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Monitoring the Placing of Concrete by Infrared Image Analysis

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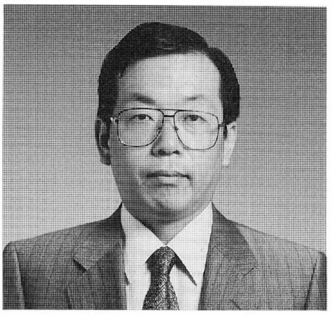

Tadashi WATANABE Taketo UOMOTO

ABSTRACT

The authors propose the use of thermal image measurement of the external surface of forms as a means of achieving realtime detection of concrete defects such as voids and honeycombing during the placing of concrete. Research was carried out to investigate a method of thermal image processing to make more quantitative and objective identification of defects possible. Using image processing to display the temperature rise at the external surface of a form caused by the difference in temperature of the placed concrete, the threshold value of the temperature rise was set and binary or ternary image processing carried out. This made it possible to quantitatively identify of defects.

Keywords: Concrete placing, Consolidation, Form, Thermogram, Image analysis

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1. INTRODUCTION

To make concrete construction of high quality and durability possible, it is essential to maintain strict control of placing. It has been suggested that early deterioration can be prevented by placing defect free concrete of the required quality [1]. However, there is currently no way to achieve realtime control and inspection objectively, and it is necessary to rely on the judgement of experienced engineers. The authors have already proposed a method for realtime monitoring of the level of placed concrete and the adequacy of consolidation, as well as the detection of voids or honeycombing caused by segregation of the concrete, by observing a thermal image of the outer surface of the form while placing the concrete [2 – 6]. The purpose of this research has been to make more quantitative and objective determination of defects possible by improving the way image processing technology is applied .

2. OUTLINE OF THE METHOD

As can be seen from the example shown in figure 1, the temperature of concrete is usually different from the ambient temperature. This means that if the temperature of the form is taken as being about the same as the ambient temperature, there will be a temperature difference between the concrete and the form. The porposed method makes use of this temperature difference. An infrared imaging device provides a thermal image of a form that has undergone a temperature change due to concrete being placing into it. The method allows noncontact, twodimensional observation of the temperature distribution. The thermal image is used to distingish the art of the form containing concrete from tha not yet filled, and at the same time detect areas of inadequate consolidation [2 – 6]. Figure 2 shows an example of a steel form into which concrete 2.5℃ – 5.0℃ above the form temperature has been poured and the change in temperature of the outer surface of the form during consolidation, as measured with an infrared imaging device. The relative temperature variation ratio, plotted on the vertical axis, is the ratio of the rise in temperature of the insufficiently filled region of the form to the rise of the completely filled region, i. e. where the fill is 100%. Although there is some degree of scattering, the degree of fill is almost proportional to the relative temperature variation ratio, and the temperature of voids is almost equal to the theoretically anticipated ambient temperature. This means that the degree of concrete consolidation can be determined by measuring the change in temperature of the outer surface of the form.

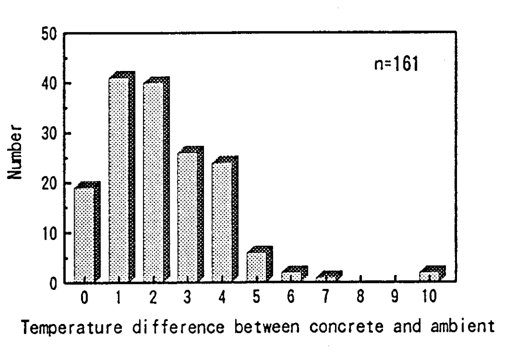


Fig. 1 Example of Temperature Difference Between Concrete and Ambient

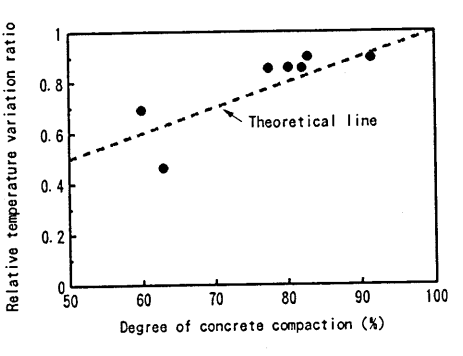


Fig. 2 Relationship between Degree of Fill and Relative Temperature

3. OUTLINE OF EXPERIMENTAL METHOD

The experiment used two models, as shown in figure 3. Model 1 was used to investigate the image processing method; model 2, to investigate the suitability of the technique when the form is in direct sunlight.

