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Failure Detection of High-Strength Tendons in Prestressed Concrete Bridges by AE

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Abstract

Three types of beams post-tensioned by steel bar, strand, and parallel wire cable with three different grout conditions (unbonded, partially grouted and fully grouted) were tested in a laboratory. Failure was introduced by artificial corrosion, charging anodic current to tendons. It is found that acoustic emission (AE) signals with extremely high amplitudes are generated by ruptures of high-strength tendons. Detectability of failure is demonstrated to be 82-86%. Then, continuous AE monitoring was carried out in two highway bridges in service. The analysis of detected AE signals proves that meaningful AE events due to tendon failure are clearly discriminated from other signals of traffic noises and hammering.

Keywords: Acoustic emission; Tendon failure; Monitoring; Prestressed concrete bridge; Wire break.

1. Introduction

With the increase in failure of high-strength steel tendons in prestressed concrete structures, proper techniques for detection and evaluation of tendon breaks are to be developed in making rational decisions for rehabilitation, repair or replacement. One promising technique is acoustic emission (AE) [1-5]. In order to apply acoustic emission (AE) techniques to this end, basic studies are conducted [6]. Three types of post-tensioned concrete beams with steel bar, strand, and parallel wire cable were tested in a laboratory. Then filed applications were conducted in two post-tensioned bridges in-service.

2. Experiments

2.1. Laboratory test

Three types of post-tensioned beams with three sheaths of different grouted conditions (unbonded, partially grouted and fully grouted) were made as beams, B1, B2, and B3 of dimensions 10 m x 0.5 m x 0.5 m. Three sheaths were arranged in the perpendicular direction to the beam axis.

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Then, three of the each-type beam were post-tensioned with a steel bar, a strand (12 wires) and a parallel wire cable (12 wires), respectively. A wire break was introduced by artificial corrosion, by charging anodic current to the steel bar, the strand and the cable.

18 channel AE system (PAC SPARTAN) and 8 channel digital AE system (PAC MISTRAS) were employed for continuous monitoring. Three types of AE sensors, PAC R3I (30 kHz resonant), R6I (60 kHz resonant) and R15I (150 kHz resonant) were combined in the measurement for three weeks.

2. 2. Field test

Continuous monitoring was carried out in two high-way bridges (Bridge A and B) in-service for 24 days. A box-girder beam was monitored in Bridge A, while a T-shaped beam was monitored in bridge B. AE signals were indirectly detected in post-tensioned specimens bonded to the beams due to artificial wire breaks by corrosion. Two specimens of dimensions 2.2 m x 0.56 m x 0.56 m were bonded along the longitudinal (Type 1) and the transverse (Type 2) directions to the bridge. Three grout conditions of unbonded, partially grouted and fully grouted were prepared in these specimens. Loads in PC bars and strains in concrete were monitored by load cells and embedded strain gages, respectively. 18 channel SPARTAN AE system was employed for continuous monitoring. AE sensors consisting of PAC R3I, R6I and R15I sensors were placed at strategically selected positions on the post-tensioned beams of the bridges.

3. Results and discussion

3. 1. Laboratory tests

Extremely large AE signals with saturated amplitudes were detected due to breaks of the steel bars in B1 beam. The amplitudes exceeded 100 dB (0 dB = 1 micro volt at sensor output) and relatively accurate source location was possible for the breaks of unbonded and partially grouted bars. However, in case of the fully grouted bar, source location was difficult because of the complicated wave paths and reflections during the propagation of AE waves.

Numbers and successful ratio of detected wire breaks in B2 (strand) beam were 14 (74%), 18 (95%) and 15 (79%) for unbonded, partially grouted and fully grouted wires, respectively. Therefore, about 82% of all the wire breaks were detected. Locations of all the detected AE events are presented in Fig. 1. As can be seen, the locations of AE sources are in reasonable agreement with the locations of sheaths. Note that the location errors were found to be 10-20 cm. Averaged AE energy and averaged amplitudes were calculated from all the event data for each AE channel in the case of the wire breaks. It was found that the amplitudes detected by R3I sensors are very high (over 100 dB), those by R6I are high (60-100 dB) and those by R15I are low (50-80 dB). Thus, the lower the resonant frequency of AE sensor is, the higher sensitivity is observed. This is because the attenuation during wave propagation depends on the frequency ranges for the measurement. It is well known that the attenuation becomes larger as the frequencies become higher.

