SIGNIFICANCE OF IN SITU STRENGTH MEASUREMENTS FOR PREDICTION OF OUTBURST HAZARD IN COAL MINES OF LOWER SILESIA

By

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ABSTRACT

Lower Silesia Coal Basin/SW Poland/ is adjacent to highly gas saturated igneous massiv and since the beginning of this century more than 1500 outbursts have occurred in four existing mines, including 1295 in the most hazardous mine Nowa Ruda. Prevailing part of these are carbon dioxide/coal outbursts of ejected masses 50-5000 tonnes/av.200/t and gas volume released from 200 m^3 to 800,000 m^3. Magnitude of these phenomena is growing with the depth and for present extraction levels/ 375-753 m/ may be expressed by a formula:

$M = 4.25/H-400/$, where M-masses ejected, t and H - depth of extraction, m.

Regulations obligatory hitherto call for gas pressure measurements to be made in 3 m long and 42 mm dia. boreholes spaces not more than 25 m along the longwall face and taking sample of drillings for desorption testing. Criteria of a hazard are following: pressure higher than 30 kPa /for CO_2/ or 80 kPa /for CH_4/ and desorption more than 1,44 cm^3/g. These criteria are not satisfactory because many outbursts occurred in spite of low values of parameters measured and for several times no hazard was evident after very high values were obtained. Moreover, observations show that a huge majority of case outbursts occurred in coal weakened by local geological distortion.

In order to improve prediction technique portable cone penetrometer was designed and supplied to mines together with instructions for use as a tool for rapid in situ point load strength tests. Subsequently, more than a hundred joint measurements were carried out when both strength index /z/ and routine data were recorded in longwall faces and gates headings of three mines. In the same time visual observations were made of cracks, gas outflow from boreholes, drillings ejection, small outbursts, etc. Graphical analysis of coal strength index/ z, N/mm versus gas pressure / Δp, kPa/ shows a line dividing two zones - one representing safe conditions and the other - evident existance of a hazard. A new criterion for outbursts prediction may be proposed as follows:

$\Delta p \geqslant K\ .\ z$, where K is a constant equal to 4.76 when initial hazard appears and 9.00 when very high level of risk is to be considered.

Whereas this sample approach may be satisfactory enough for practical applications it doesn't clarify accurately conditions of equilibrium existing before the outburst occurrence. To fill this gap a physical model of outburst was proposed and boundary conditions defined mathematically for three fundamental processes, namely failure of coal within active/ i.e. confined/ zone, pierce of a hole, and fluidized bed outflow of the products from outburst cavern.

GENERAL INFORMATION

Lower Silesia coal fields are located in south - west of Poland close to Czechoslovakian

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border and next to the igneous massiv of Sudety mountains. Four existing mines/ Walbrzych, Victoria, Thorez, and Nowa Ruda / produce annually approx. 4 million metric tons of high-grade coking coal which although only 2 percent of Poland's total hard coal production, contributes much to the nation's economy due to high quality of coal. Since its beginning, mining in Lower Silesia was accompanied by coal and gas outbursts and more than 1500 cases were recorded during recent 80 years. These are minor methane and coal outbursts at Walbrzych and Victoria mines, methane/carbon dioxide/coal outburst at Thorez mine, and large carbon dioxide/coal outbursts at the most hazardous Nowa Ruda mine/section Piast/where 1295 cases took place including two very severe sandstone/carbon dioxide outbursts. Masses ejected amount from 50 to 5000 tonnes and gas volume released from 200 m^3 to 800,000 m^3. Emissions of gas in coal seams varies from below 10 to 30 m^3/t and during mining operations 40-100 m^3 per tonne are released in shallow levels and 100-200 m^3 or more - in deeper levels. Both the number and the magnitude of outbursts are growing rapidly with the depth of extraction. In Fig.1 the effect of depth is shown on average masses ejected in single outburst in Nowa Ruda mine. For coal seams No.405 and 415 empirical formula may be given as follows:

$$M = 4.25 /H-400/ \qquad /1/$$

where M are masses ejected /t/ and H is depth /m/, whereas for fireclay shale being extracted as a destressing seam for adjacent coal seams the formula is following.

