Archives of Mining Sciences 46, 1 (2001) 3–18

JAN DRZEWIECKI *

DEPENDENCE OF ACTIVE VOLUME OF THE ROCK MASS ON THE ADVANCE RATE OF A LONGWALL COALFACE

ZALEŻNOŚĆ AKTYWNEJ OBJĘTOŚCI GÓROTWORU OD PRĘDKOŚCI POSTĘPU FRONTU ŚCIANOWEGO

The process of mining coal seams by the long wall system causes the occurrence of a number of discontinuities in the overlying rock mass with directions varying in relation to its stratifaction. The area of the rock mass shead of the longwall coalface subjected to this process is characterised by a changing geometry depending, among other things, on the advance rate of the longwall coalface. The horizontal extent of this area in the direction of the longwall coalface drive advance is directly proportional to this advance rate, and the vertical extent is inversely proportional. This area is called the "active volume of the rock mass". A method to determine this volume, together with empirical relationships and the kinetic parameter of the effect of mining for isolated layers contained in this volume are presented. The consequences of variations in the advance rate of the longwall coalface in a mine working are also discussed.

Key words: rock mass, mining, strata separation, shear, description of phenomenon.

Podziemna eksploatacja górnicza powoduje naruszanie skał zalegających w stropie wybieranego złoża. Stopień tego naruszenia zależy od systemu eksploatacji, jej prędkości i głębokości oraz naruszenia górotworu eksploatacją dokonaną. Zmiany objętościowe i postaciowe struktury górotworu powodowane eksploatacją obejmują znaczne obszary górotworu sięgające aż do powierzchni. Zmiany te w przypadku górotworu zwięzłego, a więc górotworu, w którym występuje przewaga warstw sprężystych (piaskowce i łupki piaszczyste), generują powstawanie zjawisk dynamicznych. Poziom energetyczny tych zjawisk jest uwarunkowany wielkością i intensywnością eksploatacji naruszającej równowagę górotworu. Procesy dynamiczne jakie występują w górotworze naruszanym eks-

* GŁÓWNY INSTYTUT GÓRNICTWA, 40-166 KATOWICE, PL. GWARKÓW 1

ploatacją zachodzą z reguły w bezpośrednim otoczeniu frontu eksploatacji bądź ich źródłem są strefy naturalnych koncentracji naprężeń np. uskoki. Biorąc pod uwagę wyniki prac pomiarowych zmierzających do określenia parametru $tg\beta_{(z,H)}$ w górotworze (wzór 1 i 2) oraz fakt, że poszczególne pomiary *in situ* prowadzono w dużych odstępach czasowych, ich wyniki można odnieść jedynie do wypadkowego procesu deformacji warstw zawartych w przedziale odległości pomiędzy eksploatowanym pokładem a horyzontem pomiarowym. Mając na uwadze lokalizację ognisk wstrząsów sejsmicznych indukowanych robotami eksploatacyjnymi oraz wyniki pomiarów *in situ*, których celem było określenie miejsc inicjacji nieciągłości o kierunku zbliżonym do uwarstwienia, można z górotworu w otoczeniu ściany wyodrębnić taką objętość, w której wpływy eksploatacji będą zmienne. Powyższe fakty były inspiracją dla przeprowadzenia szeregu odpowiednio zaprojektowanych pomiarów w kompleksie warstw stropowych na wybiegu ścian, mających na celu określenie jakie fragmenty stropu — które warstwy — ulegają wzajemnym przemieszczeniom. W wyniku tak prowadzonych badań możliwe było jakościowe sformułowanie modelu niszczenia górotworu na wybiegu ścian, w którym proces utraty ciągłości górotworu determinowany jest w głównej mierze technologią eksploatacji i jej intensywnością. Uzyskany materiał pomiarowy był podstawą opracowania tzw. fazowego mechanizmu niszczenia górotworu na wybiegu ścian. Według tego modelu w górotworze, w wyniku prowadzonych robót eksploatacyjnych, tworzone są nieciągłości, przy czym jak to wynika z badań przeprowadzonych dla różnych systemów i prędkości eksploatacji, jako pierwotne powstają nieciągłości równoległe do uwarstwienia. Miejsca inicjacji nieciągłości równoległych do uwarstwienia na wybiegu ściany występują w ściśle określonych obszarach. Deformacje objętościowe i postaciowe, szczególnie w strefie przegięć zespołu pierwotnie spójnych warstw, powodują powstawanie w ich przekroju naprężeń rozciągających o kierunku zbliżonym do kierunku uwarstwienia. Zasięg stref tych naprężeń w kierunku wybiegu ściany jest tym większy im większa jest prędkość postępu ściany. Ze względu na warstwową budowę górotworu, warstwy sąsiednie, przy tym samym odkształceniu, posiadają naprężenia o różnej wartości. Odpowiednio duża ich różnica powoduje zniszczenie stref kontaktowych w określonej objętości każdej z nich (w strefie kontaktowej), co może mieć miejsce nawet w dużej odległości przed frontem ściany. Obserwacje dołowe wykazały, że nieciągłości równoległe do uwarstwienia zachodzą w strefach osłabienia warstwy, bądź na kontakcie warstw o wyraźnie zmiennych parametrach mechanicznych, sukcesywnie wraz z przemieszczającym się frontem eksploatacji. Objętość górotworu, w której stwierdzono występowanie nieciągłości równoległych do uwarstwienia, nazwano „aktywną objętością górotworu". Dla tak zdefiniowanej objętości górotworu trudno jednoznacznie określić zasięg wpływów głównych prowadzonej eksploatacji jedynie jednym parametrem. $\beta_{(z,H)}$. Na podstawie pomiarów *in situ*, zrealizowanych dla różnych prędkości postępu frontu ścianowego, opracowano funkcyjne zależności określające odległości miejsca inicjacji nieciągłości równoległej do uwarstwienia w kierunku wybiegu ściany „r", oraz w kierunku powierzchni z, (wzory 3 i 4), której postać graficzną dla przykładowych prędkości frontu ściany przedstawiono na rys. 1. Biorąc pod uwagę nierytmiczność postępu frontu ściany, obszar w którym zachodzi powyższy proces podziału górotworu, jest zmienny. Powoduje to, że dla takiego obszaru zasięg wpływów eksploatacji wyznaczony może być jedynie jako chwilowy, a wynikający z prędkości postępu frontu ścianowego (wzory 5 i 6; rys. 2 i 3). Oznacza to także, że dla takiej objętości należy określić parametr zasięgu wpływów eksploatacji dla danego horyzontu obliczeniowego w funkcji prędkości postępu frontu ściany (wzór 8). Zmienność tego parametru, nazwanego kinematycznym parametrem wpływów głównych $\beta_{\mathrm{kin}(z,H)}$, dla przykładowej prędkości postępu ściany wynoszącej 2m/dobę, przedstawiono w tablicy oraz na rys. 4.

