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Comprehensive geophysical prediction and treatment measures of karst caves in deep buried tunnel

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ABSTRACT

While tunneling in karst terrains, engineers may encounter hazardous geotechnical structures such as faults, karst caves and collapse columns which may induce geohazards and seriously endanger the construction safety. Geological processes significantly affect the varieties and characteristics of karst caves, and therefore engineering geological and hydrogeological conditions of Shangjiawan Tunnel were analyzed firstly. In order to accurately predict the geometric characteristics of karst caves and their spatial relationship with the tunnel, the Ground Penetrating Radar (GPR) and Geological Drilling (Geo-D) were applied comprehensively in the present study. The Tunnel Seismic Prediction (TSP) system was also applied to forecast whether any karst cave existed in front of the tunnel face and the detection results generally agree well with the field investigation. Furthermore, the Beam–Slab method was carried out for the treatment of the karst cave which situated under the tunnel floor, while the Backfill method was applied for the karst cave which was exposed during the construction.

1. Introduction

The characteristics and behavior of karst systems commonly have a significant degree of uncertainty and heterogeneity, which makes the hydrodynamic mechanisms extremely complex and wonderful to study and explore (Milanovic, 2000; White, 2007; Carrière et al., 2013). For underground engineering constructions in karst terrains, unpredictable occurrence of cavities and well-developed karst conduits would be frequently encountered, resulting in unexpected seriously geological problems such as water inrush, tunnel collapse and surface subsidence (Song et al., 2012; Zhou et al., accepted for publication). In addition, impacts on engineering constructions are obviously immediate, requiring considerable intensification of the safety precautions in place (Milanovic, 2004; Kolimbas, 2005). For example, during the construction of the Sol-an Tunnel, the longest railroad tunnel in South Korea, excessive water inrushes and collapses occurred, accompanying with subsidence on the ground surface (Song et al., 2012). More than 350 caves were discovered in the course of the 60 km new motorways in Slovenia, including the longest cave LC-S647 (length 460 m, depth 70 m) in Kastelec tunnel (Knez et al., 2008). Numerous tunnels have been constructed in karst terrains over the past decade, such as the Chixoy power tunnel in Guatemala (Gysel, 2002), the Blessberg tunnel of Deutsche Bahn (Benedikt et al., 2009), the Gavarres tunnel in Spain (Alija et al., 2013) and the Albula tunnel II in Swiss Alps (Schneider and Lavdas, 2013).

In recent years, a great number of tunnels have been constructed, and are currently under construction in karst terrains and mountain areas of Chinese West where large amounts of carbonate rocks exist (Gong et al., 2010). For tunnel construction in karst terrains, the crossing of voids and caverns, either empty, aquiferous or filled with erodible material may induce geohazards and seriously endanger the construction safety (Marinos, 2001; Li et al., 2013). Especially in the research area of the present study, which is located in the southwest karst terrain of China, Hubei province, hundreds of karst caves have been discovered during tunnel construction. Taking the Huaguoshan tunnel of Enqian Highway in Hubei Province for example, 61 karst caves have been exposed, resulting in 3 times of water inrush and 8 times of tunnel collapses, respectively. One of the exposed caves reached up to 322 m deep. Another typical example was the Qiyueshan tunnel, even though half of the tunnel had been excavated until May 2014, 50 karst caves were discovered (Guo, 2014). Therefore, it is a crucial task to accurately predict the hazardous geological conditions in front of a tunnel face during excavation (Alimoradi et al., 2008). Geological prediction technique is commonly used in practice as it can provide related information regarding rock blocks in the project region, and make accurate predictions regarding geological conditions ahead and the possibility of disasters during tunnel construction (Chen et al., 2011). An overview of geophysical technique application to various environmental and engineering problems in karst regions is provided by Müller et al. (1997).

Methods of geological prediction are generally grouped into two major categories: destructive methods such as the Percussion Drilling and Core Drilling, and non-destructive methods including the Tunnel Seismic Prediction (TSP), the Ground Penetrating Radar (GPR), the

