Monitoring Corrosion Damage in Reinforced Concrete by Acoustic Emission

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Keywords: corrosion of rebars, estimate of chloride penetration, finite element method, cyclic dry-wet tests

1 INTRODUCTION

Salt attack to reinforced concrete is one of serious problems in concrete engineering. One main cause of the damage due to salt attack is corrosion of rebars by chloride penetration. Cyclic dry-wet tests were conducted to simulate the salt damage of concrete. During the tests, continuous acoustic emission (AE) measurement and the half-cell potential measurement were carried out. Results of half-cell potential and AE activity are compared. Chloride penetration is analyzed by the diffusion analysis. Thus, relations between the onset of corrosion in rebars and the occurrence of AE events are clarified.

2 ANALYSIS

2.1 AE parameter analysis

By employing AE parameter of count, event, amplitude, rise-time, duration in Fig.1, characteristics of AE signals are estimated. Two representatives in the analysis are RA value and average frequency. These are defined, as follows;

RA = Rise Time / Amplitude

Average frequency = Counts / Duration

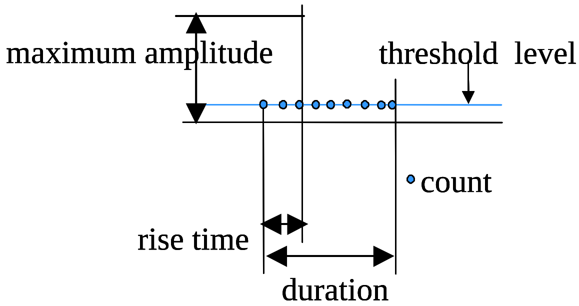

Fig.1 AE waveform parameters

2.2 Diffusion analysis

Ingress of chloride ions is governed by the diffusion equation. In the case of one-dimensioned penetration, the solution is represented in the following error-function, assuming that the chloride concentration at a surface is constant,

$$C(x,t) = C_0\left(1 - erf\,\frac{x}{2\sqrt{Dt}}\right),$$

C(x,t): chloride concentration (kg/m^3)
D: diffusion coefficient (cm^2/sec)
C_0: surface chloride concentration (kg/m^3)
x: distance from the bottom(cm)
t: measured period

In the analysis, C_0 is estimated as effective surface-chloride concentration, which is obtained as the averaged value from,

$$C_0 = \frac{C(x,t)}{1 - erf\,\frac{x}{2\sqrt{Dt}}}$$

where x and t are substituted from the test.

The diffusion coefficient is determined by JSCE Standard,

$$\log D = 4.5(W/C) + 0.14(W/C) - 8.47$$

where W/C is the water-cement ratio.

The diffusion equation is also solved by using 2-D FEM in order to clarify chloride concentration is a cross-section. The model is shown in Fig.2. The number of elements is 266 in total.

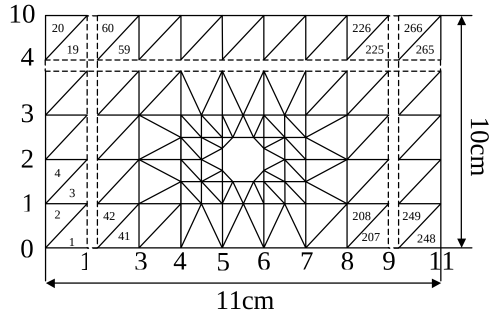

Fig.2 FEM Model

3 TEST

3.1 Specimen

Mixture proportion of concrete is given in Table1. The size of a specimen is 250mm × 400mm × 100mm and the cover thickness of rebars is 15mm. Initial chloride concentration was less than 0.19kg/m^3 in the concrete.

Table 1 Mixture Proportion

Gmax (mm)	W/C (%)	s/a (%)	Slump (cm)	Air (%)	Admixture (cc)	Weight per volume (kg/m^3)			
						W	C	S	G
10	55	43	8.5	8.0	114	178	323	690	1035

3.2 Cyclic dry-wet test

The specimen was moisture-cured at 20 for 28 days, and was coated by epoxy resin except for the bottom. In the cyclic dry-wet test, the specimen was dried and soaked every 7 days, repeatedly. After this test, core samples were taken out at two locations in Fig.3. Core samples were sliced and crashed each 1cm up to 5cm from the bottom surface. Thus, the chloride concentration was determined in depth by the potentiometric tiltration. During the cyclic dry-wet test, the half-cell potential measurement was also conducted every 7 days repeatedly. The bottom surface was divided into 20 meshes, and the potentials were measured at the divided points in the center of meshes. When at more than 10 divided points the potentials became lower than –350 mV, the test was finished, often 154 days elapsed.

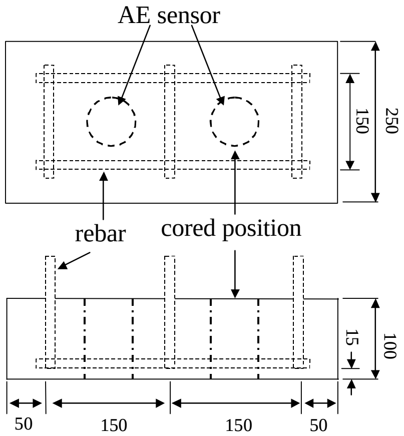

Fig.3 Specimen

3.3 Acoustic emission measurement

AE measurement was conducted along with the half-cell potential measurement. Sensor locations are shown in Fig.3. AE sensors used was 60kHz resonance frequency and threshold level was 40dB.

