Predicting the deterioration of concrete durability in various environments

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Abstract

The maintenance in infrastructure has been improving. Many concrete structures play important roles. It is important that such structures are maintained and managed rationally to ensure use of limited resources and finance. However, systematic management and maintenance requires accurate predictions of performance changes of structures and members.

The purpose of this study is to examine a modeling method for predicting the deterioration of concrete structures and members using a nonlinear exponential function model with our database which has accumulated change-in-time data of RC model specimen.

The following conclusions can be drawn from this study :

1) The deterioration prediction equation, which is an exponent function with three population parameters, is able to express nonlinear changes with age by a curve which has form with a peak. The *equation is fitted well* as the characteristics of strength increases with age at an early stage and decreases at a late stage.

2) The three population parameters of the nonlinear exponential function are made up with the population parameters which are expressed as an intercept of an deterioration indicator (coefficient B), an internal factor based on water-cement ratio, type of cement, etc. (coefficient A) and an external factor depending on exposure conditions and so on (coefficient C).

1. Introduction

The maintenance in infrastructure has been improving. Many concrete structures play important roles. It is important that such structures are maintained and managed rationally under limited resources and finance. However systematic management and maintenance requires accurate predictions of performance changes of structures and members.

The purpose of this study is to examine a modeling method for predicting the deterioration of concrete structures and members using a nonlinear exponential function model with

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* Part of this report was presented in Hokkaido branch of the JSCE in February 1997
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our database which has accumulated change-in-time data of RC model specimen.

2. Method

2.1 Study method

As shown in Fig. 1, the study flow entails making RC model specimens, extracting deterioration indicators, implementing accelerated tests and exposure tests, and finally fitting deterioration prediction equations nonlinearly by exponent function model to these experimental data.

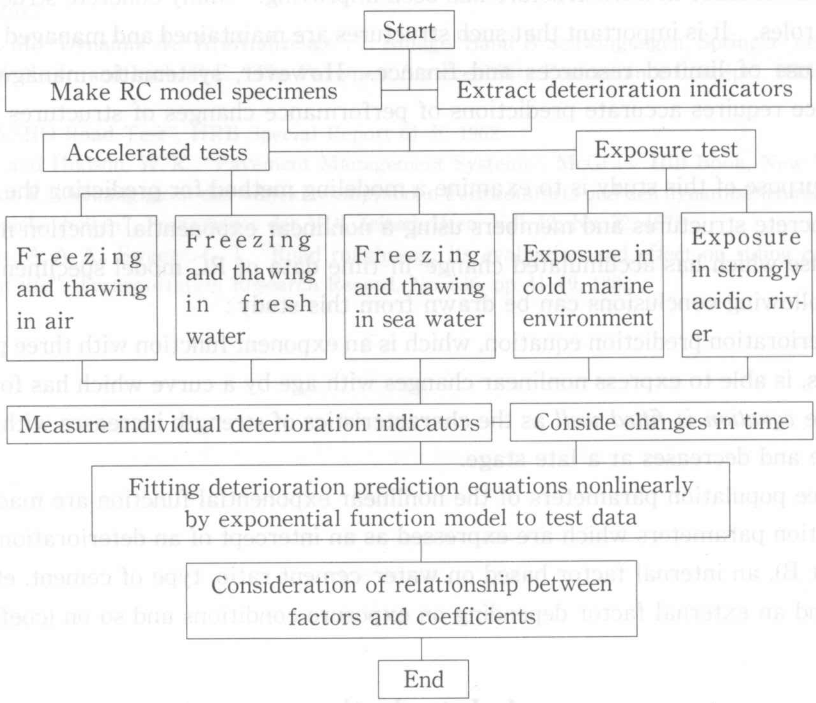

Fig. 1 Flow chart for study on predicting the deterioration of concrete durability in various environments

2.2 Experimental method

RC model specimens were made as shown in Fig. 2. Accelerated tests were carried out in fresh water, sea water, and air, and exposure tests in a cold marine environment and a strongly acidic river. In these experiments, the external factors were cycles of freeze and thaw, soaking time (number of days), and specimens' age. The internal factor was water-cement ratio, which was 45%, 55%, and 65%. The trial mix proportions at were air content of 4.5±0.5%, a slump of 8±1 cm, and a unit water weight of 152 kg. The proportions are shown in Table 1.

