Study on the mechanism and treatment measures of tunnel mud outburst induced by water leakage of pipelines

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Abstract. In order to study the mechanism and treatment measures of urban pipeline leakage inducing mud outburst in tunnels, basing on the case of tunnel mud outburst accidents, this paper analyze the mechanism of urban pipeline leakage inducing mud outburst in tunnels, and propose reasonable surrounding rock reinforcement technology and auxiliary construction method. The results show that the synergistic effect of clay properties and pipeline leakage has the most significant impact on this tunnel mud outburst, while the impact of support measures and auxiliary construction methods on this tunnel mud outburst is manifested by lack of human vigilance. Based on the analysis of the mechanism of urban underground pipeline leakage inducing mud bursting in the tunnel, comprehensive treatment measures inside and outside the tunnel are adopted to effectively reduce the moisture content of the surrounding rock of the tunnel, improve the mechanical characteristics of the surrounding rock of the tunnel, and effectively guarantee the tunnel’s subsequent excavation.

1. Introduction
There are more and more unfavorable geological conditions in tunnel engineering. Tunnel construction under unfavorable geological conditions is prone to geological hazards such as water and mud outburst, rock and soil collapse[1]. Water and mud outburst is one of the most serious disasters in the process of tunnel construction.[2].

With regard to the mechanism, prevention and treatment measures of mud bursting in tunnel engineering, scholars have made a lot of useful explorations. Qian Qihu[3] believes that water and mud outburst in karst tunnels is essentially a dynamic instability phenomenon caused by groundwater migration network or storage conditions affected by external interference. The influencing factors can be summarized as engineering factors and geological factors. Chen CZ[4] conducted an analysis of the characteristics of the No. 9 fault in the Dayaoshan Tunnel, analyzed the causes of water and mud outburst, and proposed engineering countermeasures for treatment. In 2010, the amount of urban water supply leakage was as high as 6 billion cubic meters. Some pipelines are difficult to repair due to ages and excessive buried depths, forming underground water sources, which are extremely prone to accidents. However, the current research on tunnel mud bursting mainly focuses on water-rich karst and fault mountain tunnels. Some scholars have studied the construction risks of urban tunnels under pipeline leakage[5,6], but there is a lack of relevant examples. This paper analyzes the inducing mechanism of urban underground pipeline leakage on the tunnel mud outburst, and proposes a comprehensive treatment.
2. Project overview

2.1. Engineering geology overview
Harbin rail transit line 3 Songjiang ecological park station ~ Jinxiang street station (Songjin section) start mileage DK15+192.001, end mileage DK16+141.916. The subsurface excavated tunnels in the Songjin section are distributed in the Gangfu-shaped plain landform unit. According to drilling reveals and analysis of the origin and age of the stratum, the stratum of this section is mainly mixed fill and silty clay. The buried depth of the mixed fill is 0.5-4.2m at the bottom of the layer, and the average thickness is 1.67m. The properties of the soil are as follows Table 1 shows.

| Serial number | Soil layer | Severe(kN/m³) | Cohesion (kPa) | Internal friction angle(°) |
|---------------|------------|---------------|----------------|--------------------------|
| 1-1           | Mix fill   | 19.6          | 11             | 10                       |
| 4-2           |            | 19.2          | 27             | 15                       |
| 4-2-1         |            | 19.0          | 26.1           | 19.3                     |
| 4-2-2         |            | 19.0          | 32.5           | 18.8                     |
| 4-2-3         | Silty clay | 18.7          | 25.7           | 10.2                     |
| 5-1           |            | 19.5          | 26.3           | 14.3                     |
| 5-1-1         |            | 19.3          | 27.3           | 18                       |
| 5-1-3         |            | 19.4          | 24.2           | 8.2                      |

2.2. Hydrogeology overview
The main types of groundwater in the Songjin interval include Quaternary pore pressure to unpressurized water and upper stagnant water. The buried depth of the stable water level of the survey pores is 39.1~44.50m (the elevation range is 110.78~127.38m), which is a pressure-free zone and has little impact on the construction of subway stations or tunnels.

