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BASIC EXPERIMENT FOR DAMAGE DETECTION OF STRUCTURES USING INFRARED THERMOGRAPHY DEVICE

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ABSTRACT

Infrastructures in the world get old in several decades of their service time. Falling-off of parts of deteriorated structures were often reported and sometimes caused casualties in Japan and many other countries. When an earthquake occurs, in particular, deteriorated structures have higher possibility to be damaged or collapsed. Thus assessing the health condition of structures is one of the important topics in management of infrastructures. Considering a large number of structures that have been in service more than 40 years in Japan, efficient evaluation methods are requested. Accordingly, this study focuses on the use of infrared thermography camera to detect internal deterioration of concrete structures. As a first step of investigation, thermography diagnosis, hammering test and Schmidt hammer test were carried out to detect internal deterioration of a concrete retaining wall and the results were compared to evaluate the capability of these diagnosis methods.

Keywords: Thermography, Hammering test, Schmidt hammer, Infrastructures, Deterioration

INTRODUCTION

Modern societies are highly dependent on infrastructure. But infrastructures in the world get old in several decades of their service time and hence, their retrofits and reinforcements become more and more important, especially for developed counties where most infrastructures were built earlier than a half century ago. Falling-off of walls of deteriorated structures were often reported and sometimes caused casualties in Japan and many other countries. When an earthquake occurs in particular, those structures have higher possibility to be damaged or collapsed. In addition, the evaluation of internal damage of structures after earthquakes is also important. However, considering a large number of structures that have been in service more than 40 years in Japan, efficient evaluation methods are requested.

Various non-destructive diagnosis methods, which are more efficient and economical than destructive diagnoses, have appeared in the field of civil engineering and construction. Although they draw significant attention in these days a number of researches have been carried out, their proper procedures and applicability should be examined further to evaluate deterioration of old structures. As a non-destructive testing technique, hammering test and visual inspection are often used for the deterioration diagnosis of structures. However, this method takes a long time to apply for a large extent of structures and requires scaffolding for a high place.

To overcome these problems, this study focuses on the use of infrared thermography to detect internal deterioration of concrete structures. Infrared thermography cameras can inspect a large extent of structures in a short time. This method uses thermal behavior of an object's surface for detecting deterioration parts from temperature change in time and its spatial variation. In recent years, infrared thermography is frequently used in Japan but yet there still remain problems. Heating is essential in this method, and hence if the sun is use as a source of heating, the method depends on the daytime

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weather and temperature. Otherwise this method requires a heat source and the possibility of uneven heating may lead to wrong diagnosis.

To remedy this problems, several studies have been carried out that combine multiple non-destructive methods for the detection of subsurface deterioration (Chen et al., 2008; Aggelis et al., 2010) and investigate thermal behavior with active heating and passive heating (McCann and Forde, 2001; Cerdeira et al., 2011). Thermography cameras are often used in such studies.

In this study, thermography diagnosis, hammering test and Schmidt hammer test are carried out to detect internal deterioration of a concrete retaining wall, and their results are compared to evaluate the capability of these methods. The objective of this study is to examine whether infrared thermography can accurately detect deteriorated parts of structures.

METHODS AND TOOLS OF DETERIORATION DETECTION

For evaluating deterioration of an existing concrete retaining wall located in Chiba University's Nishi-Chiba campus, thermography diagnosis, hammering test and Schmidt hammer test were carried out. In thermography diagnosis, the change of surface temperature was observed by a thermography camera shown in Fig. 1(a), which evaluates deterioration parts from the temporal change and spatial distribution of temperature.

Rotary hammering test was also carried out using a rotary hammer shown in Fig. 1(b) for the deteriorated parts that were detected by thermography and their neighbor. When the rotary hammer knocked the concrete retaining wall, the sound was recorded by a digital voice recorder and the data were analyzed to characterize deteriorated parts. Additionally, the compressive strength of the retaining wall's concrete was also measured by a Schmidt hammer shown in Fig. 1(c). The concrete compressive strength, F_c, can be estimated by the following formula (Fuji Bussan Co., Ltd, 2014):

