

# Application of a new seismic reflection imaging system TSP-SK in tunnel advanced geological prediction

Ming-xian Xu<sup>1</sup>, Yong-xia Wei<sup>2</sup>, Jun-jie Li<sup>1</sup>

<sup>1</sup>Zhejiang Design Institute of Water Conservancy and Hydroelectric Power, Hangzhou 310002, China

<sup>2</sup>Zhejiang Zhengyuan Hydropower Survey and Design Institute Co., Ltd, Hangzhou 310051, China

**Abstract.** When there are water rich-karst caves or large faults in front of the tunnel face, blind construction may easily cause safety accidents such as water inrush, mud outburst and collapse. Using advanced geological prediction methods to predict the spatial distribution of unfavorable geological bodies can greatly reduce construction risks. This paper introduces a new seismic reflection imaging system TSP-SK, and discusses the features, working mode and data processing methods of the prediction system, and verifies the reliability of TSP-SK through practical tunnel engineering prediction case. The result shows that TSP-SK can collect high signal-to-noise ratio seismic reflection data with little interference from clean first arrival when the water sealing effect of explosives in the borehole is good. Good reflection wave pickup effect can be obtained when the maximum gain of inverse Q filter and Q value are taken in the range of 15 to 30. The prediction results of TSP-SK are in good agreement with the actual excavation results, that is, the areas with low P-wave velocity indicate poor rock mass quality, and the area of low S-wave velocity is more likely to produce water from construction.

## 1 Introduction

As an important part of modern infrastructure construction, underground structure engineering has the characteristics of small impact on ecological environment and does not involve large-scale migration, so it is widely used in railway, transportation, water conservancy and municipal engineering. Tunnel engineering has stronger concealment than surface construction engineering. It is difficult to fully grasp the engineering geological conditions along the tunnel only by using conventional surface geological survey methods. When the tunnel excavation is adjacent to large-scale unfavorable geological structures (such as karst cave and fault fracture zone), blind construction will easily cause large-area water gushing, mud bursting or collapse, leading to project delay and loss of life and property. Therefore, the key to efficient and safe tunnel construction lies in the prediction of weak areas along the tunnel. Tunnel geological advance prediction methods are mainly divided into advanced drilling method and geophysical exploration method. Drilling method, as the most intuitive means of poor geological body survey, has high accuracy, but it has a great impact on the construction period and is expensive, and can only provide a single point of geological information. Geophysical methods can obtain continuous physical field information within the detection range. According to the differences of different physical properties of rock mass, geophysical methods can be divided into seismic wave method<sup>[1]</sup>, resistivity method<sup>[2]</sup>, electromagnetic method<sup>[3-4]</sup> and ground

temperature detection method<sup>[5]</sup>. The resistivity method and electromagnetic method are relatively sensitive to the water bearing low resistance body, but they are easy to be interfered by large metal objects in the tunnel, so the effective detection distance is short; the ground temperature detection method is a technology to indirectly infer the water bearing body in front of the tunnel by measuring the difference of thermal radiation temperature of rock mass. This method is very easy to be interfered by the hydration heat of shotcrete on the tunnel wall, so it is not suitable to be used as the tunnel advance prediction interpretation alone basis.

Seismic wave method is a kind of physical detection technology which can be used for long-distance tunnel prediction. This kind of method has been widely used and recognized in railway tunnel. It has strong anti-interference ability and large detection depth. According to the difference of seismic wave excitation mode, seismic wave prediction methods can be divided into blasting type and non blasting type. The former has good detection effect, but it has great influence on construction, and the use of initiating explosive device has certain risk. It is mainly used in tunnel construction by drilling and blasting method. This paper introduces a new seismic reflection prediction system TSP-SK which is compatible with acceleration and velocity sensors. Its seismic wave can be excited by hammering, vibroseis and blasting. Then we discuss the working method and data processing method of TSP-SK and proves the accuracy of TSP-SK prediction by a railway tunnel geological prediction example.

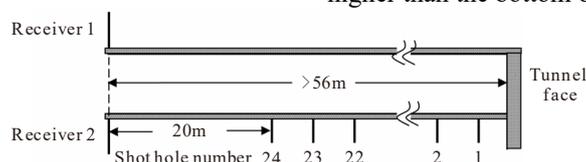
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Email: [xmx7038@mail.zdwp.net](mailto:xmx7038@mail.zdwp.net)

## 2 Working mode and characteristics of TSP-SK

TSP-SK is an advanced geological prediction system, which uses a small amount of explosives to excite elastic waves, and receives three-component reflection signals from space through high-sensitivity detectors. After processing the data, we can get the curve of wave velocity

changing with the predicted distance, so as to infer the nature and scale of unfavorable geology in front of the face. TSP-SK observation system is shown in figure 1a. A receiving hole is designed on both sides of the tunnel wall to place geophone with a depth of 2m. The drilling angle is slightly upward. There are 24 blast holes with a downward inclination of 20 ° and the channel spacing and hole depth are both 1.5m. Each borehole is 1.2-1.5m higher than the bottom of the tunnel.



