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Information Monitoring Technology for Support Structure of Railway Tunnel During Operation

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Abstract: In the process of railway construction, because of the inconvenience of geological condition, water bursting and mud surging happen frequently, and the later deformation of support structure on the happening geology section would threaten the normal running of railway. The limit difference of deformation control value of the support structure section where geological accidents frequently happen, is small, and artificial half-automatic supervisory technology cannot get the health condition of tunnel in time, resulting many cars speed-down accidents due to deformation of support structure. Through design innovation, we introduce TGMIS in the later period of Yanzishan railway construction to quickly capture the deformation of support structure, the strain of lining concrete, the strain of steel frame, stress of surrounding soil, stress of surrounding water, strain of second lining steel bar and other situ data. Also we set observation prism and measuring robot device in specific position inside tunnel, and robot laser locator laser spot is projected onto reflection target surface, by graphic processing algorithm, the receiver calculates the measured value and standard value of the 3D coordinates of the laser spot. Then the information is transmitted through transmitting device, transducer and USB-485 to computer to predict and evaluate the health condition of the support structure of the tunnel so as to provide safety warning information. Provide timely and reliable data for the operation company to avoid the occurrence of vicious accidents.

Keywords: Operation tunnel, support structure, health, data automation, monitoring, evaluation.

1 Introduction

Water bursting and mud surging accident may occur in the railway tunnel construction process because of inevitably adverse geological conditions. The structure deformation of the road section on which the accident occurred, will have an impact on railway operation and even affected the operational safety of the railway. In order to simultaneously improve the security of the tunnel during the operation, reliable monitoring data and processing method will be needed; while influenced largely by time, environment and other factors, the traditional manual monitoring technique and has a low efficiency, which

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cannot timely and quickly feedback monitoring information. Combined with a certain threat it poses to on-site monitor operators, thus, it is not suitable for monitoring the operations after completing the tunnel [Rinaudo, Paya-Zaforteza and Calderón (2016); Wang, Sun, Wang et al. (2015)]. At present, the research condition inside or outside China merely through observing the geology condition of working surface of railway tunnel, the sinking of vault, convergence of cavity circumference by informational supervision and management, so as to evaluate the stability of wall rock and reliability of supporting system by analyzing their changing trend. Yet the data about those items are few, so it is impossible to timely and accurately capture the health condition of tunnel supporting system when running, resulting that the accidents of train speeding down due to the deformation of supporting structure in many domestic tunnels happen frequently [Ariznavarreta-Fernández, González-Palacio, Menéndez-Díaz et al. (2016); Akshath and Bhatt (2016)]. So it is necessary to design a set of effective structure health condition supervisory system to automatically supervise and analyze the data about tunnel supporting structure when it is running all the time, so as to guarantee the running safety of railway tunnel [Guo and He (2013)]. This thesis, based on the data of stress of wall rock, supporting structure and displacement change in those bursting water, surging mud, broken area of tunnel of Mountain Yanzi, develops a kind of high-accuracy, automated supervisory system and corresponding testing method, and it could timely capture the later changing principle of the supporting structure of the area where tunnel accident happens, effectively improving the efficiency of data processing and data feedback, and also the intelligence, informationalization, modernization of railway management in China [Zhou and Qiao (2013)].

The newly built railway tunnel of Mountain Yanzi elongate 9888 meters, with deepest part 200 m, and the inclined opening #1 intersects the main tunnel at DK84+725, and inclined opening #2 at DK89+403. Starting on July 1, 2010, the tunnel put into traffic operation on December 30, 2013. DK84+894~DK85+156 section develops the karst cave from the surface to tunnels along the fault fracture zone. The water percolated changes with the seasons in a turbid water quality. As inclined shaft #1 rushes into the hole DK85+034, the whole tunnel section is filled with mud about 140 m due to a large-scale water bursting and mud surging in the karst cave at the top of the tunnel causing, so the arch forms a funnel-shaped cavity. Construction unit uses the C20 concrete to backfill the cavity and M20 mortar to backfill the early supporting cavity. For the reinforcement of the place ahead with the large pipe shed method, it should adopt special Ⅴ level reinforced double-layer lining (secondary lining in 80 cm thickness, third lining in 50 cm thickness). The early supporting spray applies the 35-meter-thick C25 fiber concrete, setting the whole ring I25a steel to reinforce supporting. When the tunnel of Mountain Yanzi is in the process of construction, we layered some strain, displacement, stress sensor, observing prisms, and measuring robotic devices, communication cable, USB-485 transformer, and TGMIS, to provide supervising and warning information about the health condition of the supporting structure of the part of tunnel in Mountain Yanzi where accidents frequently happen, and in the meanwhile capture the changing principle of the displacement, strain, stress, and tension in dynamic and stationary conditions. Fig. 1 is about the diagram of tunnel route of Mountain Yanzi, and Fig. 2 is the diagram of the bursting water and surging mud of the transect of DK85+034 of karst cave, and Fig. 3 is the supporting structure transect of the bursting water and surging mud area in the tunnel of Mountain Yanzi after processing.

