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Research and Practice of Monitoring Measurement Security Technology of Portal Excavation for Mountain Tunnel

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***Abstract*—In the construction process of portal excavation for mountain tunnels, the improper risk management and control result in the instability of the front slope, deformation of the tunnel portal and subsidence of the roof. In order to carry out the purport of dynamic design and informationalized construction, ensuring the quality and security of portal construction, a three-dimensional and multi-level monitoring measurement system is indispensable. Combining with the practical monitoring measurement of the portal excavation of the tunnel exit in a mountain tunnel in Chongqing, the monitoring measurement system construction process of portal excavation for mountain tunnels is expounded. Besides, the portal stability analysis method and the monitoring information feedback procedure based on multi-source data for the three-dimensional and multi-level monitoring measurement system are analyzed.**

Keywords-mountain tunnel; portal excavation; monitoring measurement; stability analysis; information feedback

I. INTRODUCTION

As the important component of transportation network including railway, highway and urban subway, tunnel is also the basic form of underground space utilization [1]. Mountain tunnels, which connect plenty of cities, are the traffic tunnels across mountains and are able to transport both passengers and goods. However, the complicated geological conditions and construction surroundings bring about much trouble for tunnel construction quality and security. As one of the three elements of the new austrain tunnel construction method, monitoring and measurement play an essential role in informationalized tunnel construction and ensuring construction security. Consequently, monitoring and measurement are the job of great concern [2].

In the process of mountain tunnel construction, portal excavation and support are the initial procedures, and their construction schedule and quality directly influence the excavation schedule and construction security inside the tunnel. With the improvement of environmental awareness and advancement of construction technology, the portal forms of mountain tunnels become diverse while some problems appear frequently, including instability of the front slope in the portal, subsidence in the tunnel roof and deformation in the portal. For the construction security, carrying out the purport of dynamic design and informationalized construction, as well as establishing a three-dimensional and multi-level monitoring measurement system, is particularly important. Therefore, based on the practical monitoring measurement of portal excavation in the tunnel exit of a mountain tunnel in Chongqing, the monitoring measurement construction process of portal excavation for mountain tunnel is explained. In addition, the stability analysis method and the monitoring information feedback procedure based on multi-source data for the three-dimensional and multi-level monitoring measurement system are analyzed, providing a security blanket for portal excavation in mountain tunnels and references for similar projects.

II. Engineering Background

A. Engineering Situation

The second section (K5+300~K11+594) of the mountain tunnel in Chongqing mainly includes the following parts. The left line (ZK5+300~ZK9+685) is 4385 meters long while the right line is 4395 meters long. Besides, there is 2# underground ventilator room and 2# ventilation inclined shaft (X2K0+000~X2K1+145) with the length of 1145 meters. Moreover, there are 2# bridge, 3# bridge, 4# bridge and Wanzhou connection road.

B. Geological Environmental Conditions

The tunnel exit is located at a slope which is north of Wanzhou Changping machinery. The elevation of the exit is about 427.58 meters. The slope aspect is S38°E and the terrain slope is 15°~30°. The overlying residual clinosol solum is silty clay with gravel and the thickness is 1.2~7.9 meters. The underlying bedrock is mud stone with sandstone. The intensely weathered zone is as thick as 3.6~8.9meters. The groundwater level in tunnel exit is 1.2~7.9 meters and the water table is 430.8~424.1 meters.

The structure of the slope in the exit is consequent slope with the terrain slope of 15°~30°. It is soil-rocky bedding slope. The surface soil layer is silty clay with gravel and the thickness is 2~5 meters. Under the overburden is mud stone with sandstone. The dip angle of strata level is 58°. The lower bedrock is mud stone with sandstone in lower Shaximiao formation of middle Jurassic (J2xs), and the inclination direction is 147° while the dip angle is 35°. The overall slope situation is stable. The slope that the elevation is over 440 meters is sporadically distributed with residual clinosol solum with the thickness of 0.4~0.8 meters. The solum is also stable.

C. Portal Design Form

The design of tunnel portal should follow the principle of get in early and get out late and the idea of safe, economic, concordant and natural. Considering the capacious portal space and the gentle slope distributed with loose accumulation on the surface, both left and right lines in tunnel exit are designed as the form of bamboo cutting to avoid large area of slope cutting and as shown in Figure 1.

