The service life prediction of concrete in cold region by model specimen and reliability theory.*1

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Abstract

The purpose of this study is to examine how durability can be evaluated and deterioration estimated for reinforced concrete structual members in a cold environment. Under such conditions, concrete components suffer frost damage and steel corrosion. Model specimens of size 10×10×40 cm were developed; these are suitable for rapid freez-thaw tests according to ASTM C 666, exposure testing, and load testing. Case studies were carried out in which many external factors. From the data obtained, an evaluation of the durability of concrete was induced by using a reliability function (R(t)).

In the case of a water-cement ratio of 45 %, the reliability in the case of set-up ratio to initial ultimate strength becomes unreliable—that is, the reliability falls below the assumed set-up ratio of 0.95 by neary 0.85%—at about 300 cycles.

In the case of a water-cement ratio of 45 %, the reliability in the case of set-up ratio to initial ultrasonic velocity becomes unreliable—that is, the reliability falls below the assumed set-up ratio of 0.90 by neary 70%—at about 300 cycles.

Thus, the durability of cocrete is influenced by the number of freeze-thaw cycles.

1. INTRODUCTION

In evaluating the durability of concrete in a cold enviornment, it is important that the influence on the reinforced concrete structure of freez-thaw cycles—an external factor—and the water-cement ratio—an internal factor—is fully understood.

The purpose of this study is to examine RC model specimens during rapid freez-thaw tests carried out according to ASTM C 666, exposure tests, and loading tests. The concrete durability is analyzed by implementing multiple regression analysis and reliability analysis.

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2. METHOD

2.1 EXAMINATION METHOD

The method of analysis is shown in Fig. 2.1. Data is collected by defining the deterioration, deciding on a deterioration limit and applying a theoretical formula. Experiment data check and arrange. The main factor is extracted by multiple regression analysis (SAS. GLM). This main factor is used to set up a reliability function (R(t)). Reliability analysis is carried out on the covariate, and the form of the reliability function (R(t)) is examined by changing the various parameters. R(t) is defined by a Weibull distribution and a number of parameters, as described below.

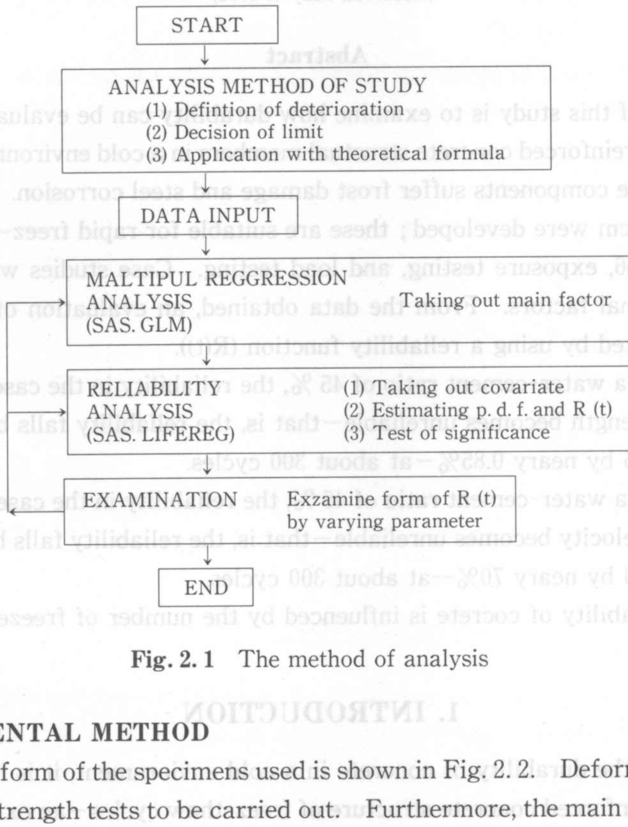

Fig. 2.1 The method of analysis

2.2 EXPERIMENTAL METHOD

The size and form of the specimens used is shown in Fig. 2.2. Deformed bars were used to allow bearing strength tests to be carried out. Furthermore, the main steel reinforcement and the stirrups were separated with vinyl tape in order to prevent particle spot corrosion. The method of load testing used to find the ultimate strength is shown in Fig. 2.3.

