Design and Construction of Automatic Monitoring System for Open-pit Coal Mine Slopes

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Abstract [**Objectives**] To monitor the stability of open-pit coal mine slopes in real time and ensure the safety of coal mine production. [**Methods**] The automatic monitoring system of coal mine slope was explored in depth, and the core functions of the system were designed comprehensively. According to the design function of the automatic monitoring system, the slope automatic monitoring system was constructed. Besides, in accordance with the actual situation of the slope, the monitoring frequency of slopes was set scientifically, and the key indicators such as rainfall, deep displacement and surface displacement of the slopes were monitored in an all-round and multi-angle way. [**Results**] During the monitoring period, the overall condition of the slope remained good, and no landslides or other geological disasters occurred. At the same time, the overall rainfall in the slope area remained low. In terms of monitoring data, the horizontal displacement and settlement of the slopes increased first and then tended to be stable. Specifically, the maximum horizontal displacement during the monitoring period was 22.74 mm, while the maximum settlement was 18.65 mm. [**Conclusions**] The automatic slope monitoring system has obtained remarkable achievements in practical application. It not only improves the accuracy and efficiency of slope stability monitoring, but also provides valuable reference experience for similar projects.

Key words Slope monitoring, Automatic monitoring technology, Global Navigation Satellite System (GNSS), Monitoring system, Early warning

1 Introduction

Open-pit coal mine slope is an important working area in the coal mine. The stability of the slope directly affects the exploitation of resources in the mining area and the safety of workers. Under the comprehensive influence of geology, climate, hydrology and other factors, landslide, collapse and other disasters may occur on the slope. In recent years, a series of researches have been carried out on the slope monitoring of open-pit coal mines. Using 3D laser scanner, Li Sen[1] monitored the slope of open-pit coal mine for a long time, and achieved good results; Song Jian[2] carried out early warning monitoring on the slope of the open-pit coal mine through Global Navigation Satellite System (GNSS) and slope radar, and proposed slope treatment measures based on the monitoring data; Li Weipeng *et al.*[3] analyzed the monitoring principle and monitoring effect of ground-based radar, and obtained the working characteristics of ground-based radar; Wang Liwen[4] monitored the stability of the open-pit coal mine slope based on GNSS slope monitoring technology, and the results showed that the technology could effectively monitor the slope deformation trend; Du Kang[5] described the current development status of slope monitoring technology in open-pit coal mines, and analyzed the application of slope radar monitoring system and GNSS monitoring system; Chen Luliang *et al.*[6] studied the early warning and safety decision-making system of slope monitoring in open-pit coal mines; Wang Xiangren[7] analyzed the applicability of IBIS-M slope monitoring and early warning system in the slope of open-pit coal mine; Li Zenglin *et al.*[8] monitored the slope of open-pit coal mine by establishing GPS slope displacement automatic monitoring system; Xiang Di *et al.*[9] studied the application of CORS system in the slope of open-pit coal mine; Shi Bo *et al.*[10] studied the composition and working principle of GPS slope stability monitoring and early warning system; Wei Zhonggen *et al.*[11] analyzed the potential landslide mode of the dump of the open-pit coal mine using the radar monitoring technology and combining the radar monitoring data with the characteristics of the slope itself; Luo Ai *et al.*[12] designed the slope monitoring system according to the geological conditions of the slope from the two perspectives of the slope surface displacement change and the deep stress change.

With the development of science and technology, the monitoring technology of open-pit coal mine slope has gradually changed from manual monitoring to automatic monitoring. Automatic slope monitoring greatly reduces the consumption of human resources, reduces the cost of monitoring, and also improves the accuracy and real-time of monitoring. The improvement and development of Global Navigation Satellite System (GNSS) provides a strong technical support for slope automatic monitoring. GNSS technology can obtain the location information of the slope in real time and accurately, and monitor the stability of the slope continuously and dynamically, so as to warn the possible landslide and collapse events, and protect the lives of miners and prevent property losses. Based on GNSS technology, according to the actual situation of open-pit coal mine slope, we designed a set of automatic monitoring system covering data acquisition, data processing, data analysis and early warning modules. We applied GNSS technology to the slope stability monitoring of open-pit coal mine to provide support for the safety production of coal mine.

