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Tangential contact behaviour of a weathered volcanic landslide material from Hong Kong

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Abstract

This study reports on the inter-particle coefficient of friction and tangential stiffness at the contacts of completely decomposed volcanic (CDV) granules taken from a landslide in Hong Kong. Micromechanical sliding experiments were conducted using a new generation inter-particle loading apparatus on pairs of granules of about 1.18–2.36 mm in size in a quasi-dry state to explore their tangential load – displacement behaviour. For this purpose, small shearing paths were applied in monotonic mode under nominal normal loads in the range of 0.5–1.0 N. The results demonstrated that the inter-particle coefficient of friction was much higher and the tangential stiffness was much lower than reported values in the literature for quartz sand grain contacts. Repeating shearing tests following the same shearing path showed a notable change of the tangential force – displacement relationship from the first to the second cycle, while subsequent cycles had a relatively small effect. Scanning electron microscope (SEM) images revealed some damage to the surface of the granules on the meso-scale, but no effect on the structure of the grains at the micro-scale was observed. It is believed that the soft nature of the grains and their high surface roughness may have contributed to these trends.

Keywords: Tangential stiffness; Inter-particle friction angle; Micromechanics; Completely decomposed volcanic granules; Roughness; Debris flow

1. Introduction

Landslides are a serious geological hazard that results in loss of life and damage to the economy. Numerous notable studies and reports on landslides triggered by earthquakes or rainfalls have been published (Kazama et al., 2012; Huang et al., 2012; Nakamura et al., 2014; Tsuchida et al., 2014, among others). In accordance with the International disaster database (EM-DAT, OFDA/CRED International disaster database), America and Africa accounted for around 1630 and 690 fatalities, respectively, over the past 10 years, while the economic damage experienced by Europe over a period the 100 years from 1900 to 2000 was 1700 million USD. Increasing rainfall due to climate change and uncontrolled urbanisation, especially in mountainous areas, together with deforestation have increased the occurrence rate of these events. Landslides are complex dynamic systems and their understanding and prediction require the coupling of geological, hydrological, physical and geotechnical material properties as well as the triggering variables, such as extreme weather conditions (Van Ash et al., 2007).

The Discrete Element Method, DEM (Cundall and Strack, 1979) proves useful insights into the simulation of granular flows because it is able to capture large particle displacements, and overcomes the need of complicated constitutive models of FEM analysis (Van Ash et al., 2007; Calvetti and Nova, 2004). DEM simulations of granular flows (dry or in saturated condition) require the definition of the particle contact parameters, such as the normal

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and tangential stiffnesses, K_N and K_T, respectively, the inter-particle coefficient of friction, μ, or the coefficient of restitution (Cleary and Campbell, 1993; Zhao and Shan, 2013; Utili et al., 2015). In DEM, micro-mechanical parameters are often calibrated in order to obtain a realistic representation of the macro-mechanical behaviour of granular materials, hence a wide range of μ values, for example, between 0.1 and 0.7, can be found depending on the simulated problems (Cleary and Campbell, 1993; Calvetti, 2008; Zeghal and Shamy, 2008; O'Sullivan, 2011).

While granular flows have been largely studied by means of numerical methods, little experimental research on the mechanical behaviour at the particle scale has been done due to the complexity of the problem. Inter-particle coefficients of friction μ obtained by means of micromechanical laboratory tests may vary between 0.12 and 0.37 for quartz particles of Leighton Buzzard sand (Cavarretta et al., 2011; Senetakis et al., 2013a, 2013b; Sandeep and Senetakis, 2017), are very low (0.07–0.09) for calcium carbonate grains of a crushed limestone from China (Senetakis et al., 2013a), and reach large values (0.42–0.46) for particles of a biogenic carbonate sand from the Philippines (Nardelli and Coop, 2016). Cole et al. (2010) and Cole and Hopkins (2016) have extensively investigated the contact behaviour of different natural materials. The inter-particle coefficients of frictions and stiffnesses of quartz sand, magnesite and gneiss grains were showed to be dependent on the normal load; the former decreasing with increasing confinement. Values between 0.02 and 0.15 were found for grains of different quartz sands (e.g. Ottawa, Eglin and Vicksburg sand), 0.09 and 0.12 for magnesite and 0.13–0.18 for gneiss with normal load varying between 10 and 1 N respectively. Friction and surface topography are also responsible for the macroscopic slip of rock joints. Biegel et al. (1992) studied the micromechanics of Westerly granite samples sheared in a rotary apparatus and Boitnott et al. (1992) linked the tangential force-displacement response to surface topography and asperities scale strength using both simple friction and simple adhesion models.

