Assessing Damage in Composite Concrete Elements by Stress Wave Methods

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1. Introduction

Stress wave methods, namely acoustic emission (AE) and pulse velocity measurements were adopted on concrete beams subjected to four-point bending. Two types of specimens included those composed of plain concrete and a vinyl fiber reinforced mortar layer. AE technique was employed to monitor the behavior of the specimens under the loading. Besides, at different loading steps, ultrasound pulse velocity was measured to facilitate construction of velocity structure, or tomogram that reflects the internal conditions of the specimen. Within the scope of this paper, discussions are limited to utilize the results of AE and velocity structure for identifying locations of fracture and evaluating occurrence of debonding between concrete and the fiber-reinforced mortar layer. The assessments results were justified by visual observation of the cracking patterns.

2. Specimens and Instrumentations

Six beam specimens of 150 x 150 x 530 mm were prepared, among which one was plain concrete beam that served as the control specimen; while the other five consisted of plain concrete and a vinyl fiber-reinforced mortar layer of similar thickness, respectively. The concrete and fiber-reinforced mortar have average 28-day compressive strength of 31.9 MPa and 48.6 MPa, respectively. The mortar layer was overlaid after seven days of concrete casting by the shotcrete method. Four-point bending test as prescribed in JSCE-G 552 was conducted on each specimen. The supports and loading configurations are given in Fig.1.

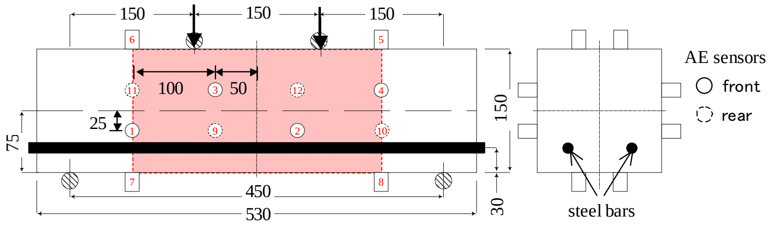

Fig. 1: Specimen and AE sensors arrangement (unit: mm)

Twelve AE sensors with resonant frequency of 60 kHz were attached to the specimen surfaces. The signals were pre-amplified by 40 dB and recorded by a 16-channel data acquisition system. During the bending tests, loading was terminated at fixed intervals to allow for pencil lead break excitations near the location of each AE sensor. The transit time of generated transient waves to the rest of the sensors was used to calculate pulse velocity.

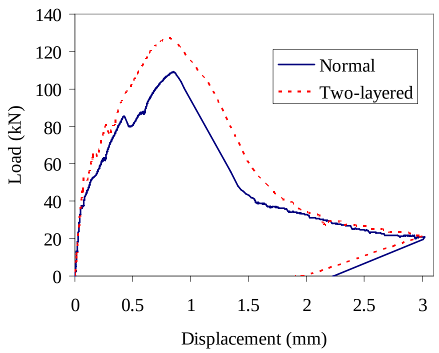

Fig.2: Load vs. displacement curves

3. Results

<u>(i) Flexural behavior</u> Fig. 2 shows example of load vs. displacement curves for both types of specimens. The composite specimen yielded higher maximum load than plain concrete specimen (129.8 MPa and 109.1 MPa respectively). Visual observations suggested no occurrence of debonding between the concrete and the fiber-reinforced mortar layer. Furthermore, the load-displacement curves of the composite specimen exhibited no abrupt change in gradient that is usually associated with significant increase in displacement due to stiffness loss. This implies that fiber-reinforced mortar has enhanced the strength performance of concrete beams without raising concerns of premature debonding.

<u>(ii) Location of AE events</u> Figure 3 illustrates typical examples of the AE event locations at specific load steps and cracks

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observed at ultimate failure. The AE events are represented by circles, with their centers situated the exact event location. The circle area is proportional to the respective amplitude and the contour color indicates the load in terms of percentage of the ultimate load when an event was detected. For the plain concrete specimen, in general it can be seen that a great number started to occur from 40% of the ultimate load, with the events concentrated mainly at the center of specimen. Visual observations revealed that this was when concrete fracture started, following the initiation of flexural cracks. At higher load percentages of 60% and onwards, events were found in the vicinity of large diagonal cracks at the left of the specimen, which confirmed that the ultimate failure was caused by shear. It is noted however that the development of cracks hindered accurate acquisition of all signals due to severe attenuation and delay. In the composite specimen a significant number of events only occurred from 60% of the ultimate load. During 70% to 90% of the ultimate load, an accumulation of events was obtained in the vicinity of diagonal crack developed at the left, and near the tip of smaller cracks at the right of the specimen. Thus, the AE results suggest no of premature debonding at the interface, which is in good agreement with the crack observation

