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Review Article

Hazards induced by anthropogenic activities, a lesson learned from recent underground construction works

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ABSTRACT

Due to the expansion of underground constructions in urban areas, numerous hazards caused by anthropogenic activities have occurred in recent years. These hazards cause catastrophic failures which could pose a danger to life and property. Therefore, it is important to investigate the required knowledge to prevent these hazards. Five anthropogenic hazards that occurred due to the underground construction works are discussed; in order to identify risks and mitigate their adverse impacts in the future projects. According to the field investigations, it was found that there were many reasons for the underground construction failures caused by anthropogenic activities such as: faults in design and implementations, grouting material, leakage water, erosion, soil deterioration, and inadequate ground improvement. The understanding of these cases provides a wealth of experience and guidance for future excavations works.

1. Introduction

Underground construction collapse can be induced not only by natural factors such as rainfall, floods, droughts, and earthquakes, but also by human factors such as pumping, drainage, construction condition and other engineering faults. Recently, many underground facilities require deep excavations and underground tunneling that are close to existing buildings and utility pipelines, which are subjected to several hazards (Cui et al., 2015; 2016; Shen et al., 2014; 2016; 2014b). Furthermore, due to the expansion and uncertainty inherent in excavation activities, tunnel excavations often represent great challenges to civil engineers, where these activities pose great hazard to public safety in urban areas, moreover lead to loss of life (Cui et al., 2015; Shen et al., 2015a; 2015b; Wallis and Kenyon, 2014; Wei et al., 2015; Xu et al., 2014; Yu et al., 2016; Zhang and Han, 2015). Therefore, it is important to prevent these hazards and achieve the serviceability of adjacent facilities. Based on the construction site records, the available failures occurred in recent years have been discussed, to estimate the safety state of the underground construction and its surrounding environment.

This paper presents a review to the underground construction failures of five case studies which occurred in recent years in China. This review aims to investigate

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Table 1 The characteristics of case studies

No.	Date of failure	Project	Method	Cause	Failure mode
1	October 11, 2010	Nanchang metro line 1	open-cut method	poor quality of grouting	Seepage of water
2	July 19, 2012	Macau Hengqin tunnel	open-cut method	Faulty design,	Ground collapse
3	December 30, 2012	Wuhan metro line 3-4 tunnel collapse	Cut and cover	Leakage of sewage pipe	Leakage-soil deterioration
4	June 25, 2015	Shenzhen metro line 7 tunnel collapse	Mud shield machine	Collapse of shield machine	Subsidence
5	September, 2015	Guangzhou Metro Line 7	Earth pressure balance shield (TBM)	poor quality of grouting	Leakage of water

the reasons of failures and promote the awareness of underground construction hazards which form a great risk to life and property.

2. Tunnel collapse

This section describes five case studies of tunnel collapse cause by anthropogenic activates in recent years in China. Each case study discussed the project description, soil conditions, the collapse and its consequence, and the possible causes of the collapse according to the site investigations. Table 1 summarizes an overview of the five case studies of tunnel collapse that have occurred in recent years.

2.1 Nanchang metro line 1

A Zhujiang road station was located in metro Line 1 of the Nanchang city, the capital of Jiangxi Province, China. This station located along North Fenghe Avenue with approximately 467 m length. The Ganjiang River located at the east of the station at a distance of approximately 800 m and the minimum distance between the station and the nearest residential area was 47 m. The metro station is a two-story underground sections and consists of siding loop, storage siding and platform, therefore, it was necessary to construct a large excavation. The excavation was divided into several segments: launch shafts for tunnel boring machines, transition segments, and standard segments. The width of the launch shaft is 23.1 m and the excavation depth ranges from 15.5 to 17.8 m. Due to the order of construction, the strut systems (reinforced concrete and steel) were installed starting with base slabs, middle slabs, and roof slabs. Moreover, the excavation retaining structure of the station consisted of cast-in-place piles, three-axis mixing piles, and bi-slurry grouting which consisted of (cement, water, and silicon).

The soil profile of this site is characterized by a layer of fill underlain by thin silty clay layer, followed by a 4.8 m thick muddy clay layer. The ground water is 5 m below the ground surface. Also, the site contains many thick sand layers (e.g. medium sand, coarse sand, and gravelly sand) with a total thickness of 10-12 m (Feng and Lu, 2016).

