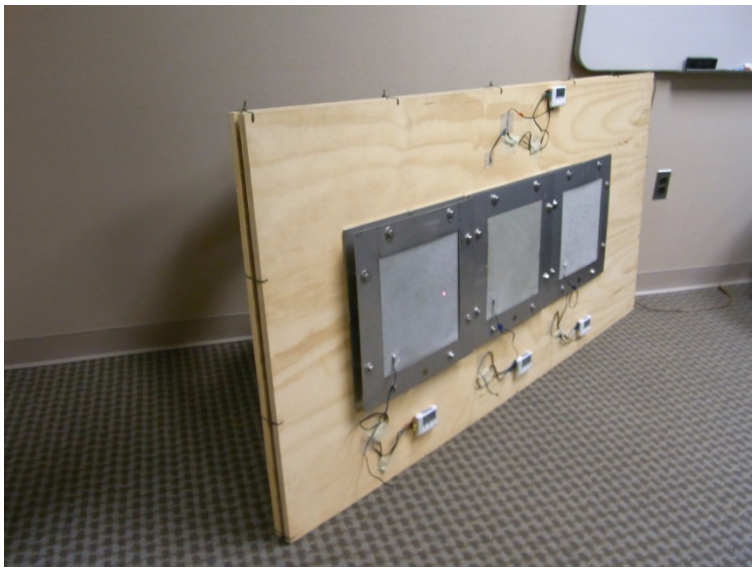
December, 2014

Comparison of Infrared Cameras for Bridge Deck Scanning:

- Vol.1 Laboratory Test -



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1. Infrared Cameras and IrBAS Software

In this research project, three infrared cameras with different specifications manufactured by FLIR systems, Inc., (shown in Table 1) were compared for accuracy in application to bridge deck scanning from a vehicle. The model T420 and T640 have the same type of detector (microbolometer) and have similar thermal sensitivities, but their resolutions are different. The model T640 and SC5600 have the same resolution, but their thermal sensitivities, detector types and spectral ranges are different. The results obtained by these three different cameras were compared to show what camera specification has noticeable effects on the results in detecting the delamination on the concrete bridge decks.

Table 1: Three Infrared cameras used in this research and their primary specifications

			
	T420	T640	SC5600
Thermal sensitivity/NETD	<0.045° at 30°C	<0.04°C at 30°C	<0.02°C
IR resolution	320 × 240 pixels	640 x 480 pixels	640x512
Spectral range	7.5 - 13 µm	7.5 to 14µm	2.5-5.1 µm
Detector type	Uncooled microbolometer	Uncooled microbolometer	InSb

In this study, the infrared images were analyzed using a special software package, IrBAS Software (Figure 1), developed by NEXCO. It is not always possible to detect concrete delaminations only from the color variation of infrared imagery, since the concrete structure itself tends to have a temperature gradient depending on location and orientation with respect to the sun (Matsumoto et al., 2013). This software, as shown in Figure 2, has an automatic damage classification system that can classify damage rating into three categories: 1) Indication: crack exists within 4cm depth from the concrete surface; currently satisfactory, 2) Caution: crack exists within 2cm depth from the concrete surface; close monitoring is recommended, and 3) Critical: crack exists and reaching on concrete surface; immediate action is required.

Raw IR image data is filtered and rated into three categories by the software to indicate and evaluate the severity of subsurface defects in concrete structures as shown in Figure 1.

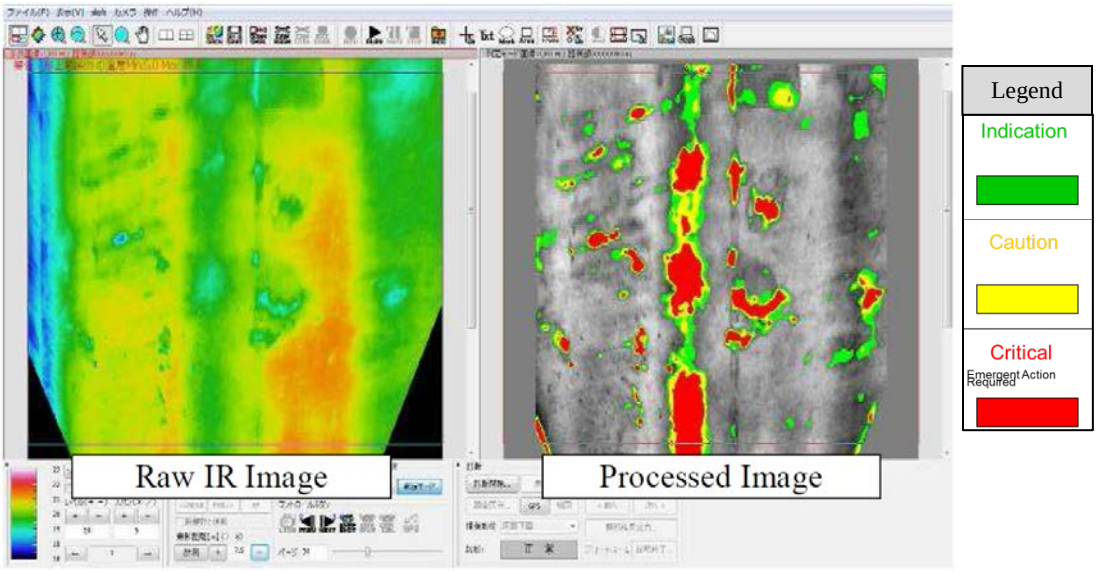


Figure 1: An example of IrBAS Software output

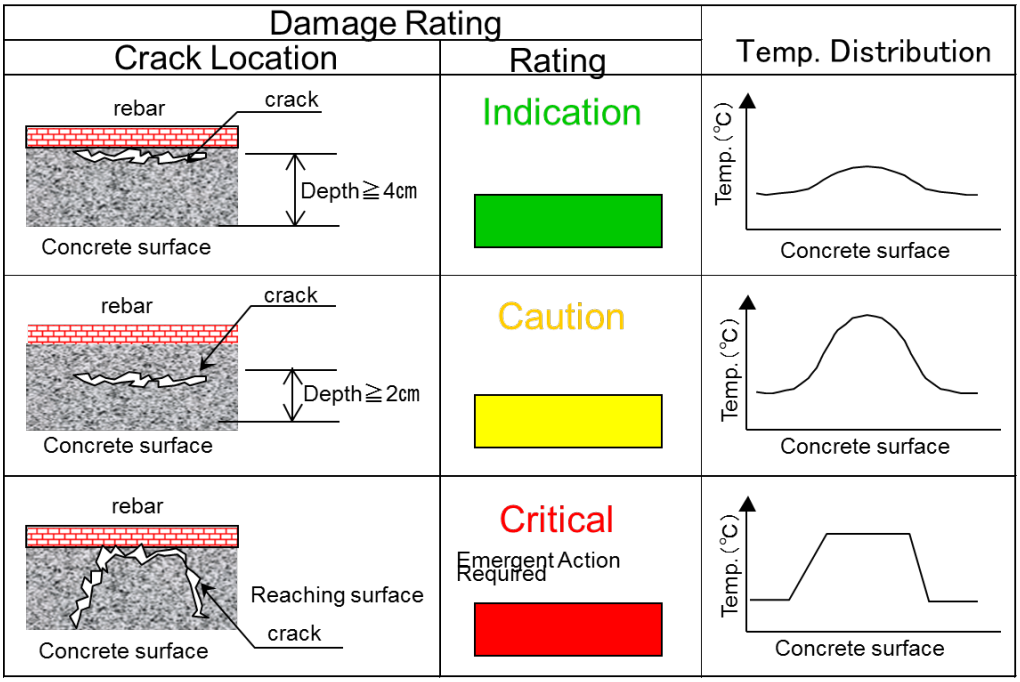


Figure 2: Damage classification by IrBAS Software

Figure 3 schematically illustrates the mechanism of infrared thermography methodology. The red line shows daily temperature variation for delaminated concrete, while the blue line shows the daily temperature variation for concrete in good condition. The delaminated concrete surface shows different temperature variation. Infrared imagery technology is applicable during the periods when temperature differentials are detectable (0.2 °C or greater) if photographed by a high end camera (SC5600). The indoor laboratory test was performed by heating up the concrete test piece to generate this temperature differential between delaminated and sound concrete areas. Chapter 2 of this report describes the equipment for the laboratory test.