$$M = 0.83 /H-500/. \qquad /2/$$

A routine technique used for the prediction of hazard consists of gas pressure increment tests in 42 mm dia boreholes, 3 m long and spaced not more than 25 m along the face, also the taking of a sample of drillings for desorption test from each borehole. Recently test boreholes are often made 6 m long for better reliability of measurements. The following criteria for evaluation of the hazard are applied:

- gas pressure increment higher than 30 kPa/CO_2/
- gas pressure increment higher than 80 kPa/CH_4/,
- desorption more than 1.44 cm^3/g, or
- desorption intensity/within 2-4 minutes/ more than 120 mm H_2O.

These criteria are not entirely satisfactory because several outbursts occurred in spite of low values of parameters measured, whereas in other cases no hazard was evident after high values were obtained.

Down to the depth of 600 m blasting is used as the main method of preventing the hazard, namely shock and communition blasting, destressing blasting and provoking blasting in single or double web. These techniques proved to be effective as also was destressing drilling of small diameter boreholes/42 mm dia., 6m long/ from the face and water injection into the seam. However, below 600 m the hazard increases significantly and working the seam 410/2-412 as a destressing one for adjacent seams is accompanied regularly by strong outbursts. The strongest one featured 3,300 tonnes of rocks ejected in a longwall, and more than 70 m of roadway support damaged. Both routine prediction techniques and prevention measures are not effective enough at this depth and more satisfactory methods must be developed. Therefore a continuous seismologic and microseismic activity monitoring was introduced at Piast section in 1977 and since that time 330 seismologic shocks have been recorded up to 15th May 1980. Overall energy of shocks counted per unit area mined varies from 67 J/m^2 (for the depths less than 730 m) to 91 J/m^2 (for depth more than 730 m). Microseismic activity data shows very high frequency of events with amplitude lower than that recorded in rockburst - prone seams of Upper Silesia. In some cases spectacular increase of microseismic energy were recorded within a few days prior to an outburst occurrence, Fig.2.

POINT LOAD STRENGTH TESTS

Experience has shown that a huge majority of outburst cases occurred or were initiated within zones of weak coal at local geologic distortions, especially those breaking continuity of a seam. Neither gas pressure nor desorption intensity measurements can render information about the strength of coal and therefore the simple direct method of point load strength evaluation has been applied using a portable cone penetrometer, see Fig.3. This instrument has been designed and manufactured at the Central Mining Institute and it's use as a tool for evaluation of strength reductions of coal adjacent to faults and other geological distortions have been described elsewhere Kidybinski (1979). At the test site the point penetrometer is pressed by hand into the coal and a readout of thrust P (N) and penetration W (mm) is taken; the index of strength being calculated as follows:

$$z = \frac{P}{W}, \text{ N/mm} \qquad /3/$$

A vertical line from roof to floor of a seam is measured first and then a horizontal line within the weakest layer of coal. Both vertical and horizontal line test - points are spaced 0.1 m.

Since March to August 1979 more than a hundred test sites at Thorez, Victoria and Walbrzych mines have been investigated. where strength index z, gas pressure increment Δp, and maximum desorption were measured. In addition visual signs of hazard were recorded, such as gas and blowout of drillings from the boreholes, shocks and jamming of boreholes during drilling, etc. These measurements were taken mostly in development roadways where the hazard is usually most severe. Results of measurements are shown in Fig.4.

