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Laboratory Drilling Test of Core Discing Phenomenon under Low Stress

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Abstract. The phenomenon of core discing has always been considered as a unique sign of high geostress area. With the in-depth study of the discing mechanism, there are various indications that the high geostress is not the main controlling factor of the core discing. Based on the geostress classification standard and engineering cases data, the stress level of complete granite prone to discing is determined in this paper. On this basis, laboratory drilling tests with different drilling speeds under high and low stress conditions are designed. The results show that high stress is not the key factor for core discing. When the drilling speed is fast, even if the confining stress is 0, core discing will occur. When the drilling speed is slow, the core can be taken completely even at high stress levels. Drilling parameters fluctuate with discing, and its peaks correspond to the core fracture location.

Keywords:core discing; geostress; laboratory test; fluctuate;drilling speed

1. Introduction

It is generally accepted in engineering that core discing is a typical manifestation of high geostress environment. High geostress is considered to be the dominant factor in the discing phenomenon. Based on this understanding, core discing in high geostress areas has become an unavoidable phenomenon, and has gradually developed into a method of geological survey and a criterion for high geostress areas. The initial purpose of the geological coring operation was to obtain as complete and continuous cores as possible, and to determine the spatial relationships and physical and chemical properties of the strata through the drilling catalogue and a series of physical and chemical tests. According to the high geostress discing theory, the core discing process is the stress relief of drilling bit on the core, which makes it deform greatly and finally break into disc. High geostress is the precondition. Core discing, as a "unique" phenomenon in coring operations in high geostress areas, has also occurred in low stress areas [1-3] several times, but it has not been paid enough attention. By means of numerical simulation, Li, Xie and Zhang also proved that the effect of unloading speed on dicsing is greater than geostress [4]. Zheng, Li and Zou reduced core discing rate in high geostress area by changing the way of drill bit design. These conclusions enrich the study of core discing mechanism, especially under various stress conditions, and preliminarily reflect that high geostress is not the main factor affecting core discing.

During the drilling tests in the laboratory, the core discing phenomenon under low confining stress has occurred many times, which is contrary to the existing high geostress discing theory. Therefore, in this paper, the initial stress range of discing of intact granite is determined in combination with the criteria of geostress level and engineering cases. Based on the recommended values of drilling machine in the drilling rules for geological cores, laboratory drilling tests of intact granite with high and low confining stress conditions and different drilling speeds are carried out to explore the effect of confining stress level on core discing.

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2. Geostress Classification Standard

The geostress refers to the undisturbed stress stored in the rock mass, also known as the original rock stress [6]. It is mainly caused by the self-weight of the rock mass and plate tectonic movement and remains in the rock mass all the time. There are different standards and methods for the division of geostress, which are mainly divided into quantitative division and qualitative division. Quantitative partitioning usually uses the following three criteria:

(1) If the normal (vertical) stress of the measured rock mass is greater than 20 MPa, it can be considered that the rock mass is in a high stress state. [7];

(2) According to the initial geostress state, when the stress field is greater than the self-weight stress, the rock mass is considered to be in a high stress state [8];

(3) The geostress level is defined by the ratio of uniaxial saturated compressive strength to maximum principal stress (strength-stress ratio). Table 1 shows the criteria for distinguishing high geostress in domestic and international engineering codes.

In general, the Strength-Stress ratio is less than 2 or 4, i.e. high geostress level, and the Strength-Stress ratio is greater than 4 or 7, i.e. geostress level.

Table 1. Geostress Classification Standard[9-11]

Institution	Low	Medium	High
French Tunnelling Association	>4	2-4	<2
Japan Applied Geology Association	>4	2-4	<2
Bass mining area of the former Soviet Union	>4	2.2-4	<2.2
China Code for Investigation of Geotechnical Engineering	>7	4-7	<4
Chian Specification for Water and Hyropower Projects	>7	4-7	2-4

3. Relationship between core disc and Geostress conditions

Some scholars have obtained the initial discing stress of rock by means of statistics combined with the phenomenon of discing in the project site and the results of geostress test. Table 2 lists rock mass mechanical conditions corresponding to core discing in some projects [4,12,13]. The initial discing stress of granite and other hard rocks is about 30MPa, greater than 20 MPa. At the same time, according to the Strength-Stress ratio stipulated in the Code for Investigation of Geotechnical Engineering(GB50021-2001), all the conditions in Table 2 belong to high geostress. Therefore, 30 MPa is taken as the initial discing stress of complete granite.