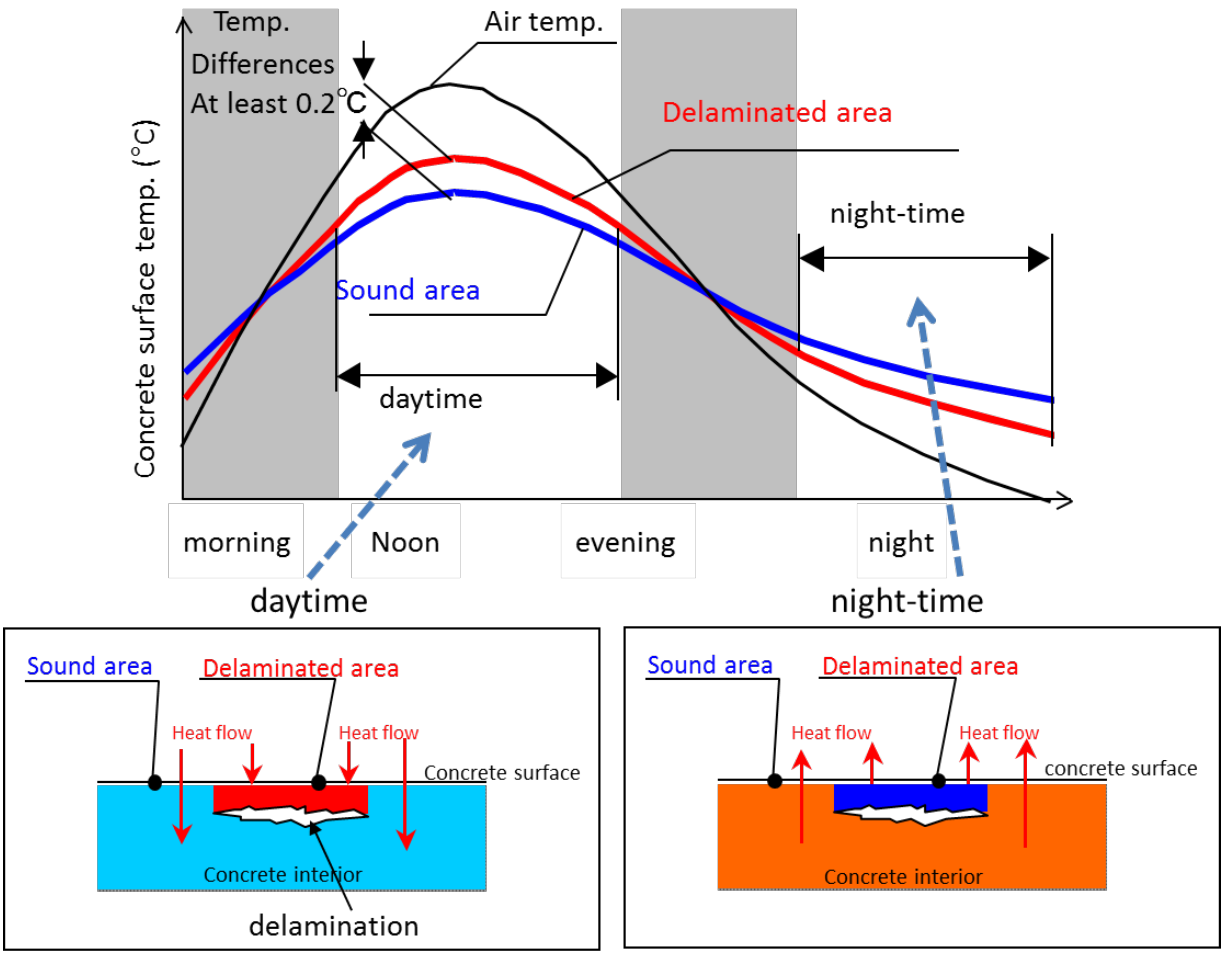


Figure 3: Mechanism of Infrared Imagery Technology

2. Indoor Testing Description

For laboratory testing, concrete test pieces were developed and used indoors to simulate artificial delamination. As shown in Figure 4, the space between the actual test piece and the concrete surface made by a 1mm thick heat conduction sheet simulates artificial delaminated area. By heat exchange through the heat conduction sheet, the part of the test piece attached to the heat conduction sheet represented the sound area of the concrete surface. On the other hand, the part of the test piece not attached to the heat conduction sheet represented the delaminated area of the concrete. In this laboratory test, three types of separate concrete test pieces (Figure 5) with different thicknesses were attached to a wooden board (Figure 6) that can be heated up by using electrically heating carpet (Figure 7), installed behind the wooden board. The temperature of the wooden board surface and the room's ambient temperature were recorded by thermocouples as shown in Figure 6. Infrared images were taken from a distance of 5.0m by the three different cameras.

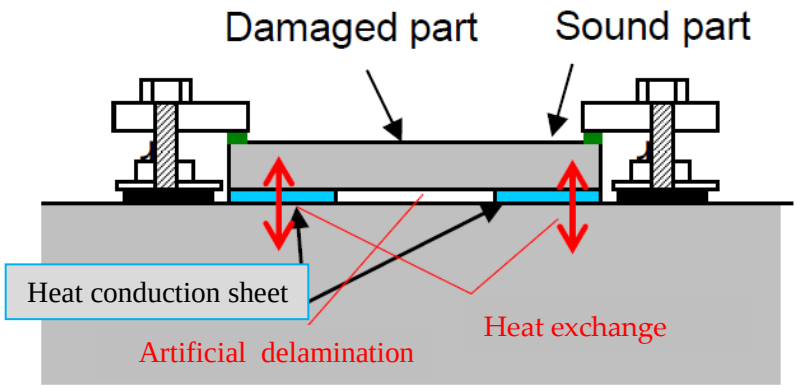


Figure 4: Mechanism of test piece

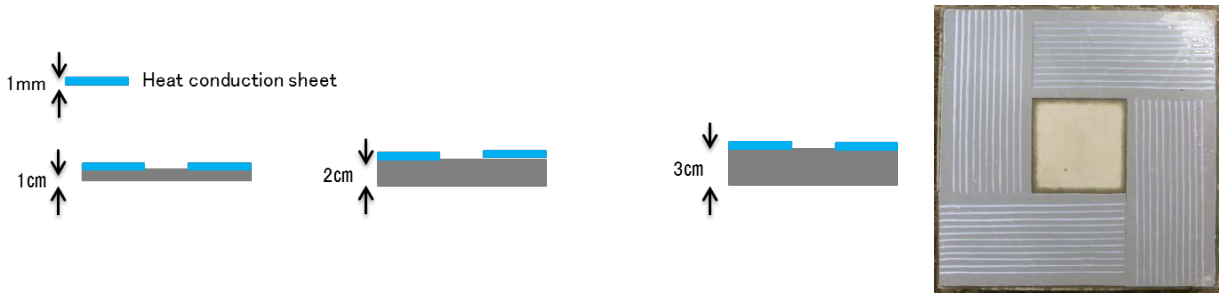


Figure 5: Test pieces (t=1cm, 2cm 3cm)

