TSWD – STATE OF THE ART AND CURRENT DEVELOPMENTS

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Abstract

The Tunnel Seismic While Drilling (TSWD) method has been developed to predict the geological situation ahead of the tunnel face without disturbing the construction progress in the case a Tunnel Boring Machine (TBM) is operating. The vibrations of the TBM are used as the seismic source and processing of the seismic data is targeted to the detection of reflections from fault zones ahead of the tunnel face. Modern TBM`s achieve advance rates up to 50 m per day. Near real time processing and at least daily prediction is essential. These circumstances put high demands on instrumentation, data transmission, processing, and logistics. The principles of the methodology and the state of the art will be presented. Until now we applied TSWD at four tunnel construction sites in Austria. Optimized adaptation of the TSWD technique to the particular TBM type represents a further challenge. It will be shown how instrumentation and processing have to be adapted individually for each tunnel. The final interpretation of the seismic data contains a prognosis about 100 m ahead of the TBM including location, thickness, and geometry of construction relevant geological features. A close collaboration with geologists on site supports an adequate interpretation. Current developments which aim further improvements will be addressed. The comparison of the TSWD results with the encountered geology shows that wider fault zones over a thickness of 10 m can be successfully resolved, smaller fault zones are partly detected. General, there is a prediction accuracy of about 5 m for the beginning of the structures. It was possible to detect 80% of the prominent faults or transition zones at all tunnel sites. On the strength of past experiences faults with a high risk impact on the tunnel construction can be clearly defined.

Introduction

Since tunneling with a Tunnel Boring Machine (TBM) became the main technique in recent years, there are great challenges and demands for the prediction and detection of geotechnical risks. One method to reduce the risks is based on results of the SWD-Seismic While Drilling (e.g., Poletto and Miranda, 2004) and named as “Tunnel Seismic While Drilling – TSWD” (Petronio et al, 2003). The TSWD-method (Brückl et al, 2008 and 2010) uses the vibration signal of the cutting head of the TBM as a seismic source and therefore does not disturb the tunneling process. Modern TBM´s can drill about 50 m per day under favorable geologic conditions and therefore a real time processing and daily update of prediction has to be done. This imposes a major challenge on data transmission and logistics, processing and prediction, which have to be adapted for every tunnel construction site. After a first research project at Hieflau in 2008, the method was successfully implemented and improved at four other tunnel construction sites in Austria.

Geometrical Layout and Instrumentation

The geometrical installation layout for the seismic instruments consists of a seismic monitoring registration unit with accelerometers at the head of the TBM and registration units with 3C geophones behind the TBM (Figure 1). At least two accelerometers (parallel and radial to the tunnel axes) are mounted near the TBM head for recording the vibrations of the cutting head during drilling. The 3C geophones are installed in deep boreholes (5 - 10 m) at the right and left tunnel side wall in cross sections to get a good receiver signal. The distance between the cross sections is 100 - 200 m, depending on the advance rate and the expected geological structures. As the tunnel progresses, the whole system moves on.

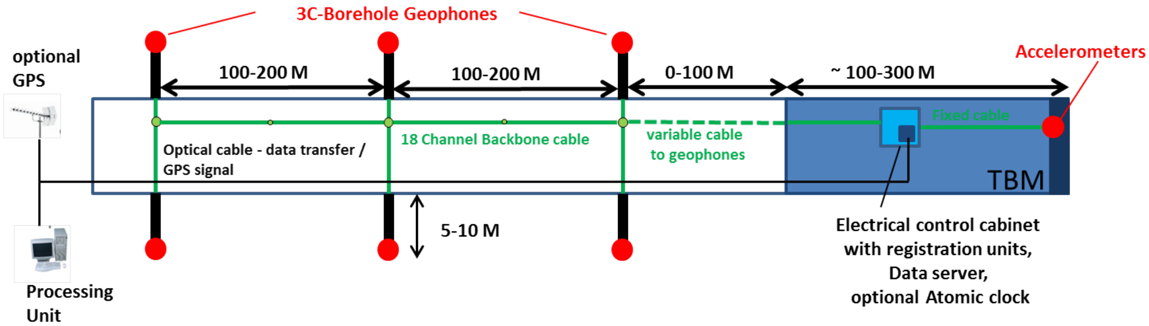

Figure 1: General geometrical layout of a TSWD registration system

The central position is the electrical control cabinet, mounted somewhere on the TBM with the data-recorders. They collect the signals from the accelerometers at the TBM head and those from the 3C geophones, sampled with at least 1000 Hz since the TBM signal can have frequencies up to 500 Hz. At this place a server can be installed which stores the data and via a connection to outside transfers the data in real time to the processing unit.