W warunkach rzeczywistych, przemieszczanie się frontu ścianowego dokonuje się ze zmienną prędkością wynikającą z bieżących uwarunkowań technicznych i geologicznych, które zaburzają rytmiczny postęp eksploatacji. Powoduje to, że w okresie kilku kolejnych dni prowadzenia eksploatacji wymiary geometryczne objętości aktywnej górotworu będą ulegać zmianie. Mając na uwadze jedynie przedział prędkości postępu frontu ściany od 0,5 m/dobę do 6.0 m/dobę można w górotworze wyróżnić objętość aktywną, w której, dla tego przedziału prędkości postępu ściany można ustalić granicę obszarów narastającej i zanikającej odkształcalności fragmentów górotworu wydzielonych w procesie jego podbierania. Powyższe ilustruje rys. 4, na którym pogrubioną linią zaznaczono granicę obszarów podziału obu obszarów o zmiennej sztywności warstw.

Kolejnym ważnym aspektem wynikającym z przyjęcia istnienia objętości aktywnej górotworu jest wpływ zmiany prędkości postępu frontu ścianowego na wyrobisko górnicze. Jak to przedstawiono na rys. 3, objętość aktywna posiada wymiary geometryczne zależne od prędkości postępu frontu ścianowego. Dla ustalonej prędkości postępu frontu, na podstawie opracowanych zależności (wzory 3 i 4), można wyznaczyć jej zasięg. Wyróżnić można trzy przypadki wzajemnego położenia wyrobiska górniczego w stosunku do przemieszczającej się objętości aktywnej. Pierwszy, w którym wyrobisko znajdzie się w objętości aktywnej w strefie narastających odkształceń uwolnionych warstw — obszar dużej swobody przemieszczeń masywu skalnego. Drugi, kiedy wyrobisko znajdzie się w strefie objętości aktywnej jednak w obszarze już zanikających odkształceń. Trzeci, kiedy wyrobisko górnicze jest wykonane poza strefą objętości aktywnej. Pierwsze dwa przypadki posiadają szereg konsekwencji ruchowych dla prowadzenia ściany. Najbardziej narażone na zjawiska dynamiczne będzie wyrobisko, które znajdzie się w obszarze objętości aktywnej, w strefie narastających odkształceń uwalnianych warstw. W przypadku drugim zmiana średniodobej prędkości frontu może spowodować, że znajdzie się ono w środowisku o warunkach charakterystycznych dla przypadku pierwszego. Tak więc, istnieje graniczna odległość eksploatowanego pokładu od wyrobiska, dla której, może ono zostać niszczone w wyniku zjawisk dynamicznych zachodzących w procesie wyprzedzającego rozwarstwiania górotworu. Każda zmiana prędkości postępu ściany określa inny zasięg obszaru górotworu, w którym mają miejsce procesy dynamiczne, a zatem, dla bezpiecznej eksploatacji czynnik prędkości postępu eksploatacji jest niezwykle istotny. Fakt ten potwierdza wieloletnia praktyka górnicza w odniesieniu do eksploatacji pokładów zagrożonych tąpaniami. W przypadku narastania silnych zjawisk sejsmicznych indukowanych działalnością górniczą, jednym z podstawowych działań profilaktycznych całej grupy zabiegów jest obniżenie prędkości postępu frontu. Wyznaczając aktywną objętość górotworu, można określić optymalną prędkość postępu ściany tak, aby zachować odpowiedni dystans pomiędzy wyrobiskiem a przemieszczającą się w/w objętością. Zwiększenie prędkości frontu, skutkujące obniżeniem zasięgu aktywnej objętości górotworu w kierunku powierzchni, może jednak powodować wyraźny przyrost energii wstrząsu górniczego wynikający ze zwiększenia zasięgu propagacji szczelin w kierunku wybiegu ściany. Ten aspekt działalności górniczej jest przedmiotem aktualnie prowadzonych prac badawczych mających na celu obliczanie energii odkształcenia warstw w ramach aktywnej objętości górotworu dla zadanych jego modeli.