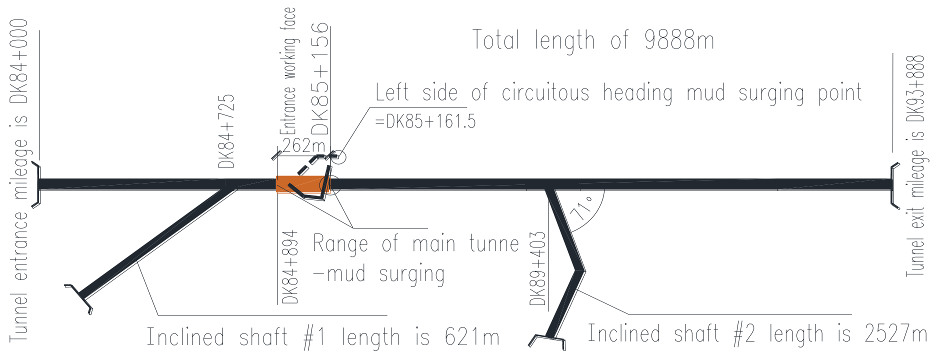

Figure 1: The planar graph of Yanzishan tunnel line

2 TGMIS design and composition

2.1 TGMIS design purpose

According to the design and construction situation of water bursting and mud surging section of Yanzishan tunnel, the monitoring would emphasize on the operating period of the main tunnel support structure at the distance of 262 m of the water bursting and mud surging section of Yanzishan tunnel. In operating period, the TMIGS system is used to monitor the tunnel inside, achieving the automation and informationalization of the tunnel monitoring measurement data. It allows operation management department to measure tunnel support structure stress, water seepage pressure of the lining and deformation characteristics and escort safety operation of the train without affecting the train operating conditions [Dend (2012)].

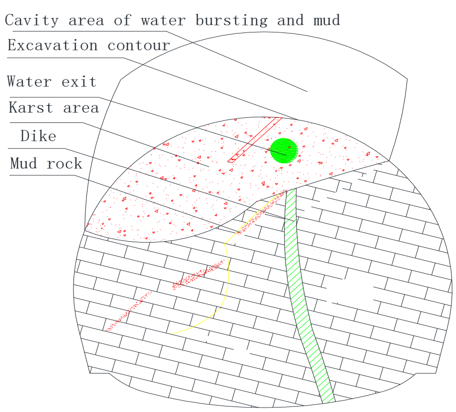

Figure 2: Schematic diagram of water bursting and mud surging at the karst cave

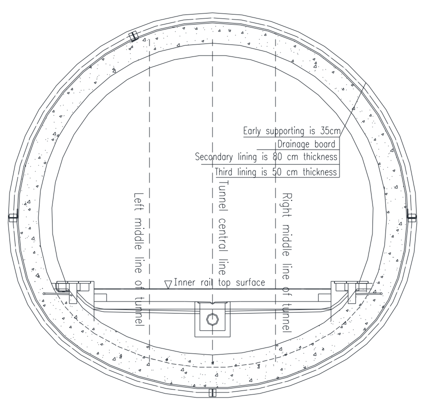

Figure 3: Support structure of tunnel after treatment of water bursting and mud surging

2.2 The composition and arrangement of supervision points of TGMIS

TGMIS is a simply, accurate tunnel supervision system which is developed for much tunnel deformation supervision. It is an automated supervision management information system consisting of computer, information capturing and processing, data communication, automation control, spot mobile communication station, sensor, observing prism, measuring robotic device, communication cable, USB-485 transformer. TGMIS mainly consists of 6 parts: Data sensing part (various sensors), data capturing part (TCA1800 station with motor, and robotic capturing device consisting of computer and software), data transmitting part (wire or wireless), control analyzing part (supervision center software, display), data processing software, warning system. All modules work together and realize all functions such as structure deformation, strain monitoring and automatic alarm during tunnel operation period. TMIGS composition and integrated data acquisition system is shown in Fig. 4， automated monitoring and transmission system as shown in Fig. 5, health data acquisition and transmission equipment conditions of the tunnel structure are shown in Tab. 1.

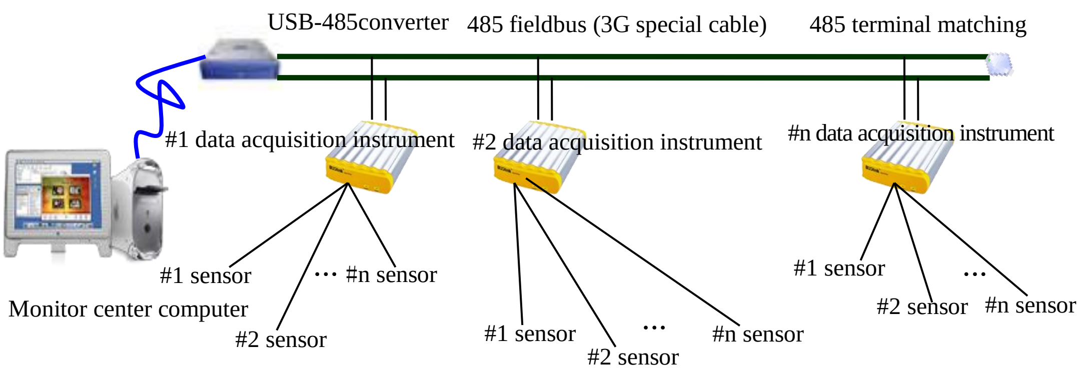

Figure 4: Schematic diagram of monitoring composition and integrated data acquisition system

