General paper

EFFECT OF INITIAL DRY AND WET CONDITIONS OF CONCRETE ON FREEZING AND THAWING RESISTANCE AND MATHEMATICAL ANALYSIS OF DETERIORATION

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Abstract : The authors have already made clear the deterioration mechanism of durability of concrete structures due to the meteorological action, especially, the fundamental mechanism of deterioration due to the dry and wet action and the freezing and thawing action, and the effect of the concrete factors on them. This paper furthermore deals with the effect of the initial moisture content of concrete on the freezing and thawing resistance and analyzes mathematically the concrete factors dominating the elastic modulus of elasticity.

Key words: *Durability, Water content, Freezing and thawing action, Wet and dry action, Surface deterioration*

1 INTRODUCTION

There is an early deterioration of durability as one of the world-wide problems in concrete structures. Especially, the Japan Islands are exposed to severe cold and severe heat owing to the regional characteristics. Therefore, the concept of the construction design must be established under severe conditions from the viewpoint of the environment of a maritime country. Kato, et al.[1] have already verified that fundamentally the water isolation to concrete is most important for the improvement in durability under "the dry and wet action". Furthermore, they[2] dealt with the verifications of the effect of surface protective or permeable type waterproofing agents of concrete on the improvement in durability under "the freezing and thawing test" recognized as the severest condition of the various durability tests, the fundamental mechanism as a process concerning the surface deterioration and the importance of the water isolation to concrete.

This paper deals with the effect of the wet or dry condition of concrete on the freezing and thawing resistance, and the mathematical analysis of the effect of the physical properties of the structural concrete on its dynamic modulus of elasticity as one of fundamental engineering characteristic values.

2 EXPERIMENTAL

2.1 Preparation of Specimen and Mix Proportion of Concrete

The materials used are normal portland cement (S.G.3.16), river gravel (S.G.2.64, F.M.6.57) and river

sand (S.G.2.60, F.M.2.63).

The specimens were the sizes of $100 \times 100 \times 400$ mm, being remolded after one day moist curing, and furthermore cured in water (20 °C) for 14 days.

The half of the total specimens were dried in a constant electric furnace by 100 °C for two hours, and afterwards put back naturally to the room temperature.

The two kinds of water cement ratios, 40% and 60% were adopted as a typical example. The specified mix proportion is shown in Table 1.

The 14 days compressive strengths for the water cement ratios of 40% and 60% were 19.6 N/mm² and 49.0 N/mm², respectively.

2.2 Freezing and Thawing Test

This apparatus is the one tank type and the "freezing in air and thawing in water" system. Its characteristic of temperature, based on JIS A 6204, is +5 °C~18 °C (± 2 °C) and 3~4 hr/cycle. The temperature control chart is shown in Fig. 1.

3 EXPERIMENTAL RESULT

3.1 Weight variation and Surface Deterioration due to Freezing and Thawing Action

Figures 2 (a) and (b) show the weight variation with increase of the freezing and thawing cycles up to 300 cycles in cases of W/C = 40% and 60%, respectively.

It can be seen that the weight of the specimens for both of them increases toward 50 cycles. Especially, the drier the specimen is and the larger the water cement ratio is, the larger the increasing rate is.

Table 1. Mix proportion.

Kinds	Slump (cm)	Air (%)	Sand Percent- age s/a(%)	Water Cement Ratio W/C(%)	Unit Content(kg/m ³)			
					Water W	Cement C	Aggregate	
							Fine S	Coarse G
A	5	1.5	37	40	184	460	603	1085
B	5	1.5	41	60	184	307	719	1092

Fig. 1. Temperature control chart.

Fig. 2. Relationship between weight variation and freezing-thawing cycle.

This fact must mean that the permeation of water into concrete is very easy because both capillary water and gel water in concrete are dehydrated due to drying and then their internal pores become like a kind of sponge.

Figure 3 shows the state of the surface deterioration of concrete. It can be understood that the degree of the surface deterioration of concrete well corresponds to its decrease of weight.

3.2 Variation of Dynamic Modulus of Elasticity due to Freezing and Thawing Action

Figures 4 (a) and (b) show the variation of dynamic modulus of elasticity with increase of the freezing and thawing cycles up to 300 cycles in cases of W/C = 40% and 60%, respectively.

The dynamic modulus of elasticity, generally, decreases with increase of the freezing and thawing cycles as similar as the above-mentioned relationship between the weight variation and the freezing and thawing cycles, so that the gradual increase of the structural loosening resulting from the scaling and the popping-out as the surface deterioration [2] can be considered. Especially, the increasing phenomenon of the dynamic modulus of elasticity of concrete in the

early stage of the freezing and thawing cycles can not only be observed in the present experiment, but also in other papers be found here and there[3]. However, this phenomenon has not yet been made clear.

4 ANALYSIS OF CONCRETE FACTORS INFLUENCING DETERIORATION

4.1 Physical Factors of Durability Deterioration

In general, the dynamic modulus of elasticity E_D can be given by Eq.(1).

$$E_D = 408 \times 10^{-5} \cdot L/A \cdot W \cdot f_1^2 \quad (1)$$

Where, L : length of specimen,

A : cross-sectional area,

W : weight of specimen,

f_1 : first resonant frequency of specimen.