One day before the accident the lowest level of the excavation on the west side of north shaft was being excavated at a depth of 15.5–17.8 m. On October 11, 2010, large water seepages and sand boils suddenly developed between the western cast-in-place piles at a depth approximately 16 m. Since the large amounts of sand and water were leaking so fast, the ground collapsed suddenly 1.5 m from the edge of the adjacent three-axis mixing piles at the west of the north launch shaft, as shown in **Fig. 1 (a).** The overall collapsed area was approximately 40 m^2 with 4 m deep, and the total amount of displaced sand was 140 m^3. On October 14, 2010, the seepage of the sand appeared again on the east side of the north launch shaft and the excavation was extended down to the deepest level, as shown in **Fig. 1(b).** Possible causes of the failure are illustrated as follows:

(i) The existence of silt and other soil between the three-axis mixing piles, the poor construction quality, and the large permeability coefficient of three-axis mixing piles allowed the soil to flow easily into the excavation pit, resulting empty holes between the piles.

(ii) Because of the bi-slurry grouting process, the soil reinforcement in the north launch shaft executed in a good manner in the coarse sand, but was poorly in the clay and silt sand, so the sand boils were developed rapidly, as shown in **Fig. 1(b).** Consequently, the ground surface collapsed after the sand submerged the excavation pit.

(iii) After grouting, parts of sandy areas were not sufficiently strengthened, due to the high difference of ground water level; resulting the occurrence of leakage water into smaller zones in sand layer.

(iv) Some monitoring data during the construction were not obtained by equipment and construction materials (Feng and Lu, 2016).

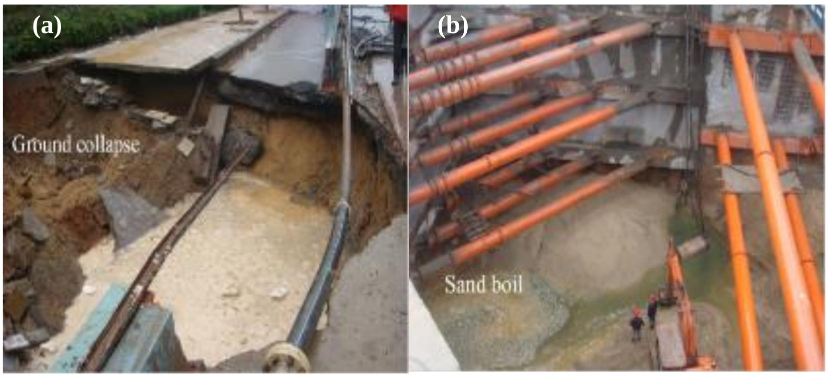

Fig. 1. Collapse at the east of the north launch shaft; (a) ground collapse; (b) sand boil (Feng and Lu, 2016)

Fig. 2. The collapse of Hengqin tunnel (Macau Daily, 2012)

Fig. 3. Wuhan metro tunnel collapse.

2.2 Macau Hengqin tunnel

Hengqin tunnel was a four-lane traffic tunnel with 1.57 km long, constructed by open-cut excavation technique. This tunnel was divided into three sections: the Hengqin approach, a 530 m long underwater section, and the Macau approach. The underwater section was being constructed within a dried cofferdam with seawater pumped out to facilitate construction. Also, there were changes in design that included the increasing in width and depth to allow for 3,000 ton vessels to cross the water channel. The soil profile of this site was consisted of three layers; fine sand with 4.5m, silt clay with 14.5m, and muck soil.

On the night of July 19, 2012, four workers were operating on the surface of the tunnel reported that they hear strange noises coming from the site and felt abnormal ground movements. They immediately informed tunnel workers through a wireless communication system to evacuate. After that the ground surrounding the tunnel entrance was collapsed, and five pieces of heavy machinery were buried inside the tunnel as shown in **Fig. 2**. The possible causes of the tunnel collapse were:

(i) The construction of support structures failed to keep up the pit breaking procedure; consequently the internal and external pressure had become unbalanced finally led to the collapse of the temporary fencing work.