In both cases a steel form was used. The dimensions and shape of form no. 1 are shown in figure 3 (a), concrete with a slump of 8 cm having been placed in two separate layers. A 15 cm PVC pipe was buried in the first layer to simulate a void and a poker vibrator used to consolidate the cocrete. When placing the second layer, to simulate honeycombing due to poor localized consolidation, two rows of 6 mm diameter reinforcing bars with a 2 cm thick protective covering were layed in the concrete in a lattice pattern with a vertical spacing between the bars of 10 cm and a horizontal spacing of placing 7. 5 cm. After placing the concrete, the upper 10 cm was compacted with a poker vibrator but the lower 20 cm was left uncompacted. The dimensions and shape of form 2 are shown in figure 3 (b), this time a void being simulated using expanded polystyrene. The form was put outside where it would be in direct sunlight and concrete of slump flow 50 cm poured into it in a single operation and without consolidation.

The performance fugures of the infrared imaging device are shown in table 1. The infrared image data was recorded on a floppy disk using drive built into the equipment, and after the test the deta was analyzed using a generalpurpose personal computer.

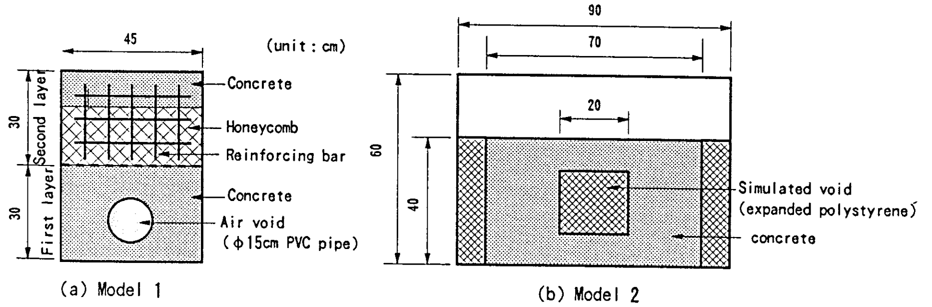


Fig. 3 Experiment Models

Table 1 Performance of the infrared imaging device

Range of temperature measurements (℃)	−40 ～ 950
Infrared detctor	InSb
Width of detection wavelength (micrometer)	3 ～ 5. 4
Minimum detection temperature (℃)	0. 1
Frame time (second)	0. 03
Moment visual field (mill−radian)	2. 2
Number of scanning line	100

4. TEST RESULTS AND IMAGE PROCESSING RESULTS

4. 1 Thermal Image Measuremet Error

As the performance of the infrared imaging depends on the device used, the scope and limitations of the equipment must be to considered [7, 9]. Before starting the experiment, the calculation frequency and setting sensitivity of the infrared imaging device were examined, as was the effect of measuring distance on measurement error levels. Using as a target object blackbody tape of emissivity 0. 96 attached to the external surface of the indoor form, the standard deviation of the 50 picture elements of the thermal image was determined. The results are shown in figure 4 (a), (b) and (c).

The measured value of the standard deviation of temperature varies greatly with the calculation frequency, n, and the setting sensitivity, SN, being inversely proportional to $1/\sqrt{n}$ and proportional to SN. Therefore to improve the measuring precision the calculation frequency must be increased while reducing the setting sensitivity. Also, although the effect was not relevant within the cotext of the experiment, it is essential to bear in mind that as the measuring distance, L, increases, the target object area per picture element, d, will increase according to the formula L·w/1000, where w is the instantaneous angle of view in milliradians.