$$F_c=\alpha_n\{13(R_0+R_1+R_2)-184\} \tag{1}$$

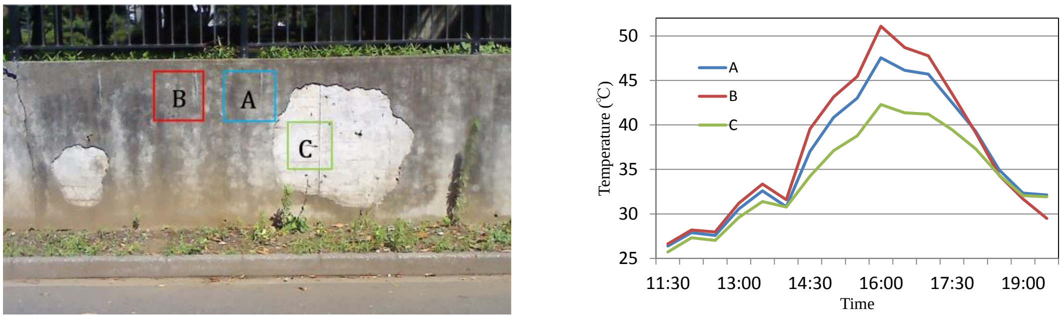
where α_n is the correction of the concrete age, R_0 is the rebound value measured by the Schmidt hammer, R_1 is the correction coefficient of moisture condition, and R_2 is the correction of the knocking angle.

(a) (b) (c)

Figure 1. Instruments used in this study. (a) Infrared thermography camera (Nippon Avionics Co., Ltd. (2014), InfReC R300SR-SS), (b) Rotary hammer (Dogyu Sangyo Co. (2014), No. 01738), and (c) Schmidt hammer (Fuji Bussan Co. (2014), Type N).

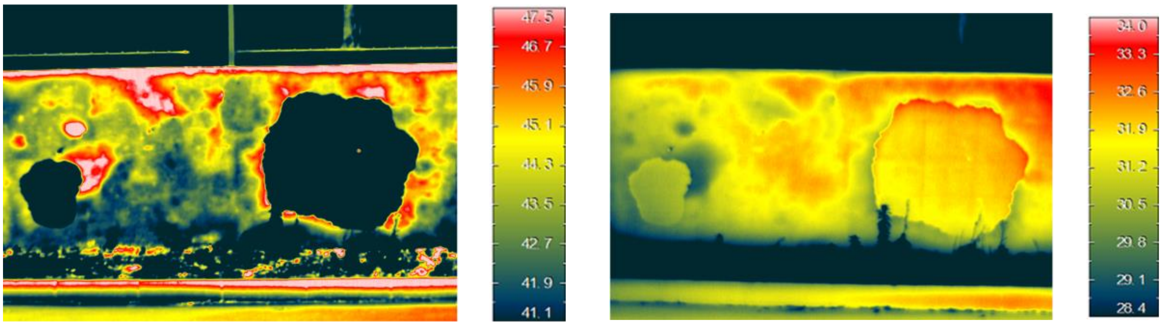
RESULTS OF OBSERVATION

Observation of the concrete retaining wall was carried out from 11:00 to 19:30 on July 8, 2014 and the surface temperature was recorded every 30 minutes by the infrared thermography camera. Figure 2 shows the photograph of the concrete retaining wall with three areas that were chosen for calculating the mean values of temperature and the temperature change at the three areas. From this figure, the amount of temperature rise is in the order of C<A<B. In the area B, in addition to the highest



(a) (b)

Figure 2. (a) The concrete retaining wall and the location of three target areas and (b) the temperature change in time at the three target areas.



(a) (b)

Figure 3. (a) The surface temperature at 15:30 and (b) 19:30 on July 8, 2014, observed by the infrared thermography camera.

temperature rise, the surface temperature dropped sharply after the sunset. If the wall has internal voids, the heat transfer is blocked by the voids and the heat is likely to accumulate in the wall surface layer. Accordingly, the temperature increased sharply in the heating time. In the cooling time, the heat in the surface layer was lost in a short time and thus the temperature decreased sharply. Based on this reason and the temperature change of each area, there is high possibility that the area B has internal voids.

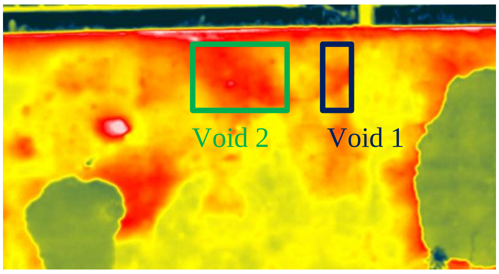
The thermal images in the heating and cooling time are illustrated in Fig. 3. It is seen that the temperature distribution is different in the areas A, B and C. The position and extent of deterioration could be clearly detected using the thermal images. Hence, thermography is considered to be useful in investigating deterioration of large concrete structures at once in a short time. Since the temperature change is different depending on the deterioration state, thermal imagery is effective for assessing the progress of deterioration.

