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THE ESTIMATE FOR DETERIORATION DUE TO ALKALI-SILICA REACTION BY ULTRASONIC SPECTROSCOPY

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ABSTRACT

This paper deals with nondestructive testing of concrete by ultrasonic spectroscopy to assess the deterioration of concrete structures due to alkali-silica reaction (ASR). The response function and its energy of specimens were calculated by applying a linear system theory, and the deterioration of specimens was assessed by the energy of response function.

Tests were carried out for mortar and concrete with reactive bronzite andesite crushed stone. Specimens were cured in the chamber with 40°C and 100% relative humidity for four months after cured in water. The deterioration of specimens was assessed while the reaction was accelerated, and after the reaction was accelerated, cores were drilled from the reinforced concrete specimens and expansion of the core was measured.

By the deterioration due to ASR, the dynamic modulus of elasticity of test specimens was decreased extremely, and the energy of response function and pulse velocity of deteriorated concrete specimens were decreased to about 88% and 95% of non-reactive specimen, respectively. The more concrete was reinforcement, the larger the core was expanded. It is easy to assess the deterioration of concrete structures due to ASR by ultrasonic spectroscopy method proposed in this study.

1. INTRODUCTION

There is a growing need for some form of assessment to be applied to concrete structures. Assessment of the potential durability is also another aim of testing which is increasing in importance. It may be very important to assess the deterioration of concrete due to alkali-silica reaction (ASR) by nondestructive testing evaluation for future maintenance and repair.

In this study, test methods for ultrasonic spectroscopy and pulse velocity were used to assess the internal texture changes of concrete due to ASR. Ultrasonic spectroscopy is the diagnosis in materials evaluation and in characterization of flaws in metal components with frequency spectra of ultrasonic pulse echo[1]. It is necessary to measure the pulse echo and to use the broad band transducers. Although the pulse echo through concrete is very difficult to measure, deterioration due to ASR can be assessed by the response function which was calculated by applying a linear system theory to the ultrasonic spectral analysis.

2. RESPONSE FUNCTION OF CONCRETE SPECIMEN BY LINEAR SYSTEM THEORY

As shown in **Figure 1,** an output $y_o(t)$ from a linear system for an input $x(t)$ is presented as,

$$y_o(t) = x(t)*h_o(t) \qquad (1)$$

where a notation * shows a convolution integral and $h_o(t)$ denotes a response function of the linear system. The response function $h(t)$ of a linear system connected in series two linear systems and an output $y(t)$ from this system for the input $x(t)$ is presented, respectively, as

$$h(t)=h_o(t)*h_1(t) \qquad (2)$$

$$y(t)=x(t)*h(t)$$
$$=x(t)*h_o(t)*h_1(t) \qquad (3)$$

Let $X(f)$,$Y(f)$,$Y_o(f)$,$H(f)$,$H_o(f)$ and $H_1(f)$ be Fourier transforms of $x(t)$, $y(t)$,$y_o(t)$,$h(t)$,$h_o(t)$ and $h_1(t)$,respectively. Then, eq.(1) and (3) are transformed as

$$Y_o(f)=X(f)\ H_o(f) \qquad (4)$$

$$Y(f)=X(f)\ H_o(f)\ H_1(f) \qquad (5)$$

From eq.(4) and (5), the frequency response $H_1(f)$ of a specimen is given by

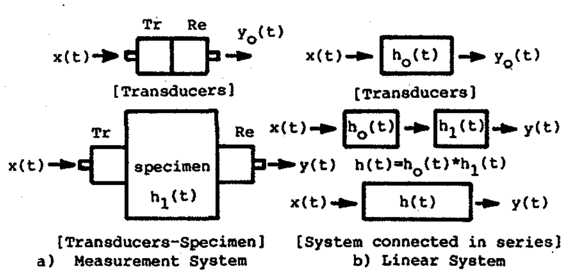


Figure 1 Relation between Measurement and linear System

$$H_1(f) = Y(f)/Y_o(f) \qquad (6)$$

The response function $h_1(t)$ of the specimen is obtained by the inverse Fourier transform of $H_1(f)$.

