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Investigation of Seam Thickness and Seam Splitting within a Longwall Panel by an In-Seam Seismic Survey

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ABSTRACT

The propagation velocity of in-seam seismic (ISS) waves depends on frequency which is also known as dispersion. This dispersion is not only determined by the thickness of the coal seam and its dirt band content (i.e. thickness and position), but also by the rock type and its condition (soft or compact) above and below the coal.

A coal panel completely surrounded by roadways was investigated using the in-seam seismic transmission survey technique. Along the roadways the immediate roof was either sandstone and shale. The seam thickness varied between 1,20 m (sandstone in the roof) and 1,40 m (shale in the roof) and a fault system (normal faults) crossed the panel with a total throw of about the seam thickness. Below this coal seam another coal seam with a thickness of about 80 cm exists. Its interval shown by exploratory drilling changes from about 60 cm to more than 6 m (seam splitting).

Tomographic inversion was applied to the dispersion of the measured ISS waves and velocity distributions were calculated at frequencies found to be most sensitive to changes in the seam thickness and the distance to the coal seam below. By correlating the velocity distributions with known values along the roadways approximate distributions of the coal seam thickness and the seam splitting within the panel were produced.

The mining of the coal panel had already been finished and comparison was made between the survey results and the actual situation as far as it was documented. Prediction by the seismic survey was partly in good agreement with the actual field conditions or showed at least the same trends.

INTRODUCTION

The coal mine Auguste Victoria / Blumenthal, one of the ten mines of the Deutsche Steinkohle AG is located in the northern Ruhr Area where it mines its deposits below the cities Marl and Haltern. The mine has a coal reserve of 55 million tons. In addition another 150 million tons of coal are obtainable in another mining area located north of the current mining site.

Mining has been focusing on multi-seam mining for the past 100 years. On average three panels are mined per year with an overall production of about 3,5 million tons of hard coal. Coal seams are mined with a thickness ranging from about 1,3 m to 3 m. But thin coal seams like seam O considered below are investigated in advance with respect to the geologic conditions to obtain a rate of face advance necessary to realise a coal output of 3000 to 4000 t/d.

While developing the main gate and tail gate for the panel O-238 unexpected geologic problems were encountered which made this special investigation necessary.

SITE DESCRIPTION AND GEOLOGY

Seam O lies in a depth of –1020 m to –1060 m. It is the upper one of five workable coal seams in the northeast part of the mine's deposit. Tectonic faults with throws of more than 100 m known from core drilling from the surface allowed a layout of a panel with a face length of 350 m and a panel length of 1,5 km. It was planned to be mined by retreat method and a U-ventilation system.

While simultaneously developing the main gate TO 7 and tail gate TO 6 for this panel which were designed as arch-type roof-bolted roadways, minor tectonic faults were encountered with throws between 0,2 m and 1,8 m (Fig. 1).

In general a sandstone layer with a thickness of about 10 m is known to lie directly above seam O. It is conglomeratic without any structure, partly streaked with thin layers of coal and less compact. But while developing the gates a layer of partly friable shale was exposed in large sections of the roof. It has a varying thickness between 0,2 m and 1,7 m and contains slickenside surfaces. Uniaxial compression tests showed a compressive strength of 4,5 N/mm^2 increasing to 55 N/mm^2 towards the sandstone layer.

Furthermore two additional geologic features were encountered: An underlying seam (coal seam N) with a thickness of about 60 cm is approaching seam O up to 80 cm from below and the thickness of seam O varies between 1,20 m and 1,50 m.

Finally a fault with a throw of 16 m was found at the end of the planned rise heading which seems to split up into several faults discovered at the end of the main gate combined with a sudden decrease of the total throw.

INFORMATION NEEDED FOR THE WORKING PLAN

All these geologic features discovered along the roadways made an investigation of the panel O-238 necessary prior to any further preparation work. The information about the distribution of the seam thickness and the distance to the underlying seam as well as the development of the binder shale within the panel were needed to select the working range of the shield support. The location of the faults and the development of its throws had to be known to determine the location of the new rise heading and to estimate the approximate mining rate of advance progress. Finally the possible presence and locations of additional unknown faults or other seam anomalies (i.e. wash-outs, which partly appeared in the former working panels in seam O) must be known to estimate the overall mining risk.