Table 2. Media and mechanical conditions during formation of rock core discing in some areas [4,12,13]

Position	Lithology	Initial Stress/MPa
Ertan, Sichuan	Syenite	30
Jinchuan Mine, Gansu	Granite	30
Tianhuangping, Zhejiang	Granite	28
Laxiwa, Qinghai	Granite	30
Indiana, USA	Limestone	40
Canadian Basement Laboratory	Granite	35
Dalian, Liaoning	Granite	35
Sanshandao, Shandong	Granite	35

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4. Core discing phenomenon in low geostress area

In the study of core discing mechanism, the discing phenomenon under low geostress has occurred in many places, which is contrary to the common knowledge that discing is a unique phenomenon of high geostress. Core discing occurs in compact granite strata with a geostress of 13.80MPa buried depth of 500-700m at the dam site of the Three Gorges Project [1], homogeneous granite strata with a geostress of only 11.12MPa buried depth of about 200m in Okayama City, Japan, and complete granite porphyry strata with a geostress of 13.00MPa buried depth of 20-120m at the dam site of Tianhuangping Hydropower Station [2]. However, core discing under low geostress has not attracted much attention.

5. Laboratory drilling test under low stress

It has been proved by experiment and numerical simulation that the faster the drilling speed, the more obvious the stress concentration effect and the easier the discing occur. Indoor drilling tests of complete granite under high and low stress are designed to study the influence of stress level and drilling speed on core discing.

5.1 Drilling Test Design

Servo drilling coring tests with different confining stresses and drilling speeds are carried out on the basis of laboratory servo drilling test platform (Fig. 1). The test platform consists of drilling system, propulsion system and confining stress system as shown in Fig. 1. The platform can control and collect drilling parameters (drilling pressure, drilling speed, rotation speed, bit torque, rock confining stress) to achieve controllable drilling under different confining stresses conditions. The test drilling pressure and bit torque are effective pressures and torques, and the errors caused by friction between the bore wall and the bit have been subtracted. Select three-edged, three-water-mouth flat-tooth impregnated diamond bit (Fig. 2) and 100 mm × 100mm × 100 mm square sample made of complete granite (Fig. 3) is shown in Fig. 4. The drilling test schematic is shown in Fig. 4.

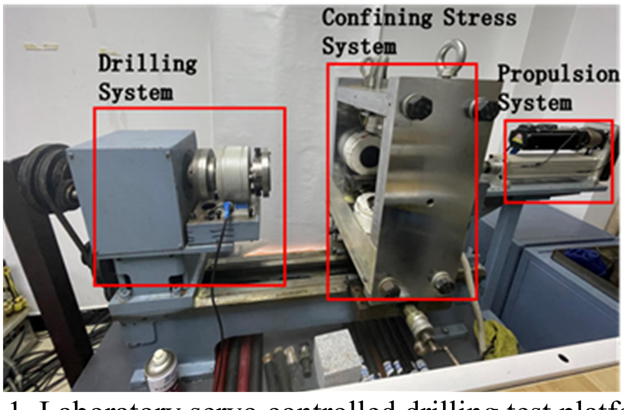

Figure 1. Laboratory servo controlled drilling test platform.

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Figure 2. Drilling bit.

Figure 3. Granite sample.

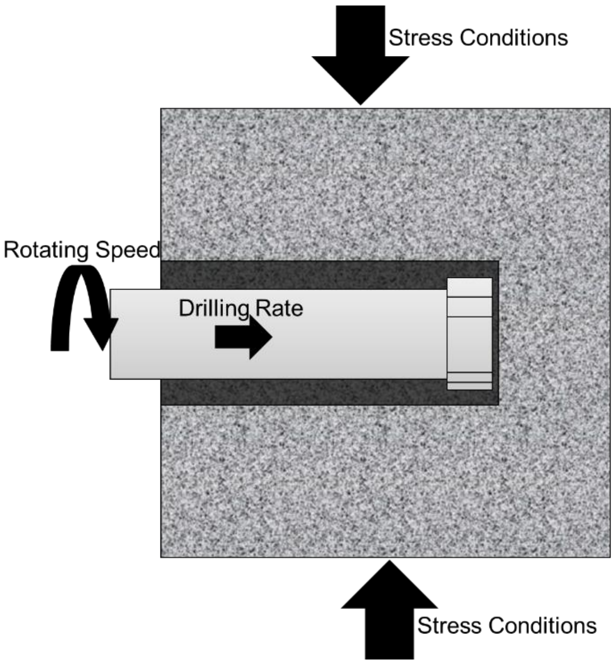

Figure 4. Drilling test

According to the preceding contents, the initial discing stress of complete granite is about 30 MPa. 0 MPa (low confining stress) and 37 MPa (high confining stress) are selected as test confining

