A Review of Field Implementation of Infrared Thermography as a Non-destructive Evaluation Technology

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ABSTRACT

The aging of highway infrastructure is a serious problem worldwide. As important constituents of this infrastructure, bridges have usually been inspected by visual inspection techniques and hammer sounding methods. In addition to these existing methods, different non-destructive evaluation technologies are also being developed and are expected to be utilized for effective management of highway structures. This study focuses on exploring and enhancing the usability of infrared thermography as a viable non-destructive evaluation technology. In this research, an experimental study was conducted to determine the most thriving time window to collect data from an object by using an infrared camera. The same setup was utilized to obtain data from existing structures. The results have shown that the nighttime was a better option to gather data from an object. It was also observed that infrared thermography could detect subsurface anomalies.

INTRODUCTION

Various non-destructive evaluation (NDE) technologies are being developed all over the world. NDE technologies range from hammer sounding tests to advanced technologies such as Ground Penetrating Radar (GPR), (Matsumoto, 2013). Traditionally, highway bridge conditions have been monitored by visual inspections and hammer sounding tests with qualified engineers and inspectors. These traditional inspection types are both time consuming and pose potential dangers to inspector because the inspector needs to be close to the object. One of the innovative technologies to make up for these negative elements of the inspection is the technology using infrared camera because the result of the thermography images, which are screening of potential concrete defects on concrete subsurface, reduce the amount of time to inspect compared to sounding test, since there is no need to inspect spot by spot (ASTM, 2007). Infrared (IR) technology has the potential to be widely used for a number of civil infrastructure applications. Infrared thermography can detect de-bonding inside concrete structures by measuring the temperature difference between the sound and the deteriorated part. However, since the accuracy of damage detection using infrared thermography is greatly affected by daily temperature variation (Washer, 2009), it is important to determine an appropriate time window for data collection by infrared thermography inspection. There are contradictory reports regarding appropriate time window for IR measurements. Some researchers recommend daytime measurements (4 to 9 hours after sunrise) for solar loading part (Washer et al., 2009) while it was mentioned in SHRP2 report (Gucunski et al., 2013) that thermal image of fabricated deck recorded 40 min after sunrise yielded much clearer image than that recorded about noontime.

PILOT PROJECT TESTS IN FLORIDA

In order to validate the effectiveness and capability of IR technology, a pilot project was conducted at a bridge in Florida in cooperation with Florida Department of Transportation (FDOT) District 5 and NEXCO-West USA, Inc. A lot of research regarding IR technology has been conducted by using test pieces with artificial anomalies. However, since those fabricated defects tend to be exaggerated the feature of the defects, it is much easier to detect them by IR technology. Therefore, it is important to prove the applicability of IR technology for detecting natural anomaly in existing structures. The objective of this project was to investigate the capabilities of IR technology on a bridge in service by exploring the use of novel images generated with this technology that will provide useful data for the inspection and evaluation of civil infrastructure system. FDOT District 5 provided some candidate concrete bridges and one of them was selected for the project, since it was found that the bridge was deteriorated to some extent and there was enough space for the demonstration based on the field survey. The bridge was No.700006 on US-1 in Melbourne (Figure 1). The bridge was built in 1959 and reconstructed in 1990. The number of lanes is seven and the total length is 116 meters. In this project, undersides of the concrete bridge deck and pier cap of the bridge (Figure 1) were inspected using an infrared camera. In this pilot project, the FLIR SC 5600M was used. Table 1 shows the specifications for this camera. The photographed images were analyzed using a special software package, IrBAS Software (Figure 2) developed for this technology (NEXCO-West USA Inc). The detected inner voids, delaminations, and spallings were categorized into three ranks as shown in Figure 3: Critical (crack exists and reaching on concrete surface; immediate action is required), Caution (crack exists within 2cm depth from the concrete surface; close monitoring is recommended) and Indication (crack exists within 4cm depth from the concrete surface; currently satisfactory). Figure 4 shows the sample of results of the inspection using IR technology. Potential damaged parts are indicated by one of the conditions classified in three different ranks as described in Figure 3. Table 2 shows the potential areas obtained from IR technology software.

