A Study on Goaf Water Accumulation Detection in Shuanglong Coal Mine with TSP Technology

Xiaoli Cui*
Department of Civil Engineering, Sichuan University of Science and Technology, Chengdu, China
*Corresponding author e-mail: cxlzxf@126.com

Abstract: Water accumulation in goaf is a great hidden danger to the coal mining safety, and detecting and removing the water accumulated in goaf has become a daily safety routine to ensure coal mining safety. This paper expounds the application of TSP technology in detecting the goaf water of Shuanglong coal mine, and it can be a valuable reference for the goaf water detection in the similar mines.

1. Introduction
Coal mining is a high-risk industry often accompanied by the disasters such as water and fire hazards, gas and coal dust explosives, roof falling etc.
Characteristically the water hazard accidents caused by goaf water accumulation happen without noticeable warning signs, and cause catastrophic human injury and death. In addition, accompanying with them are usually other disasters such as gas explosive, roof fall accident, poisoning asphyxiation) and so on. Therefore, when it comes to water disaster prevention and control for coal mining safety, handling the water accumulation in goaf is most important and critical.

2. Geological survey
Shuanglong Coal Mine is located in an area within WangCang County. The morph tectonics of this area belongs to an erosional basin located on the lower-middle high slope of a mountain.

In terms of climate, it is a part of the subtropical-cool temperature zone of the northern Sichuan Basin. This area has abundant rainfall, often see the heavy rains in summer, with annual average precipitation of 1201.8mm.

The mining area belongs to Tongjiang subdivision of Sichuan basin in Yangzi stratigraphic area. The strata in this area are relatively intact. The oldest strata in the area is T3xjhe formation of Upper Triassic Xujiahe formation, and are coal measure strata. The newest strata are J1b1B1B1 formation of Lower Jurassic Baitianba formation.

The mining area is located in the central section of the south wing of the Dalianghui anticline, which belongs to the central and northern part of the Huangjiagou mine field in the Guangwang coalfield. The strike length of the mine is about 2 km and the width is about 0.3 ~ 1.3 km. The strata are monocline structure with east-west strata strike, 178°tendecy, 35°~ 40°dip angle, and relatively stable occurrence. There are no faults in the area, only developed in the western part of the mining area are a group of folds, which are distributed in the NW-SE direction and extend more than 200 meters with the influence width 150 m, and the depth of the impact i30 ~ 40 m. The geological structure of the coal mine area is simple.
3. Principle and method of TSP
TSP (Tunnel Seismic Prediction ahead) is a method for predicting the earthquake occurring ahead of the roadway face. The basic idea of this method is to arrange the excitation holes in a certain area of the side wall near the roadway face, and to artificially excite the seismic wave through those holes. The seismic wave propagates in the surrounding rock of roadway in the form of spherical wave. When those seismic waves come across the goaf, the karst or the fault of rock layer, the change of the wave impedance causes certain portion of the waves to be reflected back, whereas rest of the waves propagate forward continually. The reflected seismic waves are picked up by a high-precision receiver and transmitted to the central processor for processing to form seismic record[1]. The data collected by TSP devise can be processed by a software called TSPwin to generate the useful intermediate information about the area ahead of the roadway face such as the time profile of P/SH/SV waves, the depth migration section, the rock reflection layer, certain mechanical properties, etc. Also the two-dimensional and three-dimensional spatial distribution of the reflection layer can be acquired as well. Based on the above data, the geological conditions, such as water-rich situation, fault, broken zone etc, of the area ahead of the roadway face can be forecasted[2].

According to the detection working principle of the TSP method, in the study the receiver was set up pointing to the goaf. Due to the high danger risk of setting up blasting devices in the coal mine roadway, the seismic wave was instead excited by the percussion method. The reflected seismic wave from the goaf picked up by the receiver can be used to analyze the rock fall and the water accumulation conditions in the goaf, as a result, serves the purpose of detecting the goaf water accumulation.

4. Setup of measuring points and observation system
According to the geological, mining conditions and the goaf locations of the mine, it was decided to arrange three survey points which were laid out as described below:

The survey point No. 1 was located in the wind-returning lane of the 2801 mining face. A seismic wave reception hole with 2m depth and 50mm diameter was put on the left side wall of the roadway. The receiver direction was directed along the wind-returning lane and pointed to the goaf. On the left wall, 15 meters away from the receiving hole, 15 holes are set up for exciting the seismic waves. Those exciting holes are located 1m away from each other and were kept about the same height as the receiving hole.

The survey point No. 2 was located in the track lane of the 2802 mining surface. The seismic wave receiving hole was on the right wall of roadway. The receiving hole has the same depth and diameters as the one in Point 1. The receiver direction was along the track lane’s tunneling direction. The firing hole setup is the same as for Point 1.

The survey point 3 was located in 670m horizontal east transportation roadway. The seismic wave receiving hole was put in the left wall of the roadway with the same depth and diameter as other survey points. The receiver direction was directed along the 670m horizontal east transport roadway and pointed to the goaf. The firing hole setup is the same as for survey point 1.

5. Data processing and interpretation

5.1 Data processing by software

5.1.1 Data length
The data length is the maximum detection range from the receiving point, and it can be calculated by the empirical formula:

\[ \text{Data length} = \frac{(\text{detection range} \times 2 \times 2.5)}{V_p} \]

Where \( V_p \) is the average speed of the P-wave, multiplication by 2 accounts for the round trip of the wave, and 2.5 is a safety factor to take into account the wave speed variation and the fact that the shear wave travels slower.

