コンクリート工学年次論文報告集　10-2　1988

論　文

[1151] AEの発生特性によるコンクリートの劣化度評価

EVALUATION OF DETERIORATION IN CONCRETE BY ACOUSTIC EMISSION ACTIVITY

Masayasu OHTSU*, Yutaka KAWAI** and Syuro YUJI**

1. INTRODUCTION

The evaluation of deterioration in concrete is recently of significant importance, because a large number of concrete structures are going to approach to their service-life limit and require proper repairing for the rehabilitation. For a diagnostic inspection, we have proposed an application of acoustic emission (AE) observation to tests of core-drilled samples from concrete members (1). AE activity during uniaxial compressive loading is analyzed in a core sample, based on the rate process theory.

To gauge of this technique and to quantify a parameter of rate, core samples are selected from reinforced concrete (RC) slab specimens, which have been tested under cyclic loading. Thus, the evaluation of the deterioration in concrete by AE activity is performed, by using core samples of controlled damage.

2. TEST OF RC SLAB SPECIMENS

2.1 Test Procedure

Mix proportion of concrete employed is indicated in Table 1. Early-strength Portland cement (ASTM type III) was employed and designed strength of concrete was 240 kg/cm^2. To simulate RC slabs deteriorated under traffic load, RC specimens of dimension 400 cm x 260 cm x 16 cm were cast. For major reinforcement, D16 rebars were arranged with 200 mm pitch. D13 rebars of 100 mm pitch were employed as distribution bars. A sketch of the specimen is shown in Fig. 1.

Loading conditions of three specimens (TP-1, TP-2, and TP-3) are listed in Table 2. The specimen was simply supported along the major sides by using H-beams. A loading plate of 50 cm long and 20 cm wide was set on the top surface. In the TP-1 specimen, the loading plate was located at the center of the specimen, which is indicated as loading position:1 in Fig. 1. This specimen was loaded monotonously up to the final failure. The failure load was 42.5 tons as indicated in Table 2.

According to extensive studies on RC slabs in highway bridges, it is known that crack patterns created in in-service RC slabs are quite different from those observed in one-point loading fatigue experiments (2). The main discrepancy results from the moving effect of load. To simulate damaged RC slabs due to traffic loads, the loading plate was moved in specimens TP-2 and TP-3 from loading position:1 through loading position:3

* Department of Civil Engineering, Kumamoto University
** Engineering and Construction Division, Kawasaki Steel Corporation

Table 1 Mix proportion of concrete

Max. size (mm)	Slump (cm)	Air (%)	Unit weight (kg/m^3) W	C	S	G
25	8	6	298	161	798	1052

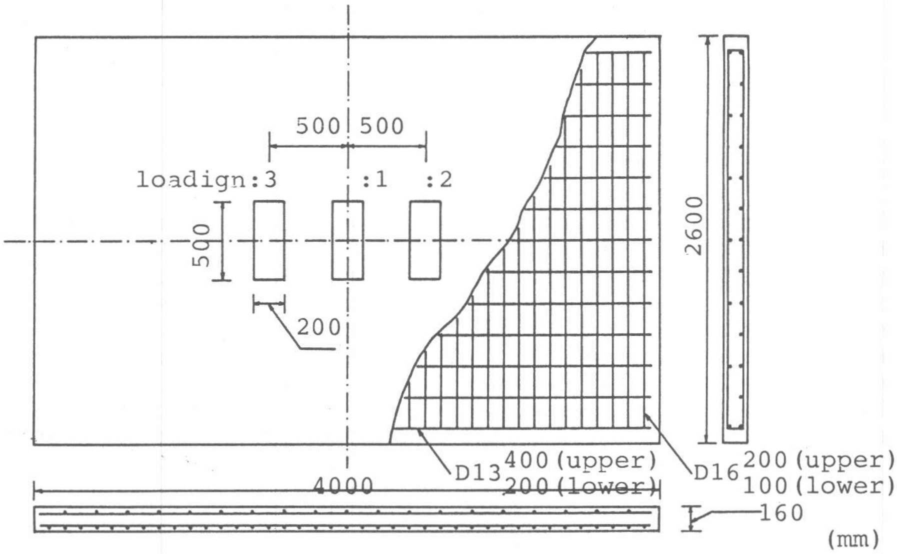

Figure 1 A sketch of a RC slab specimen.

as shown in Fig. 1. At each loading position, cyclic loading was carried out up to 1 x 10^4 times in the TP-2 specimen and 5 x 10^4 in the TP-3. Loading amplitude ranges in these experiments are indicated in Table 2.

