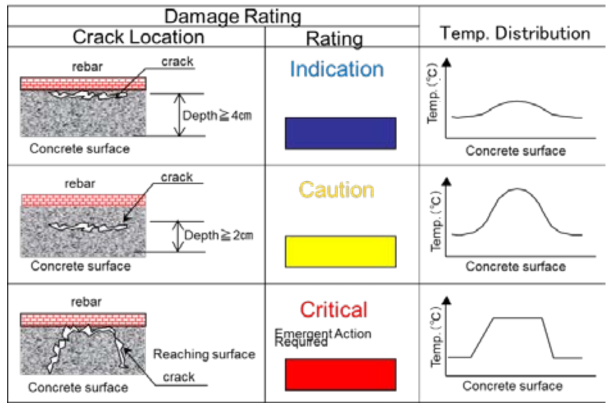


Fig.3: Damage Rating by Infrared Imagery Software

<u>Digital image and IR scanning for the deck top</u>

Digital images for the deck top were collected from a moving vehicle in the morning of Sunday, March 9th (Fig.4). The deck top surface was scanned at a speed of approximately 50mph (80km/h). Two line cameras were attached to the aluminum frame which was designed, manufactured and mounted on top of the vehicle. Infrared (IR) images for the deck top were collected from a moving vehicle at 10:30pm-11:30pm of Sunday, March 9th. The IR images were also recorded at a speed of approximately 50mph (80km/h).No lane closure of any kind was required during the field data collection. The collected images have been processed and analyzed by the digital imaging and IR software. Widths of the cracks were evaluated by comparing the magnified digital image with the electronic crack width ruler on the computer screen (Fig.5). Table 1 describes the four condition states defined in the AASHTO Guide Manual for Bridge Element Inspection (AASHTO, 2013). The element condition state (CS) for reinforced concrete deck (Element #12) was determined from the results of deck top scanning based on the area of delamination or spall, exposed rebar condition and cracking.

Fig.6 depicts typical delaminated areas found on the deck surface. This type of cracking and delamination were found at some of the joints throughout the entire bridge deck. These delaminated areas were detected by digital image and IR scanning results, and hatched in yellow (for CS2: Fair) or red (for CS3: Poor) depending on their sizes. According to AASHTO manual (AASHTO, 2013), areas of delamination or spall with 6 in. (15cm) or less in diameter should be evaluated as 'CS2: Fair', while those areas of greater than 6 in. (15cm) diameter or areas with unsound patch should be evaluated as 'CS3: Poor'. The hatched areas were automatically summarized by the software to calculate the quantity of deck surface with each condition state. Fig.7 depicts the typical cracking found on the deck surface. The spacing of the crack was less than 1.0ft (0.3048m), and these cracking areas were evaluated as 'CS3: Poor'. Fig.8 is an example of IR scanning results successfully detecting the spall on the deck surface. These spalls were less than 6 in. (15cm) in diameter and were evaluated as 'CS2: Fair'.

Table 2 is an example of element level inspection summary for the south bound bridge. The area of each condition state was also summarized for each span/lane of the bridge deck. Fig.9 is a graphical presentation for element level condition state distribution for each span of the south bound bridge. This kind of information can be a quantitative parameter for the bridge owner to monitor the overall deck condition over time and to prioritize future repair/rehabilitation programs.

Fig.4: Digital image scanning for deck top from a moving vehicle

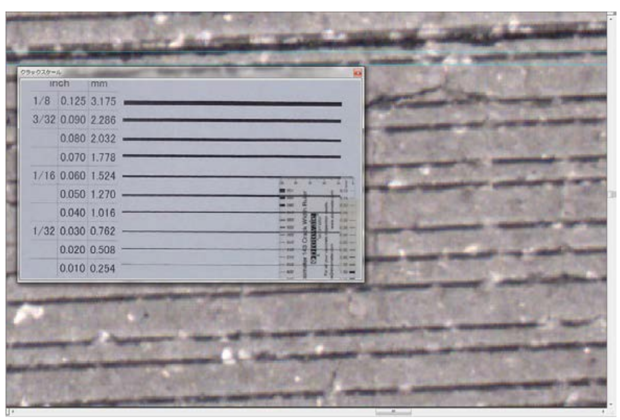


Fig.5: The electronic crack width ruler on the computer screen

Table 1: Standard Condition States for Defects in Bridge Elements (after AASHTO, 2013)

