Analysis of Shield Construction in Spherical Weathered Granite Development Area

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Abstract. The distribution of spherical weathered bodies (commonly known as "boulder") in the granite development area directly affects the shield construction of urban rail transit engineering. This paper is based on the case of shield construction of granite globular development area in Southern China area, the parameter control in shield machine selection and shield advancing during the shield tunneling in this special geological environment is analyzed. And it is suggested that shield machine should be selected for shield construction of granite spherical weathered zone. Driving speed, cutter torque, shield machine thrust, the amount of penetration and the speed of the cutter head of shield machine should be controlled when driving the boulder formation, in order to achieve smooth excavation and reduce the disturbance to the formation.

1. Introduction
Due to the randomness of the granite spherical weathered body (hereafter referred to as "boulder") distribution and the constraints of the survey method, it is inevitable that the shield tunneling meets the boulder. The shield construction encountered in the boulder, often resulting in serious tool wear, forced to frequently change the tool, the engineering cost is greatly increased. If the shield machine forced excavation, it will tend to increase the formation disturbance, aggravate the value of surface subsidence. Seriously, it may cause further engineering accidents, such as subsidence, collapse and so on. Many scholars and engineers have been concerned about a problem is that how to deal with the boulder in the construction.

Hongwei Huang and Zhuang Xie analyzed the risk of metro shield construction of the granite spherical weathered body, and put forward the control strategy [1, 2]. Leyuan Liu [3], Yuchun Li [4], Shujiang Yang [5], Heng Zhang [6], Xin Yang [7], Shifei Jin [8], Haiyong Ju [9] summarized the tunneling construction techniques of the shield machine through the granite spherical weathered body. Zhaorong He [10], Qian Li [11], Huisheng Guan [12], Yingjun Wang [13] analyzed and summarized the problems in boulder shield machine selection. Wei Huang [14], Ying Zhang [15] carried on the correlation analysis of shield tunneling parameters and geological parameters, as well as proposed a method for qualitative identification of geological features according to tunneling parameters. Qinjian Zhang [16] stressed that the synchronous grouting work must be done well during the boulder processing. Hua Wang [17] studied the correlation between cutting-tool wear degree and physical and mechanical indexes of rock, provided guidance for tool selection. Kezhi Song [18] introduced fuzzy
mathematics into the tunnel surrounding rock to provide the basis for the adjustment of shield tunneling parameters. Zhongsheng Tan [19] put forward the design idea of composite shields for the shield construction of soft-hard interphase strata of Guangzhou Metro Line 3, and studied the function and technical parameters of composite shields to analyze the adaptability of cutter-head, tool and geology. Babendererde [20] analyzed the causes of the wear of the shield in the complicated weathered granite composite formation. Shirlaw [21] summarized the complicated granite strata encountered by the various weathered layers during the construction of subways in Hong Kong and Singapore. It is believed that the shields are easily to dig in such complex formations, causing land subsidence and collapse.

From the current research results and engineering practice, when the duration is tight, there is no time to assist the construction of the boulder as well as no pipeline and pile foundation structure around the boulder section, the effect of deformation on the formation requirements construction is relatively low, we cannot carry out any auxiliary method and pass through directly by adjusting the parameters of shield tunneling.

After the shield cutter is close to the boulder, using low penetration and increasing foam injection volume, taking "small thrust, high speed, low torque, single edge hob" as the guiding ideology, so that the cutting and impacting frequency of boulders increases and it passes through the boulder area by the impact crushing of cutter-head. When using such method, it is necessary to strictly monitor the sudden changes in the attitude of the propulsion cylinder and the shield machine, as well as the changes of the soil pressure and the slag. If the abnormality is found, we need to judge whether there is a boulder and estimate the positional relationship between the boulder and the cutter-head. Try tunneling, if the tunneling process is not much affected, the boulder can be shielded directly broken and passed smoothly. Such method is suitable for dealing with a larger boulder, the contact surface of the boulder and the cutter-head is also larger.

