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Technical Note

Variability of geotechnical properties of a fresh landslide soil deposit

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ABSTRACT

Natural soils exhibit large variations in their engineering properties. It is essential to characterize the variability of common design soil properties within a large representative soil element and to investigate the effect of sample size on the variability of these soil properties. In this study, field tests on two 1.0 m cubes were conducted at a recent landslide site. Each cube was divided into 64 unit cubes of 0.25 m size, and adjacent unit cubes were combined into samples of 0.5 m and 0.75 m sizes. The variability of dry density, mean particle size (D_{50}) and coefficient of uniformity (C_u) is quantified at different size scales. Random field theory is adopted to characterize the spatial soil variability within these two 1.0 m cubes. Both the point coefficient of variation (COV_p) and the coefficient of variation of the spatial average (COV_a) of each of the three soil parameters decrease rapidly as the sample size increases. However the mean values of these soil parameters are insensitive to the sample size. The COV_p of dry density is smaller than those of D_{50} and C_u. The scale of fluctuation for dry density is much larger than those for D_{50} and C_u.

1. Introduction

Most colluvial soils on natural colluvial slopes and landslide deposits are coarse and widely distributed ranging from clay contents to meter-scale large particles (Casagli et al., 2003; Chang et al., 2011; Zhao et al., 2013b). These soils have been subjected to transportation and particle sorting. Such natural processes led to tremendous uncertainties in geological features and engineering properties of the soils (Zhao et al., 2013a). Extensive studies were conducted to investigate the variability of soil properties (e.g. Phoon and Kulhawy, 1999a; Kim et al., 2012; Rahardjio et al., 2012; Wang and Cao, 2013). These studies provide an excellent summary of statistical characteristics of clayey, silty and sandy soils. Little is known, however, on the variability of coarse granular soils in natural landslide deposits. Zhao and Zhang (2013c,d) indicated that dry density and particle-size distribution significantly affect the permeability, compressibility, shearing strength, instability behavior and other aspects of coarse granular soils. Yet, the variability of the dry density and particle-size distribution of coarse granular soils in landslide deposits has seldom been investigated, and is the primary concern in this study.

One primary source of geotechnical variability is the inherent soil variability. Inherent soil variability is modeled as a random field, which can be described concisely by the coefficient of variation and the scale of fluctuation (e.g. Vanmarcke, 1977; Phoon and Kulhawy, 1999b; Dasaka and Zhang, 2012). The spatial characteristics of soil properties were often characterized in a large-size sampling domain. So the reported variability of soil properties in the literature may be considerably larger than the actual inherent soil variability as the soil data from different geologic units were mixed and analyzed. Representative element volume (REV) is the smallest volume over which a representative measurement can be made to obtain soil properties. As shown in Fig. 1 (Brown et al., 2000), a property remains essentially constant over the REV range. The element volume must be sufficiently large to represent the statistical average of the property under consideration. The purpose here is to avoid rapid changes in soil property due to the influence of individual particles. On the other hand, the element volume should be smaller than a certain volume, V_{max}. A volume above V_{max} involves additional morphological structures that allow the property to drift to new values and result in large field variability. In order to define probable ranges of variability for common design soil properties, it is essential to quantify the spatial variability of soil properties within a reasonably large representative soil element.

Soil samples of limited dimensions vary from one to another as each sample consists of particles of different characteristics. Publications on the sampling of particulate materials indicate that the variability of soil properties is influenced by the sample size (e.g. Elkateb et al., 2003). Phoon and Kulhawy (1999a) and many others observed that the soil variability caused by the inherent heterogeneity from the geological processes can be minimized by collecting large size samples. It is important to know to what extent the sample size affects the variability of the properties of coarse granular soils.

The objective of this paper is to characterize the variability of soil properties within large representative soil elements and investigate

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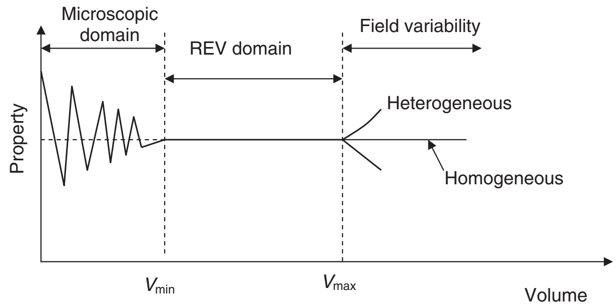

Fig. 1. Concept of representative elementary volume.

the effect of sample size on the variability of the properties of coarse granular soils. In this research, field tests were conducted on two 1-m cubes at a recent landslide site. Statistical analysis is then conducted to quantify the variability of soil density, mean particle size (D_{50}) and coefficient of uniformity (C_u). Finally, random field theory is adopted to characterize the spatial variability of the dry density, D_{50} and C_u within the 1.0 m cubes.

2. Field testing program

2.1. Test site

During the Wenchuan earthquake on 12 May 2008, a catastrophic landslide was triggered in Donghekou (105.109°E, 32.432°N), Sichuan, China as shown in Fig. 2(a). The landslide is approximately 3 km to the north of the Yinxiu–Beichuan–Qingchuan fault. This slide occurred at the confluence of the Qingzhu River and the Hongshi River (a tributary to the Qingzhu River). The landslide was extremely rapid. At least 300 villagers, two buses and a car were buried by the landslide.

