Research on the Technology of Boulder Treatment in Urban Metro Tunnel Construction

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Abstract. With the development of shield tunneling in urban metro shield technology is applied more and more in complex layer. Taking the construction of Shenzhen Metro Line 5 as an example, in this paper the formation mechanism and distribution law of isolated boulder is deep analyzed, the difficult and risk of shield tunneling in the boulder existing mix ground is discussed, and the main methods and measures for the breaking of the boulder during construction is introduced. Through comparing of eight treatment method for boulder, the advantage and disadvantage of various processing methods is proposed, therefore it could apply to different project.

1. Introduction
Underground solitary rock (spherical weathered rock) is one of the typical representatives of composite strata [1-3]. The small volume, the great difference from the strength of surrounding rock mass and most of them occur where rock mass are fully weathered to strongly weathered are its main characteristics [4, 5]. Generally, with the increase of elevation, spherical weathered body becomes denser and denser, the volume is smaller and smaller, but its spatial distribution still has great randomness. Because of the above characteristics of spherical weathered rock, it is not easy to be found by drilling, which easily affects shield construction. It will lead to greater uneven settlement of foundation that mistaking the solitary stone as footstone and bearing stratum [6, 7]. The existence of solitary stone will aggravate the inhomogeneity of stratum and the softening of the solitary stone after weathering will easily lead to soil erosion. At present, there are many successful engineering examples to deal with the solitary stones in China, including the treatment of the bottom of bridge pile (bored pile), the treatment of the bottom of building foundation and the treatment of the solitary stones in underground engineering. As far as tunnel engineering is concerned, most engineering examples adopt more traditional solitary stone treatment methods, such as manual drilling method, blasting method and cement expansion agent method. These methods are difficult to meet the requirements of efficient, economic and safe construction environment, especially in the construction conditions of poor surrounding rock and adjacent buildings. Through discussing the new technology of solitary stone treatment in the construction of soft and water-rich stratum tunnel in Shangmin Section of Shenzhen Metro Line 4 Phase II Project, i.e. hydraulic fracturing method, this paper studies the characteristics, hazards and treatment of solitary stone, and summarizes the research results of the construction technology about using hydraulic fracturing method to deal with solitary stone and shallow buried orphan stratum tunnel construction technology.
2. Project overview

The second phase of Shenzhen Metro Line 4 is 15.8 kilometers long. The tunnel between Shangmeilin Station and Minle Station runs through Meiao No. 8 Road and Danaoke Mountain, and is constructed by mining method. There are fracture faults at the foot of north side of the Danaoke Mountain. The mountain body on the west side of the line was built as a large quarry many years ago. In addition, the catchment area of the mountain body is large, and the construction section is rich in groundwater. In some places, there is a large amount of fresh water gushing out of boreholes (see Figure 1). The excavation height layers are mostly sand layers and clay layers, which easily become quicksand layers and soft clay layers, thus the mechanical parameters of tunnel surrounding rock are greatly reduced. which is not conducive to excavation support and stability of tunnel.

![Figure 1. Tunnel gushing](image1)

![Figure 2. Boulder in the field](image2)

In the weak and water-rich area, the geological conditions are so complex that it is difficult for construction of tunnel. During the construction of the tunnel, the left and right lines encounter larger granite boulder. It is found that the left line of boulder can reach 2.5m in width, 1.5m in height and 5m in length through drilling (as shown in Figure 2). Because the section cross the overpass group, explosive blasting is restricted. Therefore, the effective and safe treatment of boulder has become a major focus of the project.