The standard deviation can be considered to include both the variation due to nonuniformity of temperature and the variation due to measurement error. So these results are a reminder that when interpreting a thermal image in which the relative difference in temperature is used as the basis for identification, even if the temperature appears from the image to be uniform, this level of error is included.

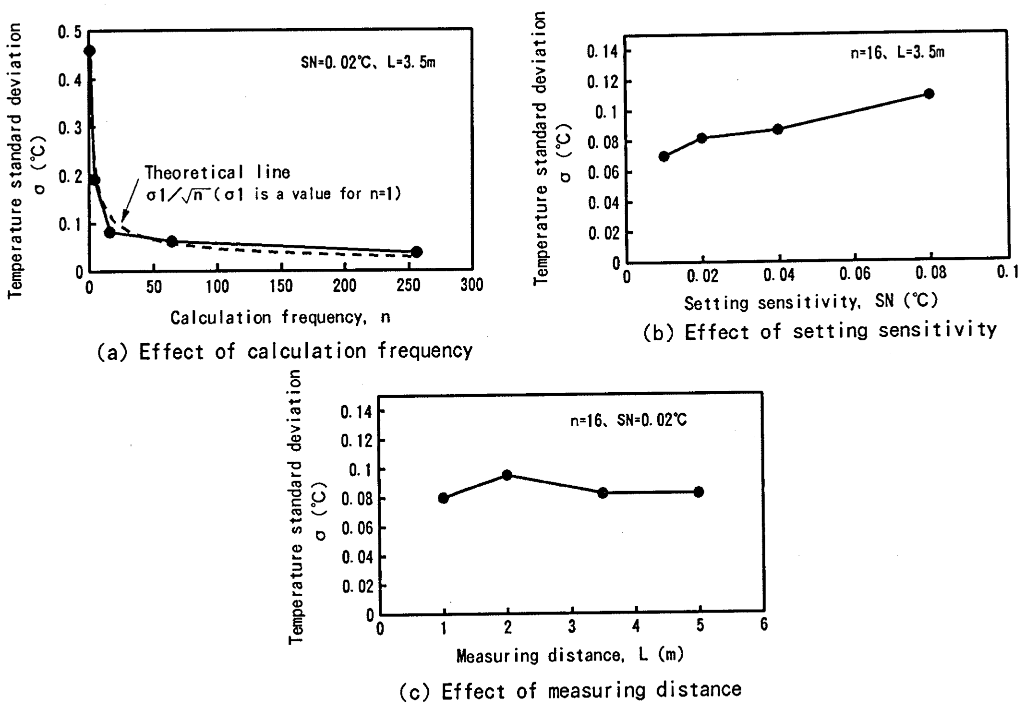


Fig. 4 Relationship between Measurment Condition and Measuring Error

4.2 Thermal Image Acquisition Results

Photograph 1 shows the external appearance of the form used for the model 1 test; only the right half was used for placing the concrete. Photograph 2 shows the concrete after removal of the form, the photography, voids can be seen in the first layer of the lower half, and honeycombing in the second layer of the upper half.

Photographs 3 (a) and (b) show the thermal image of the form surface at the time of placing the concrete. At the time of the experiment, the temperature of the concrete was 20℃ and the temperature of the form (ambient temp erature) before placing was 15℃. The thermal image was acquired in 256 gradation color with a calculation frequency of 32 times at a setting sensitivity of 0.04℃ and at a measuring range of 4.0 m. Photograph 3 (a) is the thermal image acquired immediately after pouring the first layer of concrete and compacting it with the vibrator. The area of the voids is clearly seen to be coler than the surrounding concrete. Photograph 3 (b) shows the thermal image acquired after pouring the second layer and compacting only the upper 10 cm. The void portion of the first layer has become indistinguishable because of heating of the form in that area during the 5 minutes that have elapsed since the first layer of concrete was poured. The temperature of the honeycomb part of the second layer, although slightly lower than the surrounding concrete, could not be clearly confirmed.