As it may be seen in the figure, a border line may be identified between the safe zone and that representing hazardous conditions, by the line:

$$\Delta p = 4.76\ z \qquad /4/$$

where Δp is gas pressure increment (kPa), and z is average strength index (N/mm). Two other lines representing initial and very high level of risk respectively, may be described by the lines:

$$\Delta p = 2.78\ z \qquad /5/$$

and $$\Delta p = 9.09\ z \qquad /6/$$

It appears therefore, as a result of the measurements described that a new criterion for outburst hazard evaluation may be proposed in a following form:

$$\Delta p > K.z \qquad /7/$$

where the constant K ranges from 2.78 to 9.09. Obviously, the value of K may be a subject to correction after larger numbers of measurements and observations are made in various geologic and mining conditions.

To avoid the effect of fractures, in near the-rib zone of a seam on strength results, a new penetrometer design has been prepared for making tests at the end of 3.0 m - long boreholes where routine gas pressure measurements are carried out.

PHYSICAL MODEL OF AN OUTBURST

The simple method for predicting the outburst hazard, described above, is of a purely empirical natura and even if it might be considered as a help for practical purposes it cannot contribute to the general solution of the problem, since it is obvious that many factors other than gas pressure and coal's strength are playing a role in the process. To find these factors a physical model of an outburst must be assumed and, if possible, proved by underground measurements.

The model proposed here consists of three zones in the seam ahead of mining operations, namely:

- protection/degasation zone
- high gas pressure zone/active zone/, and
- abutment pressure zone.

Measurements of gas pressure, gas outflow and seismic velocity carried out in horizontal boreholes drilled from the longwall face into the coal seam being extracted at Nowa Ruda mine show the coincidence of the suggested model with values of the parameters measured. As it may be seen in Fig.5 the protection zone is characterized by low gas pressure, zero gas outflow and low seismic velocity (approx.300-400 m/s). The active zone shows maximum gas pressures, a rapid increase of gas outflow with depth of a borehole and medium values of seismic velocity (approx.400-800 m/s). The abutment pressure zone features high seismic velocities (800-2,500 m/s) showing a considerable degree of coal compaction, as well as existing discontinuities of the seam identified by local drops of velocity.

EQUILIBRIUM CONDITIONS

Within the model assumed, three fundamental conditions must be met for outburst occurrence, namely:

1. failure of coal in compression within active zone,
2. penetration of a hole through the protection zone, and
3. fluidized bed outflow of the products from outburst cavern.

In each of the three cases the active forces should exceed the resistance and inertia of the environment. Simplified mathematical formulae for the three conditions specified may be written in the following form:

ad 1. $$k \gamma H \geqslant R_{CM} \sqrt{\frac{L}{M}} \qquad /8/$$

where k is stress concentration factor, γH is gravity load of overburden, R_{CM} is uniaxial compression strength of coal in the seam, L is the length of protection zone and M is thickness of the seam extracted. In this formula $\sqrt{\frac{L}{M}}$ is the uniaxial strength multiplication factor due to confinement Borecki and Kidybinski 1970

ad.2. $$k(\gamma H) + p > \pi DL(c + \sigma \tan \psi) . \sqrt{\frac{L}{M}}$$

where p is average gas pressure within active zone, D is diameter of a hole, (c, ψ and σ are cohesion, angle of internal friction, and average vertical component of stress respectively in the protection/degasation zone). On the boundary of active and protection zones the state of stress may be considered as critical and therefore:

$$\sigma = \sigma_{av} = \frac{R_{CM}}{2} \left(1 + \sqrt{\frac{L}{M}}\right) \qquad /10/$$

ad.3. $$\frac{4V_w}{\pi D^2} > C_o \sqrt{\mu a\ g\ D} \qquad /11/$$

where V_w is the intensity of gas desorption on the boundary of active and protection zones (m^3/s), C_o is an empirical constant of values (0.2-0.4), μ is the concentration of solid particles in a gas ($1 \div 150$), a is a constant of value $\frac{\gamma_s - \gamma_o}{\gamma_o}$, where γ_s is mass density of rock and γ_o is mass density of a gas/, and g is acceleration of gravity force (m/s^2). The latest equation expresses a condition that the velocity of gas should be higher than critical to result in fluidized bed flow of a pulverized rock Smoldyrew, 1966.

