ABSTRACT: The completely decomposed granite formation features looseness, low strength, poor self-stability and high disintegration exposed to water. It can easily cause geological disasters such as water inrush and mud gush during tunnel construction and seducing secondary disasters especially in the strongly disturbed regions. The specific full-section curtain grouting is proposed to deal with the strongly disturbed and completely decomposed granite formation. The meticulous exploration which combined the geological exploration holes and transient electromagnetic is adopted to detect the hydrogeology conditions and the main water supply channel in the strongly disturbed region. Based on the control principles of grouting amount and pressure as well as the selecting principles of grouting material, we applies the multistage casing segregation technique to reinforce the strongly disturbed region. This achievement performed well in the treatment of water inrush and mud gush in the construction of Junchang tunnel in Guangxi province, and realized safe excavation of the right tunnel which is located in the strongly disturbed region. Also it can provide model significance to the similar constructions.

Keywords: completely decomposed granite formation; strongly disturbed area; meticulous exploration; controlling principle of grouting amount and pressure; multistage casing segregation technique

1 INTRODUCTION

Granite has wide distribution in the South China. The weathering of the rock mass is very serious due to the hot and humid climate and this situation makes the granite formation low in strength and weak in stability [1-2]. With the focus of transportation infrastructure in China gradually shifting to the central and western mountainous areas, more tunnels have been built in completely decomposed granite formation, which causes frequent occurrence of the geological hazards such as water inrush and mud bursting. Affected by strong disturbance of geological disasters, it makes the porosity higher, the rock mass looser and the self-stability worse, which bring difficulties to the reconstruction after the disaster. What’s worse, it may induce the occurrence of the secondary disaster, which could prolong the construction period and huge loss of life and property.

To solve the problems of tunnel construction in the strongly disturbed and completely decomposed granite formation, scholars did many researches on the characteristics of the weathered granite such as the structural composition, mechanical properties and so on. Y.J Shang et.al [7] adopted mercury injection test, grain size analysis and X-ray diffraction (XRD) to study the pore size distribution, particle composition, mineral composition and the correlation of the indices. Irfan, T.Y. et.al [8] used the quick absorption, Schmidt hammer and point load strength tests on seven stages of weathering granite material, and summarized the quantitative weathering index to determinate the weathering stages of rock material. Y.F Shi et.al [9] proposed a combination of sub- horizontal jet-grouted columns and pipe roof to reinforce weak ground before Jiangmen tunnel passed beneath a spillway for drainage of Yu-long Reservoir. Additionally, the numerical simulation was adopted to reduce the stress of the ground settlement and strength the stability of the excavation. These studies mainly focus on the struc-
tural and mechanical properties of the weathering granite based on laboratory tests, while the researches on the engineering properties of the weathered granite and solutions to the water disaster is rare, and this situation fails to satisfy the need of disaster prevention in underground construction. J.S. Wang et al. [10] developed the technology of single-pipe retrograde grouting in the tunnel construction, which provided a better solution to the borehole collapse caused by the completely decomposed granite formation being exposed to water. S.Y. Wang [11] et al implemented laboratory and site test to study the pressure-controlled cavity expansion in completely decomposed granite soil of Hong Kong, and the results presented the correlations between the various controlling parameters such as the injection pressure and the void ratio, and also provided a basis for the compaction grouting used in the treatment of water disaster in underground construction. But there are few researches considering the pertinence treatment to the strongly disturbed weathering granite formation and the key controlling principles and techniques need further exploration.

This paper is about the curtain grouting treatment of the strongly disturbed and completely decomposed granite formation after the geological disaster in Junchang tunnel in Guangxi Province, China. Combined with the borehole method and transient electromagnetic, a meticulous exploration was implemented to detect the hydrogeology conditions in the strongly disturbed area [14]. Based on the controlling principles of grouting amount and pressure and the selection principles of the grouting material, the multistage casing segregation technique was applied to reinforce the strongly disturbed area after the disaster with targeted grouting. Additionally, the key technique of controlling grouting has been developed in this paper. The research results performed well in disaster treatment of the tunnel construction, realizing a safe excavation in the strongly disturbed area.

2.1 Engineering geology analysis

Junchang tunnel with the design length of 4.3 km is the important part of the expressway from Cenxi City to Shuiwen City, in Guangxi Province, China. Because of complex geological conditions, the tunnel becomes the key project in the construction of the expressway. Since the tunnel construction started in April, 2011, the water inrush and mud gush with large scale occurred several times and slowed down the construction progress (see Figure 1). Water inrush and mud gush caused the surface subsidence and the houses cracking in the village above the tunnel (See Figure 2). Until September, 2015, 152 m of the right tunnel and 141 m of the left tunnel were still not got through yet. Due to this situation, the curtain grouting was divided into several cycles. In this paper, the full-face curtain grouting of the first cycle from CK7+820 to CK7+857 in the right tunnel was selected for study.

