Study of 8,000 Cycles Freezing and Thawing Tests in Air by RC Model Specimen Using Non-linear Exponential Function Models*[1]

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Abstract

The rapid freezing and thawing test specified by ASTM C.666 is carried out in water. However most concrete structures in cold regions are influenced by freezing and thawing in air.

The purpose of this study is to evaluate the durability of reinforced concrete under the influence of rapid freezing and thawing in air. The specimens are reinforced concrete models (RC model specimens) of size 10×10×40 cm.

The results of rapid freeze-thaw tests in air indicate that concrete specimens with a water-cement ratio of 65 % deteriorate more than specimens with lower water-cement ratios. Further, the durability of concrete with a high water-cement ratio, such as 65 %, begins to decrease after 2800 freeze-thaw cycles in air.

A nonlinear exponential function model fitted very well to the results of ultrasonic velocity measurements before and after cycling.

1. INTRODUCTION

Most concrete structures in cold regions suffer directly from a range of weather conditions including strong sunlight, rain, snow, and wind. The effect these have is influenced by variations in temperature, freezing and thawing cycles in particular, as well as by changes in humidity due to the dry air and water penetration. The repeated freezing and thawing of concrete in water is the severest action on reinforced concrete structures in cold region. ASTM C 666 is method of testing its effects, but it is inadequate to evaluate the relationship between rapid freezing and thawing under ordinary conditions and existing concrete structures. In past studies, the authors have carried out accelerated tests under various conditions, exposure tests, and others.[1)]

The purpose of this study is to examine methods of evaluating the durability of reinforced concrete under influence of rapid freezing and thawing tests in air (until about 8,000 cycles), thus matching the actual conditions experienced in cold regions.

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2.Experiment and Examination Method

2. 1 MATERIALS

The properties of the concrete materials used to make the samples are shown in Table 1.

Table 1 Properties of concrete materials

Cement	Fine aggregate ∗	Coarse aggregate ∗	Admixture
Ordinary portland cment Specific gravity : 3.16	Specific gravity : 2.16 Absorption rate : 2.40%	Maximum size : 25mm Specific gravity : 2.66 Absorption rate : 1.63%	AE agent constitution : Anion active agent

∗ Taken from the Satunai river.

2. 2 SPECIMENS

Figure 1 shows the shape and construction of the specimens used for the rapid freezing and thawing tests in air. They are rectangular in shape, 10×10×40 cm. Two model specimens of each water-cement ratio were used in the tests.

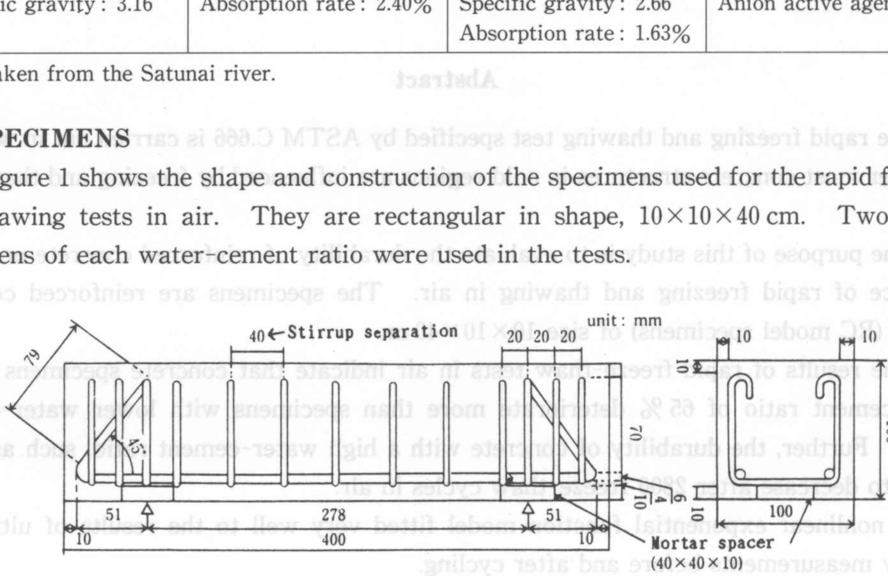

Fig. 1 Size and shape of specimens

2.3MIX PROPORTION

The concrete mix proportions are shown in Table 2. The water-cement ratios adapted for testing are 45 %,55 %, and 65 %.