Received: March 15, 2024 Accepted: May 25, 2024

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2 Monitoring system

2.1 Design principles of monitoring system The design of open-pit coal mine slope monitoring system shall be considered from the aspects of functionality, timeliness, stability and practicability. The design principles of the monitoring system are as follows:

(i) Functionality: the monitoring system shall meet the requirements of open-pit coal mine monitoring and integrate data acquisition, management and analysis.

(ii) Real-time: the monitoring system shall be able to detect the slope abnormality in time and give an alarm in time.

(iii) Stability: The design ensures that the monitoring system is stable and can operate normally in a variety of harsh environmental conditions.

(iv) Practicality: The system shall be designed to be easy to install, maintain and operate.

2.2 Functional design of monitoring system According to the requirements of slope safety monitoring and early warning of open-pit coal mine, the monitoring system shall meet the following functions:

(i) Real-time monitoring: The deep displacement, surface displacement, rainfall and groundwater of the slope are monitored automatically in real time, so as to grasp the dynamics of the slope in real time.

(ii) Data processing and analysis: analyze and process the collected data, analyze the slope deformation trend, and display.

(iii) Early warning: if the monitoring data is abnormal, the early warning information shall be released in time.

According to the design principles and functional requirements of the monitoring system, the monitoring system is divided into four modules: perception module, transmission module, processing module and display module. Specifically, the perception module mainly collects the data of the measuring point through the automatic collection of the sensor to provide information for the monitoring system. The transmission module mainly transmits the acquired data through a cable set wireless transmission mode. The processing module mainly analyzes the monitoring data of each measuring point, obtains the deformation law of the slope, and stores the data. The display module is mainly used to display the monitoring data and alarm in time when the slope deformation is abnormal.

2.3 Construction of monitoring system Considering the influencing factors of slope stability of open-pit coal mine, the final monitoring items are rainfall, deep displacement of slope and surface deformation of slope. Rainfall is the main inducement of landslide and other disasters. Coal bed is usually composed of alternating layers of coal and rock, and sliding surfaces may be formed during mining, resulting in landslides. Under the action of rainfall and other external environment, the slope surface will have displacement changes, so we selected the above items as monitoring indicators. The constructed monitoring system is shown in Fig. 1.

As shown in Fig. 1, the instruments used for monitoring are rain meters, fixed inclinometers and GNSS stations, and the data are transmitted by means of 5G, and the data are displayed on the monitoring cloud platform. The maximum slope height of the monitored open-pit coal mine slope was 21 m, which was a third-level slope. The monitoring scheme was designed for the slope.

(i) Arrangement of rainfall measuring points: rain meters were arranged at the key position of the upwind direction of the slope, so as to promptly assess the impact of rainfall on the slope stability.

(ii) Arrangement of deep displacement monitoring point: As the internal lithology of the slope is relatively complex, it is necessary to install the fixed inclinometer in the monitoring holes at different depths of the slope to ensure the comprehensive monitoring of deep changes. Six inclinometer holes were set for this monitoring, including two boreholes for the first-level slope platform, the second-level slope platform and the slope top, with the drilling depth of 40, 50 and 60 m, respectively, and the spacing between sensors was 2 m.

(iii) Arrangement of GNSS observation points: GNSS stations were installed at the top of the slope, the second-level slope platform, the first-level slope platform and the slope foot, and each station includes a GNSS receiver, an antenna and a data acquisition unit.

2.4 Monitoring frequency According to the slope conditions, the monitoring frequency of the slope was determined as follows:

(i) Rainfall monitoring frequency: the rainfall change rate should be considered for rainfall monitoring, so the monitoring frequency was set as 0.33 h/time in case of rainfall, and 2 h/time in case of normal weather.

(ii) Monitoring frequency of deep displacement: the monitoring frequency of deep displacement was 2 h/time under normal conditions, and in case of abnormal conditions, the monitoring frequency was adjusted to 0.08 h/time.

(iii) Monitoring frequency of surface displacement: the monitoring frequency of surface displacement was 1 h/time under normal conditions, and 5 min/time in case of abnormal weather conditions or slope disturbance.

3 Analysis of monitoring data

We collected the monitoring data of each measuring point of the open-pit coal mine slope, and selected the monitoring data from January to June 2023 for analysis, to deeply understand the change trend, stability and potential risks of the slope.

