Study on Dilatancy of Coarse-Grained Soft Rock by Large-scale Triaxial Test

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Abstract. Coarse-grained soft rock fill materials can deteriorate due to water-rock interactions, potentially compromising the performance of the embankment subgrade. The dilatancy of this soft rock, as an important proxy to evaluate shearing response, was investigated in this paper. A series of large-scale triaxial drained tests were conducted on the medium-dense to dense soft rock fills. Test results showed that medium-dense soft rock samples owned continuous contraction, while dense samples exhibited only very slight dilation. Compared with other dense coarse-grained materials and sandy soils, where the gradation of the soft rock fell among them, the soft rock exhibited the least dilatancy and significant particle breakage during shearing.

Keywords: Soft Rock; dilatancy; large scale triaxial

1 Introduction

Red mudstone and sandstone are widely distributed in the southern region of China, whose internal structure can significantly change when the contained clay minerals absorb water and then expand, eventually leading to material deterioration and strength reduction. The utilization of those types of materials may result in considerable subgrade deformation and settlement under conditions such as high fill volume, high filler discreteness, and frequent rainfall, potentially causing instability and failure, and posing a threat to the safety of transportation infrastructure [1].

Research on the deterioration mechanisms of coarse-grained soft rock materials primarily involves several factors, such as the disintegration of soft rock, water-induced softening, and the effects of material gradation and compaction. The microscopic water-softening mechanism of soft rock encompasses the effects of water-rock interaction on the degree of fragmentation, fracture development, and physical-mechanical properties of the soil mass [2]. Similar to conventional coarse-grained materials, compaction, and stress levels are key factors affecting the mechanical properties of soil [3]. The deformation characteristics of rockfill are dependent on external factors such as

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stress levels [4,5], and also internal aspects such as initial density, gradation, and particle breakage.

Due to the significant differences in the composition and particle shapes of coarse-grained soils, their characteristics could have obvious diversity. Most current research focuses either on the dilatancy characteristics of typical coarse-grained materials [9] or the deterioration of physical and mechanical properties under water-rock interaction [5-7]. There is still a lack of in-depth exploration regarding the intrinsic mechanisms of dilatancy specificity in soft rock soil samples. To study the influence of gradation and material composition on the dilatancy behavior of soils, large-scale triaxial tests were conducted to reveal the differences in deformation and mechanical properties between general coarse-grained materials, sandy soils, and soft rock coarse-grained materials. The focus of the study is on the dilatancy and contraction characteristics of soft rock coarse-grained materials.

1.1 Material Composition

The test soil samples were primarily composed of fully to strongly weathered siliceous rock interbedded with argillaceous siltstone, as shown in Figure 1. The block stone particles ranged in size from 10 mm to 60 mm, with obvious angularity. Through sieving, the content of soft rock particles in the 5-20 mm size range accounted for 80.22%, while the remaining portion consisted of hard rocks such as basalt. X-ray diffraction (XRD) analysis was performed to determine the composition of the rock types. In XRD, higher diffraction intensity indicates that more X-rays are reflected from a particular crystal plane at a given diffraction angle, which is generally associated with the orderliness of a specific crystal plane or atomic arrangement within the crystal. The mineral content spectrum results are shown in Figure 2, where the proportions of montmorillonite and quartz reached approximately 78.9%.

Fig. 1. Soft rock coarse-grained material

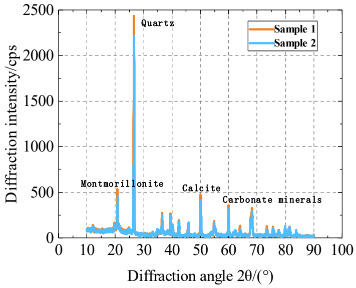


Fig. 2. Coarse Aggregate XRD Diffraction Test

Material composition analysis indicates that the montmorillonite content in the soft rock coarse-grained material samples is significantly higher than the one in typical rock samples. The water-swelling properties of montmorillonite suggest that the disintegration process of these samples could differ from that of typical rock samples, possibly accompanied by more pronounced swelling. Compared to quartz sandstone with high resistance to disintegration and fine siltstone shale with low resistance, these samples have a higher content of calcite and lower hardness.

1.2 Physical Properties

The test sample has a coefficient of uniformity (Cu) of 8 and a coefficient of gradation (Cc) of 2. The mass of gravel particles is less than or equal to the mass of sand particles, indicating a well-graded gravel (SW). The particle sizes of the sample are concentrated in the 1-10 mm range, falling between typical coarse-grained materials and sandy soils. A compaction test was conducted to determine the maximum dry density of 1.795 g/cm³ achievable under a given compaction energy. Additionally, the minimum dry density, determined by the loose-laying method is 1.082 g/cm³.

The proportions of these two mineral components indicate that the samples may exhibit characteristics such as easy expansion and fragmentation during the water-rock interaction and shear process. The particle size distribution curve of the sample is shown in Figure 3.

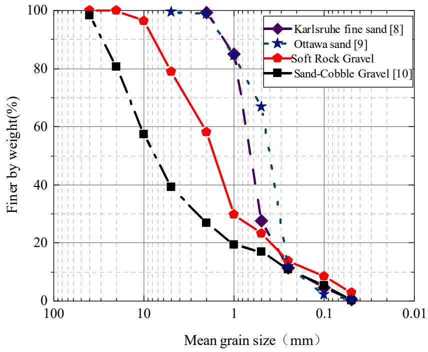


Fig. 3. Grain size distribution of specimen

2 Triaxial Shear Test

2.1 Test Results

The experimental results of drained triaxial tests are shown in Figure 4, where the confining pressure is 200 kPa. Most of the samples exhibited strain hardening and contraction characteristics, with the shear stress continuously increasing. For samples with different relative densities, the post-peak residual shear stress tends to converge, but there are some differences before the peak, where the densest sample tends to have a stiffer stress-strain response. Even though most samples consistently exhibit strong contraction characteristics, the degree of contraction is negatively correlated with relative density. When e_0 reaches 0.95, the sample tends to approach the transitioning from contraction to dilation. The trend is similar to the general patterns observed in typical coarse-grained materials [9]; however, the degree of dilatancy seems to be too low compared with other materials.