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stress. According to Geological core drilling regulations (DZ/T0227-2010) [15], the recommended range of drilling speed for 32 mm diamond bit in granite formation is 13.33-35.00 mm/min. During the test, it is found that when the drilling speed is greater than 10mm/min, even if the confining stress is very low, there is a certain probability of core discing, as shown in Fig. 5. The test drilling speed is set to 5 mm/min, 10 mm/min, 15 mm/min and 20 mm/min respectively. The test design rules are as follows: when the confining stress is 0 MPa, the drilling speed is 15 mm/min and 20 mm/min respectively; when the confining stress is 37 MPa, the drilling speed is 5 mm/min and 10 mm/min respectively. Four typical tests conditions as shown in Table 3, the phenomena and data characteristics of the remaining test groups are consistent with those of the same type of test. The test uses a operating mode that holding constant drilling speed - constant rotation speed - constant confining stress, while recording drilling pressure and bit torque.

Table 3. Core drilling parameters of rock under different confining stresses

Test	Confining Stress /MPa	Drilling Speed /mm·min-1	Rotation Speed /RPM	Disicng
1	37	5	600	NO
2	37	10	600	NO
3	0	15	600	YES
4	0	20	600	YES

The test steps are as follows: put the granite sample into the confining stress system. Install drill bit. Start power supply. Set confining stress. Start the drilling system to rotate the drill bit to a predetermined speed. Start the propulsion system to push the confining stress system close to the drilling system. Collect and save drilling parameters.

Figure 5. The phenomenon of granite core discing

5.2 Characteristics of Rock Disc and Data

The core conditions of the four groups were shown in Fig. 6. The cores of Test 1 and 2 was complete, with no scratches and cracks on the surface. Core discing occurred in both Test 3 and 4.

Figure 6. Cores of test 1-4

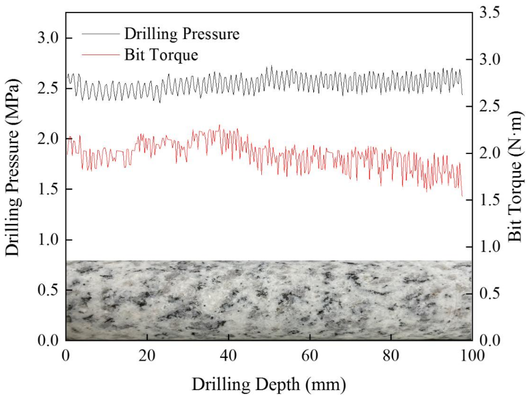

Figure 7. Drilling parameters and bit torque along with the core of test 1.

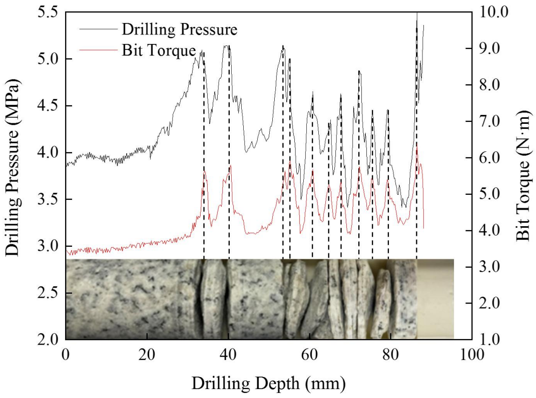

Figure 8. Drilling parameters and bit torque along with the core of test 3.