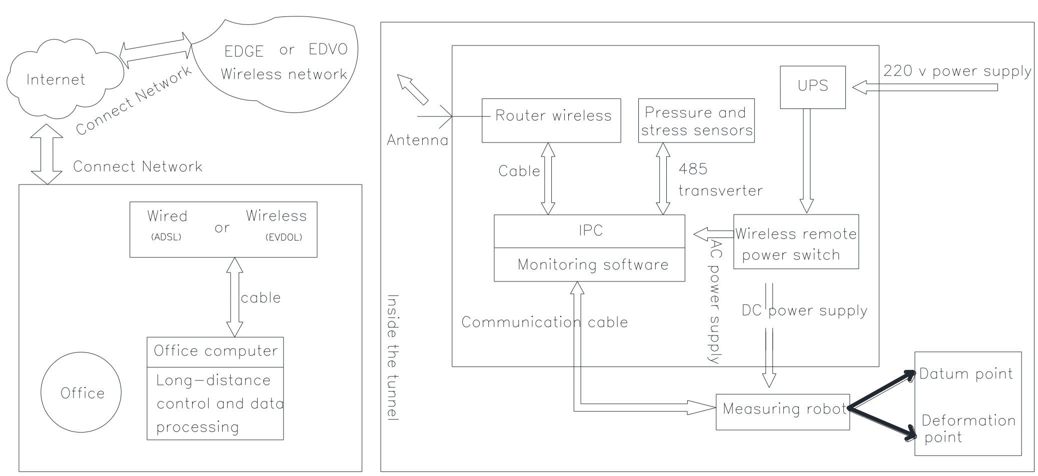

Figure 5: Schematic diagram of automatic monitoring and transmission system

Table 1: Health data acquisition and transmission equipment of the operating tunnel structure

Serial Number	*Product Name*	*Brand*	*Type*	*Number*
1	Pressure cell (sensor)	CAS Measurement and Control	Type XB-150 steel-wire	130
2	The secondary lining steel bar strain gauge (sensor)	CAS Measurement and Control	Multi-channel vibrating string type	260
3	Lining concrete strain gauge (sensor)	CAS Measurement and Control	Multi-channel vibrating string type 0.01 Mpa	130
4	Multi-channel data acquisition instrument	Bolin, JiNan	Double 24 BL800D	8
5	Water manometer (sensor)	CAS Measurement and Control	Vibrating string type water seepage pressure gauge	52
6	Transverter	CAS Measurement and Control	High-end USB-485	2
7	Multiple position extensometer (sensor)	Nanjing Industrial	VWD-20 vibrating string type displacement meter	78
8	Initial support steel strain gauge (sensor)	CAS measurement and control	Steel string type gauge 0.1 Mpa	130
9	3G special cables	CAS measurement and control	1000 m	4

2.3 Layout and installation of the monitoring cross section

The supervision this time is aimed for the 262 m water bursting and mud surging broken area, from DK884+894, we set a supervision transect in every 10 m for totally 26 ones. The position and the number of components in each cross section is embedded in strict accordance with the design requirements during the construction process; transmission cable of components, gathering on the sensor of each cross section, should be tied on the steel bar and each of the cross section should set up two sensors for data collection. The sensor is set up 1~2 m deep into the foundation line, 4G card dedicated cable is used to assemble sensors on both sides and the data acquisition instrument together for data acquisition. We arrange two sinking supervision points in ballast bed around railways in every transect, and two horizontal displacement supervision points in middle waist position, and one vault sinking point in tunnel vault, and 5 supervision points in every transect. In every supervision point we use reflection prism of small specifics, and we use setscrew and marble glue anchor to fix it in side wall and ballast wall of concrete of supervision points, and the reflecting surface of prism point to the working base point, and the arrangement of every supervision point is as Fig. 6, and the installation of reflection prisms of supervision point is as Fig. 7. Monitoring point arrangement and monitoring content as shown in Tab. 2, the corresponding support structure health monitoring points and sensor layout are shown in Fig. 8 and Fig. 9.

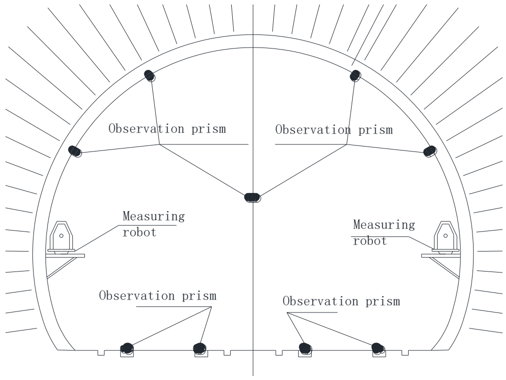

Figure 6: The arrangement of the robots

Figure 7: The installation of reflection prisms of supervision points

Table 2: Health monitoring and monitoring contents of typical cross section of the operation tunnel structure

