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Effects of void ratio and grain size distribution on water retention properties of compacted infilled joint soils

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Abstract

The effects of the initial void ratio and the grain size distribution (GSD) on the water retention properties of a compacted infilled joint soils from Beihetan (China) were investigated. Three initial void ratios (0.3, 0.4, and 0.5) and three GSDs were selected based on the in situ soil states. A total of nine drying water retention curves (WRCs) was established with the filter paper method. The microstructure of the specimens was also studied to better understand the water retention properties. It was found that the denser samples underwent smaller volume changes, and that the volumetric strain increased with the increasing clay size fraction. The void ratio had a significant effect on the WRCs in terms of the degree of saturation; however, the WRCs were independent of the void ratio in terms of the gravimetric water content. In terms of the degree of saturation, the WRCs were seen to shift upwards with the increase in clay size fraction, indicating an increase in the water retention capacity. The results from mercury intrusion porosimeter (MIP) tests revealed that the difference in the inter-aggregate pores is the main reason for the different shapes of the WRCs. Moreover, the infilled joint soils with lower void ratios and coarser particles were found to be more suitable for MIP-based evaluations of water retention properties.

Keywords: Infilled joint soil; Water retention curve; Void ratio; Grain size distribution; Microstructure

1. Introduction

Infilled joint soils are often encountered underground or in slope engineering projects that involve folded strata rocks. These soils are often considered to be the weakest part of the rock mass and can be responsible for the instability of the wall rock or the cause of landslides (Xu et al., 2012, 2013). Infilled joint soils are, by nature, very heterogeneous: (i) there is a great difference in the grain size distribution (GSD); a large difference can exist even in the same layer of infilled joint soil (Xiao and Akilov, 1991), and (ii) the void ratios are generally small due to the high overburden by the upper stratum, varying from 0.3 to 0.67 according to the investigations of Zhang et al. (1990) and Xu (1994) at several sites of hydraulic stations in China. Following the GSDs, the infilled joint soils are classified into several categories, namely, muddy soil, mud with fragments, fragments with mud, and mud with silt, as listed in Table 1 (Xiao and Akilov, 1991).

When infilled joint soils are involved in a hydraulic power station project, prior to the main construction phase, it is common practice to set up impervious walls to limit the water flow. In that case, it is important to have a firm grasp of the water retention properties of the infilled joint soils in order to further analyze their hydraulic and

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Table 1
Classification of infilled joint soils according to GSD from Xiao and Akilov (1991).

Type	Particles smaller than 0.005 mm (%)	Particles larger than 2 mm (%)	Sand group vs silt group
Mud	>20	<10	Sand group < Silt group
Mud with fragments	10–20	10–30	Sand group > Silt group
Fragments with mud	<10	>30	Sand group > Silt group
Mud with silt	<20	<20	Sand group < Silt group

Note: The sand group and the silt group are defined as containing particles larger than 0.075 mm and particles between 0.005 mm and 0.075 mm, respectively.

mechanical behavior. As the setup of impervious walls leads to a decrease in the soil water content, only a drying path is followed. It should be noted that the water retention curve (WRC) usually presents hysteresis - the drying (desorption) and wetting (adsorption) curves are not the same.

The shape of a WRC is mainly affected by the soil mineralogy (Williams et al., 1983; Li et al., 2009), the texture (Arya and Paris, 1981; Arya et al., 1999a, 1999b), and the structure (Vanapalli et al., 1999). The effect of the soil structure, defined by the initial void ratio and the initial dry density, has been studied by many researchers. Croney and Coleman (1954) found that the void ratio has a significant effect on the WRC of silty sand. Sun et al. (2007), Gallage and Uchimura (2010), and Zhou et al. (2012) worked on compacted soils and came to the same conclusion. However, some other works have led researchers to contradictory conclusions. For example, Box and Taylor (1962) reported that the WRC seems to be independent of the initial void ratio. This was later confirmed by Campbell and Garnder (1971), Krahn and Fredlund (1972), and Birle et al. (2008). It is worth noting that most of the contradictory conclusions were drawn from results of tests on soils with relatively low dry densities or large void ratios. For instance, Birle et al. (2008) studied a soil with a void ratio larger than 0.5. The effect that the soil texture, defined by the grain size distribution (GSD), had on the WRC was studied by Indrawan et al. (2006). They mixed two types of commercial sand with Singapore residual soil, at different percentages, and found that the soil suction decreased with the increase in the coarse-grained soil fraction. Gallage and Uchimura (2010) compared the hysteresis behavior of the WRCs of Edosaki sand, Inage sand, Tsukuba River sand, and Chiba soil with different GSDs and observed that a uniform coarse-grained soil has a smaller hysteresis than a less uniform, fine grained soil. Rahardjo et al. (2012) studied a mixture of 50% residual soil and 50% gravel and found that the WRCs did not exhibit a bimodal characteristic.

To the authors' knowledge, few investigations have been conducted which focus on the influence of low initial void ratios and GSDs on the water retention properties of infilled joint soils. The aim of this study is to evaluate these influences for an infilled joint soil taken from Baihetan, China, through different tests, such as MIP and water retention tests, on samples with different void ratios and different GSDs.

2. Materials and methods

2.1. Soil properties

The infilled joint soil tested here was derived from a matric rock of tuff and was extracted in an exploratory heading in the Baihetan area of Southwest China. In order to obtain the physical index properties, especially the void ratio of the soil, the water content and the density were measured in the field. Fu et al. (2002) stated that a loose zone was generated near the wall as the initial in situ stress was released and the rock mass of the side wall rebounded after the excavation. As a result, the void ratio and the dry density of the infilled joint soil embedded in the side wall varied with the distance from the side wall. Moreover, the water content also varied with the distance from the side wall as the emerging infilled joint soil was able to absorb air vapor in the environment of high moisture content. In this study, the samples used to determine the natural void ratio and the water content were taken with a cutting ring having a diameter of 79.8 mm and a height of 40 mm. They were taken every 50 mm from the side wall to a horizontal distance of 400 mm (a total of nine at each location). Three locations were selected for these tests. Location 1 was about 25 m away from the entrance of the heading; locations 2 and 3 were about 27 m and 35 m, respectively, away from it. It should be noted that the sampling and testing procedures proposed by Fu et al. (2002) were followed. The relationships between water content and the distance from the side wall, and natural density and the distance from the side wall, are shown in Figs. 1 and 2, respectively. The test results generally indicate that the water content decreases and the natural density increases with the distance from the side wall. The values tend to be constant at a specific distance from the side wall, equal to 7.1% and 2.29 Mg/m^3, respectively (see Figs. 1 and 2). It should also be noted, however, that all the soils extracted from the side wall were collected, mixed, and placed in a remolded form for subsequent laboratory tests, including GSDs and WRCs.

It was found that the mixed soil has a liquid limit of 23.8%, a plasticity index of 9.7% (ASTM, 2010a), and a specific gravity of 2.83 (ASTM, 2010b). An X-ray diffraction test showed that the clay size fraction is composed of 20% sphene, 37% hematite, and 43% illite. It can be considered as a typical infilled joint soil in China, since not only its mineralogy, but also its physical parameters (speci-