Shear Strength of a Crushed Sandstone-Mudstone Particle Mixture

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Abstract: The present study focuses on the shear strength of a crushed sandstone-mudstone particle mixture. The mixture is widely used as a main filling material in many geotechnical engineering works. In order to investigate the shear strength of the mixture, triaxial tests under different confining pressures in laboratory are performed for 108 specimens with different dry densities and water contents. The dry density of the specimens ranges from 1.80 to 2.10 g/cm^3, and the water content from 4.00 to 9.00 % and to saturation. In the tests, four confining pressures, which are 100, 200, 300 and 400 kPa, are applied. The testing results indicate that the angle of shearing resistance of the mixture in unsaturated state ranges from 16.90 to 32.98°. The angle of shearing resistance is generally decreasing with the increase of the confining pressure. With the increase of the dry density, the angle of shearing resistance increases. The angle is generally increasing then decreases as a parabola with the increase of the water content. The wetting may decrease the value of the angle about 0.4 to 2.7°.

Keywords: Mixture, shear strength, dry density, water content, wetting, experiment.

1. INTRODUCTION

The mixture of crushed sandstone and mudstone particles is often used as a main filling material in many geotechnical engineering works in Chongqing of China, where the interbedded deposit of mudstone and sandstone is widely distributed. Evaluation on its mechanics behavior is very important. Very recently, its compaction behavior was investigated by Wang *et al.* [1]. The shear strength of soils may be affected by many factors such as soil density, water content and particle size [2-4]. It may also be affected by the change of the saturation level [5-7].

For the crushed sandstone-mudstone particle mixture, the effects of the dry density and water content on its shear strength should be given special attentions. This is because the dry density and water content are often used as two parameters to control and evaluate the compaction quality in the construction of geotechnical engineering works. If the mixture is used in the waterfront geotechnical engineering works such as bank slopes of large reservoir, its saturation level after compaction may be changed from unsaturated to saturated conditions. In the present study, the effects of the dry density, water content and wetting on the shear strength of the crushed sandstone-mudstone particle mixture are investigated by laboratory triaxial tests.

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2. TESTED MATERIAL AND TESTING SCHEME

2.1. Tested Material

The preparation on the tested material includes four steps. The first step is to choice lightly weathered sandstone and mudstone blocks in the field. The rock blocks, which were excavated from a rocky mountain along the Yangtze River in Chongqing of China, are chosen. The uniaxial compressive strengths of the sandstone are 60.0-72.2 MPa (natural state) and 60.0-67.4 MPa (saturated state), and those of the mudstone 17.6-25.8 MPa (natural state) and 8.3-15.0 MPa (saturated state). The second step is to crush artificially the rock blocks into the particles with different sizes less than 20 mm, then to separate the crushed sandstone and mudstone particles, respectively, into 8 groups based on the particle sizes 20-10, 10-5, 5-2, 2-1, 1-0.5, 0.5-0.25, 0.25-0.075, and <0.075 mm. The third step is to mix respectively the particle groups of sandstone and mudstone according to the grain size distribution curve as shown in Figure **1**. The last step is to mix the sandstone particle (SP) mixture and mudstone particle (MP) mixture together according to the weight ratio of SP to MP 8:2.

2.2. Testing Method

Triaxial test in laboratory is used to determine the shear strength of the tested material. In the test, the size of the cylindrical soil sample is 100 mm in diameter, and 200 mm in height. The specimen is compacted in a trivalve split mold (Figure **2**) in five

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equal layers. Before the triaxial test for unsaturated specimen, the specimen is stored in a sealed container for at least 24 hours. But before the triaxial test for saturated specimen, the specimen is saturated firstly in saturated container. During the test, before the sample is sheared to failure with a rate of vertical loading at 0.01 mm/min, it is subjected to a confining pressure. During the whole testing process, including applying confining pressure then axial pressure, the specimen drains freely.

