Research on Risk Early Warning Mechanism of Urban Metro Construction

Li Meng, Wu Denghui*, Zou Jian
School of Management, Wuhan University of Science and Technology, P.R.China
*Corresponding Author: 386900793@qq.com

Abstract. The subway construction in China has developed rapidly in recent years, but due to the influence of subway construction technology and construction environment, risk incidents occur frequently in the process of subway construction. Referring to the experiences and practices of Beijing Metro construction, combined with the relevant knowledge of risk early warning, the function process of risk early warning is clarified, that is, the classification and identification of risk early warning grade, early warning issuance, early warning response, and early warning mitigation. The application effect of early warning mechanism in risk management of metro station construction is studied, which provides reference for risk early warning management of metro construction.

1. Introduction
In terms of alleviating the urban traffic pressure, the metro's powerful transport capacity is beyond comparison with other urban traffic tools. As metro engineering construction is mostly located in the city center, it is unavoidable for metro construction to be affected by complex and diverse engineering surroundings, engineering geology and hydrogeology conditions. There are tremendous risks in the process, and it is very easy for risk events to occur. Perfect risk early warning mechanism is an important guarantee for the safety of metro construction, which can effectively prevent and deal with the risks in metro construction. The application research of metro construction risk early warning plays a key role in safety risk management and control of metro construction.

2. Risk Early Warning Mechanism of Urban Subway Construction
Risk early warning refers to the prediction and warning of the risks based on the characteristics of the research object, the collected information and the analysis of the changing trend of the risk-causing factors, so as to take measures in advance or in time. Wang Long et al. [2-4] studied the practical application of risk early warning mechanism in safety management of railway construction. By establishing a perfect risk early warning system, this paper discusses the application principles of strengthening the monitoring intensity of construction process, risk prevention awareness and risk early warning mechanism in safety management of railway construction.

In the process of risk early warning management in urban subway construction, the management of risk early warning can be roughly divided into four aspects: 1) risk early warning classification and identification; 2) early warning issuance; 3) early warning response; 4) warning elimination.

2.1. Classification and Identification of Risk Early Warning Grade
The risk early-warning of metro engineering can be divided into monitoring early-warning, inspection early-warning and comprehensive early-warning in accordance with categories[5-6]. All kinds of early-
warning have three warning levels: yellow, orange and red. The criterion of monitoring and early warning level is to compare the monitoring data set by the third party monitoring units with the early warning values of monitoring and control standards, and to evaluate and warn the safety risk status of the monitoring points in construction; the criterion of the inspection and early warning level is to inspect the safety risk status of the construction site, and the inspectors on the site will inspect the surrounding environment of the project and the risk events that will happen to the project itself. For early warning, due to the difference of subway construction methods, the mode and location of on-site inspection are also different; comprehensive early warning is to further analyze the level and distribution of monitoring and early warning, and to comprehensively identify the early warning level by organizing expert argumentation meetings and on-site verification. When the monitoring early warning is orange or red and the inspection early warning is yellow, the comprehensive early warning is yellow; when the monitoring early warning is orange or red and the inspection early warning is orange; when the monitoring early warning is orange or red and the inspection early warning is red, the comprehensive early warning is red.

2.2. Early warning issuance

Early warning issuance refers to the analysis of the collected information in the process of subway construction, such as project monitoring, inspection information, site construction safety, to warn about the risk events that will occur, so that the relevant units can find the risks in time and take countermeasures. Early warning issuance can be divided into three categories: monitoring early warning issuance, inspection early warning issuance and comprehensive early warning issuance.

1) Monitoring Early Warning Issuance

The actual monitoring data of the third party monitoring units are compared with the monitoring and measurement control standards provided by the design units. When the monitoring data exceeds the early warning standards, monitoring early warning are issued, and the level of early warning is judged according to the specific differences of monitoring data. The standard of monitoring measurement and control is given in the design document by the design unit in combination with the specific engineering geology, hydrogeology and environmental conditions of the metro project.

2) Inspection Early Warning Issuance

Construction, supervision and third-party monitoring units conduct inspections on their safety risk status at the metro construction site. Inspectors discover potential safety hazards or unsafe conditions while inspecting various engineering sites, analyze the location and safety status of risks, and make a judgment on whether to issue early warning and warning levels.

3) Comprehensive Early Warning Issuance

The monitoring early warning situation, inspection early warning situation, evaluation of risk engineering situation and suggestions put forward by experts are comprehensively analyzed, and the early warning level is judged and issued. The early warning issued should include the specific location of the project, site safety risk status, initial reasons and so on.

2.3. Early Warning Response

The key of early warning response is the timeliness of early warning response of construction, supervision, third-party monitoring and other parties. The timeliness of response is the guarantee that risk events can be properly handled, which is related to whether risk events can be effectively prevented or avoided. After the issuance of risk early warning in metro construction, construction, supervision, third-party monitoring and safety risk consulting units and other relevant participants should strengthen the monitoring and inspection of early warning sites, and take corresponding measures in time to avoid the occurrence of risks.

2.4. Risk Mitigation

Risk mitigation refers to the early warning and eliminating work carried out by eliminating or reaching the conditions for eliminating the potential safety hazards of risk engineering through the early warning
response of risk events in the process of construction. Referring to the division of early warning issuance and response, fire fighting can also be divided into three categories: monitoring, early warning, inspection and comprehensive early warning.