Serial Number	*Monitoring Items*	*Arrangement of Monitoring point*	*Testing Method*	*Monitoring frequency*	*Testing Accuracy*	*Monitoring cycle*
1	Surrounding rock pressure	Embedding 5 points in the leveling layer of each cross section	Pressure cell	1 times/day	0.01 Mpa	Operational period
2	Reinforcement stress	Each cross section: 10 points between the secondary lining structure reinforcement	Strain gauge	1 times/day	0.01 Mpa	Operational period
3	Surrounding water pressure	Each cross section: 2 points between the surrounding rock and the leveling layer	water gauge	1 times/day	0.01 Mpa	Operational period
4	Steel stress	Embedding 5 points in each cross section	Strain gauge	1 times/day	0.1 Mpa	Operational period
5	Lining displacement	Each cross section: between the secondary and third lining	Displacement gauge	1 times/day	0.1 mm	Operational period
6	Lining structure stress	Each cross section：3 points in secondary lining and 3 points in third concrete lining	Strain gauge	1 times/day	0.01 Mpa	Operational period

3 TGMIS data acquisition and processing

3.1 Data acquisition

Corresponding sensor and tester should be embedded in TMIGS data acquisition monitoring points during construction period and connected with the data acquisition instrument for data collection. BL800D multi-channel data acquisition instrument equipped for the TMIGS system is featured by small volume, light weight, available for computer remote control, liquid crystal display and easy to handle. With 64 channels, it can achieve temperature, stress, strain and displacement data acquisition for two monitoring cross sections at the same time, quickly set up parameters through buttons and LCD screen without having a computer on the spot, and collect the super tiny strain and the strain value accurately.

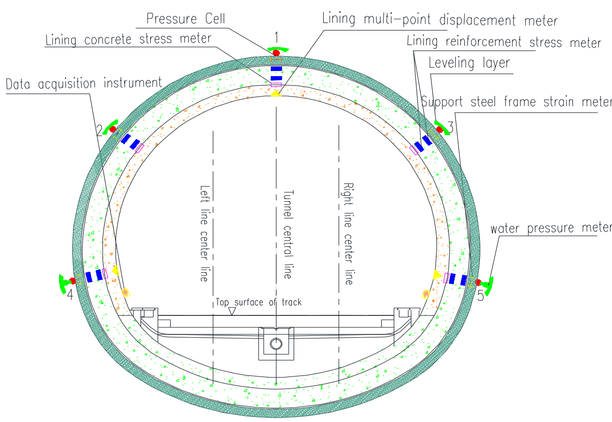

Figure 8: The arrangement of sensors on supervision transects

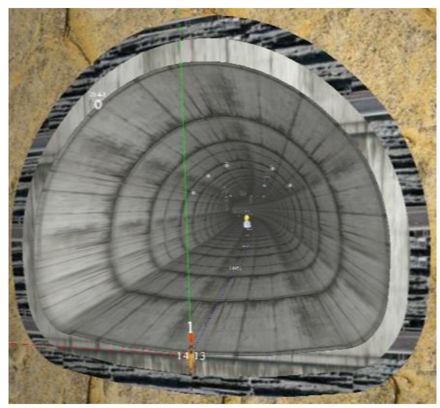

Figure 9: The model of the arrangement of supervision sensors

The data should be collected at the same time every day in order to reduce the influence of various factors. The monitoring program is that the embedded sensors should be connected to 31 channels of BL800D multi-channel data acquisition instrument, so that the different parts of the support structure could be monitored repeatedly at the same time. First connect all sensor cables or optical fiber sensors of every two monitoring cross sections to the BL800D multi-channel data acquisition instrument, and then use the USB-485 main line to connect the installed BL800D multi-channel data acquisition instrument in series, and in the end connect the USB-485 main line to the communication interface of high-end USB-485 data converter, which then transfers the data acquired to the main control computer for data management via mobile communication base station network transmission, forming a network monitoring system of data automation. That would achieve long-term data automation monitoring of the tunnel support structure stress and change characteristics in the operational period, providing an effective support for the construction or operation safety [Zheng and Zhang (2005); Huang, Li, Sun et al. (2006)].

3.2 Monitoring data input

3.2.1 Tunnel profile input

Tunnel profile consists of tunnel name, construction type, exit and entrance mileage, general situation and memorabilia, etc. Further information includes prospective design (geometric alignment, cross section information, polarization of surrounding rock, initial thickness, secondary lining thickness and the reserved deformation, etc.) and construction information (monitor embedding position, etc.) which can be used for TMIGS system analysis.

3.2.2 Monitoring data lead-in

The acquisition data collected through the interface routine of the system is transferred to special EXCEL sheet on the TMIGS interface program by using the network platform transmission. When added the data, the interface program would display all of the data in a dynamic way [Zheng (2014); Lin (2010)]. Then all of the input data would be stored in EXCEL according to the predetermined format to achieve point-by-point input; then import the added data automatically to computer database to achieve multi-point and automatic import. Finally use dedicated interface program of TMIGS system for data computation and processing to acquire a comprehensive analysis of the deformation and stress distribution of surrounding rock and support structure. Fig. 10 shows stress and displacement monitoring data input interface of Yanzishan tunnel and Nanning-Guangzhou railway.