A relatively accurate \( V_p \) value can be obtained by following the steps below:
First, assume a data length, then run the TSPwin to the third step (initial pick up) to get a $V_P$ value, this is a simple and straightforward operation.

Secondly based on the $V_P$ value acquired from the last step and the determined detection distance, calculate the appropriate data length.

Thirdly, utilizing the calculated data length to replace the assumed one, repeat the above process.

5.1.2 Zero-cut
Set zero of the values of the sharp pulses similar to seismic signals.

5.1.3 Bandpass filtering
Separation of useful signals from noise. If the quality of the original signal is good, directly use of the calculated value from the software would be a better option. If the quality of the original signal is poor, the adjustment based on human knowledge and experience may be needed.

5.1.4 Initial pick-up
When the signal quality is not good, manual signal pick-up is needed, and this manual process may need to be repeated several times to get the reasonably good data.

5.1.5 Tract resection
Different tract resection methods should be applied to help selecting the reasonable results.

5.2 Data processing
The data collected in the field are transferred to the computer for TSPwin processing. TSPwin consists of three parts: a database, data processing and the reflection interface calculation[^3]. Here the database is used to edit the field data and to define the observation system; the data processing refers to the operations of amplifying, energy-equalizing and filtering the original data; The reflection interface calculation is conducted after the waveform is processed. It extracts the longitudinal and shear waves from the seismic waveform records, and for each portion of the surrounding rock, calculates their speed $V_p$ and $V_s$ based on the distance between the explosion point and the geophone.

The magnitude of $V_P$ and $V_s$ overall reflects the physical and dynamic mechanical properties of surrounding rock. According to those values, the mechanical parameters, that is, the dynamic elastic modulus $E_d$, the dynamic shear modulus $G_d$ and Poisson’s ratio $\mu_d$ can be calculated directly. The formulas are as follows:

$$E_d = \rho v_s^2 (3v_p^2 - 4v_s^2) / (v_p^2 - v_s^2)$$

$$G_d = \rho v_s^2$$

$$\mu_d = (v_p^2 - 2v_s^2) / 2(v_p^2 - v_s^2)$$

where $\rho$ is the density of surrounding rock.

According to the principle of the diffraction superposition method, the relative position of the reflecting interface with respect to the measuring interface is calculated.

5.3 Data interpretation
According to the TSP’s working principle and users experience, the area generating the reflection wave which is close to the measuring interface and carries large energy is labeled and judged as the rock abnormal area. By comprehensively considering the spectrum analysis data, the seismic wave speed, the reflection wave’s phase and other parameters such as Poisson’s ratio, Young’s modulus etc., the rock abnormal area and the water accumulation area can be classified.
6. Detection results

1) The goaf above the wind-returning tunnel of mining face: The geophysical exploration area is 0 ~ 80m portion.

Analysis: there are about 15m protection pillar between the air-returning tunnel of 2801 mining face and the No. 8 coal seam goaf. The geophysical exploration shows that this 0-80m portion is mainly composed of weakly weathered siltstone, sandy mudstone and coal seam, and there is a small amount of fissure water at 14-22m, 37-40m locations, and no large cavities are found. The analysis
shows that after the coal mining process, the upper goaf’s roof collapse has filled the goaf, and there is no water accumulation in the goaf except for a small amount of fissure water.

2) The area ahead of the front end of the track lane of 2802 mining face: the geophysical exploration range is 0 ~ 100m portion.

(1) In the 0-29m portion, the surrounding rock and the head face is mainly composed of weak weathered siltstone without large geological variation. The surrounding rock are severely weathered and broken to pieces mostly, and the bedrock fissure water is developed, so the surrounding rock’s overall integrity and stability is poor.

(2) In the 29-67m portion, the surrounding rock is mainly composed of the weakly weathered siltstone, which is better than the front portion.

(3) In the 67-100m portion, the surrounding rock is mainly a weakly weathered siltstone with strong water permeability, so it is necessary to strengthen the support during the excavation to prevent the local falling or large collapse of the roof.

3) The goaf over the 670m level east transportation roadway: the geophysical exploration range is 0 ~ 80m portion.

Analysis: Over the 670m horizontal east transportation roadway is the goaf of No. 16 coal seam, its surrounding rock is mainly weakly weathered siltstone or sandy mudstone. The surrounding rock is relatively broken, the fissure water of bedrock is more developed, and a small amount of fissured water exists at 36-39m and 68-72m locations. The analysis shows that the post coal mining roof collapse of the upper goaf has pretty much filled the goaf, and the water in the goaf has possibly be discharged through the original aidt or be infiltrated down into the existing drainage system of the mine. Anyway there is no water accumulation in the goaf except for a small amount of fissure water.

7. Conclusions

The TSP technology is successfully applied to detecting the goaf water accumulation in Shuanglong mine. The detecting results are basically accurate, and the cause of the water accumulation is well explained. The results and conclusions drawn has been verified later by physical water explore.

References

[1] Yingkang Cai, Xiufeng Liu, Enqiang Song, Application of tsp geological advanced forecast system in coal mine production, West Prospecting Engineering,2005.17(4)

[2] Xiufeng Liu, Zhong Li, A few noteworthy problems on TSP data collection and processing, Journal of Shijiazhuang Railway Institute 2002.6

[3] Ping Xie, Min Qin, Yanli Li, Application of TSP203 geological advance forecast system in tunnel engineering, Chinese and foreign architecture,2008(6)