(a) Observation system of TSP-SK



(b) Hardware composition of TSP-SK

**Fig1.** Observation system of TSP-SK and corresponding hardware composition

TSP-SK uses reusable casing with anchor instead of pre processed steel pipe to place geophone(as shown in figure 1b), in the specific operation, first put the anchoring agent into the receiving hole, then screw the geophone and the anchor and push them into the casing, rotate the casing clockwise, so that the anchor with geophone inside is fixed on the compacted anchoring agent. After data acquisition, rotate the geophone anticlockwise to take it out, and then pull out the casing. This coupling mode improves the installation efficiency of geophone and detection, the cost is only one tenth of that of TSP203.

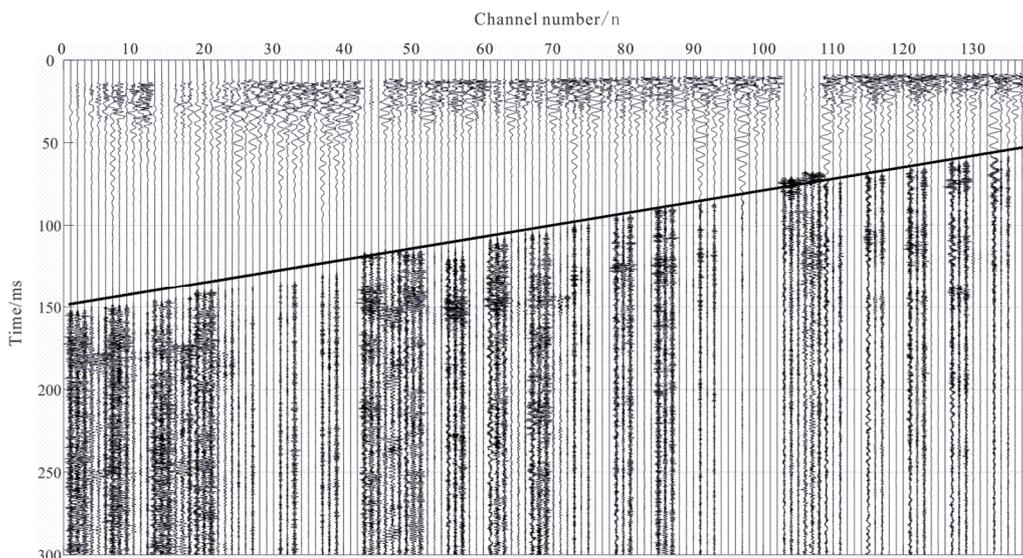
Through the steps of filtering, first break picking, gun energy equalization, anti-Q filtering, reflection wave extraction, S-wave separation, velocity analysis, depth migration and reflection layer extraction, the velocity values of P-S wave corresponding to different distances of rock mass in front of the tunnel can be obtained.

## 3 Engineering examples

A tunnel is located in Sanming City, Fujian Province. The total length of the tunnel is about 11.4km, and the

maximum buried depth is about 375m. Affected by the regional structure, the rock layer in the working area is locally disturbed, the occurrence of the layer changes greatly, and secondary folds and faults are developed. Near the TSP-SK prediction location, the surrounding rock mass of the tunnel face is mainly siliceous rock, the joint fissure of the rock mass is relatively developed, local broken, the rock mass is relatively soft, and there is water seepage in the local rock mass of the tunnel face.

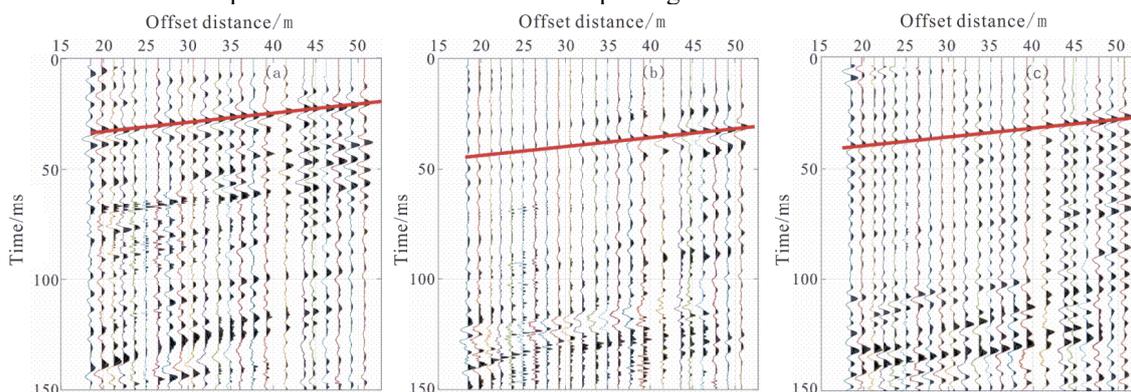
Figure 2 shows the original waveforms collected by TSP-SK at stake DK307 + 754 of the tunnel face. From left to right, the three component waveforms of X, Y and Z from the first channel to the twenty-third channel are respectively shown in the figure. As shown in figure 2, the seismic reflection waveform of TSP-SK is clear at the first arrival, and the reflected wave energy decreases gradually with time. Reflection signals with high frequency and slightly strong energy appear below the oblique line, and the slope of the oblique line is about 340m/s. It shows that the signal is acoustic interference and the signal-to-noise ratio of the collected data is high because some water is sealed in the borehole during TSP-SK data acquisition.