Słowa kluczowe: górotwór, górnictwo, rozdzielanie warstw, opis zjawiska.

1. Introduction

Underground mining causes disturbance in the rock roof overlying the extracted deposit. The degree of this disturbance depends on the system of mining, its rate and depth and disturbance by earlier mining. Changes of the volume and form of the rock mass caused by mining may also migrate to the surface to a significant extent. At the same time, as is recorded in many works in the domain of surface protection, the influence of mining work on the dynamics of ground subsidence is, to a considerable extent, dependent on the depth and the system of mining as well as on the solidity of the rock liable to deformation. The principal parameter which characterises this process is either the angle of main influence or it's parametric form $\mathrm{tg}\beta_H$.

This parameter was defined both for real cases and theoretical considerations (Knothe, 1985). At the same time, taking into consideration the necessity to protect underground structures, a number of measuring works have been performed with the aim of determining the above mentioned parameter in the rock mass (Kowalski, 1985). These works have resulted in an elaboration of the relationships defining the parameter $\mathrm{tg}\beta_{(z,H)}$ for two different types of rock mass. i.e. for rock masses of low and medium firmness and firm one.

The parameter introduced above refers to the calculation of with respect to a horizon located at a distance z from the roof of the seam being extracted at a depth H. In the former case

$$\mathrm{tg}\beta_{(z,H)} = 1.61 \cdot \left(\frac{H}{274.3}\right)^{0.51} \cdot \left(\frac{z}{H}\right)^{0.34} \tag{1}$$

for $43 \leqslant z \leqslant 230$ m and $135 \leqslant H \leqslant 567$ m, and in the latter case

$$\mathrm{tg}\beta_{(z,H)} = 1.61 \cdot \left(\frac{H}{274.3}\right)^{0.17} \cdot \left(\frac{z}{H}\right)^{0.52} \tag{2}$$

for $27 \leqslant z \leqslant 245$ m and $225 \leqslant H \leqslant 805$ m.

Taking into account that a Carboniferous rock mass has a stratified structure, the voids created in it cause changes in its form depending, among other things, on the structure of individual layers disturbed by mining operations. In the case of a competent rock mass, i.e. one in which elastic layers (sandstones, arenaceous shales) dominate, these changes initiate dynamic events. The energy level of these phenomena is conditiones by the size and intensity of the mining disturbing the equilibrium of the rock mass (Kijko, 1985; Konopko *et al.*, 1993; Konopko *et al.*, Dubiński, 1999). Dynamic processes occur in the rock mass disturbed by mining, as a rule, in the close vicinity of the mining face or they have sources in the zones of natural stress concentration, i.e. faults.

Taking into consideration the results of measurements aimed to determine the parameter $\mathrm{tg}\beta_{(z,H)}$ in the rock mass, as well as the fact that individual measurements *in situ* have have been conducted at large time intervals, these results can be related specifically to the resultant process of deformation of the layers contained in the region between the extracted seam and the measuring horizon. At present, a number of mines in which the mining of seams is conducted in the competent rock mass, often under hazard of rockburst, yield the possibility to record the dynamic events as they occur, and, as a consequence, to identify their localised sources and calculate their seismic energy. The number of seismic events and their energy, and, first of all, the location of epicentres of tremors, indicates that individual rock mass fragments (layers) constantly undergo structural deformations. Thus, as a consequence of mining operations conducted in the rock mass, it is possible to specify a volume of it called the "active volume". For such a volume of the rock mass it is difficult to determine the value of the parameter $tg\beta_{(z,H)}$. At the same time, the formulae for $tg\beta_{(z,H)}$ presented in (Kowalski, 1985) will be justified for the horizon being at a distance from the extracted seam beyond the extent of the vertical area comprising the defined volume.

Therefore, this paper presents the results of investigations to provide a basis for a definition of the active volume and makes clear how the parameter $tg\beta_{(z,H)}$ alters in the volume so defined.

