Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 26 (2011) 2360 – 2368
Procedia Engineering
www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Research on Tomography by Using Seismic Reflection Wave in Laneway

Yong-feng Liu[a], Yun-hai Wang[a], Hai-tao Ma[a]a*

[a]China Academy of Safety Science and Technology, Beijing 100012, China

Abstract

As a necessary step and an integral part of works in laneway, the geological prediction is an important means of reducing disaster losses and geological disasters in the works in laneway. This paper mainly discusses tunnel reflection tomography by using seismic reflection wave in laneway. The speed of elastic wave in front of tunnel face and the three-dimensional images can be figured out when the detector check the reflection of elastic wave from the focal points on the tunnel face. The location, size and depth of cave can be ascertained. According to the forecasts of laneway works in the Iron Mine Xishimen, tunnel reflection tomography by using seismic reflection wave can well forecast engineering geology and hydro-geological conditions in front of tunnel face. It will help to supply positive guidance for working plan and construction measures in laneway. Therefore, the construction safety and speed can be ensured, helping to lead to great practical significance and significant economic benefits.

Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: seismic waves, tomography, advanced forecasting, water damage

Introduction

At present, many ore mines have been illegally exploited by many neighborhood citizens to a varying degree. Featuring no rules and no well-planning, the predatory mining by the neighborhood citizens have made a large number of unknown mined-out area. After has been formed, the mined-out area will gradually hub a lot of water over many years when the water supply is sufficient. Therefore, lots of

* Yong-feng Liu. Tel.:+86-10-151-2008-8302; fax: +86-10-8491-1373.
E-mail address: liu_yf040811@163.com.

doi:10.1016/j.proeng.2011.11.2446

geological disasters such as mud and water gushing in mines will come into being and they will pose a serious threat for mines.

Since the CT technology has been a topic in the field research in the early 1980s, it has been widely applied and researched in the fields such as imaging of the earth's internal structure, oil exploration, exploration of metal ores , geothermal exploration, civil engineering, disaster prevention and other areas. Making use of seismic wave tomography, the three-dimensional tomography of seismic wave has integrated seismic tomography, holographic imaging technology as well as three-dimensional holographic map for generated formation. They can accurately, comprehensively and intuitively forecast engineering geological and hydro-geological conditions in front of tunnel face. The protection measures can be timely made so that the disasters can be effectively controlled in helping to lead to great practical significance and significant economic benefits. The TRT6000 technology, multi-point excitation and reception space observations that can help to gain enough space wave information for space tomography have been discussed in this paper. It will help to explain the geological conditions for smaller structures, small karst geological bodies that can not be explained by the other forecasting methods. Therefore, the positioning accuracy for defects can be greatly improved.

1. Seismic tomography technology

1.1. Experimental Principle

TRT (Tunnel Reflection Tomography) by the United States C-Thru Ground Sith terrestrial geological equipment company successfully developed the latest Tunnel Seismic advanced detection instruments They have unique features for detection method, data processing and the result evaluation.

From the engineering point of view, there are potential construction risks for soft rock, fracture zone, faults and loose stratum around holes. Compared with the complete rock nearby, they usually possess lower seismic wave velocity. The seismic velocity will be usually used as a major index for rock classification when the rock is evaluated for its quality.

Tunnel Reflection Tomography usually involves the three aspects, namely data acquisition, data processing (data inversion calculations and image reconstruction) and image interpretation of results.

1.2. Detection principle

According to the Tunnel Reflection Tomography, part of the signal will be reflected back and another part of the signal will enter into the medium in front when the seismic waves encounter the differences in acoustic impedance (density multiplied by velocity). The changes in acoustic impedance usually occur in geological formations or the discontinuous rock interface. The reflected seismic signals will be received by the highly sensitive seismic signal sensor. After being analyzed, the signals will be used to help to know the geological tunnel nature, (weak zone, fracture zone, faults, water-containing layer and etc) location and size of the work front. The reflection coefficient is positive when the seismic wave is propagated from a low-impedance material to a high-impedance material. And the reflection coefficient is negative when the seismic wave is propagated from a high-impedance material to a low-impedance material.