Table 2 Mix proportions of concrete

Type of cement	W/C (%)	s/a (%)	Specified mix(kg/m³)					Properties of fresh concrete		
			Water	Cement	Fine aggregate	Coarse aggregate	Admixture ∗	Slump (cm)	Air content (%)	Temperature (°C)
Ordinary portland cement	45	31	152	338	564	1277	40.0	4.0	3.8	18.0
Ordinary portland cement	55	33	152	276	616	1286	53.1	9.4	4.7	25.0
Ordinary portland cement	65	34	152	234	647	1289	33.4	11.0	4.2	21.5

∗ : Unit : cc

2.4 METHOD OF RAPID FREEZE-THAW TESTING

One cycle of rapid freezing and thawing in air is completed every 4 hours. The temperature at the center of the specimen is controlled between −17.8 ±1.7°C at minimum and 4.4°C±1.7°C at maximum. Measurements consisted of length, weight, resonance frequency, and ultrasonic velocity. The deterioration indicators used are change in length to initial length ($\times 10^{-6}$), change in weight to initial weight (%), change in relative dynamic modulus of elasticity to the initial value (%) and change in ultrasonic velocity to the initial value (%).

The measurement methods used are as described below.

① The accelerated freezing and thawing test in air began after measuring the initial values when the concrete had aged 28 days. The measurement is carried out every 30 cycles.

② Specimens were removed from the thawing process and kept in a curing room (at 20°C and R.H.80%) for 1 hour before taking measurements.

③ Photographs were taken to record the physical deterioration of the specimens.

The maximum cycles of the rapid freezing and thawing test in air of this experiments at the cases of W/C=45%, 55% and 65%, are about 7,300 cycles, 8,300 cycles and 7,700 cycles, as respectively.

2.5 ANALYSIS

The measurement results of change in ultrasonic velocity to the initial was mostly influenced on resistance to frost damage with ratio of ultimate strength by regression analysis. We developed the following nonlinear exponential function model and estimated appropriate values for coefficients A, B, and C by the method of least square errors.

$$U = A \times CYC \times (\exp(-C \times CYC)) + B \quad \cdots \text{Eq.(1)}$$

where, U is the change in ultrasonic velocity to the initial value(%), CYC is the number of freeze-thaw cycles, and A, B, and C are coefficients.

The coefficient B of initial value was not fixed to 100%, because the initial value is a measurement value with the error of measurement.

3. RESULTS AND DISCUSSION

3.1 RESULTS OF EXPERIMENT

The relationship between the number of freeze-thaw cycles and the change in weight is shown in Fig.2. The change in weight to the initial weight decreased by nearly 50% at around 7,000 cycles in the case of W/C=65%. In the other cases, W/C=45% and W/C=55%, there was little surface deterioration and the decrease in weight did not reach 2%.

The relationship between the number of freeze-thaw cycles and the change in length is shown in Fig.3. The change in length increases from fairly early on in the case of W/ C=65%. In the cases of W/C=45% and W/C=55%, the increase did not begin until around 6,000 cycles. It is about 1% and 0.5% in the case of W/C=55% and W/C=45% at around 8,000 cycles, respectively.

The relationship between the number of freeze-thaw cycles and the change in ultrasonic velocity to the initial is shown in Fig.4. The change in ultrasonic velocity to the initial value was to 55% at around 8,000 cycles in the case of W/C=65%. On the other hand, in the cases of W/C=55% and 45%, it did not decrease until around 6,000 cycles. After around 6,000 cycles, the change in ultrasonic velocity to the initial value decreased about 4% to the peak value in the case of W/C=55%, whereas it was scarcely decreased at all to the peak value in the case of W/C=45%.