Figure 10: Input interface of TGMIS stress and displacement data

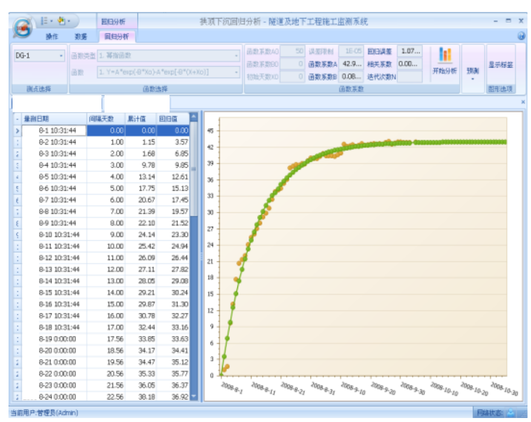

Figure 11: Linear regression analysis interface of TGMIS live data

3.3 Automatic analysis and processing of monitoring data

TGMIS is based on the operating system of Microsoft Windows 7, and the application process is as follows. At first, we number, nominate and classify the tunnel supervision points in tunnel according to the format in software, and we determine the property value of supervision point, and we initiate the data processing software to process the imported data by fitting and regression methods (the software could customize these methods according to needs), and then we enter those measured data which meet needs into software database, and then we output the plot of displacement-time and plot of strain-time of multi-points, and predict the final value and judge the stability by comparing these data to warning values, and then the software automatically generates the report and send pre-warning information to set email, and propose supervision research report periodically. The measuring robot fully exploits the superiority of whose-station device, and could directly get the 3D coordinates of deformation point, and use polar coordinates to observe, and then differentiate the observing results. At last robot sends data to computer through communication cable, control box, USB-485 transformer, and wireless transmitting device, to analyze force and displacement value of tunnel supporting structure, getting the changing principles of the sinking, horizontal displacement, strain, soil stress of observing points, predicting the possible largest values of displacement and strain of observing points. Finally evaluate the health and safety conditions of the support structure of the Yanzishan tunnel water bursting and mud surging section. Fig. 11 shows the TGMIS data processing interface; Fig. 12 shows monitoring data processing procedure of the tunnel support structure.

4 Yanzishan tunnel monitoring data analysis

After the completion of Yanzishan tunnel, the TGMIS processing program would take a comprehensive analysis of the monitoring data since it was transferred to computer database of TGMIS monitoring station. Through 6-year monitoring, TGMIS has collected a great large of data after its installation in June, 2010. This paper selects the monitoring data of DK84+974 cross section for 30 days as the TGMIS analysis object, draws a time-history curve according to the measured cumulative deformation and strain values, and makes an analysis of deformation and stability of tunnel structure according to the time-history curve of each section.

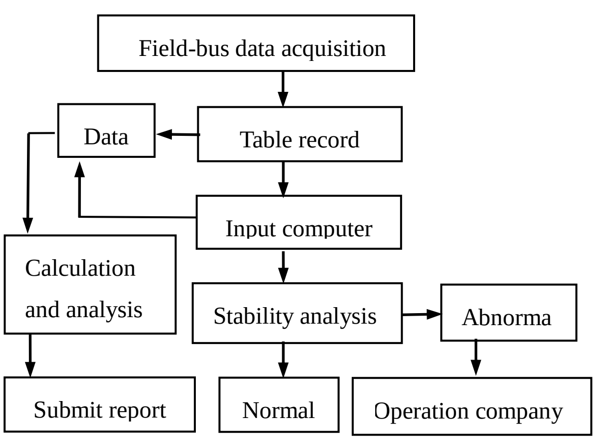

Figure 12: Monitoring data processing procedure of the tunnel

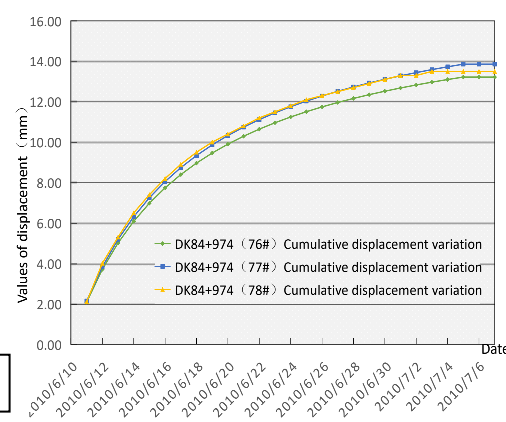

Figure 13: Displacement-time curve of tunnel support structure

4.1 Monitoring D analysis of tunnel support structure deformation

The multi-point displacement instrument should be used for tunnel lining measurement during the operational period. When installing the displacement instrument in the third lining, first drill on the selected points under the condition that the borehole axis is vertical with the tunnel wall to assure the accuracy of the measurement [Li, Chen, Yang et al. (2015); Sun (2012)]. Fig. 13 shows that the displacement of three monitoring points is larger within 15 days after the tunnel operation, and gradually become stable after 20 days. The displacement amount is within 15 days account for more than 85% of the total settlement of 30 days. There is a little displacement after 25 days, which is basically in a steady state. The maximum displacement occurs at the 77# arch crown of DK84+974 cross-section. With the maximum settlement value of 13.86 mm, it is within the alarm value range and has a little effect on the bearing capacity of the structure, being in a safe state.

