Experimental Research on Shear Strength Characteristics of Unsaturated Coal-Bearing Soils under Dry-Wet Circulation

Yakun Fan¹,², Mingxin Zheng¹ and Junhua Wu²

¹ School of Civil Engineering and Architecture, East China Jiaotong University, Shuanggang East Street, 330013, Nanchang, China
² School of Civil Engineering and Architecture, Nanchang Hangkong University, Fenghe South Avenue, 330063, Nanchang, China
Email: 294817459@qq.com

Abstract. In this paper, the shear strength experiment of unsaturated coal-bearing soil under dry-wet circulation was carried out on the conventional direct shear apparatus, the relationship between shear strength and its index parameters and water content of unsaturated coal-bearing soil was obtained. The tests show that the total stress shear strength of unsaturated coal-bearing soil was obviously affected by moisture content, and the shear strength decreases with the rise of moisture content, and the total cohesion and total internal friction angle of unsaturated coal-bearing soil are greatly affected by moisture content, which decreases with the raise of water content.

Keywords. Coal-bearing soil, water content, dry-wet circulation, shear strength.

1. Introduction

Coal bearing strata and their weathered materials are generally referred to as coal-bearing soil in engineering. The soil has the characteristics of poor bonding ability, softening and disintegrating when meeting water, and easy to destroy structure and lose strength [1]. It is a kind of soil which is extremely unfavorable to the strength and stability of highway subgrade and slope. There are lots of coal measures strata along the Chang (Nanchang) - Li (Shangli) expressway. The section is in unsaturated state under the effect of rainfall, and the slope of cutting often collapses under the influence of rainfall [2]. Many international scholars have studied the relationship between shear strength and water content of unsaturated soil which was very complex, and the relationship between them is very different in different soils [3-5]. Therefore, the research on the impact of water content upon the shear strength of coal measures soil can provide fundamental basis for the treatment of coal-bearing soil cutting slope and subgrade treatment, and has important engineering significance.

The most widely accepted formula for the shear strength unsaturated soil is Bishop effective stress strength formula and Fredlund double stress variable strength formula, both of which reflect the effect of matrix suction on the shear strength [6, 7]. Due to the difficulty in measuring and calculating matrix suction, the shear strength of unsaturated coal-bearing soil under dry-wet circulation was tested by conventional direct shear apparatus, and the nexus between total stress shear strength index and water content was discussed.
2. Shear Strength Test of Unsaturated Coal Measures Soil

2.1. Basic Characteristics of Test Soil Sample
The coal bearing soil selected in this test was taken from the landslide soil for K213 section of Changli expressway, and the specific physical and mechanical indexes are shown in Table 1.

| $d_s$ | $\omega_L$ (%) | $\omega_p$ (%) | $\rho_{d_{\max}}$ (g/cm$^3$) | $\omega_{op}$ (%) |
|------|---------------|---------------|----------------|-----------------|
| 2.69 | 31.8          | 17.8          | 1.795          | 18.27%          |

2.2. Experiment Method
In this paper, the prepared soil material is pressed into a large round sample with a diameter of 100 mm and a height of 40 mm. The capillary water absorption and air drying method are used for 0-4 dry and wet cycles in the laboratory, that is, the samples are soaked in the water holding tray until saturated, the air drying in the indoor constant temperature (20°C) and the water soaking in the water holding tray until saturation, and the 0-4 dry-wet circulations are completed. After each dry-wet circulation, samples with moisture content of 21%, 17%, 13% and 9% were selected in the dehumidification process. Figure 1 shows the surface morphology of the prepared large round sample after moisture absorption and dehumidification. The small ring cutter sample is placed in the direct shear apparatus (the permeable stone is replaced by plexiglass in the direct shear apparatus), and the overlying loads of 50, 100, 150 and 200 kPa are applied until the deformation is stable, and the undrained fast shear is carried out at a constant shear rate (0.013 mm/s) to ensure that the specimen is sheared within 3-5 min.

