Research Progress on Stability Analysis Methods of Granite Residual Soil Slope

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Abstract: Based on the instability and failure of granite residual soil slope, this paper will introduce the stability of granite residual soil slope from theoretical research, indoor and outdoor simulation tests, and numerical analysis. Based on the review of previous work and the latest research results, the stability analysis of granite residual soil slope is discussed, and the main influencing factors of granite residual soil slope instability are summarized. The main factors are: its own disintegration property; The degree of microcracks in its internal structure.

Key words: Granite residual soil; Slope instability; Theoretical research; Indoor and outdoor simulation test; Numerical analysis; influence factor.

1. Introduction

Since the 20th century, with the rapid development of urban construction, in order to ensure the highway safety, ensure the stability of embankment or cutting slope, save money, and reduce the land area as much as possible, artificial slopes formed by construction are more and more common. Among them, in Fujian, Guangdong and other coastal areas, granite residual soil is widely distributed, which accounts for more than 40% of the total slope. Through investigation, it is found that granite and residual soil account for about 35% of the total area of granite residual soil slope in Guangdong and Fujian respectively. In Guangxi, Hunan and Jiangxi, granite residual soil blocks account for about 15% of the total land area of the country [1], and the granite residual soil slopes built thereby are also widely distributed. Due to the disintegration of granite residual soil, granite residual soil slope has also become a potential factor endangering urban safety. According to research, more than 60% of countries in the world have suffered disasters in granite residual soil engineering [2]. Fig.1 shows the geological disasters of unsaturated granite residual soil in Guangdong Province and its adjacent areas, which have caused serious losses to people's lives and property. Most of the disasters are caused by subgrade collapse and slope instability.

According to statistics, there are many reasons for slope instability and failure, which can be divided into external factors and internal factors. The internal factors are mainly the lithological characteristics of the stratum and the internal structural characteristics of the slope. The external causes are mainly precipitation and earthquake, and the current main causes are human activities. If the slope is not properly treated and treated in time, life and property will be lost once the slope is unstable.

Fig. 1 Geological hazards of unsaturated granite residual soil [2]

Granite eluvial soil slope is a special slope. Its main component, "granite eluvial soil", is the debris left in place by granite under physical and chemical weathering. It contains kaolin, montmorillonite and other mineral components. The cementation structure formed by a large amount of free silicon oxide, iron and aluminum makes it have a strong structure, which is characterized by high heterogeneity, obvious anisotropy, easy to collapse under unloading, and strong water absorption, Special soil easily softened in case of water [3]. The grain grading curve of granite residual soil is also very special, with the grading characteristics of "big at both ends, fine in the middle". The coarse particles that make up the granite residual soil are wrapped by the free oxide of soluble salts, and the residual connection between some original rock mineral grains is retained between the coarse particles, forming a soil skeleton with a certain strength. However, the medium, fine sand and silt missing from the grading curve are not enough to fill the soil skeleton, which makes the granite residual soil have special structure. This structure is the main reason why granite residual soil becomes a problem soil. The special soil structure and particle size distribution of the residual soil make it exhibit the abnormal phenomenon of high compressibility and high shear strength. The problems of granite residual soil deserve attention, and most of them are unsaturated. Under saturated and unsaturated conditions, the soil properties of granite residual soil are significantly different, and the engineering properties are more complex. In view of this, domestic and foreign scholars have carried out a lot of research on the stability analysis of granite residual soil slope, mainly focusing on theoretical research, indoor and outdoor simulation tests and numerical analysis. This paper intends to introduce the basic physical characteristics of granite residual soil and the stability analysis of the slope through the research on the stability of granite residual soil slope, and point out the direction for the stability analysis of granite residual soil slope in the future.

