SEISMIC RECONNAISSANCE BEYOND THE FACES OF AN ADVANCING COAL MINE ROADWAY

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Summary

Within the scope of the current project, the aim is to develop a non-destructive investigation technique using seismic waves to obtain information on the state of the rock ahead of the faces of a coal mine roadway. First test measurements were carried out in a mine of the Deutsche Steinkohle AG (DSK) in the northern Ruhr area. A series of disturbances are expected beyond the faces of this roadway from geologic investigations. Synthetic seismograms were calculated to interpret the measured data acquired in the field experiments and to study the complicated wave propagation in the vicinity of the roadway.

Introduction

The usage of tunnel boring machines (TBM) with an advance of up to 20 m per day requires a detailed knowledge of the structure and the geotectonic properties of the rock ahead of an advancing coal mine roadway. Up to now standard in-seam seismic methods for the investigation of seam panels are common practice, but for a site investigation of the rock structure beyond the heading face of a roadway, several drillings with a length of 20 m to 30 m are carried out. These drillings are very expensive and time consuming and give only point information of the rock beyond the face. Within the scope of the current project, the aim is to develop a non-destructive investigation technique to obtain information on the state of the rock of a roadway using seismic waves. Several systems that provide such information already exist in civil engineering: ISIS (Borm et al., 2003), TSP (Sattel et al., 1992), TRT (Otto et al., 2002), SSP (Kneib et al., 2000), TSWD (Petronio and Poletto, 2002). Applications of these systems have not been realised in practice for coal mining in Europe. The existing systems are adapted to seismic reconnaissance for tunnelling in hard rock and make use of reflected body waves. Early measurements and processing techniques for seismic reconnaissance in tunnelling were carried out in cooperation with DMT and Nagra (Blümling et al., 1992). In coal mining roadways are driven parallel to the seam. As the seam is a channel of lower velocities and density, channel waves, so called seam waves, can be generated. The usage of reflected seam waves rather than reflected body waves will be more effective in this case. Furthermore the existing systems are not intrinsically safe according to the EU ATEX Directive. Wave propagation in a coal seam is modelled using an algorithm that calculates complete seismograms by computation of the Green’s function (Friederich and Dalkolmo, 1995) and using a parallel elastic 2-D/3-D finite-difference modeling code (Bohlen, 2002).

First field tests

First test measurements were carried out in a mine of the Deutsche Steinkohle AG (DSK) in the northern Ruhr area. Previous geologic investigations suggest a series of disturbances beyond the faces of the roadway. At the heading face of the roadway six 3-component geophones were installed in the seam and the neighbouring rock in boreholes of 9 m depth. Thirty 2-component geophones were positioned at the west face of the roadway (Figure 1).
Boreholes with depths of 3 m and a drill diameter of 55 mm are adequate for these types of geophones. In this experiment, seismic waves were excited by explosives. In the roadway the explosives are positioned in about 3 m deep boreholes perpendicular to the face. At the heading face the 10 m deep shot holes point in the direction of the roadway and were filled with explosives every 2 m. Cartridges of 125 g were used.

In the Ruhr area the country rock in the neighbourhood of the coal seams consists mostly of shale or sandstone. Knowledge of the velocity distribution in the vicinity of the coal seam is a prerequisite for further processing. To determine the seismic velocities a refraction tomography was carried out with the data of the 2-component geophones. The results of the refraction tomography lead to velocity distributions of the compression waves in the roof, the seam and the floor and are consistent with typical seismic velocities of the coal and the surrounding rock (Table in figure 2).