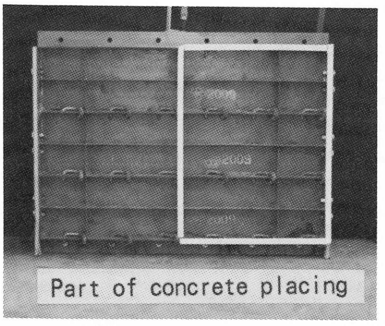


Photo. 1 External Appearance of Form

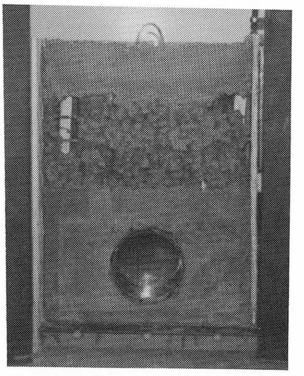
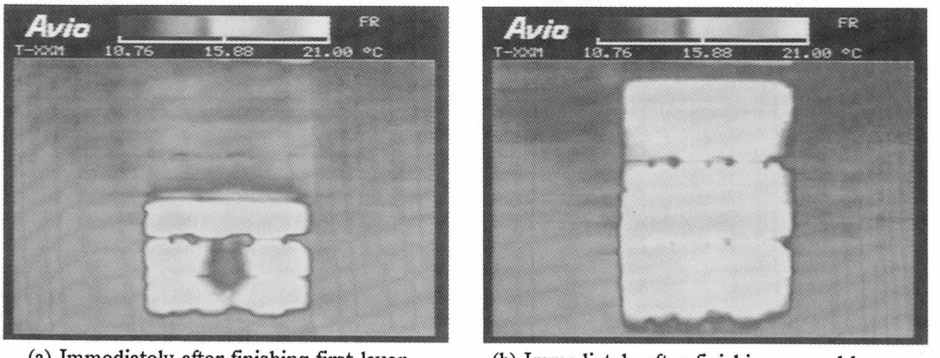


Photo. 2 Visible Image after Removing



(a) Immediately after finishing first layer (b) Immediately after finishing second layer

Photo. 3 Thermal Image of Form during Concrete Placing

4. 3 Investigation of Defect Detection Using Image Analysis

The failure to detect honeycombing described above shows that clear evidence is sometimes not obtainable with the thermal image alone. Image processing was then carried out using the following procedure.

(1) A time sequence inter-picture operation was carried out and the temperature rise due solely to the concrete being placed extracted.

(2) To make the image clearer, it was processed to increase the contrast by converting the displayed temperature width within the permissible dynamic range.

(3) To enable objective and quantitative identification of defects, a threshold value is selected based on the distribution of temperature measurements within the thermal image obtained in step 2, above, and ternary image processing carried out.

The actual content of the above processing and the results are as follows:

(1) Inter-image Differential Processing and Temperature Conversion Processing

Interimage processing involves operating on each corresponding picture element of sequentially received images. If the observed value at time A is XA, and the value at time B, XB, then in general.

$$y = f(XA,\ XB), \qquad (1)$$

where various formulas are given for the function f [10]. What is required here is the rise in temperature due to the concrete being placed so the differential operation process (XA − XB) was carried out.

To convert the display temperature, the setting sensitivity was reduced and the temperature of each picture element Z ($a \leqq Z \leqq b$) linearized to Z' by the following formula [11]:

$Z' = \{ (Zk - Z1)(Z - a)/(b - a \} + Z1,$ (2)