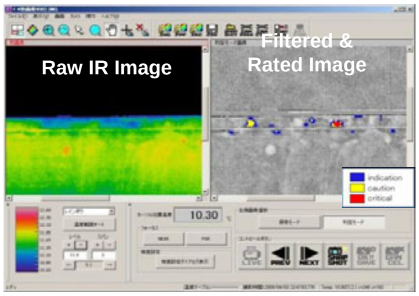

Figure 2 IrBAS Software

Table 1 Spec of FLIR SC 5600M

Infrared Camera	FLIR SC 5600M
Detector	Indium Antimonide (InSb)
Spectral Range	3µm to 5µm
Resolution	640×512
NTED @ 25°C (Thermal Sensitivity)	<25mK (20mK typical)
Full Frame Rate	Programmable 1Hz to 100Hz

Table 2 Detected potential damaged area

ID #	Potential Spall Area		
	Critical	Caution	Observation
601		4.31	
602			1.94
603		1.51	
604	4.84		
605		2.15	
606		1.29	
607	0.11		
608		2.15	
609		0.54	
610			3.77
611	0.32		
612	1.29		
Total	6.57	11.95	5.70

🔴	CRITICAL
🟡	CAUTION
🟢	INDICATION

Figure 3 Damage classification

Figure 1 Sample bridge (left), underside of the deck (middle), pier cap (right)

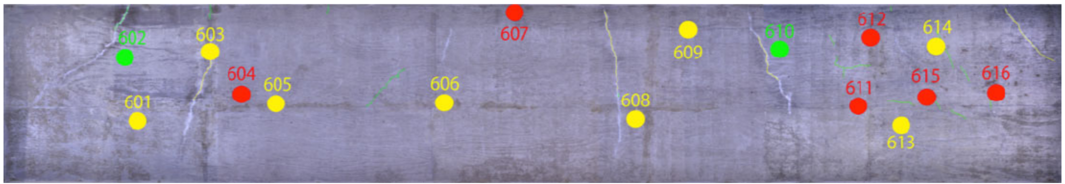

Figure 4 Detected potential damaged map

After obtaining the results from IR technology, an FDOT certified bridge inspector provided the hands-on inspection results using a hammer sounding test in order to evaluate the accuracy of the new bridge assessment method (Figure 5). The detected potential areas by IR thermography technology were verified by those results that were obtained by the hammer sounding test. It is worth to mention that one of the critical locations detected by IR technology (Figure 6) revealed a hidden plastic sheet beneath the mortar (Figure 7). Figure 8 shows an IR image depicting another anomaly. The very same spot was tested by hammer sounding test and a wooden piece was found as shown in Figure 9. The results indicate that the infrared thermography as an NDE technology could successfully detect the subsurface defects which could not be seen by regular visual inspection techniques.


Figure 5 Hammer sounding inspection

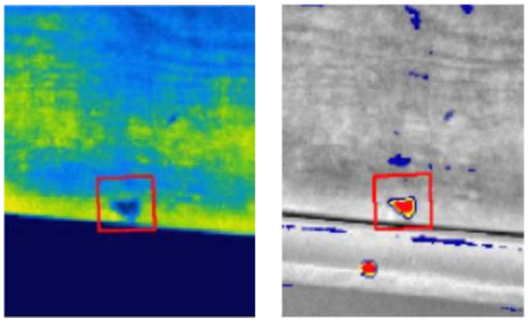
Figure 6 IR thermography (left) and software output (right)

