Analysis and Evaluation of the Engineering Geological Condition between Xishan Bridge Station and Luotang Street Station of Nanjing Metro

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Keywords: Metro construction, Underground water, Formation lithology, Geological fault, Engineering geology

Abstract: The research focuses on the engineering geological conditions of the Nanjing metro Xishan Bridge - Luotang Street station section, and analyzes the site's hydrogeological conditions, stratigraphic lithology, geological structure, topography. The study also discussed the impact of soil texture, underground water and geological faults on the metro line construction. The solution to the problems faced in metro line construction is also given, and the possible impacts of geological, hydrological, meteorological and other conditions on the construction of underground railways are summarized. In the paper, the writer used AutoCAD to make graphs of the geological section map of the metro line section and analyzed the distribution of various kinds of soil in the metro line section.

1. Introduction

With the rapid development of Chinese cities and the increasingly crowded urban traffic, the development of underground transportation system has become one of the main methods to solve urban traffic problems [1]. However, due to geological reasons, some metro lines may encounter risks such as landslides and water inflow problems during construction, which have caused great hidden dangers to the construction and normal operation of the subway. For example, in Xi'an, China, on June 9, 2009, cracks occurred in the Yong-Nan section tunnel, causing water inrush and producing considerable economic losses [2]. In Nanjing, Jiangsu Province, some metro lines are built close to the Yangtze River, which results in soil erosion and serious land subsidence [3]. In order to avoid the occurrence of various geological problems during the construction of the subway, this paper will focus on the analysis of the engineering geological conditions between Xishan Bridge Station and Luotang Street Station of Nanjing Metro Line 7 by using local regional geological data, hydrological data, meteorological data and some other data. [4] The paper will also analyze and evaluate the problems that may occur in the subway construction [5].

2. Project Profile

Nanjing Metro Line 7 is located on the south river bank of the Yangtze River, and is a metro line in the northeast-southwest direction. The line is about 35.6km long, with 27 stations, including 13 transfer stations. The entire line is laid underground, with an average station interval of about 1.35km. Among them, the section from Xishan Bridge Station to Luotang Street Station is about 1813.4m long. The shield tunneling method is used for construction. The type of the section is a circular double hole, the outer diameter of the tunnel is 6.6m, the design elevation of the rail surface is between -3.40m to -16.508m, the buried depth of the bottom plate is about 16.4m to 29.4m, and the maximum longitudinal slope is 26.8‰.

As shown in figure 1, since the metro line section is close to the Yangtze River and the geological conditions of the section are complex, it is worth analyzing the geological conditions of it and giving solutions to some possible geological problems.