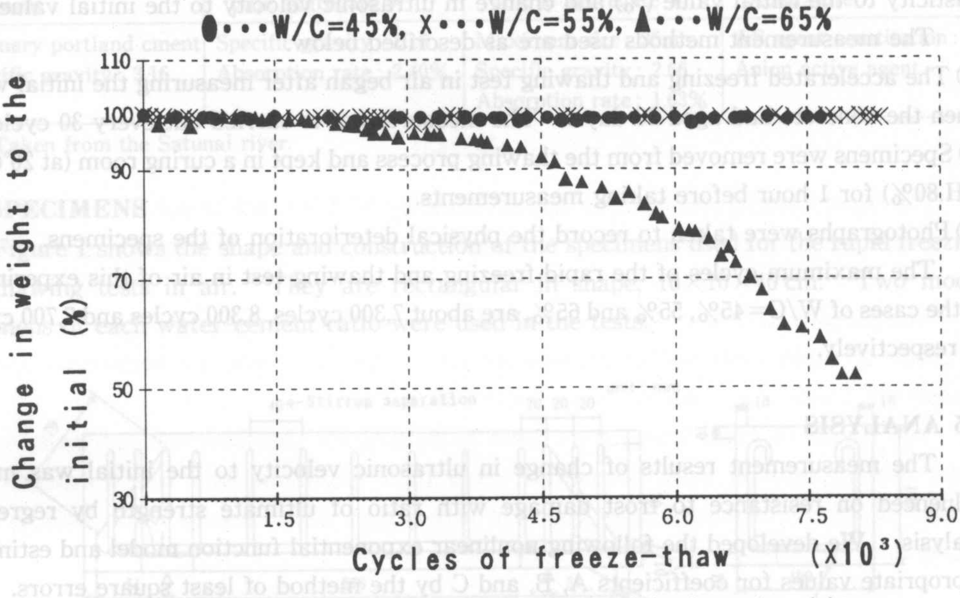

Fig. 2 Relationship between cycles of freeze-thaw and the change in weight to initial

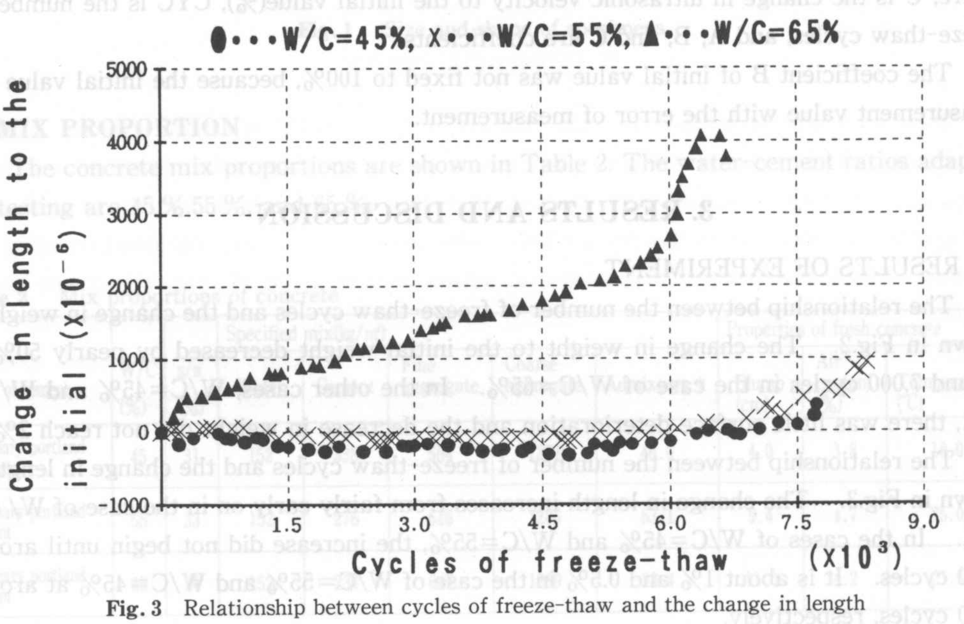

Fig. 3 Relationship between cycles of freeze-thaw and the change in length to the initial