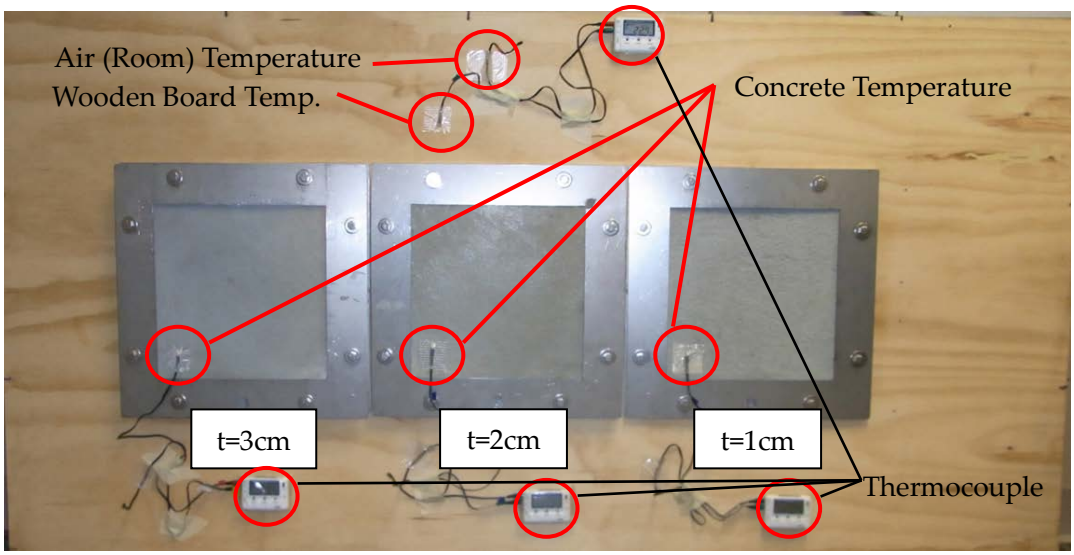


Figure 6: Test plates attached to the wooden board

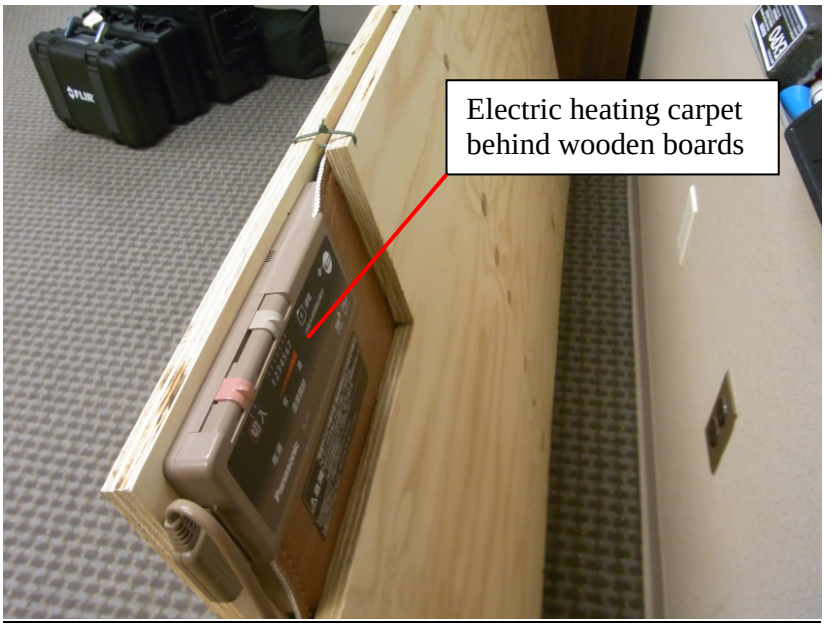


Figure 7: Electrically heating carpet behind wooden boards

3. Test Results from Three Different Angles

3.1 Case 1: Photographing Angle = 0° (Perpendicular to the test piece)

From a straight and angled view, three test pieces were photographed by three different types of IR cameras at the same time. The IR images were photographed when the artificial delamination in the 1cm test piece was first detected by the SC5600 model.

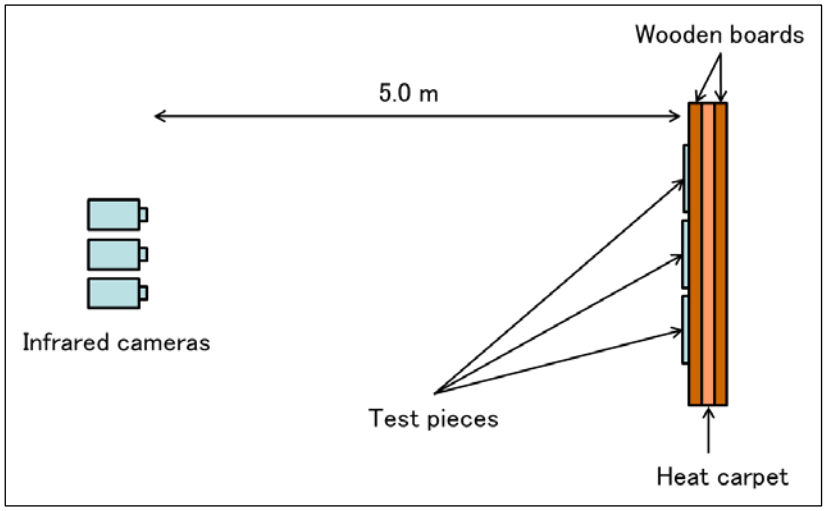


Figure 8: Schematic illustration for 0° angle photographing

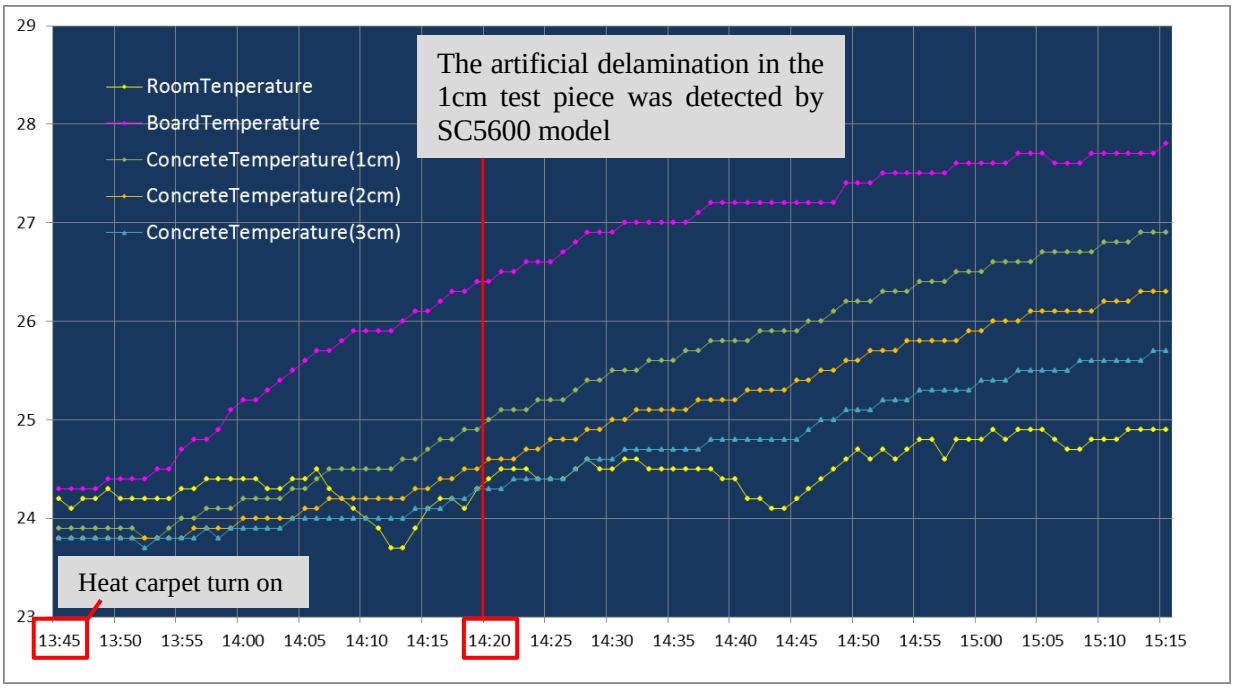
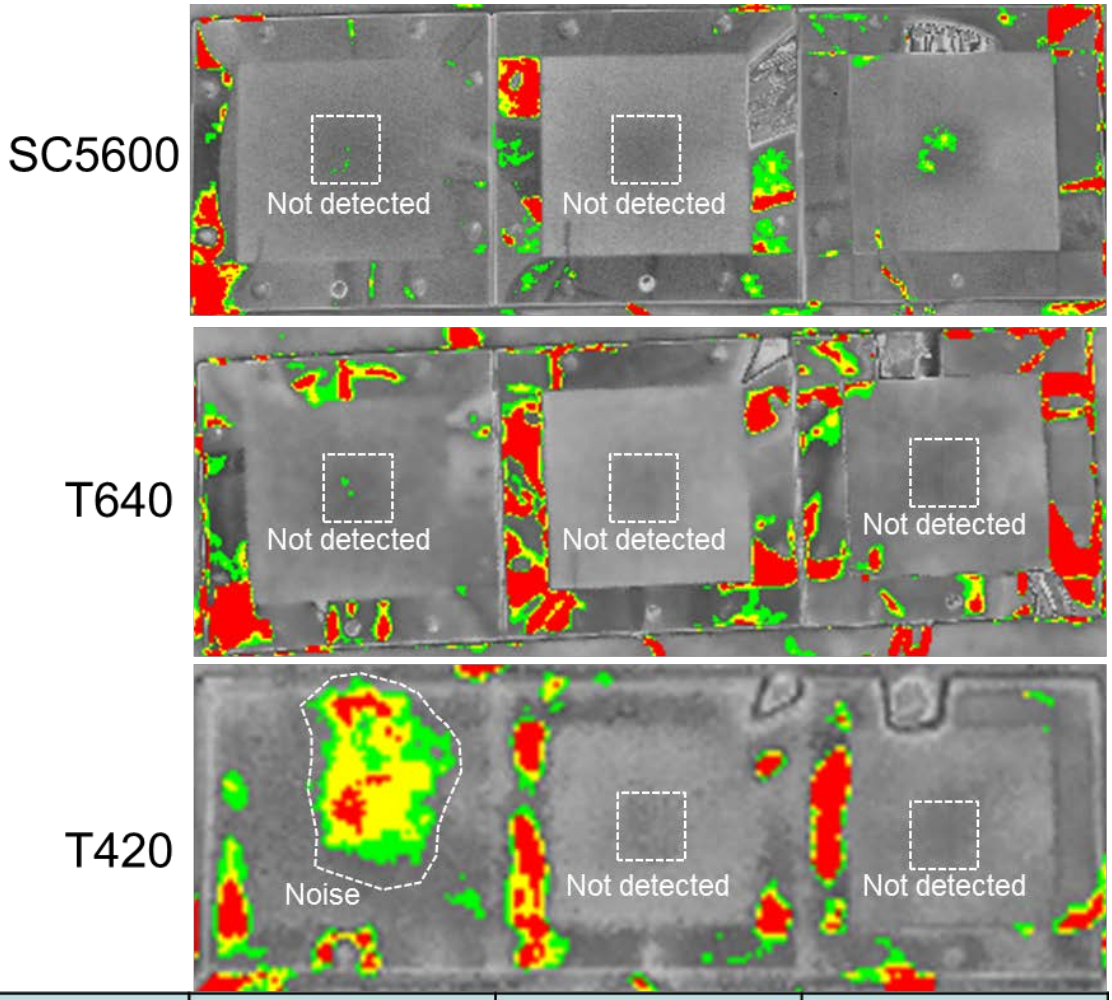