4.2 Tunnel lining concrete stress monitoring data analysis

Embed the multi-channel vibrating string concrete strain gauge respectively in the secondary, third lining of the arch crown and both sides of the skewback of the DK84+974 cross section for the purpose of monitoring the mechanic change of the secondary lining concrete in water bursting and mud surging road section.

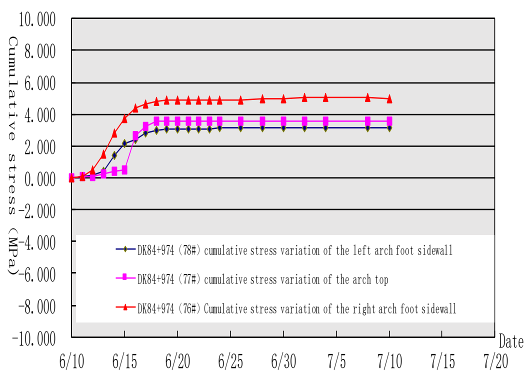

Figure 14: Second lining concrete cumulative stress and time curve

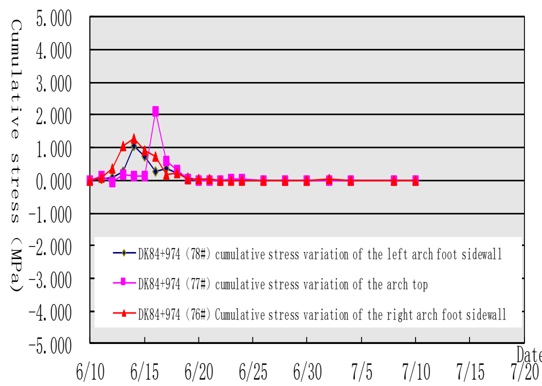

Figure 15: Third lining concrete cumulative stress and time curve

Fig. 14 and Fig. 15 show that the internal stress value of secondary and third lining concrete on the left side of the skewback is small in a steady state after 10 days. A maximum stress value of the secondary lining on the right side of the haunch appears on the 8th day with the stress value of 4.6 Mpa in a steady state after 11 days, while the stress value of the third lining arch crown appears small fluctuation and then tends to be steady with the stress value of 2 MPa. This shows that the upper load is mainly borne by initial support, and the surrounding rock bears itself, making the support structure in a steady state [Liu (2009)].

4.3 Steel frame stress monitoring data analysis

Embed the vibrating wire strain gauge respectively in the arch crown, both sides of the haunch and both sides of the skewback in the initial support of the DK84+974 cross section for the purpose of monitoring changes in steel frame stress during the operational period of the tunnel, including positive (+) as the pressure stress, negative (-) for the tensile stress. Fig. 16 shows the steel frame bears pressure stress which grows rapidly and reaches its peak 36.5 Mpa within 15 days, accounting for more than 90% of the total stress. Then the steel frame stress comes into a steady state, and the maximum stress of the primary-stage steel frame occurs in the arch crown with a value of 41.07 Mpa, which is within the alarm value; so the steel frame bears greater initial pressure released by surrounding rock but not affected by extrusion of surrounding rock. That would prevent the early rapid deformation of surrounding rock and play a larger role in protecting the steel frame support structure.

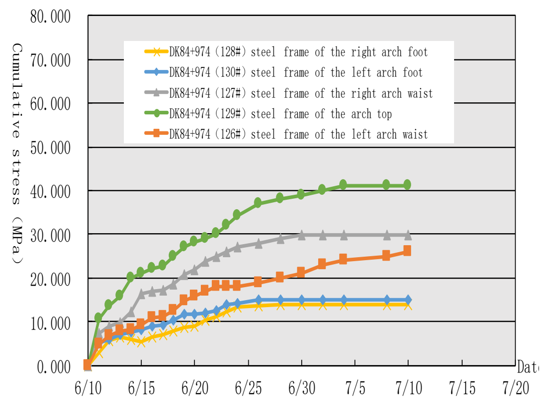

Figure 16: Steel frame stress-time curve of monitoring data

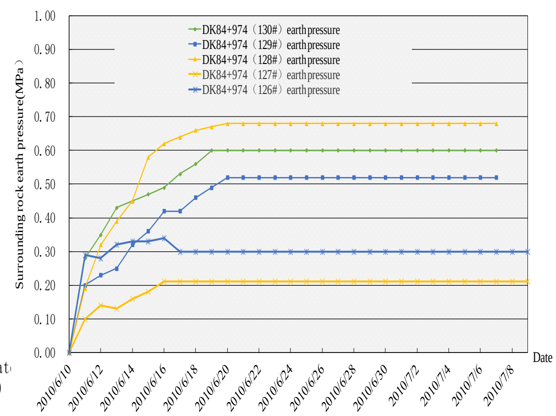

Figure 17: Surrounding rock monitoring earth pressure-time curve

4.4 Monitoring data analysis of earth pressure of surrounding rock

During tunnel construction, embed contact pressure cell between the surrounding rock and steel frame in the arch crown, both sides of the haunch, both sides of the skewback of the DK84+974 cross section for the purpose of monitoring the change of the surrounding rock pressure in the operational period of the tunnel. Pack a layer of rubber ring with the thickness of around 1~2 mm to the pressure cell before embedding the box, and tamp the surrounding rock carefully when make the pressure cell in place. Fig. 17 shows that the surrounding rock earth pressure and steel frame stress change are basically consistent. The inside earth pressure of surrounding rock grows rapidly within 10 days with maximum value of 0.68 Mpa, and the displacement on right side of the haunch is relatively larger. At this time, the earth pressure values of the five monitoring points reach more than 80% of the total displacement of surrounding rock. There is little pressure fluctuation between steel frame and surrounding rock, and the earth pressure is small caused by loosened surrounding rock after 10 days. Based on axial pressure bearing, the steel frame is completely steady and in a safe range after 15 days.

