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USE OF INFRARED DATA FOR DETECTION OF CONCRETE DEFECT IN SERVICE THRUST BLOCK BASED ON HEAT BALANCE ANALYSIS

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Abstract: The demand for non-contact methods for inspecting and diagnosing concrete structures is increasing. Detection of undesirable conditions on concrete surfaces by visual cameras is popular due to high resolution and UAVs. Detection algorithms are working by leading to defect detection based on image contrast. The accuracy and reliability of defect detection are improved using both infrared and visual images. Surface temperature from infrared images is sensitive to environmental conditions. This study introduces heat balance analysis for defect detection using visible and infrared images in service thrust block. This research investigates surface temperature trends of crack and efflorescence. Increasing albedo improves accuracy in reproducing efflorescence temperatures.

1 INTRODUCTION

Non-contact methods for inspection and diagnosis are in demand for concrete structure maintenance. Inspection methods by visual camera, laser, thermal camera and airborne ultrasound are representative [1]. A visual camera approach has been mainstream due to the improvement of resolution and the introduction of UAV (Un-manned Airborne Vehicle). Infrared images have advantages to investigate the surface layer. The problem with the image base approach is an imperfection of data on the inspected structure. Therefore, defects are evaluated and detected by manual operation and relative contrast in acquired images. High accuracy has been confirmed at several attempts, however, a disadvantage is decreased accuracy for unknown structures [2]. The detection of defects by fusion images of infrared and visual has been reported to get reliable a result [3-4]. Especially, surface temperature from infrared images is a sensitive and unique parameter determined by environment and defect conditions. The surface temperature is calculated by weather data and the thermal properties of concrete considering heat balance. Therefore, damages condition could be estimated by measured weather data. Detection utilizing not only contrast but also the calculated surface temperature was considered to be effective in terms of robustness and generalization. In this study, the surface temperature trends of cracks and efflorescences are investigated, and their surface temperatures are reproduced by heat balance analysis, which contributes to defect detection using visible and infrared images.

Infrared thermography was performed on thrust blocks with defects every hour during the day. The detected temperature is reproduced by heat balance analysis by changing the reflectance of the surface.

2 MATERIALS AND METHODS

Passive infrared thermography was conducted at the side face of the thrust block of the concrete dam. Obtained images were segmented into crack and efflorescence parts. Each surface temperature from the infrared image was fitted by heat balance analysis.

2.1 Heat Balance Analysis

The concrete surface temperature T_s (°C) in the infrared image is calculated using the following heat balance equation:

$$R_n = H + lE + G, \tag{1}$$

where R_n is net radiation (W/m^2), H is sensible heat transfer (W/m^2), lE is latent heat transfer and G is thermal conduction into underground.

Net radiation R_n is shown in Eq. 2:

$$R_n = (1 - ref)S^{\downarrow} - \varepsilon(\sigma T_s^4 - L^{\downarrow}), \tag{2}$$

where ref is the albedo of concrete surface, $S^{\downarrow}$ is the horizontal solar radiation (W/m^2), ε is the emissivity, σ is the Stefan-Boltzmann constant (5.67×10^{-8} (W/(m^2·K^4))) and $L^{\downarrow}$ the long-wave radiation from the atmosphere (W/m^2). From this equation, net radiation is determined by the surface characteristics of concrete, emissivity and albedo, long-wave radiation from the atmosphere and incident light from the sun. Emissivity and albedo are important parameters to determine net radiation. Albedo is the reflectivity of concrete surfaces, whose range is about 0.1~0.5 according to surface conditions [5]. Emissivity is the rate of thermal radiation from an object on a scale of 0 to 1. In this study, the surface temperature of the efflorescence part is fitted by adjusting the albedo parameter focusing on the contribution of net solar radiation to surface temperature rise. Sensible heat transfer is calculated using wind speed from the weather station. Since concrete has low permeability, latent heat transfer is neglected. For underground heat conduction, a heat conduction simulation is performed using the finite difference method for concrete with a depth of 15 cm, and the integrated value for each depth is calculated. The meteorological conditions used in the analysis are global solar radiation (W/m^2), wind speed (m/s), temperature (°C) and long-wave radiation (W/m^2) obtained from the observation data of the Japan Meteorological Agency at 30-minutes intervals [6].

