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ARTICLE

Analysis and Discussion on Subway Construction Accidents from Geological Perspective

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ABSTRACT

Several cave-in accidents often occur in subway construction, causing personnel and economic losses. This paper has carried on the statistics and analysis of some typical subway construction accidents in recent years. Taking the collapse accident of a subway station in Hangzhou as the engineering background, the causes of the collapse of the foundation pit were analyzed. The analysis found that groundwater, earthwork over-excavation, weak support design and inadequate monitoring are the main reasons. These factors should be highlighted in the construction of similar projects in the future to avoid similar tragedies.

1. Introduction

In recent years, China's urban rail transit construction has surged [1, 2]. By June 2019, 39 urban metro lines have been opened (sorted by the opening time of the first rail transit). With the development of metro lines in full swing all over the country, the metro construction accidents have arrived in quick succession, frequently ringing the alarm of safety [3, 4]. In the process of subway construction, the risk increases due to the properties of geotechnical complexity, unpredictable objects, the complicated construction procedures and equipment, concealment, and the permanence of construction period. Moreover, subway construction is a huge project, which needs a large number of workers. From its beginning, various risk factors have always existed. Once an accident occurs, it will cause serious casualties and property losses.

This paper gathers the typical accidents in China's subway construction in recent years, carries out corresponding analysis, especially from the perspective of hydrogeology and soil mechanics, and puts forward some thoughts and suggestions, hoping to provide some useful advice for the follow-up engineering design and construction.

2. Accident Statistics and Description

The author collects the subway construction accidents in China in recent years.

Accident 1: On September 21, 2004, the first phase construction of Shanghai Metro Line 9 was once in dan-

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ger. A sewer was broken. The construction site was soaked in water, which caused the collapse of the ground of 700 square meters.

Accident 2: On the morning of March 28, 2007, a landslide occurred in Metro Line 10 near Suzhou Street in Beijing, and six builders were buried.

Accident 3: At 4 pm., December 17, 2007, the construction surface of Nanjing Metro Line 2 suddenly broke, which resulted in the collapse of the main road, covering an area of more than 300,000 square meters. Two trees over 10 meters high fell into the landslide. Fortunately, no casualties were caused.

Accident 4: On the afternoon of January 17, 2008, Guangzhou Metro Line 5 suddenly gushed water during construction and collapsed, resulting in a sudden subsidence of the ground near Shuangqiao Rd. under the approach span of the Pearl River Bridge. There was a large cave with an area of about 100 square meters and a depth of about 5 meters. No casualties were caused by the accident.

Accident 5: On April 1, 2008, when the construction team of Metro Line 3 in Longgang district of Shenzhen was casting concrete in place for pier, the mother slab suddenly collapsed with concrete pouring down. Five people were buried, resulting in three deaths and two injuries.

Accident 6: On November 15, 2008, a large-scale collapse occurred at the construction site of Hangzhou Metro Line 1, which caused the 75-meter pavement of Fengqing Avenue to collapse with a subsidence of 15 meters. 11 driving cars fell into the pit. The collapse of the soil outside caused the wall of foundation pit to be unstable. Then the supporting system collapsed, and a large amount of mud water flooded into the foundation pit. Four crumbling dilapidated buildings were forced to be demolished around the construction site. The residents within 500m were evacuated and transferred. 35 subway stations under construction in the city had to be suspended. This accident resulted in 21 deaths and 24 injuries, which is one of the most serious accidents in the history of metro construction in China. In this paper, the author will focus on the accident as the engineering background to analyze the cause of the accident and the measures taken, as shown in Figure 1.

Accident 7: On January 28, 2013, six collapses occurred successively near the construction site of Kangwang bus station, Liwan district of Guangzhou. Six shops collapsed and the cave-in area was about 690 square meters.

Accident 8: At 11 am, August 28, 2019, a road surface collapse occurred at the intersection of Jianguo North Road and Stadium Road in Hangzhou (Figure 2).

(a)

(b)

Figure 1. The construction accident at Xianghu Station of Hangzhou Metro Line 1, China.

Figure 2. The construction accident of Hangzhou Metro Line 5, China

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3. Analysis and Discussion on the Causes of Accidents

3.1 Groundwater

In the construction process, the water in the soil has always been a nagging problem. Most of the accidents in geotechnical engineering are related to the water in the soil. In the construction process of subway stations, water is an important factor inducing accidents. According to the previous statistics, the construction accidents caused by improper water treatment account for about 21.4%.

Through the analysis of the accidents above, it is found that there are often water pipes or ground seepage around the foundation pit. For example, at the beginning of Accident 1, a small seepage appeared in the subway foundation pit, followed by a large-scale piping, and water with yellow sediment flooded into the subway foundation pit of Shanghai Metro Line 9. Meanwhile, the ground near the foundation pit began to fall, and the road about 50 meters long also collapsed in a large scale. This reason also applies in Accident 4 and Accident 6. According to the survey, the foundation soil near the Qiantang River is silty clay, and the groundwater level is high. In addition, the site is located in the main road, where traffic flow is relatively large. There are many large buses and trucks running on this road, which has brought impact on the western load-bearing wall of the foundation pit. In October 2007, a rare continuous rainfall occurred, which further increased the fluidity of soil under the foundation. Accident 8 was caused by water seepage in the construction of connecting passage of Hangzhou Metro Line 5, which resulted in pavement collapse and gas leakage.