The method of freeze-thawing adopted in the experiments was based on ASTM C 666, and freeze-thaw tests began 28 days after placing. The mix proportions of the concrete are shown in Table 2.1. The steel used was SD 30 A and the ratio of reinforcing steel was 0.3 %. According to JSCE standards, the ratio of reinforcing steel should be over 0.2 % ; thus the specimen's ratio is sufficient. The load-deflection curved line indicates elasticity until ultimate strength of one third is reached. There are 56 cycles of freeeze-thaw exposure tests in a year, according to site survey data and the Abashiri meteorological observatory. The

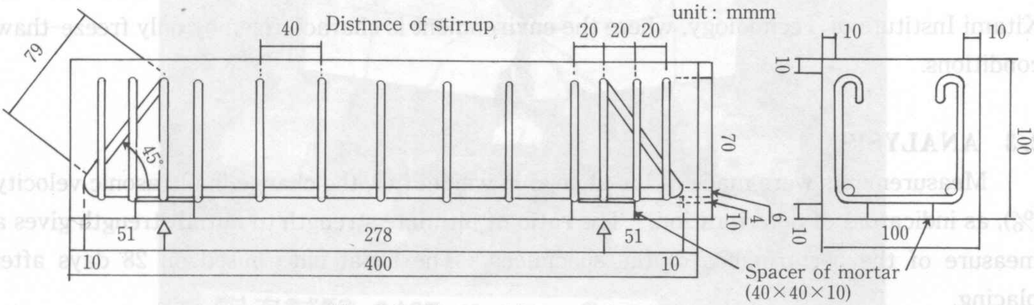

Fig. 2. 2 Size and from of the specimen

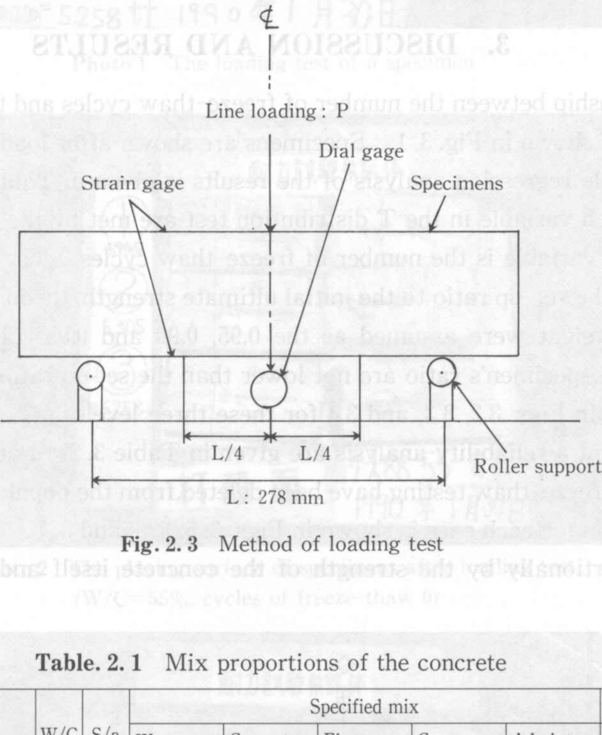

Fig. 2. 3 Method of loading test

Table. 2. 1 Mix proportions of the concrete

Kind of mix proportion	Type of cement	W/C (%)	S/a (%)	Specified mix					Property of fresh concrete	
				Water (Kg/m³)	Cement (Kg/m³)	Fine aggregate (Kg/m³)	Coarse aggregate (Kg/m³)	Admixture (cc)	Slump (cm)	Air content (%)
N451	Normal Pomtland cement	45	31	152	338	564	1277	48.5	6.3	3.5
N452	Normal Portland cement	45	31	152	338	564	1277	39.7	8.0	4.8
N55	Normal Portland cement	55	34	152	276	634	1258	46.9	8.0	4.5
N65	Normal Portland cement	65	34	152	234	647	1279	52.9	9.2	5.1

Note ; N451 and N452 are mix proportion for case 1 and case 2 respectively.

site of the exposure tests was Masuura Beach, where the environment is characterized by freeze-thaw conditions and sea water. And the other site of the exposure tests was the Kitami Institute of Technology, where the environment is characterized by only freeze-thaw conditions.

