学位論文の要約

Experimental Study on the Frictional Instability and Acoustic Emission in Sheared Granular Materials with Implications for Landslide Mobility

地すべり運動特性に関連するせん断状態下での粒状体の摩擦不安定性とアコースティック・エミッションの実験的研究

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Chapter 1 Introduction

Landslides are among the most hazardous geologic processes, annually causing thousands of casualties and substantial damage. The deforming parts of most landslides are generally composed of granular materials, in which the materials gain frictional forces to resist movement through the interactions of constituent grains. Although, over the past several decades, investigations have been carried out to examine the shear behavior of landslide materials under different conditions, the effects of particle characteristics and mechanical conditions on the frictional behavior of granular materials subjected to large shear displacement are still unclear.

Acoustic emissions (AEs) are high-frequency elastic waves generated by the rapid release of energy, and they carry important information regarding the failure mechanisms in stressed geologic materials. AE monitoring has been used in rock mechanics to provide insights into deformation processes for intact rocks, rock surfaces and other geological applications. However, the AE properties of sheared granular materials are poorly understood.

Therefore, to better understand the frictional behavior of sheared granular materials, this experimental study aims to examine frictional behavior and AE activities in granular materials during shearing, with a focus on the influence of particle size and shear speed.

Chapter 2 Experimental methods

The laboratory assemblies employed in this research including the ring-shear apparatus and the AE recording system are introduced. The basic information for the ring-shear apparatus, acoustic transducer and data acquisition system are described. The characteristics of samples and the experimental programs associated with test procedures are given in this chapter as well. Finally, the methods of data analysis are presented.

Chapter 3 Frictional instability of sheared granular materials subjected to large shear displacement

The frictional instability behaviors of locally sheared granular materials subjected to large shear displacements are primarily analyzed. Based on the observed frictional behaviors, the influence of particle size and shear speed on the parameters of frictional instability (i.e., stress drops, recurrence time and recurrence displacement) are thoroughly discussed. The relationship between the stress drop and the recurrence time is investigated as well by invoking the concept of frictional instability rate, to determine the different roles of particle size and shear speed. The possible mechanisms are systematically discussed for the frictional instabilities observed in the present research.

Chapter 4 Acoustic emission signature of dynamical failure of sheared granular materials

The experimental results of the detected acoustic signals are presented. On the basis of AE waveforms for different particle sizes and shear speeds, the AE characteristics of locally sheared granular materials, such as their average occurrence rate, the frequency-amplitude relation and, the power-frequency spectrum, are systematically discussed in detail. In addition, the sequences of shear resistance and acoustic waveforms in a time domain are analyzed, since the time-frequency spectrum is crucial to identifying whether the AE events are precursors or resultant phenomena of mechanical failures. A mechanism for the generation of AEs is proposed, and the possible roles of dynamic waves in affecting the global failures during granular shearing are discussed as well.

Chapter 5 Implications of frictional instability and acoustic emissions in landslide dynamics

On the basis of present results for the frictional instability and AEs, this chapter provides more discussion on the applications in earth sciences especially for landslide and their motion.

It has been shown that the post-slide mobility of landslide materials will be underestimated due to the occurrence of frictional instability. This is because higher energy is involved to evaluate shear strength of deforming materials by using the conventional failure envelope method. From this point, the experimental results for different particle sizes provide evidence for some experiments showing that larger particles will show higher mobility than smaller particles in terms of a more reasonable index of coefficient of friction obtained by measuring the center of gravity.

The time difference between the onset of AE amplitudes and the beginning of stress drop indicates that global mechanical failure is induced by material local failures, in which the generated AEs may dynamically induce more failures along the force chains and eventually result in global mechanical failure. The present study may provide experimental evidence for the correlation between local failure and global failure for landslide movements.

Chapter 6 Conclusions

Results show that frictional instability (stress drop) occurs in some tests on samples with larger particle sizes, and this type of frictional instability also appears repeatedly with the progress of shearing. It is found that the magnitude and recurrence time of stress drops decrease with increasing shear speed for a given particle size. However, they increase with increase of particle size at the same shear speed. By evaluating the relationship between stress drop and recurrence time, it is found that the stress drops increase logarithmically with the increase of recurrence time and particle size has a greater influence on frictional instability.

AE observation results show that the frictional instability events are correlated with the main acoustic bursts. The relationship between the magnitude of stress drops and maximum absolute amplitude of AEs follows a power-law relation. Smaller particles and higher shear speeds result in greater average occurrence rates of AEs. The primary frequency bands are in the tens of kHz ranges, and more acoustic energy is released with increasing particle size and shear speed.

By analyzing the time difference between the main AEs and global mechanical failures, it is found that the onset of AE amplitudes precedes the global mechanical failures by several milliseconds. This sequence indicates that local failures within the granular materials occur first, and result in the generation of AEs. It is inferred that such ultrasonic vibrations enable the dynamic triggering of more failures along force chains, and finally lead to the global mechanical failure.

Hopefully, these follow-up studies will increase our knowledge of landslide dynamics in terms of granular physics, and provide more information concerning landslide early warning and hazard mitigation.