For this purpose an in-seam seismic (ISS) survey was applied to the whole panel after the roadways surrounding it have been completely developed.

A SHORT INTRODUCTION TO THE ISS SURVEY METHOD

The In-Seam Seismic survey (ISS) method uses seismic waves guided along and within a coal seam to detect and locate the faults or other geologic anomalies within a coal seam (1, 2). These seismic waves are called in-seam waves or channel waves. They are produced by small explosives and measured at different positions by two-component geophones. Explosives and geophones are placed in short boreholes along the roadways within the coal seam under investigation.

The propagation velocity of the channel waves depends on frequency. This behaviour is also known as dispersion. It is determined by the thickness of the coal seam, the dirt band content (i.e. their thickness and position) and the rock type and its condition (soft or compact) above and below the coal.

There are two types of surveys in the ISS method: the transmission survey and the reflection survey. They are applied depending on the geologic problems to be investigated and on the roadways present in the survey area and their types of services.

The reflection survey is used to detect and locate geologic faults (normal faults, partly also overthrust faults and washouts), and generally speaking any geologic anomalies which suddenly interrupts the continuity of a coal seam. The detection distance is on average about 100 times the seam thickness.

The transmission surveys are generally used to investigate coal seam areas between roadways for instance the whole panels between them. They can be used to receive information in addition to the possible presence of geologic faults. Such information may be irregular shaped washouts, thickness of the coal seam, dirt band content and seam splitting. At least it can map regions within an investigated area which shows an abnormal behaviour as compared to other parts of the coal seam which are known as undisturbed. The penetration distance of this survey method is on average about 300 times the seam thickness. For instance a panel with a dimension of 400 m times 2000 m and a seam thickness of about 2 m can be completely investigated.

THE INVESTIGATION PROBLEM IN SEAM O-238 AND SURVEY LAYOUT

Fig. 1 shows the whole panel with the main geologic conditions known along the roadways (i.e. the faults including their throws with the shale exposed in the roof marked in light grey). The parts of the roadways marked in dark grey are completely developed in rock because of the presence of faults with greater throws (16 m and 20 m).

After a closer inspection of the exposed rock strata along the roadways it was found that shale or sandstone roof correlates well with the seam thickness, i.e. at locations with sandstone above the coal the seam thickness was generally smaller. Further at the locations where the underlying seam (seam N) approaches seam O from below both coal seams could be considered as one single seam containing a dirt band with varying thickness. Both the seam thickness and the thickness of the dirt band determine the dispersion of the in-seam waves. Therefore it should be possible to investigate their distribution within the panel by means of an ISS transmission survey and a closer analysis of the dispersion of the recorded channel waves.

The survey was planned with the source stations S along the main gate with an average distance of 20 m (Fig. 1). The geophone stations G were placed along the tail gate with an average distance of about 40 m to 50 m and with additional stations at locations with major changes in the geology. Finally the whole survey layout was completed with source and receiver stations placed along the rise heading in the east and along the bottom heading in the west for a better control of the tomographic inversion. With this layout also reflections from the faults might be recorded depending on their direction through the panel.

THE SURVEY

The whole survey lasted about 14 hours. A total number of 76 shots were recorded at all receiver stations located in a distance of 700 m to 800 m from the individual source stations. Two-component geophones were used to measure the complete channel wave motion polarised in the seam plane.

PROCESSING AND TOMOGRAPHIC INVERSION

First all data were analysed with respect to channel waves reflected from the faults inside the panel. But only from the northern part of the fault system crossing the panel from north to south were measured at stations east of it, from which its location was determined (partly filled circle line in fig. 2). The open circle line shows the possible extension of the fault system to the tail gate. Further indications of additional major faults (i.e. faults with throws greater than the seam thickness) were not present in the data.

In the second step all transmitted channel waves are analysed with respect to their dispersion. Time-frequency analysis was applied to the data and the travel times of the seam waves at specific frequency values were determined, which shows the greatest changes with respect to known changes of the seam thickness and the distance to the underlying seam along the roadways. Finally tomographic inversion was applied to these travel time values yielding velocity distributions within the panel, which are proportional to the corresponding distributions of the seam thickness and the distance to the neighbouring coal seam.

