Remote Real Time Monitoring System of Slope and Its Application in Sustainable Mining of Open Pit Coal Mine

Dinggui Hou*, Xinyue Song, Sifan Li, Chenmei Lu, Kelin Ma and Jianing Li

Construction Engineering Department, North China Institute of Aerospace Engineering, Langfang 065000, China
*E-mail: houdinggui@126.com

Abstract: The mining of open-pit coal resources will form a large number of mine slopes and the geological hazard of slope landslide restricts the sustainable production of open-pit coal mine, monitoring and early warning of landslide disasters can reduce the losses caused by landslide disasters but now the most widely used displacement monitoring technology can not achieve the function. Based on the mechanism of landslide mechanics, the new remote real time monitoring method is proposed and its equipment system is developed, the remote real-time monitoring and early warning work of Antaibao open-pit coal mine slope is carried out. The monitoring locations are determined by finite difference numerical simulation method, through the remote monitoring results and slope stability analysis indicate that the slope is at a stable state. It has been proved by engineering practice that the monitoring of slope mechanics can ensure security of the continuous mining of the mine.

1. Introduction
Landslide disaster is one of the major natural disasters that human beings are facing and Long-term threat to the human society, landslide monitoring means include surface displacement monitoring, deep displacement monitoring, crack monitoring and other technologies, practice has proved that they can not achieve the purpose of advance warning [1]. Based on the academic thought of sliding force variation is the necessary and sufficient condition of the landslide occurred, the remote real-time monitoring system is developed, the monitoring and reinforcement effect of the remote real-time monitoring system in the slopes of Antaibao open-pit coal mine in Shanxi Province is studied.

2. Monitoring and reinforcing system

2.1. The principle of monitoring [2-4]
Remote monitoring technology of slope stability is difficult to achieve accuracy such as surface displacement, the reason is that the phenomenon such as displacement, crack is the necessary condition of landslide but not sufficient, to give an accurate prediction of landslide the sufficient and necessary conditions of landslide must be found.
Landslide is a form of disaster that landslide along the sliding surface movement, its essence is in force and sliding resistance interactions. Slide force greater than sliding resistance is necessary and sufficient condition of landslide, the key of Landslide monitoring and prediction is to mastering the slide force and sliding resistance changes state, and the slide force and sliding resistance in landslide is a pair of “natural mechanical system”are unpredictable, certain technologies must be unpredictable system is converted into a measurable system.
By a monitoring anchor cable through the sliding surface is fixed on the slide bed inside the bedrock, apply a small force, which is called “Perturbing forces”, The disturbing force be involved in the landslide mechanical system, the disturbing force is derived as a function of sliding between power relations, and thus for the sliding dynamic monitoring, at the same time can have reinforcement effect, the mechanical monitoring model of landslide as shown in Figure 1.

2.2. Remote monitoring system
Each remote real-time monitoring system consist of mechanical data acquisition, transmission , and data reception system. Monitoring curves obtained through monitoring, according to the monitoring and early warning curve determine monitoring stations monitoring stable state of objects.

2.3. Monitoring standards
Monitoring data obtained form the curve of the dynamic change over time, on the basis of theoretical analysis and field experiment,monitoring curve is divided into four patterns, the landslide monitoring curve exists the trend of the intersecting line as a whole, monitoring curve intersects with the line finally, node position corresponding to the abscissa is monitoring and early warning time, when the monitoring curve over a cordon after reaching a certain value, the slope landslide failure.
3. Engineering geologic condition analysis
The north slope of Antaibao open-pit coal mine as shown in Figure 3, the present irregular triangular shape and the surface of the slope is 30-40° high and steep slope.

![North slope](image)

**Figure 3.** North slope of Antaibao open-pit coal mine.

Rudimentary surface water in the mining area, surface water and groundwater are not close, the discharge of groundwater are mainly mine drainage, groundwater in the area affected by the mine drainage, water level has dropped to below 400 meters. By means of selective analysis to the geological characters of the slide zone and landslide bed, make a conclusion that:
1)Topographical and geological conditions provides the material foundation for the beginning of landslide.
2)Rainfall as a "catalyst", accelerated the landslide.
3)Mining activities are the most important factor of landslide.

4. Numerical analysis of slope stability
The finite-difference method and explicit time-steps iterative solution is adopted by FLAC\(^{3D}\) which consider the complexity of rock-soil body, large deformation, large strain etc, be suitable for solving the subway excavation and other large deformation problems, the FLAC\(^{3D}\) is applied to numerical the stability of the north slope of Antaibao open-pit coal mine.

