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ACOUSTIC EMISSION FROM REPAIRED REINFORCED CONCRETE BEAMS

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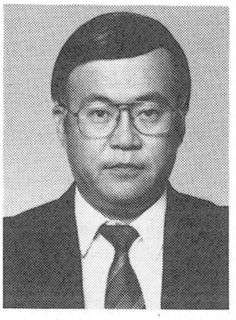
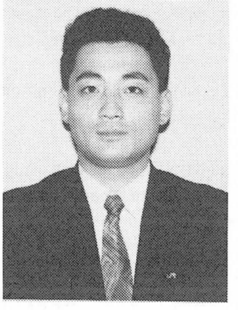
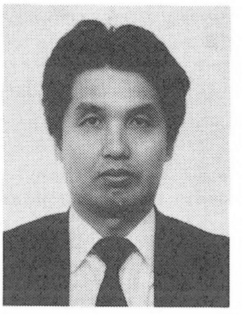

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SYNOPSIS

The acoustic emission from repaired reinforced concrete beams under cyclic loading was studied. Useful correlation was established between the acoustic emission activity and crack growth in the repaired reinforced concrete beams. Three different acoustic emission activities were observed during the flexural loading. Flexural crack initiation, flexural crack propagation and slip between repair material and old concrete were identified by monitoring the acoustic emission. The zone of slip initiation and development can be identified from acoustic emission event-location plot, showing major acoustic emission concentration areas. Repetitive loading showed that Kaiser effect was not valid after slip was happened at the connected face between repair material and old concrete. Flexural crack growth acoustic emission burst event signals were found to be of higher amplitude compared with those due to the slip. The accumulated number of burst events of these high-amplitude emissions, monitored by the use of a high threshold, showed good correlation with the crack growth in the beam.

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1.INTRODUCTION

In recent years, the deterioration and cracking of concrete structures have been significant problems. Losses sustained from these structural damages amount to trillions of yen annually. Setting the obvious loss of human life aside,the more indirect results of sudden structural failures are difficult to assess in terms of yen. To prevent such catastrophic failures proper repair is necessary in the damaged structures and evaluation of structural integrity for the repaired concrete members becomes vitally important.

Acoustic emission (AE) has been utilized for monitoring microcracks in concrete specimens by several researchers [1-3]. Cracking process and mechanism have been intensively studied in these works, using source location technique. It has been also shown that AE is one of promising diagnostic methods for evaluating the structural integrity of concrete structures [1].

Although AE has been thus effectively applied to different types of concrete specimens,no study has been made of AE behavior in repaired concrete structures. In the present work, AE and displacements are monitored during fracture of repaired reinforced beams under cyclic flexural loading. The purpose of this study is to characterize each AE source observed during the fracture by correlating the AE data with the results of visual observation and displacement measurement. An effective criterion to measure the severity of damages induced in repaired concrete beams is proposed, which gives some basic information on evaluating structural integrity of repaired concrete members.

2.EXPERIMENT

2.1 Material and Specimen

The material used to repair concrete beam is polymer-modified cementitious mortar. The dimensions of the specimen and the reinforcement arrangement in the specimen are shown in Fig. 1. Note that the shadowed area indicates repaired part. The depth and length of the repaired part are 10cm and 220cm, respectively. In addition to steel bars as longitudinal reinforcement, stirrups are embedded in the specimen to prevent beam shear failure.

2.2 Loading Sequence and Transducer Locations

The specimens were subjected to cyclic loading by a strain-control type machine. Given in Fig. 2 is the test loading sequence. During each loading, measurement of AE, crack pattern and width, slip between the repaired part and the original part, and strain of concrete and reinforcement was made by using AE and two different types of displacement transducers. Fig. 3 shows the locations of the transducers used to collect the above data. Note that tow-directional displacement (with crack) transducers were attached on both sides of the beam.