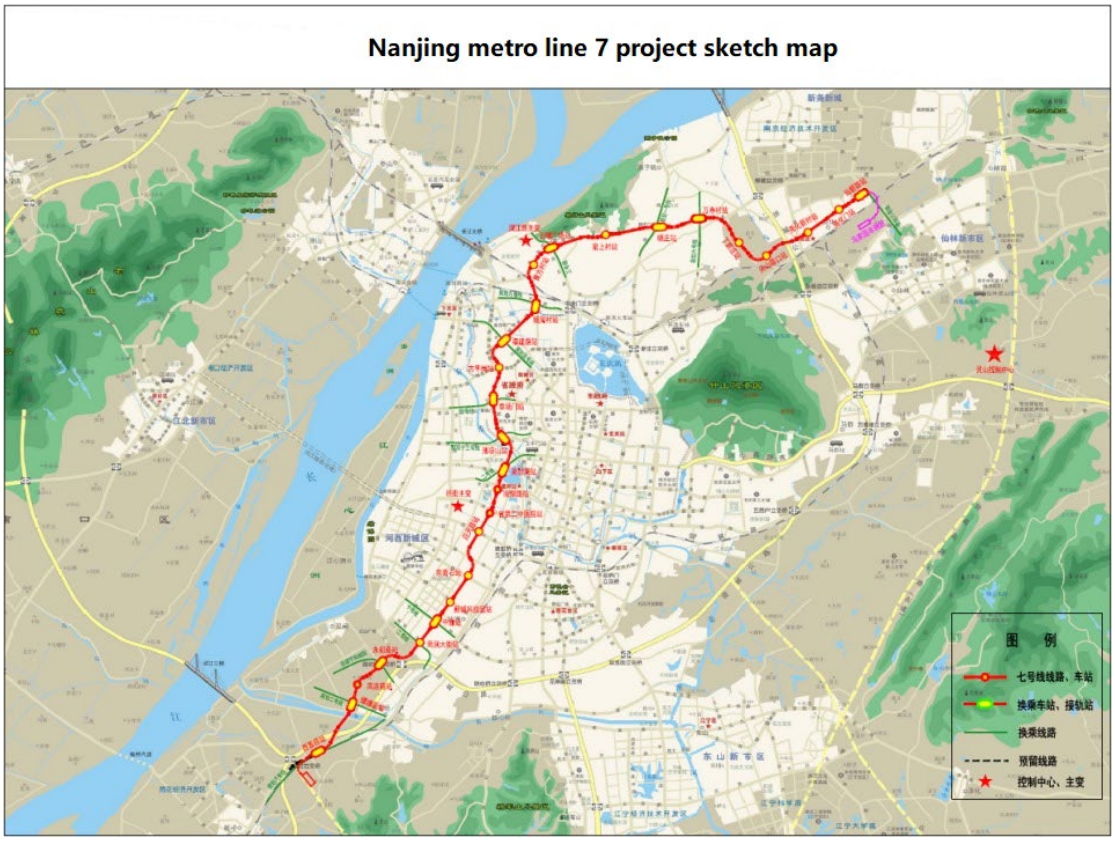

Fig.1 Geological Condition of Engineering

2.1 Hydrogeological Condition

2.1.1 Underground Water

According to the stratigraphic structure and the occurrence conditions of groundwater revealed by the geological survey, the groundwater in this site is divided into pore water, pore confined water and bedrock fissure water [6].

Pore water: The pore water aquifer includes artificial fill, silt, silty clay, and silty silty clay. Due to the great difference in permeability between silt and the upper artificial fill layer, the permeability of mucky silty clay, silty clay, silty interlayer and the overlying cohesive soil layer is quite different, and the groundwater is slightly confined.

The pore water aquifers are mainly distributed in the middle and upper part of the floodplain of the Yangtze River, which has a great impact on the construction of the metro line.

Confined water: Confined water aquifers consist of silty clay,mucky silty clay mixed with silty sand, silty clay with pebble gravel, silty fine sand, medium-coarse sand and medium-coarse sand with pebble gravel. The waterproof floor is the underlying bedrock. Confined water aquifers are mainly distributed in the middle and lower part of the floodplain of the Yangtze River and has large thickness. It has great impact on the construction of the metro line.

2.1.2 Rivers

This section passes through the Qinhuai New River. The water surface width of the tunnel crossing section of Metro Line 7 is about 180m, and the flood control level is 11.2m (Wusong elevation system, the same below). The water depth is 0.9~7.0m. According to the completed drilling data, the lowest elevation of the river bottom is about 1.0m, and the thickness of silt is 3.1~4.8m.

This section also passes through the Nannan River, and the width of river section where the line crosses is about 55m. The water surface elevation measured between January 8 to January 12, 2017 is 7.44m; the water depth is between 0.9m to 2.0m; the lowest elevation of the river bottom is 5.4m ; the thickness of silt is 0.2~0.5m.

The Surface water is mainly supplied by atmospheric precipitation, and discharged in forms of runoff, evaporation and gradual infiltration. There is a complementary relationship with groundwater. Qinhuai New River and Nannan River are both connected with the Yangtze River, and the rivers are connected by gates and dams. The hydraulic connection is relatively close, and their water levels are also controlled by upstream and downstream gates.

2.2 Formation Lithology

The thickness of the overburden layer in this section of the site varies greatly (12.1~67.2m), and the distribution of rock and soil layers is uneven and varies greatly. Affected by human activities, the thickness of the fill layer is large (0.9~12.1m); under the fill layer, most of the sections are distributed with thick soft soil (about 30m at the thickest point), and the bottom is mainly sandy soil And the soil-sand interaction layer, and the bottom is medium-coarse sand with pebbles. The shallow part located in the front of the floodplain is mainly loose to slightly dense silt, and below it is soft soil and general cohesive soil. The underlying bedrock is buried at a depth of 12.1~67.2m, and the lithology is mudstone, silty mudstone, and local gravel-bearing sandstone.[7]

Table 1 Shows the Kind of Soil in the Section and Different Characteristics of the Soil.