In terms of geology and soil mechanics, due to the seepage of surface water and groundwater, the water content in the soil increases, that is, the self-weight of the soil increases, and the effective stress decreases. The seepage of water also causes a certain dynamic water pressure on the slope soil of foundation pit. Meanwhile, the accumulated water in the vertical cracks of the soil generates a certain hydrostatic pressure. On the other hand, the increase of water content in the soil causes lubrication among soil particles, and the internal friction angle of the original soil decreases greatly. As a result, the sliding force of foundation pit slope increases and the shear strength decreases, which eventually leads to the collapse of the slope and the subsidence and cave-in of the adjacent ground. Therefore, before the subway construction, it is necessary to focus on water factors which may cause accidents.

3.2 Design Factors

In Accident 6, the geology of the site is complicated, and it's rich in groundwater. Most of the soil layers are soft clay. The engineering work such as subway foundation pit excavation and shield tunneling is like drilling a hole in the cake, which is quite risky. The specificity of the soil mechanics parameters of groundwater and soft clay should be fully considered in the design. For the stability analysis of foundation pit, it is inappropriate to use consolidated undrained strength index and saturated unit weight for saturated clay. The design team has not paid enough attention to the particularity of soft clay.

When it comes to piles, walls and inner strut in deep soft soil areas, stability in depth must be considered, including pile and wall settlement, upheave and "skirting" damage, which should be strictly calculated by various methods. If it cannot meet the requirements, it should deepen the depth of pile and wall into soil or reinforce the passive area. In Accident 6, the project design has not paid enough attention to this, and no passive zone reinforcement has been carried out.

3.3 Construction Factors

The quality of a project ultimately depends on the quality control of construction. One of the most important reasons in accident 6 is that the steel support booster was not added enough, which made the bearing capacity of the protective wall insufficient. Generally speaking, the booster should be added to more than 200 tons, even 300 tons in geological conditions such as Hangzhou, but in terms of the accident site, it is certainly not enough.

In addition, the protective wall of the west subway section underwent tremendous deformation. The sliding of the protective wall had occurred sometime before the accident. Earlier, many on-site construction workers had also noticed cracks on the wall, but no measures were taken. Besides, serious road subsidence and multiple cracks occurred one month ago, which actually reflected the change of soil mass, but it was still ignored as a result of excessive traffic flow by the construction team. Moreover, in the construction process, the foundation pit was seriously over-excavated. The supporting system had serious defects. The steel pipe support was not timely erected, and the cushion was not timely poured, either.

Because of the short construction period, many details were neglected in order to rush to meet the deadlines, which actually caused management omissions. For example, in the subway station, if the open excavation starts, the multi-section construction method must be strictly implemented, and every 20 meters should be segmented.

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However, after the accident, it was found that the interval between sections was 60 meters. Although it is difficult to establish a direct causal relationship between the shortening of construction period and cave-in accidents, facts show that the shortening of construction period indirectly promotes the occurrence of accidents to a certain extent, so that dangers which could have been discovered are ignored intentionally or unintentionally.

3.4 Monitoring Measurement

There must be an omen before the foundation pit collapses. The monitoring data of the foundation pit will certainly give an alarm according to the daily reports. General monitoring items include horizontal displacement and settlement monitoring, inclinometer monitoring, stress monitoring, earth pressure monitoring, water level monitoring.

In Accident 6, the soil near the station was relatively soft with high fluidity. The pressure caused by the traffic flow on the west Fengqing Avenue led to the soil layer below moving toward the subway construction site. In addition, the previous rainfall caused the surge of river in the east. The softer soil also increased the mobility of the soil layer. Under this background, monitoring data such as horizontal displacement, earth pressure and water level change should be able to detect the abnormal situation in advance and send out an alarm so that the construction team could take corresponding measures. But in that situation, this was obviously not well tackled.

4. Some Reflections

(1) Make a good pre-construction survey. With the deepening excavation of foundation pit, the risk of confined water is also increasing, which can easily break through the weak stratum, resulting in piping and drift sand. Therefore, a good survey should be made before the construction of foundation pit. The features of the site, the adjacent aquifers, and the hydraulic relations between aquifers and surface water should be clarified. Then make a design of dewatering.

(2) In the engineering design, it's inappropriate to use consolidated undrained strength index and saturated unit weight to calculate the strength of groundwater subsoil, to analyze the stability and to check the bottom upheave. The highly sensitive soft soil was not given enough attention and no effective measures were taken. A mistake was made at the time when Fengqing Avenue was not closed. The checking calculation of pit overload based on consolidated undrained strength was also dangerous. In addition, according to the disturbance degree of the subsoil, the disturbed soil is strengthened by layers.

(3) In the construction process, it is necessary to ensure the construction quality of the underground continuous wall, and dewatering should be carried out according to the design.

(4) Strengthen monitoring and measurement. During the excavation of the foundation pit, it is necessary to ensure the safety of the pit, the surrounding buildings and underground pipelines. Therefore, in the construction process, informationized monitoring of foundation pit and its surroundings should be strengthened, and the monitoring data should be promptly sent to the construction team.

(5) Eliminate man-made accidents from institutional mechanisms. Eliminate illegal subcontracting, and set the construction period from a scientific development perspective, which cannot be guided by the leadership's thinking. Many metro projects are constructed underground, which is highly risky. Therefore, a more complete technical support system and a stricter monitoring and risk management should be required.

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