The deterioration state of the concrete retaining wall was investigated with the rotary hammer in the area that is shown in Fig. 4. From the thermal images, the line α-α' was selected in the area of suspected deterioration and the line β-β' in the area of peeled-off but no internal deterioration. The recorded sound time-histories, the results of time-frequency analysis (Yeh and Liu, 2008), and the Fourier spectra are plotted in Figs. 5 and 6, respectively for the lines α-α' and β-β'. In the time-frequency plots, the dark color indicates large sound-pressure parts. The temperature distribution along the two lines of the rotary hammering test is shown in Fig. 7.

From the sound-pressure Fourier spectra, the line α-α' has both low-frequency and high-frequency contents but the line β-β' has low-frequency contents only. The Fourier amplitudes of sound-pressure for the deterioration area were larger than those of the health area, and especially those of the internal voids (Fig. 7) tend to be large in high-frequency contents by the rotary hammering test. From the thermal images, the line α-α' was estimated to have internal voids and the line β-β' was not. The same results were also obtained from the rotary hammering test, validating the usefulness of thermography. In addition, the areas that were suspected to be deteriorated by time-frequency analysis (Fig. 5b) match the estimated deterioration areas by the thermal image (Fig. 4b), in which the deterioration areas exhibited significantly high temperature. Comparing the temperature distributions at 15:30 and 19:30 (Fig. 7), that along the line α-α' is uneven and the deterioration areas can be observed. In addition, the high temperature area in the heating time became lower temperature in the cooling time, which is considered to be the characteristics of internal voids.

From these verification results, it was found that the rotary hammering test is more efficient than traditional hammering tests. However, the detection of the extent of deterioration and its shape is more difficult than that from thermal imagery. Hammering test cannot assess the deterioration area of large extent at one time. It is also pointed out that a video camera is needed in order to match the knocking area with the amplitudes by the time-frequency sound analysis,

(a)



(b)

Figure 4. (a) The measurement area of rotary hammering test (line α-α' and β-β') and (b) the thermal image at 15:30.

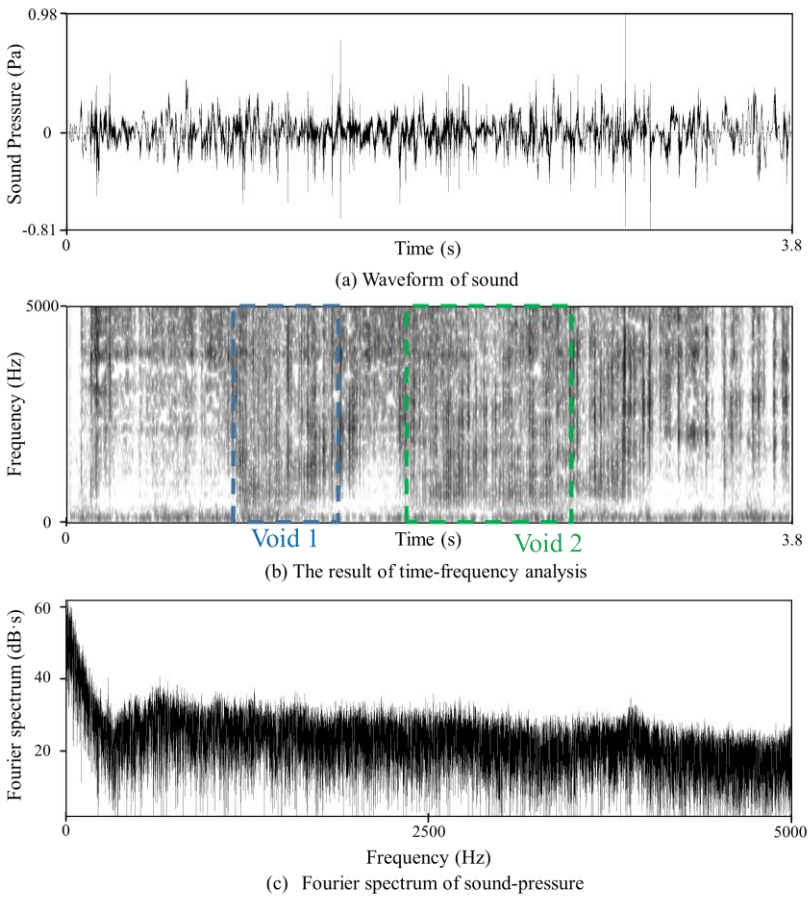


Figure 5. Recorded sound by rotary hammer along the line α-α' in the retaining wall.

