INVESTIGATION AND ANALYSES OF SUDDEN OUTBURSTS OF GAS DURING DRIVING OF MINE ROADWAYS

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ABSTRACT

When driving mine roadways in the vicinity of tectonic disturbances and fault zones, sudden outbursts of gas, along with ejections of fine coal, occur. Substantial dynamic changes occur around the roadways in the coal and around the support. The problem has several aspects.

Studies have been carried out on the technical analyses of the phenomena which occurred in the Velenje Lignite Mine from 1957 to 1988. The second part of the investigation involves systematic laboratory studies of strength and deformability characteristics of lignite samples and "in-situ" measurements of stress changes during the driving of some roadways. Analyses of events (using the model of limit convergence and the finite element method) showed the possibility of gas outbursts, taking into account the deformability conditions when crossing over from compact lignite to the disturbed region. The rate of advance of roadways and the method of support strongly influence the occurrence of the phenomenon. The preventative measures used in driving roadways under such conditions include trial drilling and the use of blasting instead of machine cutting.

INTRODUCTION

According to its genesis, the Velenje deposit is a tectonic depression into which the lake sediments were deposited in the Tertiary and Quaternary periods. The pan-like form of the lignite seam, stretching approximately 8 km in the East-West direction and 1.5 km in the North-South direction makes possible favourable conditions for the development of highly productive mining methods. The exploitation of lignite is made possible by sub-level longwall mining methods, with working lifts of between 3 m and 10 m height and with caving in the immediate roof.

Today, mining operations are being performed between the elevations of +220 m and -130 m. With the progress of mining into depth, working conditions change, especially in the form of primary stresses concentration, changed lignite structure, and the extent of breakdowns in the hanging wall around the working cavities. Since 1958, sudden coal and gas outbursts have occurred in large numbers, with 18 accidental deaths being registered up until 1978. Several more such events occurred, which, fortunately, did not cause fatalities but which were registered as coal and gas outbursts.

In the scope of studying the sudden coal and gas outbursts: mechanisms, the Velenje Lignite Mine financed several known experts and extensive investigations on the mechanisms of the events dealt with. All of the tests were performed in co-operation with the mine experts.

It is known, from the technical literature, that extensive investigations have been carried out in the world which should answer the questions relating to the cause of such phenomena and to the measures of their prevention.

The results of investigations and analyses reported in this paper indicate that all the problems in this area are not yet solved. The continuation of research in this domain is foreseen as being in the direction of looking for simple preventative measures that are practical.

A SHORT REVIEW OF SOME SUDDEN COAL AND GAS OUTBURSTS

Instantaneous coal breakdowns in roadway drivages.
connected with simultaneous fractured coal and gas outbursts, have been registered mostly in the crossing of faults and faulted areas, although this isn't always the case. Such phenomena have occurred in cases when the roadway didn't pass through a faulted area. The outbursts registered in the case of a roadway advancing towards a fault, as shown in Fig. 1, have been much more frequent than those in Fig. 2.

Fig. 1 Longitudinal sections of 28 outbursts registered from the total 32 outbursts.

Fig. 2 Longitudinal sections of 4 outbursts registered from total 32 outbursts.

From Fig. 3, which shows some registered breakdowns, it can be seen that the fractured coal and gas outbursts occurred in inclined and horizontal mine roadways. Although the coal structure is not precisely defined in the presented breakdowns, in connection with other geometrical parameters, the coal structure is considered to have a great effect on the occurrence of those breakdowns.

A very characteristic example of a coal and gas outburst was that of January 8, 1977. It was interesting that first the roadway crossed, without difficulties and breakdowns, the fault zone which was positioned as shown in Fig. 2. A few meters further, a fault of rather smaller extent was crossed, which was positioned as shown in Fig. 1.

Although the effect of the fault position is probably present at sudden coal and gas outbursts, it is felt that the immediate lignite structure is conditioned by the fault position in the given area. And this makes better or worse
conditions for the possible occurrence of the phenomenon, above all from the point of view of the failure theory.