Table 1 the Kind Of Soil in the Section and Different Characteristics

Stratum name	Soil layer color	Soil layer condition	characteristics	distribution	bottom layer depth(m)	Thickness(m)
					Min-max	Min-max
Miscellaneous fill	variegated	Medium density	It is mainly composed of gravel and clay soil, with a small amount of construction waste, etc. The filling age is more than 5 years.	partly	0.6~4.8	0.6~4.8
Plain fill	tawny	Slight density	It is mainly composed of clay soil, with a small amount of grave. The filling age is more than 10 years.	partly	1.0~3.8	1.0~3.5
Silty clay	tawny	waxiness	It contains iron-manganese nodules and smooth cut surface and has medium dry strength and medium toughness.	partly	3.7~8.5	1.1~6.5
Silty clay	tawny	Waxiness-hard	It contains iron-manganese nodules and smooth cut surface and has high dry strength and high toughness. It partly contains some weathered rock.	partly	6.9~16.4	2.7~9.8

2.3 Geologic Structure

The site belongs to the lower Yangtze fault block tectonic unit in the regional geotectonic area. It is located in the junction of the Ningzhen arc and the Ningwu basin. The regional geological structure is complex, and there are folds and faults. The Nanjing area was tectonic activated during the Yanshan period, and developed multiple secondary tectonic units. The folds were severely damaged by the structure. The north-east trending compressive-torsional faults and the north-west trending tension-torsional lateral faults were relatively developed. The depressions and rifts controlled the area. The development and distribution of the extremely thick Mesozoic strata. The faults in the near field area of the site are mainly Nanjing-Hushu fault and Xishanqiao-Yuhuatai fault[8].

Nanjing-Hushu Fault The fault extends from Chuxian County, Anhui Province to Liyang via Nanjing, and is a regional hidden fault. The area is one of the sections from Nanjing to Hushu, which is 30 kilometers long and has an unknown width. The northeast side is the Ningzhen arc

uplift belt, and the southwest side is the Ningwu volcanic rock basin.

The Xishan Bridge-Yuhuatai fault is an inactive fault.

2.4 Landform

The section between Xishan Bridge Station and Luotang Street Station of metro line 7 is located in the southwest of Hexi and Xishan Bridge Street. The section crosses Shandong Overpass, Jianning Village, the belt freeway, Nannan River and Qinhuai New River.

The buildings along the site are mainly roads, railways, rivers, enterprises, institutions, residential quarters, villages, driving schools, farmland, etc. The terrain is slightly undulating, and the elevation of Wusong on the ground is between 6.20m and 13.00m.

The geomorphological unit of the site belongs to the floodplain of the Yangtze River.

3. Analysis of Engineering Geological Problems

3.1 The Impact of Fault Fracture Zone

Among the fractures around the site, the Xishan Bridge - Yuhuatai fracture is relatively close to the site. Affected by the fault, the underlying weathered rock mass in some sections of the metro line is relatively fragmented, and attention should be paid during construction [9].

3.2 The Impact of Underground Water

The proposed site is rich in groundwater: phreatic water, confined water and bedrock fissure water are distributed in the area. The thickness of the aquifer is large, and the permeability of the aquifer in the area of the tunnel is relatively strong, which has a great impact on the construction. Combined with the burial depth of the interval, the shield tunnels ought to excavate in soft soil, cohesive soil, silty clay mixed with silt, sandy soil and strong or moderately weathered rock in order to avoid the negative impact caused by underground water.

Among them, when the shield tunnels in the diving sand layer, the confined water sand layer and the soil-sand interaction layer, due to the strong permeability of the sand layer, the phenomenon of water gushing and quicksand is easy to occur [10], which will increase the difficulty and risk of excavation, and will even cause serious accidents. The loss of flowing soil and sand caused by groundwater seepage will make the excavation surface unstable, posing a threat to construction safety, quality and progress control. In addition, the buoyancy, seepage and corrosiveness of groundwater on the tunnel will affect the safety of the use and operation of the subway. Due to the influence of quicksand, corresponding measures should be taken in some sections to avoid the generation of water gushing and quicksand.