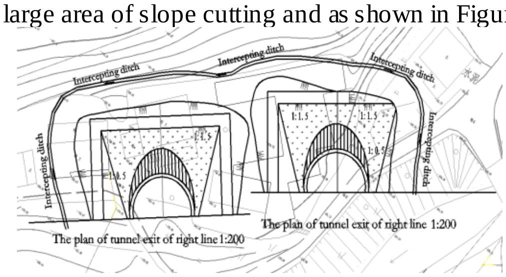

Figure 1. The plan of portal design in tunnel exit

D. Risk Source Analysis

1) Tunnel body in the exit:

The surrounding rocks of left and right lines are J2x2 sandstone with shale, with strong to moderate weathering. The surrounding rocks are relatively soft rocks with developed fractures and broken rocks. The overlying strata on the roof are relatively thin, the part of that is solum and it is shallow-buried section which has a bad tunneling condition. The arch is likely to collapse when there is no support. The jamb wall is easily to loss stability and fall-block occurs easily. Additionally, the groundwater level is higher than the roof, which may leads to linear flowing water, seepage and drip. Because the thickness of the left tunnel mountain is obviously less than that of the right, eccentric compression may be appeared related to the terrain.

2) Slope and front slope in tunnel exit:

After the excavation in tunnel exit, there are two soil-rocky slopes at the left and right of the exit with the thickness of 5~10 meters. The slopes are bedded structure with two groups of fractures. The inclination of the intersecting line of fracture L1 and fracture L2 is 335° and the dip angle is 38°. Meanwhile, a soil-rocky slope appears on the roof of the exit with the dip angle of 15°~20°. The surface soil layer is 2~5 meters. Furthermore, under the overburden is a bedded slope of mud stone with sandstone. The aspect of it is 142° and the strata occurrence is 150°∠58°. The above mentioned slopes and front slopes should be supported after excavation.

3) Natural gas pipeline in the roof of tunnel exit:

There is a natural gas pipeline of China National Petroleum Corporation in Wanzhou operation area, which is orthogonal to the tunnel, at the back edge of the front slope in the roof of the tunnel exit. The diameter of the pipeline is 110 millimeters and the burial depth is less than 1meter. The daily delivery value reaches 150 thousand cubic meters. Meanwhile, the gas pressure is 9MPa and the gas is harmful gas without desulfidation. As the shallow burial depth of the natural gas pipeline and the relatively thick overlying strata, the protection of the pipeline should be strengthened in the tunnel construction.

III. Construction of Monitoring Measurement System

The field monitoring measurement is an important part of the design and construction of the new austrian tunneling method. It is able to guide the construction, forecast the dangerous cases, ensure the safety and obtain deformation and stability status of surrounding rocks and supporting structure by monitoring data analysis, providing information and bases for structure design optimization, supporting parameter and construction technology. Besides, it is capable to accumulate data for tunneling engineering design and construction. Therefore, in the process of portal excavation of tunnel construction, carrying out monitoring and measurement is considerably important.

A. Construction Principle of Monitoring Measurement System

The construction of monitoring measurement system mainly follows the principles below [1].

1) Principle of reliability:

Reliable instruments are necessary for monitoring system, and measuring points should be protected during the monitoring at the same time.

2) Principle of multi-level monitoring:

The monitoring object is given priority to displacement while giving consideration to other monitoring projects. In terms of monitoring methods, instrument monitoring is the main method, supplemented by patrol. Measure points should be stationed in shallow buried surface, areas close to buildings and above underground pipelines respectively, forming a monitoring network covering a certain number of measure points.

3) Principle of monitoring priority on key areas:

Monitoring point arrangement should be reasonable. The relationship between time and space should be paid attention to, and the key parts should be controlled. Besides, the deformation monitoring frequency in the areas close to tunnel face should be improved.

4) Principle of convenience and practice:

To reduce the interference between monitoring and construction, the installation and measurement of monitoring system should be as convenient and practical as possible.

B. Original Data for Monitoring Measurement

Before monitoring, engineering situation, conditions related to hydrology, geology, transportation and climate in monitoring areas, construction design and organization should be appreciated adequately. Therefore, the basic data in TABLEⅠ are needed in the process of monitoring measurement system construction [3].