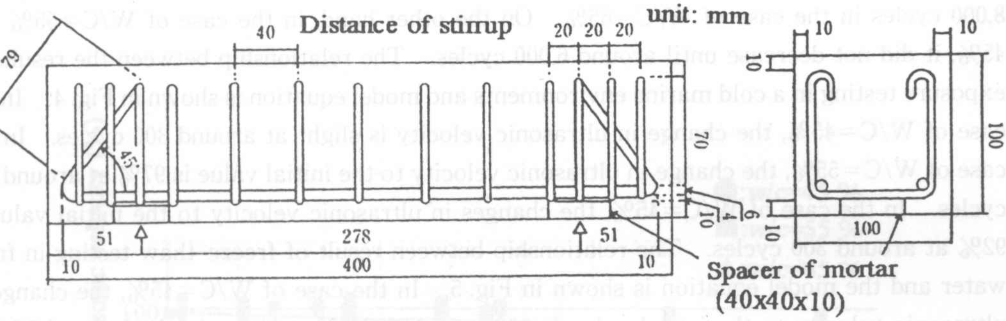

Fig. 2 RC model specimen

Table 1 Mix proportion of specimens

Kind of mix propor-tion	Type of Cement	W/C (%)	S/a (%)	Specified mix (Kg/m³)					Property of fresh concrete	
				Water	Cement	Fine aggregate	Conase aggregate	Admix-ture (cc)	Slump (cm)	Air content (%)
N45	Ordinary Portland	45	31	152	338	564	1277	44.1	7.2	4.2
N55	Ordinary Portland	55	34	152	276	634	1258	46.9	8.0	4.8
N65	Ordinary Portland	65	34	152	234	647	1279	52.9	9.2	5.1

2.3 Analysis method

The analysis was based on changes in ultrasonic velocity which is influenced by deterioration in the ultimate strength of an RC member in freeze and thaw test. The ultrasonic velocity was defined as objective value. The appropriateness of the population was checked by multiple regression analysis. The proper population parameters, which are coefficients A, B and C of deterioration prediction equations used exponent function model, were fitted nonlinearly to the test data by the method of least squares in Statistical Analysis System (SAS).

$$U = A \cdot CYC \cdot (Exp.(-C \cdot CYC)) + B \cdots\cdots\cdots\cdots \text{Equation (1)}$$

where U is the change in time of ultrasonic velocity (%), CYC are the cycles of freeze-thaw (cycles) or soaking time (Days), A, B, and C are the parameters. Besides, parameter B was analyzed without fixing as 100%, because it was recognized that the measurement data are variables.

3. Result and consideration

3.1 Study result

(1) Result of freeze-thaw test

The relationship between the results of freeze-thaw testing in air and the model equation is shown in Fig. 3 The change in ultrasonic velocity to the initial value was 55% at around

