Acoustic emission source location of saturated dense coral sand in triaxial compression tests

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ABSTRACT

Since acoustic emission (AE) could be produced because of sand particle crushing and/or sliding, more and more researchers have been exploring the potential of applying AE technique to localize such interactions on sand. In this paper, drained triaxial compression tests incorporating with an array of eight AE sensors were conducted on saturated dense coral sand under different constant loading rates, aimed at locating the shear band by AE source location technique. Like the back analysis of earthquake epicenter, the source location and the generation time of the AE event were calculated based on the principle of Time Difference of Arrival (TDOA) and an assumed constant wave velocity of 1500 m/s. Results showed that the AE sources were concentrated into an inclined band in the post-peak region, which was consistent with the appearance of the shear band developed in the specimens.

Keywords: acoustic emission, source location, triaxial compression tests

1 INTRODUCTION

Shearing resistance is mobilized in sandy soils by interactions between particles, like particle to particle sliding and particle breakage. In dense sands, shear strains are easier to be localized into concentrated shear zones to form shear bands, like inclined column chains of particles (Hasan & Alshibli, 2010).

On the other hand, AE (acoustic emission) sensors can detect the micro noises (i.e. elastic body waves) released from particle crushing and sliding (ASTM, 2015). Mao and Towhata (2015) found that particle breakage had much higher frequency content (>100 kHz) than particle sliding (<100 kHz). Lin et al. (2018) found that the loose saturated sand generated more AE than the dense one, which was possibly due to shear strains. Currently, researchers have been exploring the potential of applying AE technique to localize such interactions on sand. Mao et al. (2019) firstly used an AE source location testing approach and proved its feasibility to visualize the particle breakage behaviour during pile penetration process in dry sands.

In this research, drained triaxial compression tests incorporating with an array of eight AE sensors were conducted on saturated dense coral sand under different constant loading rates, aimed at locating the shear band by AE source location technique.

2 TEST APPARATUS AND MATERIAL

A traditional triaxial apparatus with a motor-driven axial loading device was used. It was modified with a movable pedestal, which will be introduced later. The test material was coral sand with a specific gravity of 2.81 g/cm³ and a D₅₀ of 0.75 mm, and its particle size distribution is shown in Fig.1.

![Fig. 1. Particle size distributions of the used coral sand.](https://doi.org/10.3208/jgssp.v08.j11)

In order to locate the shear band developed during triaxial drained compression, an array of eight AE sensors was attached to the surface of the membrane with a thickness of 0.3 mm, as shown in Fig.2 a. The cylindrical specimen was 50 mm in diameter and 100 mm in height. The piezo-ceramics type AE sensor was
displayed in Fig. 2 b. It was produced by Fuji Ceramics Corporation: M304A, and its working frequency is 10 kHz - 5 MHz (the resonant frequency is 300 kHz), and its sensitivity is $115 \pm 3$ dB (ref. $0 \text{ dB} = 1 \text{ V/m/s}$). The pedestal was set to move in one direction to develop a diagonal shear band in this research more easily, as shown in Fig. 2 c.

The AE measurement system was consisted of AE sensors, pre-amplifier part, data logger part and record and analysis part, as shown in Fig. 3. The original AE signal was continuously recorded by the data logger with a sampling rate of 2 MS/s.

![Fig. 2. a) Sample before test b) AE sensor c) Movable pedestal.](image)

![Fig. 3. AE measurement system.](image)

3 TEST PROCEDURES

The sample was prepared in a split metal mold using air-pluviation method. In this method, a funnel with appropriate opening was used to fall sand from 50 cm height to achieve the desired relative density of around 85 %. After finishing the sample and applying a confining stress of 30 kPa by a partial vacuum, the sample was attached by 8 AE sensors and then saturated using double vacuuming method (Ampadu and Tatsuoka, 1993). Subsequently, the sample was loaded isotropically to an effective confining pressure of 200 kPa, while applying a back pressure of 200 kPa. Then the sample was isotropically consolidated for 30 minutes. In this way, two tests were conducted under different constant loading rates of 1.0 mm/min and 6.9 mm/min. The relative densities of the samples were 84.2 % and 86.3 %, respectively. After making the samples saturated, the $b$ values were measured to be 97.8 % and 98.5 %, respectively.

4 ACOUSTIC EMISSION SOURCE LOCATION

4.1 Location of sensors

The position of sensors is displayed as small black square in Fig. 4. Thus, the location of sensors in Cartesian coordinate system are summarized in Table 1. In such case, sensors are not too far away from the potential AE source region, considering wave attenuation from AE generating to AE receiving during propagation in sand.