2. Analysis and research method of granite residual soil slope stability

2.1 Theoretical research

For the theoretical study of granite residual soil, foreign scholars have made active exploration: Sammori et al. [4] took Richaxd equation as the seepage control equation, analyzed the transient seepage on the slope according to Galerkin finite element method, and analyzed the sensitivity of factors affecting the stability of the slope using the simplified Bishop method. Finally, they proposed that soil permeability, soil layer thickness and slope shape have a significant relationship with the stability of the slope. C. W. W. Ng et al. [5,6] simulated and analyzed the transient seepage and stability changes of common slopes in Hong Kong under different rainfall conditions and initial boundary conditions with the finite element method, and proposed that the slip phenomenon was caused by the reduction of the matrix suction of the surface soil mass of the slope caused by rainwater infiltration, while the rainfall intensity and early rainfall had an impact on the slope stability.

Deng et al. [7] used a slope stability calculation method based on saturated unsaturated percolation theory, saturated unsaturated shear strength theory with softening effect, and considered the changes of substrate suction with softening effect, and found that under the same rainfall conditions, the effect of long-time minor rainfall on the increase of internal water level lines in a high diking slope with granitic residue soils was significantly greater than that of Short-time Heavy Rainfall on the increase of internal water level lines in the slope; Chan-KeeKim [8] studied the influence of different initial water content on the strength of granite residual soil, and found that the influence of initial water content and matrix suction on the internal friction angle can be ignored, while the cohesion increases with the increase of matrix suction; Saffari [9] conducted a constant rate unsaturated multi-stage consolidated drained triaxial shear test on granite residual soil in Sumatran, Malaysia, and fitted the shear strength parameters of saturated and unsaturated residual soil with mathematical formulas. The results can reflect the influence of matrix suction and net confining pressure on strength. In-MoLee [10], Zhang [11], Shen [12] respectively analyzed the strength of granite residual soil from different conditions such as vertical stress, initial dry density, initial saturation, initial suction, and found that the soil is a granular material with complex composition, whose particle composition reflects the weathering process of the soil and is closely related to the structure, mechanical properties and hydraulic properties.

Granite residual soil is a kind of soil widely distributed in South China. Whether the granite residual soil slope is under construction, completed or in the maintenance stage, its soil mass is mostly formed by the physical and chemical differentiation of granite. The soil will have a certain strength without disturbance and water infiltration. However, once affected by external factors, its meso structure will be destroyed, its strength will drop, and it can be crushed under the pressure of people. Therefore, through theoretical research, it provides theoretical support for long-term protection, design and construction, risk control and prevention of granite residual soil slope.

2.2 Indoor and outdoor simulation test

In natural state, granite residual soil has low compressibility, high bearing capacity and high shear strength, but its mechanical properties are significantly reduced due to its softening and disintegration characteristics after encountering water. Therefore, domestic and foreign scholars have discussed the physical and mechanical properties of granite residual soil through indoor tests. Wu [13], Ma [14], Frank C.Townsend [15] studied the physical and mechanical properties of granite residual soil through a series of indoor tests and in-situ tests; Chainchye E. Wang [16] learned the deformation characteristics of granite residual soil residual soil through consolidation test, triaxial compression, resonant column and torsional shear test.

Zhao [17] studied the anti-scouring ability of different grass species and soil fixation structures under different rainfall intensity and different slope conditions through the combination of different grass species and soil fixation structures in the field test area; Xiao [18] analyzed the slope erosion characteristics of different slopes, soil and plant protection measures under the conditions of rainstorm and runoff erosion through the highway slope simulation test, and studied the mechanism of rill formation in the slope; Lu [19] understood the scouring mechanism of loess slope through field investigation, and carried out indoor simulation test to study and analyze the action mechanism of grass mud protection mode, intermittent rainfall and slope ratio on slope scouring; Lin [20] learned through indoor tests that high-intensity rainfall is easy to induce sliding failure of soil slope, and long-time low-intensity rainfall is easy to induce sliding failure of soil slope and the scale of landslide is relatively large, and proposed that rainfall intensity and accumulated rainfall should be considered as the parameters for rainfall early warning benchmark; Yang [21] analyzed the impact of rainfall conditions, soil structure strength, pavement runoff and slope shape on the erosion of loess slope based on indoor model test and field investigation data, and discussed the erosion law and protection countermeasures of loess slope.