PARAMETERS OF EQUATIONS

Equations /8/, /9/, /10/ and /11/ show that 15 main parameters should be determined to assess outburst hazard, among them six are known geometrical and physical constants (γ, H, M, a, C_o and g), two are unknown geometrical values (D and L), four are unknown geomechanical values (R_{CM}, c, ψ and k), and three are unknown gas dynamics values (V_w, p and μ). From the nine unknown parameters, three may be eliminated (c ψ and p) when test - boreholes are drilled into the seam in close spacing each other, and therefore equation /9/ describing the condition for creating the hole loses its validity. In this case there are only six values necessary to be known for complete outburst hazard evaluation, namely k, R_{CM}, L, D, V_w and μ. Although direct measurements of these parameters may be difficult or even impossible to be carried out, an indirect approach might be used for most of them. The stress concentration factor (k) may be found through seismic velocity measurements, as a proportion of the peak velocity to the low stabilized velocity. An example of such an evaluation in four locations at Nowa Ruda mine is shown in Fig.6. The strength of coal (R_{CM}) may be determined through cone penetrometer tests as suggested in first section of this paper, and making use of empirical correlation of penetration resistance and unconfined compression strength. Such a correlation already exists for many kinds of rocks Kidybinski, 1979. The value of L may be measured by the drillings yield method as it is used for coal - burst hazard evaluation where a rapid increase of drillings volume at a certain depth of a small - diameter borehole shows the boundary location of the active zone. It must be mentioned, however, that first attempts to apply this method in very weak coal at Nowa Ruda and other mines were not entirely successful and more research and development work is required in this field. The intensity of gas desorption (V_w) may be calculated from routine desorption data, taking into account also the volume of coal engaged in the process. The concentration of solid particles in a gas, although varying in a broad range, may be assumed as approx. 30 as it is the limit value conditioning a flow of mixture in a hole Smoldyrew, 1968. The most difficult to evaluate is the diameter (D) of a hold, and here an empirical approach may be advised only, namely taking approximate value from local case outbursts.

CONCLUSIONS

Both an empirical and a semitheoretical approach to the problem of outbursts prediction, show the significance of in situ strength measurements of coal. Moreover, strength variations due to tectonics and sedimentary conditions are more often higher than variations of gas pressure and desorption, therefore affecting the local outburst hazard more than the latter. As a first step to improve prediction accuracy, the cone penetrometer test may be applied, supplementary to gas pressure and desorption measurements. As a further step, evaluation of the six parameters of the equilibrium equations, given in this paper, may be advised.

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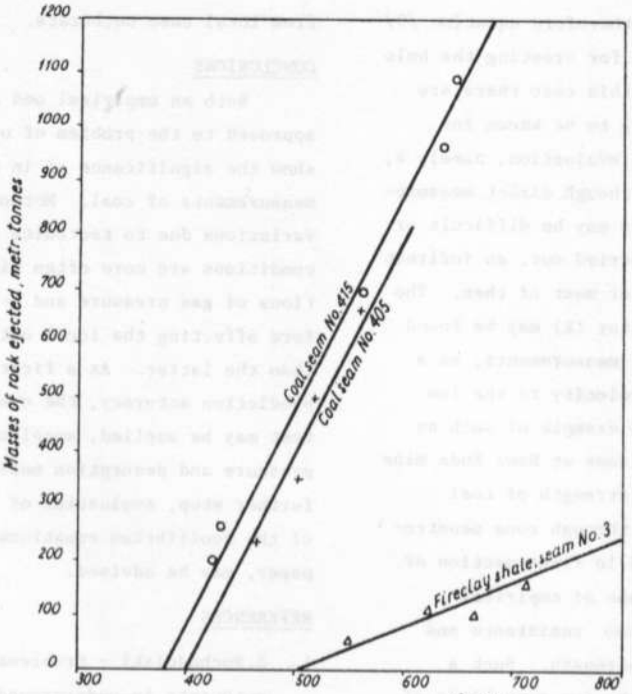

