

Postprint: Analysis of Direct Shear Characteristics of Highly Weathered Granite from a Nuclear Power Plant in Guangdong

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Abstract

To provide appropriate and accurate shear strength parameters for the highly weathered granite at a nuclear power plant, field shear tests and laboratory simulated shear tests were conducted following analysis of its basic characteristics. The study concludes that: the cohesion and friction angle obtained from field direct shear tests are substantially greater than those from laboratory direct shear tests; in laboratory direct shear tests, cohesion is directly proportional to saturation and natural density, whereas the friction angle exhibits relatively minor variation; water demonstrates a pronounced weakening effect on cohesion but only minimal influence on the friction angle. In actual engineering practice, the shear strength of highly weathered granite masses in this region is significantly lower than test values due to multiple influencing factors including structural features, discontinuities, water content, climate, and construction activities. Therefore, determination of the shear strength of such highly weathered granite masses cannot be based solely on individual shear test values, numerical simulation, or engineering analogy; rather, a comprehensive analysis and evaluation is required. This study provides a reference for research on shear strength of similar rock masses.

Full Text

Analysis of Direct Shear Characteristics of Strongly Weathered Granite at a Nuclear Power Plant in Guangdong Province

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Abstract

To provide suitable and accurate shear strength parameters for the strongly weathered granite at a nuclear power plant site, this study conducted field shear tests and laboratory simulated shear tests based on analysis of its fundamental characteristics. The research indicates that: the cohesion and friction angle obtained from outdoor direct shear tests are significantly greater than those from indoor direct shear tests; indoor direct shear test results show that cohesion is directly proportional to saturation and natural density, while the relative variation in friction angle is relatively small; water has a pronounced weakening effect on cohesion but minimal impact on friction angle. In actual engineering practice, the shear strength of strongly weathered granite masses in this region is far lower than experimental values due to multiple influencing factors including structural and discontinuity planes, moisture content, climate, and construction activities. Therefore, the shear strength of such strongly weathered granite masses cannot be evaluated based solely on individual shear test values, numerical simulations, or engineering analogies, but requires comprehensive analysis and judgment. This study provides a reference for shear strength research of similar rock masses.

Keywords: Strongly weathered granite, shear strength, cohesion, friction angle, direct shear

1 Introduction

Granite is an anisotropic rock mass, particularly controlled by its degree of weathering. As granite is widely distributed and large-scale construction projects increase, engineering problems related to strongly weathered granite have become more common. Ma Haiyi analyzed the shear characteristics of strongly weathered granite [1]. Chen Jiansheng examined vertical displacement changes during shear of strongly weathered hornfels, revealing shear dilation and contraction effects [2]. Lu Zude's research indicated that the variation pattern of shear stress with normal stress is essentially the same under natural and saturated conditions, and that shear strength decreases with increasing moisture content, with water demonstrating a significant weakening effect on cohesion [3].

While numerous studies have investigated the bearing capacity of strongly weathered granite, research on its shear strength remains limited. Consequently, this paper focuses on shear strength studies of strongly weathered bedrock in the nuclear island area of a nuclear power plant.

2 Basic Characteristics of Strongly Weathered Granite

The strongly weathered granite at this engineering site exhibits extremely non-uniform weathering, locally interspersed with moderately and slightly weathered residual bodies (such as boulders) and completely weathered cohesive soil. The

weathering characteristics are illustrated in Figure 1 [Figure 1: see original paper].

As shown in the figure, spherical weathering is intense within the strongly weathered granite, with some portions weathered into soil or gravel-like material while others remain less weathered in blocky form. Therefore, the strongly weathered granite at this site represents a special geomaterial intermediate between soil and rock, possessing neither the integrity of rock nor the plasticity of soil. Its strength characteristics are primarily manifested through interlocking and frictional effects between particles. Once its structure is destroyed, it is difficult to restore, and the shear strength may decrease or even disappear.

Influenced by geological conditions and weathering processes, joints and fissures are well-developed. The predominant joint orientation is NW, followed by NE and near NS directions, mostly exhibiting shear joint characteristics with relatively planar surfaces. Locally developed joint 密集 zones (joint dense zones) feature steep dip angles (80° - 90°), with fewer gently dipping joints that are planar and smooth. Joints generally develop as multiple conjugate sets, often forming grid-like networks that cut the rock into rhombic blocks.

The rock at this site is Early Cretaceous second-stage intrusive granite with complex mineral composition, including plagioclase, mica, potassium feldspar, quartz, hornblende, chlorite, and clay minerals, with varying particle sizes. Mineral composition content varies with weathering degree, and the material exhibits certain disintegration properties.

Overall, the strongly weathered granite at this site is mixed with completely weathered and moderately/slightly weathered materials. In terms of particle composition, it can be classified into cohesive soil, sandy soil, and gravelly soil. Therefore, in obtaining shear strength parameters: empirical values are clearly insufficient; sampling is difficult due to fragmentation; undisturbed samples are challenging for laboratory testing; and field testing faces challenges from heterogeneity, limited space, and high costs. Consequently, this study conducted specialized shear test research.