2.2 Passive Infrared Thermography

Passive infrared thermography and meteorological observation were carried out on the side face of the thrust concrete block (**Figure 1** (a)). Heavily crack and efflorescence deposits in the captured surface were observed in **Figure 1** (b). This structure was completed in 1976. Passive infrared thermography was performed every hour from 9:00 to 14:00. The infrared camera used for

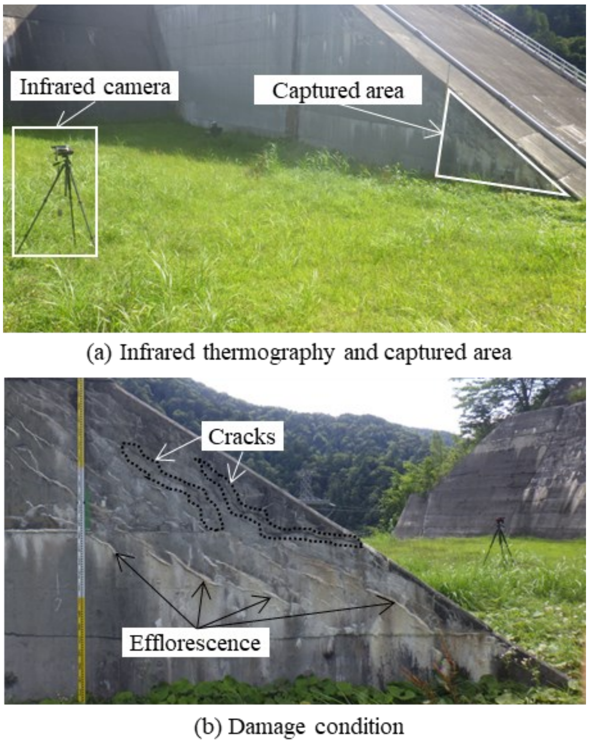


Figure 1: Measurement setups.

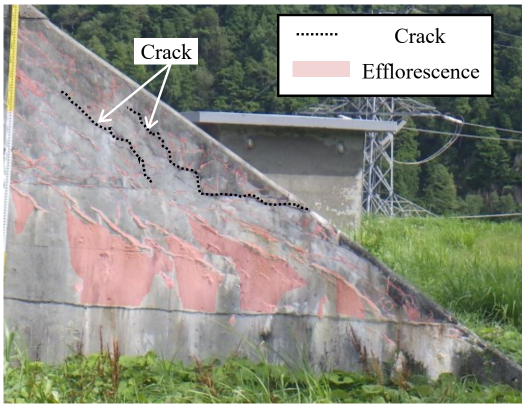
the measurement was R300 (manufactured by InfRec). The surface temperature of each pixel was obtained from the infrared image captured by the six times measurements. In this study, crack and efflorescence are analyzed objects. Efflorescence is more likely to occur in concrete which is porous near the surface. This porous surface includes cracked parts or badly made joints. Efflorescence does not directly cause heavy defects, indicating the existence of damages as a signal. In previous cases, efflorescence is also an object for detection [2].

3 RESULTS AND DISCUSSION

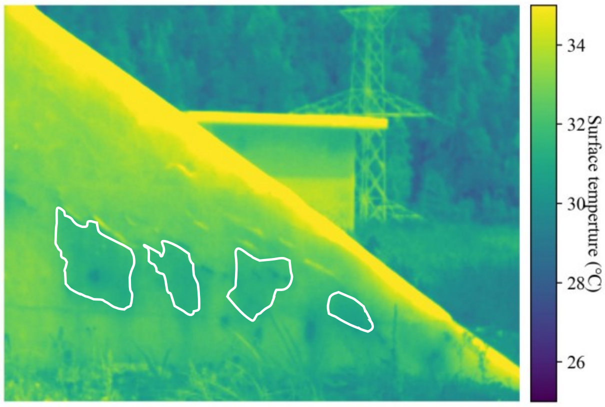
3.1 Difference in surface temperature due to surface characteristics

A segmented image and captured thermal image are shown in Figure 2. Black dotted line and red masks indicate crack and efflorescence, respectively in Figure 2 (a). These are annotated manually. Cracks are located along the surface, efflorescence is percolated through joint and crack parts [7]. The surface temperature at 14:00 is shown in Figure 2 (b). The surface temperature of the upperside tends to be a higher value than the left bottom parts. This is because direct radiation is incident from the sun's position. The crack contour shows a higher temperature than the surrounding part. The surface temperature of efflorescence at the left bottom part shows a lower temperature than other parts, especially, partially the surrounded part by a white line showing about 30 degrees Celsius (light blue).