8,000 cycles in the case of W/C=65%. On the other hand, in the case of W/C=55% and 45%, it did not decrease until around 6,000 cycles. The relationship between the results of exposure testing in a cold marine environments and model equation is shown in Fig. 4. In the case of W/C=45%, the change in ultrasonic velocity is slight at around 300 cycles. In the case of W/C=55%, the change in ultrasonic velocity to the initial value is 97% at around 300 cycles. In the case of W/C=45%, the changes in ultrasonic velocity to the initial value is 92% at around 300 cycles. The relationship between result of freeze-thaw testing in fresh water and the model equation is shown in Fig. 5. In the case of W/C=45%, the change in ultrasonic velocity to the initial value is 88% at around 300 cycles. In the case of W/C=55%, the change in ultrasonic velocity to the initial value is 84% at around 300 cycles. In the case of W/C=45%, the changes in ultrasonic velocity to the initial value is 69% at around 300 cycles. Their changes are greater than in exposure test. The relationship between the results of freeze-thaw testing in sea water and the model equation is shown in Fig. 6. In the case of W/C=45%, the change in ultrasonic velocity to the initial value is 82% at around 300 cycles. In the case of W/C=55%, the change in ultrasonic velocity to the initial value is 76% at around 300 cycles. In the case of W/C=45%, the changes in ultrasonic velocity to the initial value is 78% at around 300 cycles. The changes are greater in sea water than in fresh water. Clearly this model equation for expressing with age in a form with a peak correlates well ; strength increases with age and stabilizes at an early stage.

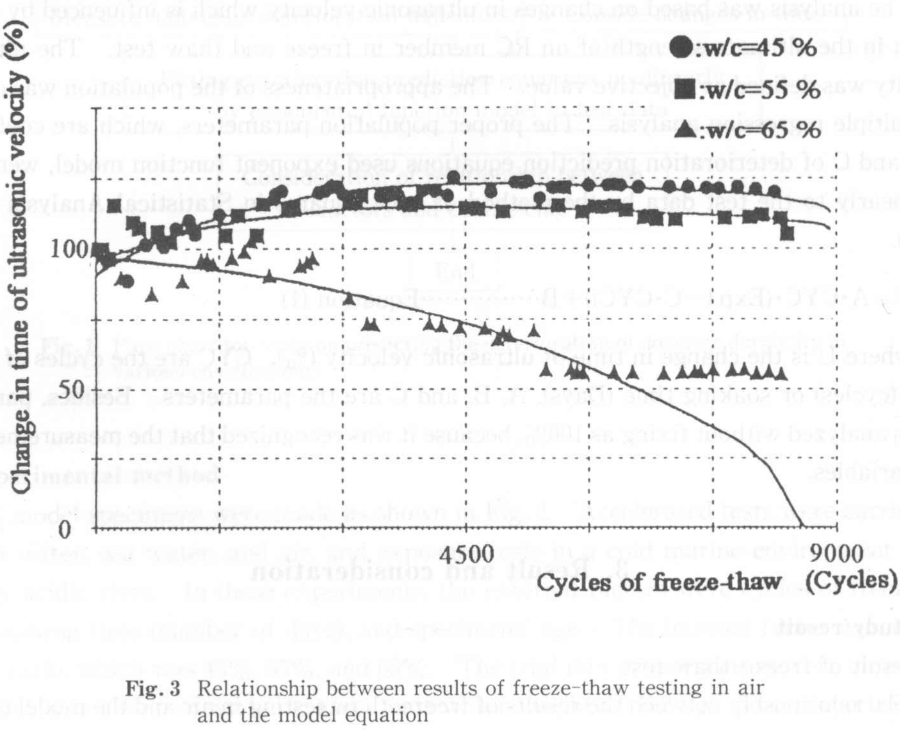

Fig. 3 Relationship between results of freeze-thaw testing in air and the model equation