To translate the velocity distributions into the distributions of the seam thickness and seam splitting, the velocity values were correlated with the corresponding values at locations, where their values were known (i.e. along the roadways and from drilling). The resulting maps are shown in the Figs. 2 and 3.

DISCUSSION OF THE RESULTS

The map for the distribution of seam thickness (Fig. 2) shows from east to west first an increase in seam thickness until it reaches its maximum values (almost 140 cm) around and east of the traversing fault system. Further to the west it decreases continuously first only slightly but gets faster towards the end of the panel, where it finally amounts only to about 120 cm.

As there was a correlation between the seam thickness and the rock type above the coal (sandstone or shale) it was concluded from this map that shale in the roof which has potential for roof falls had to be expected around the fault system and most of the eastern half of the panel. But towards the west end of the panel only sandstone will be present.

There also seems to exist a correlation between variations in the seam thickness and exposed faults along the roadways, for instance at the east end of the tail gate. These observations were interpreted as possibly extension (strike) of these faults into the panel shown by open circle lines.

The distribution of interval to the underlying seam (Fig. 3) shows a continuos increase of the interval starting from about 80 cm in the east side to about 500 cm in the west side of the panel. To the east of the traversing fault system the contour lines of interval strike partly from SW to NE, i.e. the interval along the main gate increases faster than along the tail gate.

COMPARISON WITH THE ACTUAL SITUATION

Fig. 4 shows the actual geologic situation found while mining the panel as far as it was documented. The predicted locations and strikes of the faults were very accurate. The panel had only to be shortened by about 100 m because of the fault with a throw of 16 m found at the end of the first rise heading leaving the panel to NW shortly after.

As predicted shale (light grey area) was found in the roof in great parts around and east of the traversing fault system. But it did not considerably reduce the advance of the mining face as shown by the dated lines of face advance. The reduced face advance rate occurred around the traversing fault system and was caused by the thinner coal seam towards the west end of the panel.

The seam thickness (average values along the mining face) varied almost in the same manner as it was predicted, although some deviations can be observed. For instance the decrease in the west side of the panel is much faster. But at least the general trend is correct.

Finally the development of the interval to the underlying seam (seam N) along the main gate and tale gate showed through exploration drilling a good agreement with the survey results.

ERROR DISCUSSION

The errors in the distribution of the seam thickness (and probably also for the seam splitting) were mainly caused by the correlation of the velocity distribution with the reference values. The tomographic inversion process yields average velocity values within the cells of the chosen grid. They were related to local measures of the seam thickness and the distance to the coal seam below. The ray density was not constant within the chosen grid and may have left its footprint in the inversion result (error in the velocity). Also no difference was made between the areas with sandstone or shale exposed in the roof. The influence of these errors on the results and how it can be reduced or avoided has to be further investigated.

CONCLUSION

The distributions of the seam thickness and the interval to the underlying seam (seam N) within the panel O-238 were determined by tomographic inversion of the travel times of the dispersive seam waves at specific frequencies followed by a correlation within known values along the roadways and from drilling. Both results could be checked after the mining of the panel was finished. They were found to be partly in agreement or showing at least the same trends. But different error sources still existed which have to be analysed by further investigations to reduce or at least to estimate their influence on the results.