LABORATORY INVESTIGATIONS OF LIGNITE DEFORMABILITY AND STRENGTH PROPERTIES

The laboratory investigations of deformability and strength properties of the Velence lignite were carried out. All samples for the investigation were prepared according to the ISRM suggested methods.

The investigations had the purpose of determining the maximum strengths in the axial direction. For measuring the strains in the vertical and horizontal directions, strain gauges were mounted on the opposite sides of the cylindrical specimens of H:D = 2:1 ratio. The samples were loaded axially with continuously increasing load. The axial force and specific deformations were automatically recorded at uniform load steps. Several load loops were made for each sample before its breaking load was determined. The average elasticity modulus and Poisson’s ratio were calculated from the axial force changes and the value of the unconfined compressive strength from the breaking force.

The tensile strength of lignite was determined by Brazilian test.

The elasticity modulus was determined for 23 samples; its average value was 693 MPa with a standard deviation of 313 MPa. The unconfined compression strength was determined for the same number of samples, the average value being 8.25 MPa, and the standard deviation 2.3 MPa.

Investigations of the Poisson’s ratio were also carried out on 23 samples, the average value being 0.336, and the standard deviation 0.014. The average tensile strength value of eight samples, for which the Brazilian test was performed, amounted to 0.76 MPa with a standard deviation of 0.3 MPa.

INVESTIGATIONS OF LIGNITE PERMEABILITY FOR GAS AT DIFFERENT PRESSURES

The changed stress states, together with the primary damaged lignite, have shown the need for determining the lignitic permeability for gas at different confining pressures. The naturally fractured coal from the fault zones was investigated in the laboratory using apparatus which has a high-pressure triaxial cell as its main component. To simulate pressures and stresses present in the considered underground areas, an apparatus was prepared so that tests could be carried out at confining pressures up to 24 MPa and at gas pressures up to 15 MPa. The samples tested in this cell were cylindrical and about 100 mm in diameter and about 200 mm high.

A great number of tests of permeability for gas at different external confining pressures were performed in the laboratory.

The apparatus used, with its appertaining component parts, is schematically shown in Fig.4, and in Fig.5 are shown the relations of permeability for gas $\phi$ (l/min) and confining pressures $\sigma_1 = \sigma_3$ presented for some lignite samples at different gas pressures.

Results of investigations of fine lignite samples from the technically destroyed areas show that, in general, the permeability for gas doesn’t change essentially with confining pressure on the sample decreasing to the value of about 1.0 MPa for water-saturated lignite, and decreasing to the value of 2.5 MPa for coal with natural moisture. However, the permeability for gas essentially increases...
Fig. 5 Gas permeability versus confining pressure for different lignite samples

when the gas pressure equals approximately the confining external pressure on the sample.

The investigations on the effect of water show that the permeability for gas of finely grained samples with a greater quantity of water added is such as if we had to do with grained material saturated with water. The results of investigations have shown that such samples are practically impermeable for gases. The capacity for gas absorption has a significant influence on gas processes occurring in sudden gas and coal outbursts. The results of analyses of laboratory investigations clearly show that the absolute gas pressure value does not influence the permeability for gas but the difference between the total stress state and gas pressure is essential, of course.

IN-SITU INVESTIGATIONS OF STRESS STATES CHANGES

With the purpose of finding out the relationship between the stress state changes and the approaching roadhead, in-situ measurements were carried out in the Velkép Lignite Mine. For this purpose, the development road No.7 was selected. It was in construction at that time, and is in lignite for almost all its length.

The stress state changes were measured by means of a stress monitoring station of the Glotzl type which represents hard inclusion. The stress monitoring station consists of three hydraulic cells which are turned by 45° one from another.

The measurements were performed on two locations designated as location A and location B. At location A, the stress monitoring station was built into a vertical borehole drilled from the roadway 9 m below the future roadway No.7 and at right angles to it. The vertical projection is schematically shown in Fig.6, where the arrangement of particular hydraulic cells in the measuring probe can also be seen.