4.1. The FLAC\(^{3D}\) calculation model
The FLAC3D grid calculation model of the north slope of Antaibao open-pit coal mine is shown in Figure 4. There are 24578 grid units and 23453 zones in the entire model of grid subdivision and all use the tetrahedron units. The horizontal displacement of model each side restricted and the under surface fixed. The Mohr-Coulomb yield criterion is adopted, the maximum unbalanced force ratio is set to 1e-5. The calculated parameter of material is shown in Table 1.

![Typical calculation section](image)

**Figure 4.** Typical calculation section.

4.2. The calculation results of analysis
For north slope of Antaibao open-pit coal mine landslide geological model to analyze the displacement field and plastic zone characteristics under natural conditions and heavy rain conditions of the slope, and calculate the safety factor of natural conditions and heavy rain conditions slope with strength reduction method.
Table 1. Calculated parameter of material.

| rock layer          | state    | density kg/m$^3$ | cohesion /MPa | friction angle $\phi$ ($^\circ$) |
|---------------------|----------|------------------|----------------|----------------------------------|
| silty clay          | natural  | 1920             | 0.046          | 22.6                            |
|                     | saturation| 1980             | 0.035          | 15.6                            |
| Broken mixed granite| natural  | 2620             | 0.45           | 38.5                            |
|                     | saturation| 2675             | 0.12           | 30.5                            |
| broken kaolinite rock| saturation| 2160             | 0.02           | 31.5                            |
|                     | natural  | 2620             | 45             | 44.5                            |
|                     | saturation| 2675             | 10             | 44                              |

1) Displacement analysis

![Figure 5](image)

**Figure 5.** Natural conditions of The displacement contour, (a)Natural conditions (b) Heavy rain conditions (unit:m).

The Figure 5 shows the rock slope of displacement field cloud diagram under the natural conditions and heavy rain conditions. From the results we can see that under the natural conditions slope maximum displacement is 1.6mm and Whole slope deformation small. While under the heavy rain conditions slope maximum displacement is 20mm, largest deformation area is located in the slope toe, other parts of the slope at the same time also generate large deformation, thus the slope is in unstable state.

2) Shear strain increment analysis

![Figure 6](image)

**Figure 6.** Shear strain increment, (a) Natural conditions (b) heavy rain conditions.

The Figure 6 for the contour of shear strain increment figure, the whole landslide have basically been in a stable state under the natural conditions and only the slope toe local strain concentration. While in heavy rain conditions, due to the infiltration of rainwater, the structural surface of physical and mechanical properties and the slope rock mass has changed and the cohesion and internal friction angle has decreased, but the rock density has increased and the slope silty clay layer and the broken mixed granite layer has also reached the yield. A breakthrough shear strain increment zone. Therefore, the slope has been in unstable state.

3) Stability analysis

The calculated results show that north slope of Antaibao open-pit coal mine in natural conditions in a stable state, and under heavy rain conditions in the limit equilibrium state, in order to ensure the mining safety production, the remote real-time monitoring for north slope of Antaibao open-pit coal mine must be carry out.
5. Real-time monitoring and reinforcing

5.1. Monitoring points distribution

Base on the basic of the topography and geologic feature of the sliding mass of north slope of Antaibao open-pit coal mine, in combination with the results of numerical simulation and on the premise of guarantee the slope stability, we design 5 monitoring lines and 13 monitoring points on the landslide, the monitoring points distribution as shown in Figure 7.

5.2. Analytic result

The date of 13 monitoring points was collected to capture the landslide information, the classification standards and principles for the monitoring points are as follows:

1) Flat monitoring curve of normal points (P-T curve), neglect the pulse peak point, the sample range of stress $P$ is $\Delta P < \pm 40$KN, standard deviation $s < 15$.

2) Monitoring curve of abnormal points (P-T curve) emerge a downward trend: steady rise curve, steady falling curve, suddenly rise curve, suddenly falling curve, composite curve, neglect the pulse point, the sample range of stress $P$ is $\Delta P > \pm 40$KN and standard deviation $s < 15$.