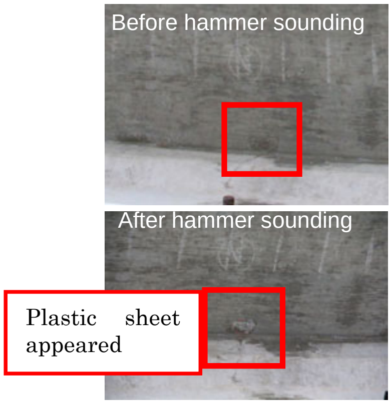

Figure 7 Hammer sounding

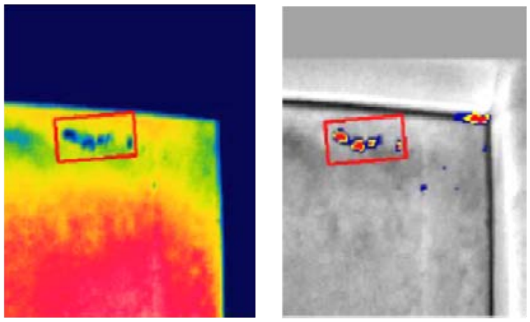
Figure 8 IR thermography (left) and software output (right)

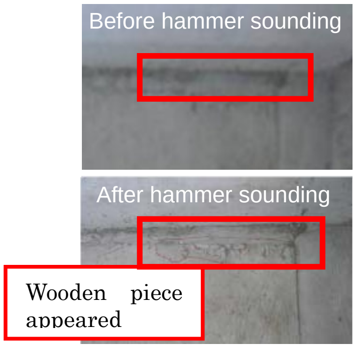

Figure 9 Hammer sounding

EXPERIMENTAL STUDY FOR PRACTICAL IMPLEMENTATION OF INFRARED THERMOGRAPHY

In this study, daily temperature variation of damaged and sound parts of concrete was investigated by using test pieces that have different volumes of delamination. Figure 10 shows concrete test pieces used in this experiment. These test pieces were attached to a concrete surface as shown in Figure 11 (NEXCO-West USA Inc), and the space between the test pieces and the concrete surface made by sticky tape, about 1mm thickness, took on a role of artificial damages. By heat exchange through the sticky tape, the part of the test piece attached to the sticky tape constituted the sound part of concrete surface. On the other hand, the part of the test piece unattached to the sticky tape constituted the damaged part of the concrete surface. Hollows in lower three concrete test pieces are located in a depth of 1cm from the surface as shown in Figure 10. Delamination thicknesses in the upper three pieces are very thin (1mm) and the others are 0.6cm, 1.1cm and 1.6cm as shown in the figure. These concrete test pieces were placed at the parking area in front of the Engineering building on the campus of University of Central Florida (Figure 12). The temperature values of the simulated sound and damaged parts and surrounding air and concrete surface were collected as shown in Figure 11. The experiment was conducted between 5/29/2013 and 6/1/2013.

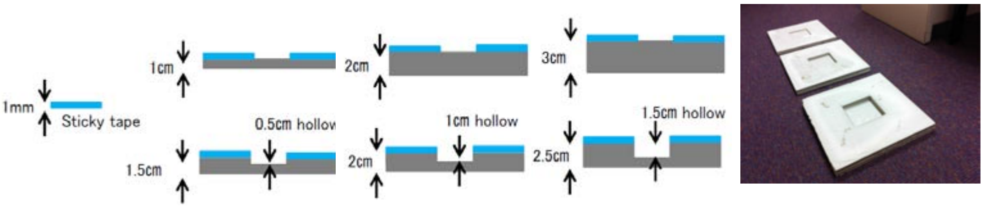

Figure 10 Concrete test pieces (right picture is test pieces have hollow)

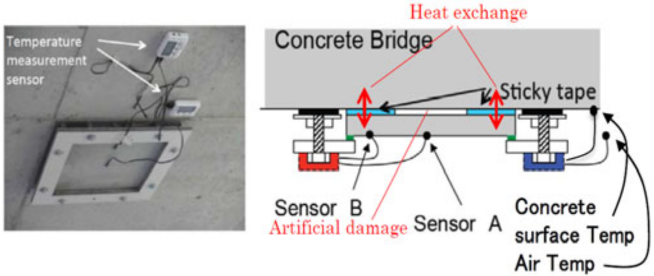

Figure 11 Composition of concrete test piece

Figure 12 Installed test pieces

Figure 13 shows temperature of concrete surface and each sound part of the concrete test pieces. Temperature of all sound parts except 1.5cm hollow is similar to concrete surface. This result indicates that every test piece except 1.5cm hollow could play a role of sound part of the surrounding concrete surface. The reason of the difference between 1.5cm hollow and the others might be the effects of inner air of the hollow. Since thermal conductivity of air is much lower than concrete, heated inner air during daytime did not cool down and the air might heat surrounding concrete.