Therefore, the deflection of the reflected-back signal will be the same with that of the wave source when the seismic waves spread from soft rock to hard rock. When the rupture zone is present in the internal rock, the reflected-back signal will become reverse. The greater the acoustic impedance difference, the more obvious the reflected-back. Therefore, it will be easier to be detected. Tunnel

Reflection Tomography can help to form the intuitive three-dimensional maps. The discrete image of the three-dimensional map at every point can be calculated from the seismic wave.

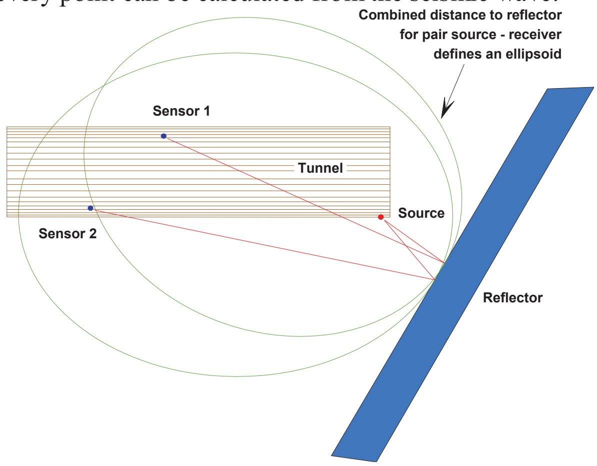
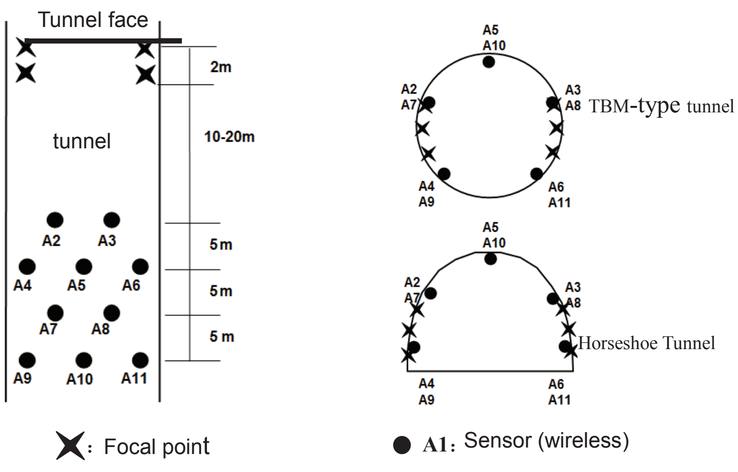


Figure 1 Detection principle

1.3. Data Collection

According to the Tunnel Reflection Tomography, the seismic waves generated by heavily "hammering" that will spread in surrounding rocks will be received by "sensor with a wireless module". Through the wireless sensor station, the sensor can help to store signals in the file of seismic signal data in the computer. There are 12 sources and 10 sensors used in this test. The hypocenters are arranged on the left and right side of the wall near the tunnel face. It has been arranged in two sections with two meters between each section. The sensor has been arranged on both sides of the tunnel walls and arch top, 10 ~ 20 m away from the hypocenter. It has been arranged in four sections with five meters between each section. The cross-section which is the closest to the hypocenter has been equipped with two detectors, with each arranged in the two sides of arch waist. The second cross-section has been equipped with three detectors, arranged in the vault and the lower part of the side wall. The third and fourth section has been arranged in the same way of that of the first and second section. The specific arrangement is shown in Figure 2.



a、Aeroview of TRT layout b、 Cross-section diagram of TRT layout

Figure 2 Work layout of TRT system

1.4. Data Processing

TRT6000 data will be processed based on the following steps:

(1) Effective signal extraction: Among all collected data concerning TRT system records, they not only include the reflected signals with obvious geological nature but also contain a lot of interference signals. With the filtering method, the ratio of the noise signal can be greatly reduced so that the effective signals can be extracted.

(2) Separation of *P* wave and *S* wave: *P* wave acts as a compressed wave (longitudinal wave) and *S* wave belongs to shear wave. The S_V-wave is a kind of shear wave that the particle will move in the vertical plane, while S_H-wave is also a kind of shear wave that the particle will move in the horizontal plane.

