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Triaxial tests of soil–rock mixtures with different rock block distributions

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Abstract

Triaxial tests on three types of soil–rock mixture (S-RM) samples with the same rock block content, but different grain size distributions, were performed in this study. To better understand the meso-mechanical behavior of soil–rock mixtures, one set of samples containing "oversized rock blocks" was designed. The oversized rock blocks in the other two sets were handled using the equivalent weight replacement method and the similar translation method. On this basis, the effect of the grain size distribution on the mechanical properties of the soil–rock mixtures was explored. The interlocking and the breakage of the large rock blocks were found to be two of the controlling factors of the mechanical properties of soil–rock mixtures. The deviator stress and the volumetric strain correlated well with the uniformity coefficient of the particle size distribution curve and performed differently under different confining pressure levels. Based on X-ray computed tomography (CT) slices of samples taken during the triaxial tests, the interaction of the internal rock blocks and the evolution of the sample meso-structure in the loading process were observed and analyzed; the present analysis provides explanations for the macroscopic mechanical behavior of soil–rock mixtures.

Keywords: Soil-rock mixture (S-RM); meso-structure; triaxial test; X-ray CT images

1. Introduction

A soil–rock mixture (S-RM) is composed of large-size "rock block" pieces with high strength and small-size "soil" with low strength. The presence of rock blocks greatly affects the physical and mechanical properties of an S-RM, especially when the rock block content is high enough to form a skeleton with many interactions between the rock blocks, which will largely control the mechanical behavior of the mixture. Xu et al. (2011) and Coli et al. (2011) performed large-scale field tests, and their test results show that there is a positive correlation between the internal friction angle and the rock block content, but that cohesion changes little when the rock block content exceeds one threshold value (25–30%). For widely graded gravelly soil, parameter K of the Duncan–Chang model, obtained from triaxial tests, increases, while parameter n decreases with an increasing gravel content (Chen and Zhu, 2010). Even with the same rock block content, the mechanical properties of S-RMs with distinct meso-structures are different. A great number of researchers (Pena et al., 2007; Ouyang et al., 2010; Mahmood and Iwashita, 2010; Pietruszczak and Guo, 2011) have conducted laboratory tests and numerical simulations to study the meso-structural characteristics of S-RMs, such as the shape and the distribution of the internal rock blocks. Liu et al. (2013) found that, under the same initial conditions, samples with wider particle distributions exhibit more contractive properties, and that the critical state line falls as the uniformity coefficient of grading (C_u) rises. Improvements to the aggregate gradation and quantity effectively enhance the strength and the performance of the aggregate

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base course and the asphalt mixture (Cunningham et al., 2013; Jiang and Zhang, 2012). Since it is difficult to observe the internal structure and to quantitatively characterize it in physical tests, experimental research on the mechanical behavior of S-RMs containing the same amount of rock blocks, but different particle size distributions, are relatively few in number. However, the existence and the spatial distribution of rock blocks in S-RMs lead to significant anisotropy and vastly different meso-structures. Adjustments to the meso-structure (such as the translation and the rotation of rock blocks and changes in porosity) and the development of internal injuries (breakage of rock blocks, etc.) are the root causes of the macro-mechanical response.