Granite residual soil is a kind of "special" soil, which is very easy to induce geological disasters. The key characteristics of granite residual soil are obtained through indoor and outdoor simulation tests to understand the influence of different factors on the stability of granite residual soil slope, and the key factors causing disasters of granite residual soil slope are investigated and studied to prevent such soil slope disasters. At the same time, the mechanical properties of granite residual soil are affected by indoor test disturbance and other factors, and its strength and deformation parameters are often difficult to reflect its true characteristics. The excellent engineering properties of granite residual soil have not been reasonably applied. This situation wastes both construction funds and foundation bearing capacity resources, so there is a large research space for comprehensive indoor and outdoor simulation tests on the properties of granite residual soil.

2.3 Numerical analysis

At present, the numerical analysis method is one of the stability analysis methods of granite residual soil slope widely used by scholars at home and abroad. Due to the difficulty in sampling and large disturbance of granite residual soil, scholars tend to adopt numerical analysis when studying the impact of rainfall on the stability of granite residual soil slope.

Yang [22] used MIDAS/GTS finite element software to simulate the working conditions of different rainfall intensity and rainfall time conditions, and analyzed the coupling of rainfall infiltration flow field and stress field, and discussed its role in the stability of residual slope soil slope; Deng [23] established a finite element model to analyze the steady or transient seepage field of the eluvial soil cutting slope, obtained the safety factor and matrix suction of the slope under rainfall conditions by using the limit equilibrium method, and analyzed the shape of the landslide mass and its formation reasons at different times under rainfall conditions; Chen [24] used the Plaxis finite element program to analyze the deformation characteristics of the slope, indicating that the existence of the weak interlayer in the granite eluvial soil not only increased the overall deformation of the slope, but also determined the position of the sliding surface when the slope was unstable and damaged; Qiu [25] analyzed the relationship between the collapse and rainfall in combination with the field survey data of the collapse disaster of the high fill residual soil embankment, and analyzed the mechanism of the collapse phenomenon of the high fill residual soil embankment using the finite element seepage software Seep/W and the limit equilibrium slope stability software Slope/w; Fang [26] studied the stress strain state and stability of the granite residual soil slope after the excavation limit by using the numerical method FLAC3D software in combination with the strength reduction method, and analyzed the stability of the granite residual soil slope by using the limit equilibrium method Slope/W software to judge the stability of the granite residual soil slope.

After the long-term development of theory and practice, the stability analysis of granite residual soil slope is becoming more and more perfect. At the initial stage, simple soil mechanics was introduced into the slope calculation, and gradually developed from two-dimensional calculation to three-dimensional calculation, from the limit equilibrium method to the stage of multi method and multi theory. After entering the 21st century, numerical simulation analysis methods are more and more used, and multi-disciplinary intersection is more and more valued. Artificial intelligence method, neural grid method and other analysis methods developed in recent years have enriched and diversified modern slope analysis methods [27-31]. At present, various analysis methods make the stability calculation of granite residual soil slope more reliable, which is a key development direction in the future.

3. Factors and forms affecting the stability of granite residual soil slope

According to the principles and methods of soil mechanics [32], the reasons for the instability of granite residual soil slope can be divided into two categories: the force generated during the construction of the project has destroyed the original equilibrium state in the soil, such as the excavation of cutting or foundation pit and the filling of embankment, which makes the side slope surface have stacking materials, vehicle loads, etc; The negative effect of reducing the soil structure strength due to the change of the external environment leads to the instability and damage of the slope, such as long-term high-intensity rainfall erosion, vibration caused by construction near the slope, and the effect of seismic force. Therefore, the influence of soil seepage, slope shape, rainfall conditions, sliding surface and other factors on the stability of granite residual soil slope can be understood by using finite element, reliability analysis, fuzzy theory and other methods. For granite residual soil slope, its slope instability is mainly affected by two factors: its own disintegration property; The degree of microcracks in its internal structure. If the soil is relatively homogeneous, the degree of microcracks is light, and most of them are sliding failures; On the contrary, it belongs to collapse.