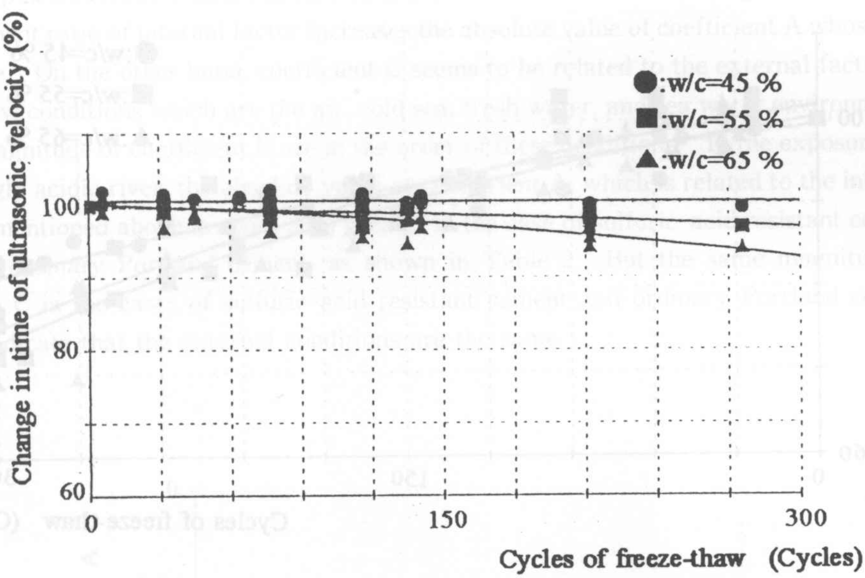

Fig. 4 Relationship between results of exposure test in cold marine environment and the model equation

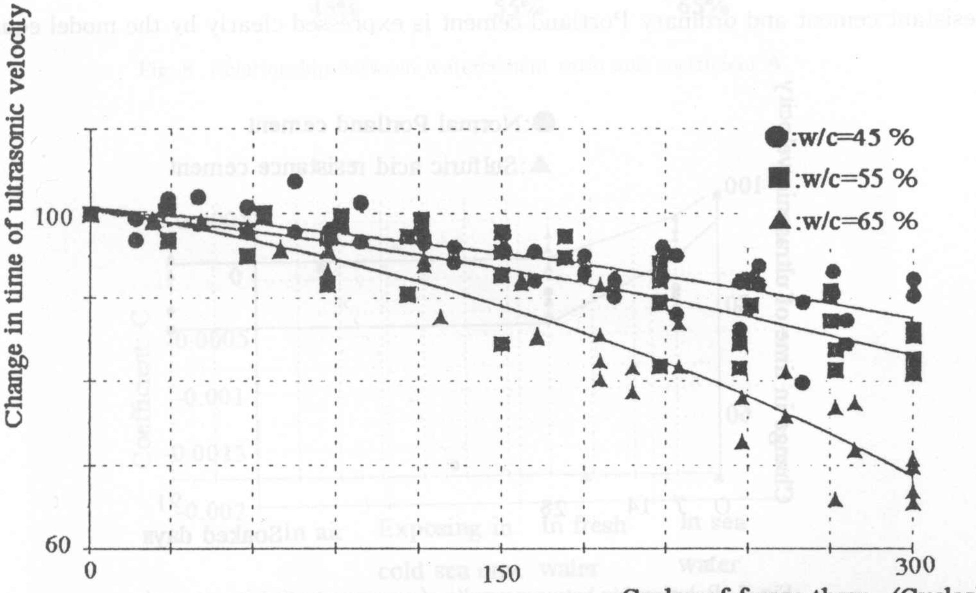

Fig. 5 Relationship between results of freeze-thaw testing in fresh water and model equation