2.3 ANALYSIS

Measurements were made of the change in weight (%), the change in ultrasonic velocity (%), as indicators of deterioration. The ratio of ultimate strength to initial strength gives a measure of the performance of the specimens. The intial date based on 28 days after placing.

3. DISCUSSION AND RESULTS

The relationship between the number of freeze-thaw cycles and the ratio of ultimate to initial strength is shown in Fig. 3. 1. Specimens are shown after load testing in Photos 1, 2, and 3. A multiple regression analysis of the results is given in Table 3. 1. The statistical test values of each variable in the T distribution test are met by the 1 % significance level. The independent variable is the number of freeze-thaw cycles. The covariates are water-cement ratio. The set-up ratio to the initial ultimate strength, the initial ultrasonic velocity and the initial weight were assumed as the 0.95, 0.90 and 0.95. The censored data are assumed that the specimen's ratio are not lower than the set-up ratio. Histograms of each index are shown in Figs. 3.2, 3.3, and 3.4 for these three levels.

The results of a reliability analysis are given in Table 3. 2. Data for specimens which did not undergo freeze-thaw testing have been deleted from the population in this case. The reliability function for each case is shown in Figs. 3. 5, 3. 6, and 3. 7. The ultrasonic velocity influencos proportionally by the strength of the concrete itself and by the square of the

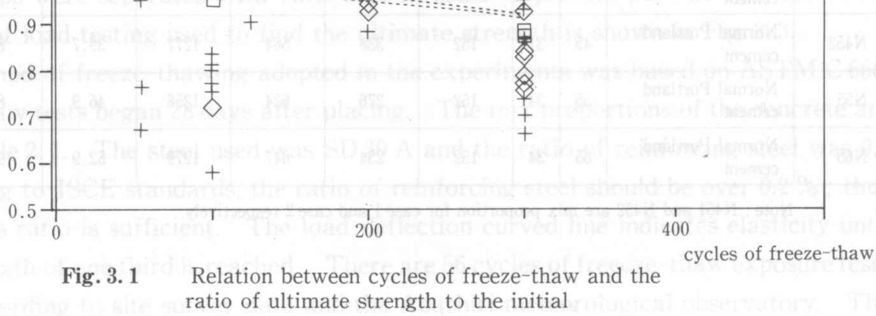

Fig. 3. 1 Relation between cycles of freeze-thaw and the ratio of ultimate strength to the initial

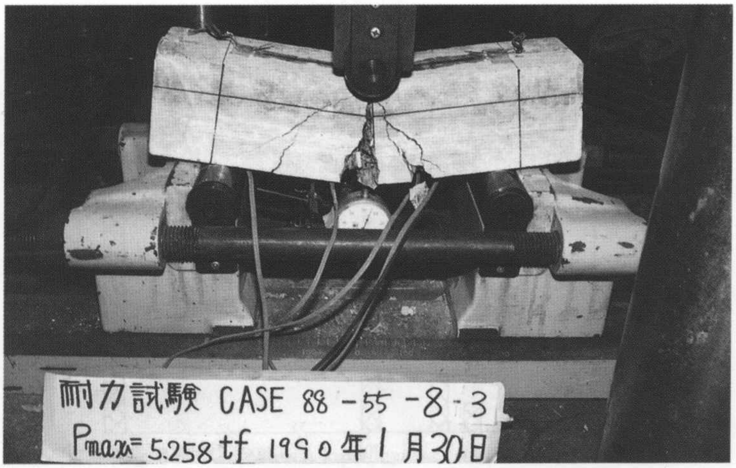

Photo 1 The loading test of a specimen

Photo 2 The placing surface of specimens after loading test
(W/C=55%, cycles of freeze-thaw 0)

Photo 3 The side surface of specimens after loading test
(W/C=55%, cycles of freeze-thaw 0)