Fig.1 - Effect of depth on tonnage of rock ejected in case outbursts (Nowa Ruda Mine)

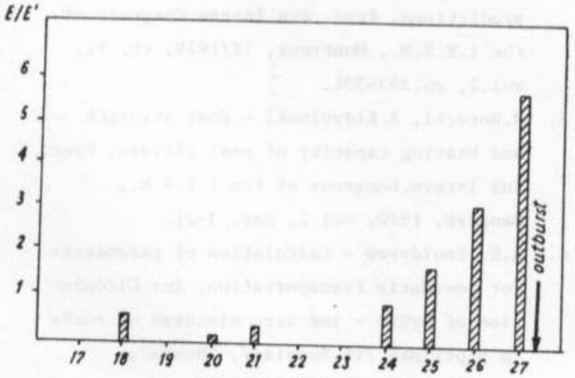

Fig.2 - Example of microseismic activity of rocks before the outburst (Nowa Ruda Mine, lower entry of a face during destressing drilling;

E - microseismic energy recorded in a particular day

E'- average microseismic energy recorded within 30 days).

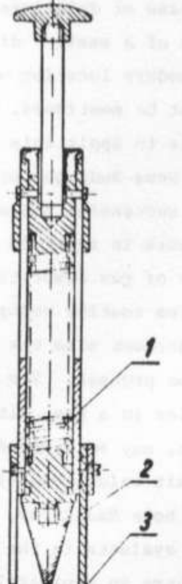

Fig.3 - Cone Penetrometer (1-spiral spring, 2-point, 3-sliding sleeve)

