Research on Pre-grouting Strengthening Technology of Shallow and Large Section Metro Tunnel through Fault Fracture Zone

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Abstract: Through the pre-grouting engineering practice of F1 fault fracture zone in People's Hall Station of Qingdao Metro Line 4, the research on the pre-grouting Strengthening Technology of shallow and large section metro tunnel through fault fracture zone is carried out, and the effective means to control the crossing fault fracture zone of the shallow and large section metro tunnel are explored. The results show that it is an effective method to treat the collapse of fault fracture zone by using the combined grouting method of first detection and grouting, and the combination of surface grouting and tunnel grouting in the shallow and large section metro tunnel. For the fault fracture zone near the sea, in order to prevent the continuous erosion of seawater ions to fault fracture zone and station structure, the cement-water glass and sulfo-aluminate cement materials can be considered on both sides of the station, and ordinary portland cement and sulpho-aluminate cement can be used in the middle of the station to ensure the safety and stability of the station, which also could reduce the cost of construction as much as possible.

1. Introduction

In recent years, urbanization and urban scale have developed rapidly in China to result in a stage large-scale construction of urban subways. In the process of urban subway construction, it often crosses harmful geology structures, such as fault fracture zones. Due to the complexity of geological conditions, it is easy to cause disasters such as sand collapse, landslides and surface subsidence under the factors of construction disturbances, which result in casualties and loss of economic property [1-3]. For example, the Hangzhou subway collapsed in 2008 which causes 21 deaths; a shield section of Foshan subway collapse accident the collapsed in2018 which cause 21 deaths.

Grouting has the function of blocking water, increasing the strength of rock mass and enhancing the deformation resistance of rock mass [4-7]. At present, advance pre-grouting method is usually used to reinforce the fault fracture zones which encountered in the construction of the subway. The things
that how to rationally design grouting parameters and select grouting materials are the key factors to reinforce the fault fracture zones [8]. By pre-grouting, the broken rock mass are filled to form a complete grouting reinforcement ring, which can effectively ensure the safety and stability of the subway tunnel during excavation [9].

Through the practice of advance pre-grouting in the F1 fault-fracturing zone of the Hall of the People Station of Qingdao subway, the research of pre-grouting reinforcement technology on shallow-buried large-section subway tunnel crossing fault-breaking zone is carried out. Effective grouting key parameters for controlling shallow-buried large-section subway tunnels through fault fracture zones were explored, including grouting drilling design and grouting material selection. It is hoped that the research results will be helpful for similar projects.

2. Engineering situation

The Hall of the People Station of Qingdao subway is located directly below of Taiping Road in Shinan District. It is a shallow buried excavation station that the buried depth is 15m. The People’s Hall Station is located in the core tourist scenic spot of Qingdao, close to the sea and People's Hall. At the same time, the station is located in old town with extremely big people currency and dense old houses. There are 500m×500m water supply pipelines, sewage pipes, rainwater pipes, streetlights and electric power pipelines distributed above the tunnel excavation affected area. What’s more, some heat pipes are distributed locally.

The area is mainly composed of Quaternary undeveloped fill soil. The thickness of soil is less than 2m, and the some bedrock is partial bare. It is dominated by moderately weathered granite and massive fractured rock. The joints are more developed. Most of rock are fragmentary and scattered, and the self-stability of surrounding rock is poor. The sidewall will often collapse. If the vault is improperly treated, it will easily collapse. The dug station is affected by the F1 fault fracture zone during construction.
3. Analysis of reinforcement difficulties
The key points and difficulties of grouting reinforcement in fault fracture zone in this station are the following three aspects:

(1) The excavation section is 20, and this is large; the thickness of the overburden, which is 2.6m, is small. The stratum above the overburden is a water-rich sand layer. During the excavation, there is a risk of collapse in the vault which was caused by inrush of sand.

(2) The tunnel passes through the sand layer, and the property of surrounding rock of the fault fracture zone is complex, and the self-stability ability is poor. Therefore, there is a high requirement for grouting reinforcement here.

(3) The inrush of sand causes the loss of the stratum above the station in the cave. When inrush of sand is serious, a ground will collapse and the pipeline will break.

(4) The buried depth of the pipeline is shallow which is 1-3m, and the road surface traffic is heavy. The grouting and surface traffic affect each other. In the process of grouting, the surface uplift and pipeline deformation are strictly controlled under the premise of ensuring the safety of tunnel excavation.

(5) The fault is directly connected with groundwater. The seawater ions, such as Cl⁻, continually erode the fault fracture zone and the station structure, which requires treatment materials to have special resistance to corrosion.