2.2 Test Results

Crack traces observed in specimens TP-1 and TP-2 are shown Fig. 2, where only the central region of dimension 100 cm x 100 cm is presented. After the tests, crack density (C.D.; total crack length per unit area) was measured in this region. It was observed that C.D. = 12.2 m/m^2 in TP-2 specimen and C.D. = 8.1 m/m^2 in TP-3.

Table 2 Loading conditions of tested specimens

Specimen	Load (ton) Ps	P/Ps	Load range (ton) P (min.)	P (max.)	Freq. (Hz)	Cycle Number
TP-1	42.5	-	-	-	-	-
TP-2	-	0.4	1.0	17.0	1	$1x10^4$
TP-3	-	0.3	1.0	12.8	1	$5x10^4$

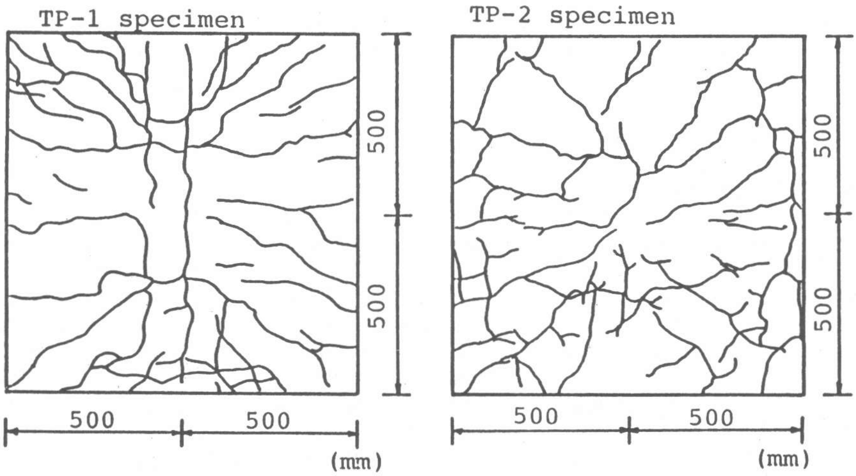

Figure 2 Crack patterns of tested RC slabs.

Concerning crack patterns, it is observed that cracks in TP-1 specimen propagate only in the radial direction from the loading plate, while some cracks are branched and connected in the perpendicular direction to the major axis (horizontal direction in the graphs) in TP-2 specimen. It implies that crack patterns observed in in-service damaged RC slabs are reasonably simulated by these fatigue experiments.

After loading experiments of RC slabs, core samples of 10 cm diameter were taken from damaged and undamaged portions in each RC slab. Locations of core sampling are shown in Fig. 3. These locations were selected so as to prevent visible surface cracks from running across core samples. Six

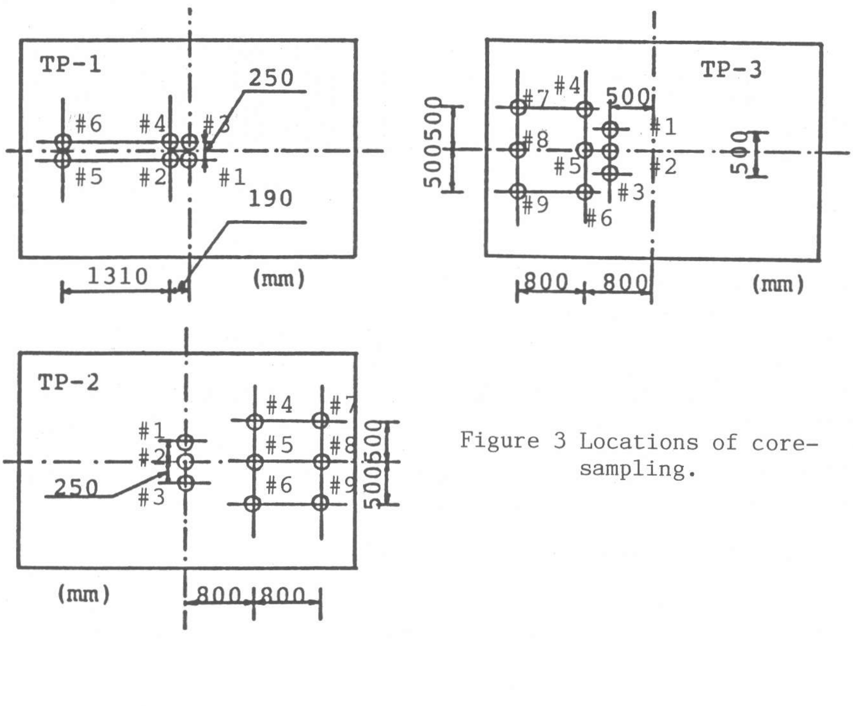

Figure 3 Locations of core-sampling.