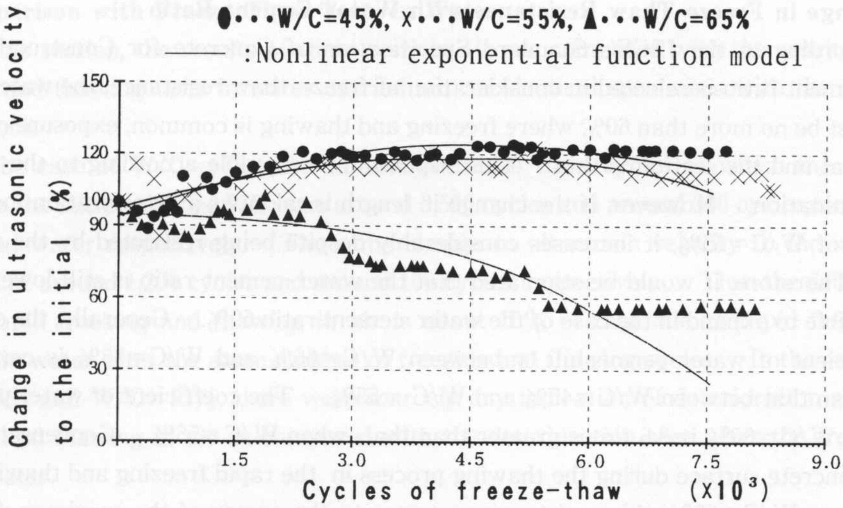

Fig. 4 Relationship between cycles of freeze-thaw and the change in ultrasonic velocity to the initial

3.2 RESULTS OF ANALYSIS

The coefficients A,B, and C in equation 1 were estimated by analysis, as shown in Table 3. The model is shown by the smooth curves in Fig.3. This nonlinear exponential function model appears to fit the results of the rapid freezing and thawing test in the cases of W/C=45% and W/C=55%. The relationship between the estimated value of coefficients A and C in Table 3 and water-cement ratio is shown in Fig.5. When the water-cement ratio is large, coefficient A tends to be small. Existing concrete structures suffer from various actions aside from freezing and thawing. In examining the prediction of service life for ordinary RC structures in air, it is necessary to study a durability model which considers growth of ultimate strength with age and its deterioration due to freezing and thawing and other effects.

Table. 3 Estimated value of coefficient

W/C	A	B	C
45%	1.90×10^{-2}	90.62	2.15×10^{-4}
55%	1.28×10^{-2}	95.02	2.40×10^{-4}
65%	-0.25×10^{-2}	96.94	-1.78×10^{-4}

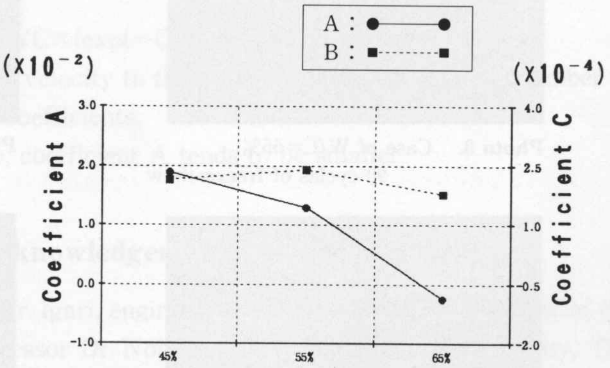

Fig. 5 Relationship between estimated value and water-cement ratio

3. 3 Change in Freeze-Thaw Resistance with Water-Cement Ratio

According to the JSCE's Standard Specification of Concrete for Construction2), if a water-cement ratio is selected in consideration of freeze-thaw resistance, the water-cement ratio must be no more than 60% where freezing and thawing is common, exposure conditions are typical and the section is thin. This stipulation acceptable according to the results of this examination. However, if the change in length is taken as a deterioration indicator in the case of W/C=65%, it increases considerably despite being restricted by the reinforcement. Therefore, it would be stipulated that the water-cement ratio is still lower because it is possible to expand in the case of the water-cement ratio 60%. Generally, the difference in coefficient of water permeabili ty between W/C=65% and W/C=55% is considerably larger than that between W/C=45% and W/C =55%. The coefficient of water permeability when W/C=65% is 3.6 times greater than that when W/C=55%. Condensation drops on the concrete surface during the thawing process in the rapid freezing and thawing test in air. When W/C=65%, this moisture penetrates to the center of the specimen due to the high coefficient of water permeability. As a result, bond strength would deteriorate due to the freezing and thawing action, causing a decrease in ultimate strength, in spite of its condition of the freezing and thawing in air in this case.

