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On the mechanism of inrush hazards when Denghuozhai Tunnel passing through granite contact zone

Guo-Hua Zhang[a], Yu-Yong Jiao[b,*], Hao Wang[a], Yi Cheng[b], Li-Biao Chen[c]

[a] State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China
[b] Faculty of Engineering, China University of Geosciences, Wuhan 430074, China
[c] Fujian Provincial Expressway Construction Directorate, Fuzhou, Fujian 350001, China

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ABSTRACT

Triggered by excavation or blasting, the underground water and debris may rush into tunnel like a mudflow, which is the essence of inrush hazards in tunnels. Three conditions are indispensible for the occurrence of inrush hazards, namely, material, space and triggering conditions. This paper introduces the inrush hazards of the Denghuozhai Tunnel, and analyses the mechanism of inrush hazards from aspects of material and space conditions. Studies on the lithofacies, minerals and alteration characteristics reveal that the inrush hazards occurred in the contact zone between geodetic granite and tuff. The types and evolution of the altered rocks are identified which indicates an intrusion of volatile-rich magma into the wall rocks at shallow depth under tensile tectonic environment. Albitized, sericitized and clayinitized alteration thus occurred near the contact zone, leading to the formation of tens of meters wide, loose and deeply-buried soft mineral belts, such as sericite, kaolinite and montorillonite, etc. These altered weak zones provide the materials and space for inrush hazards. It is found from the physical, mechanical and hydrological experiments that a high degree of alteration causes swelling, disintegration and argillization of rock and soil, and thus weakens physical and mechanical properties of rocks. This weakening further lowers the triggering threshold of inrush hazards. Therefore, when tunnel excavation approached the altered weak zone, as the weak zone was not identified and no measures were taken to avoid the accidents, inrush hazards were triggered due to excavation disturbance, stress redistribution, blasting vibrations and groundwater drainage. The experiences from these successful cases will be a valuable references and experiences in the design and construction of similar engineering in the future.

1. Introduction

Igneous rocks, such as granite and tuff, are usually hard and considered to be good surrounding rocks for underground construction. Engineering geological problems in igneous rocks, such as collapses and water inrush usually occur in the tectonic zone, fractured zone, water-rich zone and highly weathered zone (Goela et al., 1995; Dalgic, 2002; Zhang et al., 2014). The large-scale mud inrush in altered zones has seldom reported. A number of inrush events occurred in the Denghuozhai Tunnel at depth of 175 m. In order to analyse the corresponding mechanism, the sources where the great amount of loose mud and sand came from, and how the smooth inrush channels were formed have to be investigated.

The alteration process is usually accompanied by occurrence of a great amount of mineral resources. A number of studies related to alteration have been conducted in ore deposit geology. However, clayinization due to the alteration process and strength weakening of altered rocks are often neglected (Komine and Ogata, 2004; Yoshida et al., 2009), which often results in engineering geological problems. For instance, one of the reasons contributing to the well-known Malpasset arch dam break is sliding along the sericite-altered shale in gneiss in the left abutment (Londe, 1987). A large-scale seepage event in the EI cajon dam in Honduras took place along the clayinized alteration zone and altered calcite (Satoh et al., 2005). Rock strength deterioration and slope instability occurred due to kaolinitized alteration in Wheal Martyn chin clay pit (Coggan et al., 2013; Stead et al., 2000).

Based on inrush hazards in the Denghuozhai Tunnel, in-depth discussions are conducted in this paper on three aspects: the evolution of altered rock, the characteristics of argillized zone and the mechanism of inrush hazard. The analysis and conclusion will serve as an important reference for the prediction and treatment of inrush hazards in areas with similar engineering geological conditions.

* Corresponding author.
E-mail address: yyjiao@cug.edu.cn (Y.-Y. Jiao).