3.1 Slip failure

There are two main types of failure: softening slip; Slip tension crack. The former is mostly located in low-lying places, with shallow buried depth of groundwater, and the overlying soil layer belongs to alluvium. After excavation, groundwater will drain towards the slope. Once the surface of the slope is soaked, it is easy to collapse, and the soil will soften and collapse, so that the stress release of the soil will be accelerated, the micro fissures in the soil will expand, groundwater will infiltrate, and argillization expansion reaction will occur in the fissures, resulting in weak strength of the structural surface. At the same time, the small particles in the fissures will be washed away by water, and the pores will continue to expand, eventually leading to softening and sliding. The slip tension crack of slopes are mostly located in low hills, and the groundwater level is relatively stable in the residual soil. When excavating, once the groundwater level is exceeded, the soil is easy to collapse, as is the case with softening and sliding, and tension cracks are formed on the upper part.

The groundwater plays a leading role in the sliding failure. In the case of softened sliding, the water level can be lowered first, and anchor retaining walls can be used for support. If there is no drainage, anti-sliding piles should be selected. In the case of slip tension crack, shotcrete and anchor support can be selected for the upper part, and the lower part needs to be drained first, and then anchor bolts or soil nails are selected for support.

3.2 Collapse failure

Some hillsides are located in high terrain, and the groundwater is buried deep. Generally, the excavation cannot reach the groundwater level. The overlying soil layer is mostly slope deposit with low water content, which has good mechanical properties and high shear strength. At the beginning of excavation, the slope is relatively stable. However, over a long period of time, cracks expand, surface water seeps, and the strength of the slope weakens, so the anti-sliding friction resistance of each soil mass decreases. Under the action of gravity, wedge collapse is easily caused. Some slopes are easy to form mud ditches and soil caves under the scouring of rainwater, and finally collapse.

At the beginning, the collapse phenomenon is mostly local collapse, and then the area continues to expand. The key to control the collapse is to control the local collapse. In case of wedge collapse, it can be supported by anchor bolt walls, and grass can be planted on the slope. In case of scouring and collapse, surface water shall be drained in time, and turf shall be planted on the slope.

4. Strength theory of granite residual soil unsaturated soil

The behavior of unsaturated soil is more complex than that of saturated soil. In addition to solid, liquid and gas phases, the contraction membrane (i.e. water air interface) is considered as an independent fourth phase. Since the 1940s, Bishop [33], Fredlund [34], Shen [35], Miao [36], Yin [37] and Zhao [38] have successively put forward many shear strength theories of unsaturated soil.

4.1 Single variable effective stress

Fredlund and Morgenstern [34] applied the formula of effective stress of saturated soil to the theoretical study of unsaturated soil, and proposed to express the effective stress of unsaturated soil by controlling a single value effective stress or stress state variable related to soil parameters. Later, scholars found that the description of the stress state of soil should be separated from the nature of the soil itself, and the imperfections of the univariate effective stress were obvious. For example, Bishop's univariate formula has neither theoretical support nor experimental verification. "χ" in Eq. (1) is a parameter reflecting the influence of unsaturated soil gas phase, but it has no clear physical significance and has been rarely mentioned so far.

$$\sigma' = (\sigma - u_a) + \chi(u_a - u_w) \quad (1)$$

Where: σ' is the total stress; $(\sigma - u_a)$ is the net stress (the difference between the principal stress and the air pressure); $(u_a - u_w)$ is the matrix suction (the difference between air pressure and pore water pressure).

