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Large-scale in-situ test for mechanical characterization of soil–rock mixture used in an embankment dam

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ABSTRACT

To improve the mechanical behavior of core wall in higher embankment dams, soil–rock mixture obtained by mixing rock blocks to the cohesive soil is used for the first time as the core wall material of the Nuozhadu embankment dam, China. The differences in the mechanical behavior of soil and soil–rock mixture samples are studied in depth. Two large-scale compaction test fields and a series of in-situ direct shear tests have been conducted on soil and soil–rock mixture samples. The mixing of rock blocks changes the deformation behavior of the sample. The existence of rock blocks makes the deformation modulus and the internal friction angle of soil–rock mixture greater than that of the soil sample, while decreasing its cohesive force.

1. Introduction

Soil–rock mixture (S–RM) as a type of special geological body is abundant in nature[1], and is frequently used as a filling material in geotechnical engineering. For example, in embankment dams, which are more common worldwide, the core wall is one of the important parts that not only satisfies the requirement of seepage prevention but also has good mechanical strength. With the development of embankment dams around the world, their height continues to increase. To keep the deformation conformity between the rockfill of the dam and the core wall, and to decrease the arch effect in the core wall so that the stress state in the core wall can be improved and the probability of cracks occurring in the core wall reduced, the core wall material should have a higher deformation modulus.

Different from general soil (for example, clay, silt, and sand), S–RM contains a certain amount of oversize particles. The earliest work on S–RM in the laboratory was by Hall[2], who focused on the development of a triaxial apparatus for testing large soil samples of at least 30.5 cm. Donaghe and Torrey[3] studied the shear strength of S–RM using triaxial tests on 38.1 cm specimens, and found that the effective friction angle increased with increasing gravel contents. Other researchers[4–9] concluded that the shear strength of clay–rock mixtures gradually increases with increasing percentages of floating particles in unsaturated clays. Using laboratory triaxial tests, Lindquist and co-workers[10–12] studied the relationship between rock block proportion and shear strength of mélange. Through triaxial tests, Dupla et al.[13] also indicated that the volumetric fraction of gravels is the main parameter of the elastic and the material failure characteristics of coarse-grained soils. From these studies, it was also concluded that the existence of oversize "rock blocks" in S–RM will influence the mechanical behavior of the material. Furthermore, most of the previous studies have focused on laboratory tests. As we know, it is very difficult to obtain undisturbed S–RM samples, and all laboratory tests are based on reconstructed ones. A further limitation of the laboratory conditions is that the size of the sample is usually less than 30 cm, and usually with a diameter of 15 cm. Based on the recommendation of ASTM, the maximum particle size for testing dimension is less than one-sixth of the sample's diameter. For example, the large testing equipment commonly used in the geotechnical engineering is less than 30 cm in diameter and the maximum particle size accommodated is less than 6 cm.

Rock blocks of S–RM in nature or in those used in the fills of high dams and other embankments are usually larger than the requirement for laboratory tests[1,12]. Therefore, scalping/replacing or scalping is commonly used in the processing of oversized particles. However, according to[13], none of these methods yield satisfactory estimates of total stress strength parameters for the parent full-scale gradations of S–RM.

With the development of many types of large-scale engineering projects, there is an increasing need for progress in the knowledge of the mechanical behavior of S–RM. To compensate for the limitations of the laboratory studies of S–RM, more works on naturally formed S–RM is based on in-situ tests[12,14]. However,

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because of the cost and difficulty of testing, S–RM used in the fills of high dams and other embankments has seldom been tested for shear resistance in-situ. Furthermore, mixing the rock blocks in clay as the core wall material is being used for the first time in China, and is seldom applied elsewhere in the world.

The gradation and content of oversize rock blocks in S–RM will influence the distribution of the meso-stress field, deformation and failure, and the macro-mechanical characteristics. To study the mechanical behavior of the matrix before and after mixing the rock blocks, and taking the core wall material of the Nuozhadu embankment dam as an example, we conducted large-scale in-situ direct shear tests. Most of the in-situ and laboratory tests can only provide the macro-mechanical properties and deformation behavior of geomaterials, and cannot easily reveal or difficult their meso-mechanic, deformation and failure mechanism. Therefore, in the companion paper, a set of numerical tests based on the discrete element method (DEM) are presented to study the meso-mechanical behavior of the soil before and after mixing the rock blocks.

2. Background of study

2.1. Description of the Nuozhadu dam

The Nuozhadu hydropower station is located within the middle and lower reaches of the Lancang River, in Yunnan province, China. Nuozhadu dam is a core rockfill dam (Fig. 1) with a height of 261.5 m. The maximum top width of the dam is 18 m, the slope ratio of the upstream and downstream is 1:1.9 and 1:1.0 respectively, and the maximum top width of the core wall is 10 m. Nuozhadu dam is the highest embankment dam in China, and the fourth highest in the world. Because of the strength and the deformation modulus of the rockfill composition, the main body of the dam is higher and the core wall material should also have a better deformation modulus so that it can coordinate the deformation of the adjacent rockfill. The generic type of core wall fill material is residual soil. Based on the laboratory tests, to satisfy the safety requirement of the dam, the original residual soil should be blended with the rock blocks up to a content of 35%, and the diameter of the particles should be less than 120 mm.