3 Shear Test Research

Given the complex strongly weathered granite topography at this site, we employed a combination of field outdoor tests and laboratory simulation tests.

3.1 Field Direct Shear Test

The field direct shear test utilized typical strongly weathered granite as shown in the previous figure, cut into cubic specimens. Due to limited space at the site, specimens were transported to the laboratory for large-scale shear testing, with 30 cm side length as the standard. Field sample preparation is shown in Figure 2 [Figure 2: see original paper], standard specimens in Figure 3 [Figure 3: see original paper], specimen casting in Figure 4 [Figure 4: see original paper], and

shear testing in Figure 5 [Figure 5: see original paper]. Results are presented in Table 1 .

The influence of sample shear strength on cohesion and friction angle is not particularly significant. In Table 1, the first three groups are saturated samples while the last three are natural samples. Some samples exhibit relatively large cohesion and friction angle values due to selection of relatively intact specimens, and also because shearing may encounter hard rock or particles during the testing process.

During testing, the cohesion and friction angle at peak strength and residual frictional strength are generally quite close, which differs significantly from direct shear characteristics of moderately or slightly weathered rock [4]. Additionally, due to the strongly weathered nature of the samples, saturation does not show significant effect on the visual appearance.

3.2 Indoor Shear Tests with Different Saturation

Due to influences from excavation and climate, the moisture content of strongly weathered granite may continuously change. To analyze shear strength variation characteristics with changing moisture content, indoor direct shear tests were conducted at different saturation levels.

Sample preparation involved screening field-collected strongly weathered granite samples, removing strongly weathered particles larger than 2 mm, air-drying the remaining material, and measuring the air-dried moisture content. Based on the standard shear ring size of $\Phi 61.8 \times 20 \text{ mm}$, the required water amount and air-dried soil weight were calculated to prepare samples at specific saturation levels, as shown in Figure 6 [Figure 6 : see original paper]. After sample preparation, direct shear tests were conducted, as shown in Figure 7 [Figure 7 : see original paper]. With a prepared sample dry density of 1.50 g/cm^3 , direct shear test results at different saturation levels are presented in Table 2 .

In Table 2, cohesion and friction angle are maximum at 0% saturation (dry state). As saturation increases, cohesion decreases significantly then increases gradually, but with small magnitude. With increasing saturation, friction angle drops abruptly by approximately 5° then remains essentially constant. This demonstrates that strongly weathered granite cohesion is highly sensitive to water, with water exerting a strong lubricating effect that causes deterioration. The effect of water on friction angle is inferred to be similar for samples at other dry densities.

3.3 Indoor Shear Tests at Different Natural Densities

As natural density varies with burial depth, shear tests were conducted on prepared samples at different natural densities. The sample preparation method was similar to that for different saturation samples, with quantitative sampling for each density followed by standard sample preparation and direct shear testing. Specific values are presented in Table 3 .

Table 3 shows that both cohesion and friction angle increase with increasing natural density, with a relatively large increase in cohesion and a slower, smaller change in friction angle. Since the strongly weathered granite contains very little fine-grained soil, it can be inferred that cohesion is primarily composed of interparticle friction and interlocking forces rather than molecular, electronic, electrostatic, or cementation forces.

3.4 Saturated Shear Tests at Different Densities

As the site is significantly affected by rainfall, strongly weathered granite is sometimes in a saturated state. Therefore, saturated direct shear tests were conducted on prepared samples at different dry densities, with specific values presented in Table 4 .

Table 4 demonstrates that as dry density increases, cohesion in the saturated state increases relatively uniformly, while friction angle remains relatively stable between 30-32°. At higher densities, friction and interlocking forces in the cohesion increase abruptly.

3.5 Comparative Analysis of Field and Laboratory Tests

(1) Necessity of Outdoor and Indoor Direct Shear Tests

As shown in Figures 1-4, the strongly weathered granite at this site exhibits highly non-uniform weathering characteristics. Field shear tests are limited by topography, schedule, and cost, allowing only partial testing that cannot represent all samples. Therefore, indoor simulation tests are necessary as supplementary data. Additionally, more than half of the samples cannot obtain undisturbed specimens, requiring disturbance samples for simulation tests.

During indoor simulation, large weathered particles were removed due to equipment limitations and size effects (which affects partial cohesion but is unavoidable) before shearing. Comparative simulation tests were conducted to simulate direct shear strength under different depths, densities, and saturation states encountered in actual conditions.

(2) Comparison of Field and Laboratory Test Data

The test data demonstrate that outdoor shear strength is significantly greater than indoor shear strength, with cohesion differing by an order of magnitude and friction angle differing by 5-15°. The reasons include: sample shape effects; presence of original rock structural strength in the field; and sample selection bias, as relatively high-quality strongly weathered granite was selected for better field test execution.

In the comparative analysis above, both peak and residual shear strength show similar cohesion and friction angle values in field tests, and both dry and saturated states show relatively close cohesion and friction angle values. This indicates that cohesion is primarily composed of friction and interlocking forces,

which are mainly influenced by sample density and saturation. Given the complex field conditions involving varying densities and saturation levels, indoor simulation shear tests are necessary.