4.2 Two variable effective stress

For the research on mechanical properties of unsaturated soil, Bishop effective stress principle can be used for calculation, but many scholars slowly found that Bishop effective stress and deformation characteristics of unsaturated soil are not a single corresponding relationship. Scholars changed their previous inherent concepts, and began to use two stress variables to describe the stress state of unsaturated soil, which is called the dual variable theory. The stress state of unsaturated soil is described by single value stress variable. Two of the three state variables $(\sigma - u_a)$, $(u_a - u_w)$ and $(\sigma - u_w)$ can be combined in pairs to obtain these two independent stress state variables. Fredlund and Rahardio [39] think that $(\sigma - u_a)$ and $(u_a - u_w)$ are most suitable for engineering practice. They bring the bivariate effective stress proposed by Rahardio into the Mohr-Coulomb strength failure criterion, and obtain the bivariate unsaturated soil failure criterion as shown in Eq. (2):

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\tan\varphi^b \quad (2)$$

Lamborn [40] also proposed the shear strength expression with $(\sigma - u_a)$ and $(u_a - u_w)$ as double stress variables, as shown in Eq (3):

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\theta_w\tan\varphi \quad (3)$$

Where: θ_W is the volume water content of the sample; τf is the shear strength; $tan\varphi'$ and $tan\varphi^b$ are parameters related to internal friction angle.

The fitting formula proposed by Abramento and Carvallo [42] according to the test results is shown in Eq. (4):

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + \alpha(u_a - u_w{}^{\beta}) \quad (4)$$

Where: α and β are fitting parameters.

4.3 Other forms of shear strength

With the deepening of unsaturated soil strength, researchers began to consider deepening and revising the original formula. Richards [42] considered the component of solute suction in matrix suction, as shown in Eq. (5):

$$c' = \sigma - u_a + X_m + X_S(h_s + u_a) \quad (5)$$

Where, X_m is the effective stress parameter considering the matrix suction; X_s is the effective stress parameter considering the solute suction, and h_s is the solute suction. Aitchison [43] considered both solute suction and soil parameters related to stress path, and proposed a modified effective stress formula similar to Richard's.

Chinese scholars also put forward many shear strength formulas related to suction. Shen [33], from the perspective of nonlinear relationship between matrix suction and unsaturated soil, established a hyperbolic relationship between generalized suction u_s and strength as shown in Eq. (6):

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + \frac{u_s}{1+du_s}\tan\varphi' \quad (6)$$

Where, d is the fitting parameter.

5. Conclusion and expectation

The process and influencing factors of granite residual soil slope instability and failure are very complex. This paper introduces the research methods of granite residual soil slope stability, and summarizes the failure forms of granite residual soil slope. The following conclusions are drawn:

(1) The basic physical properties of granite residual soil are analyzed through theoretical research; The key characteristics of granite residual soil are obtained through indoor and outdoor simulation tests, and the effects of slope, rainfall intensity, rainfall time, protection methods and other factors on soil slope erosion under rainfall are discussed; The stability of granite residual soil slope is judged by numerical analysis, and the position of sliding surface is determined when the slope fails.

(2) The main reasons for the instability of granite residual soil slope are as follows: the force generated during the construction of seepage works destroyed the original equilibrium state in the soil; The negative effect of decreasing the soil structure strength due to the change of the external environment leads to the instability and failure of the slope. For granite residual soil slope, its slope instability is mainly affected by two factors: its own disintegration property; The degree of microcracks in its internal structure.

(3) The strength theory of granite residual unsaturated soil includes single variable effective stress, double variable effective stress and other forms of shear strength.

Through the research, the following points are found and put forward: (1) The slope stability analysis theory has been deeply and systematically studied on the basis of previous efforts, and the quantitative analysis results of slope stability have been very close to the actual engineering situation. However, the research on granite residual soil slope is few, especially the analysis and calculation research on soil slope after support is less than the theoretical analysis on soil slope stability. The effect of slope support and the design parameters introduced by support have a lot of research space; (2) The granite residual soil slope has a certain shear strength. What kind of materials can be added to enhance the strength of the slope and reduce the hazard of landslide; (3) Some scholars adopt outdoor simulation test, but outdoor simulation test is time-consuming and laborious; Some scholars adopt the research method of combining indoor simulation test with software analysis, but the basic properties of indoor remolded residual soil are greatly different from that of on-site granite residual soil. The former is obviously weaker than the latter. How to eliminate the difference between the two remains to be studied.

In a word, it is hoped that this study can provide some theoretical basis and guidance for the future stability engineering of granite residual soil slope.

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