During the construction, the excavation speed, soil bin pressure, slag output and grouting pressure should be strictly controlled to prevent slurry, formation collapse, and shield floating. Workers should also use fast-hardening and early-strength grouting materials to strengthen post-wall grouting and secondary injection.

3.3 Analysis of Soil Texture and Stratum

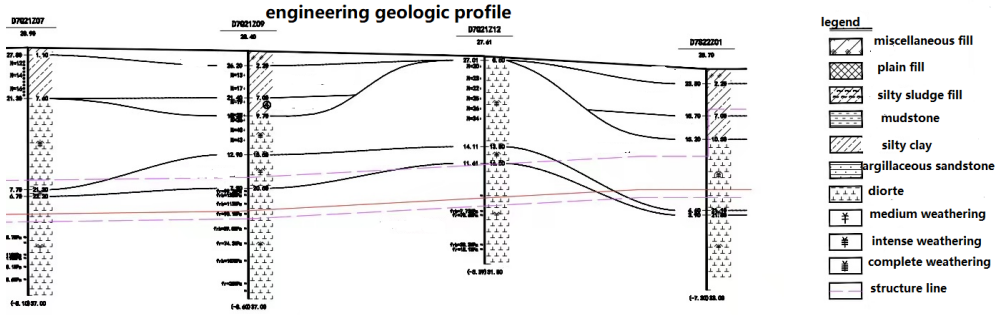

Fig.2 The Distribution of Various Kinds of Soil in the Metro Line Section

The proposed site is located in the floodplain landform unit area of the Yangtze River, where the

thickness of the overburden varies greatly (12.1~67.2m).There are several soil layers. The stratum distribution is uneven, and the underlying rock surface fluctuates a lot.

Fig.2 Shows the Distribution of Various Kinds of Soil in the Metro Line Section.

The special geotechnical soil of the site includes fill soil, soft soil, mixed soil and strongly weathered rock [11].

As shown in figure 2, the surface layer of the site is distributed with miscellaneous fill and plain fill of varying thickness, with a layer thickness between 2.0m and 14.2m. The thickness of the covering soil in some sections varies greatly, which has a certain impact on the shield tunneling. It is necessary to adjust the soil in time according to the change of the overlying earth pressure. The tank pressure is kept balanced. The composition and uniformity of the fill layer vary greatly. The density is small, and it has the characteristics of low strength, high compressibility, and uneven permeability. The silt engineering properties are extremely poor, and the tunnel is easy to collapse, so measures should be taken during construction to ensure that the tunnel is stable.

The upper part of the site is distributed with thick soft-flow plastic silty clay, silty clay, and silty clay mixed with silt. Soft soil has the characteristics of low strength and high compressibility, which will have negative effects on subway construction and future operation.

During the advancement of the shield, the earth pressure value should be reasonably set to maintain the frontal balance to prevent over-excavation and under-excavation; reduce the disturbance to the soil layer, control the posture of the shield, and strictly control the amount of correction of the shield; strictly control the grouting of the shield tail, using suitable additives to improve the soil.

The mixed soil of the site is silty clay with pebbles and gravels and medium-coarse sand with pebbles. The pebbles have different particle sizes and poor gradation. The maximum particle size is more than 10cm, and the content is uneven. The composition is quartzite and silica sand. It is easy to damage the shield cutter head. The coarse sand containing gravel is buried deeper and the impact on the shield construction is mainly because the layer contains confined water, which is prone to water gushing and collapse.

The underlying bedrock of the site is sedimentary rock (strongly weathered mudstone, silty mudstone (partially gravel-bearing sandstone)), which is strongly weathered and sandy. It has the characteristics of high strength, low compressibility, weak permeability, and soften by water. Attention should be paid to this during construction.

4. Conclusions and Suggestions

Considering the factors such as the engineering geological conditions, hydrogeological conditions, surrounding environmental conditions and engineering economy, it is recommended that the tunnel between Xishan Bridge Station and Luotang Street Station of Nanjing Metro should adopt mud-filled earth pressure balance shield machines. Appropriate shield machines should be chosen based on the most unfavorable stratum formation.

The vast majority of underground railways in the world will face many similar problems win their construction. When building various types of underground railways, the possible impacts of rock formations, soil quality, groundwater, and geological fractures should be considered at the same time, and preventive measures should be taken to ensure the safety and efficiency in the process.

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