〈Photo〉

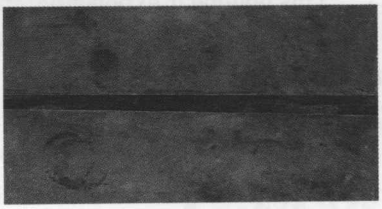

Photo 1. Case of W/C=45%, 88 cycles of freeze-thaw

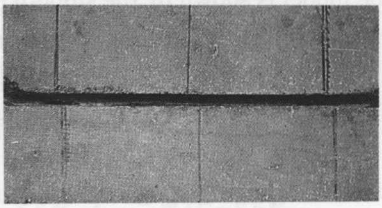

Photo 2. Case of W/C=45%, 4001 cycles of freeze-thaw

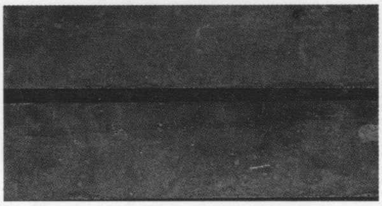

Photo 3. Case of W/C=55%, 90 cycles of freeze-thaw

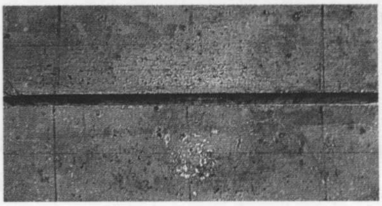

Photo 4. Case of W/C=55%, 4034 cycles of freeze-thaw

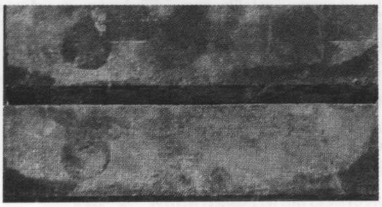

Photo 5. Case of W/C=65%, 110 cycles of freeze-thaw

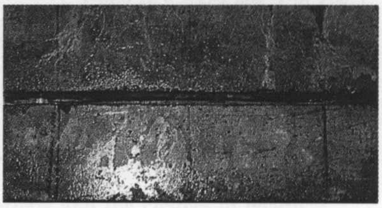

Photo 6. Case of W/C=65%, 3995 cycles of freeze-thaw

3.4 Comparison with Freeze-Thaw Tests in Water

In this section, the results of these tests in air are compared with the results of rapid freezing and thawing tests in water carried out an identical specimens with the same mix proportions.

In the case of W/C=65%, the number of freeze-thaw cycles at which the change in weight to the initial reached 95% was around 3,500 cycles and around 300 cycles,for the cases of air and water respectively. The same change in ultrasonic velocity to the initial was recorded at around 1,200 cycles and around 100 cycles, respectively. Thus the deterioration due to rapid freezing and thawing in air is about 10% of that due to rapid freezing and thawing in water after the same number of freezing and thawing cycles. In the cases of the W/C=45% and W/C=55%, there were scarcely any indication of deterioration after rapid freezing and thawing in air as compared with the deterioration seen after the freeze-thaw test in water.

4. Comclusions

In this study, freezing and thawing tests were carried out in air using RC model specimens and a nonlinear exponential function was used to model the results. The investigation can be summarized as follows.

(1) The change in weight to the initial decreased after around 2,800 cycles in the case of W/C=65%, but in the case of W/C=45% and W/C=55% there was no decrease.

(2) The change in length to the initial increased from the earliest freezing and thawing cycles in the case of W/C=65%, but in the case of W/C=45% and W/C=55% there was no increase until around 6,000 cycles.

(3) The change in ultrasonic velocity to the initial increased until around 4,500 cycles in the cases of W/C=45% and 55%, but it decreased from the earliest cycles in the case of W/C=65%.

(4) The following nonlinear exponential function fitted very well to the change in ultrasonic velocity to the initial :

$$U = A \times CYC \times (\exp(-C \times CYC)) + B$$

where. U is the change in ultrasonic velocity to the initial value(%), CYC is the number of freeze-thaw cycles, A, B, and C are coefficients.

With larger water-cement ratio, coefficient A tends to be smaller.

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References

1) Hiroshi Sakurai, Koichi Ayuta, Noboru Saeki, and Kaneyoshi Okada : Accelerating Test of Reinforced Concrete Member for Evaluating Durability, Memoirs of the Kitami Institute of Technology, Vol 21, 1988

2) JSCE : Standard Specification of Concrete for Construction, pp. 46-50, 1991