Thermal Distribution in the Direction of Depth in Concrete Structure Located Cold Region

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Abstract

The most important deterioration phenomenon which should be considered to evaluate the durability and predict the service life of a concrete structure in a cold region is frost damage. The frost damage is related to the thermal change in freezing point of water and the saturation of the concrete. This study examines the thermal characteristics of concrete at freezing and thawing and calculates thermal diffusivity before and after freezing in order to obtain basic data to predict the number of freezing and thawing cycles from weather data by measuring thermal distribution in a coastal levee located Abashiri, Hokkaido.

In this study, thermal diffusivities and the change of temperature in the concrete at the freezing and thawing phase was calculated.

1. INTRODUCTION

The most important deterioration phenomenon which should be considered in order to evaluate the durability and prediction service life of concrete structure in cold region are frost damage. The frost damage relates on the concrete. This study examines the thermal characteristic of concrete at freezing and thawing and calculated thermal diffusivity before and after freezing in order to obtain basic data to predict the number of freezing and thawing cycles from weather data.

2. PROCEDURE

2-1 MEASURING PROCEDURE

The measurement of temperature in concrete structure, which was a coastal levee, was carried out under cold sea environment as shown in Fig. 1. The structure is located on the Okhotsk coast, Hokkaido. The depth of measured points from concrete surface are 8, 33, 52, 103, 202, 402 and 663mm and the sensors were thermo-couples buried at construction.

2-2 CALCULATING PROCEDURE OF THERMAL DIFFUSIVITY

The origin is set at the surface of concrete and the axis is set in the direction of the depth.

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The temperature of concrete is expressed as a function of depth z and time t in the form.

$$\partial \frac{\theta}{\partial t} = k^2 \frac{\partial^2 \theta}{\partial z^2} \quad \cdots\cdots\cdots\cdots\cdots(1)$$

where K^2 is thermal diffusivity.

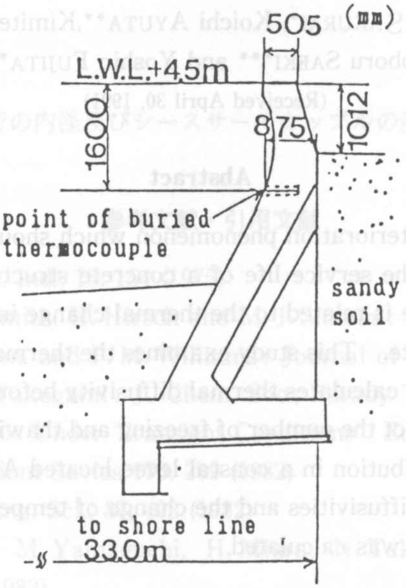

Fig. 1 Outline of coastal levee where temperature was measured

3. CONCLUSION

3-1 RESULT OF MEASURING TEMPERATURE IN CONCRETE

The daily change of temperature on November 2, December 2 and December 14 are shown in Fig. 2. It shows that the effect of atmospheric temperature and sunshine is large down to the depth of 103mm.

The daily maximum and minimum temperature at the depth of 8mm, 33mm and 103mm in the coastal levee are shown in Fig. 3. The difference of temperature near surface were largest which means that number of cycles of freezing and thawing are many.