Figure 1. Water inrush and mud gush of the right tunnel.

Figure 2. Surface subsidence above the Junchang tunnel.

The Junchang tunnel is surrounded by mountains which form a miniature basin, and the precipitation in rain season is pretty large in the construction area. The surrounding rock of tunnel site is completely decomposed granite. The tunnel is located among multiple synclines, folds and faults where the rock joints and cracks are well developed. The water inrush and mud gush with large scale occurred twice in the right tunnel in 2013 and 2015, and the location where the geological hazards occurred (CK7+835 and CK7+838) was just in the treatment section (CK7+820 ~ CK7+857). Affected by the disturbance of geological disasters, the formation of the treatment section features looseness and poor self-stability. Even worse, a backfilled region filled with gravel and sand bags existed. The drilled crushed stones were shown in Figure 3. The porosity of the backfilled region is high, and the water-abundance is good. The boreholes made by the drilling are easy to collapse which brings more difficulties to the grouting of the area backfilled with sand, thus making the curtain grouting treatment more tough.
2.2 Meticulous exploration

To master the hydrogeology conditions of the completely decomposed granite formation and backfilled region in front of the tunnel face, the boreholes of curtain grouting in the first order were selected for exploration and grouting and also the meticulous exploration needed to be combined with transient electromagnetic method. The distribution diagram of backfilled region is shown in Figure 4.

The geological information obtained by the first order holes for exploration and grouting were utilized to explore the hydrogeology conditions in front of the tunnel face. As shown in Figure 5, we designed 32 first order holes and they covered the whole region of the reinforced grouting circle which is 10 m in front of the tunnel face. The geological information of the borehole showed that the backfill (stone and sand) existed from CK7+823 to CK7+838 (15 m) inside the excavation contour. The backfilled body is weak, loose and poorly cemented, and the range of the loose and weak region almost accords with the distribution diagram (See Figure 4). The centralized water-rich area exploited by grouting holes mainly lied on the left and bottom of the tunnel, which has the characteristics of high water pressure, large inflow of water and sand concentration.

To explore the hydrogeology conditions in front of the tunnel face more accurately, we implemented transient electromagnetic exploration. The apparent resistivity contour map of the right tunnel in horizontal plane is shown in Figure 6. The left side 20 m in front of the middle image appears low-resistant anomalous body and it’s speculated to be connected with the low-resistant body which is spotted on the left image. The whole low-resistant region is suspected to be a large-scale water-bearing zone and it’s the red circle in Figure 6. More than that, the position 28 m in front of the tunnel face appears a large fracturing zone and it shows that a regional water storage zone exists in the position 20 m to 30 m in front of the right image and the water quantity seems to be getting larger from the position 35 m in front of the right image.

The first order boreholes for exploration and grouting holes and transient electromagnetic was utilized to perform a comprehensive analysis of the hydrogeology conditions in front of tunnel face in the right tunnel. The water-bearing area was mainly on the left side and bottom of the tunnel. The three-dimensional diagram is shown in Figure 7.
3 FULL CURTAIN GROUTING TREATMENT

3.1 Grouting scheme design

According to exploration results of right tunnel face in the first cycle section of Junchang tunnel, the full-section curtain grouting method is adopted. The curtain reinforcement cycle is 10m thick. The strengthened section is 37m long, and it’s composed of three sections which are CK7+820-CK7+833, CK7+833-CK7+845 and CK7+845-CK7+857. The advancing segmented grouting technique is adopted. The curtain grouting scheme designed 105 boreholes and the construction was in three steps. The first order boreholes were mainly used for the initial exploration, and the second and third order boreholes were mainly used for grouting and inspection respectively. The distribution of the boreholes and the strengthened circle are as shown in Figure 5 and Figure 8.

3.2 Grouting principle

To ensure the grouting efficiency, the control principles of grouting amount and pressure and the selection principles of the grouting materials are adopted in the first cycle of the disaster treatment of the right tunnel face.

Single cement slurry, cement-sodium silicate mixed grout (C-S) and cement-GT [15] mixed grout (C-GT) are selected for the grouting materials. The GT material was developed by Shandong University with the characteristics of high early-strength and controllable coagulation time. The density of single cement slurry is about 1.5 g/cm³. The volume ratio of the mixed grout should be in 1:1-5:1(C: S or C: GT). As the strongly disturbed and completely decomposed granite formation is very loose and easy to be broken, it needs to strictly control the grouting pressure to ensure the safety of preventing-grout wall and primary support behind the working face. The controlling standards of the grouting pressure are shown in Table 1.