Condition State (CS) #	Condition State
1	Good
2	Fair
3	Poor
4	Severe

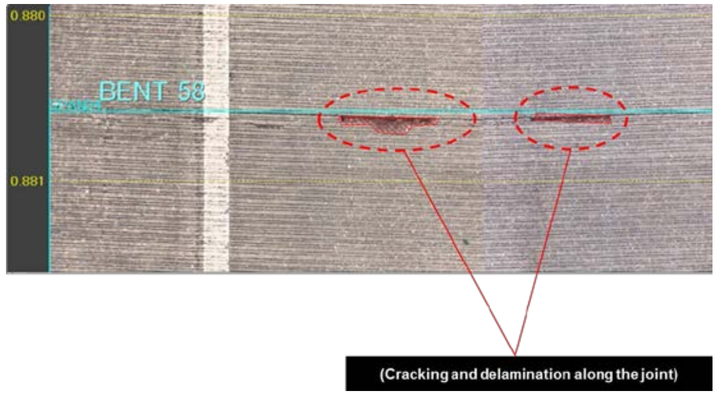


Fig.6: Typical delaminated areas on the deck surface (near the joint area)

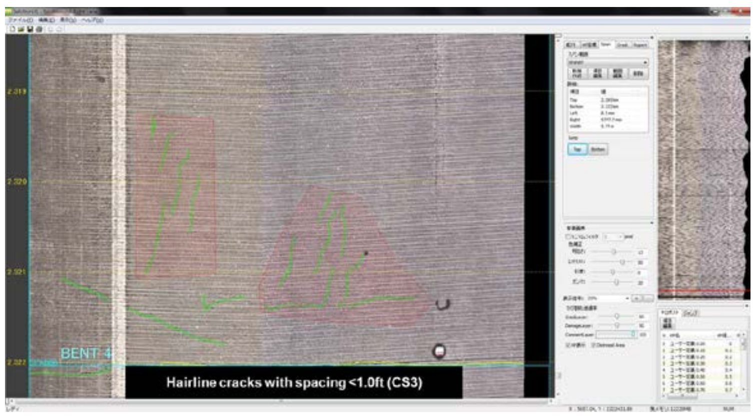


Fig.7: Typical cracking on the deck surface (hairline cracks with narrow spacing)

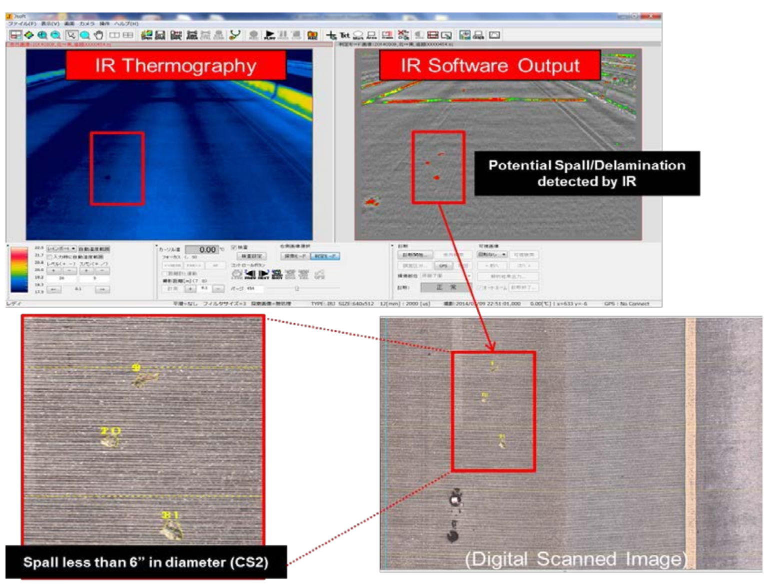


Fig.8: Typical spall found on the deck top

Table 2: Condition state summary for #12 Reinforced Concrete Bridge Deck (south bound)

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
12	Reinforced Concrete Deck	ft^2	317,520 (100.0%)	317,266 (99.9%)	119 (0.0%)	135 (0.0%)	0 (0.0%)