(3) Extraction of reflection surface: to calculate reflection coefficient and velocity. The reflection coefficient can be calculated according to the following formula:

$$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1} \tag{1}$$

R is the reflection coefficient. ρ_1 and ρ_2 stand for the rock density. V_1, V_2 are equal to the velocity when the seismic wave transmits in the rock.

1.5. Interpretation of imaging results

The nature of the reflected rock interface can be judged and interpreted from the following areas:

(1) When comparatively higher reflection amplitude, larger the reflection coefficient and a smaller elastic impedance appear, it will indicate that the rock density and wave velocity of the reflection interface will be very high.

(2) When the reflection amplitude is positive, it will indicate that the rock of reflection interface will be very hard. However, when the reflection amplitude is negative, it will indicate that the rock of reflection interface will be very soft.

(3) If the *S*-wave reflection is more powerful than the *P*-wave reflection, it will indicate that the reflection interface will be rich in water.

(4) If the average speed of tunnel longitudinal wave VP goes down, it will indicate that the cracks or porosity will be enlarged.

2. Examples of Engineering Application

2.1. Engineering profile

The distributed strata of Xishimen Iron Minie includes Paleozoic erathem, Ordovician System, Carboniferous system, Cenozoic erathem and Quaternary. Bedrock is exposed on the hillside and the Peak and the Quaternary system is located in the valley and the North. The mining area is surrounded by diorite pluton, and is enclosed by igneous rock at the bottom. There are three "holes" in the northwest, northeast and south. The limestone extends from the north to the south, and moves eastward in mine rock. It belongs to the compressed zone that contains a series of complex folds and twist fracture. There are more complex folds than twist fracture. This area is located in the compressed zone that is constructed by Bailusi brush structure that is a part of Shibanpo vortex structure. The east of mining area is blocked by the diorite pluton, there are diorite pluton acting as the barrier to the west side. There is also diorite pluton at the bottom. In the natural state, the underground water will flow out in the normal season and dry season. In the current state, there are holes in the west, which is connected with mining area. They will provide the mining area with a small amount of water. Due to the tables of falling underground water for the remaining two "holes", the limestone floor seems higher than the underground water level. Therefore, the "hole" has no reason to exist. Due to the long mining history, many ore mines have been illegally exploited by many neighborhood citizens for a quite long period of time. Featuring no rules and no well-planning, the predatory mining by the neighborhood citizens have made a large number of unknown mined-out area. After has been formed, the mined-out area will gradually hub a lot of water over many years when the water supply is sufficient. Therefore, lots of geological disasters will pose a serious threat for mines. Because these mined-out areas are very irregular and the multiple boundary layers are very common, there are no available data to trace water range and calculate the amount of water. They have brought great difficulties for water control work in the mining area. To forecast the geological hazards such as flooding in these mined-out areas in the north, TRT6000 has been applied to forecast in Transporting Lane located in the north and the 120m horizontal hole located in the south lane.

2.2. Analysis of the results

(1) Transporting 0-level Lane located in the north

According to the circumstances of rock tunnels, the scope for TRT60000 forecast has been confined to area, 120m away from the front and 20m to its four directions. The exact position of the tunnel face: X = 8810; Y = 6015; Z = 3. According to the distance between the detector and the excitation point as well as the time period for the direct wave to the detector, we can conduct inverse calculation: the average speed of rock wave for the surrounding tunnel Vp is equal to 3500m/s and the average velocity of shear wave Vs is equal to 1850m/s.The vertical and horizontal wave velocity from different focal points and detection point can be calculated as shown in Figure 3.