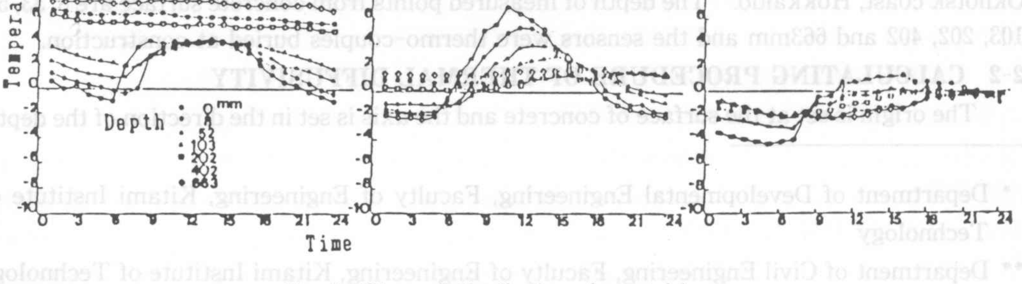

Fig. 2 Thermal distribution of coastal levee

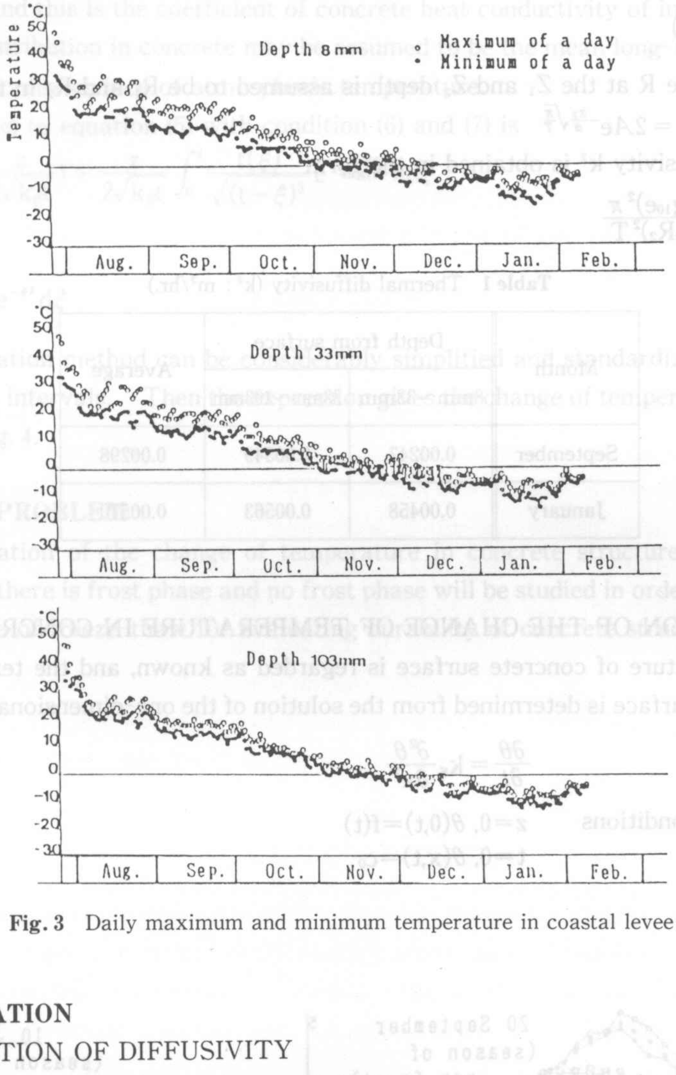

Fig. 3 Daily maximum and minimum temperature in coastal levee

3-2 CALCULATION

(1) CALCULATION OF DIFFUSIVITY

The result of the calculation of thermal diffusivity from the above data is shown in Table 1. It was 0.00298m²/hr. in September and 0.00510m²/hr. in January on average. The reason why January rate is higher is because contained water in concrete freeze at low temperature.

If the temperature at z=0 is expressed in Fourier series, the solution of equation (1) is obtained in the form.

$$\theta_{zt} = A_0 + A_1 e^{-\frac{z}{\alpha}\sqrt{\frac{\pi}{T}}\sin(\frac{2\pi}{T}\cdot t - \frac{z}{\alpha}\sqrt{\frac{\pi}{T}})} + \cdots + \mathrm{An}^{\mathrm{e}-\frac{Z}{\alpha}\sqrt{\frac{\pi}{nT}}\sin(2\frac{\pi}{nT}t - \frac{Z}{\alpha}\sqrt{\frac{\pi}{nT}})} \quad \cdots\cdots\cdots\cdots\cdots(2)$$

The change of temperature in a day at surface of concrete can be expressed approximately as sine curve and the first term of the solution is sufficient for ordinary purpose in the following form.

$$\theta_{zt} = A_0 + A_1 e^{-\frac{z}{\alpha}\sqrt{\frac{\pi}{T}}\sin(\frac{2\pi}{T}t - \frac{z}{\alpha}\sqrt{\frac{\pi}{T}})} \quad \cdots\cdots\cdots\cdots\cdots(3)$$

Since the maximum and minimum temperatures in the concrete are within −1 and +1 for following form,

$\sin(\frac{2\pi}{T}t - z\sqrt{\frac{\pi}{T}})$

and the difference R at the Z_1 and Z_2 depth is assumed to be R_1 and R_2 in the form

$R_1 = 2Ae^{-\frac{z_1}{\alpha}\sqrt{\frac{\pi}{T}}}, R_2 = 2Ae^{-\frac{z_2}{\alpha}\sqrt{\frac{\pi}{T}}}$

the thermal diffusivity k^2 is obtained in the form

$$k^2 = \frac{(z_2 - z_1)^2(\log_{10}e)^2\pi}{(\log_{10}R_1 - {}_{10}R_2)^2 T} \qquad \cdots\cdots\cdots\cdots\cdots(4)$$

Table 1 Thermal diffusivity (k^2 : m^2/hr.)