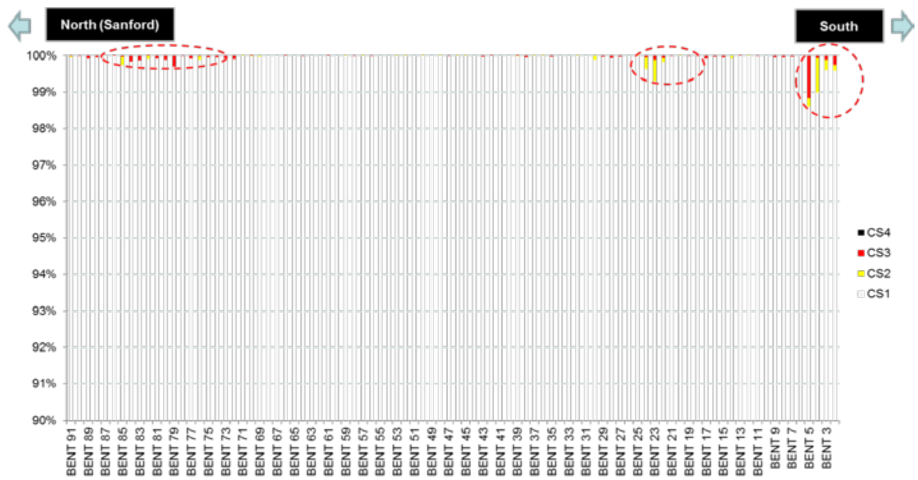


Fig.9: Element condition state distribution (south bound bridge deck)

<u>Digital image and IR scanning from the sides of the bridge</u>

Digital video images for the sides of the bridges were recorded by three high definition video cameras from a pontoon boat on Tuesday, March 11th at approximately 5 knots (5.74mph, or 9.23km/h) (Fig.10). Both faces of the north bound and the south bound bridges were scanned from a distance of 40 feet (12.2m), and it took about thirty (30) minutes for scanning each face of the entire bridge. The video image includes 30 frames of still images per second, and these images were stitched with each other to generate a high resolution digital image for the entire face of the prestressed concrete beams and reinforced concrete bridge railings. IR images for the sides of the bridge were obtained from a pontoon boat at 10:00pm to 12 midnight of Tuesday, March 11th at approximately 5 knots (5.74mph, or 9.23km/h). The recorded movie images by three high definition video cameras were used to find the indications on the concrete surface such as cracks, efflorescence and spalls. The element condition state (CS) for reinforced concrete bridge railings (Element #331) and prestressed concrete beams (Element #109) were determined based on the delamination or spall, exposed rebar condition and cracking (AASHTO, 2013).

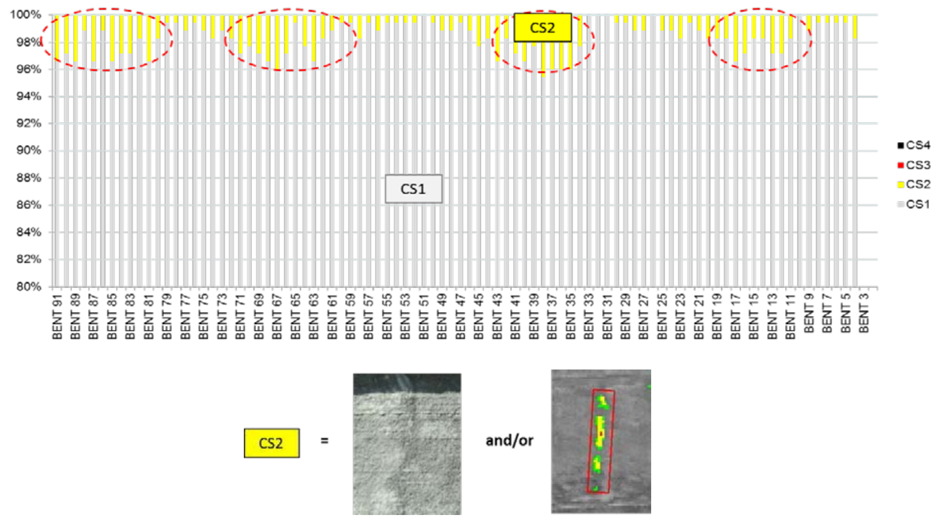
The reinforced concrete bridge railings show some cracks with efflorescence, coupled with possible delaminated areas adjacent to the cracks (Fig.11). The existence of delaminated areas was detected by IR scanning. Areas including cracks with minor delamination and/or efflorescence should be evaluated as 'CS2' based on the criteria in AASHTO Manual. Table 3 is an example of element level inspection quantity summary for the bridge railings for west face of the south bound bridge. The length of the bridge railing in each condition state can also be summarized for each span of the bridge. Fig.12 is a graphical presentation for element level condition state distribution for each span of the west face of the south bound bridge. The percentage of linear footages in bridge railings in 'CS2' varies for each span, and this information can be a quantitative parameter for the bridge owner to monitor the overall condition for bridge railings over time and to prioritize the repair/rehabilitation program.