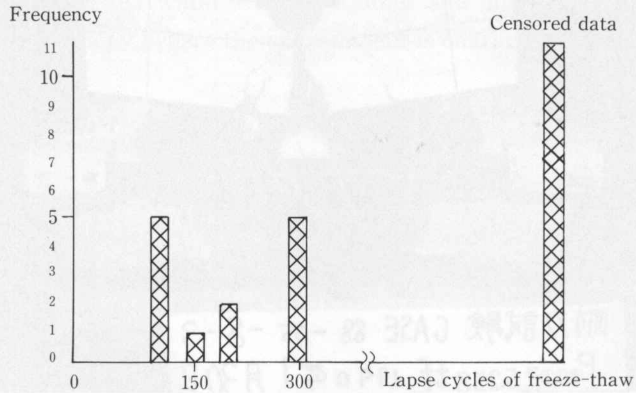

Fig. 3. 2 Histogram of lapse cycle of freeze-thaw and frequency at the hazard of the set-up ratio of the ratio of ultimate strength to the initial (0.95)

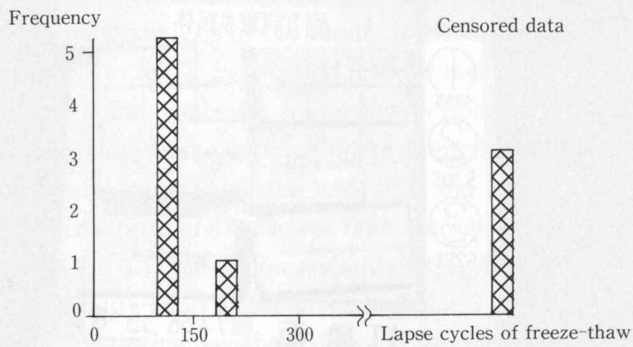

Fig. 3. 3 Histogram of lapse cycle of freeze-thaw and frequency at the hazard of the set-up ratio of the change of ultra-sonic velocity to the intial (0.90)

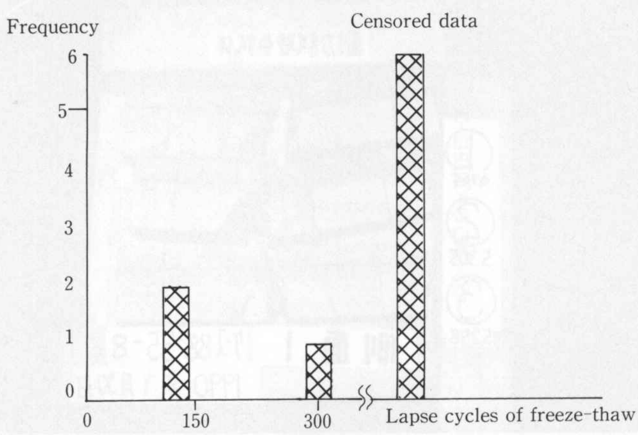

Fig. 3. 4 Histogram of lapse cyele of freeze-thaw and the frequency at the hazard of the set-up ratio of the change in weight to the initial (0.95)

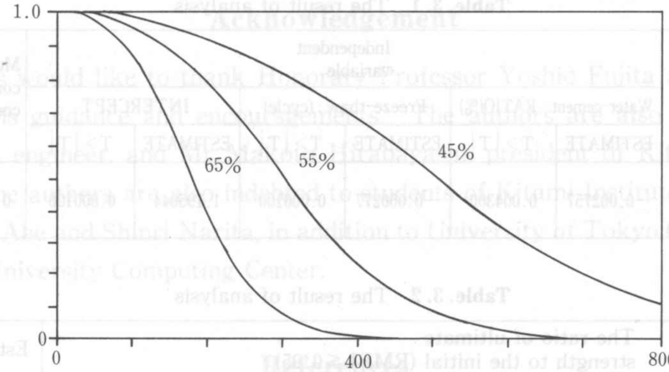

Fig. 3.5 Between lapse cycles freeze-thaw and (R (t)) to the hazard of the ratio of ultimate strength to the initial (0. 95)