Timing

The timing and synchronization of the registration units is an essential part of the method. During the last two years different techniques were used. Standard practice is to transmit the GPS signal from an antenna outside over optical fiber cable to the recorders, which is difficult in the case where the tunnel is very long. Therefore a version with an atomic clock was invented which is directly connected to the recorders. It simulates the GPS signal and guarantees the synchronization even in absolute time, as it can be synchronized with GPS. The accuracy of the atomic clock is sufficient also for longer operations (3-5 months) without permanent synchronization with GPS.

Applications in Austria

Until now the TSWD method was applied at three different tunnel construction sites in Austria and is currently under operation in a 32 km long railway tunnel. Optimized adaptation of the TSWD layout to the particular TBM type and site situation has been necessary. In the first tunnel in Reisseck the registered data was stored on compact discs at each geophone cross section and manually transferred 2-3 times a week to the processing unit. Timing was done via GPS signal from outside the tunnel over heavy copper cable. At the next construction site in Prutz there was a central registration station, but no possibility for data transfer in real time. The big challenge for the equipment and maintaining personnel was the circumstance that the tunnel had an ascending slope of 31°. With the third tunnel in Bärenwerk a real time data transfer and timing with GPS over fiber cable could be implemented. As there was an average advance rate of 40 m/day, a daily processing and interpretation was necessary. The latest application, a railway tunnel through the Koralm massive, is still operating. The data transfer is carried out via fiber cable from a data server in the control cabinet on the TBM. The great improvement is the use of an atomic clock for the timing. So far the TSWD method has accompanied nearly 10 km of tunneling.

Processing and Mapping

The main processing steps are described in Chwatal et al. 2011. First an automatic process cuts out time windows of 32 sec – 1 min of the pilot and geophone data at the same absolute time, calculates the minimum delay transformation of the pilot signal and applies this filter to the geophone signal. The results of this procedure are seismic traces with a nominal shot distance in the range of millimeters and centimeters. After eliminating traces with low signal to noise ratio, the traces are stacked to 1m bin size. Amplitude normalization is used before the removal of the first arrivals of the direct p- and s-waves. Thereafter the result only contains the reflections from structures ahead of the tunnel face. To make the results more clear and readable for the interpretation and comparison with other prognoses, the arrivals of the reflected waves are mapped using the seismic velocity to rotate the reflections. A possible discontinuity which is perpendicular to the tunnel axis can be seen then as a vertical reflection line. This changes if the discontinuity is inclined to the tunnel axis. During the ongoing processing it is necessary to adapt the seismic velocity to the changing rock material. With additional 3- component processing the exact declination and inclination of faults can be calculated.

Results

TSWD results in a geophysical forecast window of 100 m ahead of the current tunnel face. The resulting classification is based on the actual geological situation and needs to be discussed and interpreted in detail with the geologists on site.

