Research Progress on High Slope Instability of Red Clay in Southern Jiangxi Province

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Abstract: By referring to the relevant literature, this paper comprehensively analyzes the reasons for the high slope instability of red clay in Southern Jiangxi Province. It is known that the shear stress on the sliding surface exceeding the shear strength of the soil mass is the theoretical basis for the occurrence of landslide. Water content is a vital factor affecting the shear strength of soil. Continuous rainfall will increase the water seeping into the soil. Then higher and higher moisture content of soil eventually induces deep landslide. Based on the theory of soil mechanics, the influence principle of water content and compactness of red clay on its shear strength is analyzed, and the slope protection methods are proposed. In addition, through field investigation, the feasibility of vegetation and masonry slope protection measures is further demonstrated, providing reference for engineering practice.

1. Introduction

South Jiangxi Province is located in the southern margin of central subtropical zone, with complex terrain, mainly mountainous, hilly and basin. Red clay, as a typical zonal soil in subtropical area, is widely distributed in Jiangxi Province, accounting for 56% of the total area of Jiangxi Province. Red clay is formed by the long-term influence of hot and humid climate, and often covers the purple conglomerate, purple sand shale and purple sandstone. It has the characteristics of deep soil layer and strong weathering. Its profile is uniform red. From top to bottom, there are humus layer (0.2 ~ 0.4m thick), red residual accumulation layer of iron and aluminum (0.5 ~ 2.0m thick), and red weathering crust or parent material layer (2.0 ~ 20.0m thick). Most of the soil in Southern Jiangxi belongs to unsaturated red clay. During the highway construction in this area, a large number of high and steep cutting slopes appear. Due to the influence of rainy, humid and hot climate, the slope tends to lose stability after rainstorm, which will cause traffic interruption, or even serious vehicle damage or human death.

2. Physical and Mechanical Properties of Red Clay

Under the influence of humid and rainy climate conditions, the water content of red clay is far beyond the shrinkage limit. Due to natural water loss, the water film combined with soil particles becomes thinner and the particle spacing is smaller, which will make the red clay show obvious shrinkage and fracture development characteristics. In red clay, the content of cohesive particles is high, leading to a large void ratio and saturated state. The natural water content, plastic limit and liquid limit are quite high. Because the red clay mainly contains bound water, although its water content is high, the soil is still in a hard plastic or hard state, with the characteristics of high strength and low compressibility. Under the same void ratio, the bearing capacity of red clay is generally 2 ~ 3 times of that of soft clay. Moreover, the performance index of red clay varies greatly and its dispersibility is high. See Table 1 for its physical and mechanical properties.

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Table 1 Physical and Mechanical Properties of Red Clay

Void Ratio e	Natural Moisture w/%	Content Saturation S_r/%	Plasticity Index I_P	Liquid Index I_L	Cohesion c/MPa	Internal Friction Angle φ/(°)
1.1 ~ 1.7	30 ~ 60	>85	20 ~50	-0.1 ~0.4	0.04 ~ 0.09	10 ~ 18

The particularity of red clay is reflected in the following two aspects:

(1) The thickness changes greatly and there are a large number of networked fissures, destroying the integrity of soil structure, which lead to the strengthening of water activity in the soil layer and the reduction of soil strength;

(2) Strong expansion and contraction often cause relevant disasters. Red clay increases by about 15% after soaking in water compared with that in natural state. The surface layer often contains organic matter, and the lower part gradually transits to the bedrock. The contact surface between them tends to be weak. For low-lying areas, groundwater is often gathered, which makes the red clay in the soft plastic and flow plastic state, resulting in its strength reduction, compressibility increase, and adverse impact on the foundation.

According to incomplete statistics, about 80% of the engineering accidents of high slope instability of red clay occur in rainy weather. The cause is that the surface soil of the slope is eroded by a short period of heavy rainfall, and the surface layer is damaged. The long-term low-intensity rainfall will make the rainwater continuously infiltrate into the soil, increase the pore water pressure in the deep soil, and reduce its shear strength. Once the critical value is exceeded, deep landslide occurs and causes accidents.

3. Research on the Prevention and Control Theory of High Slope Instability of Red Clay

3.1 Effect of Water Content on the Physical and Mechanical Properties of Red Clay

According to Mohr-Coulomb theory, shear failure is the theoretical basis for high slope landslide of red clay. Through in-depth analysis of the high slope instability engineering cases of red clay in Southern Jiangxi Province, it is found that landslide accidents often occur in the period of frequent rainfall from May to August. Therefore, the water content of red clay has a significant impact on its shear strength. Domestic scholars have conducted in-depth systematic researches on this problem. Fu Xinhui et al. [1] have found that when the water content is in the range of 12% - 27%, the shear strength and cohesion of red clay present a “double peak” phenomenon. While the dry density of red clay is increased, its shear strength will also increase. Zhang Tianfeng et al. [2] consider that when the initial water content of red clay is in the range of 18% - 25%, the peak cohesion of red clay will not change significantly. However, the change of initial water content has a more obvious effect on the peak internal friction angle. Zhang peipeipei et al. [3] hold that the water content of 20% is the watershed of the reduction rate of shear strength of red clay. When the water content increases between 8% and 20%, the reduction range of shear strength is not obvious. When the water content increases between 20% and 36%, the reduction range of shear strength is significant. Shi Wenbing et al. [4] propose that when the water content of red clay increases in the range of less than 40% or greater than 60%, the cohesion shows an obvious decreasing trend. The increase of water content will also reduce the internal friction angle, but the effect is relatively small. The above scholars have made fruitful researches on the relationship between the water content of red clay and its shear strength. However, under the condition of continuous rainfall, the research on the law of water permeability in red clay and the safe moisture content range before deep landslide occur are few, which should be strengthened.