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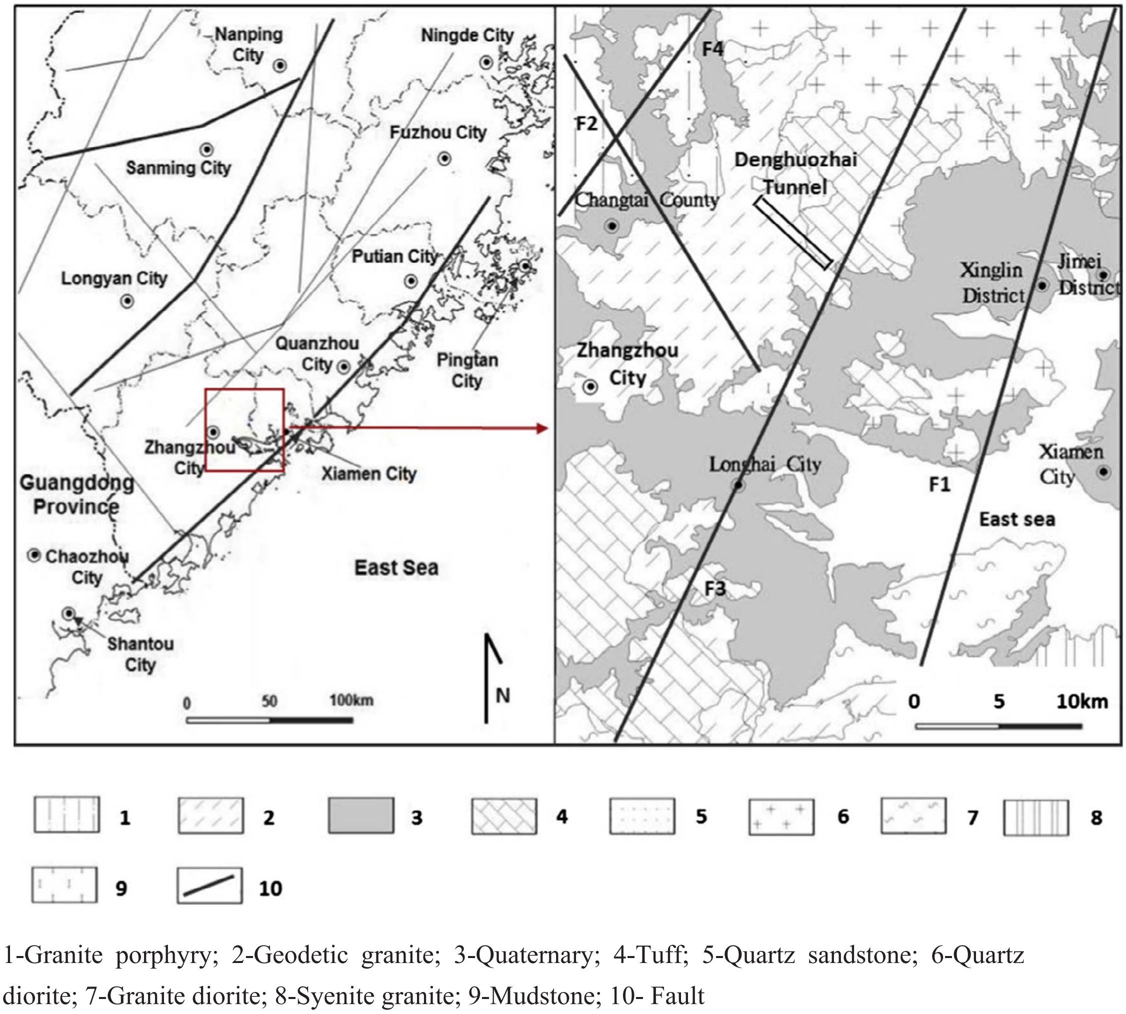

Fig. 1. Simplified geological map of study area. 1 – Granite porphyry; 2 – Geodetic granite; 3 – Quaternary; 4 – Tuff; 5 – Quartz sandstone; 6 – Quartz diorite; 7 – Granite diorite; 8 – Syenite granite; 9 – Mudstone; 10 – Fault.

2. Cases of inrush hazards

The Denghuozhai tunnel is located in Zhangzhou, Fujian Province, China, as shown in Fig. 1. This tunnel 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 during excavation in the granite contact zones.

Three inrush events occurred when the Denghuozhai Tunnel passed through the granite contact zone at a depth of 175 m. The first one took place on 7 May 2012, 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 around 450 m^3 in this phase. The inrush deposits mainly consisted of mud and sand, with some occasional gravels; the mud accounted for about 35–45% of the total volume, and the sand accounted for about 55–65% with grain sizes ranging between 0.3 and 1.0 cm. The inrush deposits are shown in Fig. 2a.

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 3.5 t) on the bench was pushed away by 15 m. The composition of the inrush materials was similar to the first inrush event, i.e., dominantly mud and sand. The photo of the inrush deposits is shown in Fig. 2b.

At 11 pm, 13 May 2012, a violent sound of collapse was heard ahead of the working face, followed by gushing of a great amount of water and mud. About 20 min later, approximately 100 m of the tunnel was fully filled by the inrush deposits and 60 m was half-filled. The huge force pushed the support frame toward the tunnel entrance by about 100 m. The photo is shown in Fig. 2c. The total volume of inrush deposits reached 24,000 m^3 and the amount of water inrush was approximately 35,000 m^3. The composition of the inrush materials was similar to the previous two inrush events, which were dominantly mud and sand. However, the content of rock fragments and gravels was significantly higher and occasionally rock blocks with diameter of 1–1.5 m were observed. After the water and mud inrush event, the groundwater inflow along the inrush channel remained at 300 m^3/h. The inrush event led to surface collapse above the tunnel. The collapse pit was nearly circular, with a diameter of about 26 m and a depth of about 15 m, positioning survey indicated that the collapse pit was located right above the cavity or breach caused by the inrush. The shape of inrush deposits is shown in Fig. 2d.

3. Conditions triggered inrush hazards

3.1. Three essences

The essence of inrush hazards in tunnels is that water and debris in the adverse geological bodies are triggered by excavation and blasting and flow into the tunnel like mudflow. Three conditions must be