Fig.10: Digital image scanning from a pontoon boat

Fig.11: Typical cracks with delamination on the reinforced concrete bridge railing

Table 3: Condition state summary for Bridge Railings (South bound, West Face)

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
331	Reinforced Concrete Bridge Railing	ft	7,938 (100.0%)	7,629 (96.1%)	133 (1.7%)	0 (0.0%)	0 (0.0%)



(Cracks w/ efflorescence and/or delamination)

Fig.12: Element level condition state distribution for reinforced concrete bridge railings

On the other hand, no significant cracks/delaminations were found in the outer faces of the prestressed concrete beams except for some minor spall and cracking at the end of the beam (Fig.13). Sections including minor cracks and delamination should be evaluated as 'CS2' based on the condition state criteria defined in the AASHTO Manual. Based on the information obtained by digital image and IR scanning, condition state for element '#109 Prestressed Concrete Girders/Beams' for the Lake Jessup Bridge was summarized. Table 4 is an example of an element level inspection quantity summary for the prestressed concrete beam for the west face of the south bound bridge. The length of each condition state for prestressed concrete beams was also summarized for each span of the bridge. Fig.14 is a graphical presentation for element level condition state distributions for each span of the beam of the west face of the south bound bridge. The percentage of beams in 'CS2' (depicted in yellow color) varies for each span, and this information can be a quantitative parameter for the bridge owner to monitor the overall condition for prestressed concrete beams over time and to prioritize the repair /rehabilitation programs. Fig.15 is an example stitched image and IR scanning results for the west face of Span 7 (Bent 84- Bent 85) of the north bound bridge. AASHTO condition state distribution for reinforced concrete bridge railing and prestressed concrete beam are also shown in Fig.15.

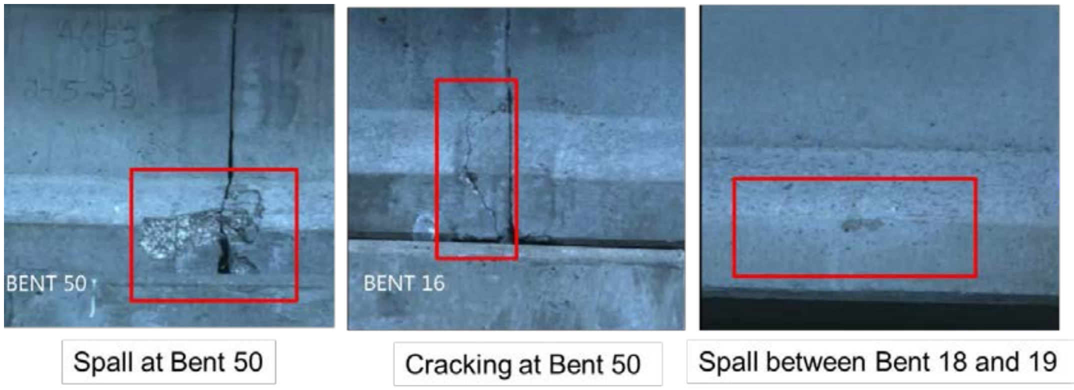


Fig.13: Typical cracking and spalls at the prestressed concrete beams

Table 4: Condition state summary for #109 Prestressed Concrete Girders/Beams

Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
109	Prestressed Concrete Girders/Beams	ft	7,938 (100.0%)	7,755 (97.7%)	6.5 (0.1%)	0 (0.0%)	0 0.0%

