INFRARED THERMOGRAPHIC INSPECTION OF DE-BONDING BETWEEN LAYERS OF AIRPORT FLEXIBLE PAVEMENT

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Abstract: Infrared thermography is widely used to detect the positions of defects within the concrete piers of roads and railways. This method is based on the surface temperature difference between bonded and de-bonded areas. This paper presents the results of field trials and thermal analysis conducted to verify the applicability of the infrared thermographic inspection method to detect de-bonded area between asphalt concrete layers, and the following conclusions are obtained. (1) De-bonding at the depth of 40 – 70 mm from the surface of pavements can be found by infrared thermography. However, the depth of de-bonding which can be detected by the infrared inspection method changes with the weather conditions. (2) The amount of solar radiation and the air temperature difference between day and night affect the surface temperature difference due to the existence of de-bonding.

INTRODUCTION

In July 2000, slippage failure occurred at the end of the runway of Nagoya Airport in Japan due to loss of bond between the surface and binder course as shown in Figure 1. The slippage area was 4 m wide and 8 m long, and the runway had to be closed for a time (Kubo et al, 2004). The reason of this slippage was due to the top layer not properly bonded to the layer below and the large horizontal load of aircraft at takeoff. Following this failure, airport flexible pavements was inspected by an impact acoustic method using a hammer on the surface to detect de-bonding between asphalt concrete layers. In this inspection method, the inspector walks around, repeatedly hits the surface of the pavement by a hammer, listens to the tone of the sound, and thus estimates the position of de-bonding. However, this method takes many days for a large airport. On the other hand, infrared thermography is widely used to detect the positions of defects within the concrete piers of roads and railways (Osada et al, 2004). The method is based on the surface temperature difference between bonded and de-bonded areas. Since heat transfer is blocked between layers due to air in a de-bonding (which acts as an insulator), the surface temperature at that area decreases at night and increases in the day compared with that on bonded areas.

This paper presents the results of field trials and thermal analysis conducted to verify the applicability of the infrared thermographic inspection method to airfield pavements.

Figure 1 Slippage failure due to loss of bond at Nagoya Airport

FIELD TRIAL OF INFRARED INSPECTION METHOD

Procedure of Field Trial

To verify the applicability of the infrared thermographic inspection method to airfield pavements, a trial inspection was conducted at Naha Airport in September. This is one of the largest airports in Japan and is located in southeastern Japan. De-bonding between layers were found at the end of the runway by the impact acoustic method in the summer of 2005. The runway-taxiway intersection near the end of the runway, measuring 10 m by 10 m, was used for the trial.

First, the inspection area was divided into small squares of 50 cm by 50 cm, and then the area was inspected using the impact acoustic method and the positions of de-bonding were marked by light chalk lines. After marking, the inspector took infrared images of the inspection area using thermography with the specifications shown in Table 1. The infrared images were taken from a height of 10 m every 30 min from 0:30 a.m. to 5:30 a.m. Air temperature and intensity of solar radiation were measured during this trial. Figure 2 shows the weather conditions of the inspection days.

Table 1 Specifications of thermography used for inspection

Item	Specification
Measurement range	–40 to 500 °C
Temperature resolution	Better than 0.06 °C with averaging
Accuracy	±2 °C
Field of view	30.6° (H) × 23.1° (V) (with 22-mm standard lens)
Spatial resolution	1.68 mrad