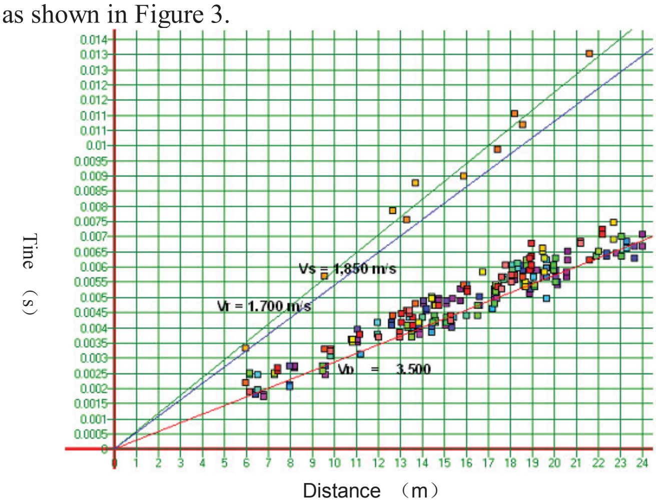


Figure 3 average velocity map of S, P-wave of 0-level in the north

From the Figure 4, 5 and 6, it will indicate that the right does not lie in the center: 24m in front of the center of the tunnel face, 10m to the right side and 5 - 20m in height. The left does not lie in the center:

24m and 36m in front of the center of the tunnel face, 8m or 5 - 20m in height. A large area of continuous low-impedance anomaly region has appeared at the two sides in front of the center. The mined-out area may be in the left while the fracture zone or gravel produced by caving mining lies in the right.

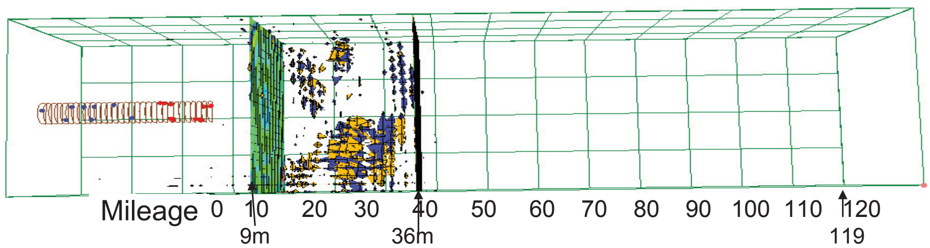
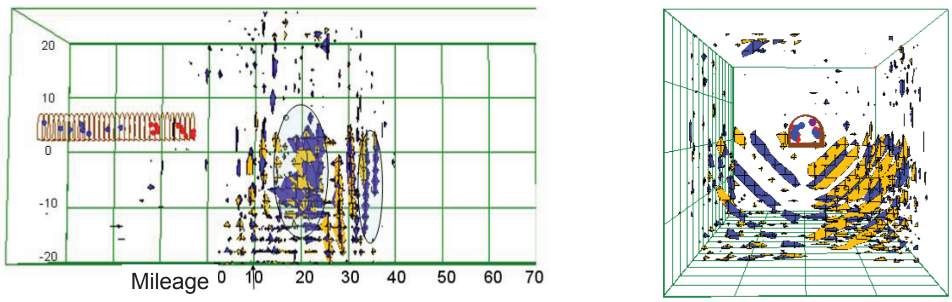


Figure 4 Front view of TRT detection results of 0-level in the north



a、Vertical section b、Cross-sectional

Figure5 Front view of TRT detection results of 0-level in the north

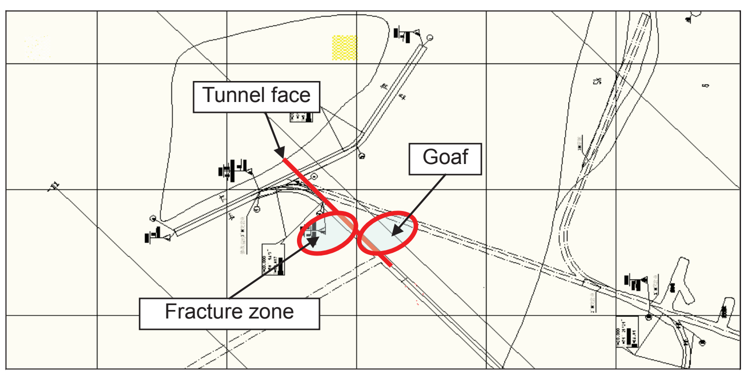


Figure 6 Plane map of engineering of 0-level in the north

Verified by drilling, in front of tunnel face are large and airy cracks. There are three airy drilled holes in the right. According to the drilling laser scanning images, the rock is broken with no holes, more than 30m away from it (Fig. 7). The results are basically in line with the above speculation.