4.5 Monitoring data analysis of water pressure of surrounding rock

Embed the vibrating string type water seepage pressure gauge between levelling layer and surrounding rock on both sides of the skewback in the initial support of the DK84+974 cross section for the purpose of monitoring water pressure changes during tunnel operation.

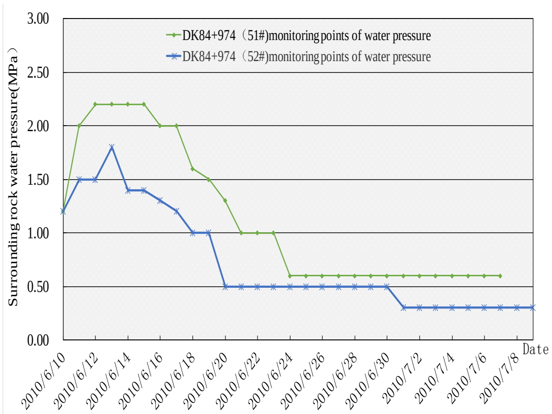

Figure 18: Surrounding rock water pressure stress-time curve

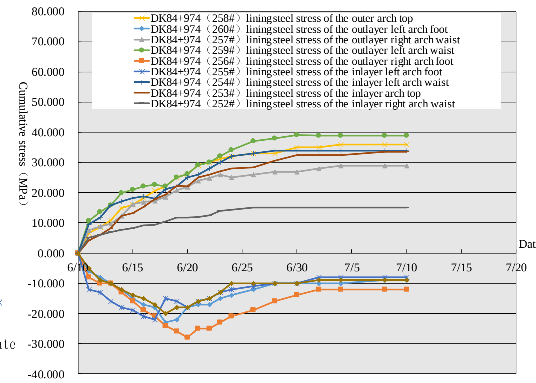

Figure 19: Secondary lining rebar stress-time curve

Fig. 18 shows the water pressure of surrounding rock grows faster in the early 2 days. On the third day, water pressure of surrounding rock on the left side of the skewback reaches 1.75 Mpa. Then it is in a decreasing trend after 6 days and becomes zero with a steady trend in the 15th day. The water pressure on the right side of the skewback is 0.3 Mpa, and the left side is 0.6 Mpa, which is within the alarm value. That indicates it is safe and has little effect on the support structure to change the status of surrounding rock water from the fissure water to a small amount of water seepage.

4.6 The secondary lining reinforcement stress monitoring

Embed the multi-channel vibrating steel stress gauge on the reinforcement inside and outside the secondary lining of the arch crown, both sides of haunch, and both sides of skewback of the DK84+974 cross section for the purpose of monitoring the mechanic changes of secondary lining reinforcement. The positive value (+) is the compressive stress, and negative value (-) is for the tensile stress. Fig. 19 shows the secondary lining reinforcement stress of each measuring point on the cross section grows fast in the early stage, reaching 38 MPa within 15 days, and after that it tends to be steady. That indicates the initial support structure is in a steady and safe state. The maximum reinforcement stress value 38.97 MPa in the outer lining on the left side of the haunch of the stabilized steel bar. The secondary lining stress of skewback and crown are relatively small, and the reinforcement inside and outside the skewback is given priority to tension, while the arch crown lining reinforcement is given priority to axial pressure. That indicates the reinforcement belongs to compression member, conforming to requirements of tunnel support structure.

4.7 Principles of setting alarm value

Early-warning (alarm) information is released by the combination of manual work and computer artificially and automatically, and the computer automatic release is achieved by setting the standard value or threshold vale of different measuring points combined with risk level. During this monitoring, each test item should determine the corresponding alarm values in accordance with the actual situation of protective objects for the purpose of justifying whether the values are beyond the scope, whether engineering construction is reliable, and whether to adjust the construction deployment and optimization of the original design scheme. In general, each alarm value is determined by two parts, namely the total variation and per unit variation. Principles of setting alarm values are: a. meet design requirements and shall not exceed the design value; b. satisfy the safety requirement of the test object for the purpose of protection; c. meet the requirements of the departments in charge; d. meet the demands of railway related existing specification.

4.8 Alarm value determination

According to above principles, combined with design requirements, the engineering monitoring project has the following alarm values.