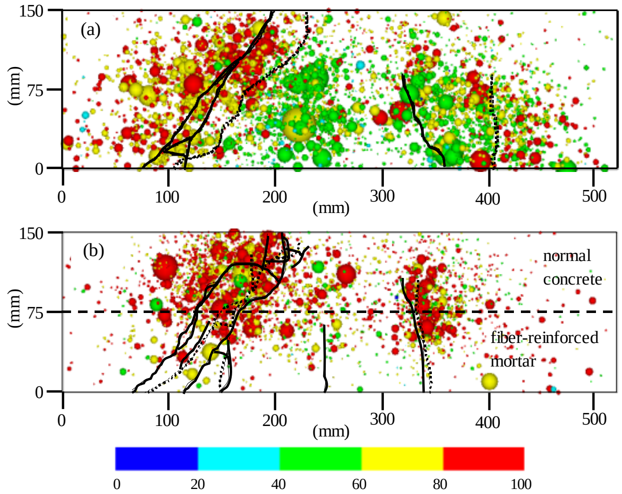

Fig. 3: Locations of AE events and actual cracking patterns for a) plain concrete specimen and b) composite specimen (solid line: crack from front view, dash line: rear view)

(iii) Tomography of ultrasonic velocity

It is known that pulse velocity is indicative of the damage. Data in the form of wave transit times of different paths were analyzed using a program specially developed for the purpose. Tomograms of the central cross-section were constructed, as exemplified in Fig. 4. At the intact condition, the pulse velocity was more than 4000 m/s. Under progressive loading, development of large-scale cracks significantly influenced the velocity structure, resulting in decrease of pulse velocity to 3000 m/s at the zone where the diagonal cracks developed. The tomography results also imply no debonding in the composite specimen, which tally with the results and observations of four-point bending test and AE measurements.

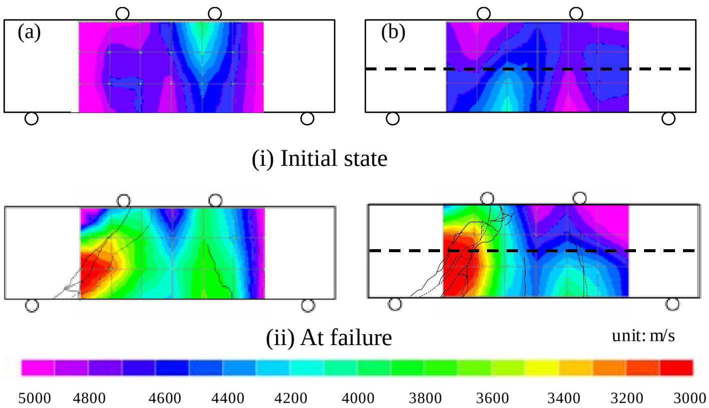

Fig. 4: 2-dimensional velocity structures of central cross section for a) plain concrete specimen and b) composite specimen

(4) Conclusions

AE and pulse velocity measurements were conducted during four-point bending tests of beam specimens composed of concrete and the fiber-reinforced mortar layer. AE event locations coincide well with the actual crack locations, showing that AE signals can be used to identify the damage in real time. The formation of cracks is also demonstrated by decrease of the velocity in the vicinity of cracks, which is visualized by the pulse velocity tomography. Both AE results and pulse velocity structures imply no premature debonding of fiber-reinforced mortar layer, and are well agreed by results of bending tests and visual observations. It is concluded that the stress wave methods can be used to evaluate the behaviour of composite concrete elements under loading, and provide the general assessment of the internal fracture process.

References: For example, Schechinger, B. and Vogel, T. (2007), “Acoustic emission for monitoring a reinforced concrete beam subjected to four-point bending”, *Construction and Building Materials*, Vol. 21, No.3, 483-490; Shiotani, T. and Aggelis, D. G. (2006), “Damage quantification of aging concrete structures by means of NDT”, *Proceedings of Structural Faults and Repair*, Edinburgh, June 13-15, (CD-ROM)Van Hauwaert, A. et. al. (1998), “Use of ultrasonics to follow crack growth”, *Ultrasonics*, Vol. 36, 209-217.