2. Characteristics of deformation and damage effects in a rock mass disturbed by longwall mining

Because of the layered structure of the rock mass and its physicomechanical properties, the individual layers will undergo identifiable deformations, continuous and discontinuous, depending on their distance from active mine workings, the mining history of the area and natural geological disturbances. This process leads to the creation in the rock mass of areas with an unstable level of stress resulting from the deformation of individual layers. Thus, each process of mining causes the generation of locations in the rock mass in which dynamic phenomena can take place. The result of their occurrence is that a specific part of the rock mass returns to a momentary stress-strain equilibrium. Accordingly, one should expect to observe a situation in which individual fragments of the rock mass retain their stability despite their own deformations. Measurements taken in hard-coal `mines using electrical resistivity and geodetic methods have made it possible to identify the areas in the rock mass with declined continuity (Biliński et al., 1982; Biliński, 1985). Simultaneously conducted seismological investigations have revealed that in the process of destruction of the medium the layers also become involved, located ahead of the active mining front, often at a considerable distance away. The above facts have stimulated a number of carefully planned measurements in the complex of roof strata ahead of longwall faces aimed at determining which roof blocks, or layers, undergo mutual displacement (Drzewiecki, 1991; Drzewiecki, 2000). As a result of investigations conducted in this way, it has been possible to evolve a qualitative formulation of a model of rock mass destruction ahead of longwall faces, in which the process of loss of the contiguousness of the rock mass is determined, principally, by the technology employed in the mining process and its intensity. Further measurements conducted in regions in which the advance rate was up to 10 meters per shift, made it possible to determine more precisely the effect of this parameter on the extent of the formed discontinuities having a direction parallel to the bedding (Drzewiecki & Smołka, 1994). The measurements obtained provide a basis for developing a model of the so-called "*phase mechanism*" of rock mass destruction in advance of longwall faces (Drzewiecki, 1995). According to this model, in the rock mass, as a consequence of mining operations, the discontinuities are created with, as it follows from the investigations carred out for various systems and rates of mining, discontinuities parallel to the bedding occurring primarily, The locations, in which discontinuities parallel to the bedding ahead of a longwall face are initiated, occur in precisely defined areas.

The bulk and shear deformations, particularly in the zone of inflection of originally competent layers cause the creation, in their-cross-section, of tensile stresses, with an orientation close to the direction of bedding. The extent of theses stress zones in the direction of the longwall face advance is the greater, the higher is the rate of advance of the longwall face. By reason of the anisotropic structure of the rock mass, in particular in the direction perpendicular to the bedding, the group of adjacent layers at the same deformation, in any cross-section perpendicular to bedding, has a stress level with a different value.

Their difference, if sufficiently large, causes the destruction of contact zones in the defined volume of each of them, which can occur even a large distance from the longwall face. Underground observations have shown that the discontinuities parallel to bedding take place either within the zones of weakness of the layers or at the contact boundaries of layers with distinctly varying mechanical parameters. Keeping in mind the mechanical properties of the medium and the way will undergo destruction, it is possible to predict say that this process will be of a progressive or dynamic character.

On the basis of measurements *in situ*, carried out at various rates of advance of the longwall face, functional relationships have been elaborated, determining the distances from the location of initiation of a discontinuity parallel to bedding in the direction of longwall drive advance r, and in the vertical direction z:

$$r \approx Vz + c(V) \cdot z^2, \tag{3}$$

where:

- r — horizontal distance of the location of initiation of parting planes from the longwall face [m],
- z — vertical direction of the created discontinuity from the roof of the seam [m],
- V — average daily advance rate of the longwal face [m/day]
- $c(V)$ — parameter depending on the rate of advance of the longwall face given by the relationship:

$$c = -27 \cdot 10^{-5} \cdot 34 \cdot 10^{-4} \cdot V - 17 \cdot 10^{-4} \cdot V^2. \tag{4}$$

The graph of the function $r = f(z, V)$ for various day-averaged values of longwall face advance rates in the range 0.5 m/day to 6.0 m/day is illustrated in Fig. 1.

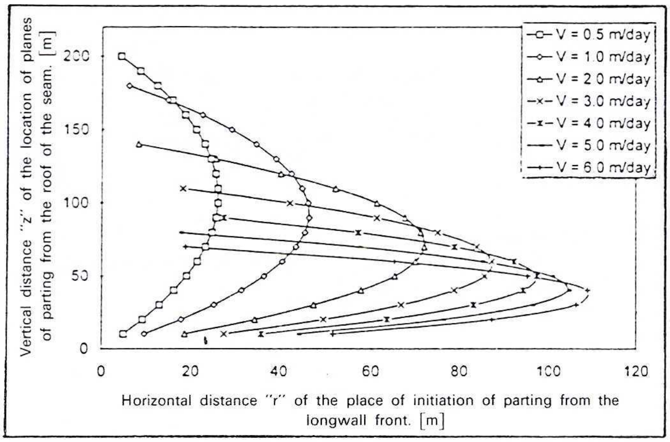

Fig. 1. Curves presenting the locations of initiation of the rock mass parting planes for given longwall face advance rates (Drzewiecki, 1977)

The curves presented in Fig. 1 specify the areas in a cross-section of the rock mass for which, for given longwall face advance rates, undergoes separation along the direction of the bedding. As one can see, the area of the rock mass, which actively takes part in the process of its destruction, depends on the rate of the longwall face advance.

The maximum extent of the active volume of the rock mass "z_H" in the vertical direction V relative to the rate of longwall face advance is given by relationship (5), the graph of which is shown in Fig. 2.

$$z_H = \frac{-V - \sqrt{V^2 - 4 \cdot c(V)}}{2 \cdot c(V)} \tag{5}$$

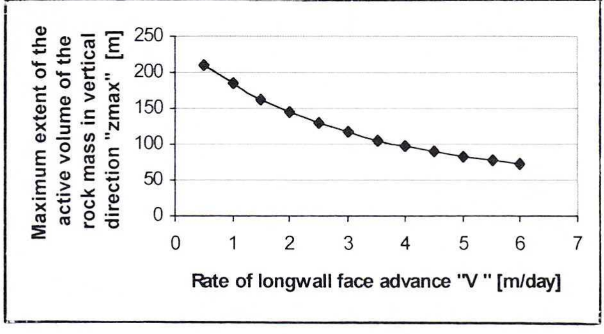

Fig. 2. Graph of function $z_{max} = f(V)$ for the face advance rate range from 0.5 m/day to 6.0 m/day

Successively,the relationship of the maximum extent of the active volume of the rock mass is given by relationship (6) and its graph is shown in Fig. 3.

$$r_{max} = V \cdot z_r + c(V) \cdot z_r^2, \tag{6}$$

where:

$z_r = -V/[2 \cdot c(V)]$ was determined from relationship (3) by differentiating it with respect to variable z.