When there is a small amount of variation (δ) in each factor in Eq.(1), let's investigate how much the conditional equation (1) is influenced by them.

Thus,

Fig. 3. Typical examples of surface deterioration.

Fig. 4. Relationship between dynamic modulus of elasticity and freezing-thawing cycle.

$$\delta E_D = (\partial E_D / \partial L) \delta L + (\partial E_D / \partial A) \delta A + (\partial E_D / \partial W) \delta W + (\partial E_D / \partial f_1) \delta f_1 \quad (2)$$

Therefore, the specific variation rate of the dynamic modulus of elasticity due to an incremental variation of each factor can be obtained as shown in Eq.(3), from Eqs.(1) and (2).

$$\delta E_D / E_D = \delta L / L - \delta A / A + \delta W / W + 2 \delta f_1 / f_1 \quad (3)$$

In the present experiment, generally speaking, too, the variations of the length and the cross-sectional area can be neglected, but those of the weight and the first resonant frequency can not be neglected. As for the weight variation, the environmental water ought to permeate into concrete itself and its pores because the thawing action is repeated in water, so that one of prime factors of the increase of the dynamic modulus of elasticity of concrete may be certainly due to the increase of its water content.

It can be understood that the first resonant frequency of the concrete specimen must be carefully measured because it influences the dynamic modulus of elasticity by its square and the variation rate of the dynamic modulus of elasticity is influenced by the twice variation rate of the first resonant frequency.

Fig. 5. Variation rate of first resonant frequency and variation rate of weight.

4.2 Mathematical Analysis of Prime Factors

Generally, the variations of the length and cross-sectional area of the specimen are not remarkable, as above-mentioned. Then, Eq.(3) can be practically approximated as shown in Eq.(4).

$$\delta E_D / E_{D_o} \approx \delta W / W_o + 2 \delta f_1 / f_1 \quad (4)$$

Here, the relationship between $\delta W / W_o$ and $\delta f_1 / f_1$ can be expressed as follows, by using the respective increments in Figs.2 and 4.

In case of W/C=40% :

(a) for dry condition

$$\delta f_1 / f_{1o} = -0.015,911 + 0.049,468\xi - 9.178,13\xi^2 \quad (5)$$

Where, $\xi \equiv \delta W / W_o$ (the rest is all the same.)

The suffix "o" means "the initial state before the test".

(b) for wet condition

$$\delta f_1 / f_{1o} = -0.000,032 + 1.469,4\xi - 105.441\xi^2 \quad (6)$$

In case of W/C=60% :

(a) for dry condition

$$\delta f_1 / f_{1o} = -0.045,651 + 0.772,858\xi - 34.369,5\xi^2 \quad (7)$$

(b) for wet condition

$$\delta f_1 / f_{1o} = 20.354,6\xi - 5,083.27\xi^2 + 412,608\xi^3 - 9.607,33 \times 10^6 \xi^4 \quad (8)$$

Figure 5 shows the relationship given by Eq.(8), as an instance.

Thus, the dynamic modulus of elasticity of concrete which is constituted by the weight variation rate easy to be detectable as a variable can be obtained finally as follows, from Eq.(4) by using Eqs. (5) to (8).

In case of W/C=40% :

(a) for dry condition

$$E_D = E_{D_o} \{ 1.000 + 1.098,94\xi - 18.356,2\xi^2 \} \quad (9)$$

(b) for wet condition

$$E_D = E_{D_o} \{ 1.000 + 3.938,9\xi - 210.882\xi^2 \} \quad (10)$$

In case of W/C=60% :

(a) for dry condition

$$E_D = E_{D_o} \{ 1.000 + 2.545,8\xi - 68.739,0\xi^2 \} \quad (11)$$

(b) for wet condition

$$E_D = E_{D_o} \{ 1.000 + 41.709,2\xi - 10,166.54\xi^2 + 825,216\xi^3 - 19.214,66 \times 10^6 \xi^4 \} \quad (12)$$

Figure 6 shows the relationships given by Eqs.(9) to (12), together.

Fig. 6. Relationship between variation rate of dynamic modulus of elasticity and variation rate of weight.

The dynamic modulus of elasticity increases with increase of the weight ratio till a certain singular point and after that it decreases just to go backward on the increasing path. It is very interesting that there is a kind of "hysteresis phenomenon" between the dynamic modulus of elasticity and the weight of concrete subjected to the freezing and thawing action.

5 CONCLUSION

Although this paper indicates the experimental and theoretical results on the case of comparatively small specimens exposed to the severer temperature condition, designated in JIS and ASTM standards, it may be well considered that the same deterioration of durability occurs fundamentally concerning the actual concrete structure, too.

The concluding resumes are the following.

(1) The drier the specimen is and larger water cement ratio is, the larger the weight reduction is and the severer the surface deterioration is, due to the freezing and thawing action.

(2) The variation of the dynamic modulus of elasticity well corresponds to that of the weight of the specimen.

(3) The weight variation of the specimen is the most prime factor of some factors dominating the modulus of elasticity of concrete.

(4) There is a kind of "hysteresis phenomenon" between the dynamic modulus of elasticity and the weight of concrete subjected to the freezing and thawing action concerning their variation rates.

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