Figure 9: Historical thermocouple data record (Case1-1)

Figure 10 shows the IR software output for three test pieces photographed by the three types of IR cameras at 14:20. In this case, only high end IR camera SC5600 successfully detected the delaminated area located 1cm from the concrete surface, since the temperature differential between delaminated and sound area was 0.2°C; while T640 and T420 could not detect the same shallow area delamination. On the other hand, delaminated areas located 2cm and 3cm from the concrete surface were not successfully detected by any type of IR camera, since the temperature differential was only 0.1°C (overall results summarized in Table 2).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	24.3 ℃	24.6 ℃	25.0 ℃
Delaminated Area	24.2 ℃	24.5 ℃	24.8 ℃
Temp difference	0.1 ℃	0.1 ℃	0.2 ℃

Figure 10: Processed infrared image Case1-1 (Room Temp=24.4℃, at 14:20)

Table 2: Result from photographing angle = 0° (Case1-1)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.1℃)	(Temp. dif.= 0.1℃)	(Temp. dif.= 0.2℃)
SC5600	NOT detected	NOT detected	Detected
T640	NOT detected	NOT detected	NOT detected
T420	NOT detected	NOT detected	NOT detected

After a while, another IR images were photographed when the artificial delamination in the 3cm test piece was detected by the SC5600 model at 14:50.

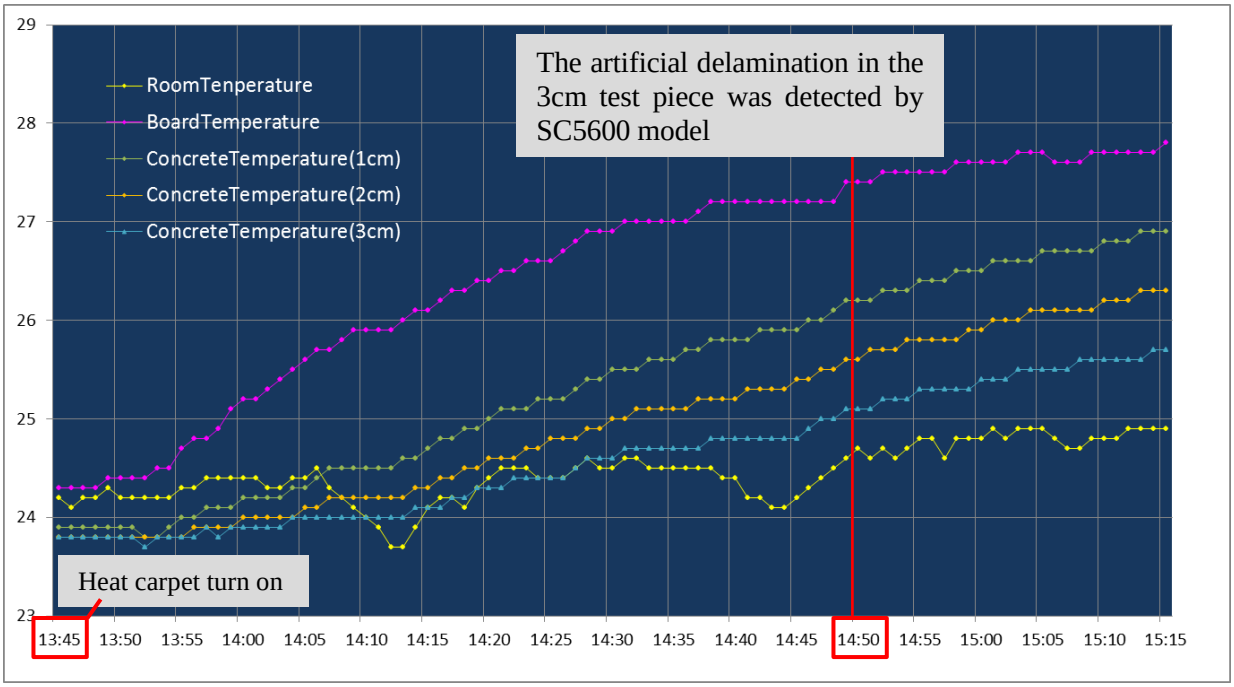
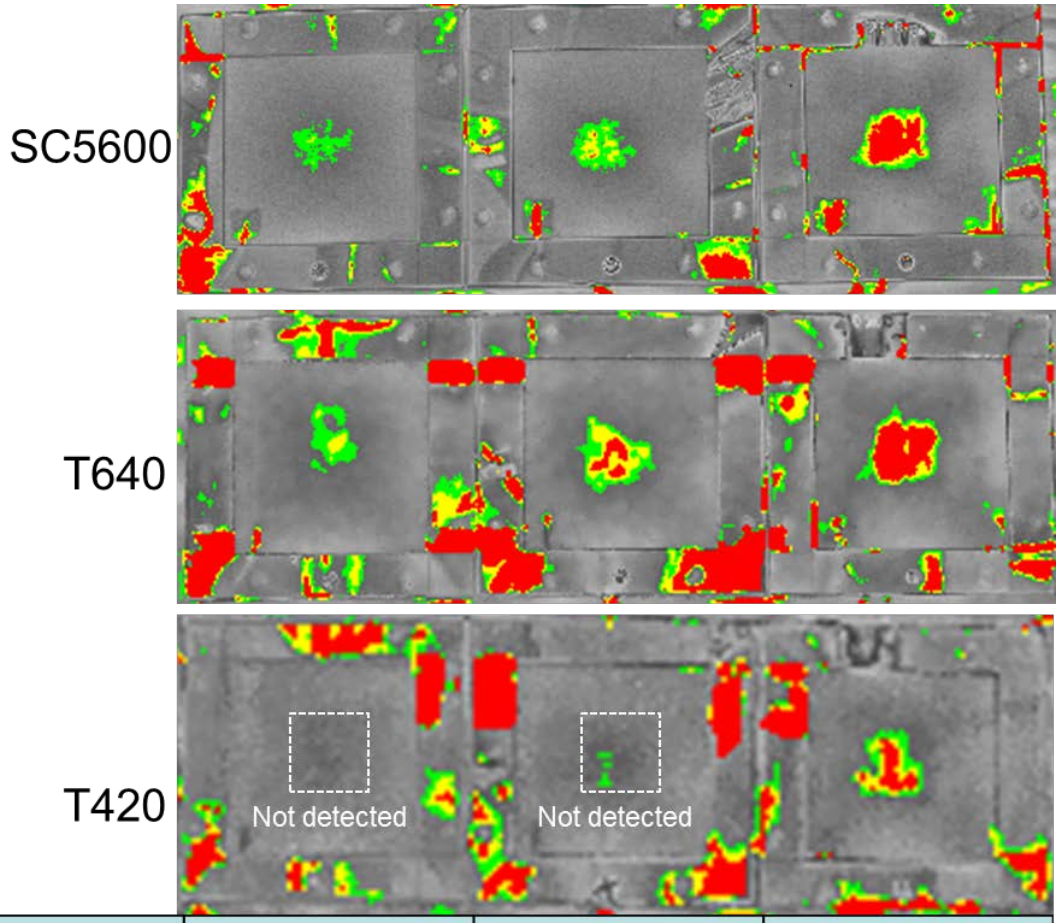