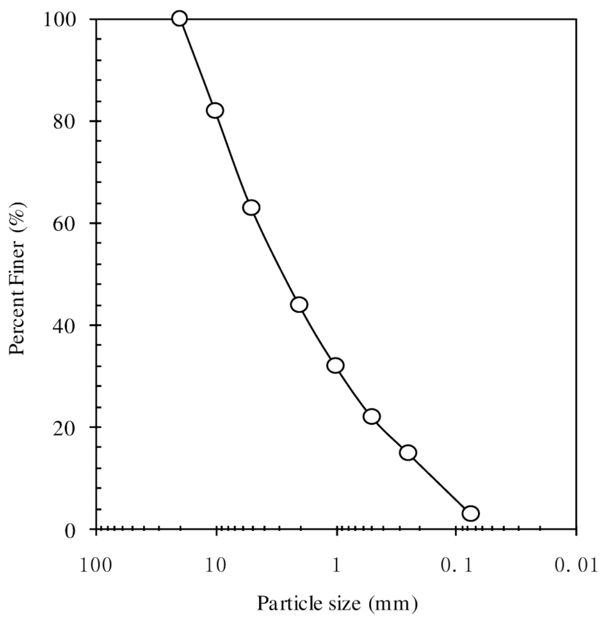

Figure 1: Grain size distribution curve of tested material.

Figure 2: Compaction device.

2.3. Testing Scheme

In order to investigate the shear strength of the unsaturated tested material and to analyze the effects of the dry density and confining pressure on the shear strength, 48 specimens, with four different dry densities (i.e. 1.80, 1.90, 2.00 and 2.10 g/cm^3) and the same water content (i.e. 6.00 %), are prepared. In the following triaxial tests, four confining pressures (i.e. 100, 200, 300 and 400 kPa) are respectively applied on the specimens.

For the purpose of investigating the effects of the water content on the shear strength of the unsaturated tested material, another 12 specimens with four different water contents (i.e. 4.00, 5.00, 8.00 and 9.00 %) and the same dry density (i.e. 2.10 g/cm^3) are also prepared. In the following triaxial tests, only one confining pressure, 200 kPa, is applied.

Otherwise, 48 saturated specimens with the four different dry densities (i.e. 1.80, 1.90, 2.00 and 2.10 g/cm^3) are also prepared in order to analyze the effects of the wetting on the shear strength. In the triaxial tests, four confining pressures, which are 100, 200, 300 and 400 kPa, respectively, are also considered. The detailed testing schemes are listed in Table **1**.

3. TESTING RESULTS AND DISCUSSIONS

The angle of shearing resistance (φ) is defined as the dip angle of a straight line, which is tangent to Mohr's stress circle and through the origin, in the plot of shear stress against normal stress. The angle is also determined by the equation as follows:

$$\varphi = \sin^{-1}\left(\frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}\right) \tag{1}$$

where, σ_1 is the critical axial stress or major principle stress; and σ_3 is the critical confining pressure or minor principle stress.

3.1. Effects of Dry Density on Shearing Resistance

The testing results from the Cases 1 to 4 in Table **1** can be used to analyze the effects of the dry density and confining pressure on the shear strength of the unsaturated sandstone-mudstone particle mixture. Figure **3** shows the testing results. The value of the angle of shearing resistance ranges from 17.94 to 32.98°. It is clear from the plots that the angle is generally decreasing with the increase of the confining

Table 1: Testing Schemes

Case No.	Dry density ρ_d (g/cm^3)	Water content *w* (%)	Confining pressure σ_3 (kPa)	Number of specimens	Test objective
1	1.80	6.00	100, 200, 300, 400	12	To investigate the shear strength of the unsaturated tested material and to analyze the effects of the dry density and confining pressure on the shear strength.
2	1.90	6.00	100, 200, 300, 400	12	
3	2.00	6.00	100, 200, 300, 400	12	
4	2.10	6.00	100, 200, 300, 400	12	
5	2.10	4.00	200	3	To investigate the effects of the water content on the shear strength of unsaturated tested material.
6	2.10	5.00	200	3	
7	2.10	8.00	200	3	
8	2.10	9.00	200	3	
9	1.80	Saturated	100, 200, 300, 400	12	To investigate the effects of the wetting on the shear strength of the tested material.
10	1.90	Saturated	100, 200, 300, 400	12	
11	2.00	Saturated	100, 200, 300, 400	12	
12	2.10	Saturated	100, 200, 300, 400	12	

pressure. This agrees with the works reported by [4, 8, 9]. In the triaxial tests, three specimens with the same dry density and water content are sheared to failure under the same confining pressure. It is also clear from the figure that the three angle values are different. For the purpose of analyzing conveniently, the average of the three angle values is used in the following investigation. Figure **4** shows the variation of the average angle with the dry density. It is clear from the plots that the average angle is increasing as a parabola with the increment of the dry density. The larger the dry density, the greater the interaction force among the particles in the specimen. The shearing resistance is therefore increasing with the increase of the dry density.