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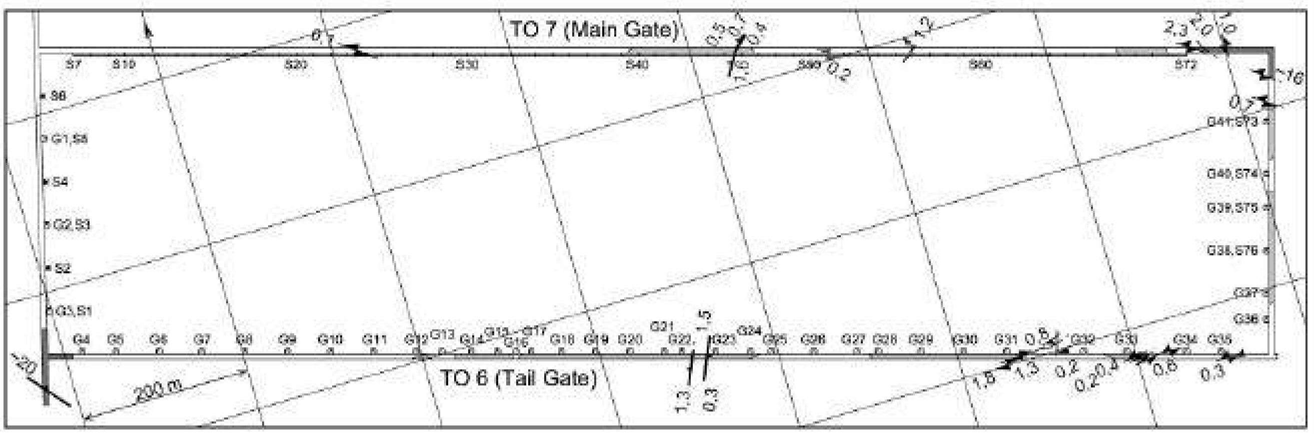

Figure 1. Panel O-238 with fault locations along the road ways and the layout of the in-seam seismic survey. In the sections along the road ways marked in light grey shale is exposed along the roof. Dark grey sections of the road ways are completely developed in rock.

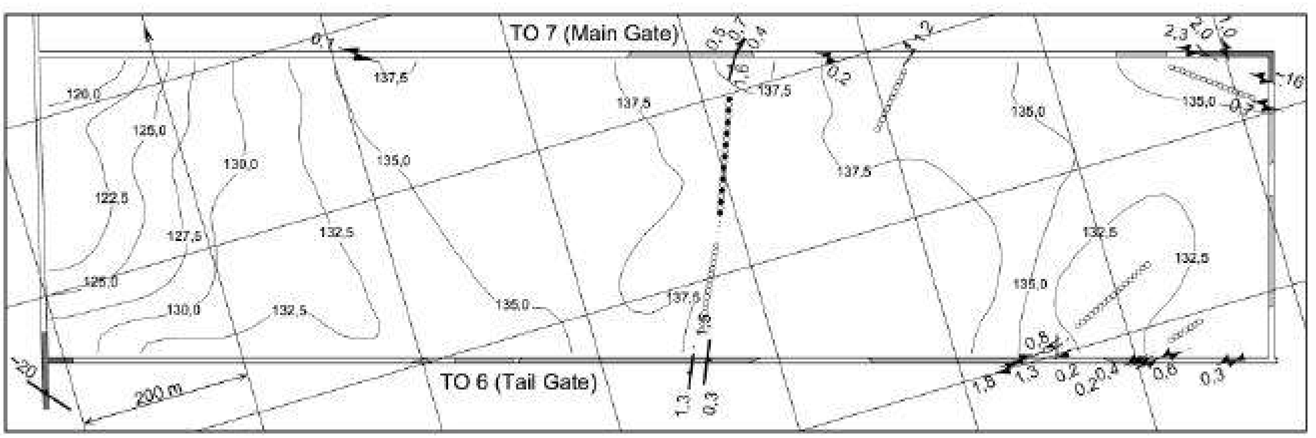

Figure 2. Distribution of the seam thickness within the panel O-238 in cm. Fault locations detected by the in-seam seismic survey are shown with partly filled circle lines, possible fault locations with open circle lines.