2.3. Overview of tunnel mud bursting
On June 29, 2017, a mud outburst occurred in the Songjin section. The silt-like soil poured into the tunnel about 35m, forming a silt zone with a height of about 1.8m and a length of 35m, which was distributed in the lower half of the tunnel, and poured into about 216 m³ of earth. A collapse pit with a radius of about 4m and a depth of about 4m is formed on the ground, and about 200m³ of soil are lost. The collapse pit is 4.8m in front of the tunnel excavation.

3. Tunnel Mud Burst Mechanism

3.1. Leaking water from underground pipelines
The diving water level is more than 10 meters below the tunnel, and the excavated tunnel is a pressure-free zone. However, the soil layer revealed by the tunnel excavation shows that the soil is soft plastic or flow plastic and has a large water content (as shown in Table 2). The water content of the soil layer at the DK15+684.4 vault is 37.1%. After investigation, it was showed that the high water content was caused by the leakage of underground pipelines.
### Table 2. Tunnel soil moisture content

| Mileage | Left side walls | Arch crown | Right side walls |
|---------|----------------|------------|------------------|
| 676.4   | 33.83          | 35.41      | 36.11            |
| 677.4   | 32.92          | 35.38      | 33.11            |
| 678.4   | 36.27          | 36.18      | 36.97            |
| 679.4   | 36.28          | 32.77      | 34.79            |
| 680.4   | 34.57          | 34.62      | 35.64            |
| 681.4   | 35.22          | 32.92      | 34.10            |
| 682.4   | 34.45          | 32.55      | 36.59            |
| 683.4   | 34.32          | 36.43      | 32.91            |
| 684.4   | 34.57          | 37.10      | 34.92            |
| 685.4   | 34.23          | 34.78      | 35.63            |
| 686.4   | 33.52          | 33.43      | 36.50            |
| 687.4   | 36.12          | 35.95      | 34.54            |
| 688.4   | 34.12          | 36.31      | 35.87            |
| 689.4   | 37.01          | 34.33      | 33.25            |
| 690.4   | 33.68          | 36.08      | 34.32            |

The mud outburst section of the Songjin section is located in the reserve land between the No. 1 and No. 2 shafts. The site was originally the Songjiang Electric Machinery Plant and the village. Due to the early construction time, the relevant pipeline drawings have not been saved, and there are many privately connected pipelines. In addition, due to long-term disrepair, there is serious water leakage from underground pipelines in the site.

After the mud burst occurred in the tunnel, 3 tap water pipelines were found around the site that were leaking water, and a tap water pipe with a diameter of 300mm was found above the subsidence. However, the soil moisture content of the tunnel is still greater than 30%. It is estimated that there is an undiscovered underground pipeline in the depth of the soil. Due to the proximity of the road and the limited excavation conditions, it is still difficult to determine its exact location after two supplementary surveys.

#### 3.2. Atmospheric precipitation

According to on-site investigations, Harbin, from June 1st to June 29th, 2017, the Songjin section tunnel was in a total of 13 days of rainfall. The rainfall was abundant, the hardened area of the ground site was small, A large amount of precipitation infiltrates into the ground and changes from surface water to groundwater. The self-weight of the soil layer increases. The infiltration of rainwater will reduce the shear strength of the soil layer and induce mud outburst in the tunnel.

#### 3.3. Supporting measures and auxiliary construction methods

Insufficient attention was paid to the water seepage situation in the early stage, and the water source problem was not fully understood. The traditional support measures of steel grid + steel mesh + shotcrete were still used in the mud burst section of the Songjin section. The impact of construction on the ground disturbance and the stability of the surrounding rock was not considered, and the necessary water stop measures were lacking, which eventually caused the tunnel to burst into mud.