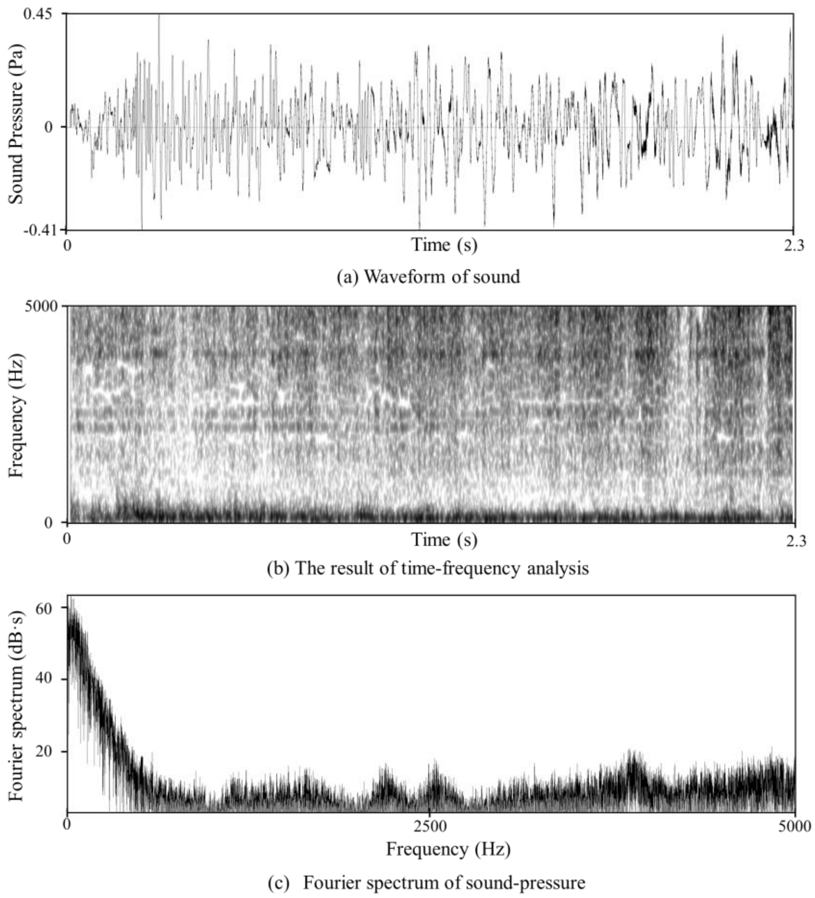


Figure 6. Recorded sound by rotary hammer along the line β-β' in the retaining wall.

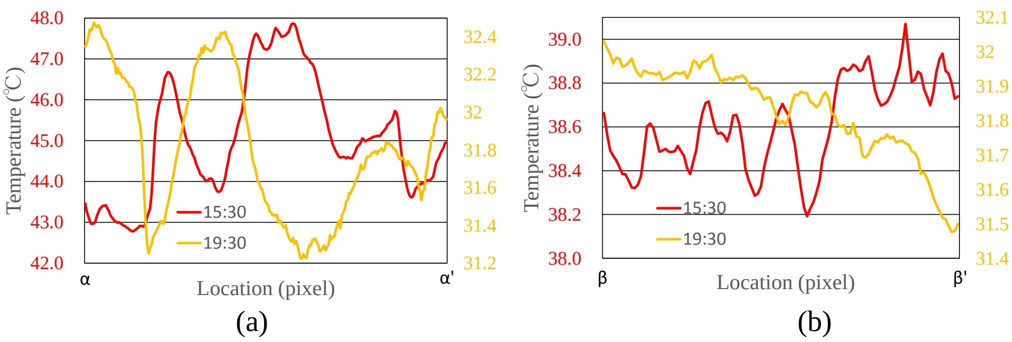
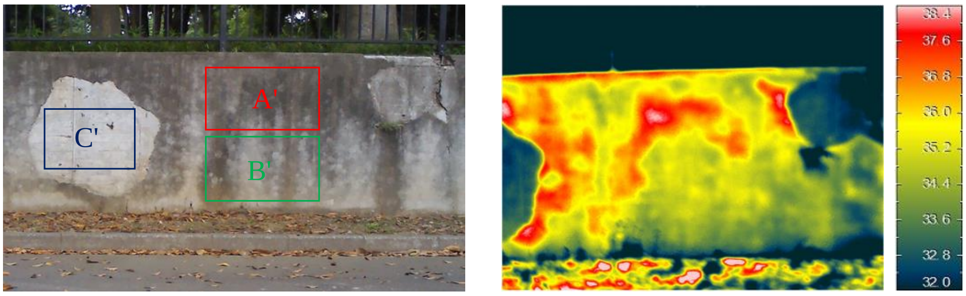


Figure 7. Temperature distribution at 15:30 and 19:30 along (a) the line α-α' and (b) the line β-β'.