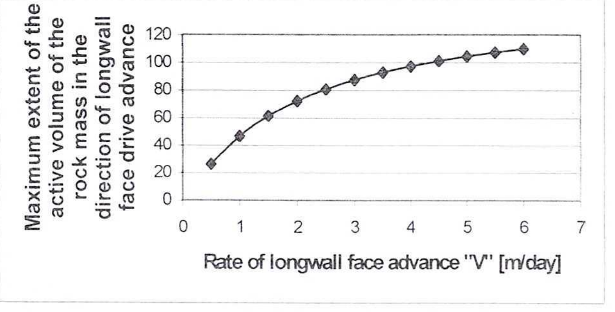

Fig. 3. Graph of function $r = f(V)$ for the face advance rate range from 0.5 m/day to 6.0 m/day

In the area of active volume of the rock mass, in the course of displacement of the dynamic edge which the longwall face constitues, the rock mass parts into layers, which is a rapid reaction of the rock mass to the presence of newly created extracted spaces. In other words, for this area, it is difficult to define unambiguously the extent of the main effects of the mining operation, using only one parameter. Taking into account the frequently disturbances in the rhythmicity of the longwall face advance rate, the area in which the above mentioned process takes place is variable. This gives rise to a situation where, for such an area, the extent of the effects of mining can only be predicted for a short time-span. Also, the parameter of the angle of dissipation of effects $tg\beta_{(z,H)}$, in the form given by (Kowalski, 1985) can be defined only for the area located beyond that being considered. This means that, for specified conditions of conducting extraction of the seam using the longwall system, one can determine an interface inside the rock mass that separates the area in which the parameter $tg\beta_{z,H)}$ will be variable (active area of the rock mass) from its remaining part in which the parameter $tg\beta_{(z,H)}$ can be determined by equations 1 and 2.

3. Determination of the kinematics parameter of the angle of influence of mining $tg\beta_{(z,H)}$ within the active volume of the rock mass

The information presented in the section above is intended to define a concept of the active volume of the rock mass and to determine its location, as well as how it can be distinguished and what factors influence its variability. Further consideration will refer to an analysis of the influence of the longwall mining system on the process of failure of the rock mass. At this point it should be stressed all considerations will refer to a planar system, i.e. the cross-section of the rock mass in the vicinity of the longwall mining in which the direction of the OX axis is determined by the plane of the extracted seam, and that of the OY axis by the plane of the longwall side. For a co-ordinate system oriented in this way, the active area of the rock mass, for a given rate V of the longwall face advance, is contained within a figure bounded from the one side by the OY axis, and from the other by the curve described by relationship (3). The roof strata located in this area undergo splitting by which I mean that the layers of sedimentary rock develop planar cracks in the interstices of the bedding plane and parallel to it, as a result of mining, and the zones of initiation of the splitting processes are found in the vicinity of the curve defined by the function as shown above.

On the assumption that the conditions of conducting extraction are constant, such a system will move in a direction consistent with the direction of the mining operation. At the same time, the layers separated in the process of rock mass division will undergo intensive shear deformation only along the sections initiated by parting planes. Marked in Fig. 4 are the positions of individual, separated layers which, as a consequence of the undermining operations, will have a different degree of freedom in relation to the adjacent layers and the remaining part of the rock mass. For these layers, it is possible to determine an angle of mining effects $\mathrm{tg}\beta_{(z,H)}$, which will vary depending on the position of a separated layer within the area of the active rock mass.

The angle of mining influence of the layers within the limits of the active volume of the rock mass is defined by the axis OIX and the straight line running through the origin of co-ordinates and the zone of initiation of discontinuities. The position of these zones was calculated on basis of relationship (3), while the variability of the kinematics parameter of influences the angle of mining $\mathrm{tg}\beta_{\mathrm{kin}(z,H)}$ (V). The rate of advance of the longwall face is given by relationship (7)

$$\mathrm{tg}\beta_{\mathrm{kin}(z,H)}=\frac{z}{V\cdot z+c(V)\cdot z^2}. \tag{7}$$

Table 1 shows how the angle of main influence changes for longwall mining conducted with an average advance rate of 2 m/day, and for location of the rock mass parting planes with at intervals of 10 m.

Included in Fig. 4. are also graphic illustrations of selected values characterising the zones of initiation of discontinuities parallel to the bedding and the position of straight lines determining the kinematics angle of mining influence of $\mathrm{tg}\beta_{\mathrm{kin}(z,H)}$.