3.1 Analysis of rainfall monitoring data The daily cumulative rainfall data for this slope from January to June 2023 is shown in Fig. 2. As shown in Fig. 2, the rainfall in this area was relatively scarce, with only a small amount of rainfall at the end of March and the middle of April. The seasonal rainfall distribution may have some short-term impact on the stability of the slope. However, the maximum daily cumulative rainfall during the monitoring period was 6 mm, the overall rainfall was small, and there was no significant impact on the slope during the monitoring period.

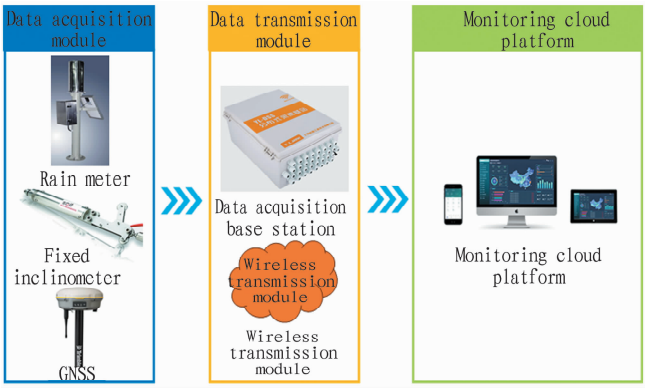

Fig. 1 Composition of monitoring system

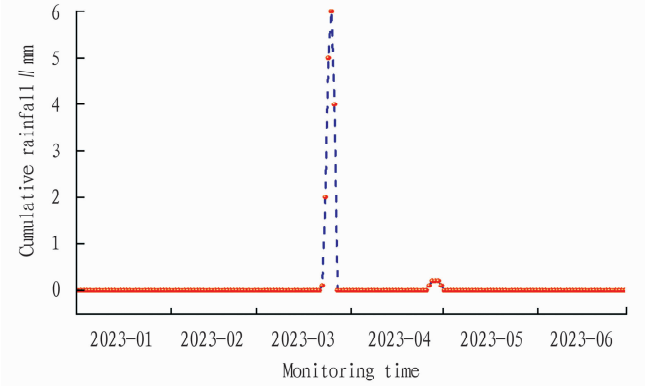

Fig. 2 Rainfall change curve

3.2 Analysis of deep displacement monitoring data As the monitoring range of slope top inclinometer hole covers the whole slope, we extracted the monitoring data collected from the slope top inclinometer hole in the monitoring system for analysis. The changes in displacement vector of the deep displacement monitoring point of slope top inclinometer hole are shown in Fig. 3.

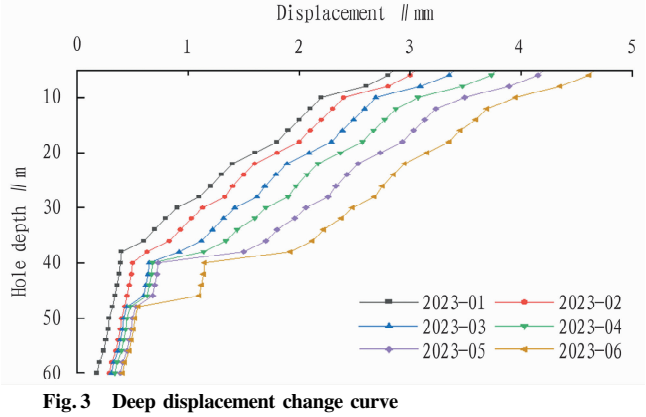

Fig. 3 Deep displacement change curve

From Fig. 3, it can be seen that during the monitoring period from January 2023 to June 2023, the deep displacement curve presents a "V" shape. The overall trend is that the deep displacement decreases with the increase of the hole depth. No significant sliding surface was formed during the monitoring period, and the displacement at the same monitoring point showed an increasing trend with the increase of monitoring time, but there was no sudden change, and the maximum displacement was 4.72 mm. With the increase of the depth of the monitoring points, the displacement of the slope decreased gradually, and the overall condition of the slope is good, which has been in a stable state during the monitoring period.

3.3 Analysis of surface displacement monitoring data The surface displacement monitoring data of the GNSS monitoring points at the slope top, the second-level slope platform, the first-level slope platform and the slope foot were analyzed separately. The horizontal displacement data of each monitoring point is shown in Fig. 4, and the settlement data is shown in Fig. 5.

