APPLICATION OF TUNNEL SEISMIC PREDICTION FOR THE HSUEHSHAN TUNNEL

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ABSTRACT

The Taipei-Yilan Expressway, also referred to as the Peiyi Expressway, will run from Nangang in Taipei City to Yilan City, passing through Pinglin and Jiaosi on the way. The Hsuehshan Tunnel, in difficult circumstances, is scheduled to become operational in December 2005. The 12.9km Hsuehshan Tunnel made engineers to prosecute a pilot tunnel for the most difficult stretch of what will be the longest expressway tunnel in Asia.

Using the technique of tunnel seismic prediction with survey, it could be helpful in detecting where the fracture zone was. From the 33 TSP records for demonstration with actual geology in conclusion, we got a suitable result to prove its practicability. It can be verified to improve security at drilling and predict some pitfall for engineers in safety reason.

INTRODUCTION

The pilot tunnel, some 750m underground, was primarily designed to give engineers more data about the rock formation of the site. Despite some fatalities of the project has occurred, it became the great challenges and risks of this job. The digging work was often suspended by the reason which the gush of groundwater. To get more information for this complex pilot tunnel's geology, the Tunnel Seismic Prediction (TSP) became the one of some important techniques by the geophysical way to explore some specific faults in underground construction. The TSP (shown as figure 1.), which was used for keeping industrial safe, plays an important role to find the lurked dangers. In fact, the TSP technique was designed to produce an uninterrupted advance with calculable risks and a high degree of efficiency. Ground conditions can, as always, be a source of unexpected difficulties where hidden geological hazards lie in wait. Unforeseen changes in rock quality all too often cause costly downtime and problems, which especially was happened in Hsuehshan Tunnel. Advance notice of lithological heterogeneity and any variation in rock mechanical parameters that could have an effect on the construction techniques selected, is an important factor in the success of this tunnel advance. Such early warning makes it possible to ensure that the specific counter-measures and logistical procedures are planned in good time.

Continuously, high-quality predictions make the risks inherent in tunneling quantifiable. Without prediction, the TBM may run the risk of cave-in, collapse, heavy water inflow, expensive downtimes, fault entrapment, or endangerment of people and equipment. The TSP also convinces with regards to cost. If we calculate not only the usual costs for equipment, material and measurement time, but also consider downtime costs invariably associated with conventional prediction techniques, The TSP has nice cost advantages whether for blasting or TBM heading operations in the Hsuehshan Tunnel shown as figure 2.

This study aim to show the application for the fault-distribution analysis in tunnel. Section 2 states the

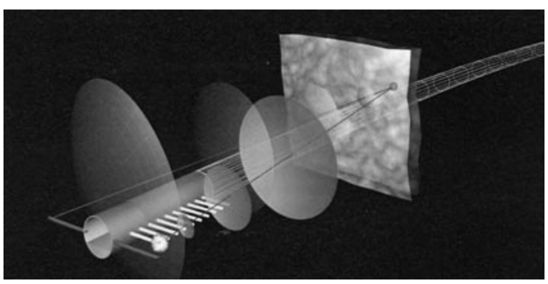

Figure 1. The diagram of TSP (This diagram abridged from the website of Amberg Measuring Technique Ltd.)

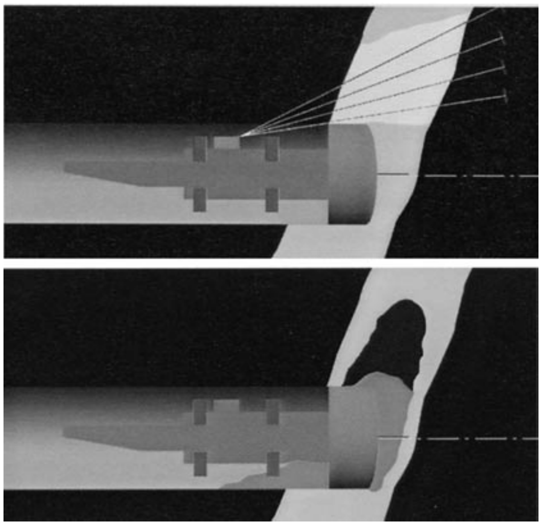

Figure 2. The TBM mire in collapse (This diagram abridged from the website of Amberg Measuring Technique Ltd.)

local situation about the Hsuehshan Tunnel area. The main principle of TSP, analysis mode for TSP data and the collocation for equipment are showed in Section 3. Finally, the demonstration and conclusion by using TSP for the Hsuehshan Tunnel is given in Section 4.