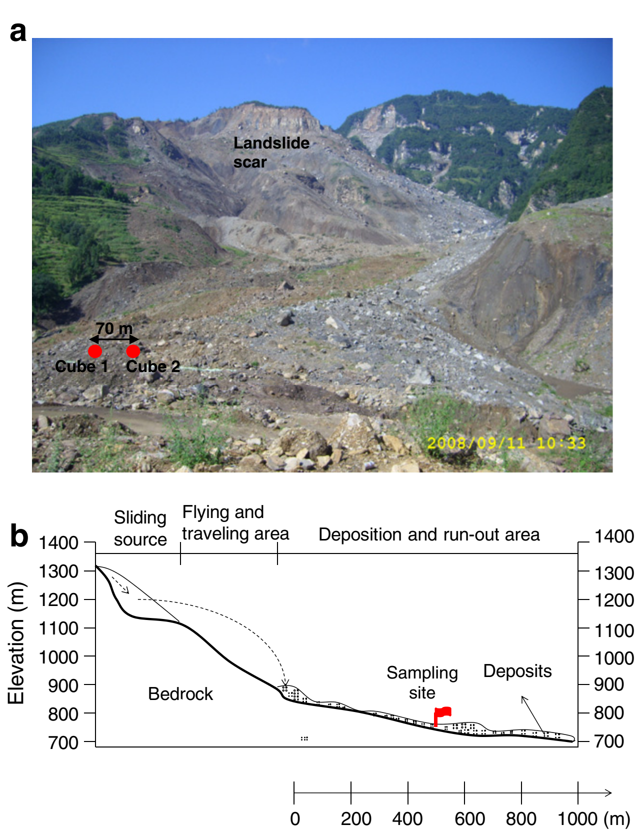

Fig. 2. (a) The Donghekou landslide; (b) cross-section of the landslide.

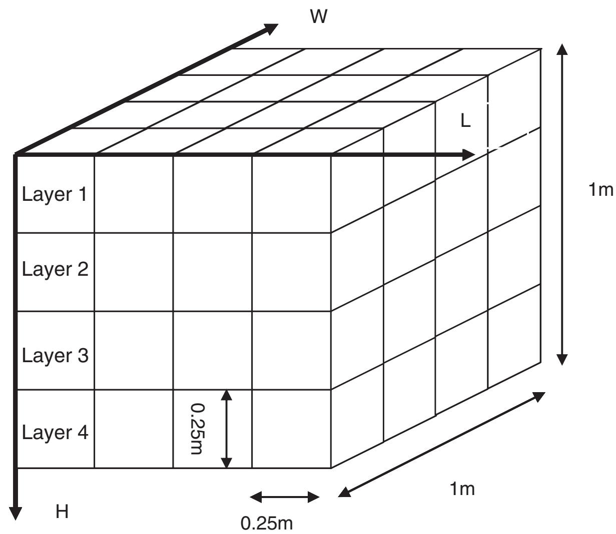

Fig. 3. Schematic diagram for sampling a one-meter cube.

The landslide is a type of shattering-ejection landslide caused by the prolonged ground shaking of the earthquake. According to the characteristics of the movement and deposition of the landslide debris, the landslide can be divided into a sliding source area, a flying and traveling area, and a deposition and run-out area as shown in Fig. 2(b) (Zhang et al., 2011). The landslide has a carrot shape with a wide scar and a narrow but long deposition and run-out area due to topographic constraints. The sliding source was located at elevations between 1080 m and 1330 m. The scar consisted of Cambrian-age weathered dolomitic limestone with inter-bedded coal seams. During the earthquake, approximately 6×10^6 m^3 of dolomitic limestone detached from the scar (Chang et al., 2011). The landslide debris ran out 2700 m, with a total volume of approximately 30 million m^3. The run-out area is 1.09 km^2 with an elevation difference between the scar and the toe of approximately 700 m and widths in the range of 150–600 m. The elevation of the run-out area is in the range of 800–900 m and the average travel angle near the toe is 11°. The thickness of the landslide deposit varies greatly. The thicknesses of the residual deposits at the landslide scar and the deposit near the frontal area are in the ranges of 50–70 m and 30–40 m, respectively. Part of the sliding mass accumulated in the Qingzhu River, forming two landslide dams, one blocking the Hongshi River and the other blocking the Qingzhu River.

Particle segregation or sorting occurring in the particle flow process of a landslide event induces heterogeneity in the fabric, structure, and properties of the landslide soil deposits. Such particle sorting leads to a tremendous amount of uncertainty in geological features when managing the risks imposed by large landsides. As the life span of most landslide dams is short (Chang et al., 2011; Peng and Zhang, 2012), it is necessary to quickly obtain the dry density and grain size of the newly deposited landslide soils to facilitate the assessment of the risks posed by such landslide dams. The behavior of a fresh deposit differs from that of an old deposit in that the fresh deposit has not yet been subject to post-depositional processes and typically has higher fine contents and lower density, stiffness and shear strength. The test sites in this study are located in the deposition and run-out area in Fig. 2(a) and (b).

2.2. Test plan and procedure

Shortly after the Wenchuan earthquake in May 2008, a field study was conducted at the Donghekou landslide. The tests were completed before the originally fresh soil deposit was disturbed by storm or