C. Monitoring Contents and Methods

The determination of the contents and methods of monitoring should follow the basic principles mentioned in Ⅲ-A. They should be determined with comprehensive analysis and adequate understanding of geological and hydrological conditions around the portal, specific risk sources, construction design and organization. Therefore, the following monitoring projects and methods listed in TABLE are formulated according to the conditions around the portal in the tunnel exit.

D. Layout of Measure Points

1) Observation of geology and support condition:

After each blasting excavation, the relevant circumstances and phenomena obtained from geological observation, geological sketch, and photography or camera technology are recorded in detail. In the observation, the discovery time, specific mileage position as well as the description of abnormal phenomenon must be recorded in detail when the abnormal phenomenon is found.

2) Horizontal convergence and crown settlement:

According to the requirements of relevant specifications [4], the layout of measure points for horizontal convergence and crown settlement, in terms of the excavation construction of benching tunneling method, is implemented according to Figure 2.

3) Three-dimensional surface displacement monitoring of shallow layer in front slope:

The measure points are positioned mainly in the portal section where the top of front slope is perpendicular to the tunnel center line. In the tunnel area, points are positioned every 2 meters from the crown with bilateral symmetry. In the area less than 45°, points are positioned every 4 meters with bilateral symmetry, as shown in Figure 3.

TABLE I. BASIC DATA FOR TUNNEL MONITORING MEASUREMENT

Serial number	Name of data
1	Geological investigation reports of tunneling engineering
2	Documents of construction drawing design
3	Documents of construction organization
4	Specifications for highway tunnel design, Specifications for construction technology of highway tunnels

TABLE II. THE MAIN MONITORING PROJECTS DURING THE PORTAL EXCAVATIO

Serial number	Name of project	Monitoring method	Monitoring purpose
1	Observation of geology and support condition	Geological observation, geological sketch, photography or camera technology	Master of the occurrence of surrounding strata, structure plane characteristics, karst caves, faults and seepage conditions of portal and front slope, observe fractures of support structure
2	Horizontal convergence monitoring of portal	Various types of convergence gauges	Obtain the convergence trend of tunnel portal and sections of tunnel exit, influence of eccentric compression of slope and front slope on the trend
3	Crown settlement monitoring	Trigonometric leveling	Obtain the crown settlement trend of tunnel portal and sections of tunnel exit, influence of vertical load of front slope on the trend
4	Three-dimensional surface displacement monitoring of shallow layer in front slope	Geodetic method	Obtain the deformation trend and stability condition of in the shallow layer of front slope
5	Deep displacement monitoring of front slope	Automatic monitoring of deep displacement	Obtain the deformation trend and stability condition in the deep layer of front slope
6	Settlement monitoring of roof pipeline	Leveling survey	Master the influence of portal excavation on gas pipeline in tunnel roof

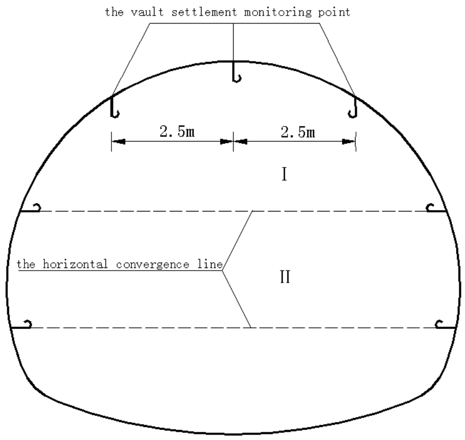

Figure 2. Measure points diagram of benching tunnelling method

4) Deep displacement monitoring of front slope:

To accurately judge the overall stability of the portal, surface displacement monitoring of shallow layer and deep displacement monitoring in front slope should be combined for comprehensively judgment. Some deep displacement monitoring points are stationed along the portal section where the front slope is vertical to the tunnel center line. Meanwhile, the other deep displacement measuring points are stationed every 5 to 10 meters in both left and right line in tunnel area. To check the three-dimensional monitoring points in shallow layer, points of deep displacement should coincide with points of displacement in shallow layer, as shown in Figure 3.