An important element is here the fact that individual fragments of the rock mass within its active volume have different lenghts. This means that only these fragments of the rock mass, i.e. liberated layers, will undergo rapid shear deformation in the course of the continuing advance of the longwall face. The kinematics angle of

TABLE

Variation of the parameters of extent influence of mining in the active volume of the rock mass defined for the rate of face advance being 2 m/day

Vertical distance z of parting plane from the seam	Horizontal distance r of the zone of parting initiation from the longwall face	Kinemaics parameter of extent of the angle of mining influence at $tg\beta_{kin(z,H)}$	Angle of mining influence of $\beta_{kin(z,H)}$
[m]	[m]	—	[°]
10	18.6	0.537	28.3
20	34.5	0.581	30.2
30	47.5	0.631	32.3
40	57.8	0.692	34.7
50	65.3	0.765	37.4
60	70.1	0.856	40.6
70	72.1	0.972	44.2
80	70.4	1.123	48.3
90	67.7	1.330	53.1
100	61.3	1.631	58.5
110	52.2	2.108	64.7
120	40.3	2.980	71.5
130	25.6	5.079	78.9
140	8.1	17.182	86.7

mining influence of $tg\beta_{kin(z,H)}$ varies over a range from 0° to 90°, in actual conditions, the lower ragne of this angle being determining by the location of initiation of the first discontinuity of the layer that keeps linear continuity in the space above the unmined coal of the seam. The upper range of the angle results from the location of the point of initiation of the last discontinuity within the originating active volume of the rock mass.

An analysis of Fig. 4. also allows the specification of two areas separated by the curve that defines the active volume of the rock mass. The first one, located above the seam up to the horizon marked by the plane of discontinuity, most protrusive in the direction of the longwall face drive advance, i.e. the area in which the length of subsequent liberated layers increases. The other one relates to the fragment of the rock mass in which the length of the discontinuity planes decreases. This means that the degree of freedom of individual liberated fragments of the rock mass increases with the distance in the vertical direction up to the height of location of the longest plane of discontinuity. Above this plane, gradual stiffening of the rock mass takes

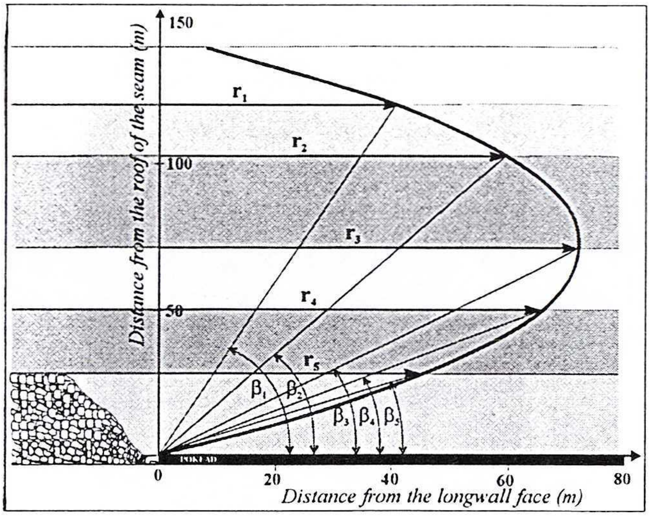

Fig. 4. Cross-section throughout the longwall environment with indication of position of the rock mass parting planes for an average rate of face advance of 2 m/day

place, which results from the fact that its development of cracks diminishes towards zero. Thus, the second region is a special sort of "natural support" with a defined compliance resulting from the range of reversible deformation of the liberation laminae. The movement of the longwall face in real conditions is accomplished, as a rule, with a variable advance rate, being a result of current technical and geological conditions that disturb the cyclic advancement of the process of mining. This has the result that, within several days of mining taking place, the geometrical dimensions of the active volume of the rock mass will be subject to a change; this, in turn, determines the chronological changes of the dimensions of both above-defined areas within the active volume of the rock mass. Taking into consideration only the range of longwall face advance rates of 0.5 m/day to 6.0 m/day, one can distinguish in the rock mass the boundary of the areas of increasing and attenuating deformabilities of the rock mass fragments, separated in the process of its undermining. The above is illustrated in Fig. 5, in which, in the *XYZ* system (longwall face advance rate, panel size, distance from the roof), the interface has been marked which separates both defined areas. Here, the bold line indicates an interface between two areas with variable layer rigidity.

Hence, as a result of an analysis, one can say that in the rock mass, in the direction of the longwall face advance, above the seam extracted by the longwall system, it is possible to distinguish a fragment in which shear deformations of individual layers takes place in a very short time. This fragment is defined by a function defining its extent, depending on the rate of the longwall face advance. The above discussed area is called the active volume of the rock mass, while, due to the lack of inrhythmicitiy of longwal face advance it will be subject to changes both in the direction of the surface and the longwall face drive advance.

