DISCUSSION ON THE RELATION BETWEEN THE INTERNAL TRANSFORMATION OF CONSTRUCTION AND SURFACE TEMPERATURE JOINTLY USING THE THERMAL IMAGE AND HEAT BALANCE MODEL

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ABSTRACT

Many of civil engineering constructions have superficial and internal transformation along with the elapse of time. High attention is gathered on the investigation method using thermal image as it allows effective investigation by non-destructive and non-contact methods. In the application of this method, it is necessary to know in advance what kind of time serial changes in temperature the construction surface may show under specific conditions

In this study, we made thermal image observation and empirically discussed the relation between the environmental change and construction surface temperature. Also, we studied the heat balance model to predict the time serial temperature change of structure under the outdoor environment.

As a result of this study, we were able to clarify that the environmental changes such as in the atmospheric temperature and solar insolation would exert great influence on the surface temperature of construction which had a internal transformation. We were also able to construct a heat balance model which can predict with fairly high accuracy the temperature change of construction reflecting these environmental conditions.

1. INTRODUCTION

Many of civil engineering constructions have superficial and internal transformation due to the deterioration along with the elapse of time. Especially, in the case of concrete bridge, there is an apprehension that the surface layer concrete may exfoliate because of the corrosion of internal reinforcement bars. High attention is gathered on the investigation method using thermal image for the diagnosis of exfoliation locations as it allows effective investigation by non-destructive and non-contact methods.

This method places focus on the fact that the existence of internal exfoliation gives an influence on the apparent thermal capacity of surface layer of construction and, in turn, on the surface temperature of the construction, and judges the existence and situation of the exfoliation by measuring the temperature distribution of construction surface. On the other hand, the surface temperature of construction is influenced to large extent by the environmental conditions such as insolation and atmospheric temperature in addition to the existence of exfoliation. In the application of this method, therefore, it is necessary to know in advance what kind of changes in temperature and what kind of time serial change the construction surface may show under specific conditions.

One of the methods for this purpose is to measure the surface temperature of a construction or test structure which has deformation by some means, and accumulate the data of time serial changes under various conditions. In the past researches, however, the studies were concentrated mainly on the test structures, and the adequate studies have not been made on the time serial changes of actual outdoor structures under the various conditions. Another method is to make a model of thermal balance at the surface and inside of construction, and to determine time serial temperature change under the various conditions by theoretical calculation. However, since there were problems in structure of model and setting of parameter in the past studies, it is not likely to have accurately identified the actual time serial temperature change.

In this study, we made thermal image observation on the slab and rail of bridge having an internal exfoliation, and empirically discussed the relation between the environmental change of outdoor and time serial change of construction surface temperature. Also, we studied the heat balance model which is necessary to accurately predict the time serial temperature change of structure under the outdoor environment.

2. GENERAL DESCRIPTION OF THE STRUCTURE USED FOR THE ANALYSIS

The structure used for the analysis is a concrete bridge. It has reinforcing bars at the depth of 30 mm from the surface, and internal exfoliation has taken place at some parts of it due to the corrosion. At the parts where the exfoliation is intense, the structure and surface layer are completely separated, which can be detected from the surface shape. However, the extent of separation is small at most parts of exfoliation, and is difficult to visually confirm from a remote place. Since the bridge has a height of more than 10 m, it takes much labor to confirm the state of exfoliation by touching it. It can be said an effective object for non-destructive, non-contact investigation based on thermal image.

In this study, we selected the slab and rail of the bridge as the objects of observation and analysis taking into account the difference in the conditions of insolation. Figure 1 shows the schematic shape of the structure and the study locations. As the slab are located behind the bridge deck and are free from the insolation all the day, the surface temperature of structure is considered to be governed only by the atmospheric temperature change. Also, since the rail have vertical surfaces facing the due south and are exposed to solar radiation during some time range in a day, the surface temperature of the structure is considered to be determined by the combination of insolation and atmospheric temperature change. The purpose here was to identify the influence of different environmental conditions exerted on the actual temperature change of structure. Also, it was one of the purposes to make a model of heat balance between the surface and internal temperatures of structure under the outdoor environment, apply it to the structure under study, and to discuss the possibility to logically trace the actual temperature change of the structure.