Fig. 4. Collapse of Shenzhen metro tunnel

Fig. 5. Leakage of water at gap in between assembled segments (Ren et al, 2016).

(ii) The designers didn't take the effect of heavy rains during the period of construction into consideration. The heavy rains led to increase the water in the stratum, causing high ground water levels.

(iii) The soil borings were not adequate and the structure of the ground was weak, causing much more pressure on the foundation pit pile (Geotechnical Engineering Office, 2015).

2.3 Wuhan metro intersection of line 3 and 4

Wangjiawen station is considered a transfer station between line 3 and line 4 in Hanyang District at Longyang Road Station in Wuhan city. This station is 480.6 m long, 20.35 m wide and the excavation depth was about 20.6 m. The profile of soil was divided into three layers; fill layer, silty clay layer, and clay sand layer. The bored piles which used in this case study with1 m diameter, 31.6 m length, and the spacing between piles is 1.2 m. To support the excavation depth, three levels of struts were used, the reinforced concrete was used for first and second struts and the third one was steel with 0.8 m diameter.

On December 30th, 2012 after finishing 17m from excavation, cracks were found in the first reinforced concrete struts. The cracks become evident in the side of the road around the excavation, especially in the southern shaft. Seepage of water filled the pit and before the end of the day it collapsed. Furthermore, 12 bored piles were destroyed, and cracks and settlements were appeared in the crowded roads around the excavation, as shown in **Fig. 3.** The collapse occurred because of break the outside sewage pipe which caused leakage into the excavation, finally caused failure piles. Although the design was safe and reliable enough, it was found that not only the diagonal struts that used to support the excavation sides not enough for any unexpected failure but also struts are not located in its right positions.

2.4 Shenzhen metro line 7

The tunnel of Wong Fook section is located in the intersection of Fuk Man Road and Fuqiang Road in Shenzhen metro tunnel line 7 at Futian District. The total depth of the tunnel is ranges from 20 to 25 m. The field investigation showed that the soil profile consists of three layers; medium sand, gravelly sand, and weathered rock.
On June 25th, 2015 ten meters of Shenzhen tunnel Metro line 7 collapsed, causing 10 m diameter and 3 m deep potholes on the surface above. The collapse caused one

death and three injuries, with an additional person trapped in addition to, two cars parked on the roadside dropped into the pit, as shown in **Fig. 4**. The possible causes of this collapse were the local subsidence that occurred during the process of changing the cutter tools of the shield machine. The rupture of the upper part of water supply pipe and the influx of mud shield machine warehouse.

2.5 Guangzhou Metro Line 7

The Xie-Zhong area is a section of the tunnel from Xiecun Station to Zhongcun Station in Guangzhou Metro Line 7, and it consists of two-story metro station, north tunnel with 1,626 Km long, and south tunnel with 1,636 Km long. Two earth pressure balance shield TBM of 6 m in diameter are used for the construction of Xie-Zhong section with the buried depth ranging from 16 to 28 m. The field investigation displayed that the soils of the site consist of four layers; Plain fill, sand, silt clay, and slight to high weathered mylonite (Liu et al., 2016).

In September, 2015 after the construction of Xie-Zhong section they found that there were a lot of water filled the tunnel from the gaps in between assembled segments as shown in **Fig. 5.** The main reason of the leakage is the poor quality of grouting causing voids between segments leading to water filled the tunnel.

3. Conclusions

Based on the review of five case studies induced hazards by anthropogenic activities of underground construction, the conclusions can be drawn as the following:

(i) The poor quality of grouting material causes many hazards such as water seepage, sand boil, and ground deterioration. Therefore, assuring the quality of grouting is essential to determine how to deal with these hazards during construction.

(ii) Faults in design (excavation method and low designer experience) also, faults in the implementation (in correct installation struts, and changing the order of construction sequence) maybe cause hazards. Consequently, reviewing designs and following the order of construction sequence should be taken into account.

(iii) Leakage of pipes should be avoided by conducting the compressive pipeline test. Furthermore, it is important to take any temporary loading caused by change in the weather condition, and construction duration during the design, to achieve a successful design of tunneling construction.

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