3. TEST PROGRAMS

3.1 Test Specimens

The test program was divided into two parts. In **Part I,** The deterioration of mortar bars (1x1x11 inches) due to ASR was assessed. Proportion of the dry materials for the test mortar was used 1 part of cement to 2.25 parts of graded aggregate by weight. An amount of mixing water was decided such as to produce a flow of 180 to 200 mm. Mortar was made by ordinary portland cement containing 0.63% equivalent Na_2O (Mix:**N**). In order to accelerate the reaction, the alkali content was adjusted to 1.5% (Mix:**MR1**) and 2.0% (Mix:**MR2**) by the addition of NaCl, and the specimens were cured under the accelerated condition of 40°C and R.H. 100%

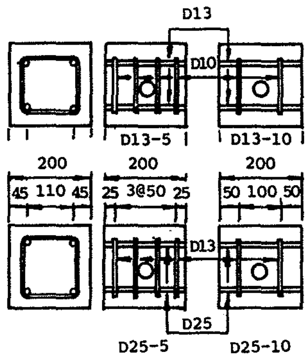
Table 1 Details of Concrete specimens

KIND	axial steel		stirrup	
	As	Pl (%)	As	s (cm)
D13-5	D13	1.28	D10	5
D13-10				10
D25-5	D25	5.07	D13	5
D25-10				10

after curing in water for three weeks.

In **Part II,** the deterioration of concrete due to ASR was assessed. The cylindrical and the cubic reinforced concrete specimens was prepared. The steel ratio and arrangement of steel bars are shown in **Table 1** and **Figure 2.** Mix proportion of concrete is shown in **Table 2.** The following materials were used:

- Yasu river sand as normal fine aggregate;
- Bronzite andesite crushed stone as reactive coarse aggregate and Takatsuki crushed stone as normal aggregate, maximum size=20 mm;
- Ordinary portland cement containing 0.65% equivalent Na_2O.



Note:○ is Sampling Position

Figure 2 Specimens and Arrangements of Steel Bars

The total equivalent Na_2O of reactive concrete was 6.88 kg/m^3 which was adjusted by the addition of NaCl, and the specimens were cured under the conditions of 40°C and R.H. 100% after curing for two weeks in water at 20±2°C.

Table 2 Mix proportion of concrete

Mix	required slump (mm)	required air (%)	W/C (%)	S/a (%)	unit weight (kg/m^3) W	C	S	GN	GR	NaCl
N6		6		40			685	1064	0	0
R6	80	6	50	40	172	344	685	532	504	8.86
R2		2		42			763	545	517	8.86

GN is Non-Reactive Aggregate and
GR is Reactive Aggregate

3.2 Test Procedures

In **Part I,** response function, ultrasonic pulse velocity, length change and dynamic modulus of elasticity were measured while the reaction was accelerated. Pulse velocity was measured in accordance with ASTM C 597-83.

In **Part II,** response function, pulse velocity and dynamic modulus of elasticity were measured as same as Part I, and then concrete cores with diameter of 50 mm were taken from the reinforced concrete specimens after four months. Residual expansion and pulse velocity of the cores were measured. The length changes of mortar and core were measured in using the apparatus specified in ASTM C 490 and by Lenzer's method[2] respectively.

The response function of specimens was calculated by the fast Fourier transform method as follows: the rectangular impulse having 1 μs in width and 22 volt in amplitude produced by a function generator was impressed on the transmitter. An output signal from the receiver was measured at a sampling interval of 2.44 μs and then analyzed by the fast Fourier transform to obtain the response function of specimens. The signals were analyzed up to the frequency of 102.3 KHz. The transducers with the resonance frequency of 54 KHz were used.

4. TEST RESULTS AND DISCUSSIONS

4.1 Part I

Figure 3 shows the changes of expansive strain, pulse velocity and energy of mortar bars while the reaction was accelerated. In this study, the energy is defined as the integral of energy spectral density of response function. This is the total energy of response function integrated in the frequency domain from DC to 102.3 KHz. The pulse velocity of deteriorated mortar bars decreased with the expansive strain. The energy of two deteriorated bars (Mix **MR1** and **MR2**) decreased abruptly to about 50% of the non-reactive bar **N**, and the decrease of the energy for **MR1** was slowly than for **MR2**. The pulse velocity and the energy of the deteriorated bars decreased until a minimun value and then recovered. It may be concluded that this recovery is caused by the silicate gel filling the cracks.