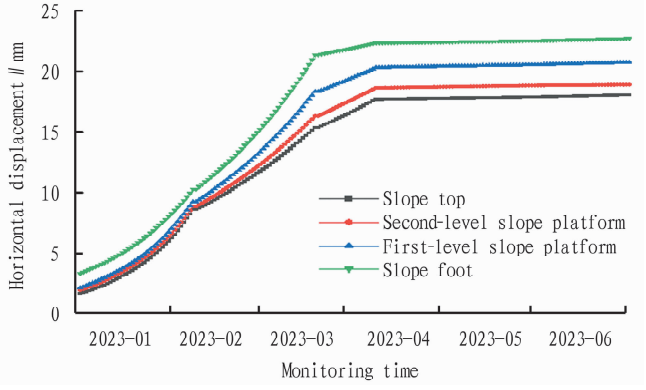

Fig. 4 Horizontal displacement curve

From Fig. 4, it can be seen that the change trend of horizontal displacement of each measuring point is basically the same, the order of horizontal displacement at the same time period is: slope foot > primary slope platform > secondary slope platform > slope top, and the maximum horizontal displacement in the monitoring time period was 22.74, 20.73, 18.91 and 18.03 mm, respectively. The horizontal displacement increased rapidly in the early stage of monitoring, and the horizontal displacement tended to be stable with the increase of monitoring time. During the monitoring period, the horizontal displacement of the slope did not change suddenly, and the slope was in a stable state.

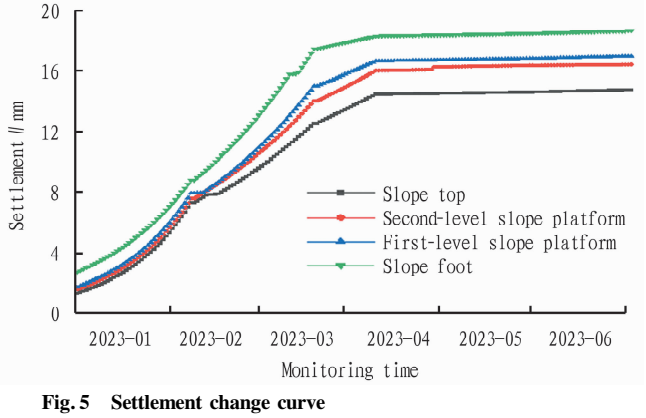

Fig. 5 Settlement change curve

It can be seen from Fig. 5 that the settlement change trend of each measuring point is basically the same, and the order of settlement in the same period is: slope foot > first-level slope platform > second-level slope platform > slope top, and the maximum settlement in the monitoring period was 18.65, 17.01, 16.43 and

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mentation. Through policy support, the development of sediment utilization as building materials can be promoted. In the future, sediment utilization as building materials may develop in the following directions: first, higher-performance sediment building materials are developed to improve their strength, durability and safety; second, the production process is further optimized, to reduce costs, and improve economic benefits; third, the integration with environmental protection technology is strengthened to realize the seamless connection between sediment treatment and building materials production; fourth, the application field is expanded, and not merely limited to traditional building materials, it can also be applied to decorative materials, *etc.*; fifth, the formulation of relevant standards and norms is promoted to ensure product quality and safety.

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14.78 mm, respectively. The increase rate of settlement in the early stage of monitoring was fast, and the settlement value gradually tended to be stable with the increase of monitoring time. During the monitoring period, the settlement value of the slope did not change suddenly, and the slope was stable. The monitoring results show that the values of rainfall, deep displacement and surface displacement of the slope were relatively stable during the monitoring period, and the slope was stable.

4 Conclusions

According to the condition of the open-pit coal mine slope, we designed and constructed the slope automatic monitoring system, determined the monitoring frequency of rainfall, deep displacement and surface displacement, and analyzed the slope monitoring data. The results show that the maximum daily cumulative rainfall in the monitoring period was 6 mm, and the overall rainfall was small, which had no significant impact on the slope. No significant sliding surface was formed during the monitoring period, and the overall condition of the slope was good. The horizontal displacement increased rapidly in the early stage of monitoring, and the horizontal displacement tended to be stable with the increase of monitoring time. The maximum horizontal displacement of the slope was 22.74 mm in the monitoring period. The growth rate of settlement in the early stage of monitoring was fast, and the settlement value gradually tended to be stable with the increase of monitoring time. The maximum settlement value of the slope in the monitoring period was 18.65 mm, and the slope was in a stable state. In summary, the application of slope automatic monitoring system in opencast coal mine can provide support for coal mine safety production.

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