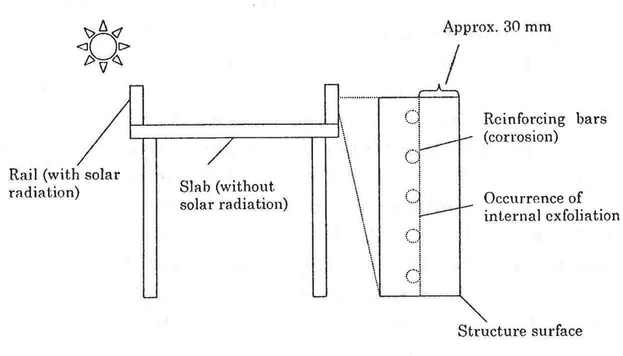


Figure 1: Schematic shape of structure

3. EQUIPMENT USED FOR THE STUDY

Table 1 shows the detailed list of equipment used for the study. A sensor of long wave type was used for the observation of thermal image as it is insensitive to the influence of reflective light components. Also temperature / humidity sensor and actinometer were used to observe the environmental conditions. Contact thermometer was used to measure the temperature at specific locations of structure surface to use it for the temperature calibration of thermal image.

Table 1: Details of equipment used

Type	Name of equipment	Details
Thermal image sensor	AVIONICS TVS-2000LW	Range of detecting wavelength : 8～12 μm Temperature resolution : 0.1℃ Measuring accuracy : ± 0.4 % (full scale)
Temperature / humidity sensor	VAISALA HMP-132Y	Accuracy of temperature : ± 0.2℃(at the time of 20℃) Accuracy of humidity : ± 2～3%(same as above)
Actinometer	EKO MS-42	Sensitivity : 7mV/kW·m^{-2}
Contact thermometer	ADVANTEST TR2114H	Temperature resolution : 0.1℃ Measuring accuracy : ±0.3℃

4. METHODS OF OBSERVATION / ANALYSIS

The Figure 2 shows the methods of observation and analysis. The detailed description of each item is shown in the following.

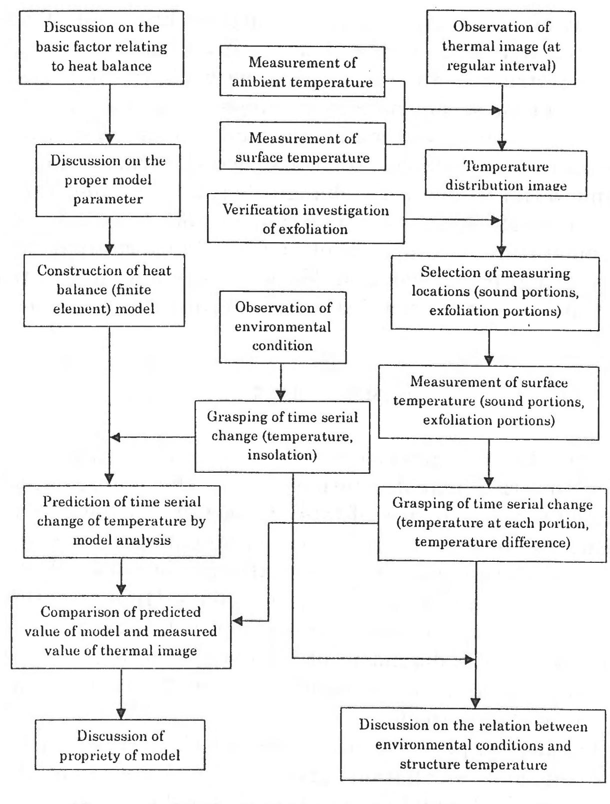


Figure 2: Method of observation and analysis

On-site Observation: We acquired each kind of data used for the analysis by the on-site observation. We observed the thermal image by a regular interval of, for example, one hour, and acquired the time serial images. The environmental conditions such as temperature and insolation were continuously measured by automatic recorder and summarized as the time serial data. Also, we measured the specific locations of structure surface temperature by a contact thermometer to calibrate the temperature of thermal image. Furthermore, in order to identify the typical locations of exfoliation, we made verification investigation after the observation by removing the surface layer of the study area.

Grasping of Time Serial Changes: The observed thermal images were converted into temperature distribution images referring to the measured value of environmental temperature sensor incorporated in the thermal image sensor and actually measured surface temperature. Then, we extracted typical exfoliation portions and sound portions based on the result of exfoliation verification, measured the surface temperatures of those portions at each specific time by temperature distribution image, and acquired the time serial data.

Discussion on Relation between Environmental Condition and Temperature of Structure: We compared the time serial change of pattern of thermal image, measured surface temperature and temperature difference with the time serial change of environmental condition, and discussed the relation between them.

Construction of Heat Balance Model: We extracted the basic factors relating to the heat balance between the structure surface and internal structure. Also, discussion was made on how to select the appropriate parameters for the model. We constructed a heat balance model to predict the time serial change of structure surface temperature by first constructing the finite element model of structure surface and then incorporating therein the extracted factors and parameters relating to heat balance.