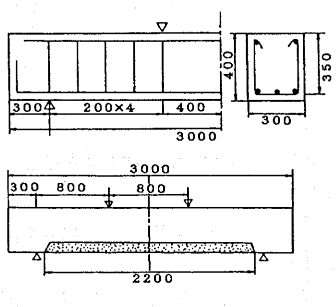

Fig.1 Dimensions of the specimen
and reinforcement arrangement

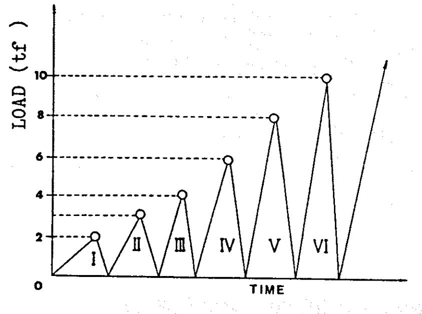

Fig.2 Test loading sequence

2.3 AE Instrumentation

PAC SPARTAN AE system was employed for AE data acquisition, signal processing and data analysis. AE signals detected by six PAC R15 (150 kHz resonant) sensors were bandpassed from 100 kHz to 300 kHz and amplifiered to 40 dB in 1220 A preamplifiers. The signals were further amplifiered to 40 dB in main amplifiers, so that the total system gain was 80 dB. The system was set up with a 100 micro V (40 dB) threshold at sensor output. AE hit activity, amplitude, and source location (both arrival time difference and zone) were analyzed in this study.

3.RESULTS AND DISCUSSION

3.1 Crack Initiation and Propagation

Fig. 4 shows relationship between displacement at the bottom center of the specimen and the applied load. Residual displacement starts to be observed after the fourth loading i.e. after the applied load has reached 6 tf.

Crack initiation and propagation process is represented in Fig. 5. Note that each number in the figure indicates the load at which crack initiation or propagation occurred. Early tensile microcracks in the repaired part, slips (shear cracks) between the repaired and original parts, and main tensile cracks propagating through both the repaired and original parts were visually observed, which agreed with the results of displacement measurement by two different types of displacement transducers. Fig. 6 presents the relationship between the displacement at the bottom center of the specimen and slip length measured by two directional displacement transducers placed along the interface between the repaired and original parts. It is observed that slips occurred during the fifth loading cycle at the transducer location No.1, during the fourth cycle at the location No.3, and during the third cycle at the location No.8. It is also seen that once these slips have occurred residual slips remain in the slipped area even after the specimen has been unloaded.

