THE DESIGN OF A ROADWAY SUPPORT SYSTEM FOR DYNAMIC LOADS OF TREMORS AND ROCKBURSTS

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ABSTRACT
A forecast of mining conditions in Upper Silesia collieries for the beginning of the 21st century has special focus on average depth of mining, energy of seismic tremors induced by mining and energy of dynamic loads on roadway supports. A method of dynamic loads calculation is based on volume of failed rock surrounding an opening and the seismic energy of tremors anticipated. New types of yielding steel arch supports have been designed to resist massive static and dynamic loads and a system of supports has been tested both on 1:10 scale models and in natural size. The support sections used are 29, 36 and 44 kg/m.

INTRODUCTION
In the Upper Silesia Coalfield 65 underground mines produce 192 million tonne of saleable coal annually from slightly inclined seams of thickness 0.7 to 2.0 m, averaging approx. 2 m. More than one half of these mines experience severe rockburst hazards due to ever increasing depth of working and the appearance of massive sandstone strata in the overburden. It is the breakage of sandstone which causes 1400 to 3700 strong tremors annually, and the seismic energy of a single tremor affecting stability of mine openings may vary from 1 x 10^5 to 1 x 10^6 J. The traditional roadway support consisting of yielding steel arches with open floor is extensively damaged due to mine-induced tremors and rockbursts triggered by seismicity. According to statistics, the average length of roadway damaged during a single rockburst depends upon the depth of working.

\[ S_d = 23 + 0.1488 \times (D - 400) \]  
(1)

where \( S_d \) is av. length of roadway damaged and \( D \) is the depth of mining in metres.

Fig. 1 illustrates average depth of coal mining throughout the recent decade, and the line of trend may be expressed by

\[ D = \exp (6.19 + 0.01462 (Y - 1978)) \]  
(2)

where \( Y \) is the year.

![Fig. 1. Average depth of coal mining in Upper Silesia Coalfield.](image)

When existing trends are projected to the year 2000 one can find an average depth of mines 673 m and average length of roadway damaged during a single rockburst - over 63 m.

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Moreover, analysis of seismic energy of mine-induced tremors shows that although the number of tremors is slightly decreasing in time, the average energy of a single shock is rising, (Fig. 2). Here the line of trend is expressed by

\[ E = \exp (14.1 + 0.1177 (Y - 1977)) \]  \hspace{1cm} (3)

where \( E \) is energy in J. If the trend is steady the average shock energy anticipated in the year 2000 will be within the range of \( 2 \times 10^7 \) J.

Taking into account contemporary rate of roadway deterioration in Silesian coal mines, it is clear that the closure of mine openings will be the main obstacle to mining after year 2000.

\[ v_2 = \left( \frac{\alpha}{a} \right) \left( \frac{2aD}{R} - 1 \right) \left( \frac{g_0 - 1}{g_1} \right)^{\left( \frac{t}{2t} \right)} \]  \hspace{1cm} (7)

where \( a \) is the radius of opening cross-section
\( M \) is thickness of coal seam exposed
\( g \) is overburden density
\( D \) is depth of opening from the surface
\( R \) is compressive strength of a coal seam
\( d \) is distance from the source of tremor to the mine opening analysed
\( E \) is seismic energy of a tremor
\( t \) is duration of dynamic disintegration process
\( g_0 \) is original density of coal, and
\( g_1 \) is density of coal after rupture.

All but three of the variables involved are constant for given mining conditions, and only \( D, t, \) and \( E \) should be properly foreseen to anticipate dynamic load on supports in future years.

**FORECAST OF MINING CONDITIONS**

Existing trends of the recent decade may be projected into the beginnings of the 21st century and approximate data for designing roadway supports may be found this way. Increasing depth of mine operations and increasing average energy of seismic tremors have already been mentioned. The reason for the first is the exhaustion of shallow coal reserves, and the second may be explained as a result of the sandstone at depth having greater strength. In fact, as reported by Kidbyński (1982), rock samples taken from deep exploration boreholes in Upper Silesia and tested in the laboratory revealed that, whilst the strength of sandstones is regularly increasing with depth, the average compressive strength of coal is decreasing with depth, according to the formula

\[ R = 19.4 - 0.006 D \]  \hspace{1cm} (8)

where \( R \) is compressive strength in MPa, and
\( D \) is depth in metres.