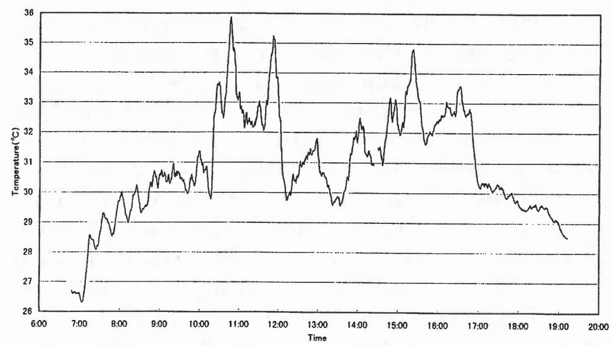
Discussion on the Propriety of Heat Balance Model: We applied the environmental conditions measured at the site to the constructed heat balance model, and predicted the time serial change of structure surface temperature by the model analysis. And then, we discussed the propriety of model by comparing the result of prediction with the measured value of time serial change of surface temperature obtained from the thermal images.

5. RESULT OF OBSERVATION / ANALYSIS BY THERMAL IMAGES

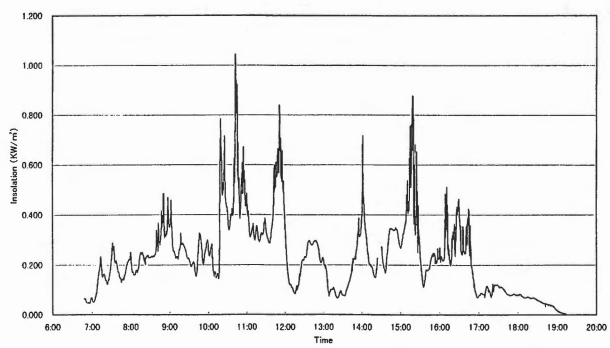
5.1 Result of Rail Observation / Analysis

5.1.1 Environmental Condition at the Time of Rail Observation: The observation was made on July 15, 1997. Figure 3 shows the time serial change of environmental condition at the time of rail observation. The weather of that day was cloudy and occasionally fine and insolation changed acutely, and therefore, the temperature at the observation site showed a drastic change. Especially, the cloud became thick and there was hardly any insolation between 12:00 and 14:00, and accordingly, the temperature showed lower values. It was different from typical environmental condition under the fine weather all day long, but in some sense, it was a general condition that we may have frequently.

5.1.2 Observation Result of Rail on Thermal Images: Figure 4 shows the time serial change of rail on the thermal image. In the figure, white portion shows the high temperature and black portion indicates the region of low temperature. From the time of observation start at 7:00 to 12:00, the portion of exfoliation shows the white color, indicating that it has higher temperature comparing with the sound portions. The portion of exfoliation becomes indiscernible after 13:00 but it shows white pattern (high temperature) again from 14:00 to 15:00. After becoming indiscernible at 16:00, it shows clear black pattern after 17:00 indicating that it has lower temperature comparing with the sound portions. This state is maintained until the end of observation at 19:00.