LOCAL SITUATION

Development of the tunnel, which began in July 1991, has been a trying task. If work remains on schedule, the journey between Taipei and Ilan will be reduced from the current two hours to just 40 minutes. Now, the Peiyi Expressway is considered a major breakthrough for Ilan's transportation and road development. Because of the high-mountain barrier, people from Ilan have had to trek along the coastal way to Taipei or by lengthier and more treacherous mountain routes. When completed, it will become a key to improve the road efficiency which just like to link Switzerland and Italy or another that links

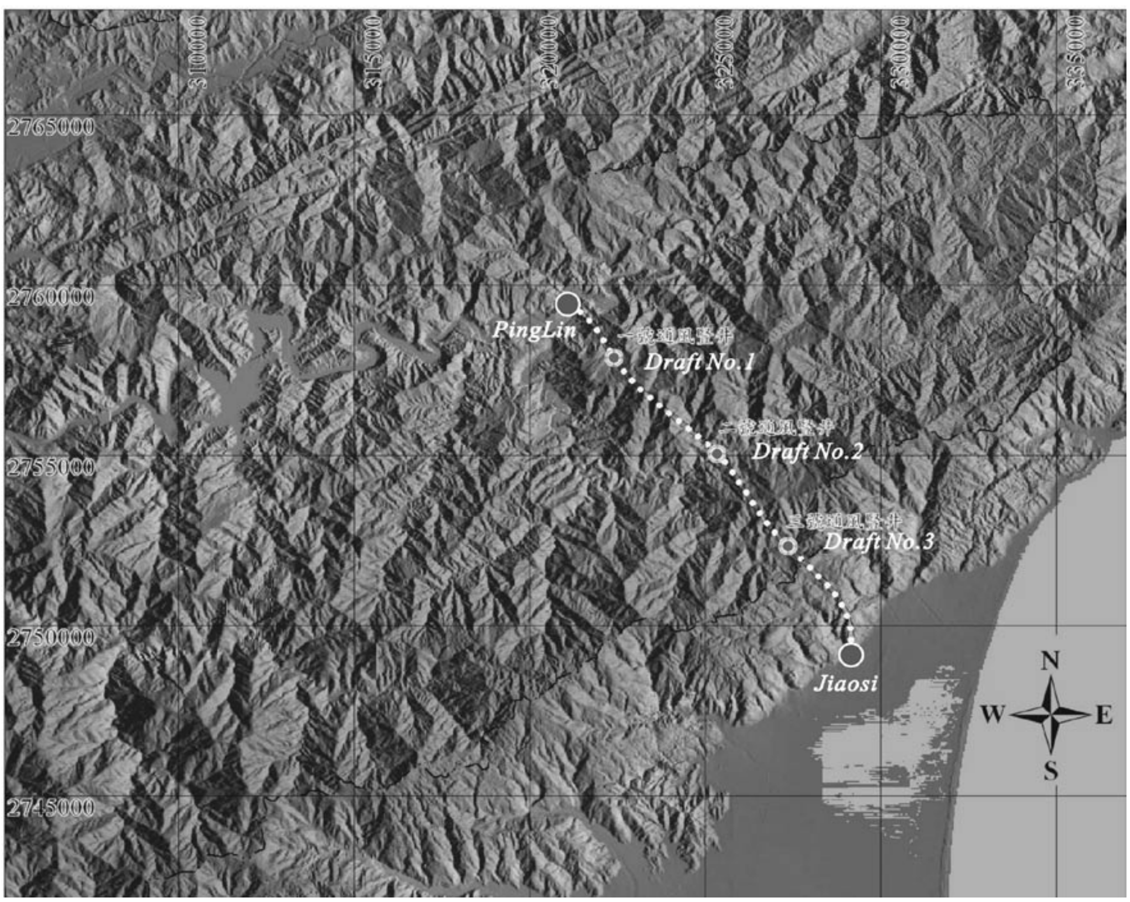

Figure 3. The designed route for the Hsuehshan Tunnel

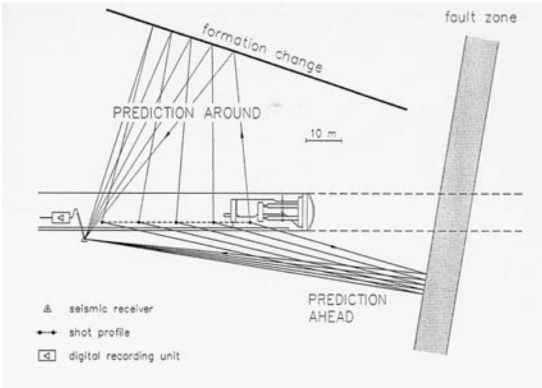

Figure 3. The basic principle of TSP (This diagram abridged from the instruction of Amberg Measuring Technique Ltd.)

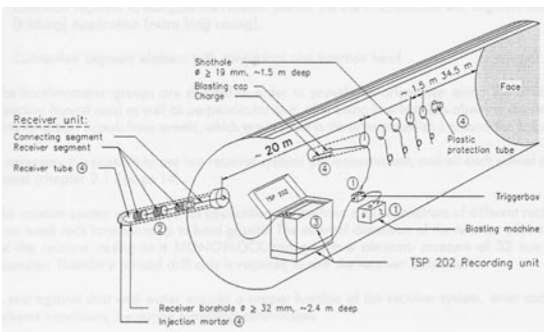

Figure 4. The basic components of TSP (This diagram abridged from the instruction of Amberg Measuring Technique Ltd.)

Switzerland and France.

The greater part of the Hsuehshan Tunnel consists of a might sequence of indurated and metamorphosed argillaceous Tertiary sediments. The structure of the metamorphic rocks is complex by many folds and faults owing to the plate cataclysm near Taiwan. Through the Hsuehshan Range, there is a high rock-cover over 700m. The stratigraphic distribution, which stretched from the Tertiary Miocene to the Tertiary Eocene, consisted of Fangchiao Formation, Magun Formation, Tatungshan Formation, Tzuku sandstone, Kankou Formation and Szeleng Sandstone. In major, the lithology of Hsuehshan Tunnel's west mouth was sandstone, shale, argillite and alternations of sandstone and shale. The other way, the lithology of Hsuehshan Tunnel's east mouth was argillite and Szeleng Sandstone. The