This phenomenon may be attributed to the higher rank of coal from deeper horizons due to greater geological age and higher overburden pressure.

Having established most probable \( D, t, \) and \( E \) as data for future mining operations, one can easily calculate the dynamic loads anticipated. The forecast for the years 2000 to 2020 for variables \( D, t, \) and \( E \) is presented in Fig. 3. Although this seems to be the very distant future, it is short when compared with the history of coal mining in Silesia, over 200 years.

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The projection shows that the average energy of the dynamic load on the supports may reach 50 t/m5 x 10^3 J per m length of opening by the end of the period analysed. This figure exceeds ten times the average resistance of the standard three-piece arches used at present, and three times the resistance of the closed arches being now introduced into mines. It seems to be proved, therefore, that the new generation of supports should be designed and submitted to trials well in advance to ensure the operation of highly productive coal mining systems of the 21st century.

Fig. 3. Mining conditions forecast in Upper Silesia at the beginning of 21st century (D-average depth of mines in metres, e-average energy of mine-induced seismic tremor in 10^7 - 10^8 J, l-average energy of dynamic load on roadway support due to single tremor and/or outburst in Jm)

NEW SUPPORT DESIGN

The ever increasing rockburst hazard with the growing static and dynamic loads acting upon roadway support require the development and implementation in mines of new roadway support designs. As indicated by Maloszewski, Podk, and Sawka (1988), on the basis of current mining experience, the leading type of support employed in these conditions will be the close-profile yielding support, designed in the different versions: arches with a floor bar, circular support and elliptical support.

Meeting the demands of successful protection of openings under high dynamic loads is conditioned by

1. the application of heavy-duty steel sections, 36 or 44 kg/m, ensuring good strength and impact resistance,
2. a wide range yield of arch joints, providing at the same time high support strength and stabilized operation characteristics so that most of the dynamic load energy is balanced by the yield of arches at joints, not exceeding the limited elasticity of support elements,
3. the application of proper accessories (sprags, lining, couplings) and the lateral stabilization of arch sets and the prevention of rock lumps falling into openings.
4. the filling of the space between the support and the side wall with a layer of packing material of proper thickness and high elasticity ensuring uniform distribution of support load and enabling suppression of dynamic loads acting upon the support, and
5. in extreme conditions, the application of double arch sets of different size and filling the space between them with such packing material to suppress the dynamic energy.

Examples of such roadway support design are illustrated in Figs. 4, 5, 6 and 7.

Fig. 4. Closed profile arch support

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SUPPORT TESTING PROCEDURES

The development of new roadway support designs, evaluation of their capacity to withstand considerable static and dynamic loads requires extensive testing of prototypes. At present, 1:10 scale model tests are performed to evaluate the elastic and plastic strength of support elements and to characterize the load/yield performance of arches under dynamic load. Test methods cover the dynamic bending of steel bars, load/yield characteristics of straight joints and complete arches, as well as the strength of arches subject to dynamic mass impacts.

The next stage of research work to be carried out during the forthcoming years will cover full-scale support tests in specially designed rigs, Fig. 8. The test rigs will allow for testing of support elements as well as complete arch sets; the objective is to evaluate the dynamic strength under conditions close to natural, with the dynamic load energy of up to 5 x 10^3 J, (approx. 50 t·m) and to determine the relations between the support dynamic strength, static strength, initial static load, direction and distribution of dynamic load over the support, influence of packing, etc.

Test data will allow for the final design of new roadway support types and a proper selection criterion for a particular mining and geological condition.

At present, roadways experiencing the rockburst and tremor hazards are more and more commonly protected by closed-profile and circular support of V29 and V36 type. Underground experience has proved their effective protection of roadways within the rockburst and tremor zones, justifying therefore the implementation of closed-profile support under such conditions. Under the extremely hard conditions experienced in the Wujek and the Katowice mines, the double closed-profile support employed ensured roadway maintenance in spite of the rockbursts of magnitude 10/0 occurring in the area.

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