When studying the engineering characteristics of red clay, He Xiaomin et al. [5] have found that red clay has a weak expansibility, but it will be quite obvious in case of high compaction. Its shrinkage characteristics under natural water loss state are also more significant. Compared with the optimal moisture content, the plastic limit of red clay is much larger. The lower the clay particle content, the greater the liquid and plastic limits. In addition, with the increase of soil compactness, the cohesion increases obviously, while the internal friction angle changes little. Liu Xiaowen et al. [6] think that the shear strength value of red clay after compaction under partial dry condition is

larger than that under optimal moisture content, showing brittle failure characteristics. While for red clay with partial wet compaction, its shear strength value is smaller than that under partial dry compaction, showing plastic failure characteristics. Under the condition of the same moisture content and normal stress, the greater the dry density, the greater the shear strength. Huang Ying et al. [7] agree that under the condition of the same blow number, with the increase of water content, the shear strength of dry red clay gradually increases, while that of wet red clay gradually decreases. When the water content is less than 5%, there is a maximum shear strength. The above literature has conducted a relatively in-depth study on the compactness of red clay. However, how to effectively improve the compactness of red clay requires further research. Moreover, slope cracks are also essential factors to induce deep landslide. Once cracks are formed in soil, under the condition of continuous rainfall, rainwater infiltration will inevitably lead to the expansion of cracks, increase the soil moisture content and affect the slope safety factor. Therefore, the prevention and control of slope cracks is also an urgent problem to be solved.

3.2 Mechanism of Slope Instability and Theory of Prevention and Control Technology

After studying the slope stability, Zou Xinxin et al. [8] have discovered that the physical and mechanical properties of red clay are the main internal causes of landslide, while water infiltration is the main external cause. The sensitivity of the internal friction angle to the slope stability is stronger than the cohesion. Therefore, the slope stability can be improved by adopting slope water blocking measures. Zhang Lianying et al. [9] consider that the structure, structural characteristics, excavation unloading and water effect are the dominant factors of red clay slope collapse. Fang Wei et al. [10] propose that the anchor frame support can effectively enhance the stability of the middle part of the slope and facilitate the mechanized construction. Moreover, the pile sheet wall has a good reinforcement effect on the slope toe, so adding anchor cable will further improve the stress state of the pile sheet wall. In addition, appropriately increasing the length of the anchor rod deep into the bedrock layer can block or weaken the growth of the potential sliding surface. The above literature has studied the red clay slope protection. However, for the engineering practice, how to adapt measures to local conditions and integrate various protection methods to maximize the slope stability is the next research focus. Meanwhile, since the slope stability can be enhanced through soil improvement, it is the key breakthrough direction to determine the type and amount of soil conditioner that meets the engineering requirements.

4. Field Investigation of Red Clay Slope Protection

Through field investigation of red clay slope, it can be seen that there is no protective measures for the slope in Figure 1. The soil particles are relatively loose, and the surface suffers obvious erosion due to rainfall. The slope soil in Figure 2 is protected by vegetation. Because the vegetation has strong water absorption and soil consolidation capacity, there is basically no erosion phenomenon. Obviously, planting vegetation on red clay slope can reduce water infiltration into the soil and slow down water infiltration. In addition, it can be seen from the masonry slope protection in Figure 3 that the masonry blocks the path of rainwater infiltration into the slope soil to a great extent, and plays a good protective effect.

Fig.1 Red Clay Slope without Protection

Fig.2 Red Clay Slope with Vegetation Protection

Fig.3 Red Clay Slope with Masonry Protection

5. Theoretical Analysis

Based on Mohr-Coulomb theory:

$$\tau_f = \sigma \tan\varphi + c \quad (1)$$

Where: τ_f is the shear strength of the soil, kPa;σ is the normal stress on the sliding surface, kPa;c is the cohesion of the soil, and kPa;φ is the internal friction angle of the soil. It can be seen from formula (1):

(1) The essence of the instability of red clay slope is that the shear stress on the sliding surface

exceeds the shear strength of the soil;

(2) Simultaneously increasing the normal stress, cohesion and internal friction angle on the sliding surface of red clay can improve the shear strength of soil;

(3) If the normal stress, cohesion and internal friction angle on the sliding surface of red clay do not increase or decrease at the same time, the increase or decrease of shear strength should be determined quantitatively.

6. Conclusion

The research focus of red clay in the future mainly lies in the following three aspects:

(1) Under the condition of continuous rainfall, it is essential to master the permeability law of water in red clay and the safe moisture content range before deep landslide of soil mass. This will provide data support for preventing deep landslide of red clay, facilitate timely taking economic and efficient targeted measures to ensure slope stability, and save manpower and material resources to the maximum extent.

(2) It is of necessity to find out effective measures to improve the compactness of red clay, especially select the appropriate construction equipment to increase the shear strength of red clay. For the prevention and control of slope cracks, it is mainly to avoid the soil cracking caused by stress concentration, as well as carefully select materials to seal the cracks. Once the slope cracks, timely plugging is required.

(3) The red clay slope protection scheme should be determined according to local conditions, so as to effectively prevent the slope soil from deep sliding. For soil improvement, it is essential to determine the type and amount of conditioner that meets the engineering requirements. Specifically, the economic and improvement effect of each conditioner can be comprehensively compared, and the optimal selection needs to be made, so that the soil improvement can be quantified, with strong operability in engineering practice.

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