3) Based on the principle that the monitoring curve steady rise and steady falling. Further subdivision: Stress rising type, stress falling type, stress stable type, and this can real-time track the variation trend of unsteady-state monitoring curve, the partition principles are as follows:

$$
\begin{align*}
&\Delta P_{total} = P_{max} - P_{min}; \\
&\Delta P_{total} < -40KN, s > 15; \text{stress falling type} \\
&40KN > \Delta P_{total} > 20KN, 15 > s > 5; \text{stress rising type} \\
&20 > \Delta P_{total} > -20KN, 5 > s > 0; \text{stress stable type}
\end{align*}
$$

Among them:

1) Sample range: $\Delta P_{total} = P_{max} - P_{min}$;

2) Sample standard deviation $s$:

$$
\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \left(\frac{\sum_{i=1}^{n} x_i}{n}\right)^2}{n-1}}
$$

4) According to the rise or falling trend of the curve of the abnormal point, further divide into: stress rising type and stress falling type, the principles are as follows($\Delta P_{total} = P_{max} - P_{min}$):

$$
\begin{align*}
&\Delta P_{total} < -40KN, s > 15; \text{stress falling type} \\
&\Delta P_{total} > 40KN, s > 15; \text{stress rising type}
\end{align*}
$$

Among them:

1) Sample range: $\Delta P_{total} = P_{max} - P_{min}$;
② Sample standard deviation $s$:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \left(\frac{\sum_{i=1}^{n} x_i}{n}\right)^2}{n-1}}$$

Through the monitoring curve and computing the rate of change and standard deviation, the conclusion as follows:

Stress steady monitoring points: NO.1-1, NO.1-2, NO.1-3, NO.2-1.

Stress rising monitoring points: NO.2-2, NO.2-3, NO.3-3, NO.4-1, NO.4-2, NO.5-2.

Stress falling monitoring points: NO.3-1, NO.3-2, NO.5-2.

The sliding force of monitoring point NO.3-1 and NO.3-2 and NO.5-2 obvious rising though the diagram above, others monitoring curves are very smooth, therefore the sliding mass is in a steady state.

6. Conclusions

(1) The occurrence of landslide is the sliding force greater than the anti-sliding force of the sliding surface, and the sliding force changes can regarded as the main parameters of landslide monitoring and forecasting, based on this theory the SPRM is invented.

(2) Numerical simulation is used to simulate the stability of north slope. The study found that the sliding mass is stable under the nature condition but may landslide during heavy rain. The monitoring methods must be taken to ensure the production safety.

(3) SPRM is used for the stability monitoring and reinforcing north sliding mass, the date of 13 monitoring points was collected to capture the landslide information, with the the monitoring date analysis showed that sliding mass is at the stable state and the abnormal variation of individual monitoring points is in the initial stage.

(4) The successful application of SPRM ensure the mine safety production and have realistic significance guiding for similar landslide prediction.

Reference

[1] Yang X J, Hou D G, Hao Z L, Wang E Y 2016. J. Fuzzy comprehensive evaluation of landslide caused by underground mining subsidence and its monitoring. IJEP. 59(2/3/4): 284-302.

[2] Tao Z G, Zhang B, He M C 2011. J. Research on mechanism and monitoring and early-warning technology of landslide in luoshan mining area. CJRME. 30(5):2931-2937.

[3] He M C, Tao Z G, Zhang B 2009. J. Application of remote monitoring technology in landslides in the Luoshan mining area. MST. 19(5):10-614.

[4] Ou X P, Bai K, Zhu Y S, Yuan C, Wang J, Liu D T, Liu H J 2009. J. The Strength Reduction Method for Stability Analysis of Slope Based on FLAC-3D. JWUT. 31(9): 59-61.

[5] Yang X J, Hou D G, Hao Z L, Wang E Y 2016. J. Fuzzy comprehensive evaluation of landslide caused by underground mining subsidence and its monitoring. Int.J. Environment and Pollution. 59(2): 284-302.

[6] Chen Z Y, Jiang X G, Yang J 2005 Rock slope stability analysis-Theory Methods and Programs (Beijing: China Water Power Press)

[7] He M C, Cui Z Q, Jiang Y, Jiang W B, Yao A J 1999. J. Study on 3S engineering analysis system of the slope stability in the Three-gorges. EJ. 7(2): 113-117.

[8] Yang X J, Hou D G, Tao Z G, Pang Y Y, Shi H Y 2015. Stability and remote real-time monitoring of the slope slide body in the Luoshan mining area. IJMST. 25(5): 755-765.

Acknowledgement

Financial support from the Young Fund of Scientific and technological research projects of higher education institutions in Hebei Province under grant No.QN2019183 and Ph. D foundation project of North China Institute of Aerospace Engineering under grant No.BKY-2018-21 and project for Young Top-Notch of langfang are gratefully acknowledged.