east-side rock structure was more broken than the west-side. It was expected to cross six faults(Shihchiao fault, Shihpai fault, Palin fault, Sanghsin fault and Chingyin fault) and two synclines(Yingtzulai syncline and Daodiaotzu syncline). The whole geological changes could not understand well before the drilling-work started. So that, there is a suitable mode to make it safely by keeping sliding method with geophysical exploration and geological intensification.

Along with the more predictable difficulties of building on mountainous terrain, the unique geological factors in areas the tunnel is passing through have tested the mettle of construction teams. The reason for the work stoppage was once again the appearance of water, the source of which has puzzled the development team, was often springing forth unpredictably. Seeking to learn the source of the water, the construction team had the water carbon-dated. They discovered that some of the water at the construction site is about 4,800 years old. No word yet, though, on where it is coming from, but the fault had the highest chance to store water.

The tunnel builders conducted a thorough scanning of the geology of the strata of the range by airlifting sonar, a global positioning system and other advanced equipment by helicopter to the top of the range in order to find out what exactly was in the mountains that made the engineering task so Herculean. However, they were only able to scan about 300m into the mountain, leaving more than 100m of further depth still a mystery. It should progress a more accurate method to explorate the particularity of rock and the position of fault in depth over 300m.

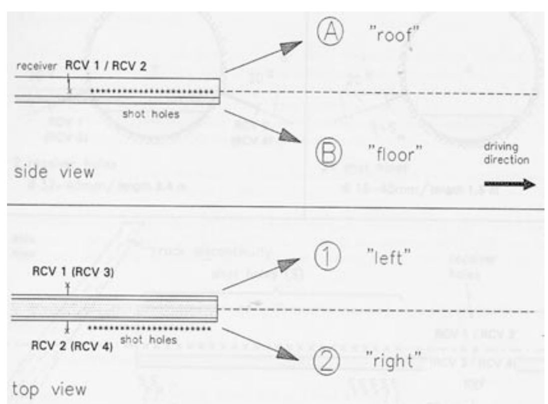

Figure 5. The investigated axis of TSP (This diagram abridged from the instruction of Amberg Measuring Technique Ltd.)