Despite the significantly reduced particle size compared to the original state, indoor simulation test data remain representative because cohesion is primarily composed of friction and interlocking forces. Key findings include: water significantly weakens cohesion with minimal effect on friction angle; natural density states show significantly greater cohesion and friction angle than moist states; both cohesion and friction angle are proportional to natural density, though cohesion is more sensitive to density changes.

4 Comparative Analysis Between Test Values and Actual Conditions

In field conditions, strongly weathered granite can maintain stability in its natural state, but experiences significant cohesion reduction and becomes prone to sliding and collapse once disturbed or subjected to wind, rainfall, or excavation. Primary causes include: (1) stress release after excavation; (2) water erosion effects and water-soil interaction, where water entering the granite lubricates particles, increases saturation and sliding potential, reduces cohesion, and transforms the material; (3) presence of completely weathered granite that has weathered into clay, which expands when water enters, further destroying bonding strength—though this component is minor, its expansion effect exceeds its bonding contribution, causing deterioration; and (4) numerous near-vertical joints, weathering joints from non-uniform weathering, and new joints formed by engineering activities, all of which are detrimental to rock mass stability.

Therefore, the shear characteristics of strongly weathered granite are completely different from those of ordinary rock and soil. The shear resistance of strongly weathered granite rock masses is significantly lower than that of completely and moderately weathered granite rock masses.

In actual engineering, evaluation must consider not only shear strength but also multiple factors including structural and discontinuity planes, moisture content, climate, and construction activities. The properties cannot be evaluated simply based on individual shear test values, numerical simulations, or engineering analogies, but require comprehensive analysis and judgment.

For the strongly weathered granite at this site, protective measures including plastic sheeting coverage, slope piles, slope spraying, and anchors were implemented according to different construction conditions and geological conditions. Due to the heterogeneity of strong weathering, measures were applied to all areas of the project, with some regions receiving multiple protective measures. For strongly weathered granite bands occurring locally at the nuclear island base, considering the characteristics of the strongly weathered granite and the importance of the project, concrete replacement was performed to effectively improve bearing capacity and safety factors, mitigating potential geological risks.

For other similar strongly weathered granite projects, attention should be paid to: (1) During excavation, bearing capacity of some strongly weathered granite masses will significantly decrease under water and stress release effects, and bearing capacity cannot be easily restored after additional loading—residual structures and joints in the strongly weathered granite can easily form weak structural planes affecting stability [5]; (2) In most working conditions, appropriate saturation and dry density can be selected for reinforcement treatment of strongly weathered granite masses [6]; (3) To ensure stability of strongly weathered granite masses, surface protection and drainage measures must be considered to reduce and prevent water infiltration, minimize water-rock interaction time and scope, and reduce groundwater deterioration effects—prevention of disintegration and softening of strongly weathered granite is necessary to avoid damage to bored piles, building settlement and cracking, support structure deformation, and surrounding softening [7]; and (4) Due to significant property variations in strongly weathered granite, engineering solutions should be tailored to specific conditions, such as foundation trench inspection and sealing, blasting excavation methods, groundwater seepage prevention measures, slope sliding surface stability calculations, and earth-rock classification, excavation methods, and support stability calculations—all requiring comprehensive consideration of physical-mechanical parameters and field geological and engineering conditions.

5 Principles for Direct Shear Strength Analysis and Judgment

- (1) Direct shear tests must be representative and cover all working conditions and geological states. Indoor simulation tests should consider actual working conditions and analyze reasons for numerical differences.
- (2) Direct shear strength should be analyzed dynamically, such as strength under original topography versus conditions after heavy rainfall, slope excavation, or tunneling.
- (3) For complex geological conditions like this project, shear strength parameters should be provided separately for different regions and locations when necessary. For extremely non-uniform strongly weathered granite, conservative and safe test parameters should be provided, with overall treatment of strongly weathered granite masses in the project when required.

The shear strength of strongly weathered granite masses is determined by their inherent characteristics. Field shear tests show cohesion of 200-300 kPa and friction angle of 35-43°; indoor simulated direct shear tests at natural density of 1.50 g/cm³ show cohesion increasing with saturation but with small values, and friction angle of 26-30°; cohesion increases significantly with different dry densities, from 9 kPa to 44.5 kPa, while friction angle increases from 29.8° to 35.4°. In saturated shear tests, cohesion gradually increases from 4.5 kPa to 34.6 kPa with increasing dry density, while friction angle remains around 30-32°.

In actual engineering, shear strength of strongly weathered granite is lower than

test values due to effects of structural and discontinuity planes, moisture content, climate, and construction. Shear strength analysis cannot simply consider test values alone but must comprehensively incorporate various construction conditions and macroscopic/microscopic geological features, with implementation of relevant engineering measures. This analysis provides a reference for construction projects under similar geological conditions.

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Note: Figure translations are in progress. See original paper for figures.

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