While the literature includes a number of notable studies on the micromechanical behaviour of geological materials including both normal contact and frictional responses (e.g., Cole and Peters, 2007, 2008; Cole et al., 2010; Senetakis et al., 2013a, 2013b, 2017; Cole and Hopkins, 2016; Nardelli and Coop, 2016 among others), limited work has been published on the micromechanics of weathered volcanic granules. These materials are of major interest in landslide problems in tropical and sub-tropical regions. In this study, the tangential force-displacement and inter-particle friction of a volcanic material taken from a landslide are investigated: the material was characterized as breakable with very rough surface granules. The data provided may be useful in numerical simulations, for example, in debris flow studies. The main contributions of this study are the characterization of a volcanic material at the micro-scale with potential applications in numerical simulations of landslides, as well as the reporting of data associated with the frictional response of geological materials and potential mechanisms that contribute to friction.

2. Materials characterization and experimental methods

The study was conducted at the City University of Hong Kong using a micromechanical sliding apparatus designed and constructed by Senetakis and Coop (2014) and modified by Nardelli (2017). The apparatus has been designed to measure friction and stiffness at sand sized grain contacts, typically between about 0.5 and 5.0 mm, using a system of linear micro-stepper motors, high resolution load cells (0.02 N) and non-contact eddy sensors with a resolution of 10^{-5} mm. The apparatus allows the interface response at extremely small displacements to be captured between, for example, 0.1–0.5 μm of shearing path, which is necessary to measure stiffness for this type of experiments and contact types (Senetakis and Coop, 2014). The compliance of the apparatus was taken into account by using correction factors for displacements and forces. These correction factors resulted from the calibration exercise of the apparatus testing reference brass columns instead of soil grains and probable errors after corrections in displacements and the coefficient of inter-particle friction are 1% and 2%, respectively (Senetakis and Coop, 2014; Nardelli, 2017). These corrections factors are applied to raw data for analysis to obtain normal and tangential force-displacement behaviour. A typical path during the shearing of grains and the measurement of the frictional response may vary between about 50–300 μm, which is, in general, the typical range for obtaining a close steady state sliding and to measure the inter-particle coefficient of friction. A close-up view of the apparatus is given in Fig. 1.

The material tested in the study is composed of completely decomposed volcanic (CDV) granules taken from the top of a landslide in Sai Kung, Hong Kong. Granules

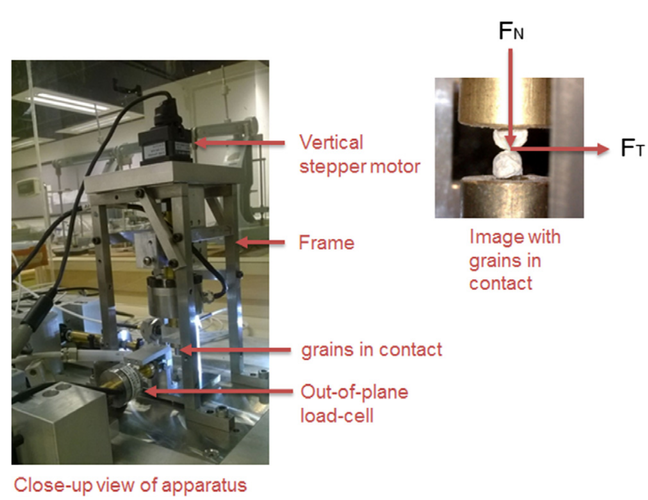

Fig. 1. Close-up view of micromechanical sliding apparatus used in the experiments and image of CDV granules in contact during a test.