Construction measures to prevent hazards in karst cave ground under soft sand strata

Qing-Long Cui i), Huai-Na Wu ii), Ye-Shuang Xu iii) and Shui-Long Shen iv)

i) Ph.D Student, State Key Laboratory of Ocean Engineering, Department of Civil Engineering, Shanghai Jiao Tong University, 800 Dong Chuan Road, Minhang District, Shanghai 200240, China.
ii) Assistant Professor, ditto.
iii) Associate Professor, ditto.
iv) Professor, ditto.

ABSTRACT

This article presents a case history of karst cave treatment technique to mitigate possible hazards during shield tunneling in karst region with caves. A field test of shield tunneling excavation was conducted using the karst cave treatment in the karst region of Guangzhou, China. The test site is a tunnel section on Metro line 9. 98 karst caves were found along the tunnel and 13.3% of karst caves are higher than 5 m. Construction program of karst cave treatment is introduced, which includes investigation, treatment determination, grouting and effectiveness check. Field investigation includes unconfined compressive strength (UCS) of borehole samples of grouted materials, standard penetration test (SPT), core recovery (CR). All of the UCS values of the borehole samples are greater than 0.2 MPa, the modified SPT values are more than 10 and the CR values are larger than 90%. These test results demonstrate the applicability of this treatment technology in karst region.

Keywords: case study, karst, tunnel, grouting

1 INTRODUCTION

With the rapid urbanization in China during last decades, large numbers of underground structures have been constructed, in which metro and railway tunnels account for the largest proportion. During the construction of metro tunnels, the following three types of strata are often encountered: soft soils (clay, silt, and sand), sand and gravels, and mixed ground (karst, variably weathered granite). Buried karst is mostly distributed in Guangdong.

Every karst starts with micro karst corrosion, and then a cave system is constructed in a long process. Karst is widely distributed in China (Yuan, 1976; TMPRC, 1997; Lu, 2010). In south China, there is buried karst, which is rich in fissure water, easy to collapse with disturbance, of high permeability, variable shapes and irregular locations. The tunnel construction method includes shield method, mining method, cut and cover method, among which shield method is the main method (Yilmaz, 2007; Liao et al., 2009; Shen et al., 2013; Wu et al., 2014). However, the karst cave exerts a significant impact on the shield tunnel excavation. During the tunnel construction using shield method in the caved karst stratum, karst caves could cause a number of hazards (Xu et al., 2012; Shen et al., 2014). As shown in Fig. 1, depending on the presence of geological flaws, the formation of water ingress passages in a karst tunnel falls into two categories, which are water ingress tunnel with geological flaws and water ingress tunnel with no geological flaws (Zhang et al., 1993; Ju and Zhu, 2007; Zhao et al., 2007; Gui, 2008; GMDRI, 2010; Xu et al., 2013a, 2013b). To ensure the construction safety and successful advance of the shield, karst cave treatment is proposed.

This paper presents a field trial of karst cave treatment in the karst strata of Guangzhou, China. The object of this study was to verify the applicability of the treatment technology in karst region based on unconfined compressive strength (UCS), standard penetration test (SPT), and core recovery (CR).

![Fig. 1. Water or stone ingress.](image-url)
2 DESCRIPTION AND INVESTIGATION OF THE TEST SITE

The test site is a tunnel section of Maanshan Park Station to Liangtangnan Station (Ma-Lian section) on Metro line 9, which became under construction by two earth pressure balance shield machines in November 16, 2013 and was completed in July 1, 2014. The metro tunnel axis is located at a depth of 9.8 m. The lining of the tunnel is 6 m in outer diameter and 5.4 m in inner diameter.

Geological drilling method was used to investigate the karst caves in Ma-Lian section[16]. Three holes were drilled to get the soil samples. They were located in the middle or on either side of the tunnel section with 3 m spacing. After the analysis of the drilling soil samples, 98 karst caves were found along the tunnel. And 13.3% of karst caves are higher than 5 m. This investigation focused on a selected monitoring zone with 43 karst caves, which were densely distributed in Ma-Lian section. Fig. 2 (a) shows the plan view of these 43 karst caves. The length of the corresponding tunnel is about 285 m. Among the 43 karst caves, 25 karst caves, labeled as K1 to K25, need to be treated. The “blue” karst caves indicate that they need to be treated. On the contrary, the red karst caves do not need to be treated.