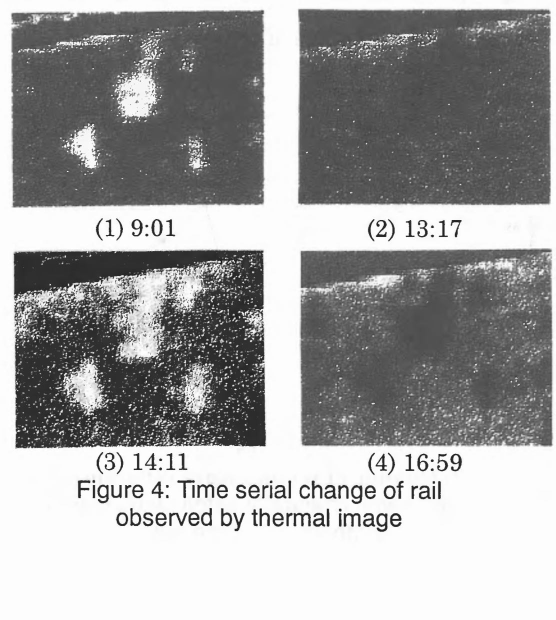


(1) Atmospheric temperature



(2) Insolation

Figure 3: Environmental conditions at the time of rail observation

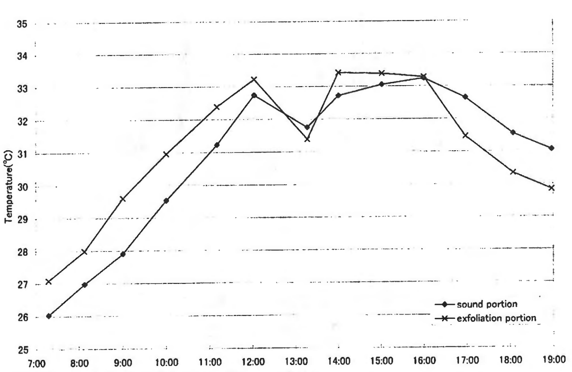


(1) 9:01 (2) 13:17

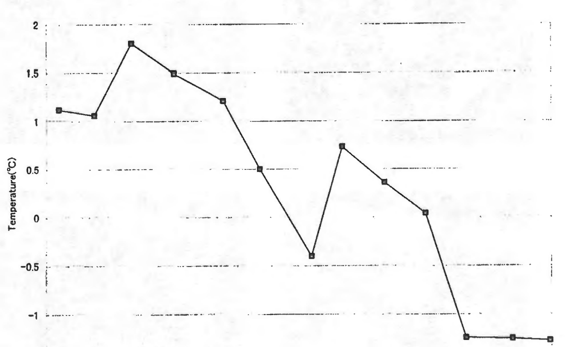
(3) 14:11 (4) 16:59

Figure 4: Time serial change of rail observed by thermal image

5.1.3 Result of Temperature Analysis of Rail: Figure 5 shows the time serial change of surface temperature and temperature difference between exfoliation portion and sound portion based on the thermal image observation. As shown in Figure 5 (1), it is clear that the surface temperature of both sound portion and exfoliation portion repeats up and down along with the change of environmental condition. Especially, at around 13:00, the temperature shows acute decline by about 2 ℃ susceptively reflecting the decrease of temperature resulting from the reduction of Insolation. This tendency is more conspicuous in the temperature difference between exfoliation portion and sound portion. As shown in Figure 5 (2), the exfoliation portion clearly shows the tendency of higher temperature by 1 – 2℃ comparing with the sound portion during the time from 7:00 - 12:00, but reversing phenomenon takes place at 13:00 as the exfoliation portion shows the tendency of lower temperature, though be it very slight, by about 0.5℃ comparing with the sound portion. After recording the high temperature tendency again, the exfoliation portion shows the temperature difference of 0℃ at 16:00 and then exhibits the second reversing phenomenon. After 17:00, it maintains clear tendency of low temperature by 1℃ or more. This result shows in more detail the qualitative tendency seen from the thermal image patterns described in 5.1.2 above. As stated in the above, it was confirmed that the surface temperature of exfoliation portion and sound portion sensitively reflect the change in environmental conditions indicating the possibility to create various patterns of time serial change.



(1) Change of temperature



(2) Change of temperature difference

Figure 5: Time serial change of exfoliation / sound portion temperature at the rail

5.2 Result of Slab Observation / Analysis

5.2.1 Environmental Conditions at the Time of Slab Observation: Observation of slab was conducted on December 4. 1996. Figure 6 shows the time serial change of environmental conditions at the time of slab observation. Only the air temperature was measured (by contact thermometer) because the slab were not exposed to solar radiation. The weather of that day was fine and subsequently cloudy. Therefore, the air temperature rose rapidly by nearly 10℃ between 7:00 and 13:00, but it stayed at almost constant level after 13:00 though there was a slight trend of decrease. Similarly with the case of rail observation, it was not a typical environmental condition but is general condition we may commonly encounter.

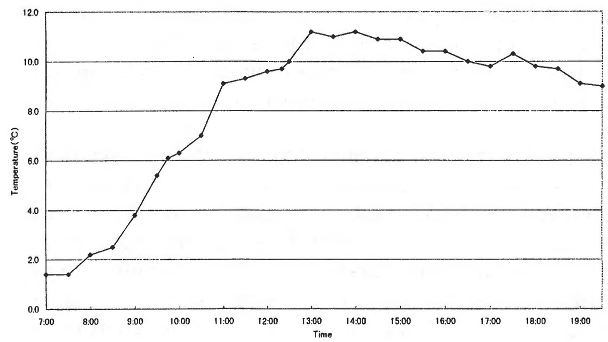
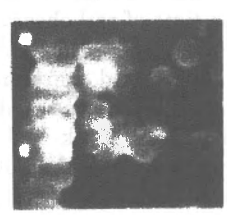


Figure 6: Environmental condition (atmospheric temperature) at the time of slab observation

5.2.2 Observation Result of Slab on Thermal Image: Figure 7 shows the time serial change in thermal image observation of slab. The exfoliation portion was almost indiscernible before 9:00 when the observation was started. However, it showed vague white color at 10:00 indicating that it has higher temperature than the sound portions. At 12:00 it indicated clear white (high temperature) pattern, and although the clearness was lost to some extent, this tendency was maintained until 19:00 when the observation was terminated.