Measurement of the concrete retaining wall by the Schmidt hammer was carried out on June 27, 2013. Three areas measured by Schmidt hammer are illustrated in Fig. 8. From the thermal image, the area A' was considered to have internal voids, the area B' to be sound and the area C' was already collapsed. In the area A', the rebound value R was 24.46 and therefore the compressive strength F_c was calculated by Eq. 1 as 7.88 N/mm^2. In the area B', the rebound value R was 28.24 with F_c 10.77 N/mm^2. The compressive strength of the area B' is about 3 N/mm^2 larger than that of the area A'. In the area A', it is believed that the internal deterioration separates the decorative material from the wall concrete. For this reason, it seems that the rebound value measured by Schmidt hammer became small. The internal state of structures affects the rebound value and thus Schmidt hammer can detect internal deterioration.

The rebound value of area C' was 37.95 with F_c 18.19 N/mm^2, which was much larger than those of the areas A' and B'. Therefore, it was found that the both areas A' and B' have internal deterioration and, in particular, it is remarkable in the area A'. However, the area B' was estimated sound from the thermal image. Accordingly, if the deterioration spreads in a wide area, the selection of comparison objects is very important to avoid wrong diagnosis.



(a) (b)

Figure 8. The measured data on June 27, 2013. (a) The measurement area by Schmidt hammer and (b) the thermal image.

CONCLUSION

In this study, basic measurements of deterioration for a concrete retaining wall were carried out by infrared thermography, rotary hammer and Schmidt hammer methods. In the deterioration evaluation by rotary hammering and thermography, the both evaluation results were consistent. Thus, it was found that the deterioration diagnosis by a thermography camera is effective for concrete infrastructures. Rotary hammering test is an easy and simple diagnosis method but it cannot be used for a large extent of structures in a short time. Hence, infrared thermography is considered to be very effective to confirm the shape and size of internal deterioration quickly. In the deterioration evaluation by Schmidt hammer and thermography, two deteriorated areas were detected by Schmidt hammer but one of them was not detected by thermography. From the rebound values by Schmidt hammer, it is considered that the both areas have internal deterioration and the retaining wall is deteriorated significantly as a whole.

The diagnosis by a thermography camera detects deterioration from the temperature difference with respect to the surrounding. Therefore, comparison areas have to be selected carefully to prevent overlooking of deterioration. To do this, thermal images of a healthy state of structures need to be captured before deterioration is in progress and it is considered that accurate evaluation is possible by comparing the multi-temporal thermal images.

REFERENCES

Aggelis, D.G., E.Z. Kordatos, D.V. Soulioti and T.E. Matikas (2010). "Combined use of thermography and ultrasound for the characterization of subsurface cracks in concrete," *Construction and Building Materials*, 24, 10, 1888-1897.

Cerdeira, F., M.E. Vázquez, J. Collazo and E. Granada (2011). "Applicability of infrared thermography to the study of the behaviour of stone panels as building envelopes," *Energy and Buildings*, 43, 8, 1845-1851.

Cheng, C.C., T.M. Cheng and C.H. Chiang (2008). "Defect detection of concrete structures using both infrared thermography and elastic waves," *Automation in Construction*, 18, 1, 87-92.

Dogyu Sangyo Co., Ltd. (2014). "Exterior Wall Testing Device" http://www.dogyu.jp/product/test/

Fuji Bussan Co., Ltd. (2014). "Schmidt Concrete Test Hammer Type N and NR". http://www.fuji-bussan.co.jp/seihin/index_1_1.html

McCann, D.M. and M.C. Forde (2001). "Review of NDT methods in the assessment of concrete and masonry structures," *NDT & E International*, 34, 2, 71-84.

Nippon Avionics Co., Ltd. (2014). "Infrared Thermal Camera and Industrial Measuring Instruments" http://www.avio.co.jp/english/products/infrared/index.html

Yeh, P.L. and P.L.Liu (2008). "Application of the wavelet transform and the enhanced Fourier spectrum in the impact echo test," *NDT & E International*, 41, 5, 382-394.