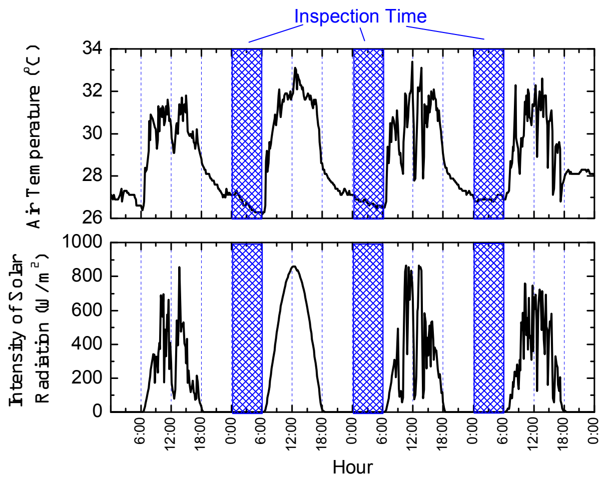
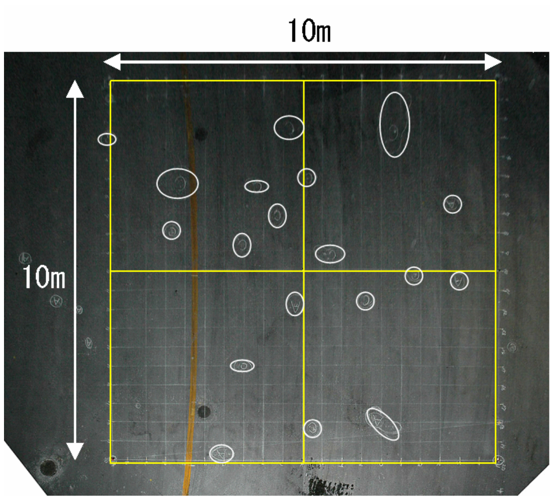


Figure 2 Weather conditions of inspection days

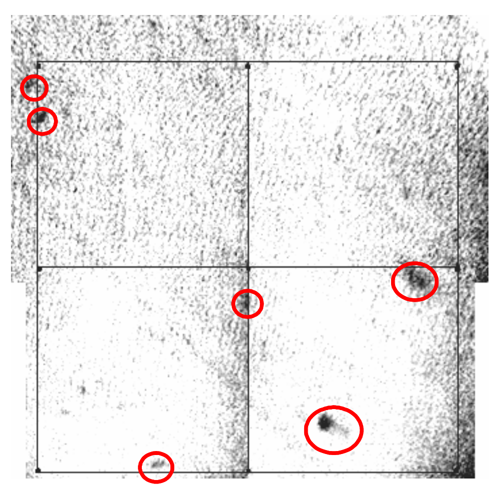
Result of Field Trial

Figure 3(a) shows a visible image of the inspection area from a height of 10 m. Circular marks indicate de-bonded areas found by the impact acoustic method. Figure 3(b) shows an infrared image of the same inspection area. In Figure 3(b), the black areas were cooler than the white areas. Comparing these two images, the low-temperature areas generally match the de-bonded areas found by the impact acoustic method.

After taking infrared images of the inspection area, core boring was carried out at seven low-temperature areas to confirm the depth of de-bonding. As a result, we confirmed de-bonding at all seven areas at a depth of 40 – 70 mm. Figure 4 shows the change of temperature measured on surface of both the de-bonded area (the depth of de-bonding is 50 mm) and its surrounding by using infrared thermography. These results clearly show that the surface temperature on the de-bonding was lower than that of its surrounding from midnight to morning.



(a) Visible image



(b) Infrared image (black = low temperature)