3. The construction technology of hydraulic split method

3.1. Working principle and process

Hydraulic splitter is composed of cleavage gun, frame and hydraulic system, as shown in Figure 3 and Figure 4. Hydraulic splitter uses high pressure hydraulic oil as energy source. The hydraulic station of the splitter supplies pressure oil to the splitting gun. The cleavage gun can generate tens of tons of thrust with the wedge in the splitter at the end of the cleavage gun pushing wedge block to both sides and the expansion force can reach hundreds of tons. Using the principle of wedge splitting, huge rocks can be separated from the inside in a predetermined direction. Figure 5 and Figure 6 show the wedge block and wedge of the splitter at the end of the cleavage gun. As shown in the figure 3, the wedge connected with the piston of the hydraulic splitter does not directly split the rock, but when the splitter intrudes into the rock, the wedge block on both sides of the wedge produces a resultant force perpendicular to the wall of the hole, which causes the brittle rock to split longitudinally.

![Figure 3. The structure of cleavage gun](image3)

![Figure 4. Hydraulic splitter](image4)
The construction process of treating solitary stone by splitter is shown in Figure 7. The technical parameters of this construction using splitter to deal with boulder are shown in Table 1 below.

Table 1. Technical parameters of QL-P38 cleaver

| Parameters                        | Numerical value |
|-----------------------------------|-----------------|
| Maximum splitting force           | 480t            |
| Bottom hole diameter              | Φ42mm           |
| Minimum depth of bottom hole      | >500mm          |
| Working oil pressure              | 60MPa           |
| Tank capacity                     | 24L             |
| Working oil temperature           | 5~50℃           |
| Motor power                       | 4.0KW           |

3.2. Construction technology of hydraulic splitting machine

(1) Holes are drilled vertically every 1 m on the rock whose diameter depends on the size of the external diameter of the wedge block assembly of the hydraulic cleaver. The hole diameter during the field construction is 42mm. The hole depth is generally 10-15 cm deeper than the insertion length of the wedge block assembly. The depth of the hole is about 60-90 cm, and the hole spacing is 50 cm. The hole should be drilled perpendicular to the rock surface where it is located to ensure the efficiency of drilling. It is forbidden to drill oblique, shallow holes and in the position where the force is not good.

(2) Before starting the machine, we need to check whether the pressure oil amount reaches more than 2/3 of the vernier indication. When the oil level is less than 1/3 of the length of the liquid level gauge, the hydraulic oil must be added; the tubing must be straightened out to avoid it bending too large; the inclined surfaces of the wedge of the splitting gun are coated with high pressure grease. Two wedges are fastened well, and the wedges are not distorted and seamless so as to ensure that there is no impurities in the working face of the wedge block.

(3) Insert the splitter head into the hole and adjust the splitting direction properly. The wedge must inserted into the bottom of the head to avoid the wedge block breaking.
(4) Start the oil pump and Pay attention to the direction of motor operation (motor fan should run clockwise)
(5) Start the reversing valve of the oil station to let the pressure oil enter No.1 tubing (or No.2 tubing), pay attention to the oil inlet direction, feel the oil pressure by touching the oil inlet pipe, if the oil inlet direction is wrong, move the handle of the reversing valve of the oil station to the other end. Note: the oil inlet of the oil station must be connected to the oil inlet of the gun body (only No.1 position of the gun body is the oil inlet), as shown in Figure 8.

![Figure 8. The reversing valve of oil station and gun body](image)

(6) The wedge block of the splitter extends outward and the splitter begins to cleave when the handle of the reversing valve on the gun body turned to No.1 position. When the oil pressure reaches 60 MPa and the rock is not completely separated, the thicker wedge block can be used for secondary or tertiary separation. The type of wedge block is shown in Figure 9. It is forbidden to use the gun head as a crowbar.

(7) After the stone is split, the handle of the change-over valve is moved to the No.2 position, and the power head moves upward to return. The handle is moved to the middle position to unload oil and the gun body is extracted from the rock for the next splitting operation when the power head is recovered in place and the oil pressure rises.