Shield machine directly to get rid of boulders needs to meet two conditions: (1) Shield provides enough cutting force to break the rock. (2) In the process of boulder’s being broken by the tool, the surrounding soil cannot produce damage, that is, the boulder does not follow the rotation of the cutter-head and it will not be pushed forward. Therefore, the selection of shield machine and the control of driving parameters should be done well when adopting this method.

2. The selection of shield machine

From the selection of shield machine for granite boulders, the following factors should be considered:

(1) Shield machine can choose earth pressure balance shield or slurry balance shield. The earth pressure balance shield is easy to change tooling; using slurry shield. The slurry balance shield is easy to discharge boulder. At the same time, the reasonable type should be considered from the overall construction factors of technology and economy. Mudding-type earth pressure balance shield should use a screw conveyor row and hobs break large diameter boulders to 300 ~ 400mm.

(2) Compared to the spoke type, the cutter-head usually adopting the panel type is easier to use manual work to explode boulders.

(3) When the cutter-head is equipped with the hob, it needs appropriate hob spacing and hob number, including the front hob and edge hob. The hob cutter face should be higher than the scraper blade and tools should be easily replaced to be wear-resistant.

(4) The wear-resistant device is installed around the cutter-head, which should have enough stiffness and strength to maintain a suitable excavation outline, wear-resistant as well as not easy to break.

(5) The opening size of the cutter-head should be as large as possible on the basis of the whole opening rate so that the rock can be removed and discharged.

(6) The size of the screw conveyor or the sludge pipe should be adapted to the opening of the cutter-head, as well as using large openings as much as possible.

(7) Adding a boulder-breaking device in the soil, such as a hammer or a crushing fixture.
Fig. 1, Fig. 2 is the transformation of Dongguan city rapid rail transit line interval shield R2 for cutter-head of boulder. In addition to increasing the number of hobs, the aperture opening ratio will increase from 34% to 37%.

At present, most of the shield machines used in Guangzhou and Shenzhen subway sections are composite earth pressure balance shield machine. The cutter-head is equipped with 35 single bladed disc, 4 center double-edged sword, 64 cutter, 16 edge blade. The maximum thrust is 3412t, the breakout torque is 5300MNm, and the cutter-head opening rate is 24%, which can basically meet the shield machine in composite formation with boulders in tunneling.

![Practicality picture of shield cutter-head modified for cutting boulder](image1.jpg)

**Figure 1.** Practicality picture of shield cutter-head modified for cutting boulder

![Basic construction drawings of shield cutter-head modified for cutting boulder](image2.jpg)

**Figure 2.** Basic construction drawings of shield cutter-head modified for cutting boulder

3. Shield driving parameters control

The presence of spherical weathered granite body resulting in a large difference between the hardness of adjacent soils and shield tunneling shield construction process is extremely difficult. What’s more, it is easy to cause damage to the shield machine tool, which brings great inconvenience to the construction. Therefore, it is quite important to select the appropriate tunneling parameters according to the engineering geological conditions in the shield construction process. There is a certain correspondence between the excavation parameters and the engineering geological parameters and this relationship is studied to control the tunneling state of the shield machine to meet the safety, quality and economic requirements during the construction of the shield, and effectively controlling surface subsidence is of great importance.
Due to the slow tunneling speed, the unstable attitude of the shield and other reasons, the disturbance of the surrounding strata is great in the shield tunneling through the boulder stage. In order to reduce post-construction subsidence, synchronous grouting must be done well in the construction. The amount of grouting per cycle is generally 5～5.5m³. In addition, in order to ensure the safety of the ground building, the monitoring frequency of the building on the ground should be encrypted during the shield tunneling through boulder, which is generally 2 times a day. When the construction monitoring shows the land subsidence is abnormal, the secondary complement grouting in the tunnel should be carried out in time to stabilize the subsidence as early as possible. Cement slurry can be used as secondary grouting material, cement water ratio is 0.8~1. Grouting pressure cannot be too high, the control of the following 0.3MPa is usually appropriate.