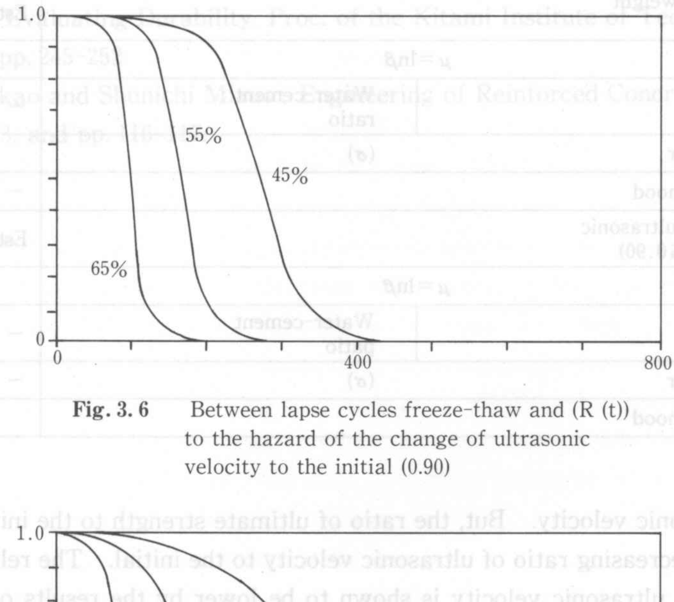

Fig. 3. 6 Between lapse cycles freeze-thaw and (R (t)) to the hazard of the change of ultrasonic velocity to the initial (0.90)

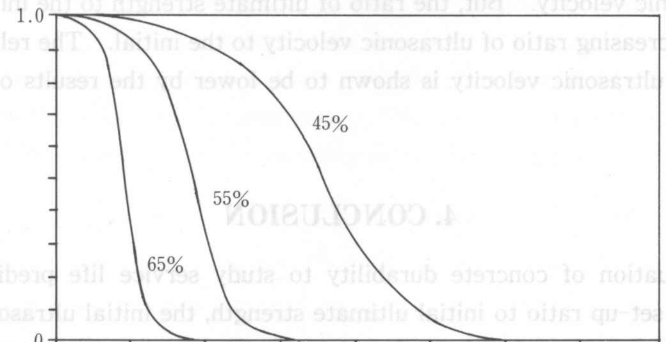

Fig. 3. 7 Between lapse cycles freeze-thaw and (R (t)) to the hazard of the change in weight to the initial (0.95)

Table. 3. 1 The result of analysis

<table>
<tr><th rowspan="3">Objective variable</th><th colspan="6">Independent variable</th><th rowspan="3">Multiple correlation coefficient</th><th rowspan="3">(PR : >F)</th></tr>
<tr><th colspan="2">Water-cement : RATIO(%)</th><th colspan="2">Freeze-thaw : (cycle)</th><th colspan="2">INTERCEPT</th></tr>
<tr><th>ESTIMATE</th><th>T>|T|</th><th>ESTIMATE</th><th>T>|T|</th><th>ESTIMATE</th><th>T>|T|</th></tr>
<tr><td>The ratio of ultimate strength to the initial</td><td>−0.002757</td><td>0.004300</td><td>−0.000277</td><td>0.000100</td><td>1.195044</td><td>0.000100</td><td>0.306602</td><td>0.000100</td></tr>
</table>

Table. 3. 2 The result of analysis

The ratio of ultimate strength to the initial (RMBL≦0.95)		Estimate	PR>CHI
Intercept (μ)	$\mu=\ln\beta$	8.703	0.0001
Covariate parameter	Water-cement ratio	− 0.052	0.005
Scale parameter	(σ)	0.391	
Most log. likelihood		−15.259	
The change of weight (CW≦0.95)		Estimate	PR>CHI
Intercept (μ)	$\mu=\ln\beta$	8.911	0.0001
Covariate parameter	Water-cement ratio	− 0.066	0.0001
Scale parameter	(σ)	0.223	
Most log. likelihood		− 2.772	
The change of ultrasonic velocity (CUV≦0.90)		Estimate	PR>CHI
Intercept (μ)	$\mu=\ln\beta$	8.099	0.0001
Covariate parameter	Water-cement patio	− 0.055	0.0001
Scale parameter	(σ)	− 0.055	0.0001
Most log. likelihood		0.171	

change in ultrasonic velocity. But, the ratio of ultimate strength to the initial is decreased as little to the decreasing ratio of ultrasonic velocity to the initial. The reliability drop-off of the change in ultrasonic velocity is shown to be lower by the results of this reliability analysis.

4. CONCLUSION

In this evaluation of concrete durability to study service life prediction in a cold environment, the set-up ratio to initial ultimate strength, the initial ultrasonic velocity and the initial weight are assumed as hazard, which event is lower than the set-up ratio. And, reliability analysis can be used, with the water-cement ratio as the covariate.

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Acknowledgement

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