(1) 8:50


(2) 10:03


(3) 11:57

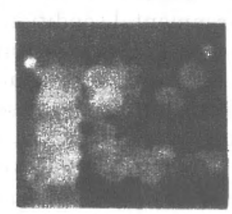
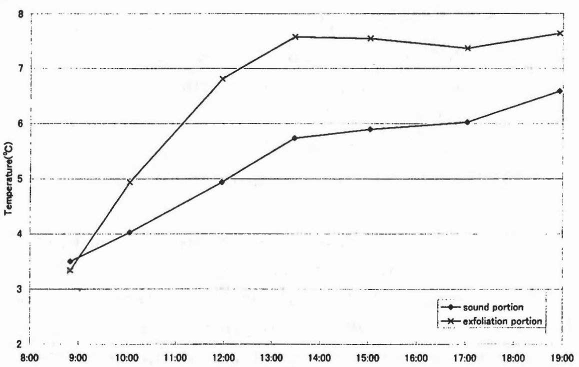
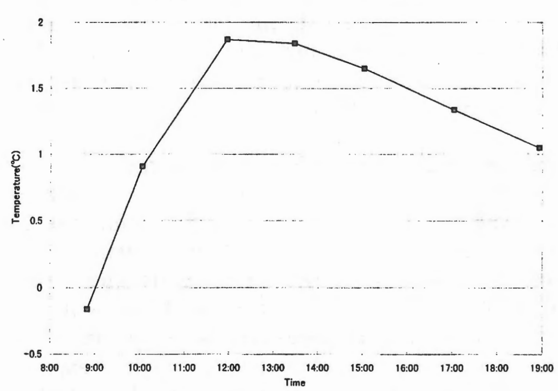

(4) 18:56

Figure 7: Time serial change of slab observed by thermal image

5.2.3 Result of Temperature Analysis of Slab: Figure 8 shows the time serial change in the surface temperature of and temperature difference between the exfoliation portion and sound portion based on the thermal image observation. As shown in Figure 8 (1), both sound portion and exfoliation portion showed the temperature change almost faithfully along with the change of atmospheric temperature. Unlike the case of rail, it is noted that the trend of change is rather gradual because the slab are not influenced by the insolation which may change acutely. A slight increase of temperature is observed at 19:00 comparing with 17:00.



(1) Change of temperature



(2) Change of temperature difference

Figure 8: Time serial change of exfoliation / sound portion temperature at slab

As for the temperature difference between exfoliation portion and sound portion as seen in Figure 8 (2), the exfoliation portion had the tendency of slightly lower temperature by about 0.2℃ comparing with the sound portions before 9:00 when the observation was started. However, along with the increase of atmospheric temperature, it turned to show the higher temperature than the sound portions. The temperature difference reached to the peak of approximate 2℃ from 12:00 to 13:00, and the exfoliation portion maintained the tendency of higher temperature until 19:00 although there was a gradual trend of decrease. There was no reversing phenomenon of temperature as seen in the case of rail. This is considered to be an influence of environmental condition (there is almost no change in the atmospheric temperature in the afternoon). As stated in the above, it was confirmed that the surface temperature of both exfoliation and sound portions creates the pattern of time serial change faithfully reflecting the change of environmental conditions. It was understood from the comparison with the rail that the pattern of temperature change would change substantially according to the environmental condition such as the existence or otherwise of insolation, etc.

6. CONSTRUCTION AND ANALYSIS RESULT OF HEAT BALANCE MODEL

6.1 Construction of Heat Balance Model

6.1.1 Discussion on basic factors: Basically, the surface temperature of structure is dictated by heat conduction in the internal structure and heat convection at structure surface and internal boundary (such as internal transformation) as well as the heat radiation. Figure 9 shows the basic structure of heat balance model. The details of basic factors and their treatment in the model can be summarized as follows.

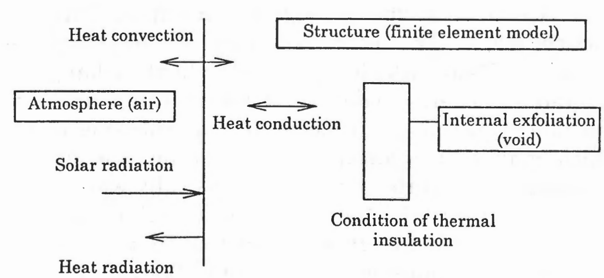


Figure 9: Basic structure of heat balance model

Heat Conduction at the Internal Part of Structure: Out of these factors, the heat conduction at the internal part of structure is a factor which shows the transfer of thermal energy generated by the irregularity of temperature distribution (temperature difference). The basic theory of it is indicated by Fourier's partial deferential equation (example of one-dimension) of heat conduction as shown in Equation (1) below.

$$\partial T / \partial t = (\lambda / C p \rho)\, \partial^2 T / \partial x^2 \qquad (1)$$

