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AE monitoring of reinforced concrete squat wall subjected to cyclic loading with information entropy-based analysis

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ABSTRACT

Reinforced concrete (RC) squat walls have been widely used to resist horizontal force given its high lateral stiffness and strength. In this research, the crack development process of squat wall under non-parallel cyclic loading was monitored using an acoustic emission (AE) technique. In addition, a novel AE signal analysis method based on information entropy was studied. The results show that the AE technique is effective in monitoring the crack process of the squat wall. A strong correlation between the result of basic AE parameters analysis and real cracking state is also determined. Furthermore, accumulated AE energy shows a good correlation with the accumulated hysteretic energy and the damage assessment based on RA-AF analysis indicates the shear cracks are the dominant crack mode. Information entropy-based analysis was conducted, and its feasibility in monitoring the development of main cracks was validated. A comparison between information entropy-based analysis and b-value analysis was conducted finally, which shows that the information entropy value is more sensitive and specific than *Ib* value.

1. Introduction

Reinforced concrete (RC) squat walls are widely used nowadays given its high lateral strength and stiffness, especially for some special structures, for instance, nuclear facilities. When faced with cyclic loading situations like earthquake, shear would be a predominant action and lead to the failure of wall. Extensive analytical and experimental research have been conducted in this field [1–3]. Based on softened strut-and -tie model, Hwang et al. [4] proposed a solution to calculate the shear strength of squat wall and verified by available experimental results. Salonikios [5] tested 11 RC squat wall with shear span ratio of 1.0 and 1.5 under cyclic loading and the result shows that the specimens can reach their flexural capacities with proper design. However, most of the experimental results from available research are studied based on the assumption that loading direction is parallel to the long side direction of the wall section, which is not always the case in reality. Seismic waves can reach the structure from any direction and therefore, the wall would undertake a biaxial bending action, which renders the failure process much more complex.

Acoustic emission (AE) technique is a monitoring method that is widely used in mechanical engineering, rock excavation and civil engineering. It is based on the elastic waves that are generated from damage position in material and it allows researchers to determine the damage state without regular visual inspection. Some typical AE parameters can be acquired from the AE signals, including amplitude, energy, duration, which can reflect the state of some inaccessible places. Moreover, with deliberate deployment of AE sensors, the location of irreversible change can be identified. Many different RC components under cyclic loading have been monitored based on AE technique and the cracking process was studied in the past [6–10]. Amadeo et al. [11] monitored a RC exterior beam-column joint and found that the AE energy histories has a strong correlation to hysteretic strain energy. Alireza et al. [12] monitored a large-scale wall and identified critical damage condition based on b-value outlier analysis. However, research studying crack monitoring of squat wall under non-parallel direction has not been reported. Compared to the parallel loading, the crack process would be more complex for non-parallel structures because of biaxial bending. Therefore, it is meaningful to study and monitor the crack process and damage states of squat wall under non-parallel cyclic loading.

In 1949, Shannon [13] proposed information entropy as a method to describe the properties of information as well as its quantitative metric and can also describe the uncertainty of a system. A smaller entropy value represents that less uncertain information is existed in the system. Entropy theory is widely used in computer science, economics, astrophysics and so on [14,15]. In different subjects, extended

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definition of entropy value is different and some of them are very important parameter in their fields. Santis [16] applied the information entropy theory to study the development of earthquake and good agreement was found with the seismic sequence of two real case. Because of the similarity between earthquakes and AEs, and the uncertainty in AE signals, information entropy-based analysis of AE signals is possible.

In this paper, the crack process of squat wall under non-parallel cyclic loading are studied based on AE technique. The loading was applied at the top of the specimen and the AE signals were collected by AE sensors attached on the wall. The cracking process and damage state were investigated by analyzing AE parameters, improved b-value (*Ib*), and information entropy value. Finally, a comparison between b-value analysis and information entropy-based analysis was conducted.

2. Experimental test

2.1. Specimen specification

A rectangular squat wall of shear span of 1.11 was tested in this research. The width, height and thickness of the wall were 0.9 m, 1 m, and 0.15 m respectively. There is an angle of 10° between the direction of the loading and width of the wall to simulate the cyclic action from nonparallel direction, as illustrated in Fig. 1.