![Figure 1: Location of sources (stars) and receivers (circles) of the first in-mine test measurement.](image1)

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![Figure 2: Left: Dispersion curves of the fundamental Love seam wave for a three-layered model and varying seam thickness. Right: The table shows typical seismic velocities and densities for the coal and the surrounding rock.](image2)

<table>
<thead>
<tr>
<th>Seismic velocities</th>
<th>$\omega$ [rad/s]</th>
<th>$\beta$ [rad/s]</th>
<th>$\rho$ [kg/m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>country rock (i.e. shale, sandstone)</td>
<td>$200 \leq \omega \leq 4000$</td>
<td>$1600 \leq \beta \leq 18000$</td>
<td>$2.8 \leq \rho \leq 2.8$</td>
</tr>
<tr>
<td>coal</td>
<td>$1600 \leq \omega \leq 2400$</td>
<td>$700 \leq \beta \leq 1400$</td>
<td>$\rho = 1.3$</td>
</tr>
</tbody>
</table>

Characteristics of seam waves and modelling results

Coal shows physical properties distinctly different from the neighbouring rock. It is an example for a channel of lower seismic velocities, were channel waves, so called seam waves, can be generated. The shape of the dispersion curves is mainly influenced by the velocities and the layering of the coal. Especially the thickness of the coal layer affects the frequency of the airy phase. Figure 2 shows dispersion curves calculated for a three-layered model (Krey, 1963). Numerical calculation of Love and Rayleigh seam waves (Räder et al., 1985) for
models with an additional layer of higher velocities and density in the seam show the strong influence of dirt bands.

To interpret the measured data acquired in the field experiments, synthetic data were calculated using an algorithm that calculates complete seismograms by computation of the Green’s function (Friederich and Dalkolmo, 1995). In addition synthetic data were calculated with a FD modelling code (Bohlen, 2002) to study in particular the complicated wave propagation in the vicinity of the roadway and at different disturbances. For the computations a three-layered model was used with the P-wave velocities determined from the refraction tomography (Figure 3). A seam of 2 m thickness was assumed. The corresponding frequency-wavenumber spectrum shows the body waves and the seam wave mode. Receivers and sources were located in one straight line in the centre of the coal layer. Synthetics for the same basic model and the same source and receiver locations were calculated with the FD algorithm for comparison. Snapshots of the corresponding horizontal and vertical components of the seismic wave field show, that a fundamental antisymmetrical Rayleigh seam wave is generated. Antisymmetrical Rayleigh seam modes have a maximum of the amplitude-depth distribution in the centre of the seam for the vertical component and a node at the horizontal component.

![Figure 3: Left: FK spectrum for a three-layered seam model. Middle: Synthetic data calculated with the green function method for a three-layered seam model. Right: Snapshots of the horizontal and vertical component of the seismic wave field.](image)

In a seismic layout like in the first test measurements, the wave propagation is mainly influenced by wave forms generated at the roadway faces. A FD Modelling was carried out for a three-layered seam model with a tunnel. The source is located 10 m beyond the heading face. The propagating seam wave generates a tunnel Rayleigh wave when reaching the heading face of the tunnel (Figure 4).

Conclusions

First test measurements were carried out in a mine of the Deutsche Steinkohle AG (DSK) in the northern Ruhr area. The velocity distribution beyond the faces within the first five meters could be calculated using standard refraction tomography. To interpret the measured data acquired in the field experiments and to study the complicated wave propagation in the vicinity of the roadway, synthetic data were calculated using an algorithm, that calculates complete seismograms by computation of the Green’s function and using a parallel elastic 2-D/3-D finite-difference modeling code. These computations show that an antisymmetrical fundamental seam mode is dominant for a simple three-layered model. When a dirt band with higher velocities and density is considered within the seam, higher modes dominate the wave

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propagation, depending on the thickness of the dirt band. The FD algorithm is very efficient to model the wave propagation in a seam with a tunnel and at different disturbances. These computations show that seam waves are converted into Rayleigh waves at the front tunnel face and vice versa. The tunnel Rayleigh wave propagates along the roadway and interferes with the seam wave. The existence of assumed disturbances of the coal seam may be tested by comparison of numerically calculated synthetics with measured data. For this reason synthetics will be calculated with 3-D FD modelling.

**Figure 4:** Snapshots of the divergence and curl of the seismic wave field in the X-Y-plane for a three-layered seam and with a tunnel.

**Acknowledgments**

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**References**