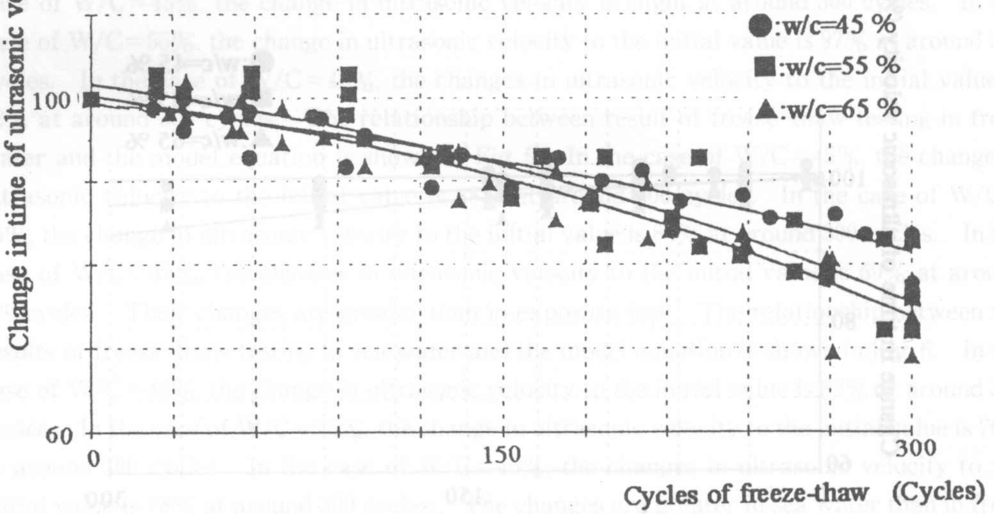

Fig. 6 Relationship between results of freeze-thaw testing in sea water and model equation

(2) Results of exposure test in strongly acidic river

The relationship between the results of exposure testing in a strongly acidic river and the model equation is shown in Fig. 7. The difference in durability between sulfuric-acid resistant cement and ordinary Portland cement is expressed clearly by the model equation.

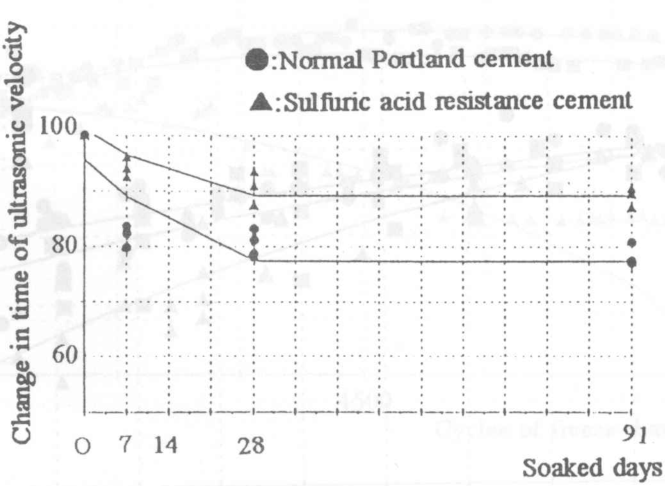

Fig. 7 Relationship between results of exposure testing in a strongly acidic river and the model equation

3.2 Consideration

The relationship between water-cement ratio and coefficient A is shown in Fig. 8. The relationship between environmental factors and coefficient C is shown in Fig. 9. The larger water-cement ratio of internal factor increases the absolute value of coefficient A whose sign is negative. On the other hand, coefficient C seems to be related to the external factors of freeze-thaw conditions which are the air, cold sea, fresh water, and sea water environments, and the magnitude of coefficient C are in the order of these conditions. In the exposure test in a strongly acidic river, the absolute value of coefficient A, which is related to the internal factor as mentioned above is about 30% greater in the case of sulfuric-acid resistant cement than with ordinary Portland cement, as shown in Table 2. But the same magnitude of coefficient C in the cases of sulfuric-acid resistant cement and ordinary Portland cement seem to indicate that the external conditions are the same.