![Image](image1.png)

(a) Saturated large round sample to be dried (b) Large round sample after drying (c) Ring-knife sample

Figure 1. The surface morphology of the large circular sample after hygroscopicity and dehumidification and the ring-knife sample.

3. Experiment Results and Analysis

3.1. Effect of Water Content on Shear Strength
The relationship between total stress shear strength and normal stress of unsaturated coal-bearing soil samples with different moisture content under 0-4 dry-wet circulation is shown in Figure 2. The shear strength of unsaturated coal measures soil has a good linear relationship with normal stress. In the same drying and wetting cycle, the shear strength of unsaturated coal-bearing soil samples raises with the decrease of the water content. For example, when normal stress of 0 drying and wetting cycles is 200 KPa, when the moisture content is reduced from 21% to 9%, the shear strength of coal measures soil samples decreases from 128 KPa to 30 KPa, and decreases by 77%. In addition, the shear strength raises with the raise of normal stress. For example, when the normal stress increases from 50 KPa to 200 KPa, the shear strength increases from 72 KPa to 128 KPa. The shear strength of unsaturated coal-bearing soil samples reduces with the raise of dry-wet cycles.
3.2. Impact of Water Content on Total Stress Shear Strength Index of Unsaturated Coal-Bearing Soil

The total stress shear strength of coal measure soil samples with different moisture content under dry-wet circulation condition was obtained from the test. The undrained shear strength of soil can be reflected by total cohesion and total internal friction angle. The relation curve of total cohesion, water content and total internal friction angle were shown in figure 3. The experimental results show that the total cohesion and the total internal friction angle of unsaturated coal-bearing soil are greatly affected by water content and decrease with the increase of water content.
Figure 3. Relation curve between shear strength index and total cohesion of coal-bearing soil.

Under the dry-wet circulation, the total stress shear strength of unsaturated coal-measure soil is greatly affected by water content and decreases with the raise of water content. Therefore, some drainage measures should be taken to ensure the stability of coal-measure soil slope.

4. Conclusion
(1) Under the same dry-wet circulation condition, the total stress shear strength was obviously affected by the water content, and the shear strength decreases with the raise of water content.

(2) At the same moisture content, the shear strength reduces with the increase of dry-wet circulations.

(3) In the same dry-wet circulation, the total cohesion and the total internal friction Angle of unsaturated coal-measure soil were greatly affected by water content, while both tend to decrease with the raise of water content.

Acknowledgements
This work was financially supported by Project (51568022) of the National Natural Science Foundation of China, Key Project (20202ACB202005) of Jiangxi Natural Science Foundation, Project (51869013) of the National Natural Science Foundation of China, Project (GJJ180530) of the Science and Technology of Jiangxi Education Department, Innovation and Entrepreneurship Course Cultivation Project(KCPY1917) of Nanchang Hangkong University.

References
[1] Wang Y H and Hong B N 2014 Physico-mechanical properties of giant soil of coal measure strata for Guangwu high way Henan Science 32 (11) 2309-2312.
[2] Yang J K and Zheng M X 2018 Soil-water characteristic curve of coal measure soil under the condition of density and dry and wet circulation Journal of East China Jiaotong University 35(3) 91-96.
[3] Huang K, Wan J W, Chen G and Zeng Y 2012 Testing study of relationship between water content and shear strength of unsaturated soils Rock and Soil Mechanics 33(9) 2600-2604.
[4] Liang B and Mo K 2010 Research on remodelling red clay’s shear strength with different moisture ratios Shanxi Architecture 36(4) 101-102.
[5] Zhang F Z and Chen X P 2010 Influence of repeated drying and wetting cycles on mechanical behaviors of unsaturated soil Chinese Journal of Geotechnical Engineering 32(1) 41-46.
[6] Bishop A W, Alpan I, Blight G E, et al. 1960 Factors controlling the shear-strength of partly saturated cohesive soils ASCE Conference on Shear of Cohesive Soils Boulder University of Colorado p 503-532.
[7] Fredlund D G, Morgenstern N R and Widger R A 1978 The shear strength of unsaturated soils *Canadian Geotechnical Journal* **15** 313-321.