Fig. 6 Stress monitoring station on location A

The monitoring station was built in such a way that firstly, a 6 m long column was inserted and sealed in the preliminarily borehole of 142 mm in diameter. Then the measuring probe was inserted in a borehole prepared in this way and filled with a special injection mass at a pressure of 10 bar. The measuring probe installation is schematically shown in Fig.7. At the time of installation, the roadway face was 44 m away from the probe at location A. Then the measurements were made depending on the roadway face.
The rate of advance towards location A

![Diagram showing stress monitoring station A](image)

Fig. 7: Installing the stress monitoring station A

The results of measurements are shown in Fig. 8 and show the pressures in particular hydraulic cells and reduced to the initial pressure after injection or installation, as a function of the distance from the roadway face. Up to a distance of 15 m from the roadway face, a slow rise of pressure can be seen. At a distance of 12 m from the monitoring station, the first maximum is registered and the second one appears at a distance of about 7 m from the face. At a distance of about 3 m from the face the hydraulic cells showed such values as though the horizontal stresses were already in the tensile region.

![Graph showing stress monitoring station A](image)

Fig. 8: Results of measurements of stress changes on location A

At location B, the stress monitoring station was installed in a sub-horizontal borehole (α = 5°) drilled in the wall of the wall of the adjacent roadway No. 2 parallel to the future roadway No. 7. As at location A, a measuring probe with three hydraulic cells was installed (Fig. 9). At the time of installation, the roadway face was more than 27 m away from the monitoring station. The results of measurements at location B are given in Fig. 10 where pressures in particular cells, reduced to the initial state, are shown relative to the roadway face distance.

Figure 10 shows a slow rise in pressure up to a roadway face distance of 5 m from the measuring probe, and then, the values rise quickly. The greatest changes of vertical stresses were measured at the moment, when the roadway face was about 2 m away from the monitoring station B.

![Diagram showing stress monitoring station B](image)

Fig. 9: Plan showing stress monitoring station on location B and cells in inclusion.

![Graph showing stress monitoring station B](image)

Fig. 10: Results of measurements of stress changes on location B

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OUTBURST ANALYSIS BY THE FINITE ELEMENT METHOD

The outburst were analysed using the finite element method taking into account the non-linear analysis. The expansion of secondary stress-states were followed by simulating the roadway face advancing. The vertical longitudinal cross-section of roadway No. 7 was taken into account. The geological composition of the area can be seen in Fig. 11 and the situation has also been analysed. The analysed part of the roadway runs through coal as far as the fault zone area, where there is fractured coal. A smaller parting of harder rock is also to be found in this area.

![Diagram](image.png)

Fig. 11 Longitudinal geological cross-section

In the calculation, the anistropic nonlinear material model took into account the plane strain conditions. In the computer program used, the criterion is defined by the improved von Mises' yield condition. The values of input parameters were assumed, according to the laboratory in situ investigations considering the Q method. Firstly, the primary stress state was calculated on the supposition that the ratio of horizontal to vertical stresses was $\sigma_1/\sigma_3 = 0.8$. In the subsequent calculation, the roadway face advance was simulated in approximately equal steps and the expansion of secondary stress-strain fields and yielded zones was pursued.

Fig. 12 shows the changes of horizontal and vertical stresses ahead of the roadway, calculated for different face distances from the fault zone. The comparison with the measured horizontal and vertical stresses presented in Figs. 8 and 10 shows satisfactory conformity with the relative curve shape and the achieved maxima, but minimum agreement with respect to absolute values of the measured stresses.

The results of calculations show that the yielded zones increase to a high degree especially immediately ahead of the roadway face where there is the faulted coal zone. That is, the secondary stress state changes to a high degree with roadway advancing. The influential areas as a result of mining operations in roadway driving are widened above all in the direction of roadway advance. The ratio of vertical to horizontal stresses, immediately behind the roadway face, changes with the advance towards the fault zone. The vertical stresses increase whereas the horizontal stresses decrease. Thus, the deviatoric stress state increases and in certain conditions, especially at geological and technological conditions, the horizontal stresses can even go over from compressive into tensile, which increases the possibility of sudden coal and gas outbursts.