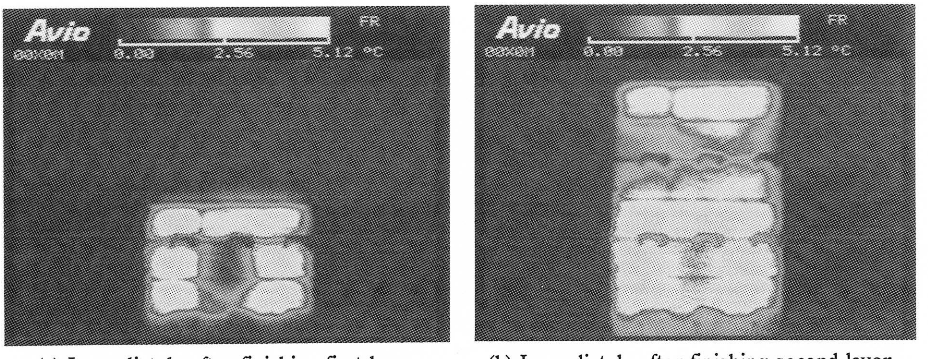
where Z' is the image output temperature,

Z is the image input temperature,

Z1 and Zk are the maximum and minimum allowable temperatures, and

a and b are the maximum and minimum input temperatures,

photographs 4 (a) and 4 (b) show the processed image (differential image) obtained by subtracing values of the thermal image obtained prior to placing each level of concrete (as shown in photographs 3 (a) and 3 (b)) from the thermal image acquired just after placing the concrete, and converting the displayed temperature range to the original thermal image setting sensitivity of 0.02℃. In this way, with interimage differential processing, the sequentially differing temperatures can be extracted. So although the voids in the first layer and the honeycombing in the second are cooler than the surrounding concrete, they are easier to distinguish than in the original image. Most of the regions experiencing no change in temperature are due to form jointing, and as previously described [2 − 6], it was impossible to determine the condition of the concrete in these areas.



(a) Immediately after finishing first layer (b) Immediately after finishing second layer

Photo. 4 Differential Image

(2) Thermal Image Processing

Next, selection of the threshold value will be considered. In general the methods used to choose threshold values for binary image analysis can be divided into several major types: fixed threshold value processing, automatic threshold value determination, and dynamic threshold value processing [10, 11]. In this research, the following must be remembered:

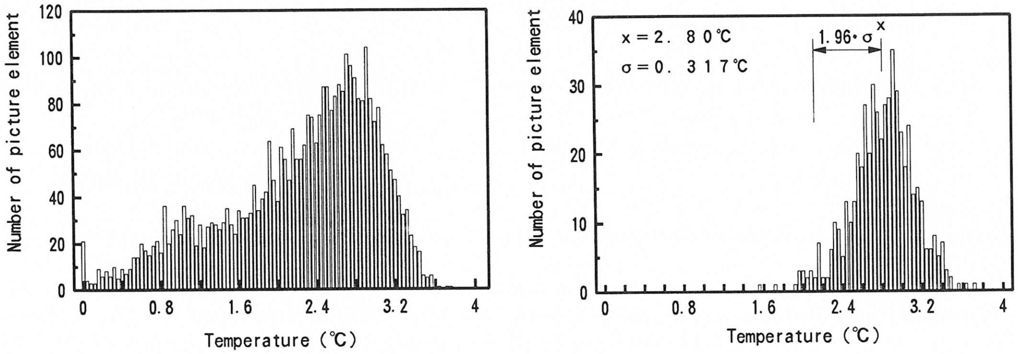
1. As stated in part 3 above, the measurement error varies with changes in the measuring conditions.
2. It is important to bear in mind that the difference in temperature between the form and the concrete is not constant.

Figure 5 (a) is a histogram based on differential image photograph 4 (a) of the form temperature (picture element temperature) of the first of layer concrete. Two temperature peaks can be seen, one at around 1 ℃ and the other at around 2.6℃. It can be inferred that the hightemperature areas represent regions where the concrete has filled the form, and the lowtemperature areas represent voids. The method where the threshold value is based on the part of the image judged to have been filled with concrete was investigated. In other words, as the filled part represents the region of hightemperature differential, the part above the void (approximate height 5 cm and width 40 cm) was selected as the datum region. The histogram for that region is shown in figure 5 (b). The image element temperature follows an approximately normal distribution with a mean temperature of 2.80℃ and a standard deviation of 0.317. Therefore, to specify the fill region with 97.5% probability, it is necessary to take a threshold value of 1.96s (where s is standard deviation) less than the mean temperature X; that is, $2.80 - (1.96 \times 0.317) = 2.18$℃, as t1 and any temperatures lower than that are to be taken as inadequately filled regions. Also, an additional threshold value, t2, can be set at $1.96s = 1.96 \times 0.317 = 0.62$℃ to eliminate the error arising for interimage processing. In other words, as shown below, the threshold values with respect to the temperature difference T, t1 and t2, are determined and ternarized (3 quasi color display).

