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Acoustic emission monitoring of grouted splice sleeve connectors and reinforced precast concrete bridge assemblies

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HIGHLIGHTS

- AE monitoring is performed for two types of grouted splice sleeve (GSS) connectors.
- AE event history curves are representative of each GSS connector type.
- AE monitoring is performed for precast bridge assemblies built with GSS connectors.
- The AE method is able to identify concrete cracking up to full crack development.

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ABSTRACT

Acoustic emission (AE) monitoring was performed for two types of grouted splice sleeve (GSS) connectors used in reinforced precast concrete structures. The GSS connectors were subjected to monotonic tension tests. AE assessment of the GSS connectors demonstrated that AE events and event rates could be used to identify failure modes which were steel bar fracture for the first type of connectors and steel bar pullout for the second type. The AE event history curves can be taken as representative of each GSS connector type. AE monitoring was also performed for reinforced precast concrete column-to-footing and column-to-pier cap bridge assemblies utilizing GSS connectors. The bridge assemblies were subjected to quasi-static cyclic loads simulating earthquakes. The failure modes of the GSS connectors were also observed in the cyclic tests of the bridge assemblies. AE monitoring was able to identify column concrete cracking and full development of concrete cracks using a small number of sensors. The AE method was also able to identify rotation of the column for the column-to-footing assembly after fracture of column longitudinal bars.

1. Introduction

Acoustic emission (AE) monitoring is a recognized nondestructive test (NDT) method commonly used to detect and locate faults in structural systems. One difference between AE and other NDT methods is that AE monitoring is generally passive and relies on energy released from damage formation within the structure undergoing the test. Advantages of the AE method include greater speed, better reliability, and no disturbance to the structure; it is the only reliable NDT method able to detect a damage process in real time.

AE wave propagation properties depend on material makeup and structural component characteristics. Early applications of the AE method to structural concrete include testing of laboratory specimens [1], and concrete structures [2]. Other studies have investigated the AE method as a damage characterization technique for various reinforced concrete (RC) structures, such as foundations [3], columns [4–6], prestressed concrete girders [7,8], beams and slabs [9–12], bridge decks [13], bridge superstructure systems [14], building frames [15], and bridges [16,17].

Overall, little research has been performed using AE techniques to monitor structures under seismic loads. AE monitoring of masonry towers affected by local seismicity has been performed [18]. AE monitoring of an exterior RC beam-column assembly subjected to cyclic loading was very effective in assessing joint damage [19]. AE monitoring of a RC slab under dynamic loads was performed using a shake table; AE monitoring was effective for assessing damage to the slab and an AE energy index for damage evaluation of RC slabs under seismic loads was proposed [20]. Recently, a cyclic test of a RC column assembly was performed

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with concurrent AE monitoring; strong correlation between hysteretic strain energy and AE energy was obtained [21].

Accelerated Bridge Construction (ABC) is gaining acceptance because of reduced construction times and minimal traffic interruption. Grouted splice sleeve (GSS) connectors have gained attention as a possible precast concrete ABC method in seismic regions for reinforced precast concrete column-to-footing and column-to-pier cap bridge assemblies [22,23]. In the present study, an AE system with a small number of AE sensors is used to monitor two types of GSS connectors under monotonic load, and two reinforced precast concrete bridge assemblies connected with GSS connectors under cyclic quasi-static loads simulating earthquake induced forces.

2. Measurement system for acoustic emission monitoring

AE monitoring is a NDT technique which uses sensors to detect transient elastic waves produced by rapid redistribution of stress in a material. AE energy derives from the energy stored in the elastic stress field created by loading the structure. Acoustic emission is produced at the source due to rapid release of energy from damage formation as a short pulse of elastic and kinetic energy that travels through the material as an elastic wave. The AE methodology is based on detection, using acoustic sensors, of the elastic waves caused by changes in material properties due to deformation and cracking [24]. AE sensors are transducers that convert mechanical waves in a material into electrical signals; thus, information about the existence and location of possible damage sources is obtained.