EVALUATION OF THE INFLUENCE OF ROADWAY RATE OF ADVANCE ON THE COAL AND GAS OUTBURST OCCURRENCES

As a consequence of face advance, the stresses in the surroundings of the roadway change with time. The cause of the stress increase is not only the rheological properties of surrounding rock and the influence of time, but also the rate of advance. In the case of a roadway of circular cross section, constructed in an homogeneous, isotropic, linearly visco-elastic environment, the parameter $\lambda$ is usually introduced for analytical solution, making use of the plane deformation problem. In the analysis, the radial stress $\sigma_r$ decreases along the roadway circumference, from the initial value of $\sigma_b = YH$ (hydrostatic primary stress state) to the value of zero in the case when the roadway is left unsupported. The expression for radial stresses illustrating the influence of the roadway face and the unloading of surrounding rock is $\sigma_r = (1 - \lambda)\sigma_0$, where the parameter changes from 0 to 1. The latter is increased with the...
The secondary stress state was analyzed on the basis of the "convergence confinement" method. A computer program was prepared which made possible the time analysis of surrounding rock and supports interaction (prevailing the influence of advancing).

The technology changed in the Velenje Lignite Mine in 1979. The increased cross-section of roadways reflects, above all, in a greater plastic zone radius and partly in greater final convergence of the unsupported roadway. The time analysis, however, also shows the differences as a result of a different average rate of advance before and after the year 1979. At the same assumed retardation time, T, the parameter f/T changes because of the changed average rate of daily advance of roadways, of the advance coefficient f (f = 1/ν). This parameter changed from a value of 0.71 selected for the average daily advance of 7 m/day before 1979, to a value of 1.11 after 1979 when the average daily advance decreased to 4.5 m/day.

The coefficient f/T appears above all as an indicator of viscosity effects. With the value of the parameter f/T > 1, the viscosity effects are not significant and the effect of face advance prevails. Hence it can be concluded that a higher rate of advance is characteristic for the pre-1979 technology of supporting. Since the year 1979, the number of sudden coal and gas outbursts has considerably decreased in the Velenje Lignite mine as a consequence of all the roadway...
driving technology changes mentioned above, and primarily because of the decreased rate of advance.

CONCLUSIONS

Because of the very specific circumstances, both geological and technical, that occur in the Veluwe lignite mine, it is very difficult for some already well tested methods of prognosis of sudden coal and gas outbursts to be transferred from those mines elsewhere, where they have already been well introduced.

The analyses performed show that an outburst of coal and gas always occurs in the vicinity of, or at, the transition from lignite with lower compressibility and higher strength into lignite of weak properties. On the contrary, the cases of outbursts when the roadway passes from lignite of lower strength and greater deformability into more compact lignite, are very rare. These phenomena occur in the vicinity of fault zones and tectonic shear zones. Although the particular causal factors are interconnected, a strong effect is to be ascribed to the fact that the secondary time-dependent stress-strain field, occurring around the advancing mine working, expands in different directions. The intensity and form of the secondary stress-strain field, however, depends on the mechanical properties of lignite, stress state in the seam, rate of roadway advance, support rigidity and other less influential factors.

Based on the investigations, results of observations and numerical analyses, it can be concluded that for the occurrence of a sudden coal and gas outburst, several conditions must be satisfied. The most significant among them is the condition of artificially increased the deviatoric stresses on the face which from the aspect of time represents a compact lignite pillar of smaller and smaller load bearing capacity. The opening, and additional occurrence, of some fractures in which the pressure of the absorbed gas acts, promote the dynamic caving-in process representing a sudden fractured coal and gas outburst. On the basis of the findings above, it can be stated that in the surroundings of a roadway driven through the fault zones, the stress scattering is conditioned by the stress state in the seam before the influence of the roadway, and therefore, the deformability indices do not satisfy the regular evaluation of the outburst danger.

The further investigations which are being carried out are planned in such a way that by means of manufacturing in the scope of exploratory drilling, the minimum criteria for the occurrence of the treated phenomenon will be sought. Although also other investigations are in course, above all the acoustic emission, the success is uncertain because of too low a strength and too high a porosity of lignite.

REFERENCES