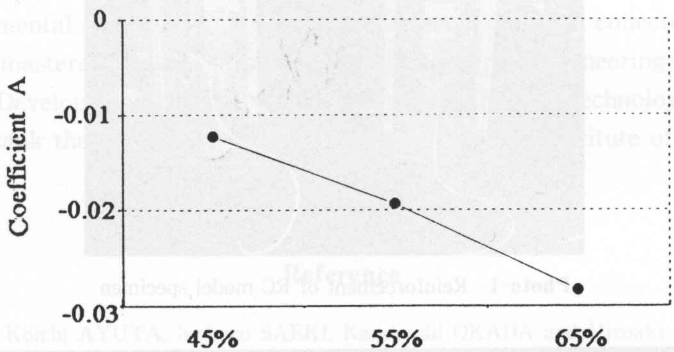

Fig. 8 Relationship between watercement ratio and coefficient A

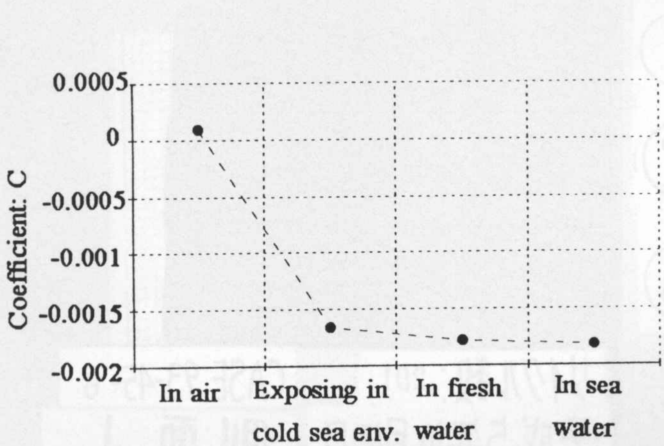

Fig. 9 Relationship between environmental factor and coefficient C

Table 2 Relationship between type of cement and coefficient A & coefficient C in the results of the exposure test in a strongly acidic river

	Coefficient A	Cofficient C
Ordinary Portland cement	−1.09348	−0.018731
Sulfuric-acid resistant cement	−0.72014	−0.018743

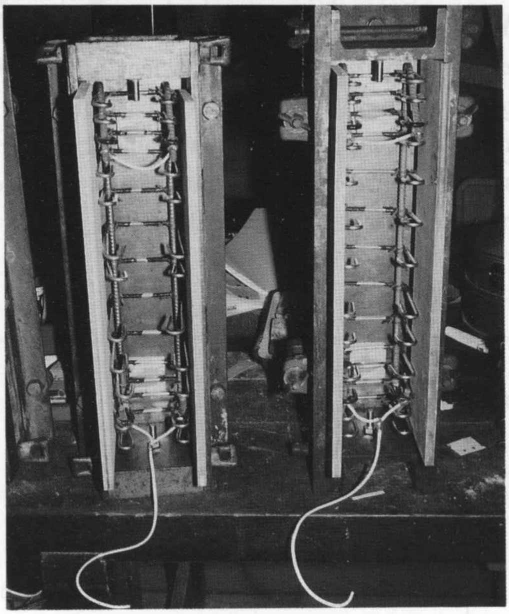

Photo-1 Reinforcement of RC model specimen

Photo-2 Experiments of freezing and thawing in sea water (W/C=45%, 201 cycles)

4. Conclusion

The following conclusions can be drawn from this study on the deterioration prediction of concrete durability in various environments :

1) The deterioration prediction equation, which is an exponent function with three population parameters, is able to express nonlinear changes with age by curve which has form with a peak. The equation is fitted well as the characteristics of strength increases with age at an early stage and decreases in the late stage.

2) The three population parameters of the non-linear exponential function are made up with the population parameters which are expressed as an intercept of an deterioration indicator (coefficient B), an internal factor based on water-cement ratio, type of cement, etc. (coefficient A) and an external factor depending on exposure conditions and so on (coefficient C).

Acknowledgement

The experimental data and analysis in this paper have been collected since 1986 by students taking masters and bachelors courses at the concrete engineering laboratory in the Department of Developmental Engineering, Kitami Institute of Technology. The authors would like to thank them and Dr. Atsuya, president of Kitami Institute of Technology, for their assistance.

Reference

1) H. SAKURAI, Koichi AYUTA, Noboru SAEKI, Kaneyoshi OKADA and Hiroaki ARAI : The service life prediction of concrete in cold region by model specimen and reliability theory