2.1. AE system

The Digital Wave FMI-08 AE system was used to monitor two types of tests: monotonic tensile tests of grouted splice sleeve connectors and quasi-static cyclic tests of reinforced precast concrete bridge assemblies [25]. The system consisted of a portable computer, a signal conditioning board, pre-amplifiers, AE sensors, and coaxial cables [26]. When an AE event occurs, an elastic wave is initiated and is picked up by an AE sensor which converts the mechanical wave into a digital signal. The digital signal is amplified by preamplifiers before it reaches the signal conditioning board, which conditions the signal by filtering out unwanted frequencies; trigger levels are set to increase or decrease sensor sensitivity to events and amplify the signal before sending it to a computer. Computer software is subsequently used to analyze and display the signals. The 16 bit FMI system samples the signal at 20 MHz and provides full control of gains and filter settings. AE system settings for the monotonic tensile tests of the GSS connectors and the quasi-static cyclic tests of reinforced precast concrete bridge assemblies are given in Table 1.

Table 1
AE Settings for Digital Wave FMI system.

FM settings	GG tension tests	FG tension tests	Assembly cyclic tests
Pre amplifier (dB)	20	20	20
Signal gain (dB)	12	6	36
Signal HP filter (kHz)	20	20	20
Trigger gain (dB)	3	9	38
Trigger HP filter (kHz)	50	50	50
Trigger LP filter (MHz)	0.75	0.75	0.75
Sampling rate (MHz)	5	5	2

Note: GG = Grouted-grouted splice sleeve; FG = Fixed-grouted splice sleeve.

2.2. AE sensors

Two different AE sensors were used in this study. Digital Wave B-1025 ceramic sensors were used for the GSS connector tests and column exterior surface for the reinforced precast concrete bridge assembly tests; these sensors have a 6.4 mm diameter and a frequency bandwidth of 1 kHz to 1.5 MHz. Measurement Specialties SDT film sensors, which operate reliably in the frequency range of 1–100 kHz, were used for the GSS connectors embedded in the reinforced precast concrete bridge assemblies.

Elastic waves are generated by cracking, plastic deformation, friction due to aggregate interlock and debonding of aggregate and mortar. Fig. 1 shows a traditional elastic wave corresponding to an AE event and its recorded characteristics with narrow band sensors. For an elastic wave to be recorded as an event, the wave amplitude has to be larger than the threshold. The energy of the event is the area above the threshold and below the envelope of the wave. This value is given in ue, energy units; 1*ue* = ln (Volts*seconds), where "ln" is the natural logarithm.

3. Grouted splice sleeve connector tension experiments

The first step in assessing the damage of reinforced precast concrete assemblies constructed with GSS connectors is to obtain the AE characteristics of the latter. Two types of GSS connectors were tested to failure under monotonic tension while being monitored with AE sensors; two loading rates were used to determine if the rate had an effect on AE characteristics: 10 and 100 mm/min. The first GSS connector, referred to as a grouted-grouted (GG) splice sleeve, uses non-shrink high strength grout to splice both bars as shown in Fig. 2(a). The second GSS connector, referred to as a fastened-grouted (FG) splice sleeve shown in Fig. 2(b), has a bar fastened to one end with threads while the other bar is grouted using non-shrink high strength grout at the opposite end. The tension test setup and AE sensor locations for both GSS connector types are shown in Fig. 3; two sensors were attached on the exterior surface of the steel sleeves: AE-1 was attached adjacent to the factory dowel end and AE-2 adjacent to the field dowel end. In this research, D25 steel bars with specified yield strength of 414 MPa were used along with the specified splice sleeve size and grout. The actual material properties of the steel bars and grout used for each splice sleeve type are presented in Table 2. Both GSS types are proprietary systems which are supplied with a unique prepackaged non-shrink grout. As a result of using different grout types for each system the grout compressive strengths are different.

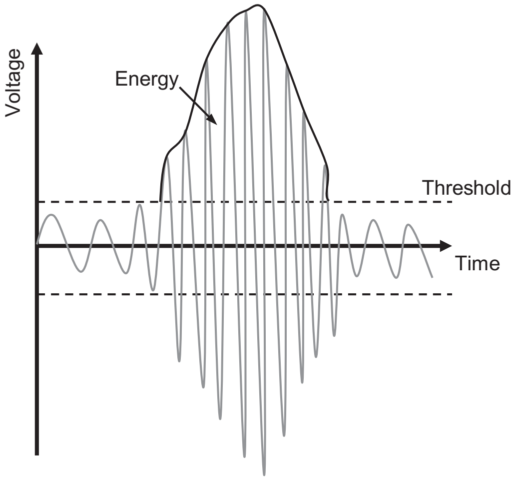

Fig. 1. Traditional AE event and characteristics using narrow band sensors.