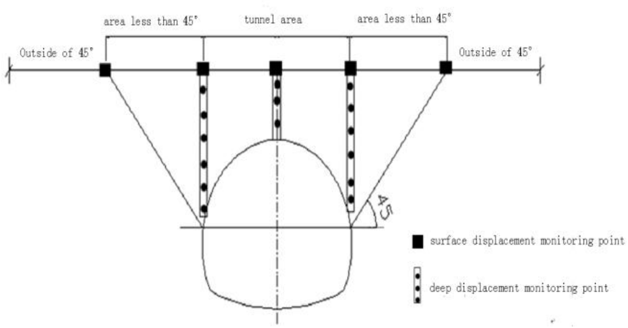

Figure 3. Diagram of measure points of surface and deep displacements in the shallow layer of front slope

5) Settlement monitoring of roof pipeline:

To master the influence of portal excavation on the natural gas pipeline in tunnel roof, subsidence monitoring points are stationed every 5 to 10 meters in the soil mass over the pipeline. The points are monitored and the influence of construction excavation on the stability is paid close attention to.

E. Monitoring Frequency

According to relevant specifications, the monitoring frequency of the projects is shown in the TABLE Ⅳ.

IV. MONITORING DATA ANALYSIS AND INFORMATION FEEDBACK

A. Monitoring Data Analysis

Through processing and analyzing data timely, the purpose of monitoring measurement is to forecast and feed-back the stability and deformation trend of threat objects, effectively guide the tunnel construction, and ensure construction safety. Taking the actual monitoring measurement data of tunnel portal excavation of the project as the analyzed object, this paper elaborates data analysis process under the multi-source data, and makes a judgment of stability and deformation trend of threat objects [6].

Gas pipeline settlement of tunnel roof: On April 22, 2016, five measurement points were arranged along the vertical profile of gas pipeline. By June 29, 2016, total 42 times daily monitoring work were conducted. TABLE Ⅲ shows various points' accumulated subsidence and maximum subsidence rate. Figure 4 shows the curves of time of each point and settlement values.

TABLE III. DISTORTION STATISTICS OF GAS PIPELINE SETTLEMENT OF TUNNEL ROOF OF MONITORING SITES

Point No.	Maximum subsidence rate (mm/d)	Accumulated subsidence (mm)
G1	1.2	1.8
G2	1.5	2.4
G3	3.4	6.7
G4	2.6	5.5
G5	1.7	3.5

The combination of subsidence rate of each point and settlement curves shows that the deformation mainly occurred from May 5 to May 25. The main reason is that the tunnel face was close to the vertical profile of gas pipeline during construction and the construction of tunnel face had effects on gas pipeline. As tunnel face gradually moved away from the vertical profile of gas pipeline (after May 25), the deformation trended to be slowly and measure points became stable.

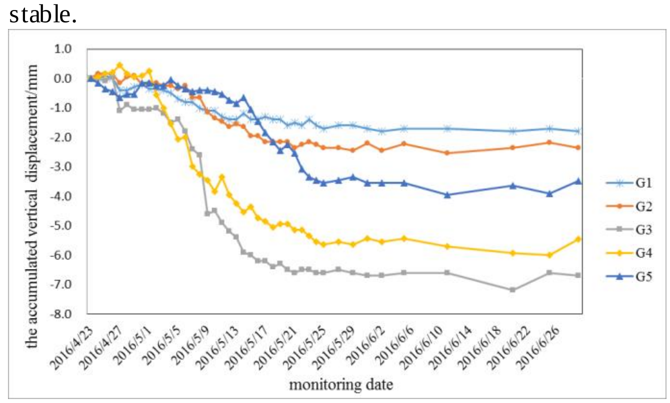

Figure 4. Time of gas pipeline settlement of monitoring points-settlement curves

Front slope of tunnel roof: The stability of the front slope of tunnel roof directly affects the construction progress and construction safety, so it is necessary to closely master the stability status of front slope of tunnel roof during the construction and excavation of tunnel portal and tunnel body. On April 1, 2016, 10 shallow displacement and settlement points and 5 deep displacement points were arranged along the top of the front slope of tunnel roof. The drilling depth respectively are 16m (ZK1), 20m (ZK2), 17m (ZK3), 15m (ZK4) and 18m (ZK5). By June 29, 2016, total 66 times daily monitoring work were conducted. Due to the heavy rainfall on May 8, the junction between the tunnel roof of front slope in right line and the side slope became obviously distorted during the subsequent days, and the tunnel roof of front slope in left line basically stayed stable. Therefore, the stability of the front slope of tunnel roof and deformation trend are judged comprehensively below by analyzing the data of 5 shallow displacement and settlement points and 3 deep displacement points of front slope of tunnel roof in right line.