Fig. 2 (b) shows the geotechnical sectional view of the shaft. The karst caves are all below the tunnel zone. The level of ground water fluctuated from 0.9 to 3.1 m below the ground surface. The subsoil profile here consisted of backfill, limestone. The sand layer is of high hydraulic conductivity. The water content of these soils ranged from 13.4% to 48.4%, with permeability varying between 0.003 and 25.
3 KARST CAVE TREATMENTS

Fig. 3 (a) shows the treatment range of the karst caves around tunnel. The karst cave must be treated if it is above the tunnel axis. In horizontal direction, if L (distance from the tunnel in the horizontal direction) < 3 m, the karst cave must be treated. However, in the vertical direction, if H (distance below the tunnel in the vertical direction) < 5 m and the karst cave is not filled up, the karst cave must be treated. What’s more, no treatment is taken if 5 < H < 10 m and the karst cave is completely filled up. If the karst cave is partially filled and 5 < H < 10 m, the karst cave must be treated. If H >10 m, the karst does not have to be treated.

Fig. 3 (b) shows schematic diagram of the karst cave treatment. The construction program is as follows: first, a preliminary investigation is conducted to explore the karst caves. The detecting techniques applied may include geological drilling, rayleigh wave, CT (computed tomography), and geological radar. Then, the quantity, location and filling of the karst caves are further detected to determine whether to take the treatment or not. If a cave treatment is necessary, the karst caves will be treated by grouting method, for example sleeve-value-pipe grouting. Finally, UCS tester SPT is conducted to check the effectiveness of the treatment. Besides, the quality of the grouting mass and core recovery can also be inspected according to the drilling samples. Fig. 4 (a) shows the layout of the grouting holes. The grouting holes are drilled in a rectangular pattern at 2 m spacing, to a depth of 0.2–0.3 m below the bottom of the karst cave. The peripheral holes are grouted first and then the center holes are grouted. Fig. 4 (b) shows slurry grouting into the karst cave. Two kinds of slurry, single slurry and binary slurry, are applied to fill the karst caves. The single slurry, which is made of water, cement and sand with a mass ratio of 0.8:1:1, is used to fill the central holes. The binary slurry, which consists of water, cement, sand and sodium silicate with a mass ratio of (0.8–1): 1:1:(0.08–0.2), is used for the grouting of the peripheral holes. The cement is Ordinary Portland Cement and the baume degree and the modulus of the sodium silicate are 38–43 Be’ and 2.4–3.0.

Fig. 5. SPT, UCS and CR values of KCN1 to KCN25. Note: KCN = karst cave number.

4 RESULTS

Unconfined compressive strength test and standard penetration test were conducted on borehole samples of
K1-K25 after 28 days. Fig. 5 shows the modified SPT and UCS of the 25 karst caves. As can be seen the modified SPT values are all beyond 10. The minimum and maximum values of UCS are about 1.1 MPa and 1.5 MPa, respectively. And the UCS values are all beyond 0.2 MPa. These test results indicate that the construction of these 25 karst caves can satisfy the requirement. Soil sample of one karst cave was obtained by geological drilling after grouting the karst cave for 28 days. The CR value is also shown in Fig. 5, and the values are all greater than 90%. The drilling sample achieved from each drilling hole at the same depth of the karst cave was cemented soil. It can be concluded that the quality of the treatment of the 25 karst caves is good, which created safe conditions for the subsequent tunneling excavation.

Surface collapse has appeared due to destroy of the self-stability of the karst cave of Ma-Lian section of Guangzhou metro line 9. A pit suddenly turned up during the tunneling. The reason was that there was a karst cave above the tunnel axis and the karst cave had not been treated due to unknown reason. Fortunately, there was no loss of life or other things. After that, all the karst caves were checked and the same phenomenon has not appeared again. No other accidents happened during the tunneling excavation of right line and left line.

5 SUMMARY

1) A treatment technique is proposed to fill the karst caves in this study. After geology investigation of the tunneling zone, the quantity, location and filling of the karst caves are determined to determine whether to take the treatment or not. Then the karst caves are treated by grouting single slurry or binary slurry, for example sleeve-value-pipe grouting. In the end the effect of the karst cave treatment is inspected through UCS, SPT, and CR after 28 days.

2) The construction quality and environmental impacts are examined through a case study. The modified SPT values of the karst caves were all greater than 10. Besides the UCS values of the drilling samples were all larger than 0.2 MPa. It can be concluded that the treatment of these 25 karst caves can satisfy the requirement.

3) Based on this case, it can be concluded that the karst cave treatment method can satisfy the engineering requirement and provide a database to guide the future engineering practice in the karst region.

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