Figure 11: Historical thermocouple data record (Cace1-2)

Figure 12 shows the IR software output for three test pieces photographed by the three types of IR cameras at 14:50. In this case, SC5600 and T640 clearly detected the delaminated areas located at 1cm, 2cm and 3cm from the concrete surface, with temperature differential of 0.2℃ from the sound area concrete. T420 could not detect the delaminated areas located at 2cm and 3cm from the surface (overall results summarized in Table 3).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	25.1 ℃	25.6 ℃	26.2 ℃
Delaminated Area	24.9 ℃	25.4 ℃	25.9 ℃
Temp difference	0.2 ℃	0.2 ℃	0.3 ℃

Figure 12: Processed infrared image Case1-2 (Room Temp=24.7℃, at 14:50)

Table 3: Result from photographing angle = 0° (Case1-2)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.3℃)
SC5600	Detected	Detected	Detected
T640	Detected	Detected	Detected
T420	NOT detected	NOT detected	Detected

3.2 Case 2: Photographing Angle = 30°

In the second case, three test pieces were photographed by three different types of IR cameras at the same time from the 30° angle view. Again, the IR images were photographed when the artificial delamination in the 1cm test piece was first detected by the SC5600 model.

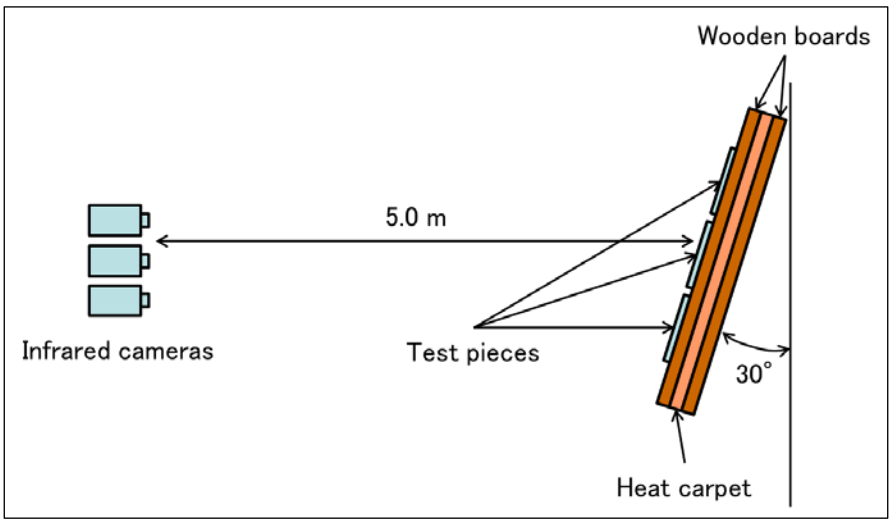


Figure 13: Schematic illustration for 30° angle photographing

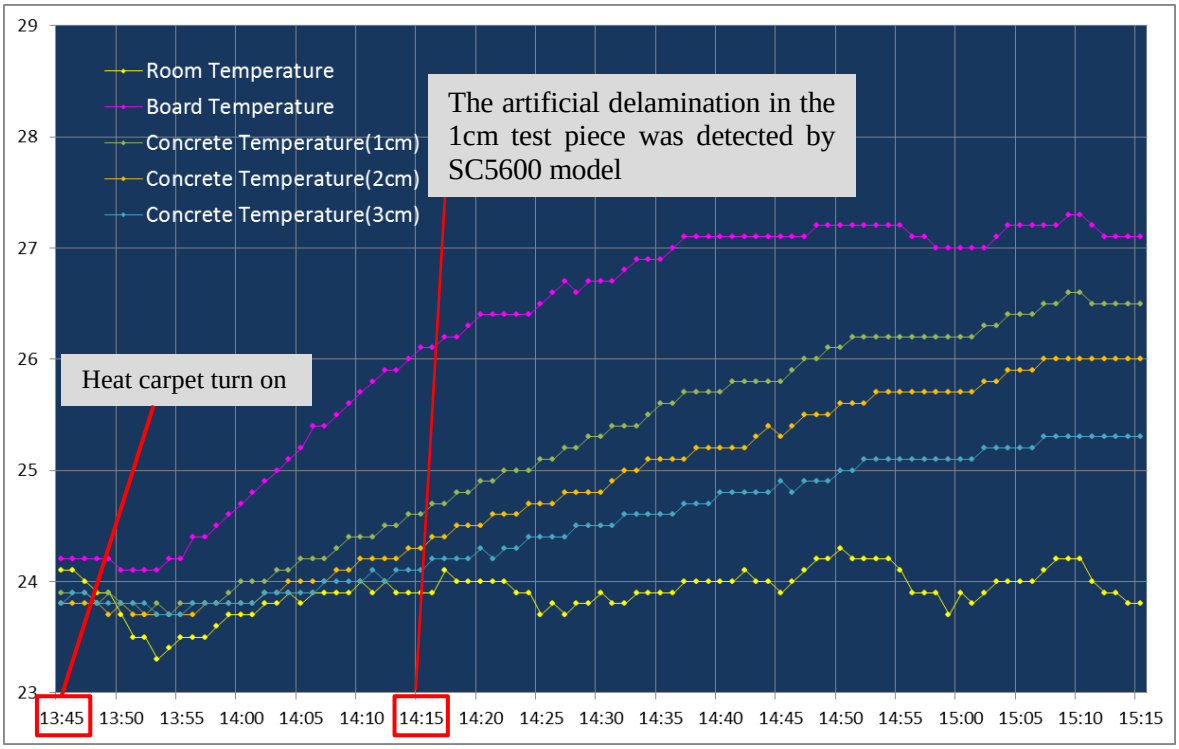
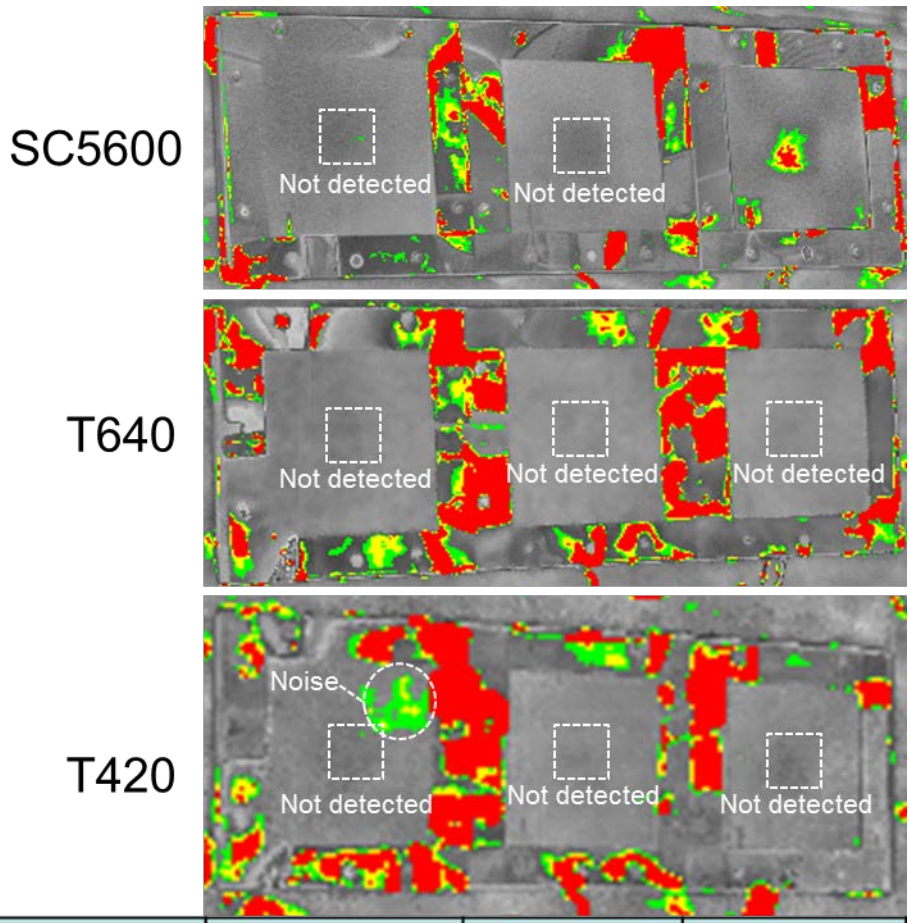