3.3. **Key technology of hydraulic splitting method**

The direction of boulder cracking should be controlled in the treatment of large-scale boulder by hydraulic fracturing which usually depends on intensive drilling, but the dense drilling will lead to time-consuming, labor-consuming and poor economic [8]. If we make full use of the property that the compressive strength of rock is great but the tensile strength is small, we can cut grooves in the borehole so as to make it produce stress concentration, which can not only reduce the number of borehole, control the direction of cracking, improve the working efficiency but also reduce the production cost. It is found that the hole with groove is 20% less than that without groove through the experiment of splitting machine. In the experiment of expansion agent 10 through-holes with a spacing of 20cm must be drilled for marble without groove, and the spacing of holes with groove is 35-40mm, which saves labor and time by more than one third. The slot is shown in Figure 10.

![Figure 10. Slot in borehole](image)

![Figure 11. Drilling blasting of isolated boulder](image)
4. Other treatment methods of boulder

In addition to the above-mentioned hydraulic splitting method, there are other methods for the treatment of boulders, such as shield machine propulsion after grouting reinforcement, drilling and blasting of boulders, artificial excavation and breaking of boulders, punching pile crushing method, advance grouting of shield machine, shield propulsion, static blasting, direct propulsion of shield machine, etc. The following briefly describes the characteristics of several methods.

Drilling and blasting boulder: The small-diameter drill bit is used to drill down from the ground, and a blast hole is drilled on the boulder, then a proper amount of static explosive is placed in the hole for blasting, and finally the slag is removed. This method has short construction period and good adaptability to real estate. The structure of drilling hole in boulder blasting is shown in Figure 11.

Advance grouting of shield machine: This method can be applied to the situation where is no place for grouting reinforcement or shield tunneling in the stratum with better geological conditions. It can be applied to all kinds of boulders. During the construction, low penetration and high rotation speed are adopted to cut the boulder face, which passes through the boulder area by the impact breaking capacity of the cutter head. Grouting reinforcement for boulder is shown in Figure 12.

Ground grouting reinforcement: After confirming the boulder area, the sleeve valve pipe is used to reinforce the strata around the boulder in a certain range from the ground. After the slurry solidifies, the slurry tightly encloses the boulder. When the shield machine advances, the boulder is broken by the cutting action of the front of the cutter head, which will not cause large disturbance to the soil mass, and the shield posture is easy to control. Ground strengthening area is shown in Figure 13.

Static blasting: Carry out static blasting for boulders, big rocks and small rocks, and then move the small rocks from the front of the cutter head into the soil bin, which is discharged by the screw conveyor. This method does not reinforce the ground and also requires that after static blasting and handling of one meter Boulder the shield machine should immediately advance one meter and always ensure that the distance between the cutter head and the boulder is not more than one meter so as to prevent ground collapse caused by soil collapse.

Direct propulsion of shield machine: when the construction period is tight and there is no time to take auxiliary construction measures for the boulder, and there are no pipelines and pile foundation buildings around the boulder section, the requirements for the deformation of the stratum during the construction are relatively low, then no auxiliary construction method can be used. By adjusting the tunneling parameters of the shield machine, tunnel boring machine can be pushed directly.

5. Comparison to other methods

Different treatment methods of boulder have different characteristics and application situations. In engineering construction, cost construction risk, construction period, size of Boulder, impact on surrounding environment and other factors should be considered comprehensively which can seen from Table 2.
Table 2. Processing method for isolated boulder

| Method                        | Formation adaptability | Boulder size | Impact on environment | Construction risk | Effect | Construction period | Enclosure |
|-------------------------------|------------------------|--------------|-----------------------|-------------------|--------|---------------------|-----------|
| Ground grouting reinforcement | poor                   | all          | small                  | small             | moderate | short               | Yes       |
| Borehole blasting             | better                 | smaller      | small                  | small             | well    | short               | Yes       |
| Manual hole digging           | well                   | bigger       | moderate               | moderate          | well    | long                | Yes       |
| Punching and crushing         | better                 | bigger       | large                  | small             | well    | long                | Yes       |
| Advance grouting of shield machine | better          | all          | small                  | moderate          | poor    | short               | No        |
| Static blasting               | well                   | smaller      | small                  | big               | moderate | moderate           | No        |
| Hydraulic split method       | better                 | smaller      | small                  | big               | well    | moderate            | No        |
| Direct advance of shield      | better                 | bigger       | large                  | big               | little  | short               | No        |