T ≧ tl (= 2.18 ℃) : Concrete filled region (displayed red)
tl > T > t2 : Incompletely filled region (displayed blue)
T ≦ t2 (= 0.62 ℃) : Region where temperature change has not occurred, mostly background (displayed white)

The processed image is shown in photograph 5. It shows the result of taking the differential image of the concrete just after placing layer 1 (photograph 4 (a)) and ternarizing; then with the first layer processed image frozen, photograph 4 (b) was also ternarized using the same threshold value. If this processed image is compared with photograph 2, which shows the external appearance of the concrete after removal of the form, the size and position of the void show close agreement. As for the honeycombing of the second layer, although the top and bottom regions on the right are shown as filled regions, overall there is a good match.

In this way it was shown that by displaying the differential image, obtained by subtracting the initial thermal image of the outer surface of the form before placing the concrete from the thermal image acquired just after placing, it is possible to isolate the parts that have undergone a change in temperature, and so it becomes easier to identify and ascertain the nature of defects than with the original image.



(a) First layer (b) Filled part of first layer

Fig. 5 Histogram of Form Temperature

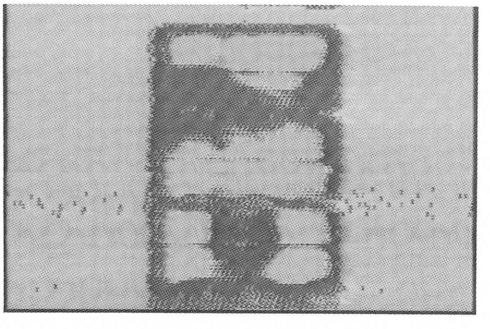


Photo. 5 Processed Image (Three Color Image by Thresholding)

4.4 Fill Ratio Determination

An investigation of the fill ratio determinable by this method makes use of the fact that the fill ratio shown in figure 2 is proportional to the relative temperature change ratio. Figure 6 shows curves obtained utilizing the standard deviation, s, and the value of t from the t distribution table with the mean temperature of the filled part of the form X. Using these, a one-sided test on the relative temperature change ratio as t X s/X, to define the limits of determinability of the adequately and inadequately filled regions as related to probability.

The example given shows curves calculated for values of the coefficient of variation, s/X, over the range 2% to 10% in 2% increments. Figure 7 shows the relationship between fill ratio and relative compressive strength, (relative value gained by taking strength as 1 for 100% fill ratio), [12].

What can be said from figures 6 and 7, is that with respect to the quality of various structures, if the problematic fill ratio can be fixed, then in order to recognize the regions having lower fill ratios, prior decision of the necessary thermal image acquisition conditions can be carried out and quantitative supervision is made possible.