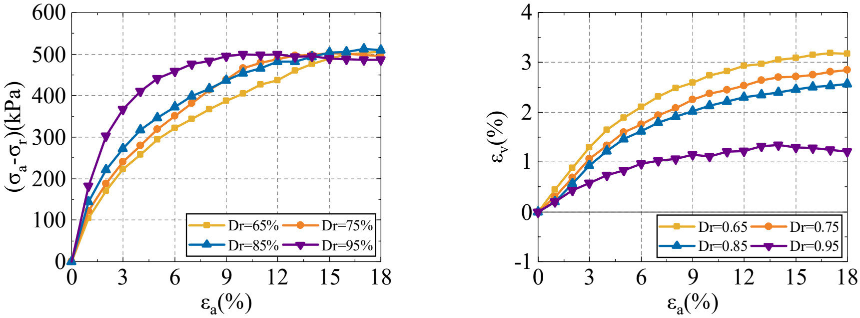
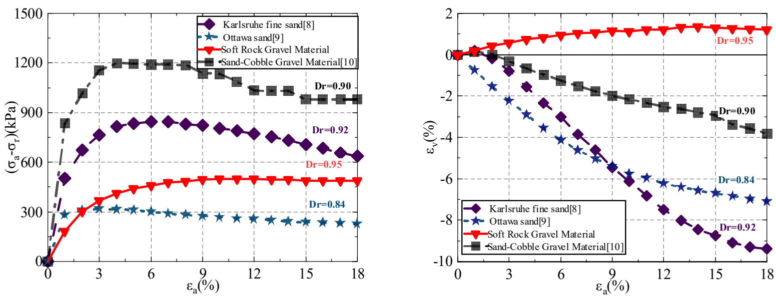


Fig. 4. Test results of consolidated drained triaxial tests on different soils(200kPa)

To quantify the degree of dilatancy on coarse-grained soft rock material, the stress-strain curves of samples under a confining pressure of 200 kPa are compared with those of typical coarse-grained soils and sands, as shown in Figure 5. The relative density of Karlsruhe fine sand is 0.92 [8], Ottawa-F65 sand is 0.84[9], and sand-cobble coarse-grained material is 0.90[10]. Compared to both types of sand and non-disintegrating sand-cobble coarse-grained material, the coarse-grained soft rock samples continue to exhibit slow and sustained strain hardening at very high relative densities, without showing any obvious stress peak or softening. Additionally, the shear strength (σ_a - σ_r) of the soft rock coarse-grained material is significantly lower than that of the non-disintegrating sand-cobble material and sands with higher relative density. In terms of volumetric strain results, both the sand samples and the non-disintegrating coarse-grained material exhibit significant dilatancy, in which the sands show the strongest dilatancy characteristics. In contrast, the soft rock coarse-grained material only displayed contraction, which persisted throughout the entire shearing process [11,12].



(a)Shear Stress - Axial Stress (b)Volumetric Strain - Axial Strain

Fig. 5. Consolidated drainage test curves for different soil samples (200kPa)

2.2 Particle Breakage

End-of-shearing gradation of those samples were measured by drying and sieving, aiming to reveal the coarse particle fragmentation due to shearing. A comparison of the particle gradation curves before and after shear failure is shown in Figure 6. The results indicate that all samples suffered from particle fragmentation. As relative density increases, the end-of-shearing proportion of particles in the 5-10 mm size range gradually decreases. It is shown that a larger sand proportion (particle size<2mm and >0.075mm) tends to be achieved in denser samples, accompanied by a higher tendency to dilatancy. The accompanying relationship is explained as particle breakage increases the proportion of sand-like particles with a slightly finer size than coarse, which is just enough to fill the voids among coarse particles, leading to the enhancement of the interlocking hardening process and the reduction of the likelihood of particle rolling. It eventually causes higher peak strength and enhances the dilatancy tendency in the saturated samples.

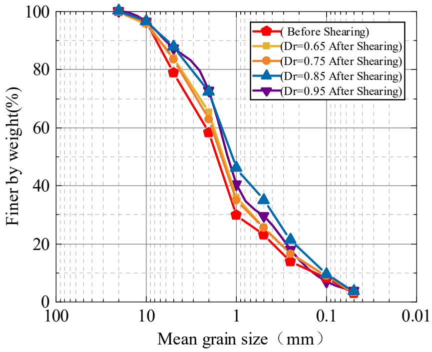


Fig. 6. Grain size distributions before and after drained triaxial shearing

3 Conclusions

Medium-dense soft rock coarse-grained samples exhibited continuous contraction, while dense samples showed a weak contraction followed by weak dilation. Compared with general coarse-grained materials and sandy soil, the soft rock exhibited lower peak stress levels and weaker dilatancy trends under the same confining pressure and relative density conditions. It was found to relate to the significant particle breakage during shearing due to the filling of interparticle voids.

This study found that the dilatancy specificity of soft rock is related to the materials damaged by the water-rock interaction. However, the influence of moisture on the dilatancy behavior of soft rock remains unclear, and future research could focus on this aspect.

Acknowledgments

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