![Fig. 4. 3D view of sensors arrangement.](image)

| Sensor No. | Coordinate/m |
|-----------|--------------|
| $x$       | $y$          | $z$          |
| S1        | 0            | 0.025        | 0.085        |
| S2        | 0            | -0.025       | 0.085        |
| S3        | -0.025       | 0            | 0.075        |
| S4        | 0.025        | 0            | 0.075        |
| S5        | 0            | 0.025        | 0.015        |
| S6        | 0            | -0.025       | 0.015        |
| S7        | -0.025       | 0            | 0.025        |
| S8        | 0.025        | 0            | 0.025        |

4.2 Time Difference of Arrival (TDOA)

Like the back analysis of earthquake epicenter, by using the method of AE source location testing by Mao et al. (2019), the source location and the generation time of the AE event can be calculated based on the principle of Time Difference of Arrival (TDOA). The travel distance between AE source and the $i$-th sensor can be obtained by formula (1) (Kundu, 2014):

$$d_i = (t_i - t) \times v = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}$$

where $(x, y, z)$ are the unknown location of AE event and $t$ is the generation time, $(x_i, y_i, z_i)$ are known location of AE sensors and $t_i$ is detected arrival time by AE sensors, $v$ is the AE wave velocity, which is assumed to be 1500 m/s for saturated sand specimen according to Lin (2018). Theoretically, one AE event is possible to be located by four sensors, while in practice, more sensors are used to reduce the potential errors.

5 TEST RESULTS AND DISCUSSIONS

5.1 Photos of shear band

The photos of shear band were taken after finishing tests and moving the cell out. From Figs. 5 and 6, it was known that the shear band at the loading rate of 1.0 mm/min was not along the direction of movable pedestal, which was not very clear to be observed, while a diagonal shear band was clear to be observed at the...
loading rate of 6.9 mm/min.

5.2 Drained triaxial test results

Deviator stress-axial strain and volumetric strain-axial strain curves were shown in Figs. 7 and 8, respectively. The shapes of their curves were very similar even if the loading rates were different. During the pre-peak, peak and immediately after the peak stress states, the curves were almost the same, while there were obvious differences among the post-peak and residual regions. According to Di Benedetto et al. (2002), loading rate has little influence on the stress-strain curves of sands. Thus, such differences may be due to that the shear band was developed incompletely at the loading rate of 1.0 mm/min while it was completely developed on the other one.

Fig. 5. Observed shear banding after test at the loading rate of 1.0 mm/min; a) front view and b) back view.

Fig. 6. Observed shear banding after test at the loading rate of 6.9 mm/min; a) front view and b) back view.

5.3 Acoustic emission source location

Detailed results of AE source location were shown with a time interval of 300 s (i.e. axial strain of 4.85 %) for the loading rate of 1 mm/min and 45 s (i.e. axial strain of 5.01 %) for the loading rate of 6.9 mm/min in Figs. 9 and 10, respectively. The whole picture was an area of 50 mm in width and 100 mm in height. The spatial distributions of the AE source were represented by the percentage of source number falling within each patch.

As to the test at loading rate of 1.0 mm/min, because the shear band was not along the direction of movable pedestal, the AE sources were rotated 150° clockwise to be observed more clearly from the front. During the pre-peak region (0 ~ 4.85 %), the AE sources were distributed randomly. Near and immediately after the peak stress state (4.85 % ~ 14.55 %), the AE sources started to concentrate. In the post-peak region (14.55 % ~ 24.24 %), the AE sources were concentrated into an inclined band, which was consistent with the appearance of the shear band developed in the sample shown in Fig. 4. Such concentration continued for the residual stress state (24.40 % ~ 29.10 %).

At the loading rate of 6.9 mm/min, the results showed a similar tendency, especially, in the post-peak region (15.04 % ~ 25.07 %), the AE sources were concentrated into an inclined band, consistent with the appearance of the shear band developed in the sample shown in Fig. 5. However, AE sources that started to concentrate into an inclined band seemed to concentrate earlier at higher loading rate case (at the stage of 10.03 % ~ 15.04 %) than the slower loading rate case (at the stage of 9.70 % ~ 14.55 %).

In addition, the spatial distribution of AE sources at different loading rates showed obvious difference from the very beginning, even if the primary shapes of the deviator stress-axial strain and volumetric strain-axial strain curves were similar.

6 CONCLUSIONS

Aimed at locating the shear band by AE source location technique, two drained triaxial compression tests incorporating with an array of eight AE sensors were conducted on saturated dense coral sand under different constant loading rates of 1.0 mm/min and 6.9 mm/min, some conclusions can be obtained as below:
Fig. 9. Calculated results at the loading rate of 1.0 mm/min; a) stress-strain curve with axial strain of 4.85 % and b) spatial distribution of AE source.

1) AE source location method can be applied to locate shear band of triaxial drained tests of saturated coral sands, based on the principle of Time Difference of Arrival (TDOA) and an assumed constant wave velocity of 1500 m/s.

2) The AE sources were concentrated into an inclined band in the post-peak region, which was consistent with the appearance of the shear band developed in the samples.

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