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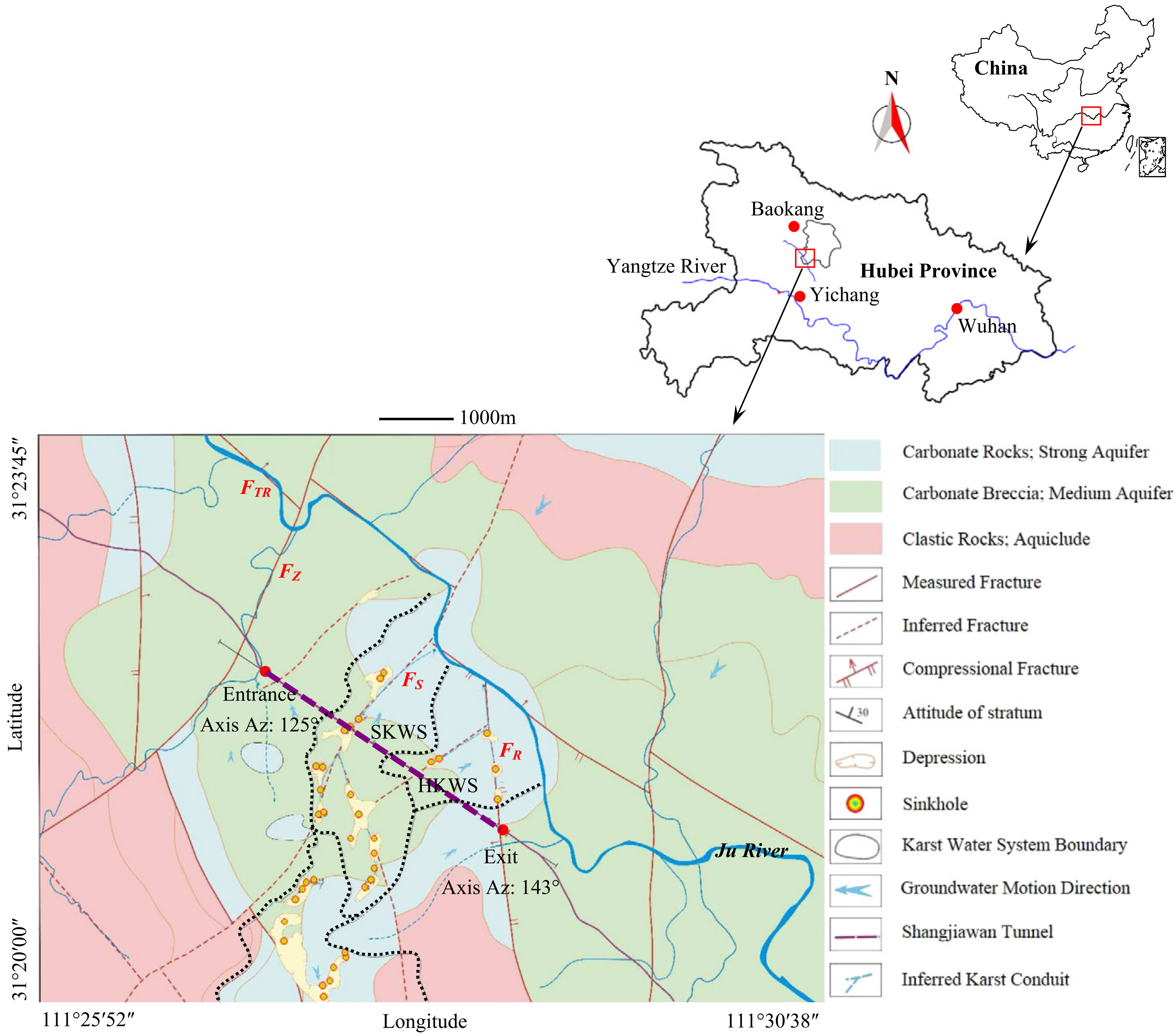

Fig. 1. Regional hydrogeological profile of Shangjiawan tunnel, where the boundaries of karst water systems are indicated with black dotted lines.

True Reflection Tomography (TRT), the Time Domain Electromagnetics Method (TEM), the Induced Polarization Method (IPM), the Microgravity (MG), the Electrical Resistance Topography (ERT) or the Seismic Refraction (SR). The destructive methods are time-consuming and costly. On the contrary, the non-destructive geophysical methods are developed fast and utilized commonly for prediction in China, especially the GPR and TSP methods (Osanloo, 1996; Madani, 1998; Locatelli et al., 2001; Delatte et al., 2002; Alimoradi et al., 2008; Chen et al., 2011).

The GPR method, a nondestructive geophysical technique, was first proposed and developed in 1956 (Cook, 1975), and had been applied to image the rock mass from underground excavations for more than 50 years (Grodner, 2001). The GPR method is based on the contrast in electrical properties of the materials and cannot be used to derive mechanical parameters. Therefore, the precision of the GPR prediction results can be somehow degraded. A new geophysics prediction technology, the TSP method, emerged in the year 1994 which can evaluate

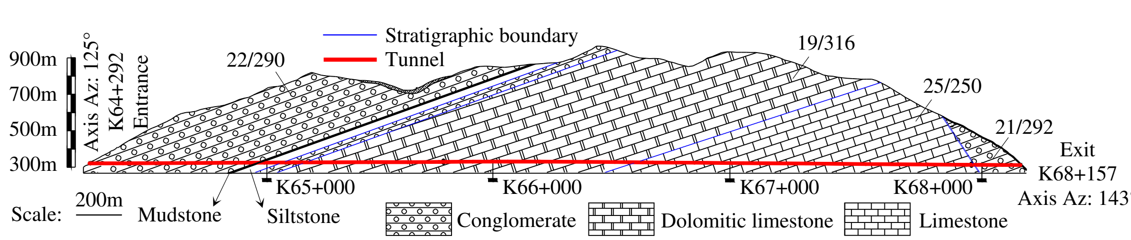

Fig. 2. Engineering geological profile of Shangjiawan tunnel.