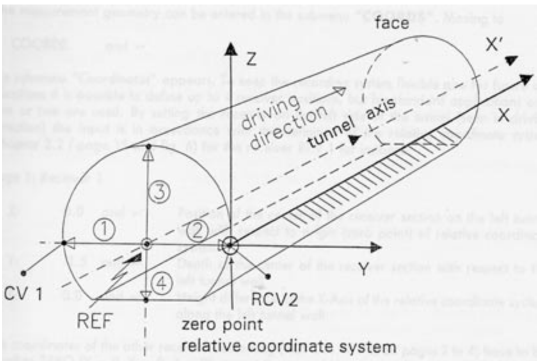

Figure 6. The relative coordinate system of TSP (This diagram abridged from the instruction of Amberg Measuring Technique Ltd.)

THE DATA ACQUISITION AND ANALYSIS FOR TSP

The consistent application of innovative technologies allow to construct even extreme complex underground buildings within a short time limit. This is possible due to the use of tunnel boring machines, with advance rate such as 20 meter per day or even more. The safety of the operation and the drilling performation assume a fair knowledge on the structure as well as the rock mechanical characterisitics of the rock formation of tunnel face. With the newly developed TSP system, it is possible to reach an investigation range of 100m in most of the rock formations, in hard rock even up to 200m. The tunnelling operation will not be held up by the use of seismic registrations, or insignificantly only, so that the seismic prediction method can be used continuously as an accompanying measure to the tunnelling construction. Using the seismic prediction method continuously while driving a tunnel a profile along the tunnel axis showing the distribution of rock mechanical parameters such as elastic modules and poisson ratio will be obtained at the same time. On one hand this information is important for the reinforcement of the rock and the tunnel lining installed later on and on the other hand it shows up gradually appearing changes of the rock quality, which are most likely not discovered by the use of other methods.

On a so called shot profile along the tunnel, acoustical signals are produced, which are propagating also in the direction of the tunnel axis. Changes in rock strength as they occur for example in connection with fracture zones or changes of rock formations, will reflect part a certain part of the signal transmitted. If these events are located ahead of the tunnel face, the reflected signal will arrice after a certain travel time at the acoustic receiver. Converting the travel time of the echo signals with the velocity of the rock formation allows to determine the event's intersection angle with the tunnel axis as well as the distance to the tunnel face. The result of the seismic prediction can be compared directly with the geological profile and if necessary be completed.

Together with other documents such as the engineers record for instance it provides an important base for the further tunnelling operation as well as to decide on appropriate measures for operational safety and tunnelling improvement. The TSP system is composed of the following components as shown in figure 4. It's including of shooting equipment, receiver system, recording system and consumable material. The shooting equipment is conventional blasting machine with an external trigger-box inserted in the shooting circuit.The receiver system is designed for applications throughout a large spectrum of different rocks, from weak rock formations up to hard granite. The recording system consists essentially of an electronic part which performs an analog-to-digital conversion of the seismic signals and a HUSKY data logger which is used to oprate the unit, to plot the records and to store the data. The consumable material includes explosive charges, receiver casing and injection mortar. For safety reasons and in accordance with standard regulations, it is advised to use explosives with detonation velocity above 6000 m/s and proper weight which depend on the distinction of site.

As figure 5 shows, 4 investigation sectors are distinguished, which are generally defined as follows:

(1A) Against face and roof of left tunnel side

(1B) Against face and floor of left tunnel side

(2A) Against face and roof of right tunnel side

(2B) Against face and floor of right tunnel side

And then, we could define the face location, receiver lcation(RCV) and shot postion with the relative coordinate system(X, Y, Z). The diagram is showen as figure 6. In a so called shot hole, a seismic signal is generated by firing of a small charge, from where the seismic waves are propagating on surfaces of spheres within the rock formation. In every shot record, the signal phase serves to distinguish whether the rock change at the planar discontinuity is from hard to weak or from weak to hard.