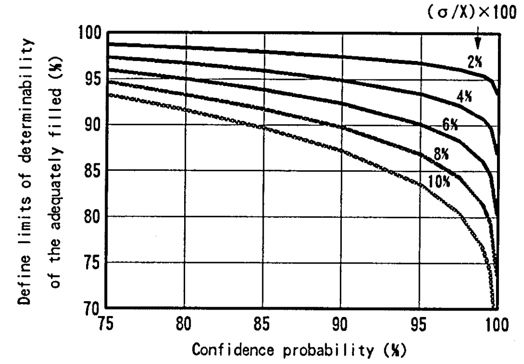


Fig. 6 Defined Limits of Determinability of Adequate Fil

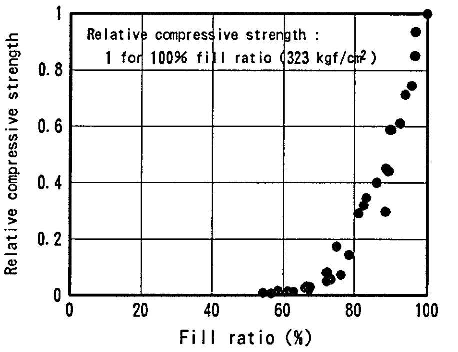


Fig. 7 Relationship between Fill Ratio and Relative Compressive Strength

4.5 Applicability In Cases Of Direct Sunlight

As actual concrete placing is often carried out in cases where the surfaces of the form are exposed to direct sunlight an investigation was carried out to ascertain the applicability of the proposed method under such conditions. Model 2 was used for this experiment; it was put outside and the concrete placed. The temperature of the concrete at the time of the test was 20.7℃ and the air temperature around the form was 26.9℃, in the shade the temperature was 19.0℃. The thermal image was filmed in 256-gradation color with a calculation frequency of 16 times at a setting sensitivity of 0.04 or 0.05℃ and at a measuring range of 4.5 m. The external appearance of the form is shown in photograph 6. Photograph 7 shows the concrete after removal of the form where honeycombing can be seen to the left of the expanded polystyrene used to simulate a void.

Photograph 8 (a) is the thermal image taken just before placing the concrete and photograph 8 (b) is the thermal image taken just prior to completion of placing. In both images, unevenness can be seen in the form surface temperature. This is because the exposure to sunlight is not uniform over the form surface due to shadows caused in some places by such things as form ribs. However, even in this case a difference in temperature occurred between the regions where concrete had been placed and where it had not been placed, and the region where the polystyrene had been used to simulate a void was distinguishable.

The same image processing was applied to the filmed thermal image as that described in the previous section. However, for the differential processing in this case, because the form temperature had fallen in the region where concrete had been placed, the image obtained prior to completion of the placing, figure 8 (b), was subtracted from that obtained before placing, figure 8 (a), the temperature difference was extracted and temperature conversion (setting sensitivity 0.03 ℃) was carried out. The results of this can be seen in photograph 9. In this image the lower region of the form considered to be filled with concrete was selected and the mean temperature and standard deviation obtained, the mean temperature was found to be 5.310℃ and the standard deviation was 0.747℃. Using these values the threshold value tl becomes 5.310 − 1.96 X 0.747 = 3.846. The threshold value, tl, was set with regard to the temperature difference T and binarization (2 quasi-color display) carried out.

T ≧ tl (= 3.846℃) : Concrete filled region (displayed red) t1 > T : Incompletely filled region or background (displayed white)

The processed image is as shown in photograph 10. Overall, it can be concluded that it matches well the external appearance of the concrete after form removal, shown in photograph 7. In particular it can be seen that the honeycombing to the left of the polystyrene that occurred during placing was distinguishable. From the above it can be concluded that even in situations where the form surfaces are in direct sunlight, the image processing method described in the previous section can be applied to provide a quantitative determination of the defects.

