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Alteration characteristics of granite contact zone and treatment measures for inrush hazards during tunnel construction – A case study

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ABSTRACT

Several large-scale mud and water inrush events occurred during excavation of the Denghuazhai Tunnel at a depth of 175 m in the contact zone between geodic granite and tuff. By analyzing the inrush process, the characteristics of the inrush hazards, such as high pressure, abundant water, high mud and sand content and strong destructive power, were revealed. In addition, the inrush hazards were intermittent, uncertain and sudden. An intrusive contact zone between geodic granite and tuff was revealed by regional geological investigation. Large-scale alteration occurred both in geodic granite and tuff near the contact zone. Petrographic analyses indicated that alteration to albite, sericite and kaolinite occurred in geodic granite, and alteration to quartz and montmorillonite took place in tuff gradually toward the contact zone. Furthermore, the changes were gradational within and between various alteration grades. The closer to the contact zone, the higher degree of alteration, the less the primary minerals including quartz, K-feldspar and plagioclase, the more the secondary minerals such as sericite and clay minerals. Tests on porosity, saturated water content and uniaxial compressive strength indicated that alteration led to significant deterioration of physical and mechanical properties of rocks (except for silicified tuff). Especially, for the zonal clay in the central area of contact zone, the physical and mechanical properties were poor and obvious swelling, disintegration and argillation were observed. Tunnel excavation triggered swelling, disintegration and argillation of clay, leading to several large-scale inrush events. In terms of treatment of inrush hazards, first of all, a comprehensive exploration method based on petrographic analyses, geophysical detection and borehole drilling was established according to the alteration characteristics, so as to identify the scale and composition of the altered zone. The principle of “consolidation before removal” was adopted to deal with the inrush deposits for breach sealing and reinforcement. Energy release and stress reduction during tunnel construction and regular drainage during operation were achieved by dewatering measures, namely, “drainage supplemented by sealing, water drainage and solids remaining”. Reinforcement measures, including full-face curtain grouting and double-layer pipe sheds, were adopted to reinforce and seal the highly disturbed rock and soil in advance. Finally, technical measures, including “bench excavation, enhancement of support stiffness and timely installation of secondary support”, were employed to effectively prevent large deformation in disturbed rock masses. With the above measures, the left and right tunnels of the Denghuozhai Tunnel have passed through the altered zone successfully.

1. Introduction

For mountain tunnels constructed in soluble rocks (such as limestone, dolomite etc.), when the water conducting passages are disturbed or exposed due to excavation, water inrush and mud outburst or other hazards are likely to be triggered. Many accidents during tunnel construction were reported in the past years, such as the Solan Tunnel (Song et al., 2012), the Sanyang Tunnel (Zhang et al., 2014), the Xiangshan Tunnel (Zhang et al., 2016), the Yesanguan Tunnel (Li et al., 2015) and the Malujing Tunnel (Li et al., 2017). However, water inrush and mud outburst in tunnels excavated in non-soluble rocks have seldom been reported, and even less for tunnels in granite. Compared to tunnels located in soluble rocks, water inrush and mud outburst in non-soluble rock stratum usually occurred in the tectonic fractured zones (Zhang et al., 2012; Lin and Lee, 2009), deep weathered troughs (Tseng et al., 2001; Goel et al., 1995) and the interfaces of different strata

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(Dalgic, 2002; Zhang et al., 2011; Zhang et al., 2017). The composition of inrush materials is significantly different, compared to soluble rocks. The solid components of inrush materials in non-soluble rocks mainly consist of rubbles and gravels with a small amount of water and the content of fine mud and sand particles are generally high. The inrush event in non-soluble rocks is usually sudden and the exact location can hardly be identified. Its scale and properties can hardly be predicted. It is usually highly destructive and results in severe damage. Meanwhile, the inrush hazards usually lead to instability of surrounding rock masses, tunnel clogging, inundation of equipment, tunnel abandonment and human death or casualties, and eventually result in great economic loss and delayed project schedule.

Recently, more tunnels need to pass through highly-stressed water-rich fractured zones or altered zones in granite and sandstone. Water inrush and mud outburst has gradually become the bottleneck restricting safe construction of mountain tunnels (Wang et al., 2011; Zhang et al., 2014). Understanding the rocks alteration characteristics near the contact zone and accurately forecasting the scale and properties of adverse geological structures are considered as the effective means for identifying the potential mud outburst and water inrush risks. Comprehensive advanced reinforcement measures, proper excavation methods and support measures are the effective measures for avoiding and dealing with water and mud inrush hazards.

At present, most engineering practices and researches on mud outburst and water inrush hazards focused on soluble rocks (Parise et al., 2008). There is a lack of systematic studies on the treatment measures for inrush hazards in granite tunnels. Taking the mud outburst and water inrush hazards in the Denghuozhai Tunnel as case studies, this study presents the alteration characteristics, exploration techniques and treatment measures in granite tunnels.

2. The Denghuozhai Tunnel

The Denghuozhai Tunnel is located in Zhangzhou, Fujian Province, China, as shown in Fig. 1. It is a six-lane separate dual tunnel of the Xiamen-Zhangzhou Highway. The left and right tunnels are 3372 m and 3390 m long, respectively, with a maximum cross-sectional area of 170 m^2. Several large-scale water and mud inrush events occurred in the right tunnel during excavation in the altered zone.