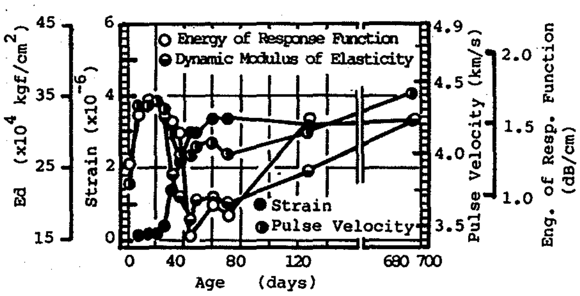


Figure 4 Comparison of Tests Results for Mortar made by Mix **MR2**

Figure 4 compares the changes of expansive strain, pulse velocity, energy and dynamic modulus of elasticity for **MR2**. The change of dynamic modulus of elasticity with the expansion due to ASR was significantly large, but dynamic modulus of elasticity is not used to assess the deterioration of concrete structures. The change of the energy due to expansion was larger than that of pulse velocity.

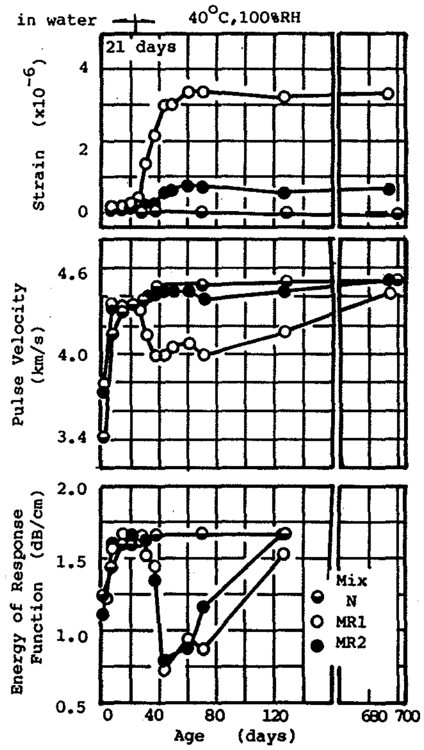


Figure 3 Changes of Strain, Pulse Velocity and Energy for Mortar Bars

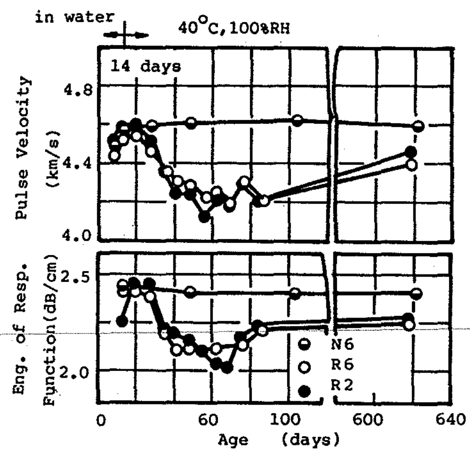


Figure 5 Changes of Pulse Velocity and energy of Concrete

4.2 Part II

Figure 5 shows the changes of pulse velocity and energy of the concrete specimens while the reaction was accelerated. Although the energy and the pulse velocity of mortar bars decreased immediately after the reaction was accelerated, these of concrete cylinders decreased after one week from the start of accelerated cure. It may be influenced by the difference of volume-surface area ratio (V/S) because pulse velocity of cube specimens decreased about one week slow than that of cylinder as shown in **Figure 7.** The V/S ratios of cube and cylinder were, respectively, 3.3 cm and 2.0 cm.

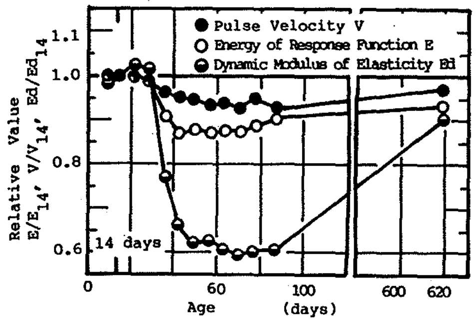


Figure 6 Comparison of Test Results for Mix **R6**

Figure 6 illustrates the results of non-destructive testing for concrete cylinders of Mix **R6** as the value at the age of 14 days is one. Although the decreases of energy and pulse velocity were occurred almost simultaneously, the energy and the pulse velocity of deteriorated concrete were about 88% and 95% of that at the age of 14 days respectively. Although pulse velocity method is easily than ultrasonic spectroscopy method, the energy calculated by ultrasonic spectroscopy may be advantageous for assessing the deterioration of concrete structures due to ASR.

