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Tunneling induced geohazards in mylonitic rock faults with rich groundwater: A case study in Guangzhou

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ABSTRACT

This paper presents a case history of geological hazards and treatment measures during the shield tunneling of Metro Line No. 7, in water-rich mylonitic faults in Guangzhou, China. The site selection of Metro Line No. 7 is introduced based on the land use and the geology in Guangzhou. Metro Line No. 7 passes through a number of dead faults, which are unavoidable due to the presence of urban residences and geological formations. The mylonitic rock faults feature rock fractures, high rock permeability, complex formation structure, susceptibility to collapse, and rich groundwater. Geohazards during tunneling in groundwater-rich mylonitic faults include ground collapse, groundwater in-flows, land subsidence, and long-term instability of tunnel. These types of hazards would delay the construction of tunnels and potentially cause significant damage to the tunnels. Preventions and treatments for these hazards aforementioned are analyzed based on the tail grouting material optimization, advanced ground monitor, grouting treatment and shield machine modification, with monitoring the feedback data. The mechanism of ground collapse is discussed according to the cavity expansion principle.

1. Introduction

The number of metro and railway tunnels in China has grown rapidly in recent years due to increased traffic requirements to satisfy the large population and to address the increased congestion of ground transportation in recent years (Yilmaz and Marschalko, 2012; Shen et al., 2009, 2010, 2014, 2015a, b; Xu et al., 2012, 2013, 2014, 2015, 2016; Du et al. 2014; Cui et al., 2015; Wu et al., 2014, 2015a, b, c, d, 2016, 2017a, b; Lyu et al., 2016, 2017). Regarding tunneling projects in the western and southern cities in China, the various and complicated strata would increase the difficulty of metro construction, such as sand and gravels, karst strata, variably weathered granite, and water-rich mylonite (Aydin et al., 2004; Xu et al., 2013; Zhao et al., 2007; Tóth et al., 2013; Fargnoli et al., 2013; Alija et al., 2013; Ye et al., 2015).

Mylonite is a fine-grained, compact metamorphic rock produced by dynamic recrystallization of the constituent minerals resulting in a reduction of the grain size of the rock. Mylonite can have many different mineralogical compositions; and it is a classification based on the textural appearance of the rock (Trouw et al., 2009; Passchier and Trouw, 2005). As the special formation condition of dynamo-thermal metamorphism, mylonite is commonly distributed with certain mineral resources such as gold along tectonic movements of faults and suture zones (Singleton and Mosher, 2012; Zhang and Yu, 1992; Zhang et al., 2013). Also, mylonite is a common rock distributed in faults (Trouw et al., 2009; Passchier and Trouw, 2005; White 1996) which are commonly distributed in China, as a result of geotectonic movements. Furthermore, mylonite has been reported to cause problems in the construction of tunnels locally along the planning line (Sun 2014; Li et al., 2003). Past research on mylonite has focused more on the properties such as mineralization, micro-mechanism and the formation in natural environments (Williams et al., 1995; Chen et al., 2013; Chen et al., 2015; Hansen et al., 2013; Zhu et al., 2014; Jiang et al., 2015; Ye et al., 2013, 2015; Zhang et al., 2015; Du et al., 2014). However, very limited study has been conducted to its important to investigate the engineering properties of mylonite and analyze relevant geohazards in conducting construction. Under the influence of strong tectonism, the stratigraphic condition near mylonitic rock faults is very complicated, and the geohazard mechanism such as ground collapse should be considered in the context of the inhomogeneity of strata. In addition, China is located at the border along the Eurasian, Indian Ocean, and Pacific Plates. The plate movement is active along the eastern and southern coastlines, particularly in the Himalayan region located in the

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southwest of China. The active plate movement results in China being a mountainous country with significant mylonite formations, therefore, the geology and geohazards countermeasures for mylonite are of great benefit to the tunneling engineering in China.

This study will focus on the geohazards and treatments when tunneling in water-rich mylonitic rock faults. The objectives of this paper include: (i) to analyze the engineering hazards of a field tunneling case study in Guangzhou located in a mylonitic formation, (ii) to introduce the measures for preventing the relevant hazards, and (iii) to discuss the mechanism of ground collapse in mylonitic rock faults.

2. Hydrogeology and engineering geology

2.1. Characteristics of mylonite

Mylonite is usually located at bilateral sides of faults and its formation is closely affected by geotectonic movements, rock material, and element migration (Trouw et al., 2009; Passchier and Trouw, 2005; White 1996; Sibson, 1977). Although there are various views on the formation of mylonite, it is generally accepted that crystal-plastic deformation, fracturing and cataclastic flow contributes to the formation of mylonite. During the development of mylonite, virgin rocks possess certain dislocations, and also grind and crush into finer rock pieces under the pressure and torsional stress of the ground. These finer rock pieces then are directionally arranged in the plastic flow state, which form serious plastic deformation of rocks. The particle size in mylonite is so fine that a microscope is required for recognizing the grain contour, and lenticular porphyroclast can also be observed in certain sections. In general, the essential characteristics of mylonite can be summarized as follows: (1) the particle sizes of mylonite are much smaller than that of virgin rocks; (2) pervasive foliation and lineation structures in mylonite develop significantly; (3) mylonite is mainly located in the highly strained zone; (4) particles of mylonite are in a compact and solid state, featured by its texture structure; (5) mosaic structures, including base material and porphyroclast can be observed with a microscope, presenting visual plastic deformation.