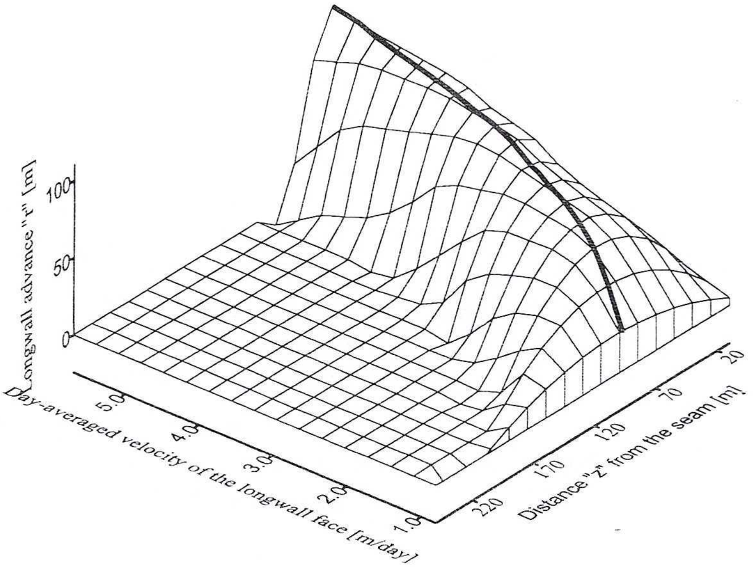

Fig. 5. Graphic illustration of the active volume of the rock mass for given average longwall face advance rates in the range from 0.5 m/day to 6.0 m/day

4. Possibility of utilisation of results

The geodetic measurements carried out in the mine of the Upper Silesian Coal Basin enabled a functional relationship to elaborated describing the influence of mining as a basis of calculating the radius of principal influence at any horizon within the rock mass (Kowalski, 1985). At the same time, on the basis of *in situ* measurements aimed at developing a mechanism of parting planes of rigid roof rocks (Drzewiecki, 1994), it has been found that for the roof rock located in the area of active volume of the rock mass, the deformation of subsequent separated layers can be described by the equations of subsidence curves using an individual kinematics angle of mining influence of $\mathrm{tg}\beta_{\mathrm{kin}(z,H)}$ for each layer.

The results of field measurements presented in table 2 (Kowalski, 1985), which provide a basis for the calculation of the parameter $\mathrm{tg}\beta_{(z,H)}$ point out that the radius of extent of the main influence was, in each case, greater than 100 m at the vertical distance of the calculation horizon from roof of the mined seam higher than 65 m. Such an extent of the main mining influence, in relation ot location of the active volume of the rock mass, reveals that the measurements were conducted in the places in which the rock mass did not react "immediately" to the mining process. Introducing the kinematics parameter of the extent of mining influence of $\mathrm{tg}\beta_{\mathrm{kin}(z,H)}$ enables us to determine the area in which the process of loss of firmness along the bedding plane takes place for any day-averaged velocity of the longwall face advance. At the same time, determining the so-called active volume makes possible to distinguish a fragment in it, in which momentary energy of deformation is accumulated. This energy undergoes dissipation following either the development of the number or propagation of discontinuities already created parallel to the bedding. The creation of such discontinuities or their propagation causes a step change of the value of deformation of the whole group of layers in the surroundings of the source of the tremor, up to a level that restores a state of balance to the layers. The phenomena of this type constantly accompany the mining operations, whilst, depending on the volume of the rock mass which takes part in this process, the energy released from such an area of the rock mass differs. In the volume considered in this way, the creation or propagation of discontinuities is identified by the source of a seismic tremor. At the same time, a consequence of the tremor is a sudden change in the deformation of the set of layers that includes a much larger area of the rock mass. The extent of the area of the rock mass in which an instantaneous change of its shape takes place is different and results from the level of its deformation before the discontinuities occur. It seems highly likely that this area is responsible for dynamic phenomena considered as rockbursts. Taking this into account, it is possible to assume that the origin of rockbursts is newly created discontinuities in the rock mass from which seismic energy is emitted, whilst a cause of the roof rockbursts can be shear changes often taking place in areas considerably distant from the sources of tremors. In particular, in the conditions of a strongly disturbed rock mass, the origination of subsequent discontinuities, parallel or transverse with respect to the bedding, causes a directional displacement of the above described area of the active rock mass. Important in this process is the capability of the rock mass, in the area of the active volume, to move to the undisturbed area of the rock mass, momentary horizontal displacement — (slip model of the source) and vertical ones — (model of a fault-type source).

The above-discussed mechanism can periodically cause momentary additional loading of such a fragment of the rock mass, and this, in turn, gives rise to the creation of high-level stresses in it. The active volume separated from the rock mass, in which the kinematics parameter of the main influence $\mathrm{tg}\beta_{\mathrm{kin}(z,H)}$ applies, affects, to a decisive extent, its surroundings. At the same time, as mentioned earlier, within the limits of this volume, it is also possible to specify a fragment in which the degree of freedom of separated layers increases with the vertical distance. Particularly, for this rock mass fragment, it is possible to speak about a momentary "additional loading" with the active volume of mine workings in the area of mining operations. A sudden movement of rock strata in the area in which break of continuity of one or more layers takes place causes a displacement of a defined volume of the rock mass in the direction in which its degree of freedom is the highest. The largest displacements will occur in those areas where the rock mass has the highest degree of freedom. This phenomenon can, under proper value of displacement of the set of layers, cause the strength of the rocks in the vicinity of the working to be momentarily exceeded, the consequence of which can be rockbursts. In such a case, in the picture of the damage, one can observe its directional character, which allows the evaluation of the direction from which the rockburst has come. The documented so-called roof rock bursts indicate a distinct occurrence in the dominating direction of displacement of the mass of rock in the surroundings of the source of tremor (Dubiński & Mutke, 1996). For such cases of rockbursts, of vital importance is the fact of the displacement of the mass of rock, i.e. the "active volume", in the direction of the working, by a distance which results from the conditions of the constraint of individual layers on the direction of their displacement. When comparing the active volume of the rock and its mass moving along a given path towards the working with the possibility to stop this movement, as provided by the construction of supports, one realises how weak is the resistance of mine supports. In view of this statement, the process of displacement of such large rock mass volumes must be prevented, not by the supports themselves, but as a result of achieving a stress-strain balance within the active volume of the rock mass.