samples numbered #1 to #6 were extracted from TP-1, while specimens TP-2 and TP-3 were core-drilled at nine locations, of which samples are numbered #1 to #9.

3. TEST OF CORE SAMPLES

3.1 Rate Process Theory

The concept of Kaiser effect suggests that the amount of critical microcracks in concrete can be evaluated by the monitoring of AE activity under loading (3), although successful results are still limited to determine the load level previously applied (4). When concrete contains a number of critical microcracks, AE generation is expected from low loading levels due to the propagation of the microcracks. On the other hand, AE activity of concrete containing few critical cracks is considered to be low in the low loading.

To quantify the AE activity in the uniaxial compression test of core samples, the concept of a rate process is introduced. In this case, the probability density function f(V) of AE occurence from load level V (%) to V+dV (%) is represented,

$$f(V)dV = dN/N, \quad (1)$$

where N is the total event number of AE up to load V (%), which is normalized by the failure load. The probability function f(V) is referred to as a rate and assumed , as follows;

$$f(V) = a/V + b, \quad (2)$$

where a and b are constants. Thus, a relationship between the number of total AE events N and load level V is obtained from equations (1) and (2),

$$N = C\, V^{a} \exp(\, bV\,), \quad (3)$$

where C is an integration constants. Equation (2) suggests two possible relations between the probability function f(V) and the load level V. If the value of "a" is positive, the probability of AE occurence is high in the low load range. On the other hand, the probability of AE generation is low in the low load range when the value "a" is negative. Since the value of "a" is considered to depend on the number of critical microcracks and the unstability due to loading, the detertioration of concrete is possibly evaluated on the basis of the value "a".

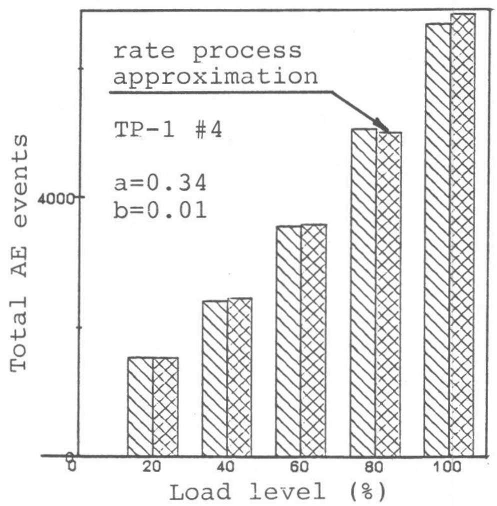

Figure 4 AE total event N vs. load level V in a core sample.

3.2 Uniaxial Compression Tests of Core Samples

In order to quantify the relation between the value of "a" and the deterioration degree of concrete, core samples were tested under uniaxial compressive loading. During the test, axial strains were measured and AE events were counted up to final failure. An example of AE observation is shown in Fig. 4. The hatched bar graph shows a relation between AE events and load level. This relation was approximated by equation (3). The constants a, b, C were determined from the least square procedure by using data of the hatched bar graph. An approximated relation is indicated by the crosshatched bar graph in the same figure. It is observed that an essential feature of AE activity is recovered by the rate process approximation. Note that the value of "a" is positive in #4 core sample of TP-1 specimen, which was taken from the damaged region as can be seen in Figs. 2 and 3.

Figure 5 shows strengths and Young's moduli of all core samples. Since crack patterns were approximately symmetric with respect to center lines and the damaged region was concentrated near the center portion, these quantities of the same distance from the vertical center line in Fig. 3 were averaged. Except for TP-1 specimen, the tendency that strengths and Young's moduli increase slightly with the distance apart from the damaged portion is observed. It is in reasonable agreement with failure modes in RC slabs.