In recent years, X-ray computed tomography (CT) has become an effective method for examining the meso-structure of geotechnical materials, especially in terms of studies on the strain localization and the formation mechanism of shear bands for homogeneous materials such as sand. Based on CT images, the three-dimensional Digital Volume Correlation (DVC) technique (Hall et al., 2010; Sjödahl et al., 2012) and the sand particle tracking technique (Watanabe et al., 2012) were used to observe and to quantitatively analyze the 3D displacement and the strain fields of sand samples. Fu et al. (2008) studied the 3D motion and the strain field of particulate material during soft confined compression tests. Tagliaferri et al. (2011) analyzed the porosity, the cement density and the strain field of bio-cemented Ottawa sand in triaxial compression tests from digital images and found that the deformation mechanism changes from homogeneous deformation to localized dilatant shearing at peak stress. In addition, the variation in sand porosity with changes in the sand particle radius can be analyzed using the CT images to determine the representative volume element size of the sand (Razavi et al., 2007), which could be the bridge that connects the meso-scale and the macro-scale. X-ray CT has also been widely used in the research of the meso-structural mechanics of concrete and granular materials. On the one hand, the CT technique facilitates the observation of the mesoscopic structural damage of concrete. Changes in the pore distribution and the whole process of the internal initiation, the expansion and the penetration of micro-cracks during loading were evaluated based on CT images, and the cracks in concrete samples were generally found to exist in the mortar around the aggregate (Su et al., 2013; Tian et al., 2012; Zhao et al., 2010). On the other hand, obtaining a 3D model based on CT image reconstruction is an effective means to combine laboratory and numerical tests (Wang et al., 2004, 2007; Matsushima et al., 2009).

Under a constant rock block content condition, the oversized particles in the S-RM samples are handled using different methods to prepare remolded samples with three different particle size distributions. Together with a set of soil samples, these unsaturated samples were used to conduct a series of consolidated undrained triaxial compression tests. Based on these tests, the effect of particle gradation on the mechanical properties and on the meso-structure evolution of the S-RMs was explored using X-ray CT. Through image processing and an analysis of the CT images, a visualized 3D internal structure of the mixtures, which can display the interaction between internal rock blocks, was obtained. Accordingly, the influence mechanism of the meso-structure and the confining pressure on the macro-mechanical behavior of the S-RM samples was revealed at the meso-scale.

2. Triaxial tests

2.1. Control parameters of tests

Xu and Hu (2006) noted that the threshold grain size for distinguishing "soil" from "rock blocks" in S-RMs, namely, the soil / rock threshold, is relevant to the scale used in the research on the fractal dimensions of a large number of grain-sieving data on site. Additionally, according to the research on some Franciscan melanges in California, USA, by Medley (1994) and Medley and Lindquist (1995), the soil/rock threshold used in this study, $d_{S/RT}$, was set at $0.05L_c$, where L_c is the diameter of the triaxial sample. The sample is 100 mm in diameter and 200 mm in height; therefore, a uniform soil / rock threshold of 5 mm was selected in this triaxial test scheme, which considered any particle greater than 5 mm in size to be a "rock block" and particles less than 5 mm in size to be "soil".

Through the ages, earthquakes have occurred frequently in China and other countries of the world. S-RMs represent a class of complex geotechnical media formed when landslides have been induced by earthquakes. The physical and mechanical properties of these mixtures have a significant impact on slope stability and secondary geological disasters in earthquake disaster areas. Therefore, the S-RM materials used in the triaxial tests here were taken from the Tangjiashan Barrier Dam, formed during the Wenchuan Earthquake (May 12, 2008) in the Sichuan Province, China. The natural content of "rock blocks", defined above as consisting of particles greater than 5 mm in size, reached up to 61%. Additionally, the maximum rock block size was found to be 100 mm. According to previous studies, the strength of geotechnical materials is jointly controlled by rock blocks and soil when the rock content of an S-RM is between 25% and 75% (Xu and Hu, 2009). To obtain universal research conclusions, the rock block contents of all the S-RM samples were set to a moderate value of 50% under the premise that the ratio of the rock block content in each grain set would be exactly the same as that of natural S-RM materials. Considering the fact that the loose S-RM sample was taken from the colluvium formed in the Wenchuan Earthquake and has yet to consolidate, the natural density of 1.73 g/cm^3 and the natural moisture content of 10.4% were chosen as the control parameters during the sample preparation. The tests were conducted with a triaxial apparatus at the Yangtze River Scientific Research Institute, China. The lifting platform for this apparatus was mechanically controlled. The shear rate was 0.24 mm/min.

2.2. Triaxial test scheme

The three sets of S-RM samples in the triaxial test scheme had the same rock block content, but the size distributions of