Three water and mud inrush events occurred when the Denghuozhai Tunnel passed through the altered zone at a depth of 175 m. The first one took place on 7 May 2012 after the upper bench of the right tunnel was excavated to Sta. YK22 + 136. Fragmented granite blocks filled with soft sandy soil were exposed at the left side of the working face. The fractured rock masses were loose, in a soft plastic state, had a low strength and can be easily broken by hand. At the same time, groundwater seeped out in streams from the fissures and loose soil. When the primary shotcrete was sprayed, collapses suddenly occurred in the left hance of the upper tunnel section and the mixture of water and mud rapidly gushed out. The amount of water inrush was about 1500 m^3 and the volume of the inrush deposits was about 450 m^3. The inrush deposits mainly consisted of mud and sand, with some gravels; the mud accounted for about 35–45% of the total volume and the sand, with sizes ranging between 3 and 10 mm, accounted for about 55–65%. The rate of groundwater inflow generally remained at 250 m^3/h. The mud and sand deposits caused by the first inrush and the shape of the accumulated inrush deposits are shown in Fig. 2a and e, respectively.

At 9 am, 8 May 2012, the second mud and sand gushing event occurred at the left hance. The inrush materials suddenly gushed out in a form of mudslide with a volume of about 1800 m^3. The whole upper bench was inundated and the excavation frame (about 3500 kg) on the

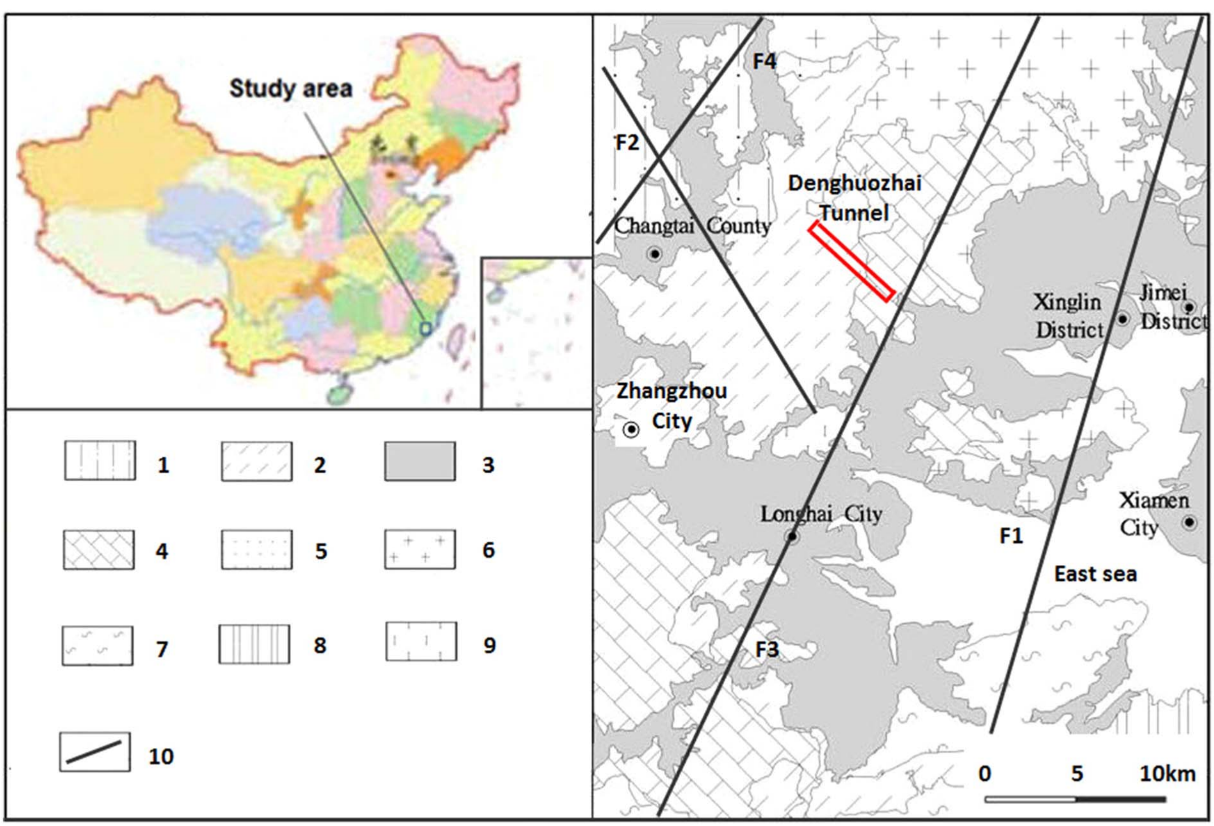

Fig. 1. Simplified geological map of study area.
a) The mud and sand deposits caused by first inrush. b) The second mud and sand inrush, the breach of inrush and destroyed primary support structure. c) The third mud and sand inrush, the buried equipment and the destroyed secondary lining trolley, d) the surface collapse pit. e) The sketch of the shape of accumulated deposits.

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