4 RESULTS AND DISCUSSION

4.1 Experimental results

Results of the half-cell potential and AE activity are compared in Fig.4. The first AE activity is observed on the 42nd day. At this stage, total chloride concentration at cover thickness was 0.37kg/m^3. Then, the half-cell potentials begin to decrease after the 126th day, when the total chloride concentration of cover thickness was 2.04kg/m^3. As a result, it is considered that corrosion in rebars begins at the first stage and cracking in concrete is nucleated at the second stage.

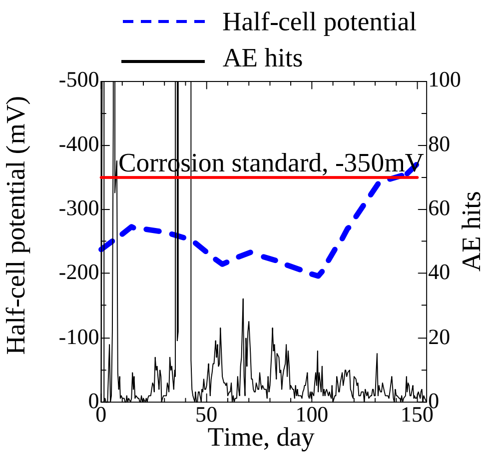

Fig.4 Results of half-cell potentials and AE activity.

4.2 Analytical results

Results of FEM analysis, the error-function analysis and measured values are compared in Fig.5. Values of FEM analysis are higher than actual values. The error-function analysis shows lower values than actual. Results of AE parameter analysis are given in Fig.6, and b values analyzed are given in Fig.7. In all the results, remarkable change is observed at the 42nd day. At the stage the chloride concentration becomes over 0.3kg/m^3. Both RA value and b value clearly change on 126th day. So, the second stage is also identified by AE monitoring. As a result, the first AE activity is remarkable as the increase in the number of AE events and the half-cell potential begins to decrease at the second stage. The chloride concentration at a cross-section is illustrated in Fig.8. It is clearly found that the concentration is observed near the rebar. This is a reason why results of FEM analysis give higher concentration than the actual in Fig.5.

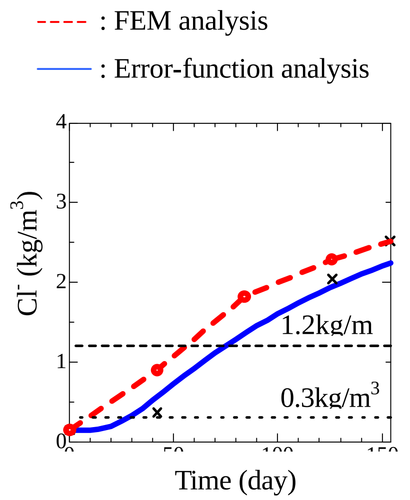

Fig.5 Chloride concentration at rebar location

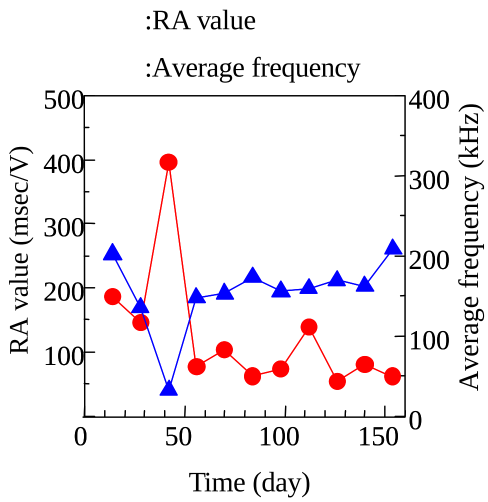

Fig.6 Variations of RA value and average frequency

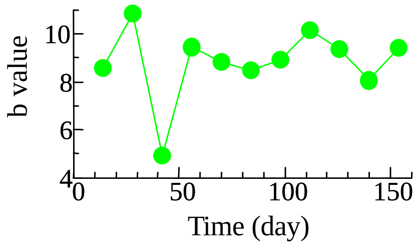

Fig.7 Variation of b value

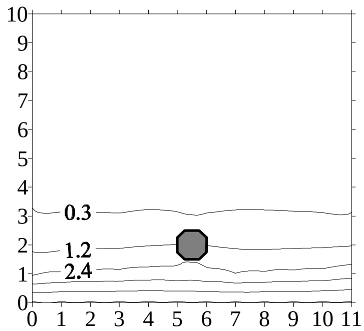

Fig.8 Chloride distribution at the 126th day by FEM analysis

5 CONCLUSIONS

1. It is clarified that corrosion in rebars begins as the first high AE activity, cracking in concrete occurs at the second stage when the half-cell potentials begin to decrease.
2. The second stage is also identified by AE parameter analysis. Thus. AE monitoring of rebar corrosion in reinforced concrete is very promising.