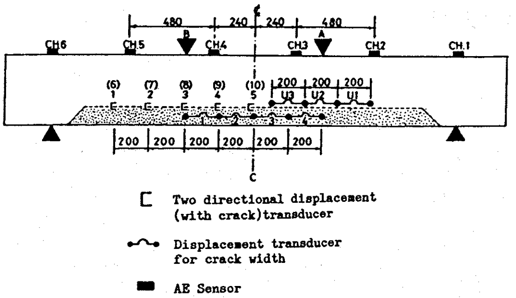

Fig.3 Transducer location

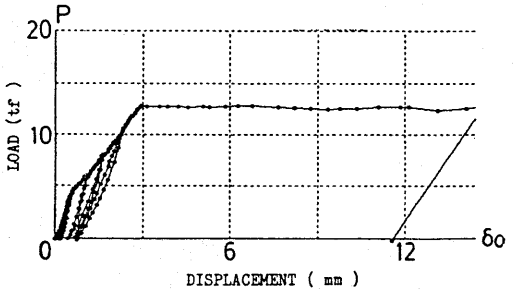

Fig.4 Relationship between center displacement and applied loading

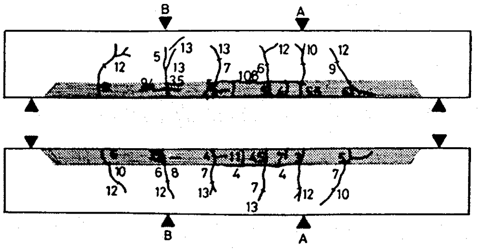

Fig.5 Cracking initiation and propagation process

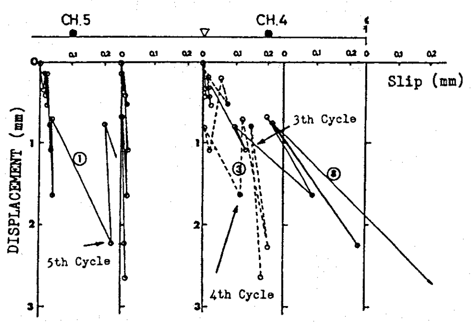

Fig.6 Relationship between center displacement and slip

3.2 AE Activity

AE hit rates (per 20 seconds) for channels 2,3,4 and 5 are shown in Figs. 7,8,9 and 10, respectively, together with displacement history at the bottom center of the specimen. As seen in Figs. 7,8, and 9, high AE activities are observed at channels 2,3 and 4 during the second loading to 3 tf, which corresponds to the initiation of the early tensile cracks in the repaired part, shown by 3 in the shadowed area of Fig. 5. The high AE hit rates measured at channels 2 and 3 during the second unloading from 3 tf and the third loading to 4 tf should be attributed to the initiation of the local slip (shear crack) found at the interface between the repaired part and the original concrete under loading point A because the occurrence of the slip was visually observed at about 4 tf in this area as shown in Fig. 5. Also it should be noted that a main tensile crack was first found visually at about 3.9 tf during the third loading just under the loading point A. On the other hand, large-scale slips (shear crack) took place during the third loading to 4 tf and the fourth loading to 6 tf in the channel 4 zone as shown in Fig. 6. This resulted in high emission activity during the third loading and especially very high activity during the fourth loading, observed in Fig. 9. In the channel 5 zone, it is shown, in Fig. 6, that slipping started during the fifth loading to 8 tf, which corresponds to the AE activity observed during the fifth loading Fig. 10. Fig. 11 shows the hit rate for all channel data, together with the displacement history at the bottom center of the specimen. It is observed that the initiation of the early tensile microcracks, main tensile crack, local slip and large-scale slips are clearly detected by AE hit measurement. A very important fact shown in Figs. 7, 8, 9, 10, and 11 is that once large-scale slips have occurred at the interface between the original concrete and the repaired part, AE starts to emanate at much lower load than the previous maximum load, that is, the Kaiser effect starts to break from the next loading and high AE activity starts to be observed during even

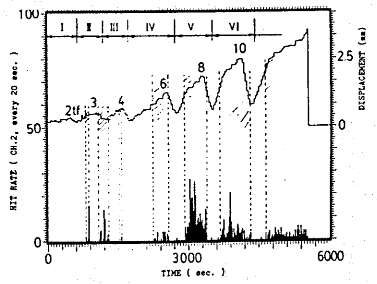

Fig.7 AE hit rate per 20 sec.(CH.2)

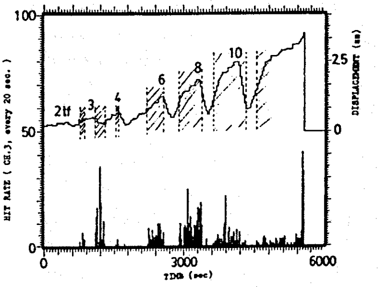

Fig.8 AE hit rate per 20 sec.(CH.3)

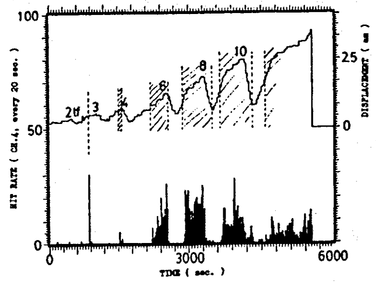

Fig.9 AE hit rate per 20 sec.(CH.4)

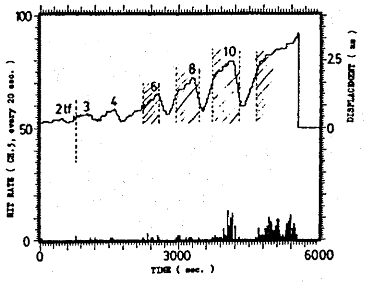

Fig.10 AE hit rate per 20 sec.(CH.5)

unloading. Thus, the breakdown of the Kaiser effect and the high AE activity during unloading can be a good indicator for the occurrence of large-scale slips in repaired concrete.

In Fig. 6, it is shown that if large-scale slip has occurred, the previous status cannot be recovered and residual slip remains in the slipped area even after the specimen has been unloaded. This interlocked state between the slipped faces should cause mechanical rubbing during loading and unloading. therefore, it is quite probable that the failure of the Kaiser effect and the high AE activity during unloading are due to

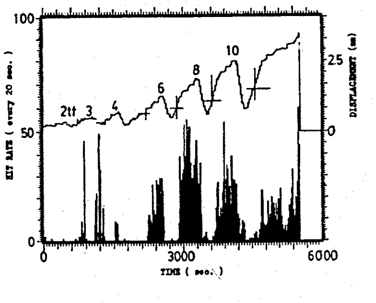

Fig.11 AE hit rate for all channel data

these rubbings between interlocked faces. Since the Kaiser effect started to break during the fifth loading in channel 2 and channel 3, it is speculated that large-scale slipping started during the fourth loading to 6 tf in the channel 2 and 3 zones.