3.2. Effects of Water Content on Shearing Resistance

Cases 5 to 8 and Case 4 (only the confining pressure 200 kPa) listed in Table **1** are tested to investigate the effects of the water content on the shear strength of the unsaturated tested material. In the tests, only one confining pressure, 200 kPa, is applied. The testing results are shown in Figure **5**. The value of the angle of shearing resistance ranges from 20.88 to 28.98°. It is clear from the plots that the angle is generally increasing then decreases as a parabola with the increase of the water content. The moisture may affect the interaction force among the particles in the specimens, and therefore also affect the value of the angle.

3.3. Effects of Wetting on Shearing Resistance

It is well known that the wetting, which makes the unsaturated soil into saturated state, may affect the shear strength of soils. Comparing the testing results from the Cases 9 to 12 in Table **1**, which are for saturated sandstone-mudstone particle mixture, with those from Cases 1 to 4, which are for unsaturated mixture, the effects of the wetting on the shear strength of the tested material may be analyzed. The testing results from the Cases 1 to 4 have been shown in

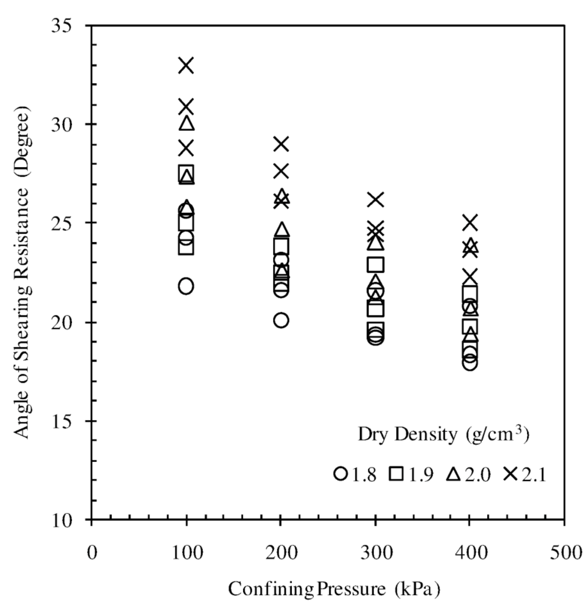

Figure 3: Variation of angle of shearing resistance with confining pressure for unsaturated specimens.

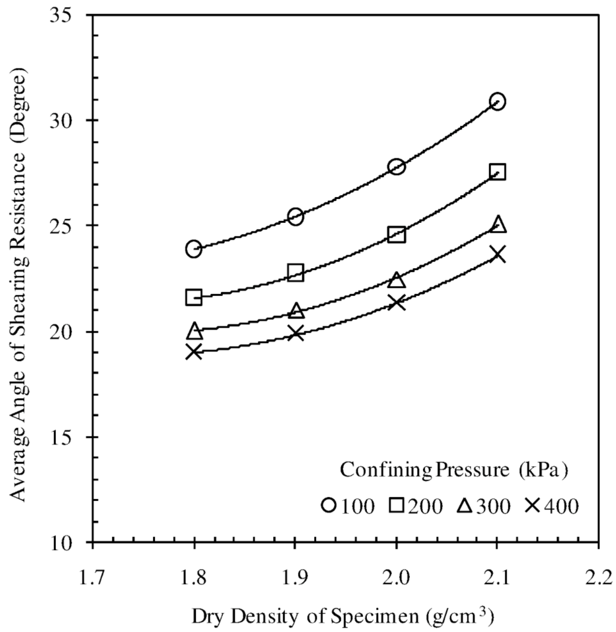

Figure 4: Variation of average angle of shearing resistance with dry density for unsaturated specimens.

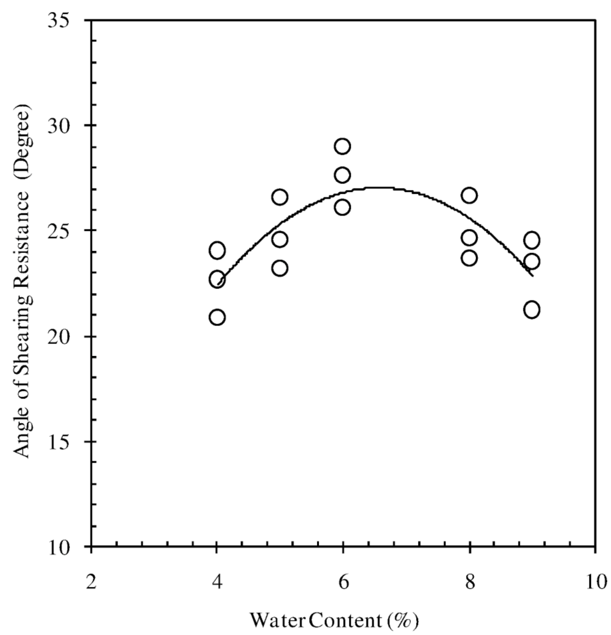

Figure 5: Variation of angle of shearing resistance with water content for unsaturated specimens.