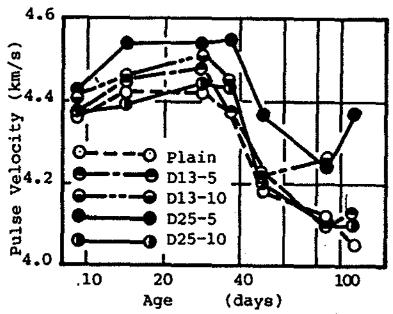


Figure 7 Changes of Pulse Velocity of Concrete

Figure 7 shows the changes of pulse velocity of concrete made by **Mix R6** encaged by axial steels and stirrups while the reaction was accelerated. The pulse velocity of D25-5 which had most reinforcement was larger than that of

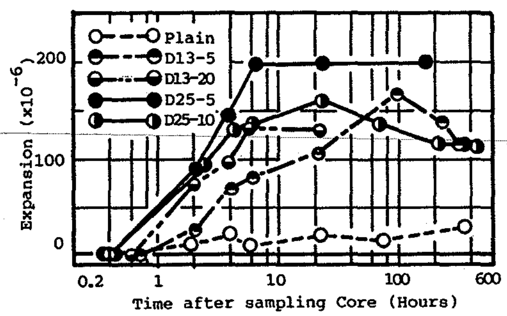


Figure 8 Changes of Residual Expansion of Concrete

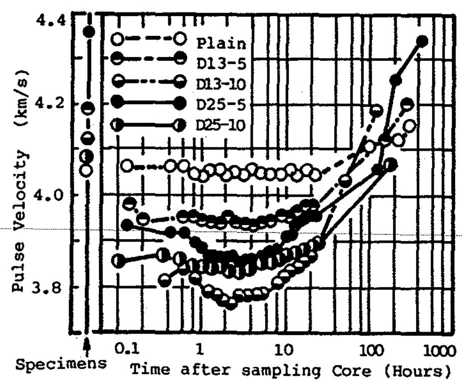


Figure 9 Changes of Pulse Velocity of Concrete Cores another specimens, and the decrease of pulse velocity due to expansion was most slowly. It may be concluded that the expansion of this specimen due to ASR was restricted largely by reinforcement more than another specimens.

Figures 8 and **9** show the residual expansion and the changes of the pulse velocity of concrete cores sampled after the age of four months respectively. The expansion of plain concrete was very small, and the pulse velocity was almost constant. On the other hand, the residual expansion of reinforced concrete grew large with the area of reinforcement, and the pulse velocity immediately after drilling the concrete core was decreased very largely. Furthermore, the pulse velocity of the core that was taken from the cube with large area of reinforcement decreased until a minimum velocity, and then recovered to near or more than that test specimen. It may be concluded that this recovery of pulse velocity is caused by the silicate gel filling the cracks.

5. CONCLUSIONS

The following conclusions may be drawn that was obtained from this study.

(1) By the deterioration due to ASR, dynamic modulus of elasticity of mortar and concrete was decreased extremely. The energy of the response function and the pulse velocity of deteriorated concrete were decreased to about 88% and 95% of the non-reactive concrete respectively.

(2) The energy of the response function was significantly affected by the change of the texture due to ASR more than for the pulse velocity. Although the pulse velocity method is easily than the ultrasonic spectroscopy method proposed in this study, the energy calculated by ultrasonic spectroscopy may be advantageous for assessing the deterioration of concrete structures due to ASR.

(3) The larger the reinforcement, the larger the residual expansion. On the other hand, the velocity of concrete core slightly decreased due to the residual expansion after sampling the core, and then it increased to more than the velocity of the test specimen because the silicate gel formed by the reaction may be filled in the cracks.

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[2] Lenzner, D., and Ludwig, U., Zum Erkennen von Alkali-Kieselsaure-Reactionen in Betonbauwerken, Zement-klak-Gips, Nr.8, 401 1979. (for journals)