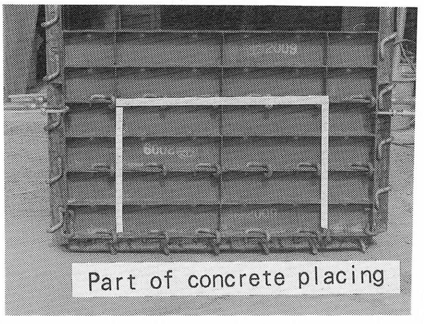


Photo. 6 External Appearance of Form

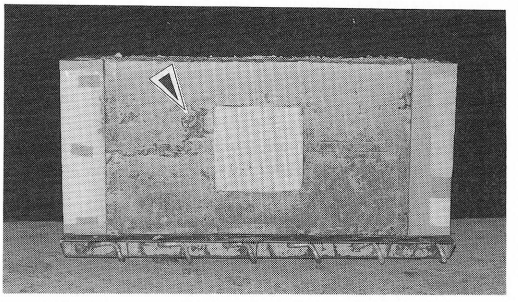
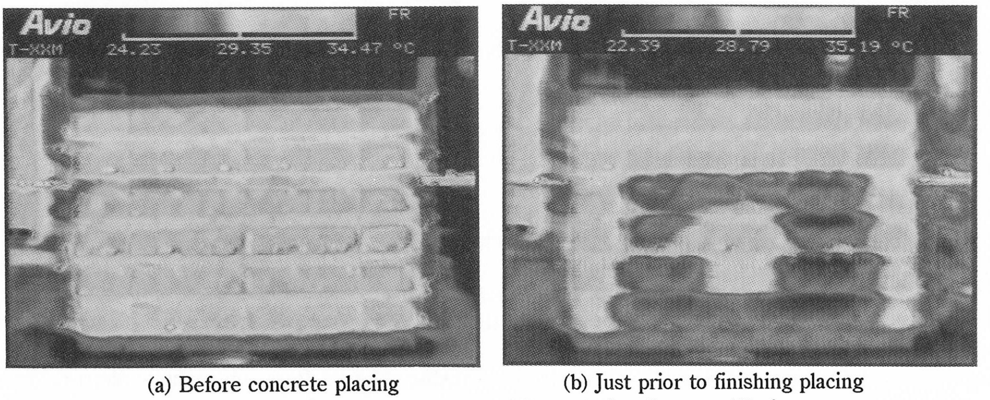


Photo. 7 Visible Image after Removing



(a) Before concrete placing (b) Just prior to finishing placing

Photo. 8 Thermal Image of Form during Concrete Placing

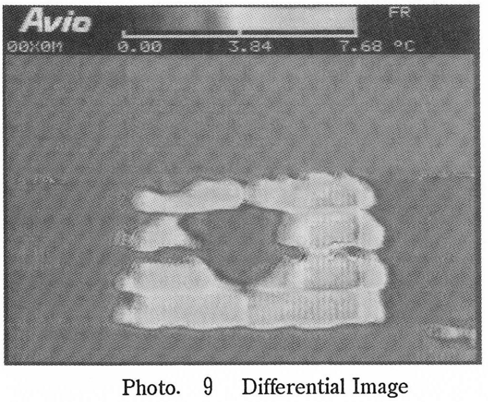


Photo. 9 Differential Image

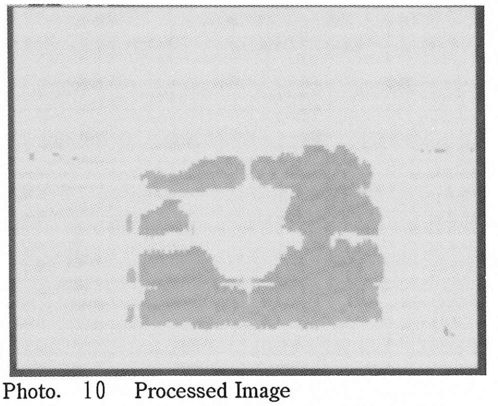


Photo. 10 Processed Image (Two Color Image by Thresholding)

5. CONCLUSIONS

The following conclusions were arrived at as a result of this experiment.

(1) In acquiring the thermal image, the performance of the device, the measuring conditions and the nature of the object being measured are all contributory factors to error so it is essential to consider these when interpreting the image.

(2) By inter-image differential processing of the thermal images of the form outer surface before and after placing the concrete, it is possible to isolate the parts that have undergone temperature change and it becomes easier to identify defects than with the original image.

(3) By selection of the threshold value for the temperature change and applying quasi-color binarized or ternarized image processing, defects and their nature can be objectively discriminated.

(4) A suitable threshold value should be selected according to the temperature variation of the concrete filled region while taking due account of the errors caused by the measuring conditions or the temperature distribution caused by the nature of the form surface.

(5) It was confirmed that the image processing method above was applicable even when the form is in direct sunlight.

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