<table>
<thead>
<tr>
<th>Grouting section</th>
<th>Pressure</th>
</tr>
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<tbody>
<tr>
<td>0–10m</td>
<td>≤2.5Mpa</td>
</tr>
<tr>
<td>10–15m</td>
<td>≤3.5Mpa</td>
</tr>
<tr>
<td>&gt;15m</td>
<td>≤4.5Mpa</td>
</tr>
</tbody>
</table>

The geological conditions of strongly disturbed and completely decomposed granite formation are extremely complicated, and the connectivity of the disturbed region cannot be explored. The single cement slurry is easy to spread out the reinforcement area along the main flow channel, which made it hard to strengthen the grouting pressure. To ensure effective filling of the disturbed backfilled region, it needs to replace the single cement slurry to the mixed grout if the grouting pressure of the single cement slurry fails to reach the requested pressure within 48h.

Based on the controlling principles of the grouting amount and pressure and the selection principles of the grouting materials, it can not only guarantee the effective filling of the strongly disturbed and unconsolidated formation, but also avoid grout waste and grout diffusion to the invalid area.

3.3 Multistage casing segregation technique

As the completely decomposed granite formation is loose and highly fractured, long-distance gymnostomous grouting is very difficult. The loss of the grout and pressure makes it hard to reinforce the key positions like the vault, especially the strongly disturbed region and the backfilled section and cannot ensure the reinforcement quality of the loose surrounding rock. Also it leaves potential dangers to the following construction.

To solve the above problems, we proposed the multistage casing segregation technique. In the
long-distance grouting, we first filled and reinforced the shallow rock and then applied secondary casing (or three-level casing) to perform targeted grouting to the deep rock on the top of the vault. The selection of multistage casing adopts the gradual decline principle. The primary casing chose the seamless geological steel pipe with the diameter of 146mm, the secondary casing with 127mm and the three-level casing with 108mm. All casings are shown in Figure 9. Multistage casing segregation technique is mainly on the multistage casings and supported by the grouting vein formed by grout filling and diffusion, thus forming a double reinforcement to the broken rock in the vault. Therefore, the safety of the following construction can be ensured. Based on the conditions of the backfilled region in the first cycle section, the boreholes used to drill through the backfilled region and reinforce the vault of the tunnel are selected to perform multistage casing (as shown in Figure 10).

With the study of the surrounding rock in the tunnel excavation, it was found that the grouting materials penetrated into the formation, especially backfilled region with high porosity. Also, under high grouting pressure, the grouting materials could press the loose formation and strengthen the density of the rock mass, thus reinforcing the surrounding rock. During the excavation, the main grout vein formed in the loose and weak region and main water channels were wide and thick, and they were spread throughout the whole tunnel face. It played a supportive role as the main framework. The secondary grout vein was relatively narrow in width and developed from the branches of main grout vein, and it also spread the whole tunnel face to improve the integrity of the surrounding rock. The surrounding rock above the backfilled region reinforced by the multistage casing segregation technique was hard and compact, and the problems of large deformation and seepage didn't appear during the excavation, which proved that the surrounding rock had good stability and integrity after the grouting treatment.

The surrounding rock of tunnel face in the excavation was dry, compact and strong in self-stable ability. The deformation of broken rock mass caused by excavation disturbance significantly decreased, and it finally realized the effective control of the water in-rush and mud gush in the strongly disturbed and completely decomposed granite formation. The surrounding rock and grout vein are as shown in Figure 11.

4 EXCAVATION EXAMINATION

The boreholes used in the first circle full-curtain grouting of the right tunnel totalled 105 and all kinds of grouting materials were more than 6400m³. During the excavation, the boreholes were used to keep better track of the hydrogeology conditions and guide the construction. In addition, it was argued that the surrounding rocks should to be disturbed to minimum extent and for the casings and steel bars buried in the rock mass, we applied gas cutting rather than forcible pulling by the machines, and thus it would not develop a penetrating channel within the excavation contour. With various effective technical measures, the right tunnel in the first cycle realized safe excavation from CK7+820 to CK7+840.
5 CONCLUSION

(1) The strongly disturbed and completely decomposed granite formation features looseness, low strength, poor self-stability, and strong water storage capacity and transmission ability. The meticulous exploration which combined the geological exploration holes and transient electromagnetic was adopted to master the hydrogeology conditions in front of the tunnel face, which provided reliable guidance for plan for the grouting and the tunnel construction.

(2) The full curtain grouting is attributed with strong reinforcement ability, excellence in water plugging and high safety. During the grouting treatment, the control principles of the grouting amount and pressure and the selection principles of the grouting materials were adopted to ensure the grouting effect.

(3) The multistage casing segregation technique was applied to reinforce the strongly disturbed and completely decomposed granite formation after the disaster with targeted grouting, and it ensured the grouting effect in the key areas. The safe excavation through comprehensive use of various techniques in this paper has strong reference to the similar engineering.

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