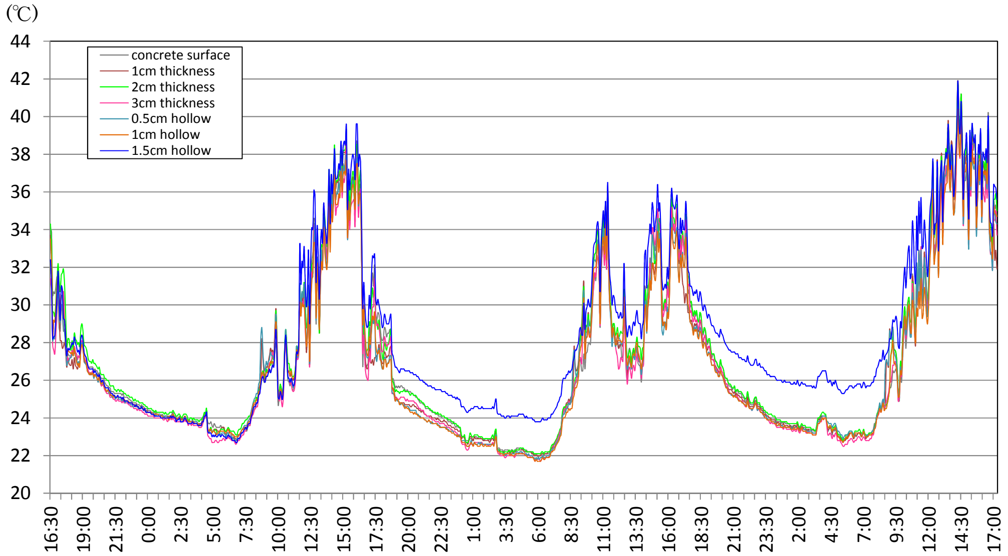

Figure 13 Temperature of Concrete and each sound part

thickness and 0.5cm hollow test pieces. The others also show same results that the temperature of damaged areas heats up faster than that of sound areas during daytime and cools down faster than that of sound areas during nighttime. When comparing these two graphs, it is found that the temperature differential between the damaged area and the sound area of 0.5cm hollow is much larger than 1cm test piece during nighttime. Figure 15 depicts temperature differences between “d (damaged part)” and “u (undamaged part)”, between “d” and “c (concrete surface)”, and between “u” and “c”. During daytime, those three differentials move up and down significantly and frequently while they move steadily during nighttime. If the difference between damaged and undamaged part is the only concern, then daytime would be an ideal time window for IR thermography. However, both “d - c” and “u - c” also move up and down significantly. Moreover, the trends of those movements are not same. This means that temperature of concrete surface must be strongly affected by both sun loading and the color of the concrete surface during daytime, not damaged parts. If IR thermography is used for deck inspection during daytime, there is a possibility to miss some of delaminated parts of the deck, and there must be a lot of noise in the thermal images which makes it difficult to detect anomalies in the subsurface as mentioned in SHRP2 report (TRB, 2013). On the other hand, temperature differences during nighttime are very stable, even though the differentials are very small, below 0.5℃. However, since the sensitivity of IR camera is normally from 0.02 to 0.05℃, IR camera might be able to detect delaminated parts without troublesome noise during nighttime.