8 mm rounded bars (R8) and 6 mm rounded bars (R6) with a spacing of 150 mm were arranged in the web as longitudinal reinforcement and transverse reinforcement respectively. At the edge of the wall, 16 mm deformed bars (T16) and R6 bars with a spacing of 75 mm were applied for the consideration of buckling of longitudinal reinforcement and maintaining the integrity of wall segments. The ratio of horizontal and vertical reinforcement was 0.25% and 0.45% respectively. Detailed specification of the wall is shown in Fig. 2. The compression strength of concrete tested in site is 31.0 MPa and the material properties of reinforcements are listed in Table 1. A RC pedestal of 1.5 m × 1.5 m × 0.5 m was fabricated together with the wall and it was connected with the strong floor of the lab by anchor rod.

2.2. Loading set-up

Cyclic loading was applied on the steel beam above the specimen to simulate seismic action. The steel beam was connected to the specimen by anchor rod, and a hydraulic jack was installed above the steel beam to exert axial force, as illustrated in Fig. 3. The axial force ratio was kept constant at 0.1. The cyclic loading program is stated in Fig. 4, where the first and second step was conducted at drift ratio (DR) of 0.05% and 0.1% respectively. After that, the loading step was set as multiple of DR of 0.25%. There are two cycles in each step, except the last cycle at 1.5% DR.

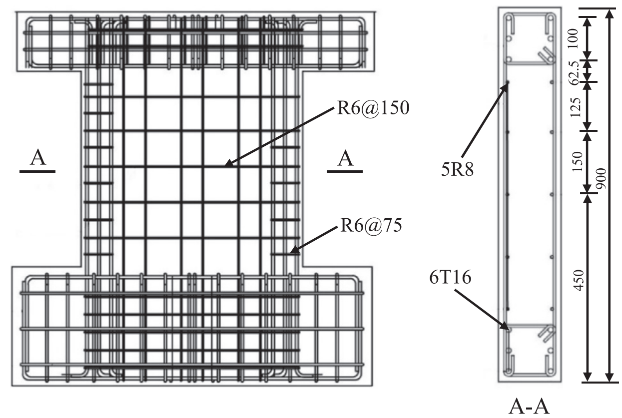

Fig. 2. Details of RC squat wall specimen.

Table 1
Material properties of reinforcement.

Rebar	Yield strength (MPa)	Ultimate strength (MPa)
R6	565	705
R8	560	695
T16	545	675

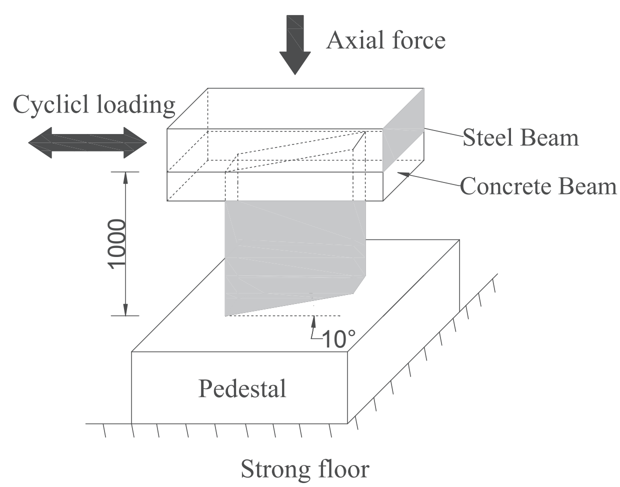

Fig. 3. Cyclic test of RC squat wall specimen.

2.3. AE system

In this experiment, Micro-II Digital AE System with 16 channels (Physical Acoustics Corporation) was adopted to collect the AE signal

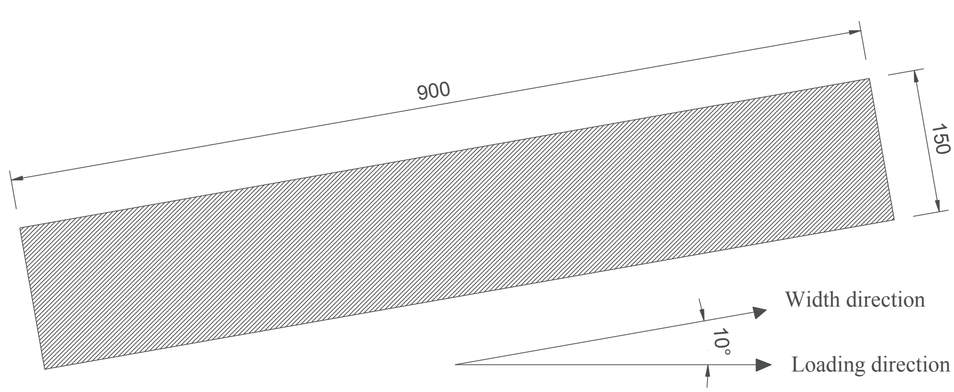

Fig. 1. Loading direction.