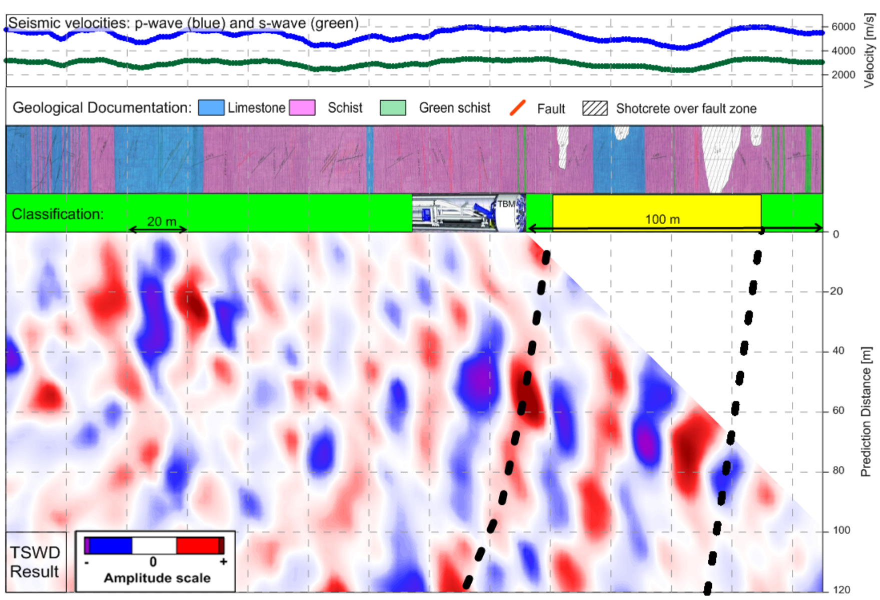

Figure 2: Example of the reflection image of a fault zone with the classification, the encountered geology and seismic velocities of the p- and s-waves obtained after drilling through it; the reflections are presented with positive and negative amplitudes; dashed lines indicate a fault zone.

The location accuracy of the beginning of fault zones is limited to about 5 m. Fault zones wider than 10 m are successfully detectable. Depending on seismic impedance contrast and the position relating to the tunnel axes, smaller faults are also visible in the data. Figure 2 shows the reflection image of a fault zone compared with the geology and seismic velocities that were obtained afterwards. High amplitudes indicate this fault zone (dashed lines). A classification of the observed reflections has been implemented via a traffic light system: green represents no faults, yellow is a possible weak fault zone and/or change in rock quality and red strongly indicates a fault zone. This has to be calibrated and adapted constantly with the actual geological situation. For all projects where TSWD has been under operation so far, approximately 80 % of the relevant structures have been detected and no high risk structure for the tunneling has been missed.

Conclusions

The TSWD system has been successfully under operation at four different tunnel sites in Austria. The implemented instrumentation, data transfer and logistics guarantee processing on a daily basis. To be more flexible in long tunnels, an atomic clock can be used for the timing. Careful processing provides a good separation of the directed and reflected wave field. The results are updated nearly daily and for that reason reflections of fault zones can be observed over long distances. Their interpretation is supported by the applied mapping method and also includes a classification of the reflections. Finally the permanent comparison to the encountered geology and the growing experience of the interpreter sharpen the prediction and yield a high hit rate of relevant structures. Further investigations are currently taking place regarding the resolution of the thickness of fault zones and the radiation pattern of the TBM.

References

Brückl, E., Chwatal, W., Mertl, S., Radinger, A., 2008, Exploration Ahead of a Tunnel Face by TSWD Tunnel Seismic While Drilling, Geomechanics and Tunnelling, Volume 1, Issue 5, p. 460-465

Brückl, E., Chwatal, W., Mertl, S., Radinger, A., 2010, Continuous Exploration Ahead of a Tunnel Face by TSWD-Tunnel Seismic While Drilling, Proceedings at 23rd SAGEEP - EEGS Annual Meeting Keystone, Colorado April 11-15, 2010, p. 353-360

Chwatal, W., Radinger, A., Brückl, E., Mertl, S. Freudenthaler, A., 2011, Tunnel Seismic While Drilling – State of the art and new developments, Proceedings of the ITA-AITES World Tunnel Congress, 20-26 May, 2011, Helsinki, Finland

Petronio, L., Poletto, F., Schleifer, A. and Morino, A., 2003, Geology prediction ahead of the excavation front by Tunnel-Seismic- While-Drilling (TSWD) method, Society of Exploration Geophysicists, 73rd Annual International Meeting, Expanded Abstracts

Poletto, F. and Miranda, F., 2004, Seismic while drilling: Fundamentals of drillbit seismic for exploration, Handbook of geophysical exploration, Seismic exploration series, Vol. 35, Elsevier, Amsterdam