Table 3 shows the comparison between the construction characteristics of the hydraulic fracturing machine and the traditional method. It is not difficult to see that the hydraulic fracturing machine has unique advantages in the tunnel construction. It has no vibration, impact, noise and dust during the construction, and can complete the splitting in a few seconds. Compared with the traditional method, the hydraulic fracturing machine has the following main characteristics in the treatment of boulders: Compared with the traditional method in tunnel construction, the hydraulic splitting method has the following main characteristics.

Table 3. Comparison with the traditional method

| Method                        | construction characteristics |
|-------------------------------|-------------------------------|
| Manual drilling               | It will take at least 16 hours to break a 20 m³ boulder manually, and it is very difficult to split, slow in speed, high in labor intensity and slow in progress. |
| blasting                      | The secondary blasting of large rocks is of great danger, high potential safety hazard, frequent casualties, environmental pollution, waste of resources and other problems. Besides, there are many tunnels passing through busy downtown areas or surrounding residential areas, important structures, etc. blasting with explosives is not allowed at all. Blasting is not suitable for large and medium-sized boulder and dangerous rock in loose and broken, joint developed, thick weathered layer or near fault fracture zone, loose and unevenly weathered residual layer, large and medium-sized boulder and dangerous rock near slope deposit and large and medium-sized boulder and dangerous rock in rock pile section. |
| Cement expansion agent method | Large amount of hole drilling. At least 500 holes need to be drilled for a 20m³ rock, and secondary holes are often needed after one expansion split. The construction efficiency is low, but the cost is high. Moreover, the process of expansion and split is long, which seriously affects the construction progress. |
| Splitter method               | The drilling machine is used in combination with the splitting machine. The splitting time is short. It only takes 2-3 minutes for 1 m³ of boulder to be broken, and the construction cost is only 1% of that of the splitting method of cement expansion agent. It is very suitable for the treatment of local boulders with narrow working space in the tunnel because of its small volume and light weight. |

Safety: splitter is controllable under the static hydraulic environment. It will not produce some hidden dangers like the blasting machine and other percussive demolition and drilling equipment.

Environmental protection: It will not produce vibration, impact, noise, dust, flying debris etc and the surrounding environment will not be affected when the splitter is working.
Economy: the machine can complete the splitting process in seconds, and can work continuously without interruption, with high efficiency and low operation and maintenance costs. It does not need isolation or other time-consuming and expensive measures like blasting operation.

Accuracy: differing from most of the traditional demolition methods and equipment this machine can accurately determine the splitting direction, shape and size in advance.

Applicability: the usage of the machine is simple and easy to learn. It only needs a single person to operate and is very convenient to carry. It is convenient to maintain and have a long service life.

High efficiency: the drilling speed can reach 1 meter per minute by using the hydraulic drill gun whose efficiency is 3 to 5 times that of the ordinary air drill with low energy consumption that is only one third of that of the air drill. Its cost is the lowest of all mining methods at present.

6. Conclusion
Because of the difference between the compressive strength of rock and its tensile strength and shear strength (that is, the compressive strength of most rock is far greater than its tensile strength and shear strength, and the ratio is about 10:1) we can find a time-saving and labor-saving way that Using a splitter to split the rock from the inside of rock, In this project, the hydraulic splitting machine is used to break the boulders, which overcomes the difficulties in tunnel construction and ensures the progress of the construction schedule. Hydraulic splitting machine is an extremely efficient rock breaking means in mining engineering, tunnel excavation and building demolition engineering, the best choice of static blasting and an ideal equipment that can replace secondary blasting and manual disintegration. It has a broad development prospect.

7. References
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