Shallow displacement and settlement points (T1 - T5) of front slope of tunnel roof in right line - displacement curve and time - settlement curves are shown in Figure 5 and Figure 6 respectively.

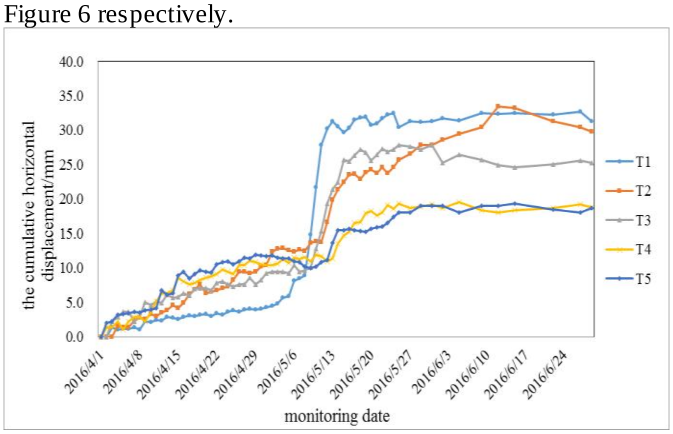

Figure 5. Time-displacement curves of measure points of shallow surface

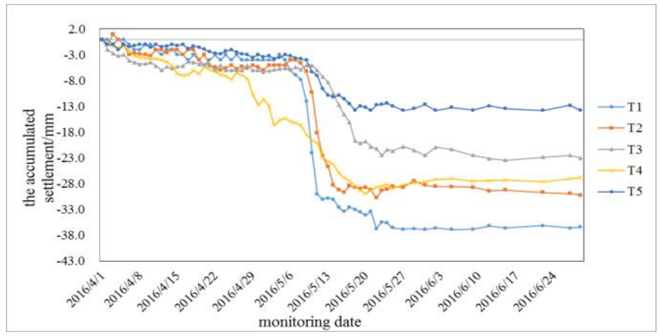

Figure 6. Time-settlement curves of measure points of shallow surface

In order to further understand the deformation of deep rock-soil mass of the front slope, the monitoring data for ZK1, ZK2, and ZK3 is analyzed. By June 29, displacement curves of the deep displacement points are shown in Figure 7.

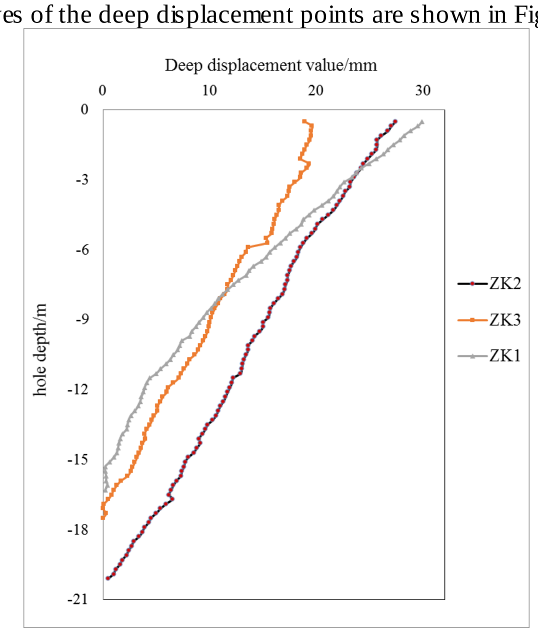

Figure 7. Deep displacement curves of front slope

TABLE IV. MONITORING FREQUENCY OF MONITORING PROJECTS

Serial number	Project name	Monitoring frequency			
		Monitoring time			
		1-15 days	16 days -1 months	1-3 months	More than 3 months
1	Observation of geology and support condition	After each blasting and initial support			
2	Horizontal convergence monitoring of portal	1-2 times / day	1 time / 2 days	1-2 times / week	1-3 times / month
3	Crown settlement monitoring				
4	Three-dimensional surface displacement monitoring of shallow layer in front slope	The distance between excavation face and monitoring section ≤ 2B, 1-2 times / day The distance between excavation face and monitoring section ≤ 5B, 1 time / 2 days The distance between excavation face and monitoring section > 5B, 1 time / week			
5	Deep displacement monitoring of front slope				
6	Settlement monitoring of roof pipeline				