Drilling parameters are the concrete manifestation of the interaction between bit and rock, and the change of drilling parameters can reflect the situation at the bottom of the borehole. The cores from tests 1 and 3 were compared with drilling parameters as shown in Figs. 7 and 8. The drilling pressure and bit torque maintained the same fluctuation characteristics, and the positions of wave peaks basically coincided. It can be observed from Fig. 7 that the core surface of test 1 was complete without obvious defects, and the corresponding drilling parameter curve fluctuates steadily without obvious peaks and troughs. It can be seen from Fig. 8 that the drilling parameters corresponding to the complete core area in test 3 are relatively stable when the drilling depth is within 0-30 mm. It can be observed that the peaks of the drilling pressure and bit torque curve in the discing core area with the drilling depth greater than 30 mm roughly coincide with the position of the rock disc. Before core fracture, the curve rises, and the drilling pressure and bit torque increase.

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When the peak value is reached, the core breaks, and then the curve drops sharply, and the drilling pressure and bit torque decrease. The core continues to fracture, forming rock discs.

When the core is discing, the drilling pressure and bit torque will increase, the internal energy of the core will accumulate, and finally the core surface will be damaged or broken, the internal energy will be released, and the drilling parameters will decline again. It is worth noting that the core locations in Figs. 7 and 8 are recovered according to the drilling process. A considerable part of the rock disc is a thin slice with thick center and thin edge, or even broken rock debris that has been longitudinally fractured. Many rock discs have irregular edges. At the same time, many small particle rock cuttings are discharged with cooling water during drilling. The reduction of the core can only ensure that it is roughly the same as the actual situation. Therefore, the peaks of the drilling pressure and drill torque curves are roughly consistent with the position of the core section, which can explain the response of drilling parameters to the core discing phenomenon.

By comparing the results of test 1, test 2, test 3 and test 4, the following conclusions can be drawn: under low confining stress, when the drilling speed is high (15mm/min or 20mm/min), rock core discing phenomenon will occur, that is, high confining stress is not a necessary condition for rock core discing. The drilling parameters is an important factor that leads to core discing. Under high confining stress, when the drilling speed is low (5mm/min or 10mm/min), core discing will not occur. This means that when drilling in high stress area, the core discing rate can be reduced by reasonably controlling the drilling parameters. The drilling speed can be properly reduced at key sampling positions to obtain complete rock samples and data. The response relationship between rock disc and drilling parameters can also be used for core discing monitoring based on measure with drilling technology. When the drilling parameters fluctuate greatly, the integrity of the core can be ensured by adjusting the drilling parameters.

6. Discussion

The rock mass stress includes initial stress and induced stress. The initial stress refers to the stress in the rock mass without any disturbance. Induced stress is the stress caused by human disturbance or natural change. Although the definition of high and low geostress is aimed at the initial stress field, the high geostress phenomenon (core disc, rock burst, etc.) is almost related to engineering disturbance, which is inevitable whether it is drilling, exploratory tunnel excavation, large-scale excavation or mining. Engineering disturbance will cause 2-3 times of stress concentration [16]. When the drilling speed is 20mm/min, the peak drilling pressure is about 6 MPa, and the stress concentration factor is 3. Even if the confining stress is 0 MPa, the local stress near the bit can reach 18 MPa, which is close to the tensile strength of granite in this paper, 20MPa. Core disc is the result of the combination of geostress and engineering disturbance. This paper proves that the drilling speed during coring has a greater impact on core disc than the stress level.

7. Conclusion

Based on the classification criteria of high and low geostress and engineering phenomena, the stress conditions (initial discing stress about 30MPa) under which complete granite is prone to core dsicing are defined in this paper. Based on the initial discing stress of granite and the recommendations of geological core drilling procedures, four types of drilling tests with different stress levels and different drilling speeds are designed. Combined with literature investigation and laboratory drilling test results, the following conclusions are drawn:

(1) High geostress is not the main controlling factor for the occurrence of core discing, and the influence of drilling speed on discing is greater than geostress. In this paper, when the rotating speed is 600 RPM and the drilling speed is greater than 15mm/min, the core discing will also occur under low confining stress; under the condition of high stress, complete coring can be realized by

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controlling the drilling speed. Drilling operation in high stress area can improve core integrity by controlling drilling speed.

(2) There is a certain corresponding relationship between the discing phenomenon and the fluctuation of drilling parameters in the laboratory drilling test. The rock disc interface corresponds to the wave peaks of drilling pressure and bit torque. When the disc is about to occur, the drilling pressure and bit torque show an upward trend; when the core breaks and the rock disc forms, the drilling pressure and bit torque decrease.

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