4. Grouting Design
In view of the hydrogeological conditions of the People's Hall Station of Qingdao Metro Line 4, the surrounding buildings and pipelines, and the geological characteristics of the fracture zone of F1 fault, the combined grouting method of first detection and grouting, and the combination of surface grouting and tunnel grouting is proposed.
In the early stage of treatment, geological radar, transient electromagnetic and other geophysical methods are used to explore the surface grouting treatment area in a wide range to determine the direction and orientation of the pipeline (Fig. 4). The method of trench digging is used in the later period of treatment for accurate exploration of high-risk areas (Fig. 5), especially the location of boreholes distributed around the pipeline, so as to prevent the drilling holes from hitting the pipeline by mistake.

The vertical grouting hole is adopted on the ground surface to reinforce the excavation area above the tunnel excavation face, and the lateral and conventional areas of arch roof are strengthened by advanced pre-grouting in the tunnel, in which the surface grouting should take precedence over the grouting in the tunnel. The aim is to minimize the risk of sand collapse. In addition, the inspection of surface grouting reinforcement area and the supplementary grouting hole are arranged in the tunnel to ensure that there is no blind area.

The full-section curtain grouting is used to advance the tunnel excavation affected area, focus on strengthening the tunnel vault impact area, comprehensively analyze the hydrogeological data, monitoring data and other multi-information, dynamically determine the grouting reinforcement area and key grouting parameters, and finally a grouting reinforcement region mainly composed of split grouting veins is formed on the tunnel vault and both sides to ensure the stability of the surrounding rock of the tunnel and the safe excavation of the tunnel.

4.1 Drilling design

4.1.1 Surface grouting drilling design
As shown in Fig. 6, the width of the surface grouting reinforcement area is 15m (pavement width), the height is 6m, the grouting segment length is 3m, the interval between holes is 1.2m. There are 13 grouting holes in each row, a total of 97 rows. The sleeve valve tube grouting technology is divided into two sequence holes, and the one-sequence hole adopts the combined grouting method of the casing + film bag + sleeve valve tube, and the mold bag is opened and pressed by injecting rapid setting and solidifying material into the film bag to form an artificial sealing batholite. Considering the compaction effect of the one-sequence orifice film bag, the second-sequence hole is only grouted by the sleeve valve tube and inserted into one-sequence hole.
4.1.2 Grouting design in tunnel

In the tunnel, the lateral part and conventional area of arch roof are strengthened by advanced grouting. The reinforcement length is 15 m per cycle, the excavation length is 12 m, and the 3 m grouting section is set as the next artificial sealing batholite.

In order to avoid the blind area of grouting, the length of each cycle grouting section is divided into three sections, which are respectively strengthened in the range of 0-7m, 7-11m and 11-15m. The first sequence drilling reinforcement range is 0-7 m, the second sequence drilling range is 7-11 m, and the third sequence drilling and grouting hole reinforcement range is 11-15 m.

The plum-shaped cloth hole method is adopted. The hole spacing between the holes is 2.5 m in the dome and 4 m in the rest. The spacing between holes varies in size and has been marked in the drawing. The details are shown in Figure 7.

4.2 Grouting materials

Three grouting materials of cement-water glass, sulpho-aluminate cement and ordinary portland cement are selected. Considering that the fault conducts seawater, in order to prevent the continuous erosion of seawater ions on the fault fracture zone and the station structure, cement-water glass and sulpho-aluminate cement materials are used on both sides of the station. The intermediate area uses ordinary cement and sulpho-aluminate cement materials. Under the premise of ensuring the safety and stability of the station excavation, the construction cost should be reduced as much as possible.
Cement-water glass slurry ratio is W:C=1:1, C:S=3:1~4:1. It is used to control the diffusion range of the slurry and form an artificial anti-slurry wall to prevent the slurry from spreading to the periphery of the reinforcement area. The ratio of sulpho-aluminate cement slurry is W:C=1:1. It is used to resist seawater erosion and to strengthen fault fracture zone. The ratio of ordinary cement slurry is W:C = 1:1, the price is low, and the reinforcement fracture layer is supplemented.

5. Grouting reinforcement effect
At present, the curtain grouting has been implemented to complete the partial cycle. Judging from the excavation of the grouting section (Fig.8), the curtain grouting scheme can effectively strengthen the fault fracture zone. After the grouting reinforcement, the surrounding rock is relatively stable, which can ensure the safety of the subway tunnel excavation.

6. Conclusions
(1) It is an effective method to treat the collapse of fault fracture zone by using the combined grouting method of first detection and grouting, and the combination of surface grouting and tunnel grouting in the shallow and large section metro tunnel.

(2) For the fault fracture zone near the sea, in order to prevent the continuous erosion of seawater ions to fault fracture zone and station structure, the cement-water glass and sulpho-aluminate cement materials can be considered on both sides of the station, and ordinary portland cement and sulpho-aluminate cement can be used in the middle of the station to ensure the safety and stability of the station, which also could reduce the cost of construction as much as possible.

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