損傷が蓄積した既設コンクリート頭首工のひび割れとAEパラメータの関連に関する解析的検討

Analysis of the relationship between cracks and AE signal parameters in in-service concrete head works with accumulated damage

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1. Introduction

The evaluation of concrete fracture mechanisms containing accumulated damage is significant because many unstable fractures occur in concrete structures as a result of cracks evolving. To describe accurately the cracking process in the material is very challenging due to the high influence of various parameters[1]. By the author, damage estimation method is developed by AE and related elastic wave methods[2)-3)]. In this research, the AE technique is employed to detect and monitor the crack evolution. AE signal parameters are analyzed to evaluate the influence of accumulated cracks on concrete fracture performance.

2. Materials and Methods

2.1. Specimens tested

The tested samples were taken from the in-service concrete head works which has been operated for about 50 years. Five concrete cylindrical samples of 150 to 204 mm in height and about 100 mm in diameter were selected. According to the X-ray CT results, each sample has a different accumulated cracking pattern (Figure 1).

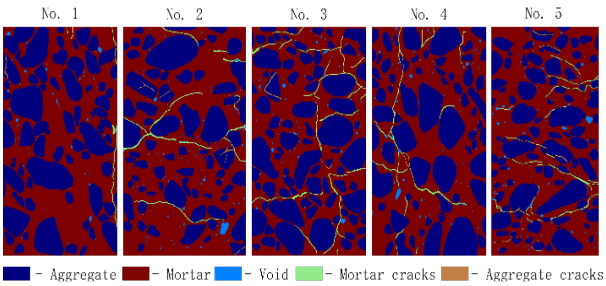

Figure 1. Internal cracking system

2.2. Compression test

The material mechanical properties were investigated by a compression test with an AE measurement system.

Based on the elastic wave theory, AE signal parameters can give insight into the types of damage occurring and their progress. According to rate process theory[4)], the AE energy release characteristics are evaluated by the cumulative AE energy occurrence frequency ratio (Eq. 1),

$$f_e(U)dU = \frac{dE_{AE}}{E_{AE}}, \quad (1)$$

where $f_e(U)$ is the probability function of AE energy at strain energy level U, dE_{AE} is AE energy per unit strain energy U and E_{AE} is the total number of AE energy.

2.3. AE signal analysis

The SiGMA-AE analysis is conducted to determine AE source kinematics of AE source location, crack orientation, and crack-motion direction[5)]. The corresponding amplitude and frequency of each AE event are also calculated.

To better understand the signal source locations, an image-gridding method is applied to establish a relationship between defects and AE event characteristics. The number of cells in each sample is equal to 9 and their size is the same varying in each sample in accordance with its dimension.

3. Results and Discussion

3.1. Concrete mechanical properties

All samples showed low mechanical properties. The compressive strength of concrete samples is 14,5 N/mm^2 with the dispersion of the values: of 18.3 N/mm^2 in sample No.1 and 12.0 N/mm^2 in sample No.3. The average value of maximum compressive strength is about 1,700 × 10^{-6} with the dispersion of the values: of 1,749 × 10^{-6} in sample No. 1 and 737 × 10^{-6} in sample No. 4. The average value of strain energy is 14.5 J with maximum and minimum values in samples No.1 (18.3 J) and No.3 (12.0 J), respectively.

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3.2. AE energy behaviour

Due to the crack system's uniqueness in each concrete sample, the AE energy release trend reflects different fracture processes varied in each sample. The average AE hit value is 69,800 hits with maximum and minimum values in samples No.3 (119,056 hits) and No.1 (33,133 hits), respectively. The average value of total AE energy is 20,639 V^2 with maximum and minimum values in samples No.2 (28,661 V^2) and No.1 (13,320 V^2), respectively. The AE energy release behaviour for all samples has a continuous trend corresponding to the uninterrupted development of the defects and has AE energy release events of different magnitudes varying in the samples.

3.3. Fracture analysis

Figure 2 depicts the correlation between cracking damage and AE signals observed in various concrete samples. The black line is the average crack density in the sample. As can be seen, Sample No. 1 (Figure 2a) has low cracking damage concentrated only on the right side (high value of amplitude and peak frequency in the respective cells), while other samples have more space-distributed damage. In sample No.2 (Figure 2b), cracks in cell no. 4 contribute to slower development and lower peak frequency of AE signals, while adjacent cells of no. 5 and no. 7 show an increase in AE events indicating crack development in those directions. Samples No. 3 and No. 5 (Figures 2 c and d) have similar features, with high amplitude (more than 100 dB) and peak frequency (about 200 kHz) AE signals in central cell no. 5 indicating active fracture processes. The peak frequency in samples No. 3 and No. 4 (Figures 2 c and d) is higher than in others, possibly due to the prevalence of vertical cracks in those samples. It is noted that crack propagation parallel to the loading axis is faster[2] than that of the perpendicular one, which can result in higher peak frequency in vertically-oriented cracks.

4. Conclusions

This study analyzed the relationship between cracks and AE signal parameters in in-service concrete with accumulated damage. The results showed that AE signal parameters can provide insight into the types of damage occurring and their progress. The study also highlighted the importance of using AE techniques to detect and monitor crack evolution in concrete structures.

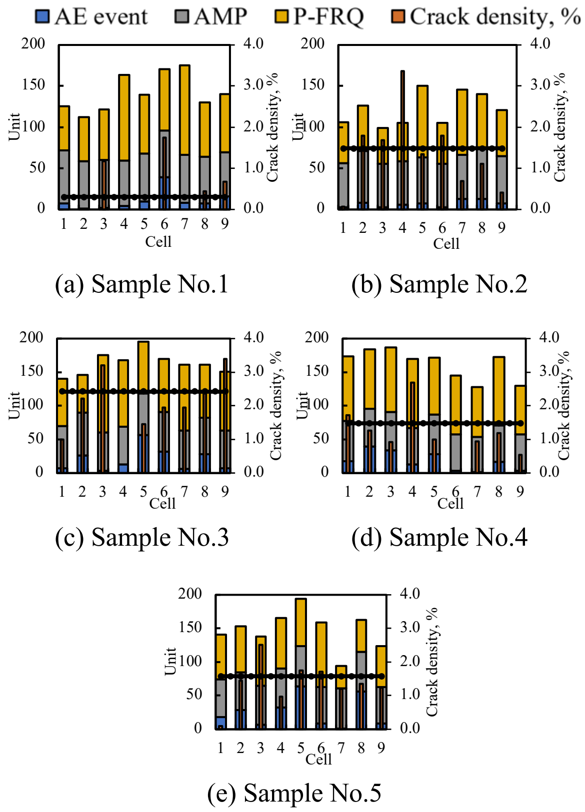

Figure 2. Relationship between cracks and AE signal parameters

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