Mylonite detected in the site is silicolite, due to the tenso-shear effect of tectonic movement. The silicolite distributes in the center and south of Guangzhou (Fig. 1(a)). The distribution of mylonite relies on distribution of faults. Fig. 1(b) reveals the main faults in Guangzhou region and several secondary faults around the construction site. Main faults principally contain Guangcong fault, Shougouling faults and Guangsan faults. While faults near the construction site are subject to the Shanwan faults and Shougouling faults. Mylonite along Shougouling fault mainly resulted from ductile deformation of the ground and rocks at deep level. Besides, mylonite here had a southern foliation with angle ranging from 20 to 35° (Zhou et al., 2009; Zou et al., 2001). Fig. 2 presents the crushed rock sample and fractures in the tunnel excavation face in mylonite in this case study. The particles are French grey or tawny in general (Fig. 2(a)) and tend to disintegrate or degrade in strength once water is encountered. Furthermore, mylonite present in the field is heavily weathered and fractured (Fig. 2(b)).

2.2. Description of construction site

Fig. 3 presents the land-use type and the location of Metro Line No. 7 in Guangzhou. The land-use type in Guangzhou city at a resolution of 1000 m is extracted from remote sense image data using ENVI (The Environment for Visualizing Images). In this study, the region of shield tunneling is located from Xiecun to Zhongcun station on line No. 7 in Guangzhou. The tunnels include the north tunnel, with a total length of 1626 m and the south tunnel with a length of 1636 m. As various types of rocks of different strengths are present in the region, the Earth Pressure Balance Shield Machine (EPBM) is usually applied in tunnel construction projects.

Guangzhou in China is termed as a 'geological museum', owing to the various and complicated geological conditions, such as karst caves, sand and gravel, underground rivers, faults, and boulders (Cui et al., 2015; Aydin et al., 2004; Xu et al., 2013; Zhao et al., 2007; Tóth et al., 2013; Fargnoli et al., 2013; Alija et al., 2013; Ye et al., 2015). Therefore, it is unavoidable to traverse through problematic geological conditions during the planning of metro lines. Metro Line No. 7 passes through residential areas with a high population density and provides public transport in Panyu district, Guangzhou, as shown in Fig. 3. Some geological faults lie close to the Xiecun village and Zhongcun village where the economic and the population is more concentrated at the location of Metro Line No. 7. The faults present at Metro Line No. 7 are dead faults. The results of early geological investigations indicate that the faults would not affect the operational stability and safety of Metro Line No. 7. According to the tunnel construction code in China, the metro line is allowed to pass through locations of special strata, including faults where necessary, while corresponding measures should

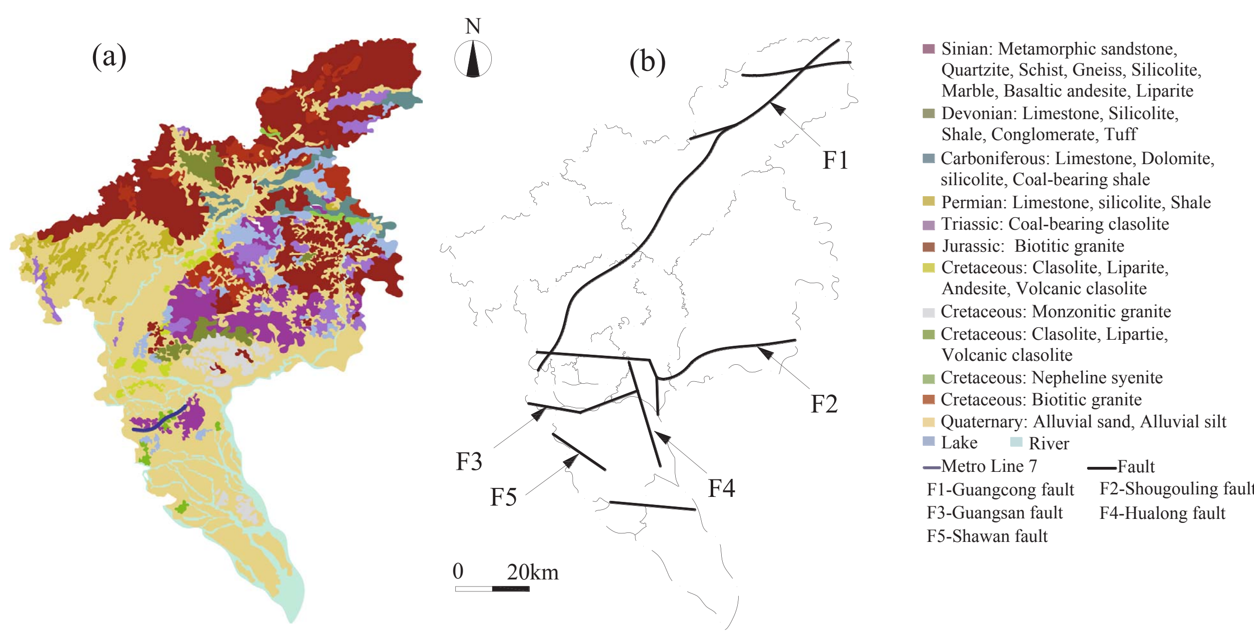

Fig. 1. Geological fault structure map of Guangzhou (data from Ren et al. (2016)).