Numbers and successful ratio of detected wire breaks in B3 (parallel wire cable) beam were 9 (75%), 10 (83%) and 12 (100%) for unbonded, partially grouted and fully grouted wires, respectively. Therefore, about 86% of all the wire breaks were detected. The source location errors were again 10-20 cm. The history of AE events detected is shown in Fig. 2. Thus, the reliability for the wire break detection by AE monitoring was found to be over 82% from the tests in

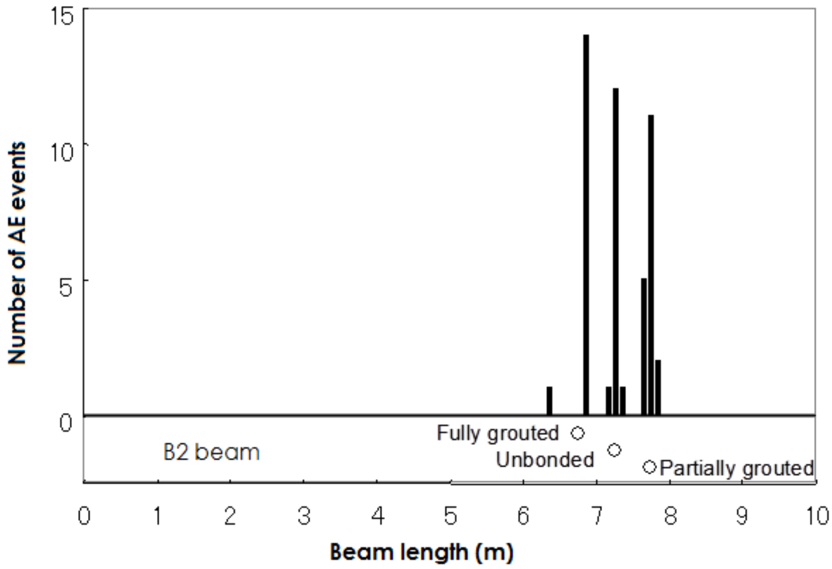

Figure 1. Locations of AE sources in B2 beam.

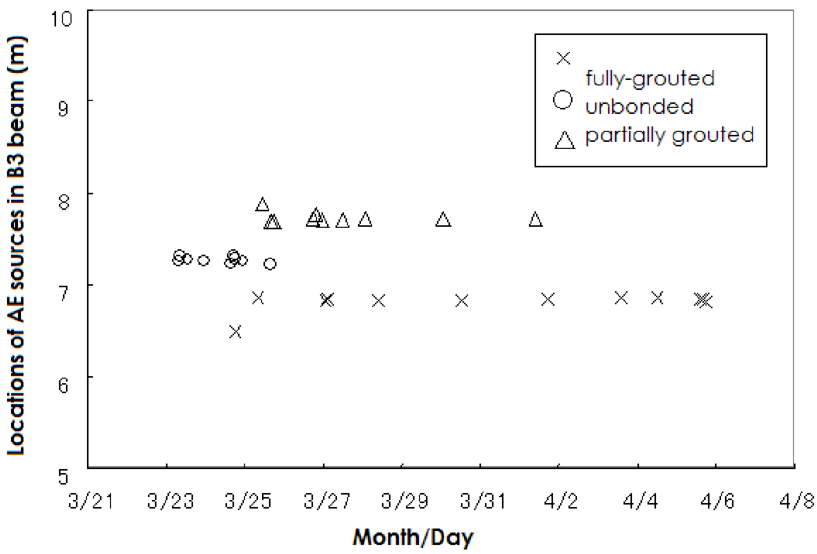

Figure 2. Time history of AE events in B3 beam.

B2 and B3 beams. Since the location errors in both B2 and B3 beams were around 10-20 cm, it is concluded that the error should be 2-4% of the sensor distance (5 m) in the laboratory tests.

3. 2. Field tests

In Bridge A, the linear source location was difficult to be analysed, because the artificial AE sources due to the wire breaks in the specimens were generated on the floor of the box-girder beam and thus considerable attenuation occurred. As a result the wave paths to the AE sensors were so complicated that the difficulty was encountered in the source location analysis.