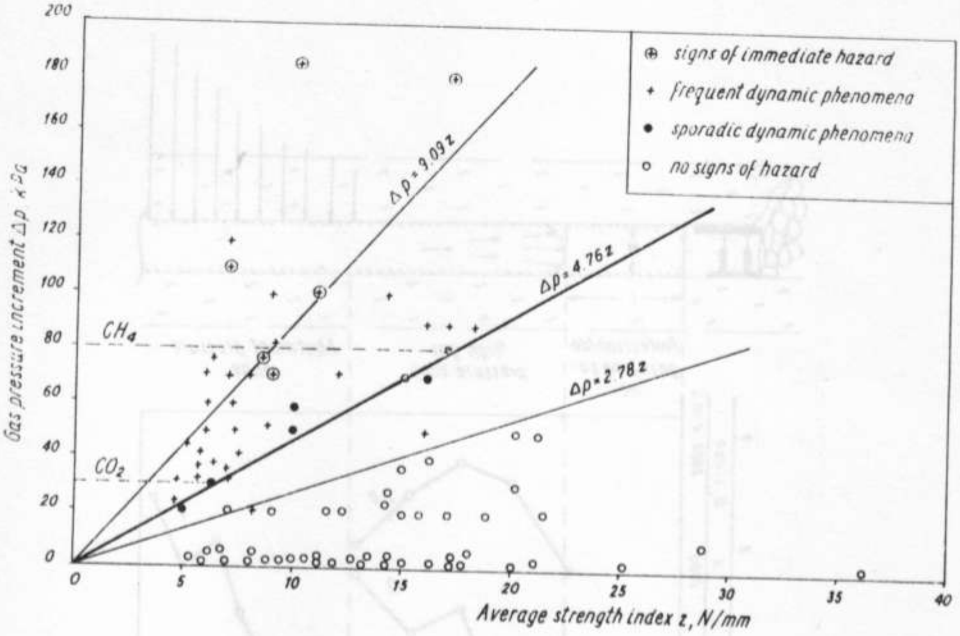

Fig. 4 - Gas pressure increment versus strength index of coal

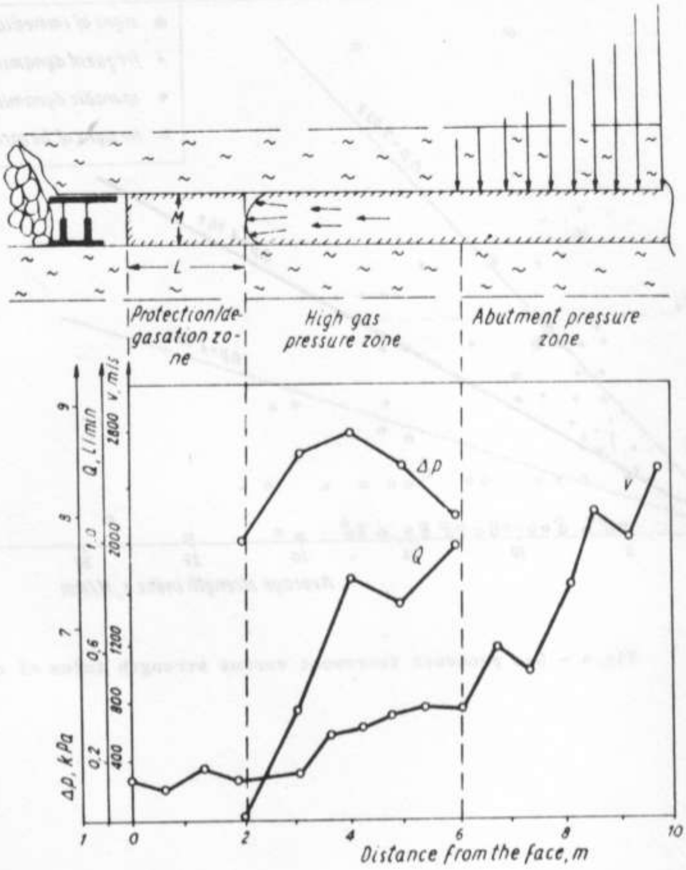

Fig.5 - Physical model of an outburst and its confirmation through measurements in boreholes. (Δp-gas pressure increment, Q-gas outflow, v-seismic velocity)

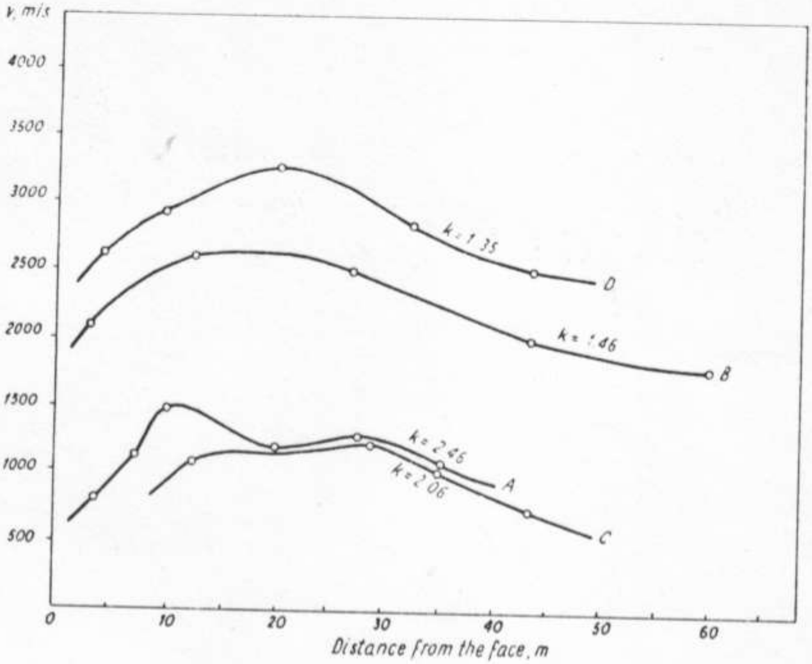

Fig.6 - Seismic location of stress concentration zone-test results from Nowa Ruda Mine (A-longwall No.314 in seam 410/2÷412; B-lower entry to the longwall in fireclay seam; C-upper entry to the longwall in fireclay seam; D-lower entry, level-240)