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AE-SiGMA Analysis in Brazilian Test of Concrete

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Abstract

The moment tensor analysis of AE waveforms has been developed and is now available for identifying crack kinematics of a location, a crack-type and a crack orientation in a material. The procedure has been implemented as the SiGMA analysis. Mechanisms of cracking can be visually and quantitatively studied at the meso-scale in concrete. Since the tensile strength of concrete is normally evaluated by the Brazilian test. Mechanisms of macro-scale tensile failure in concrete are clarified as the cracking process at the meso-scale determined by the SiGMA analysis. Evolution of the fracture process zone under the combination of tensile and compressive stresses is discussed.

Keywords: Acoustic emission; SiGMA analysis; Concrete; Tensile strength; Brazilian test

1. Introduction

Fracture mechanisms in engineering materials can be kinematically identified by applying the moment tensor analysis of AE signal-based method [1]. One powerful technique for the moment tensor analysis has been developed as SiGMA (Simplified Green's functions for Moment tensor Analysis) analysis, by which crack kinematics of locations, crack types and orientations are quantitatively determined [2]. In concrete, the tensile strength of concrete is normally evaluated by the Brazilian test, where a cylindrical specimen is compressed in the diagonal direction, and macro-scale tensile failure is observed. As applications of the SiGMA analysis, a relation between the generation of macro-scale tensile cracks and the accumulation of meso-scale cracks is studied.

2. Brazilian Tests

2.1. Tensile strength of concrete

The Brazilian test is known as a split-tensile test for the tensile strength of concrete. Although the test has been widely conducted, a direct tensile test was alternatively applied in some cases. This is because the Brazilian test is conducted under compression, and thus the fracture process might be different from that in the direct tension test.

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As well known in elasto-statics, stresses at the center of a disk of diameter d and unit thickness under compressive load P in the diagonal direction is known as [1],

$$s_{xx} = \frac{2P}{pd} \text{ and } s_{yy} = -\frac{6P}{pd},$$

where s_{xx} is the tensile stress in the horizontal direction and s_{yy} is the compressive stress in the vertical direction. s_{xx} is the maximum tensile stress, and stresses near loading plates are even more compressive than s_{yy} in the cross-section. This implies that a tensile crack at the macro-scale could start from the center of the disk. But, experimental observations suggest that the crack start with the areas near the loading plates. It is realized that the fracture process zone is nucleated prior to final failure in the direct tensile test. So, observation of the fracture process in the Brazilian test could provide a new insight for cracking mechanisms at the meso-scale in concrete.

2.2. Experiments

Cylindrical specimens of 150 mm diameter and 100 mm height were made. The compressive strength of concrete at 28 days under the standard curing was 37.2 MPa and the velocity of P wave was 4410 m/s. AE measurement was performed by employing AE Win SAMOS (PAC). Eight sensors of 1509 kHz resonance (R15I-AST) were attached to the specimen. The frequency range was 10 kHz to 2 MHz and total amplification was 60 dB gain. Three specimens were tested to confirm the reproducibility of results.

Prior to the test, the sensor array was determined by a simulation analysis. AE sources are assumed at lattice points with 5 mm grid at five cross-sections of 5 mm apart. The velocity of P wave was set to 4000 m/s and arrival times were estimated with 1 µsec. sampling. It was found that computational errors of the source locations were the minimum within 1.6 mm in the case AE sensor array selected

2.3. SiGMA analysis

In order to classify crack type, the eigen-value analysis of the moment tensor was developed [1]. The eigen-values of the moment tensor are to be composed of the combination of the shear crack and the tensile crack. The decomposition leads to the shear component (X), the deviatoric tensile component (Y), and the hydrostatic component (Z) of the tensile crack. In the present SiGMA code, AE source with the shear ratio X > 60 % is classified as the shear crack, one with X < 40 % as a tensile crack and one with 40 % < X < 60 % as a mixed-mode crack. The crack-motion vector ***l*** and the normal vector ***n*** are determined from three eigenvectors. Results are visually displayed, by using a graphic software (Light Wave 3D, New Tek). Three models of these cracks are illustrated in Fig. 1. Cracks are classified into three types of shear, mixed-mode and tensile, and their crack planes normal to vectors ***n*** are illustrated by circles and directions of crack motions ***l*** are shown by arrows.