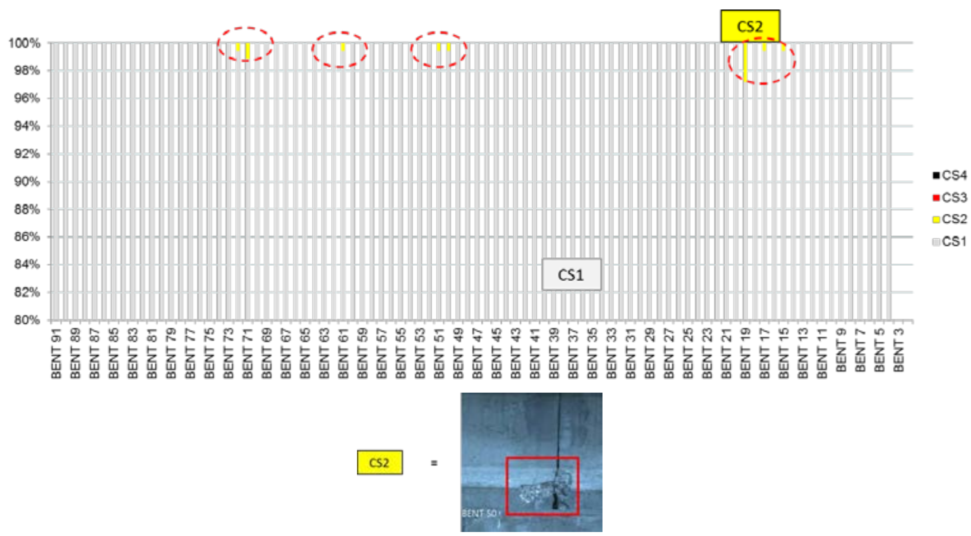


Fig.14: Element condition state distribution for prestressed concrete beams

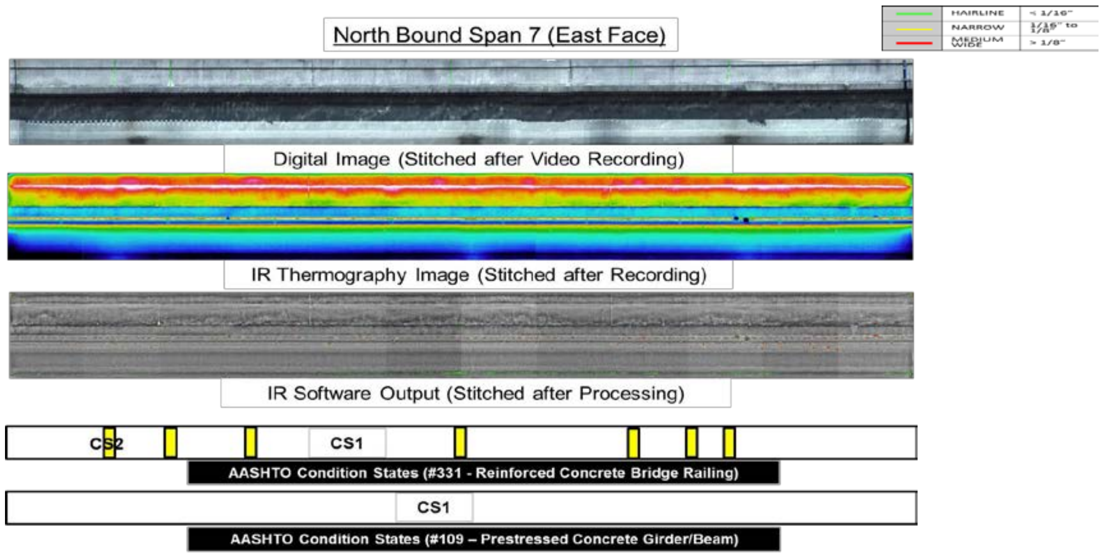


Fig.15: Example of Digital image, IR thermography image and software output

Summary and Conclusions

The full scan and analysis of Bridge #770054 (Lake Jessup Bridge) resulted in the discovery of only nominal delaminations and spalls. All findings were categorized and defined based on AASHTO's guideline for bridge elements. By utilizing the imaging and IR technology at high speeds, what would have taken perhaps weeks traditionally was accomplished in a matter of days. Not only was the data taken rapidly, but it proved to be accurate to a degree which more than satisfied AASHTO standards for crack width, spacing, and length, as well as area of delamination. This information can be easily stored and referenced for future repair and rehabilitation.

The deck showed frequent cracking and delamination around the joints: very rarely were they observed elsewhere. Some other areas showed signs of very fine groups of cracks, especially towards the south end of both northbound and southbound sides. The barrier or railing showed very little sign of wear, save a few thin vertical cracks. The prestressed concrete beams were also sound. When reviewing the bridge during future examinations, the cracks near joints and the groups of cracks observed in Bent 60-91 (southbound) and 1-30 (northbound) should be closely monitored for consideration of future repair.

Objective condition assessment can contribute information to make better decisions for safety and serviceability of roadway bridges. Understanding the real, as-is condition of the structure is important to better plan and prioritize maintenance activities, to make operational decisions and to assure the highest level of safety at the lowest cost. Applying more efficient methods of collecting and managing data is becoming more and more critical, especially in the face of the growing amount of aging and degrading bridges across the country. Also, increasing government regulations pose a need for effective record keeping and continued observation. Technologies described in this paper demonstrate significant time and cost reduction for bridge owners.

Acknowledgments

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