In the similar manner, the values of "a" in the rate process approximation were averaged and are shown in Fig. 6. In TP-1 specimen, the values of "a" go rapidly down negative with the increase of the distance. It results from the fact that only central portion is damaged due to one-point loading. In specimens TP-2 and TP-3, the values of "a" are not explicitly dependent on the distance. Note that the values of "a" in TP-2 specimen is less negative than those in TP-3 specimen. It

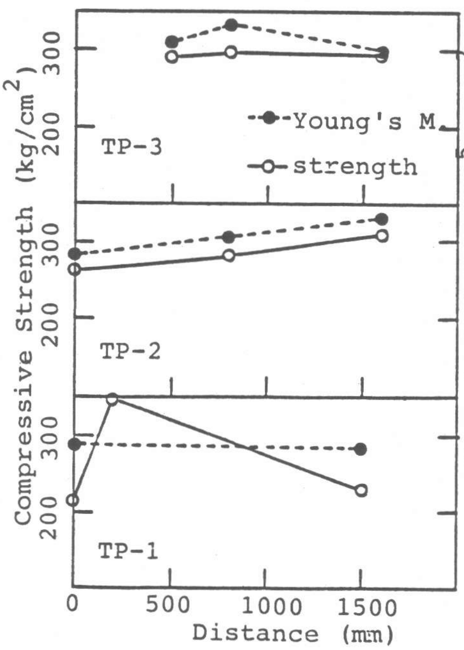

Figure 5 Strengths and Young's moduli of core samples.

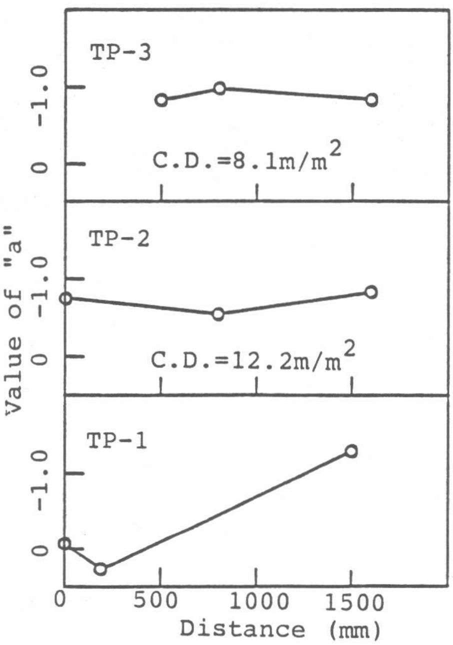

Figure 6 Values of "a" in core samples.

implies that the probability of AE occurence in the low loading level is higher in core samples of TP-2 specimen than those of TP-3 specimen. It corresponds reasonably to the fact that the C.D. value of TP-2 specimen is higher than that of TP-3 specimen. These results imply that the deteriration degree of concrete in in-service RC slabs can be evaluated by the core test on the basis of the rate process theory, in particular, using the value of a.

4. CONCLUSION

To assess the deterioration of concrete structures, a method to monitor the AE activity of core specimens under uniaxial compressive loading was invesigated. Core samples were extracted from three RC slabs. One of three RC slabs was loaded monotonously up to final failure, and the others were tested by cyclic loading. Thus, controlled damaged concrete members were obtained.

Since AE activity becomes high when concrete concrete contains many critical microcracks, the tendency was quantitatively evaluated on the basis of the rate process theory. Although extensive systematic study is still required to link the value of "a" to the deterioration degree of concrete, some quantitative relations between the values of "a" and the crack densities (C.D) of the RC slabs were found. It shows a great promise for the quantitative evaluation of deterioration in concrete by AE observation of core tests.

REFERENCE

(1) Ohtsu, M.:"Acoustic Enmission Characteristics in Concrete and Diagnostic Applications," Journal of Acoustic Emission, Vol. 6, No. 2, 1987, pp. 99-108.
(2) Matsui, S.:"Fatigue Strength of RC-Slabs of Highway Bridges by Wheel Running Machine and Influence of Water on Fatigue," Proc. of the JCI, Vol. 9, No. 2, 1987, pp.627-632.
(3) Ohtsu, M.:"Diagnostics of Cracks in Concrete Based on Acoustic Emission," The ACI Annual Convention, San Antonio, Texas, March 22-27, 1987.
(4) Uomoto, T.:"Application of Acoustic Emission to the Field of Concrete Engineering," Journal of Acoustic Emission, Vol. 6, No. 3, 1987, pp. 137-144.