(1) accumulative maximum displacement of the lining structure monitoring ≤20 mm, alarm value is 15 mm;

(2) accumulative stress control value of steel frame in the initial support is 50 MPa, cumulative stress control value of the secondary, third lining concrete is 5 MPa, the secondary lining reinforcement stress control value is 10 MPa, and the alarm values of steel frame, lining, lining reinforcement are 0.7 times of the total stress control value;

(3) water pressure and earth pressure of the surrounding rock respectively are 4.5 MPa and 1.0 MPa, and the alarm values of them respectively are 0.7 times of the control values.

5 Pre-alarming and evaluation of the tunnel health and safety

Through the automatic monitoring of data, TGMIS transmits the data to the computer of monitoring center and analyzes the data through TGMIS processing program, then gives a pre-alarming about whether lining structure could crack, predicts the structure failure trend, and finally conducts an analysis of the possible influence and influence scope of structure deformation on the study result. TGMIS will determine the standard double control indexes of risk source (stress and displacement rate) and compare it with the alarm value according to the position, spatial relations with engineering, environment, construction method and other factors of the monitoring points. And when appearing the abnormal data, the system will trigger the corresponding alarm mechanism and generate pre-alarming reports in different grade.

TMIGS carries out management by three-level warning mechanism (including pre-warning value, warning value and control value), designing four-color safety warning mechanism (blue, yellow, orange, red), giving responsive warning about supporting structure in the cave so as to remind, warn, and pre-warn railway manager to carry out safety control. Based on the engineering examples, i.e. the survey and collection of the conditions in the spot of running tunnel, the collection of supervision data of one month, we get that the variations of the supervision values of double control index of every station are within warning range. The relationship between the change of sinking data of supporting structure of the tunnel in Mountain Yanzi and the warning values are as Fig. 20 and Fig. 21.

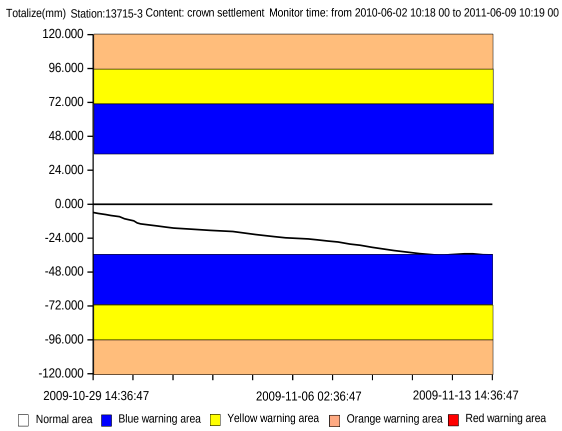

Figure 20: The relationship between data changing curve and warning value

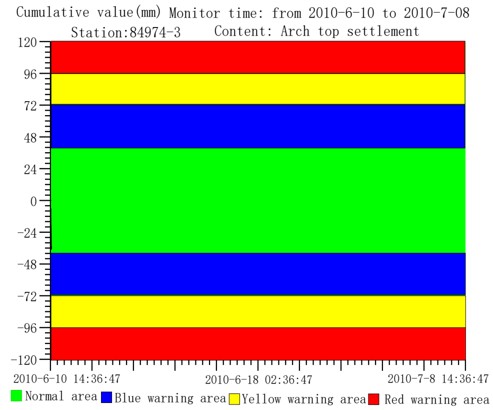

Figure 21: The state of data changing and comprehensive warning

6 Conclusion

Based on the research of tunnel structure safety supervision condition, TGMIS, trials of health supervision of supporting structure in the water bursting and mud surging area in the tunnel of Mountain Yanzi when railway running, this thesis has drawn the following conclusions.

(1) As a monitoring system integrated with data acquisition, transmission, analysis, processing and automatic alarm, TGMIS not only can transfer the data from the monitoring station dozens of kilometers away from the tunnel to the tunnel spot, but also conduct a remote control, circulation monitoring, data query, etc. on terminal computer. Also TGMIS can find potential safety hazard and generate reports and sum up changing rules of monitoring data every day; In case of special problems, it can directly analyze the reason and generate abnormal report; During normal use, TGMIS conducts a real-time analysis of structure and generate the structure health report on a regular basis, greatly improving the real-time performance of monitoring.

(2) TGMIS can quickly obtain the monitoring data such as tunnel support structure deformation, lining concrete stress, steel frame stress, earth pressure and water pressure of surrounding rock, secondary lining steel stress, etc. make a real-time statistical analysis and pre-warning release of the monitoring data, and grasp the steady state of surrounding rock in a real time and the bearing capacity of support structure, etc.

(3) After obtaining the monitoring data, TGMIS can identify the healthy and safe conditions of the monitoring point and conduct a safety grade evaluation, thus the management efficiency of monitoring data has been significantly improved, reducing to 1 day from 7 days. Also it provides a reference for railway managers in subsequent

operations of the tunnel in a timely manner.

(4) The automatic monitoring analysis shows that stress values of the arch crown, both sides of the haunch, each side of the skewback of the DK84+974 cross section are within the alarm value, and stresses of the support structure are relatively small and in a safe and steady state.

(5) TGMIS can help maintain a health monitoring of the tunnel structure support system in water bursting and mud surging section in the operational period of the tunnel so as to timely master the safety status of tunnel structure, providing a timely warning to tunnel operation managers for safety control of the tunnel. Featuring by a broad application prospect, it ensures the safety of railway operation.

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