Figure 14: Historical thermocouple data record (Case2-1)

Figure 15 shows the IR software output for three test pieces photographed by the three types of IR cameras at 14:15. In this case, only high end IR camera SC5600 successfully detected the delaminated area located 1cm from the concrete surface, since the temperature differential between delaminated and sound area was 0.2°C; while T640 and T420 could not detect the same shallow area delamination. On the other hand, delaminated areas located 2cm and 3cm from the concrete surface were not detected by any type of IR camera, since the temperature differential was only 0.1°C and 0.05 °C, respectively (overall results summarized in Table 4).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	24.1 ℃	24.3 ℃	24.6 ℃
Delaminated Area	24.05 ℃	24.2 ℃	24.4 ℃
Temp difference	0.05 ℃	0.1 ℃	0.2 ℃

Figure 15: processed infrared image Case2-1 (Room Temp=23.9℃, at 14:15)

Table 4: Result from photographing angle = 30° (Case2-1)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.05℃)	(Temp. dif.= 0.1℃)	(Temp. dif.= 0.2℃)
SC5600	NOT detected	NOT detected	Detected
T640	NOT detected	NOT detected	NOT detected
T420	NOT detected	NOT detected	NOT detected

After a while, another IR images were photographed when the artificial delamination in the 3cm test piece was detected by the SC5600 model at 14:50.

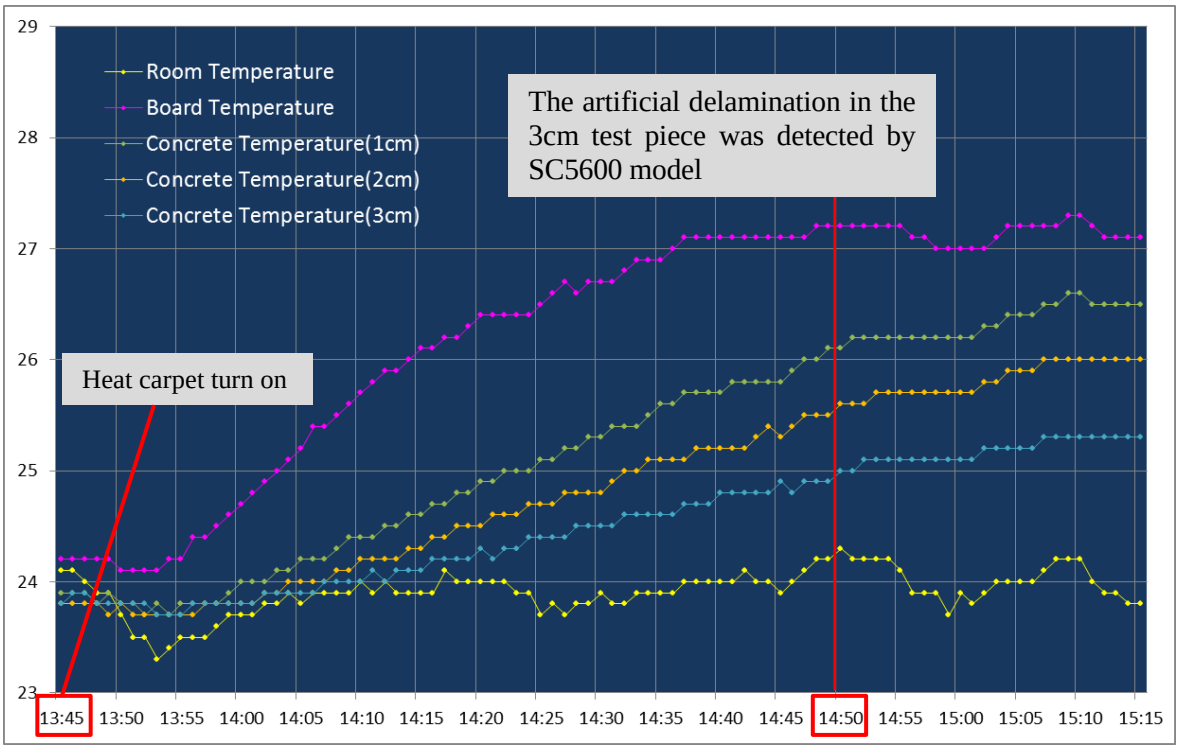
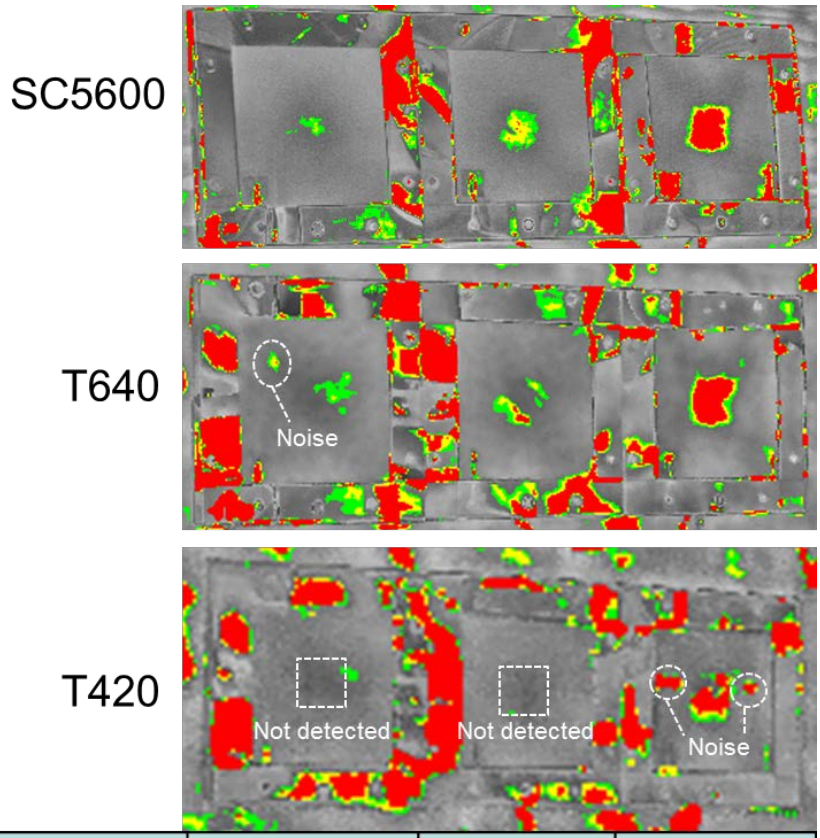


Figure 16: Historical thermocouple data record (Case2-2)

Figure 17 shows the IR software output for three test pieces photographed by the three types of IR cameras from 30° angle. In this case, SC5600 and T640 successfully detected the delaminated areas located at 1cm, 2cm and 3cm from the concrete surface, since the temperature differential between delaminated and sound area was 0.2°C. However, the result by T640 for 3cm test piece includes a noise that indicates a false positive detection. On the other hand, T420 could detect only 1cm (shallow) delamination including some false detection. Delaminated areas located at

2cm and 3cm from the concrete surface were not detected by T420 (overall results summarized in Table 5).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	25.0 ℃	25.6 ℃	26.1 ℃
Delaminated Area	24.8 ℃	25.4 ℃	25.9 ℃
Temp difference	0.2 ℃	0.2 ℃	0.2 ℃

Figure 17: processed infrared image Case2-2 (Room Temp=24.3℃, at 14:50)

Table 5: Result from photographing angle = 30° (Case2-2)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.2℃)
SC5600	Detected	Detected	Detected
T640	Includes false detection	Detected	Detected
T420	NOT detected	NOT detected	Includes false detection

3.3 Case 3: Photographing Angle = 45°

In the third case, three test pieces were photographed by three different types of IR cameras at the same time from the 45° angle view. Again, the IR images were photographed when the artificial delamination in the 1cm test piece was first detected by the SC5600 model at 21:20.