T : Temperature (K)
λ : Thermal conductivity (W/m・K)
Cp : Specific heat (W・s/kg・K)
ρ : Density (kg/m3)
x : Distance (m)

In our study, we decided to construct a finite element model of two-dimension which indicates the actual cross section geometry (including the exfoliation) of study object structure, and to obtain the temperature distribution of internal part and surface of structure at each time range by applying a differential method obtained by developing the Equation (1)

Heat Convection at the Boundary Section of Structure Surface, etc.: Heat convection at structure surface is a factor which indicates the heat exchange generated between the structure surface and atmosphere. As expressed in Equation (2), the heat flux originating from the heat convection is proportionate to the deference between structure surface temperature and atmospheric temperature.

$$q = h\ (T_1 - T_2) \qquad (2)$$

q : Heat flux at the structure surface (W/m^2 : when the direction of the outside of structure is taken as positive)
h : heat transfer coefficient ($W/m^2 \cdot K$)
T_1 : Surface temperature of structure (K)
T_2 : Atmospheric temperature (K)

This factor was incorporated in the model as a factor to determine the environmental condition on the structure surface. Although there is a possibility that heat balance takes place at the internal exfoliation section due to the heat convection, the exfoliation section (void) has little temperature difference with the structure and its influence is small; therefore, we treated it as thermally insulated condition in our study.

Heat Radiation at the Boundary Section of Structure Surface, etc.: The heat radiation at the structure surface is a factor which indicates the heat exchange by the radiant energy balance. If there is not adjacent substance (such as a structure at a neighboring place) which makes substantial heat radiation, the energy flowing in (or out) the structure is basically worked out from the balance of incident energy by solar radiation and electromagnetic energy emitted from structure surface in accordance with the Stefan - Boltzmann's law as expressed by Equation (3).

$$E = \sigma T 4 \qquad (3)$$

E : Emissive power (W/m^2)
σ : Stefan - Boltsmann's constant ($5.67 \times 10^{-8} W/m^2 \cdot K^4$)
T : Surface temperature of structure (K)

Similarly to the heat convection, this factor was incorporated in the model as a factor to give the boundary condition of the structure surface. The internal exfoliation was also treated as the thermally insulated condition.

6.1.2 Discussion on the Model Parameters: In addition to the basic factors, we discussed how to determine each model parameter so that the energy balance under the outdoor environment can be expressed as close as possible to the actual phenomena. Especially, we mainly discussed the model of solar radiation which gives large influence the thermal distribution on the structure surface.

Calculation of Diffuse Solar Radiation Energy: Solar radiation energy is a factor which gives the largest influence on the surface temperature when the structure is located at sunny place. Therefore, the accuracy in making its model is an important issue to enhance the precision of assumption of surface temperature distribution. The solar radiation energy is composed of direct radiation component and diffuse radiation component. Out of them, the diffuse radiation component is equal to the sky light, and has less energy volume comparing with the direct radiation component and gives smaller influence on the surface temperature of structure. However, since the energy volume of diffuse radiation component would become large in relative terms under the condition that the direct radiation component is not present and it has an omnidirectional nature, its energy volume must be calculated separately from the direct radiation component which has the directional nature. In our study, we decided to calculate the solar radiation energy for each time range by the Equation (4).

$$I_s = 1.2\, I_0 \sin h (1\text{-}P)(1\text{-}P^{\mathrm{cosec}h}) / (1\text{-}1.4 \log_e P) \qquad (4)$$

I_s : Diffuse solar radiation energy (W/m^2)
I_0 : Solar radiation outside the atmosphere (W/m^2)
h : Altitude of sun (degree)
P : Atmospheric transmittance

Since the solar radiation outside the atmosphere and altitude of sun can be worked out directly from the positional relation between sun and earth, they were defined as the functional type parameter of date and time. Also, the atmospheric transmittance may vary according to the weather condition, we determined it to be 0.6 as an average value in summer season. This calculation was conducted only for the investigation of rail. Since the slab are not exposed to solar radiation including the diffuse radiation, we treated it as zero in the model in case of the slab.