**Figure 2** Original waveform of TSP-SK in position of tunnel face stake No. DK307 + 754

Figure 3 is the seismic reflection waveforms of *X*, *Y* and *Z* components of geophone on the same side of borehole after inverse Q filtering processing, as shown in figure 3, the event of reflected wave is clear (indicated by the red line in figure 3), which creates conditions for accurate extraction of subsequent reflected waves. Inverse

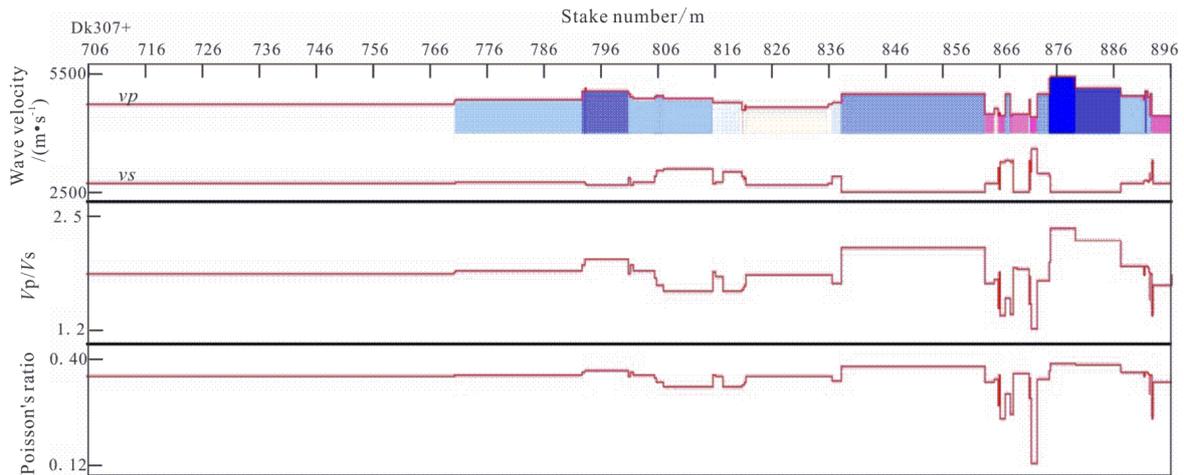
Q filtering is one of the key factors affecting the prediction accuracy of TSP-SK. In this step, the maximum gain and Q value are set in the software, a large number of prediction experiences show that when the maximum gain and Q value are between 15 and 30, better reflection wave picking effect can be obtained.



**Figure 3** Seismic reflection waveforms of *X*, *Y* and *Z* components of geophone on the same side of borehole after inverse Q filtering processing

Figure 4 shows the magnitude and curve variation characteristics of wave velocity, wave velocity ratio and Poisson's ratio of rock mass in section DK307 + 754 ~ DK307 + 896. As shown in figure 4, three obvious abnormal areas of P-wave velocity distribution can be delineated, which are respectively located in sections DK307 + 816 ~ DK307 + 838, DK307 + 863 ~ DK307 + 872 and DK307 + 888 ~ DK307 + 896. the actual excavation shows that it is mainly composed of greenish gray thin-medium siliceous rocks, the rock mass is soft, and the fissures are developed as a whole, and most of

them are medium low angle joints which are crushed locally. During the construction process, there is water seepage in the local rock mass of the tunnel wall, the surrounding rock mainly belongs to class IV-III. Among them, the rock mass integrity and stability in the abnormal area delineated by TSP-SK are poor, the groundwater is locally developed, and the tunnel wall has local linear seepage, the surrounding rock is class IV. TSP-SK detection results are consistent with the actual tunnel excavation results which reflecting the accuracy of TSP-SK prediction.



**Figure 4** TSP-SK detection results of section DK307 + 754 ~ DK307 + 896



**Figure 5** Tunnel face condition in stake No. DK307 + 826

(YJKYYQ20170033)

## 4 Conclusion

Firstly, TSP-SK as a seismic reflection imaging system has the characteristics of low prediction cost and high geophone installation efficiency. It has good working effect when used in tunnel geological advance prediction. In order to obtain high-quality seismic reflection data, water should be injected into the borehole before blasting.

Secondly, Anti-Q filtering is an important premise to ensure the extraction effect of reflection wave in front of the tunnel. Experience shows that the maximum gain and Q value in the range of 15-30 can obtain good prediction effect.

Thirdly, TSP-SK can reflect the quality of rock mass by detecting the P-wave velocity of the rock mass in front of the tunnel. The area with low P-wave velocity corresponds to the poor integrity of rock mass, and the area with low S-wave velocity and wave velocity ratio or high Poisson's ratio is more likely to cause water seepage during construction.

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