#### 3.4. The mechanism of pipe leakage induced mud burst in tunnel

After the underground water supply pipeline leaks, the tap water leaks outward under the action of water pressure, and a stable pipeline leakage area is gradually formed near the leakage point of the pipeline. Before the tunnel excavation, a dynamic water pressure balance has been formed. Clay has poor permeability, so the pipeline leakage area is small, and the pipeline leakage water volume is relatively small. Traditional survey methods are expensive and difficult to detect.
A large number of studies have shown that: the more developed the groundwater, the higher the frequency of instability of the tunnel face, that is, the worse the stability\textsuperscript{[7,8]}. After the tunnel is excavated, an open surface is formed at the tunnel face, the original hydrodynamic pressure balance in the stratum is broken, the seepage path of pipeline leakage water is changed, and groundwater seeps into the tunnel face under the effect of seepage stress (as shown in Figure 3). Under the effect of water, the weight of the surrounding rock of the tunnel increases, and the mechanical strength index of the soil decreases, which induces mud outbursting in the tunnel.

4. **Comprehensive treatment of tunnel mud burst**

After the mud burst occurred in the tunnel, emergency measures were taken quickly on site, the tunnel face was basically stable and the ground no longer subsided. In order to ensure the subsequent excavation of the tunnel, the comprehensive measures are adopted to treat the tunnel in the pipeline leakage area. The water volume has dropped significantly, and the soil mechanics indicators have been comprehensively enhanced.

4.1. **Radial grouting**

In order to stabilize the primary structure, the completed primary structure is reinforced by radial grouting. The side walls are first grouted and then the arch crown is grouted. The length of the grouting pipe is 3.5m, the circumferential spacing is 1m, and the longitudinal spacing is 1m, the grouting pressure is controlled at 0.8~1MPa.

4.2. **Ground grouting reinforcement**

The backward segmented grouting method is used to reinforce the soil in front of and around the handshaft through ground grouting. The grouting area is 15m×14m, the hole spacing is 1m, the plum blossom type is arranged.

4.3. **Grouting reinforcement**

Deep hole grouting is carried out on the tunnel face. The grouting depth is 4m and the grouting pressure is controlled at 0.8~1.0MPa. The hole spacing is 600mm, divided into two rows. There are 21 holes in total with a distance of 500mm. Considering the uniform penetration of the slurry, it is arranged in a plum blossom shape. The radius of influence of grouting is 0.5~0.75m to ensure that the soil in front of the handle is connected as a whole after treatment.

4.4. **Ground vacuum precipitation**

| date (No.) | water output (m\textsuperscript{3}) | pressure (MPa) |
|------------|------------------------------------|----------------|
|            | No.1 | No.2 | No.3 | No.1 | No.2 | No.3 |
| 10.22      | 11   | 14   | 12   | -0.08 | -0.09 | -0.08 |
The engineering site is mainly composed of impermeable water layers such as silty clay, and the effect of ordinary dewatering wells is poor, so vacuum dewatering wells are used for dewatering. The filter pipe is a bridge water filter pipe with the same specifications as the well pipe, with an 80 mesh nylon filter outside, and a 1m long sedimentation pipe at the bottom; a solid pipe of about 6m is set on the top of the filter pipe. And backfill the cohesive soil to seal it to facilitate vacuum pumping. Table 3 shows the operation status of vacuum dewatering wells.

### 5. Conclusion

1. The leakage of urban underground pipelines has the most significant impact on the mud bursting of the tunnels in the Songjin section, which is the main reason for this tunnel mud bursting. Abundant atmospheric precipitation before the mud burst, inadequate support measures and auxiliary construction methods are secondary factors.

2. After the underground water supply pipeline leaks, a stable pipeline leakage area is gradually formed near the pipeline leakage site. After the tunnel is excavated, an empty surface is formed at the face of the tunnel, and the original hydrodynamic pressure balance in the stratum is broken. The seepage path of the pipeline leakage water changes, and the groundwater seeps into the tunnel face under the effect of seepage stress. The weight of the surrounding rock of the tunnel increases, which induces mud outburst in the tunnel.

3. Based on the analysis of the municipal underground pipeline leakage water-induced mud outburst mechanism in the tunnel, the comprehensive measures are adopted to treat the tunnel in the pipeline leakage area. The water volume has dropped significantly, and the soil mechanics indicators have been comprehensively enhanced.

### Acknowledgments

This research was financially supported by the Applied Basic Research Project (main subject) of the CCCC Second Harbour Engineering Co.,Ltd.(No. HT-2017-A-07-007). And also the authors are grateful to the reviewers for their precious comments and advice.

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