Figure 3 Visible and infrared images of inspection area

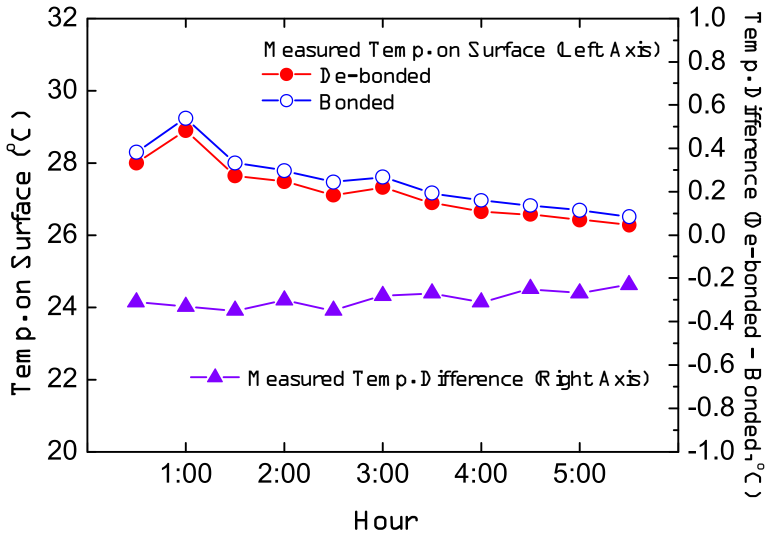


Figure 4 Variation of temperature and temperature difference on surface

THERMAL ANALYSIS

FEM Model

To clarify the weather conditions under which the infrared thermographic inspection method can be used, unsteady-state thermal analysis was performed using FEM using several conditions of maximum and minimum temperature in a day, intensity of solar radiation, and depth of de-bonding. The boundaries of the bottom and both sides of the model were given as insulation boundaries as shown in Figure 5. The analysis conditions as shown in Table 2 were determined through a trial and error process by using temperature measured in a field trial.

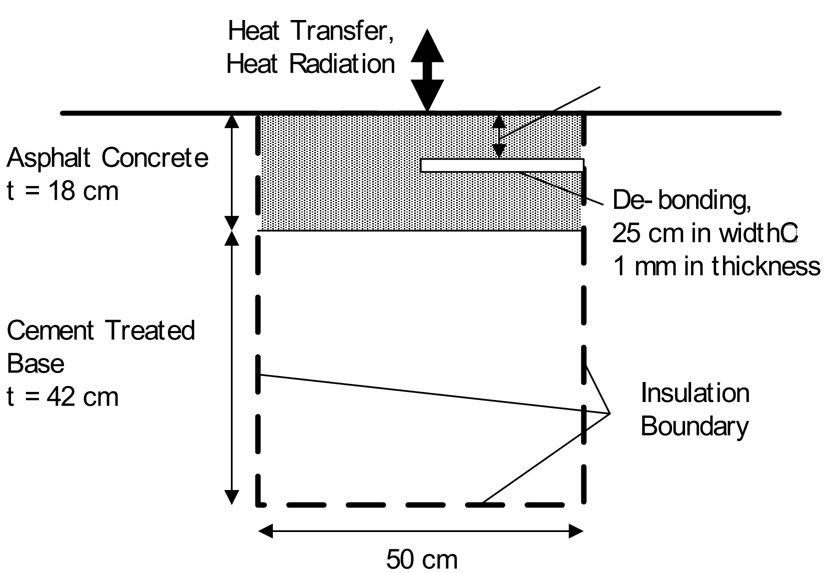


Figure 5 FEM model for thermal analysis

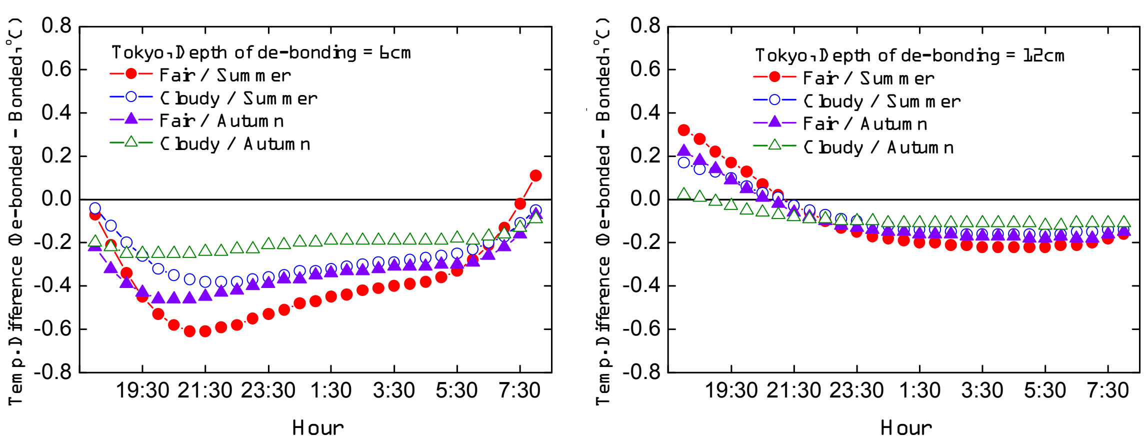
Table 2 Analysis conditions

Item		Condition
Heat conductivity (W/m/K)	Asphalt concrete	1.3
	Cement treated base	1.2
Heat transfer coefficient ($W/m^2/K$)	Asphalt concrete	0.92
	Cement treated base	0.90
Thermal emissivity		1.0
Solar radiation absorptance		1.0