Table 1. The TSP result in the Hsuehshan Tunnel

Position	Geological condition	Wedth(m)	TSP position
A. Szeleng Sandstone			
37k+200~37k+190	Joint grown zone	10	37k+270, 37k+216
36k+765~36k+740	Fault zone with water	25	36k+765
36k+650~36k+685	Fracture zone	35	-
36k+000~35k+950	Dense joint with water	50	35k+876
B. Tatungshan Formation, Tzuku sandstone, Kankou Formation			
34k+835~34k+880	Joint grown zone	45	34k+960
34k+300~34k+340	Joint grown zone	40	-
34k+100~34k+140	Fault shear zone	40	-
33k+805~33k+850	Fault shear zone	45	33k+717
33k+550~33k+575	Fault shear zone	25	-
32k+470~33k+075	Fracture zone with fold	605	32k+415
C. Section Shihchiao fault			
31k+820~32k+150	Fault zone with water	330	32k+130
32k+045~32k+085	Fault zone	40	32k+130
32k+485~32k+525	Fault zone	40	32k+342
D. Magun Formation, Tungshan Formation			
30k+880~30k+920	Shear zone	40	30k+890
31k+310~31k+120	Shear zone	50	31k+156
31k+310~31k+390	Fracture zone	80	31k+156
31k+665~31k+700	Shear zone	35	-
31k+725~31k+750	Fault shear zone	25	-
31k+785~31k+830	Fault shear zone	45	-

The ratio of the incident to the reflected signal is defined by the reflection coefficient R:

$$Rdisc=(\rho_{disc}*Vp_{disc}-\rho_{rock}*Vp_{rock})/(\rho_{disc}*Vp_{disc}+\rho_{rock}*VP_{rock})$$

Where Rdisc is the reflection coefficient caused by the discontinuity, ρ_{disc} is the density behind the discontinuity, Vp_{disc} is the compressional velocity behind the discontinuity, ρ_{rock} is the density before the discontinuity, and Vp_{rock} is the compressional velocity before the discontinuity. We can distinguish the reflected signal with the seismic traces that is shown as figure 6.

Firstly, the data analysis should start from picking first break. It can measure the velocity of P wave for rock. And then, the wavefield processing will continue to extract the weak reflection signals from the recorded raw data and to enhance the reflection signals. The wavefield processing includes several modules. The first module is preprocessing. It could make some process to correct the trace, such as static correction, frequency filtering and amplitude decay compensation. The result, which is preprocessed, will be displayed automatically as a plot of the processed traces with proper parameter. Then, the wavefield separations could keep processing. The wavefield separations can enhance the direct wavefield, subtract the noise from the total wave field, and segregate the secondary wavefield arrivals. If the wavelet within the operator length will be compressed to a single sharp pulse by inverse filtering, the deconvolution module can transform the minimum phase wavelet into a zero phase wavelet at the same time.

All of these modules that was designed for reflector enhancing can process by diffraction stack evaluation. In the diffraction point groups diagram, the selection of many events complicates the result of the seismic prediction ahead. The intersection lines of adjacent events should not intersect if possible, except the geological conditions are complex. The lay out of the the output presentation is deliberately kept very simple in order to provide a base for the entry of other information, such as geological information and data from the engineers record.

DEMONSTRATION AND CONCLUSION

With an investigation range of 100m and more, the tunnel engineer using the Tunnel Seismic Prediction has a method at his disposal, which has important advantages, compared with geological prognosis and probing by predrilling. There are 33 TSP records which predicted for the Hsuehshan Tunnel to avoid the hidden risks as shown in table 1. Actually, it is not designed for precision measure of any fault, fracture or share zone. Many site factors will disturb the result, but it is practicable to build a database to compare the real condition with evaluation. The successful ratio of predicting will increase visibly by holding of the more exploration and geological survey. Especially, TSP become a rapidly investigatable system solution developed for tunnel construction, and evaluates normally associated with discontinuities in rock masses by seismic echo signals reflected from changes in elastic rock characteristics. It provides accurate spatial information concerning the geology and rock mechanical properties in front of the face. So, together with additional information, the interpreted TSP result provides an important basis for the further driving as well as for the required safety of tunnelling opreation, supporting and lining measures.

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