The lithology of the rock blocks used in S–RM is granite, with a uniaxial compressive strength of 69.4–165.2 MPa, and it is difficult to crush. Fig. 2 shows the typical particle-size distribution of the original residual soil and the residual soil mixing the rock blocks.

2.2. Preparation of the test field

To study the difference of the mechanical strength of the residual soil and the S–RM with mixing rock blocks, we carried out large-scale compaction tests for both materials. Each testing field is 30 m long and 20 m wide. The compaction pattern of the two testing fields is the same, all using a vibratory padfoot roller (working mass of 18,700 kg, exciting force of 380 kN, and height of padfoot of 10 cm). The thickness of the filling layer is approximately 35 cm, and the total rolling time of each layer is 12. After the 6th time has finished, the compacted density of the compacting layer is tested using a test pit (diameter of the pit is 30 cm). If the compacted density satisfies the designer requirement, we proceed with the remaining rolls. The total filling height of the compaction test is about 5 m. Fig. 3 shows the compaction test of the S–RM.

Fig. 4 shows the excavation section of S–RM after compaction, where the oversized rock blocks “float” uniformly in the compacted matrix clay with very few direct contacts between the rock blocks. The sample is denser, and the compaction test attained the ideal effect.

3. Large-scale in-situ test procedures

Despite there being many limitations to direct shear testing, including the non-uniformity of the stresses and strains within the box[15,16], owing to its simplicity and suitability for testing, the direct shear box is one of the most widely used devices for obtaining shear strength parameters (cohesive force and internal friction angle) for geotechnical material. After the preparation of the compaction field of soil and S–RM, four large-scale in-situ direct shear tests were carried out to understand the macro-mechanical behavior of the materials. The scale of the direct shear

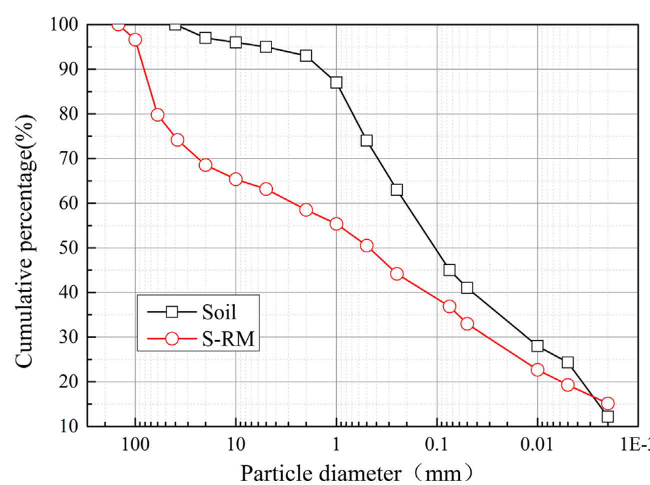

Fig. 2. Typical particle-size distribution curves of soil and soil–rock mixture (S–RM).

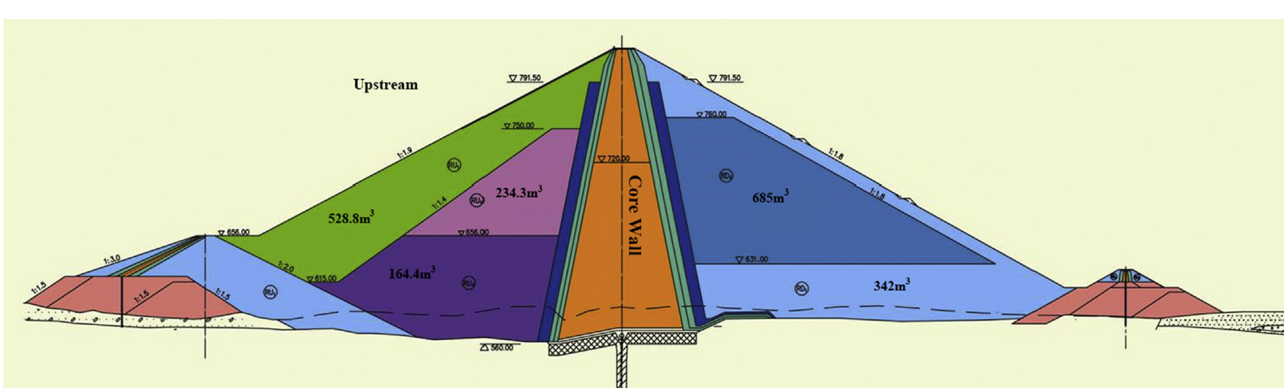

Fig. 1. Main section of the Nuozhandu embankment dam.