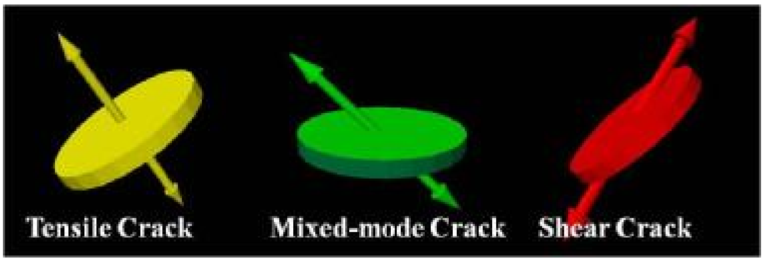
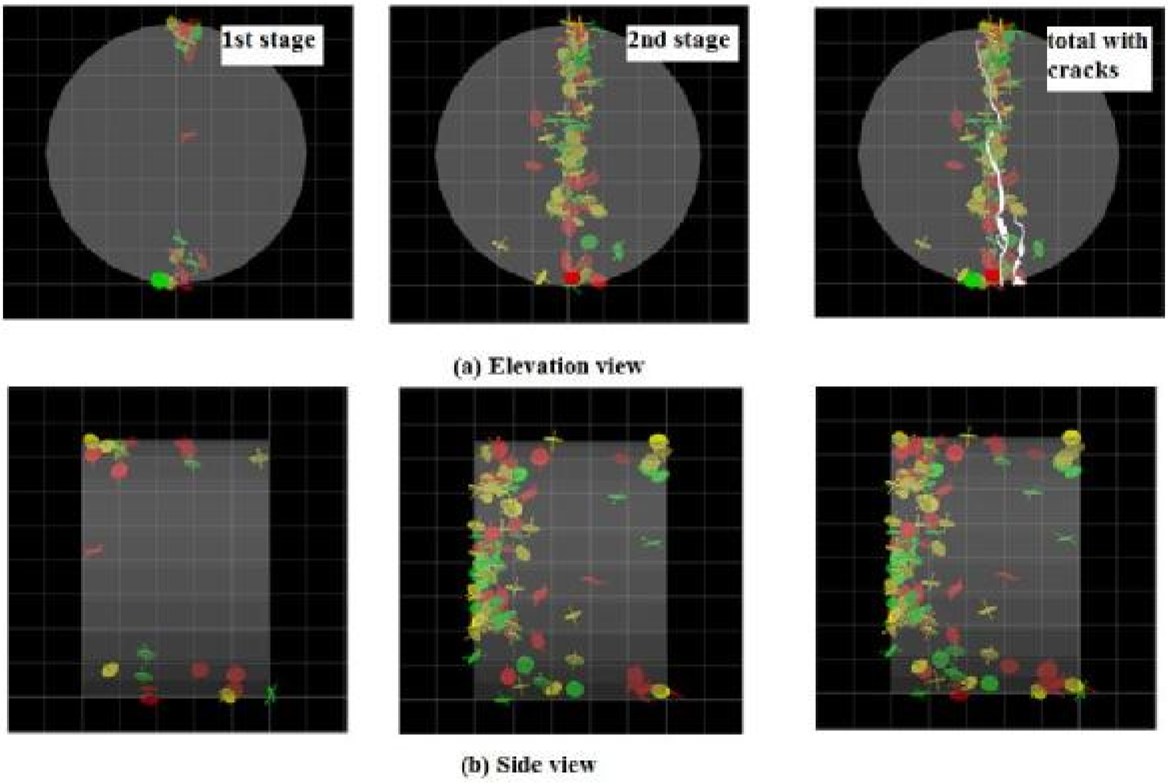


Figure 1. Models for tensile crack, mixed-mode crack and shear crack.

3. Results and discussion

Because all results of the SiGMA analysis are similar in three specimens, one case of three specimens is shown in Fig 2. At the beginning (1st) stage, AE sources are observed only near two loading plates in the diagonal direction. Although a few events are identified, dominant cracking-modes are tensile and mixed mode. This suggests that tensile cracks in the meso-scale are generated due to contact between the loading plates and the cylindrical specimen under compressive loading in the diagonal direction. In the all three specimens, it was demonstrated that AE sources



were observed near the loading plates at the 1st stage.

Figure 2. Results of SiGMA analysis in the Brazilian test.

At the 2nd stage, AE sources of all kinds distribute near the final tensile failure-plane. In the elevation view, AE sources are concentrated near the failure plane at the macro-scale, while they distribute widely at the cross-section in the side view. It is noted that no visual cracks were found at this stage in the test. In total, all events are plotted and compared with the macro-scale tensile cracks finally observed at the surface. Agreement between AE cluster and the final failure surfaces is quite reasonable. At the macro-scale, tensile-type cracks are observed, while all kinds of tensile, mixed-mode and shear cracks are identified at the meso-scale. These results suggest that the fracture process zone is nucleated around the diagonal cross-section, and these meso-scale cracks are coalesced to create macro-scale tensile cracks. This fact is in good agreement with detailed observation in the direct tensile test [3]. Thus, in the both Brazilian test and direct-tensile test, the fracture process zone is, in advance, nucleated around the final failure surface. Coalescing process of meso-scale cracks identified by the SiGMA analysis results in the fact that the tensile strengths estimated by the both tests become comparable.

4. Conclusion

The SiGMA analysis is applied to the Brazilian test of concrete cylinders. A relation between macro-scale tensile failure and nucleation of AE sources in the meso-scale is clarified in the Brazilian test for the tensile strength of concrete. At the macro-scale, tensile-type cracks are only observed, while all kinds of tensile, mixed-mode and shear cracks are identified at the meso-scale. During propagation of tensile cracks at the macro-scale, other types of AE sources of mixed-mode and shear cracks were actively identified. Thus, nucleation of the fracture process zone is confirmed around the final failure surface. This is a reason why the tensile strengths estimated by the Brazilian test are comparable to those by the direct-tensile test, although stress distributions are quite different.

References

[1] Timoshencko, S. P. and Goodier, J. N. *Theory of Elasticity*, 1907, McGraw-Hill Book Company, New York.

[2] Ohtsu, M., Okamoto, T. and Yuyama, S. *Moment Tensor Analysis of AE for Cracking Mechanisms in Concrete*, ACI Structural Journal, 1998, **95**(2): pp. 87-95.

[3] Akita, H., Koide, H. and Tomon, M. *Uniaxial Tensile Test of Unnotched Specimens under Correcting Flexure*, Fracture Mechanics of Concrete Structures, Aedificatio Publishers, Freiburg, 1998, **1**: pp. 367- 377.