TABLE V. DEFORMATION CONDITION AND TREND OF MONITORING SECTION AROUND TUNNEL PORTAL LINES

Monitoring section	Accumulated convergence value (mm)		Accumulated subsidence value (mm)			Deformation trend
	Measure line 1	Measure line 2	Left Measure point	vault	Right Measure point	
Portal of the left line (K9+695)	18.5	14.0	5.0	7.0	6.5	Tend to be stable
Portal of the right line (K9+680)	15.0	12.5	8.5	8.0	7.5	Tend to be stable

The analysis of monitoring data from the shallow layer of front slope shows that the shallow surface of the front slope in right line had significant displacement and settlement from May 8 to May 8. Meanwhile, the deformation of points (T1, T2 and T3) near the side slope was more significant. Through analysis, the soil mass at the junction between right line front slope and side slope was thicker. As a result of the consecutive heavy rainfall in the evening of May 8, and the intercepting drain of tunnel roof being far away from here, the rain immersed into the soil, and the top of slope cracked, which led to unstable slope. After informing the construction unit about the dangerous cases by monitoring and warning, the existing cracks were timely filled and the support was reinforced. The deformation curves show that the deformation trend of the front slope surface became gentle. Meanwhile, combined with the deep displacement curves, the front slope deep surface did not slide, and no significant deformation appeared in the deep zone. Based on the analysis above, the front slope of tunnel roof is basically in a stable state without deformation development trend.

Horizontal convergence and crown settlement: In this project, since the overlying rock and soil layer of the tunnel is thin, and there is no eccentric compression in the surrounding rock around left and right tunnel lines, the vertical and horizontal loads of the tunnel body are small. Therefore, during the construction of tunnel portal, significant or sustained deformation around tunnel portal didn't occur in both left and right lines. As the tunnel face moved far away, the portal section was stable in normal conditions. By June 29, the horizontal convergence and crown settlement of the monitoring section in tunnel portal are shown in TABLE Ⅴ.

B. Feedback of Monitoring Information

During the monitoring measurement of portal excavation, the establishment of a scientific and reasonable monitoring information feedback process is the safety blanket for tunnel portal and surrounding facilities. And through the feedback of the monitoring information, status quo of deformation objects can be obtained in time, providing optimized structure design, supporting parameters and construction technology with information basis, accumulating data for tunneling design and construction, and providing similar references for future design and construction [6].

Feedback of monitoring information, including monitoring results and recommendations, is informed to owners and relevant departments by weekly reports, monthly reports and summary reports, etc. When the abnormal deformation appears, owners or relevant departments should be informed by monitoring and warning in time. In addition, information feedback should be given not only between monitoring units and owners, but also between investigation and design units and construction units. When the owners are informed with the abnormal circumstances, they should transfer the relevant information to investigation and design units as well as construction units, jointly consulting for solutions when necessary.

V. CONCLUSION

After combining with the monitoring measurement of portal excavation of a mountain tunnel in Wanzhou, Chongqing, a complete monitoring measurement system for portal excavation is constructed, and the analysis method of tunnel portal stability based on multi-source data under the three-dimensional and multi-level monitoring system is studied. Besides, the corresponding monitoring information feedback process is given. Through the engineering practice, the following conclusions are obtained.

During the tunnel portal excavation, the selection of monitoring measurement should be based on adequate understanding of the surrounding geological and hydrological conditions, the specific risk sources, construction design and organization. It should be determined after comprehensively analysis.

The frequency of monitoring measurement shall be implemented according to the relevant specifications. When the abnormal circumstances of monitoring points appear, the monitoring frequency should be appropriately improved.

In monitoring data processing, monitoring data should be classified and processed in the form of section or profile, and the stability of deformation body should be judged according to comprehensively analysis combining with different types of monitoring.

In portal excavation of mountain tunnel, stability of the front slope and the side slope directly affect the progress and safety of construction. In the monitoring measurement, if significant fractures or progressive deformations appear, the fractures should be closed and filled timely to reduce rainwater infiltration. And drainage and interception of the roof should be conducted. Meanwhile, support of front slope should be strengthened.

In the monitoring measurement, if abnormal deformation appears, owners and construction units should be informed by monitoring and warning. Monitoring information feedback should be conducted in time.

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