Box plots of surface temperature for categories and each captured time is shown in **Figure 3**. A horizontal line in the box is the median value. For all timing, the median of surface temperature was highest in order of crack, concrete and efflorescence. The reason why the temperature of cracks is higher than others is the formation of a pseudo-blackbody surface (**Figure 4**). A blackbody surface absorbs a hundred percent of incident electromagnetic waves and emits thermal energy. Since the crack is a semi-enclosed space, the incident electromagnetic wave is



(a) Segmented image



(b) Surface temperature at 14:00

Figure 2: Captured visual and thermal images.

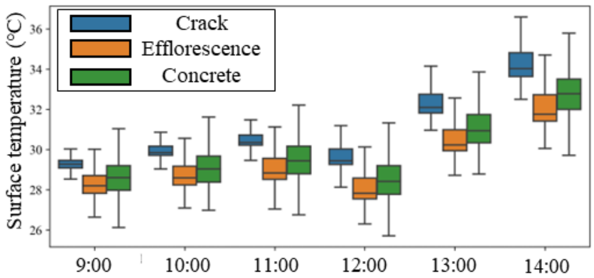


Figure 3: Boxplots of surface temperature for each class.

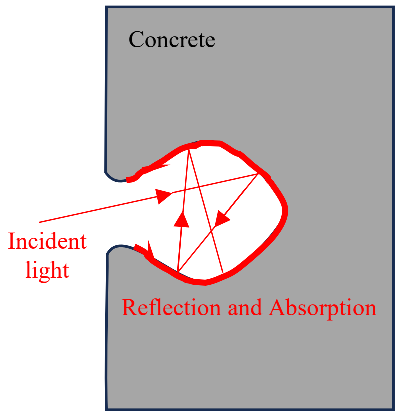


Figure 4: Pseudo-blackbody surface.

reflected and absorbed inside the crack, and the surface temperature inside the crack becomes higher. The reason for the low value of efflorescence is the reflectance of the surface. Even in visual observation, the surface color is white and the albedo is large. Next, the effect of surface temperature increase due to albedo is verified by heat balance analysis.

3.2 Reproduction of temperature change by heat balance analysis

Figure 5 shows the measured values from infrared images and calculated values of the efflorescence part and the concrete part. The measured value is the average surface temperature. MAE (Mean Absolute Error) between the measured temperature of concrete and the calculation value using albedo = 0.28 was 0.738 degrees Celcius. This result suggests that the heat balance analysis is effective for verifying the surface temperature of infrared thermography. MAE between the measured temperature of efflorescence and calculation value using albedo = 0.28 was 0.921 degrees Celcius. MAE between the measured temperature of efflorescence and calculation value using albedo = 0.40 was 0.694 degrees Celcius. It was confirmed that when the albedo is increased, the MAE becomes smaller and the efflorescence area can be reproduced.

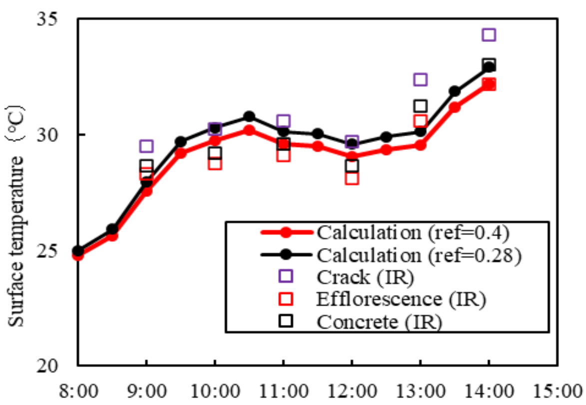


Figure 5: Measured values and calculated values from infrared images.

4 CONCLUSIONS

In this study, passive infrared thermography and heat balance analysis were conducted to reveal irregular heat parts based on surface defects and heat transfer.

From the results of infrared thermography, the median of surface temperature was highest in order of crack, concrete and efflorescence. The surface temperature of the crack is higher than one of the others due to the formation of a pseudo-blackbody surface.

The surface temperature of the efflorescence part was lower than that of the surrounding area. This is thought to be due to the albedo, and the surface temperature was reproduced by heat balance analysis. The MAE was smaller at albedo 0.4 than at 0.28, and could reproduce the surface temperature of the efflorescence region. It was suggested that defect detection incorporating heat balance analysis is effective to get robustness and generalization results.

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