Monitoring Early Warning Mitigation

The third-party monitoring unit is responsible for the analysis of monitoring early warning, and the safety risk status evaluation of where orange monitoring early warning is issued. When the evaluation result is safe, orange monitoring early warning can be reduced to yellow monitoring early warning; when the evaluation result is high risk, orange monitoring early warning should be upgraded to red monitoring early warning; after management of orange monitoring early warning is completed, the design unit shall formulate the next monitoring. The monitoring early warning standards are used to guide the construction of metro projects on site. The upgrade and downgrade process of monitoring early warning is shown in Figure 1.

![Figure 1. Upgrading and Downgrading Process of Monitoring Early Warning](image)

3. **Study on risk early warning mechanism of subway station construction**

The metro station is located in the green space of Xinxing Bridge area where a road intersects with the West Third Ring Road. The net width of the two main structures is 13.25 m in East and west, and the roof covering soil is about 5 m. The main single-storey section of the station passes through the existing station with "zero distance" rigid contact. In order to avoid bridge piles, the station adopts the platform station of separate island type, and its structure is a double-storey single-span arch straight wall structure. The station passes through an existing metro station and transfers with it in the form of "double crosses". The station passes through 10, 11 and 12 axes piers on the south side of Xinxing Bridge.

The open-cut shaft in the northeast of the main body of the station is adjacent to the new pier, and yellow comprehensive early warning of pier sedimentation occurs during construction. The cumulative sedimentation values of piers are shown in Table 1.

| Number of measuring points | QCJ01-01 | QCJ01-02 | QCJ01-03 | QCJ01-04 | QCJ01-05 | QCJ01-06 |
|---------------------------|----------|----------|----------|----------|----------|----------|
| Accumulated settlement value /mm | -7.6     | -7.4     | -8.2     | -8.7     | -9.3     | -9.7     |

From Table 1, it can be seen that the sedimentation monitoring data of 6 piers with 10, 11 and 12 axes on the south side of Xinxing bridge show that the maximum cumulative sedimentation reaches 9.7 mm, and the sedimentation rate of 4 surface sedimentation measuring points exceeds the limit of orange warning, and the sedimentation situation of piers and surface still has a trend of development. On-site inspection found that cracks appeared on the road surface above the main body of the station, and the surface of the south end of the Northeast excavation section of the main body of the station had obvious subsidence. The project monitoring sub-center comprehensively analyzed the monitoring data and field inspection information of 10, 11 and 12 axes piers on the south side of Xinxing Bridge, and issued yellow comprehensive early warning.
After the early warning is issued, supervision units immediately organize survey, design, third-party monitoring, construction, construction and other units to hold analysis meetings of comprehensive early warning response. Combined with the early warning situation and data of ground cracks station and pier sedimentation by the third party monitoring unit, the causes of ground cracks and pier sedimentation are analyzed as follows: 1) water leakage may occur in the construction shaft of No.1 and No.2, which causes the change of stratum structure and soil sedimentation; 2) the Xinxing Bridge piles are friction end-bearing piles, and the stratum disturbance makes friction loss at the side of the bridge pile during tunnel excavation, and partial sedimentation of bridge piles may occur.

Early warning response analysis will formulate response measures based on the reasons concluded by the analysis: 1) Construct in strict accordance with the "eighteen-word" principle of shallow-buried excavation method, form closed structure in time, strengthen advanced and backfill grouting; 2) Strengthen the monitoring and inspection of newly-built bridge piles, adopt grouting reinforcement combined with ground and tunnel grouting and effective water-stopping measures to prevent groundwater loss, control the continuous development of sedimentation, and ensure the safety of bridges.

According to the opinions of the early warning response analysis meeting, the construction unit forms a specific risk treatment scheme (implemented after supervision and approval): increase the monitoring frequency of piers and surface survey points; adopt grouting reinforcement measures combining inside and outside the cave (directional grouting in the cave and deep hole grouting in the surface outside the cave) to achieve the goal of "controlling sedimentation, comprehensive treatment and ensuring the safety of the bridge area".

After treatment, the sedimentation curves of the six piers tend to be stable, the piers do not have large deformation, and there is no further trend of sedimentation. The sedimentation rate of four measuring points of ground sedimentation (DB01-23, DB01-24, DB01-25 and DB01-29) is over the limit. The main reason is that the ground heave is caused by the advanced grouting of the underground excavation conducting tunnel. By taking measures, the ground sedimentation has become stable. The curve of surface sedimentation and deformation is shown in Figure 4.

After the issuance of the yellow comprehensive early warning, the relevant early warning units attached great importance to the early warning, and took early warning response actions in a timely manner, effectively controlling the further development of sedimentation.

4. Conclusion
Risk early warning mechanism of metro construction can effectively avoid or reduce the project risk, and it is an important guarantee for the safety of metro construction. In the process of the risk early warning mechanism, the timeliness of responsive action plays a key role in preventing risk early warning events from developing into accidents. In risk identification, assessment and early warning information release, the risk assessment managers mostly rely on their usual work experience, which may lead to that the accuracy of risk analysis results is difficult to guarantee, and that is not conducive to the development of risk management in metro construction. In order to do well in the application of early warning mechanism and ensure the smooth construction of metro projects, measures or methods should be taken to improve the ability of risk management personnel to assess and identify risks.
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