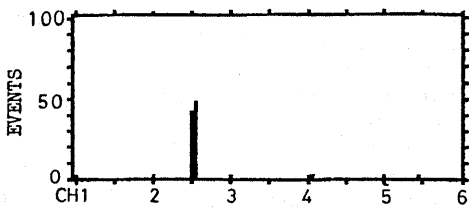

Fig.12 Source Location at the initiation of the main tensile crack

3.3 Source Location

It has been shown in the previous section that approximate locations of cracks, types of cracks and load levels at crack initiation can be known by analyzing AE hit rate activity for each channel.

Shown in Fig. 12 is the result of linear source location obtained immediately after the initiation of the main tensile crack at about 3.9 tf just under the loading point A. The AE events, located by measurement of arrival time differences, are strongly concentrated near the center between channels 2 and 3, well corresponding to the location where the main crack initiation was observed visually on the beam surface. The result of AE source location at the end of the test is given in Fig. 13. AE events due to the main crack initiation and the local slip initiation are strongly concentrated near the center between channels 2 and 3, but events due to the large-scale slips are seen to be widely spread between the different channels.

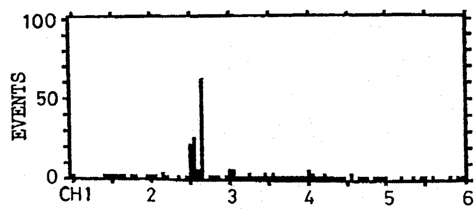

Fig.13 Source location at the end of test

3.4 AE Sources

As has been shown in the previous sections, that is 3.2 and 3.3. the high AE hit rates produced during the second and the third loading or unloading correspond to the initiation of the early tensile microcracks, the local slips or the main tensile crack which were visually found on the beam surface.

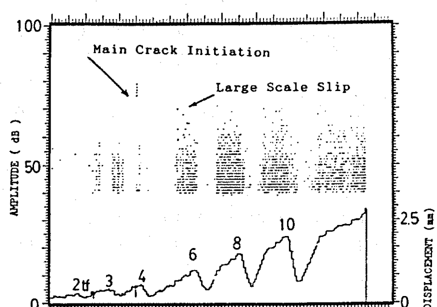

Fig.14 Amplitude plots versus time

The visual observation and the measurement by the displacement transducers also confirmed that exhibiting the breakdown of the Kaiser effect, the high AE activity measured during later than the fifth loading and unloading cycles is ascribed to mechanical rubbings between the interlocked faces introduced by the large-scale slips. Amplitudes of all hits are plotted versus time together with the displacement in Fig. 14. Fig. 15 is a three-dimensional plot showing amplitude distribution histograms of all hits recorded for every 1,000 seconds. From Fig. 14 and 15, it is obvious that the initiation of the early tensile microcracks or the local slips and the mechanical rubbings of the interlocked faces due to large-scale slips gave amplitude level of 40-60dB, while the initiation of the main tensile crack at 3.9 tf produced very high amplitudes which reached nearly 80 dB. Thus, the different AE sources can be clearly distinguished by comparing the amplitude data with the results of the visual observation and the measurement by displacement transducers.

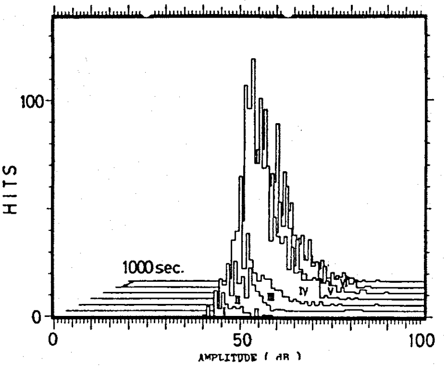

Fig. 15 Amplitude distributions for each 1000 sec. step

4. CONCLUSIONS

The fracture process of repaired reinforced concrete beams was monitored by AE, visual observation and displacement transducers. From the experimental results presented in this paper, the following conclusions can be drawn.

(1) It was shown that distinctive AE signals were produced by the initiation of early tensile microcracks, local slips, main tensile crack and large-scale slips. All these different AE sources and their amplitude levels could be clearly discriminated by comparing the AE data with the results of visual observation and the displacement measurement.

(2) The time and approximate location of the initiation of tensile cracks and slips could be clearly detected by monitoring AE. This results leads to the conclusion that the AE can be a very useful and powerful means to evaluate integrity of repaired reinforced concrete structures.

(3) It was found that the Kaiser effect starts to break and high AE activity is observed even during unloading once the large-scale slips have occurred. This is thought to be due to the rubbings of interlocked faces on the slips produced during the previous loading.

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