Calculation of Direct Solar Radiation Energy: Direct beam component has a large energy volume and gives significant influence on the surface temperature of structure. Since it has a directional nature and the volume of incidental energy is heavily dependent on the relation of orientation of structure with the altitude and azimuth of sun, it is necessary to make an accurate model of it in the case of structure which is exposed to the direct radiation component. In this study, we defined the Equation (5) for the rail which can be considered to have vertical surface facing the due south, and made a model to calculate the energy of direct solar radiation on such surface by each time range.

$$I_d = (I_h - I_s) \cot h \sin \theta \qquad (5)$$

I_d : Direct solar radiation energy (W/m^2)
I_h : Insolation on horizontal plane (W/m^2= actually measured value)
I_s : Diffuse solar radiation energy (W/m^2= the value obtained by Equation (4))
h : Altitude of sun (degree)
θ : Azimuth of sun (degree)

Similarly to the calculation of diffuse radiation component, we defined the altitude and azimuth of sun as the function of date and time. When the diffuse radiation energy component obtained by Equation (4) was larger than the solar radiation measured on the horizontal plane, we deemed that the total solar radiation energy is composed of the diffuse solar radiation, and no correction was made to it. Namely, we inputted the value of insolation measured on the horizontal plane into the model as the diffuse radiation energy (incidental energy) without adding any correction.

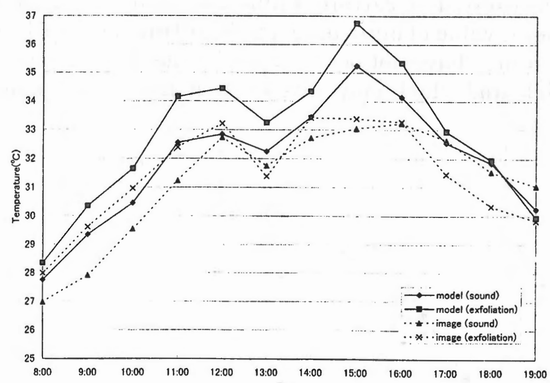
Other Parameters: We defined each parameter necessary for the calculation other than the solar radiation energy as shown in Table 2. We gave the value of general concrete as the physical property of structure material referring to the existing literatures. The limited factor model of structure was made in a form considering the situation of actual exfoliation of the structure. Strictly speaking, the heat transfer coefficient of structure and atmosphere is influenced by the wind velocity, etc., but we defined it as an average constant value taken from the existing literatures. Also, we employed general value of concrete for the thermal emissivity and solar radiation absorptance. As for the initial temperature of structure when the calculation was started by this model, we gave the atmospheric temperature of that time to all the elements as a constant value. The calculation step of the model was decided to be 10 minutes.

Table 2: List of parameters given to the model

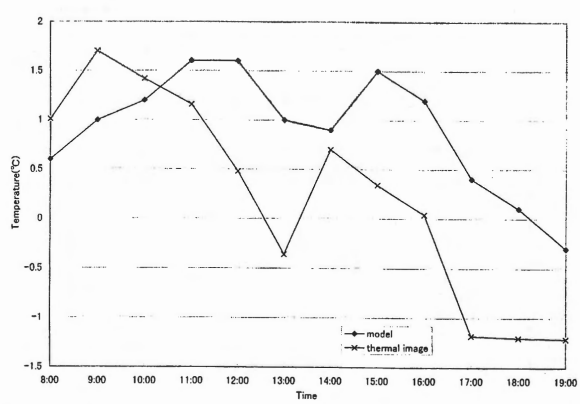
Items	Set value
Density of structure material	2100kg/m^3
Specific heat of structure material	900J/kg · K
Thermal conductivity of structure material	1.75W/m · K
Thermal emissivity	0.98
Solar radiation Absorptance	0.7
Heat transfer coefficient	25W/m^2 · K
Insolation	Insolation actually measured on a horizontal plane at the site
Atmospheric temperature / humidity	Actually measured value at the side and the data of AMEDAS
Initial temperature of structure	Initialized by the atmospheric temperature at the time of start of calculation
Calculation time step	10 minutes

6.2 Result of Analysis Made by the Heat Balance Model

6.2.1 Analysis Result of Rail: Figure 10 shows the comparison between the value of rail calculated by the model and measured value of thermal image. When the time serial change of temperature at each portion is compared, the value calculated by model has a tendency to show a higher temperature comparing with the value of thermal image for both sound portions and exfoliation portions. But the difference is around 1℃ on average and trend of temperature change pattern is quite similar. Therefore, it is considered that the change in surface temperature of rail section can be predicted with a fair accuracy by the heat balance model we constructed. On the other hand, the temperature difference between measured value and model calculation value increases to 2 – 3℃ at around 15:00 o'clock. As shown in the insolation measuring data of Figure 3, the insolation (on horizontal plane) becomes relatively large in this time range, and when it is converted into incidental energy volume imposed on actual structure having the vertical plane facing the due south, the energy volume becomes the largest among all the time ranges. Therefore, some unsolved issues are considered to be still remaining as for the calculation accuracy of actual incidental energy.
As for the time serial change of temperature difference between each portion, a good coincidence is observed between the model calculation value and measured value of thermal image similarly as in the case of temperature. However, there are some inconsistent points such as the temporal difference in the peak point of time serial change pattern of temperature difference. This is considered to be influenced by the calculation accuracy of incidental energy as mentioned in the above, set value of physical property of structure material, setting of initial temperature at the time of calculation start, etc.