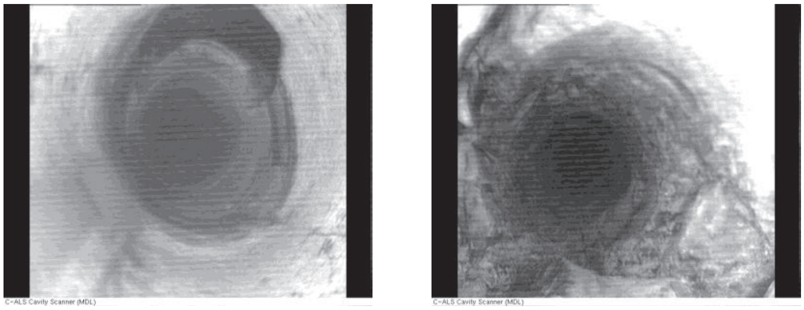


Figure 7 Laser scanning images of drilled holes

According to the analysis above, tunneling projects should come to a stop. The drilling from the surface or other location indicates that the lower resistivity anomalies and ore bodies have been damaged in front. After the mining ore has been identified damaged, the lane should be reasonably arranged.

(2) 120m-level lane located in the south

The scope for TRT60000 forecast has been confined to area, 120m away from the front and 20m to its four directions. The exact position of the tunnel face: X=6845； Y=5032； Z=-119. The average longitudinal wave's velocity in the surrounding tunnel Vp is equal to 5500m/s and the average velocity of shear wave Vs is equal to 2900m/s.The vertical and horizontal wave velocity from different focal points and detection point can be calculated as shown in Figure 8.

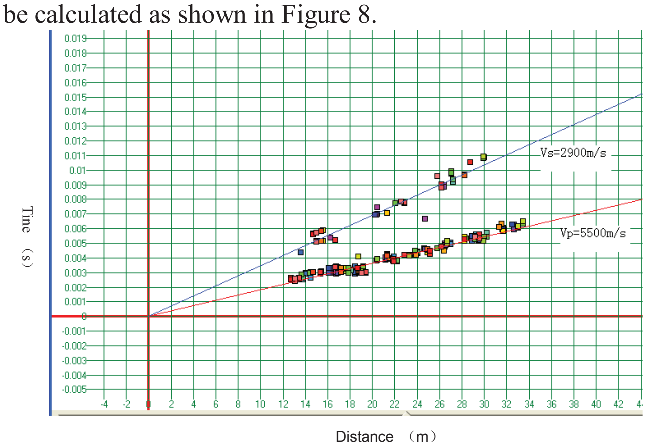


Figure 8 Average velocity map of P-wave and S-wave of 120m level in the south

From figure 8, 9 and 10, a fracture zone is located at 12.1-32.1m in front of the tunnel face. The anomalous area lies in the right: the center line is 8m to the right, 20.1m in front of the center of the tunnel face, -114m in height. The anomalous area lies in the left: the center line is 5m to the right, 29.1m in front of the center of the tunnel face, -114m in height. There are no significant changes in rock properties. It has been inferred that the main body in the front belongs to fracture zone of geological fault. There are great possibilities for mined-out area or mining projects.

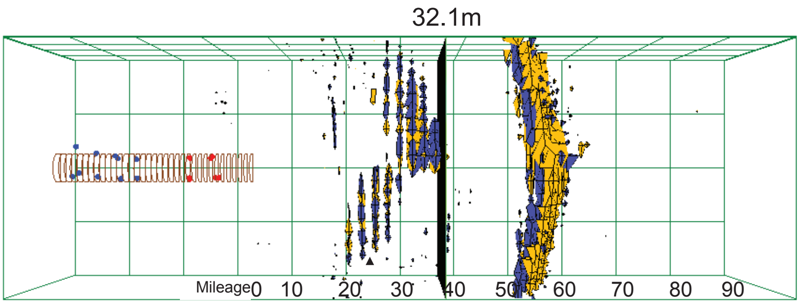


Figure 9 top view of TRT detection results in the south of 120m level in the south