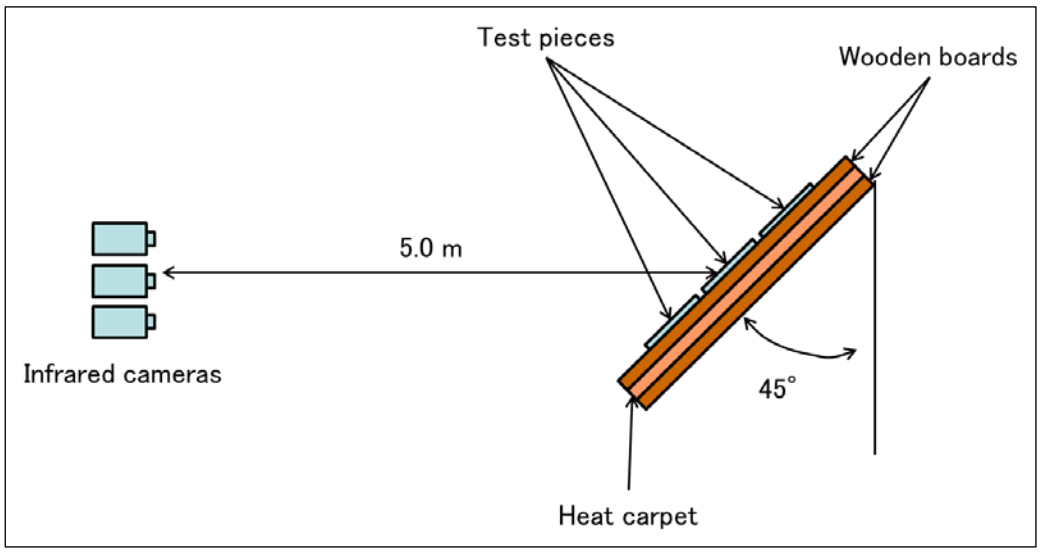


Figure 18: Schematic illustration for 45°angle photographing

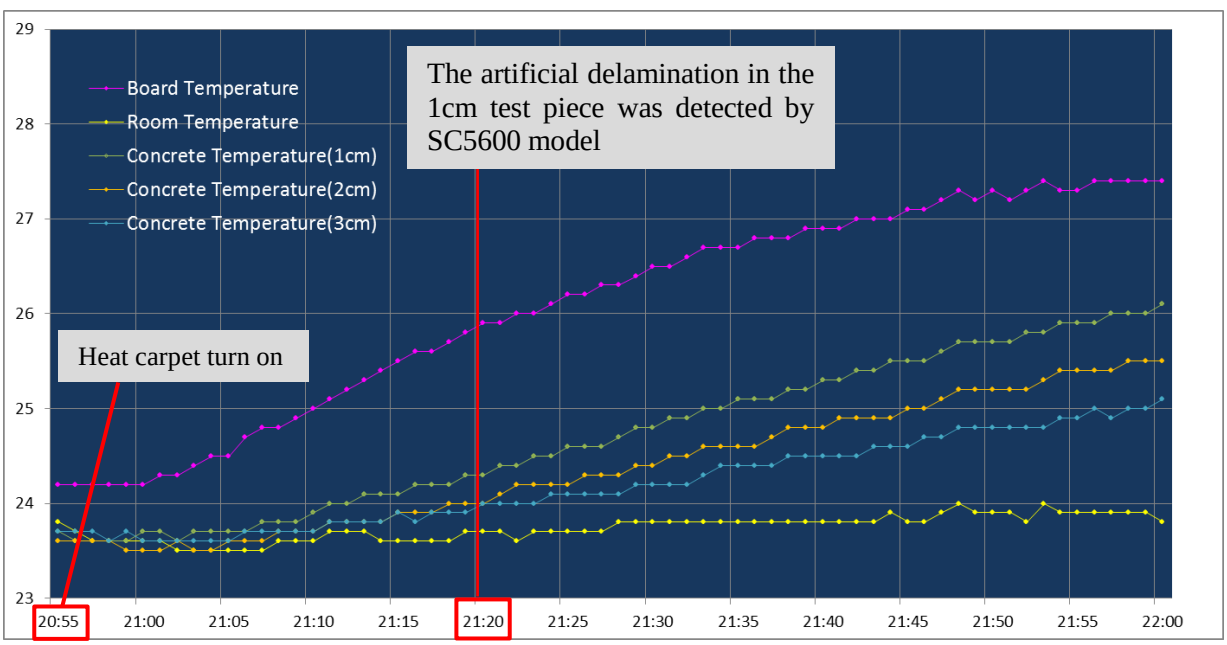
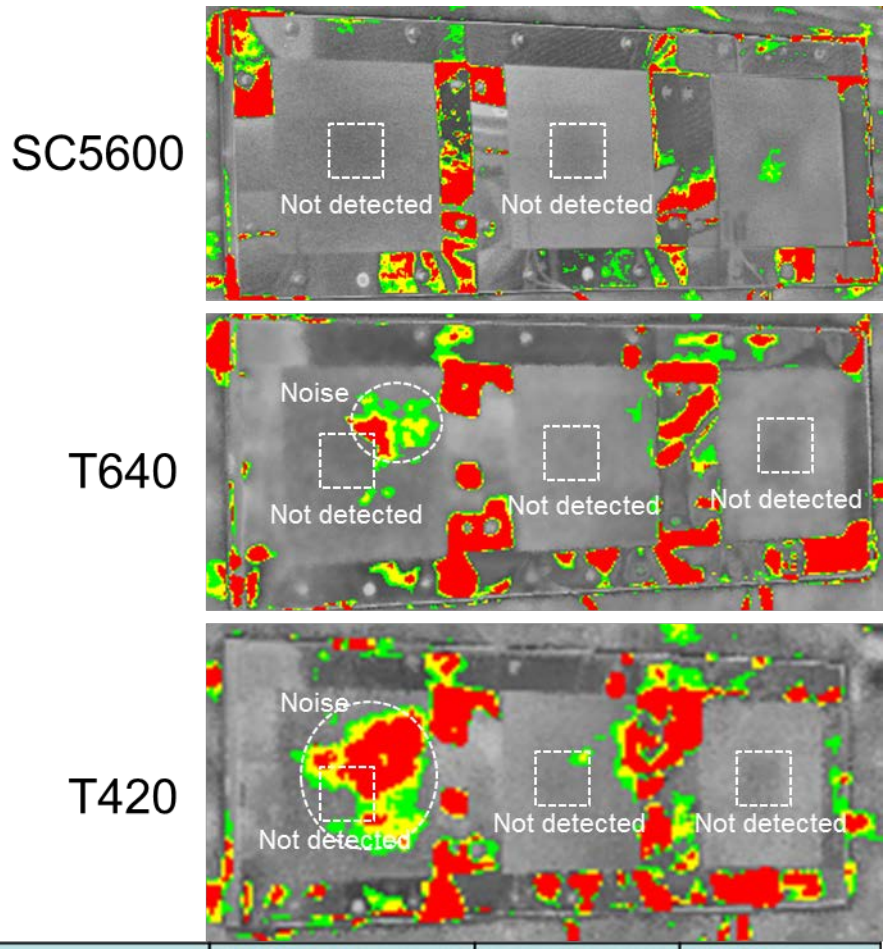


Figure 19: Historical thermocouple data record (Case3-1)

Figure 20 shows the IR software output for three test pieces photographed by the three types of IR cameras at 21:20. In this case, only high end IR camera SC5600 successfully detected the delaminated area located 1cm from the concrete surface, since the temperature differential between delaminated and sound area was 0.2°C; while T640 and T420 could not detect the same shallow area delamination. On the other hand, delaminated areas located 2cm and 3cm from the concrete surface were not successfully detected by any type of IR camera, since the temperature differential was only 0.1°C (overall results summarized in Table 6).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	24.0 ℃	24.0 ℃	24.3 ℃
Delaminated Area	23.9 ℃	23.9 ℃	24.1 ℃
Temp difference	0.1 ℃	0.1 ℃	0.2 ℃

Figure 20: Processed infrared image Case3-1 (Room Temp=25.9℃, at 21:20)

Table 6: Result from photographing angle = 45° (Case3-1)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.1℃)	(Temp. dif.= 0.1℃)	(Temp. dif.= 0.2℃)
SC5600	NOT detected	NOT detected	Detected
T640	NOT detected	NOT detected	NOT detected
T420	NOT detected	NOT detected	NOT detected

After a while, another IR images were photographed when the artificial delamination in the 3cm test piece was detected by the SC5600 model at 21:45.