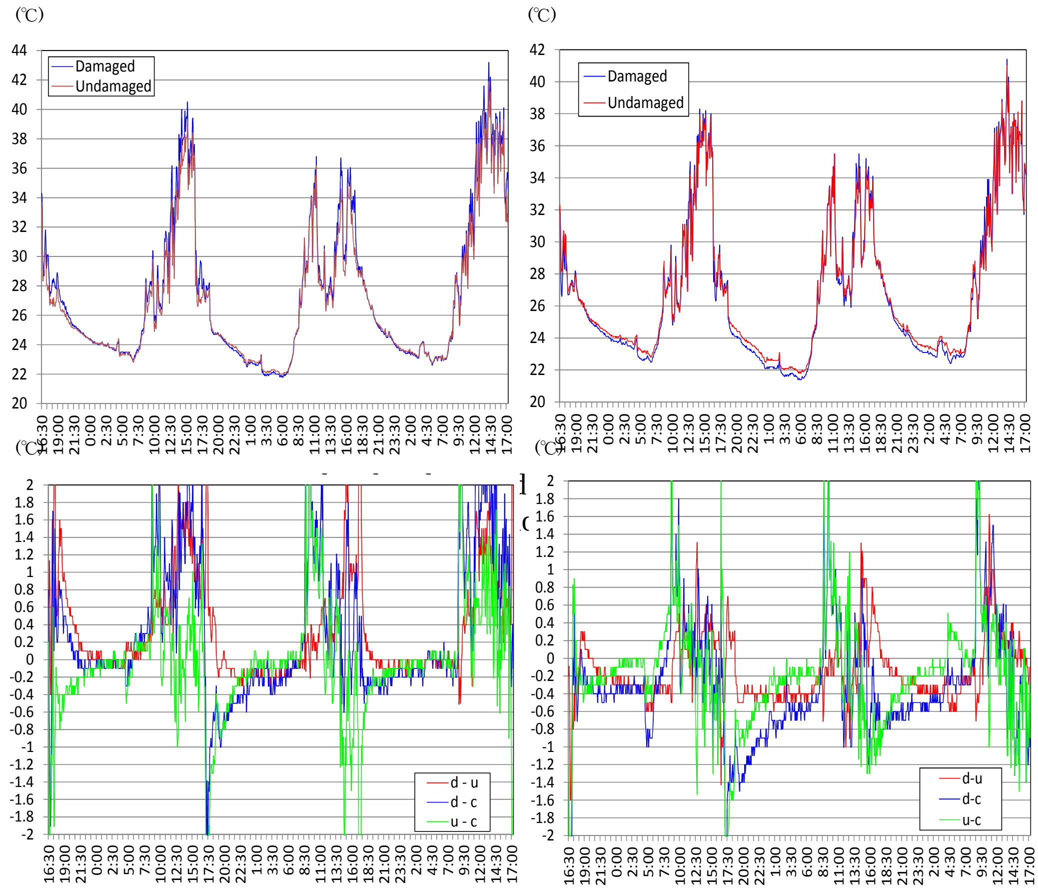

Figure 15 Temperature difference between “d and u”, “d and c” and “u and c” of 1cm thickness (left) and 0.5cm hollow (right)

CONCLUSIONS

The infrared camera and related software mentioned above were utilized on existing structures. The results obtained from the structures indicated that infrared thermography could successfully detect subsurface natural defects which could not be seen by regular visual inspection techniques. The experimental study showed that the test pieces could represent damaged and sound parts of the surrounding concrete surface artificially. It was found that temperature differential between the damaged and the sound parts of a concrete deck depends on the volume of the delamination. It also indicated the possibility that temperature of shined concrete surface was strongly affected by both sun loading and the color of the concrete surface during daytime, not damaged parts. Therefore, there is a possibility to miss some of delaminated parts of the shined parts during daytime. It was also observed that nighttime might be the ideal inspection time to collect data from an object by using an infrared camera because temperature difference during nighttime is stable, and there would be fewer noise compared to thermal images during daytime.

ACKNOWLEDGMENTS

This research is mainly based on the M.S. graduate study of Ms. Azusa Watase (2013), 3rd author of this paper, at the University of Central Florida. We would like to express sincere appreciation to Florida Department of Transportation for their support for providing us insight about their bridge inspection and maintenance operations, helping with identifying test bridges and structures, and exchanging information. Particularly, we would like to thank Mr. Andrew DeVault and Mr. Ron Meade.

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