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Different Acoustic Emissions Source from the Evolution of Granular Stick-slip Events

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1 Introduction

Debris flows and landslides are composed of granular materials with different grain sizes, shapes and mineral compositions. These geological hazards are complex evolutionary processes of granular structure from stable state to unstable destabilizing deformation, followed by large deformation flow. From the view of particle matter mechanics, the occurrence of these hazards is the process of the development of the particle assemblage comprising the geological body from a blocked state to a rheological state under the constraints of external boundaries. During the deformation process, the mutual collision, friction, fragmentation and structural changes between the particles will release strain energy and disperse it in the form of elastic waves, which is called acoustic emission (AE). Consequently, the characteristics of the acoustic emission signal generated during the deformation of granular materials and the changes of its parameters can be used to reflect the stability state inside the granular structure. Herewith, we report on a series of direct shear — AE tests to investigate the relationship between characteristics of AE and mechanical behavior of granular in stick-slip events.

2. Methods

We used spherical glass beads (1.0–3.0 mm diameter) to represent particles. Shearing was performed in a strain-controlled way at a constant shear speed of vs = 0.1, 0.4, 0.8 or 1.2 mm/min and constant normal stress of σn = 50, 100, 200 or 300 kPa. In order to detect the energy released inside the samples, three equally spaced acoustic emission (AE) transducers were installed around the shear box. Additionally, using the external parameter interface of the AE system, we collected the AE waveform, shear stress and displacement at the same time, which allowed us to accurately explore the relationship between characteristics of AE and mechanical behavior in the shear process.

3. Results

Our results suggested that during the granular shearing process there was a strong correlation between stick-slip events and the distribution of AE characteristics. (Fig. 1). AE features vary with the stick-slip event cycle. Then, we divided the stick-slip phenomenon into 11 stages from start to finish and indicated them with different colors.

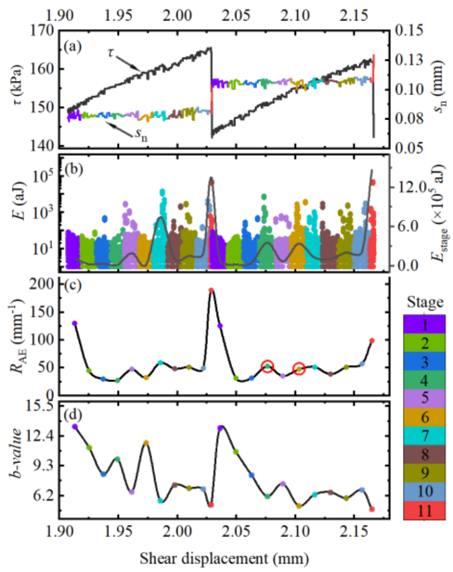

Fig. 1 One representative result showing correlations between stick-slip and AE features. (a) shear stress and vertical displacement, and (b) AE energy; (c) AE rate; and (d) the b-value.

Based on the correlation analysis of AE features, we found that energy and Root Mean Square (RMS) of AE waveform showed significant spatial clustering (Fig. 2(a)). We divided the area into four blocks. Then, by statistically analyzing the phases of occurrence as well as the changes in the number of occurrences and the time-frequency characteristics of the waveforms in the four regions, we concluded that region A represents the signal of inter-particle friction. Its amount occupies more than 98% of the overall acoustic emission quantity. The AE in this type is low in energy and short in duration. With the increase of stress, the contact between particles is closer, the interaction between particles increases, and the number of AEs generated increases. It can be concluded that the incidence of AEs in region A reflects the overall stability of the particle structure. The more unstable the structure is, the more significant the friction between particles will be, and the more AEs will be generated (Fig. 2(c)).

Region B represents the signal of structural failure. AEs only occur in the stress-drop process. The energies of these AEs events are much higher than those in other regions, and each stress drop is associated with a single AE event in each AE sensor. It can be seen that the high-energy AE is generated by the large amount of energy released from structural failure.

Region C represents the signal of local failure of the structure. This type of AE appears only sporadically and gradually in the later stages of structural deformation. Spectral analysis shows that the AEs in the C and B regions are similar and represent a sudden energy release from the particle structure. And, the energy of AE in Region C is much smaller than that in Region B. So, we conclude these signals characterize small-scale damage of the internal structure and are important precursor features of instability.

Region D represents the strong vibration after structural failure. The acoustic emission signals in this region all occur after structural failure and were consecutive. Although these AEs are small in energy, they have a very high RMS which similar with Region B . These AE signals represent the gradual dissipation and duration of the high-energy elastic wave generated after the stress drops.

4. Conclusions

The most important finding of this study is that many different types of acoustic emissions are generated during particle shearing. The high-energy AE signals (Region C) can accurately indicate structure failure. In addition, friction AE and local failure AE (Region A and B) can represent the gradual damage process and can be used as important characteristic indicators for particle stability monitoring.

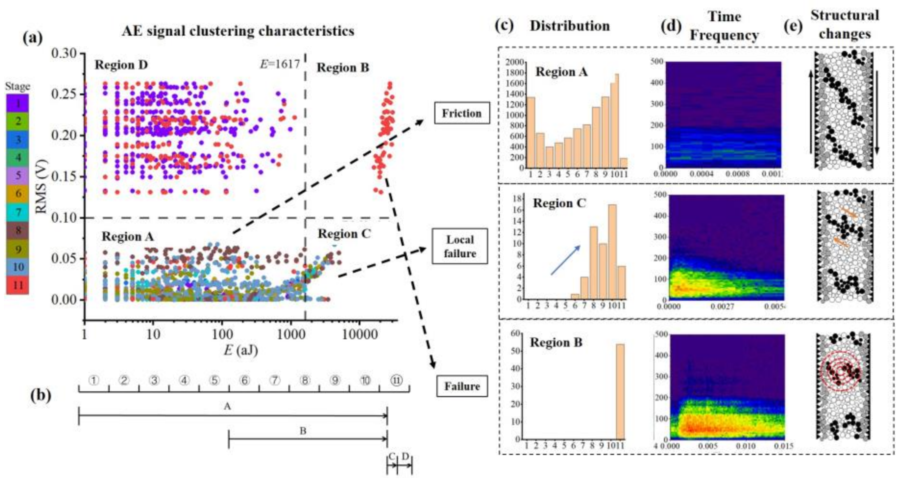

Fig. 2 (a) RMS-energy scatter plots of different stages; (b) The occurrence law of four regions AEs in stick-slip event; (c) Statistics on the numbers of AEs in different regions; (d) Time-frequency graphs of typical AE waveforms in different regions; (e) Schematic diagram of particle structure change