Effect of Weather Conditions and Depth of De-bonding

Figure 6 shows the variation of surface temperature difference between bonded and de-bonded areas. The temperature difference in summer tends to be larger than that in autumn, and fair weather seems to lead to larger temperature differences than cloudy weather. These results suggest that a large temperature rise of the pavement surface in the daytime due to high air temperature or large amount of solar radiation may lead to a large temperature difference between bonded and de-bonded areas.

Comparing Figures 6 (a) and (b), it is apparent that deep de-bonding cannot be found easily by surface temperature difference since the temperature difference is very small even in fair summer weather conditions. This indicates that the effect of the insulator (air in de-bonding) on the temperature of pavement may not reach as far as the de-bonding. The result also indicates that the depth of de-bonding between layers that can be detected by the infrared inspection method may change with the weather conditions.



(a) Depth of de-bonding is 6 cm (b) Depth of de-bonding is 12 cm

Figure 6 Variation of temperature difference on surface

Based on the results of FEM thermal analysis using weather conditions in five cities, multiple linear regression analysis was conducted to clarify the weather conditions under which the infrared thermographic inspection method can be used. In multiple regression analysis, the surface temperature difference calculated by FEM thermal analysis was set as a dependent variable, and the maximum difference of air temperature in a day and amount of solar radiation in a day were set as independent variables.

Figure 7 shows the result of multiple regression analysis. It is apparent that the surface temperature difference (ΔT_{pav}) due to the existence of de-bonding can be estimated accurately by using the maximum difference of air temperature in a day (ΔT_{air}) and amount of solar radiation (Q) in a day. From these results, the infrared thermographic inspection method should be performed at night after a sunny day in seasons in which the maximum difference of air temperature in a day is large.

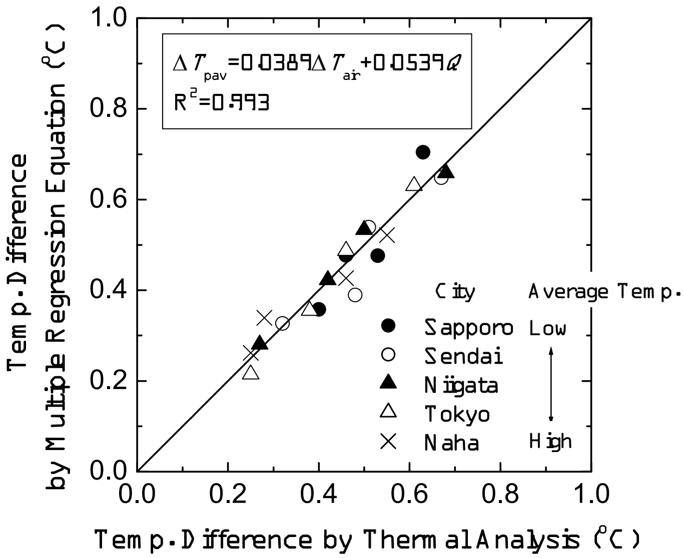


Figure 7 Result of multiple regression analysis (depth of de-bonding is 6 cm)

CONCLUSION

The following conclusions were obtained from this study.

(1) De-bonding at the depth of 40 – 70 mm from the surface of pavements can be found by infrared thermography. However, the depth of de-bonding which can be detected by the infrared inspection method changes with the weather conditions.

(2) From the results of field trial and thermal analysis, the amount of solar radiation and the air temperature difference between day and night affect the surface temperature difference due to the existence of de-bonding.

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