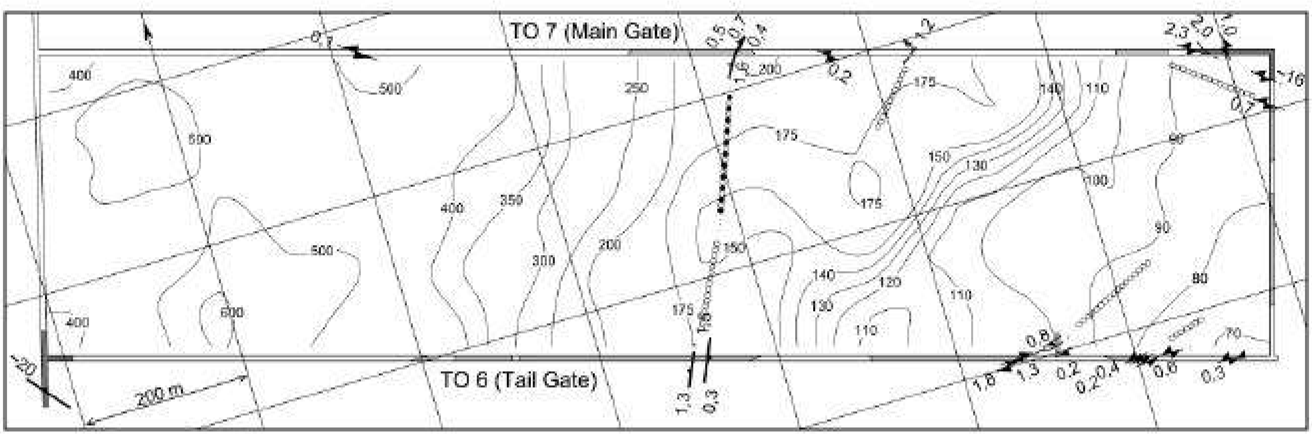

Figure 3. Distribution of the interval to the underlying seam (seam N, seam splitting) within the panel O-238 in cm

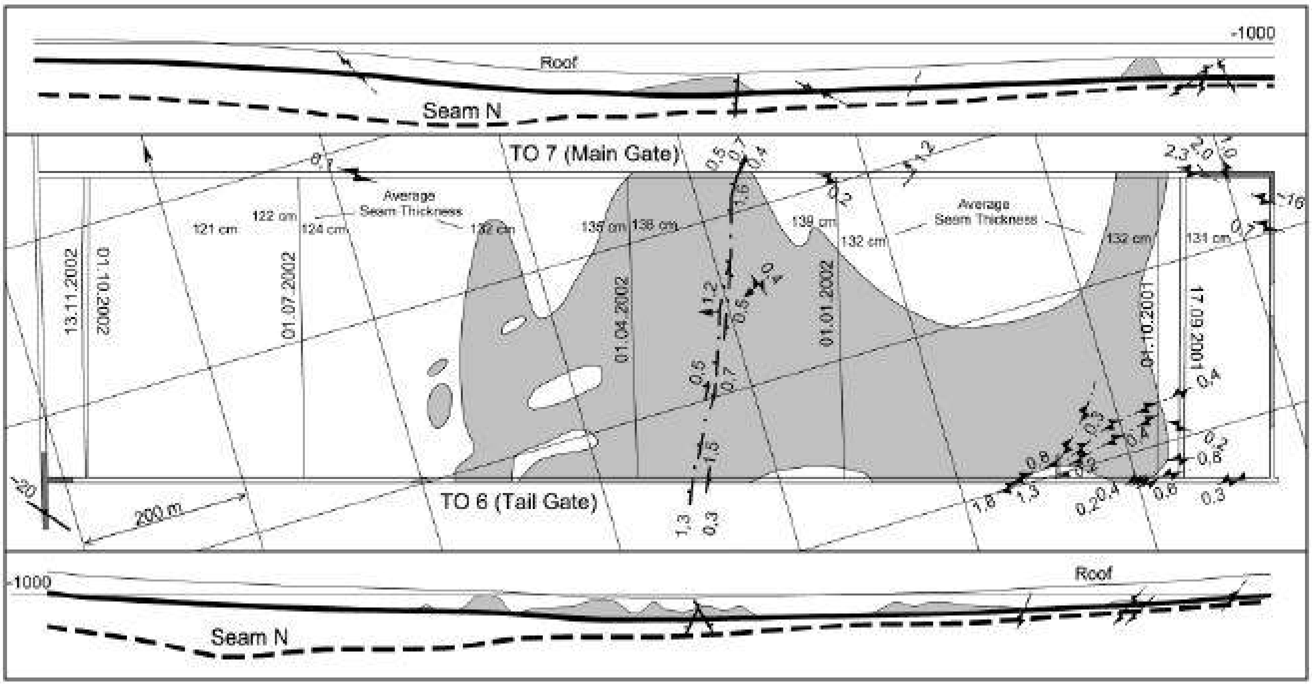

Figure 4. Geologic situation found during the mining of the panel as far as it was documented and from further drilling along the road ways.