Another picture of the consequences of rockbursts is associated with the dynamic phenomenon comprising the active volume of the rock mass, together with the rock surrounding it, in which mining has taken place. In the picture of damage of such a rockburst we see practically no damage to the supports despite damage sustained by the machinery and injuries to the miners. From time to time such types of rockbursts occur with, on the basis of geophysical studies of the phenomenon, displacement taking place in the direction of a major fault while the seismic tremor can be defined as a tectonic tremor (Dubiński & Lipowczan, 1997). At the current state of recognition of the mechanism of loss of continuity by the roof strata parallel to the bedding, it is difficult to evaluate the level of energy accumulated in the active volume of the rock mass. However, the results of investigations in this field obtained by Drzewiecki (1998) and Smart (Smart & Crawford, 1989) point out that one of the important elements, influencing the dynamics of the phenomena accompanying mining operations, is the loss of continuity of elastic layers along their bedding-planes. The mechanism of dynamic splitting parting of layers described in the works (Gibowicz, 1898; Stec, 1996) constitutes the next confirmation that mining-induced seismic tremors are very frequently characterised by the fact that the dominating modal plane has an alignment close to the sedimentation planes of the layers.

Another important aspect is the influence of variations longwall face advance on a working located in the longwall face advance area. As shown in Fig. 1., the advance rate of the longwall face governs the geometry and dimensions of the active volume. For a given rate of longwall face advance it is possible to determine the extent of the latter on the basis of the relationships explained earlier in the paper. Can be distinguish here the cases of mutual position of a mine working in relation to moving active rock volume. The first one, is when such a working is found within the active volume in a zone of increasing deformation of liberated layers i.e. an area of great freedom of displacement. The second, when the working is found within the zone of the active volume, but in an area of displacements which are already vanishing. The third case occurs when the mine working has been made beyond the zone of the active volume, i.e. about 250 m above the extracted seam. The first two cases bring a number of operational consequences for driving the longwall face. A working which is sited within the active volume, in the zone of increasing deformation of the liberated strata, will be the most exposed to dynamic effects. In the second case, alteration of the average daily rate of advance can create an environment similar to the conditions present in the first state. Therefore, there is a limiting distance of the mined seam from the working for which the working is at risk of damage as a result of dynamic effects causing parting of layers of the rock mass occuring as a result of the process of advancing. Each change of the rate of longwall face advance defines a different area of the rock mass in which dynamic processes take place, therefore to keep the process of mining safe, the factor of the rate of advance of mining is of vital importance. This fact is confirmed by many years' mining practice in relation to extraction from seams in areas at risk of rockbursts. In the case of increasingly strong seismic events induced by mining activities, one of the principal preventative actions from the whole range of possible interventions is to lower the rate of the longwall face advance. By determining the active volume of the rock mass, it is possible to determine an optimum rate of longwall face advance, to maintain a proper distance between the working and moving active volume. However, increasing the longwall face advance rate, resulting in a reduction of the extent of the active volume can bring about a considerable rise in the energy of a mining tremor arising from increasing the extent of propagation of subsequent fissures of longitudinal discontinuities parallel to the bedding. This aspect of mining performance is the subject of research work currently being conducted, aimed at calculating the energy of deformation of layers within the active volume for specified models of the rock mass.

The paper has been supported by the Polish National Committee of Scientific Research (grant no. 9T 12A 03 617)

REFERENCES

Biliński A., Budzikur K., Ożana P., 1982 „Wpływ dynamiki pękania mocnych skał stropowych na zagrożenie tąpaniami w wyrobiskach górniczych", Górnictwo, Rok 6 Zeszyt 2, pp. 141–154.

Biliński A., 1985. „Tąpania w świetle mechaniki górotworu odprężonego", Zeszyty Naukowe AGH, Górnictwo, Rok 9, Zeszyt 2, pp. 105–132.

Drzewiecki J., 2000. „Przemieszczenia podbieranych warstw stropowych na wybiegu ściany" Referat na XXIII Zimową Szkołę Mechaniki Górotworu", Geotechnika i budownictwo specjalne 2000" Bukowina Tatrzańska 13–17 marca 2000; pp. 39–47.

Drzewiecki J., 1998. „Laboratoryjne badania granicznych wartości krzywizn próbek skalnych", Przegląd Górniczy No 7/8, pp. 6–11.

Drzewiecki J., 1997. „Roof rock failure machanism in area of mining by the longwall system". Int. Conference „Geomechanics 96", Balkema, Rotterdam, pp. 9–11.

Drzewiecki J., Smołka J., 1994. „Przodki ścianowe o wysokiej koncentracji produkcji", Wydawnictwo Politechniki Śląskiej. Katowice–Gliwice, pp. 176–206.