Figure **3**. Figure **6** shows the angle of shearing resistance tested from the Cases 9 to 12. The value of the angle shown in the figure ranges from 16.90 to 30.20°. The two figures (Figures **3** and **6**) are very similar but the values of the angle are different. In order to display clearly the effects of the wetting, the difference, between the angle from the Cases 9 to 12 and that from the Cases 1 to 4, should be analyzed. Figure **7** shows the difference. It is clear from the plots that the wetting may decrease the values of the angle. The decrement of the average value of the angle induced by the wetting is increasing as a straight line with the increase of the dry density, but decreases with the increment of the confining pressure. The decrement of the average angle is about 0.4 to 2.7°.

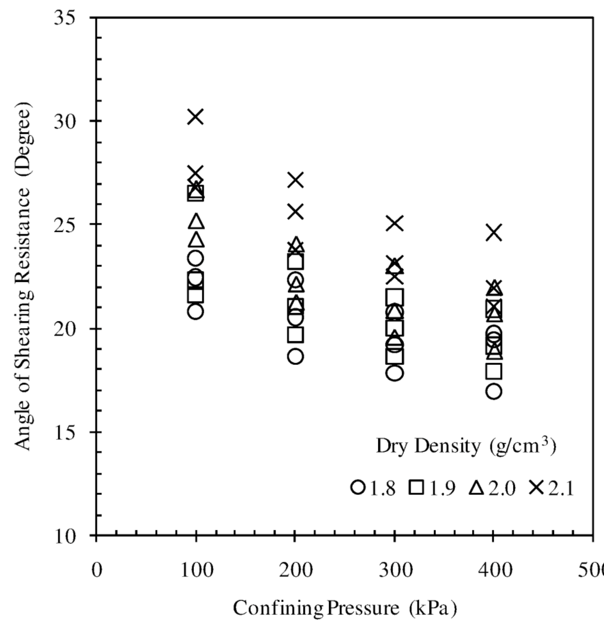

Figure 6: Variation of angle of shearing resistance with confining pressure for saturated specimens.

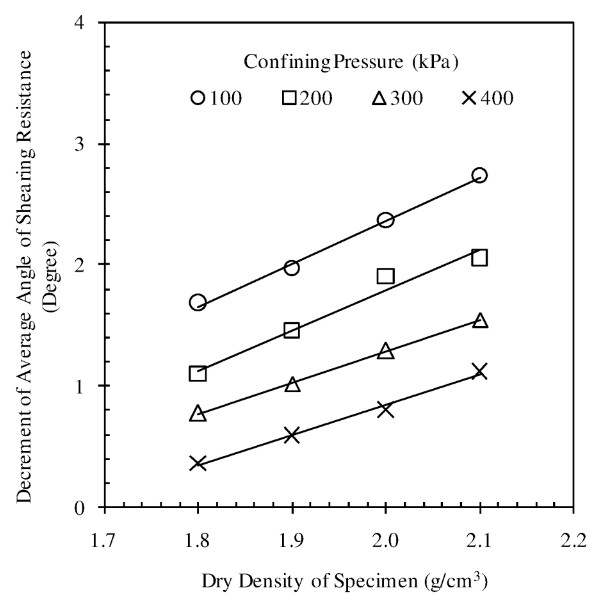

Figure 7: Variation of average angle's decrement induced by wetting with dry density.

4. SUMMARIES

The crushed sandstone-mudstone particle mixture is widely used as a main filling material in many geotechnical engineering works. Evaluation on the shear strength of the mixture is very important. The shear strength of the mixture in both unsaturated and saturated states was investigated by the triaxial tests in laboratory. Based on the testing data, the effects of the confining pressure, dry density, water content and wetting on the shear strength were analyzed. The testing results indicate that the angle of shearing resistance of the mixture in unsaturated state ranges from 16.90 to 32.98°. The angle of shearing resistance is generally decreasing with the increase of the confining pressure. The average value of the angle of shearing resistance is increasing as a parabola with the increment of the dry density. With the increase of the water content, the angle of shearing resistance is generally increasing then decreases as a parabola. The wetting may decrease the values of the angle of shearing resistance, and the decrement is about 0.4 to 2.7°.

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