There are 19 spherical weathered bodies in the left line of Shenzhen Metro Line 5 Minzhi to Wuhe interval. The earth pressure balance shield machine is used in the construction. From the distribution characteristics and the mechanical properties of the boulder, the tunneling parameters of shield machine crossing boulder are analyzed and achieved construction effect. Tab.1 is the main tunneling parameters statistics of shield cutter-head driven in boulders in Shenzhen metro Line 5 Minzhi to Wuhe interval and Fanshen to Lingzhi interval. Fig.3 is mean value curve of driving parameter with tunneling process in Shenzhen metro line 5 Minzhi to Wuhe interval.

According to the depth and geological conditions of the running tunnel, the control range of tunneling parameters for direct cutting of granite spherical weathered body by shield machine is as follows: the rotate speed of cutter-head is 1.1~1.6rpm, the torque of cutter-head is 0.9~2.3MN·m, total thrust is 10746~14322KN, tunneling speed is 15~45mm/min. The control range of excavation parameters in construction of granite spherical weathered body by hole crushing and backing construction method is as follows: the rotate speed of cutter-head is 1.2~1.7rpm, the torque of cutter-head is 1.4~2.8 MN·m, total thrust is 10172~13467 KN, tunneling speed is 22~54 mm/min.

| Project name                                | The uniaxial compressive strength of boulder | Excavation parameters of shield machine in boulders |
|----------------------------------------------|---------------------------------------------|---------------------------------------------------|
|                                             | MPa                                         | the rotate speed of cutter-head | torque of cutter-head | total thrust | tunneling speed |
|     |                                             | rpm | MN·m | KN     | mm/min      |                     |
| Shenzhen Metro Line 5 Minzhi - Wuhe interval | 150~180 | No pretreatment | 1.1~1.6 | 0.9~2.3 | 10746~14322 | 15~45              |
|                                             |                                             | Digging broken boulders | 1.2~1.7 | 1.4~2.8 | 10172~13467 | 22~54              |
| Shenzhen Metro Line 5 Fanshen - Lingzhi interval | 81.8~164.7 | Drilling and blasting boulders | 1.4~1.6 | 0.5~1.2 | 9000~11000 | 5~20               |
4. Conclusion

(1) According to the formation situation, the reasonable choice of shield machine, shield machine excavation capacity, cutter arrangement, the number and intensity of hobs should meet the requirements of shield tunneling. The Herranknet shield machine selected owing to Guangzhou metro line 3 existing boulders once resulted in slow tunneling speed and frequent tool change by following factors: the larger hob spacing, the fewer number of edge hob and the low strength of hob.

(2) When driving in boulder formation, the shield machine ought to control the speed of tunneling, the torque of the cutter-head, the thrust of the shield machine, the penetration and the rotate speed of the cutter-head, so as to achieve a smooth excavation and reduce the disturbance to the formation. Observe the abnormal situation of the shield machine and the abnormal changes of tunneling parameters (such as the sudden slowdown of speed, the sudden increase of thrust and torque, the vibration of the cutter-head, the noise of the shield machine and so on.) to determine whether the touch on the boulder.

(3) In Boulder formation excavation, the main destructional form of the shield machine is the tool ring broken and partial wear, the tool holder and the cutter-head deformation, etc. We should control the tunneling speed, the torque of the cutter-head, the penetration and the rotate speed of the cutter-head to reduce the tool ring broken and partial wear. Through controlling the thrust to reduce the deformation of the tool holder and cutter-head.

In conclusion, it is necessary to strengthen the pre-construction engineering survey and process well before encountered the boulder so as to reduce the probability of the boulder during shield tunneling. At the same time, targeted shield selection is to improve the flexibility between the shield machine and the boulder. Enhancing the probability of the direct broken boulder when it happens. Only when the above methods do not work, the corresponding boulder processing technology would be taken into consideration with the specific characteristics. However, such method often needs to pay a higher economic and construction costs, so it should be avoided as much as possible.

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