It is noted that very low AE activities were observed during the weekends or holidays due to less heavy traffic as compared to week days. Still, very high amplitudes over 100 dB were detected by the sensors placed near wire breaks. Detailed analysis shows that R3I sensor had the highest sensitivity but it detected too many noises because of the high sensitivity in the low frequency range (20 – 60 kHz), while R15I sensor had too low sensitivity since the attenuation was quite high in the high frequency range (100– 400 kHz). Consequently, it is demonstrated that R6I sensor is the best selection for this application.

In Bridge B, more than 90 % of the wire breaks could be detected by AE monitoring in Type 1, while 82 % in Type 2. In addition, the linear source location could be accurately performed in this monitoring. Presented in Fig. 3 are results of the source location. An intense AE cluster is observed between CH 5 and 6 where wire breaks occurred. Other clusters are seen between sensor locations of CH 2 and CH 3, those of CH 4 and CH 5, those of CH 6 and CH 7, and those of CH 8 and CH 9 are due to mechanical movements of the beam supports which cross the bridge in the transverse direction. It is found that the location errors are less than 8 % of the maximum sensor distance.

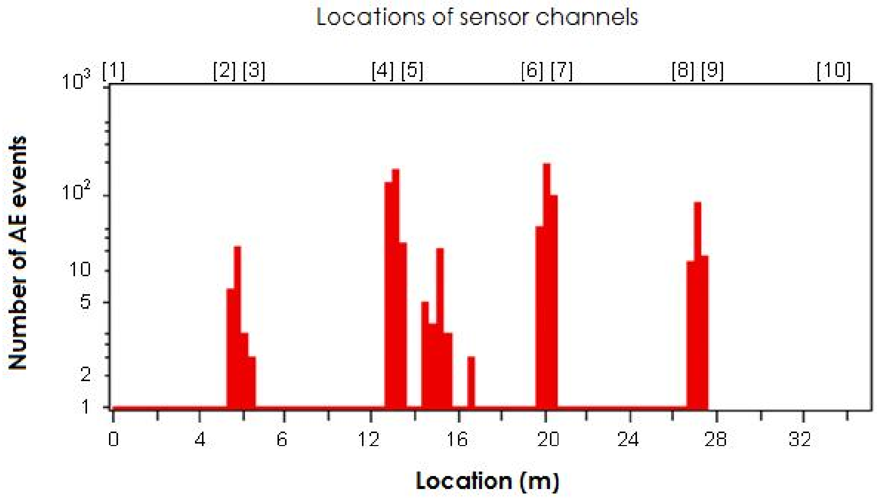

Figure 3. Locations of AE sources in Bridge B.

4. Conclusion

In order to investigate an applicability of AE monitoring to detect and locate the break of steel tendons in prestressed concrete bridges, a basic study is conducted. The following conclusions can be drawn:

(1) In the laboratory tests, extremely large signals with saturated amplitudes (over 100 dB) were produced by breaks of steel bars. Very large amplitudes that reach 100 dB were produced by wire breaks.

(2) Numbers and successful ratio of detected wire breaks in B2 (strand) beam were 14 (74%), 18 (95%) and 15 (79%) for unbonded, partially grouted and fully grouted wires, respectively. Therefore, about 82% of all the wire breaks were detected. Numbers and ratio in B3 (parallel wire cable) beam were 9 (75%), 10 (83%) and 12 (100%), respectively. Thus, about 86% of all the wire breaks were detected.

(3) Accurate linear source location was possible in B2 and B3 beams. The location error was found to be 2-4% of the sensor distance (5m).

(4) In the field tests of two bridges in-service, very high amplitudes that may reach 110– 140 dB are produced by wire breaks and linear source location is possible.

(5) Traffic noises produce AE signal sets with lower amplitudes than 90 dB, continuing for 1 - 2 seconds.

(6) It is very easy to discriminate meaningful AE signals due to wire breaks from such AE sources as traffic noises and hammering. Reliability in terms of the percentage of wire breaks detected under traffic conditions was higher than 90% in Bridge B, while it was about 80 % in Bridge A. The difference could result from the fact that the signal intensity introduced to the beam was much

stronger and the wave path was much simpler in Bridge B (T-shaped beam) than Bridge A (Box-girder beam)

Thus, AE is a very promising method to detect and locate wire breaks of prestressed concrete bridges in service.

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