(1) Change of temperature

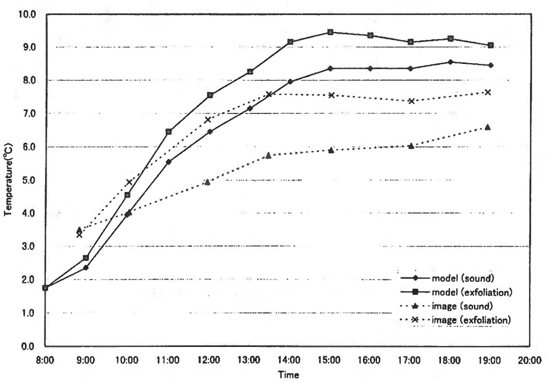


(2) Change of temperature difference

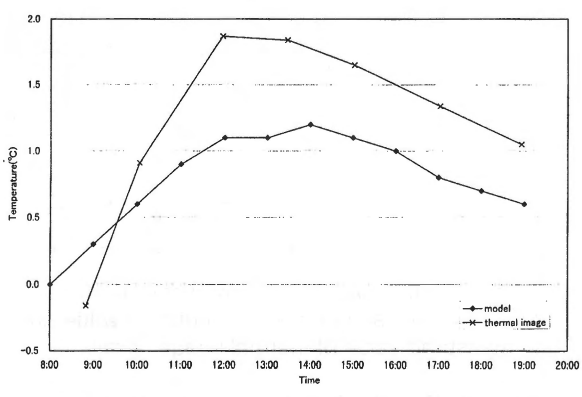
Figure 10: Comparison of model calculation value and measured value of thermal image of rail

6.2.2 Analysis Result of Slab: Figure 11 shows the comparison between the value of slab calculated by the model and measured value of thermal image. When the time serial change of temperature at each portion is compared, the value calculated by model has a tendency to show a higher temperature comparing with the value of thermal image for both sound portions and exfoliation portions. Especially, the difference in the sound portions is 2 – 3℃, which is substantially larger comparing with the case of rail. However, since the trend of temperature change pattern is coincidental, it is considered that the change in the surface temperature of slab can be predicted by the heat balance model with a certain degree of accuracy. On the

other hand, the trend of slight increase of temperature (or constant temperature) during 17:00 - 19:00 as mentioned above is also indicated by the value of model calculation. As a result, it was confirmed that these phenomena have been caused by the change of external environment (atmospheric temperature) and that this situation can be reproduced by the heat balance model.
As for the time serial change of temperature difference between each portion, the difference between the model calculation value and measured value of thermal image is around 0.5℃ on average indicating that they are relatively coincidental as in the case of temperature. However, the temperature difference increases to rather large value a little less than 1℃ during 12:00 - 14:00 o'clock. We regarded the solar radiation energy as zero in our present calculation, but there is a possibility that the diffuse radiation from the vicinity of bridge may have exerted a certain influence. Also, we used the general value of outdoor as the heat transfer coefficient, but it may have not been proper for the closed space like a slab, and which may have exerted another influence.



(1) Change of temperature



(2) Change of temperature difference

Figure 10: Comparison of model calculation value and measured value of thermal image of rail

7. CONCLUSION

It was confirmed through the observation of thermal image in our present study that the surface temperature of structure having internal transformation is largely influenced by the change of environment such as atmospheric temperature and insolation. In this context, it is considered to be inevitable to clarify the pattern of temperature change taking into account the environmental condition at the time of observation in order to accurately diagnose the structure using the thermal image. We studied the heat balance model which can be used for this purpose, and was able to construct a model which can predict the surface temperature of structure reflecting these environmental conditions with a substantial level of accuracy. Also, we could understand that it is necessary to set each parameter relating to the model more precisely in order to predict the surface temperature of structure with higher accuracy.
Through the present study, it was confirmed that the pattern of temperature change can be predicted by a model calculation for the surface of structure actually located at the outdoor. However, in the case of actual structure, the environmental conditions and the situation of structure itself are interrelated complicatedly each other. Therefore, it should be necessary to acquire the data necessary for identifying these conditions in order to detect the causes of error and to enhance the accuracy of prediction by model. It is considered to be necessary in the future to conduct the experimental observation using a different test object and to discuss the propriety of model parameters basing thereon in order to discuss the heat balance model more strictly for the structure itself. Also, it can be pointed out as a future issue to establish an accurate transformation diagnosis model based on the surface temperature predicted by the heat balance model and the surface temperature actually measured by the thermal image.

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