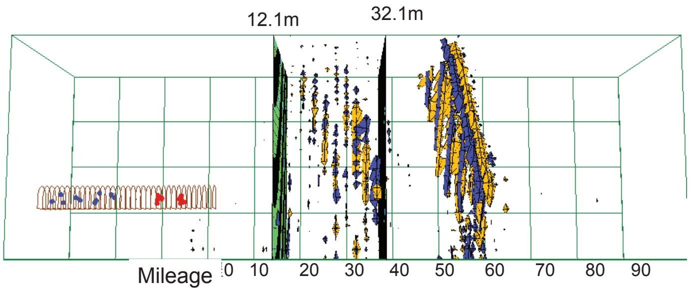


Figure 10 side view of TRT detection results in the south of 120m level in the south

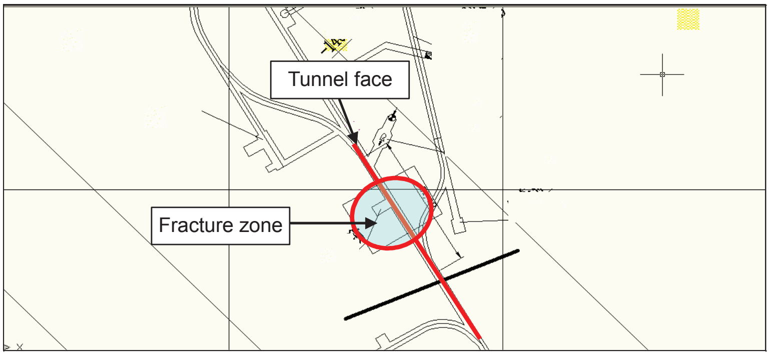


Figure 11 Project Plan of 120m level in the south

Verified by drilling, there are broken rocks 19m in front of the tunnel face. With further 0.5m forward, the rock is complete. It can be speculated that the fracture zone of fault is present 19m in front of the tunnel face. The results are basically in line with the TRT results.

According to the above analysis, the lane can be moved forward. Near the fracture zone, the second tunnel supporting such as spraying, anchoring and netting can be applied. All-screwed strong steel, with a diameter of 20mm and length of 2200mm and spacing of 1000 × 1000mm, will be used. Metal mesh will be 5000m in width by 15000m in length. The pray thickness will be 150mm.

3. Conclusions

By using the theory of seismic reflection wave in laneway, tunnel reflection tomography and holographic imaging technology can help to predict geological disaster. This method is seldom used in the country. According to the forecasts of laneway works in the Iron Mine Xishimen, tunnel reflection tomography by using seismic reflection wave can well forecast engineering geology and hydro-geological conditions in front of tunnel face. It will help to supply positive guidance for working plan and construction measures in laneway. Therefore, the construction safety and speed can be ensured, helping to lead to great practical significance and significant economic benefits.

Acknowledgements

Funded by the National "Eleventh Five-Year" research subject of state science and technology support program (2007BAK24B01-5); and the Surface Project of National Natural Science Foundation of China (51074142).

References

[1] Lei Dong, Hu Xiangyun. Review of Seismic Tomography Methods [J]. Journal of Seismological Research,2006,29(4): 418-425.

[2] Xin Hailiang. Seismis Tomography Technical Research [D]. Lanzhou: Lanzhou Institute of Seismology, 2008.

[3] Liu Zhan. Application of Earthquake Refracted Wave Method in Tunnel Forecast [D]. Jilin: Jilin University,2008.

[4] Zhao Yonggui，Jiang Hui. Tunnel Seismic Prediction Technology Current Situation and new Progress [J]. Highway Tunnel, 2010,1:1-7.

[5] Wu Wei, Deng Shuaiqi. Coal Tunnel seismic geological prediction technology and Application [J]. Energy technology and management,2008,5:59-61.

[6] Liu Jie, Liao Chunmu. TRT Technology in Tunnel Geological Prediction Application [J]. Railway Engineering,2011,2:77-79.

[7] Yan Gaoxiang. Application of Forecasting System through TRT Tomography [J]. Railway Investigation, 2009, 2: 40-43.