Month	Depth from surface		Average
	8mm~33mm	33mm~103mm	
September	0.00247	0.00349	0.00298
January	0.00458	0.00563	0.00510

(2) CALCULATION OF THE CHANGE OF TEMPERATURE IN CONCRETE

The temperature of concrete surface is regarded as known, and the temperature field below concrete surface is determined from the solution of the one-dimensional heat equation,

$$\frac{\partial\theta}{\partial t} = k_g \frac{\partial^2\theta}{\partial x^2} \qquad \cdots\cdots\cdots\cdots\cdots(5)$$

with boundary conditions $z = 0, \theta(0,t) = f(t)$ ……………(6)

$t = 0, \theta(x,t) = c_0$ ……………(7)

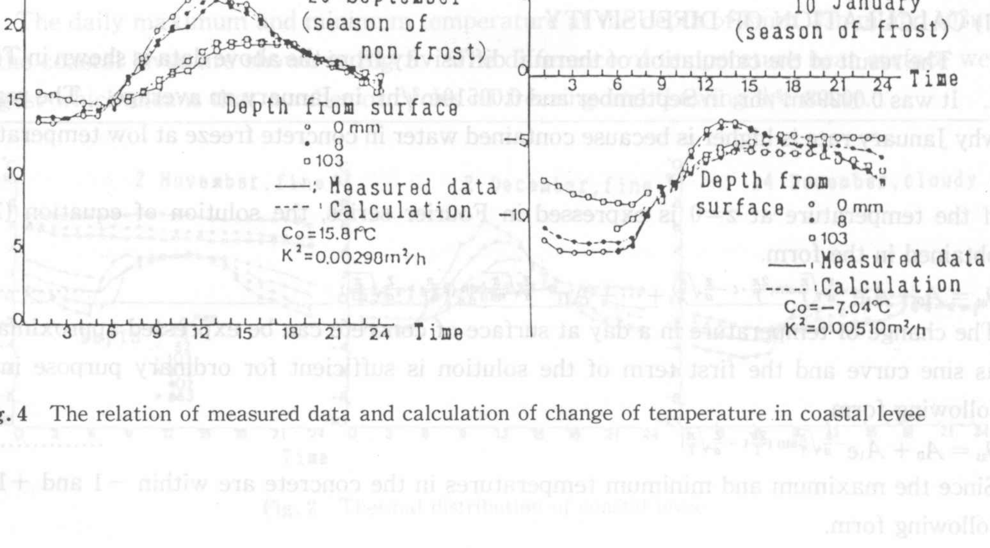

Fig. 4 The relation of measured data and calculation of change of temperature in coastal levee

where $kg = k^2$ and this is the coefficient of concrete heat conductivity of inside. The initial temperature distribution in concrete may be assumed to be the mean long-term temperature of the near concrete surface of atmospheric temperature.

The solution to equation (5) with condition (6) and (7) is

$$\theta(z,t) = c_0 \mathrm{erf}\left(\frac{z}{2\sqrt{k_g t}}\right) + \frac{z}{2\sqrt{k_g t}} \int_0^t \frac{t(\xi)}{\sqrt{(t-\xi)^3}} e^{-\frac{z_2}{4kg(t-\xi)}} d\xi \quad \cdots\cdots\cdots\cdots\cdots(8)$$

where

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\xi^2} d\xi \quad \cdots\cdots\cdots\cdots\cdots(9)$$

The calculation method can be considerably simplified and standardized by stipulating with equal time intervals. Then the expression gives the change of temperature of concrete, as shown in Fig. 4.

3. 3 FUTURE PROBLEM

The calculation of the change of temperature in concrete structure in freezing and thawing where there is frost phase and no frost phase will be studied in order to calculate the number of cycle of freeze-thaw for evaluating durability of concrete structure.