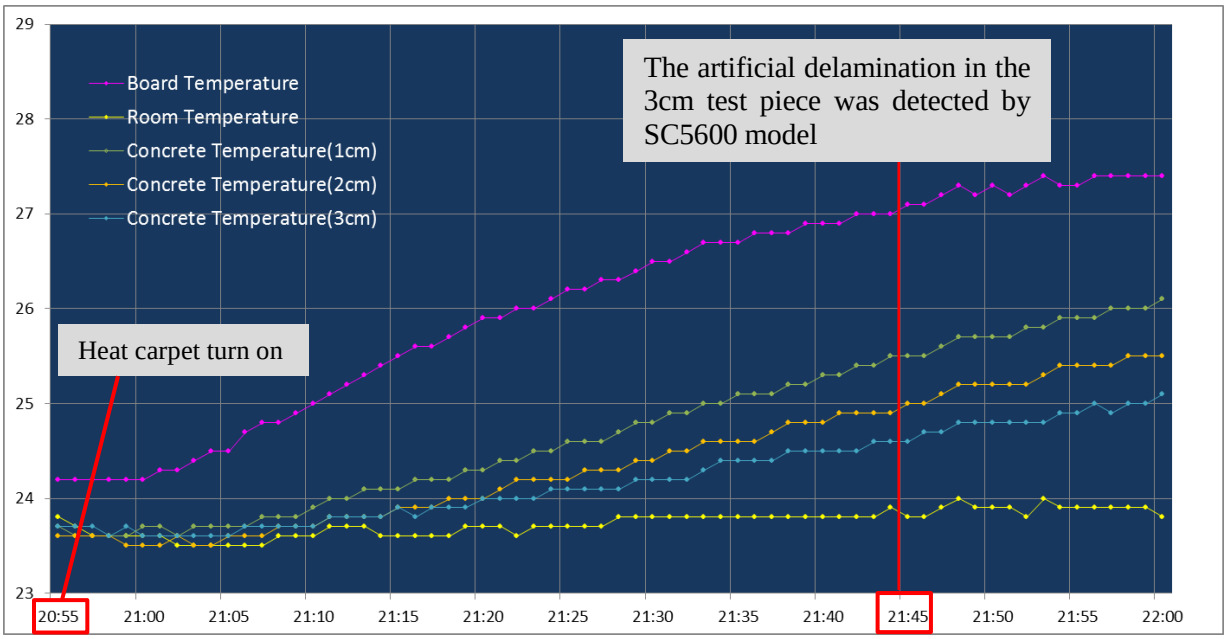
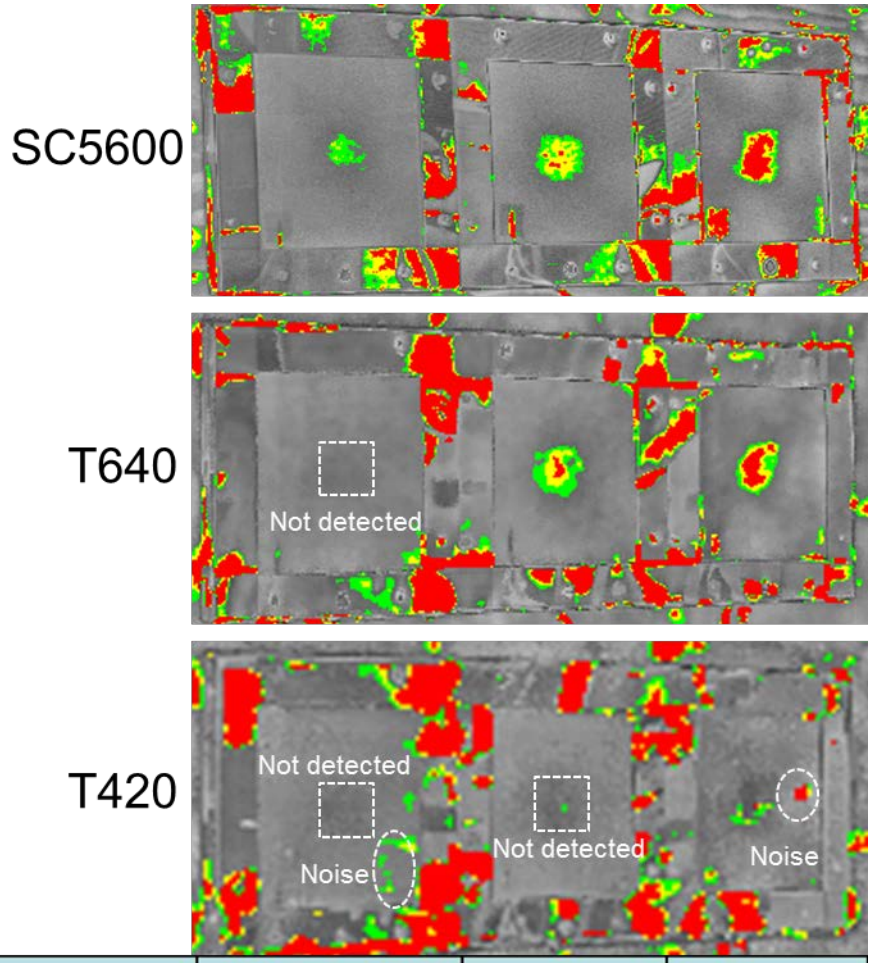


Figure 21: Historical thermocouple data record (Case3-2)

Figure 22 shows the IR software output for three test pieces photographed by the three types of IR cameras from 45° angle. In this case, SC5600 successfully detected the delaminated areas at all locations; however, T640 could not detect the delaminated areas located at 3cm from the concrete surface, although the temperature differential is 0.2 °C. Again, T420 could not detect the delaminated areas at all location (overall results summarized in Table 7).



	t = 3 cm	t = 2 cm	t = 1 cm
Sound Area	24.6 ℃	25.0 ℃	25.5 ℃
Delaminated Area	24.4 ℃	24.8 ℃	25.3 ℃
Temp difference	0.2 ℃	0.2 ℃	0.2 ℃

Figure 22: Processed infrared image Case3-2 (Room Temp=27.1℃, at 21:45)

Table 7: Result from photographing angle = 45° (Case3-2)

IR Camera model	t = 3cm	t = 2cm	t = 1cm
	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.2℃)	(Temp. dif.= 0.2℃)
SC5600	Detected	Detected	Detected
T640	NOT detected	Detected	Detected
T420	NOT detected	NOT detected	NOT detected

4. Conclusions

Figure 23 to Figure 25 are the overall summary of delamination detection results when temperature differential is 0.1°C, 0.2°C and 0.3°C, respectively. When the temperature differential between delaminated and sound concrete surface was 0.1°C, the delaminated areas were not detected by any type of IR camera. When the temperature differential became 0.2°C, SC5600 successfully detected the delaminated areas at any photographing angle, while T640 could not always detect the same delamination. T420 could not successfully detect the delaminated area at all although the temperature differential was 0.2°C.

Figure 23: Overall summary of delamination detection results when temperature differential is 0.1°C

IR Camera model	Photographing angle		
	0°	30°	45°
SC5600	×(NOT Detected)	×(NOT Detected)	×(NOT Detected)
T640	×(NOT Detected)	×(NOT Detected)	×(NOT Detected)
T420	×(NOT Detected)	×(NOT Detected)	×(NOT Detected)

Figure 24: Overall summary of delamination detection results when temperature differential is 0.2°C

IR Camera model	Photographing angle		
	0°	30°	45°
SC5600	○(Successfully Detected)	○(Successfully Detected)	○(Successfully Detected)
T640	△(Depends)	△(Depends)	△(Depends)
T420	×(NOT Detected)	×(NOT Detected)	×(NOT Detected)

From the test results, we drew the conclusion that the SC5600 model performs better in delamination detection than T640 and T420 models. The quality of delamination detection was more reduced if photographed by T420. The SC5600 model with Insb detector clearly detected the delaminations even from a 45° angle, whenever the temperature differential between the delaminated and sound concrete surface is greater than 0.2°C. The introduction of the angle lead to more noisy images in T640 and T420 models, which in some cases produced false detections

in delaminated areas.

SC5600 proved to have the highest quality and accuracy in detection of delaminations during stand-still photography. In the interest of expanding upon this research and further exploring the differences in capability between these three camera models, UCF (University of Central Florida) and NEXCO intend to perform a high-speed on-site test by mounting the cameras onto a vehicle and taking passes over a bridge with known defects (Haymarket Bridge in Haymarket, VA).

The findings from the on-site comparison test will be summarized in the Vol. 2 of the report.