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ASSESSMENT OF THE SUBSIDENCE RATIO b_e BASED ON SEISMIC NOISE MEASUREMENTS IN MINING TERRAIN

WYZNACZANIE WSPÓŁCZYNNIKA OSIADANIA b_e NA PODSTAWIE POMIARÓW SZUMU SEJSMICZNEGO NA TERENIE GÓRNICZYM

Subsidence process in the rock mass disturbed by mining can be complicated and can be faster or slower depending on the geological structure and physical and mechanical properties of the rock mass, changes in exploitation geometry, and changes in the rate of exploitation. The most frequently, the subsidence process develops over years in a way that is difficult to observe over a short period (days). It has been proven in practice of coal mines in Poland that Knothe's model describes subsidence process with high accuracy. It is based on treating the rock mass as a stochastic medium and describing subsidence with stochastic equations.

It can be assumed that, the complicated stress field as a result of mining activities induce a series of displacements of different sizes in rock mass. The inelastic deformation in rock mass is accompanied by a microseismicity that can be recorded and processed. We assumed that seismic noise with weak seismic events is a low-energy part of the microseismicity. We proposed an analytical solution to examine the distribution of the energy of the seismic noise during subsidence process development based on Knothe's model. In general a qualitative method of subsidence process assessment by the registration of the seismic noise was described.

Keywords: microseismicity, seismic noise, subsidence, Knothe's theory, subsidence ratio b_e

Proces osiadania w górotworze naruszonym działalnością górniczą może być skomplikowany. Może przebiegać szybciej lub wolniej w zależności od budowy geologicznej, fizycznych i mechanicznych właściwości górotworu, zmian w geometrii eksploatacji i zmian prędkości eksploatacji. Najczęściej proces osiadania rozwija się przez lata w sposób trudny do zaobserwowania w krótkim okresie (np. dni). W praktyce udowodniono, że w kopalniach węgla w Polsce model Knothego opisuje proces osiadania z dużą dokładnością. Opiera się on na traktowaniu górotworu jako ośrodka stochastycznego i opisuje osiadanie za pomocą równań stochastycznych. Można przypuszczać, że skomplikowane pole naprężeń wytworzone w wyniku działalności górniczej wywołuje w górotworze serię przemieszczeń o różnej wielkości. Niesprężystemu odkształceniu w górotworze towarzyszy mikrosejsmiczność, która może

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być rejestrowana. W badaniach przyjęliśmy założenie, że szum sejsmiczny wraz ze słabymi zjawiskami sejsmicznymi należy do niskoenergetycznej części sejsmiczności. Zaproponowaliśmy rozwiązanie analityczne, w celu zbadania rozkładu energii szumu sejsmicznego w czasie rozwoju procesu osiadania w oparciu o model Knothego. W efekcie zaproponowano jakościową metodę oceny procesu osiadania poprzez rejestrację szumu sejsmicznego.

Słowa kluczowe: mikrosejsmiczność, szum sejsmiczny, osiadanie, teoria Knothego, współczynnik osiadania b_e

Explanations to equations

$b(t)$ – parameter in distribution (5),
b_e – subsidence ratio,
c – constant,
E – energy of the seismic signal,
$f(\varphi, t)$ – probability of displacement distribution,
φ – energy of seismic noise,
$g(E, t)$ – modified model of f distribution,
H – depth of exploitation,
$K(\varphi, \kappa)$ – probability of transformation from state φ to state κ,
$W(s, r)$ – mining subsidence at the point (s, r),
W^k – final mining subsidence,
$W(t)$ – temporary mining subsidence,
$W_{\max}$ – maximum mining subsidence,
β – constant, the angle of main influence according to Knothe's theory,
$d\sigma$ – stress drop on the rupture surface dS.

1. Introduction

By performing field measurements of seismic noise in the mining terrain of an active hard coal mine, above an exploited panel, we observed the high-frequency seismic noise during the Saturdays and Sundays, when mining operation was terminated. We noticed that the amplitude of the seismic noise recorded in the mining terrain is much greater compared to the amplitude of the recorded noise outside the mining terrain (Fig. 1a). In addition, the seismogram from the mining terrain contained weak seismic events. These events did not occur on seismograms registered outside of the mining terrain. Measurements were carried out using Guralp 6TD wideband seismometers in the frequency range of 0.0033 to 100 Hz at undeveloped locations, away from anthropogenic sources of seismic noise such as road traffic. The recorded seismic noise was in the range of frequencies up to a dozen Hz (Fig. 1b, c). The amplitude spectrum values and the main frequencies of the noise were greater in the mining area compared to the noise recorded outside the mining terrain. In the mining terrain the amplitude of the noise spectrum was in the order of 10^{-12} and the main frequency was about 10.9 Hz (Fig. 1b). Outside the mining terrain, the amplitude was smaller in the order of 10^{-14} and the main frequencies were also smaller approx. 2.9 Hz and 6.1 Hz (Fig. 1c). We assumed, that the participation of global noise in the records of seismic noise registered in the mining terrain is rather small (Fig. 1b).

Field observations allowed us to formulate an assumption that a significant part of seismic noise with a small energy seismic events recorded in the mining terrain can be the effect of inelastic deformation in the rock mass. In other words, this seismic noise can be a result of the subsidence process developed in the rock mass above the exploited coal seam up to the terrain surface.

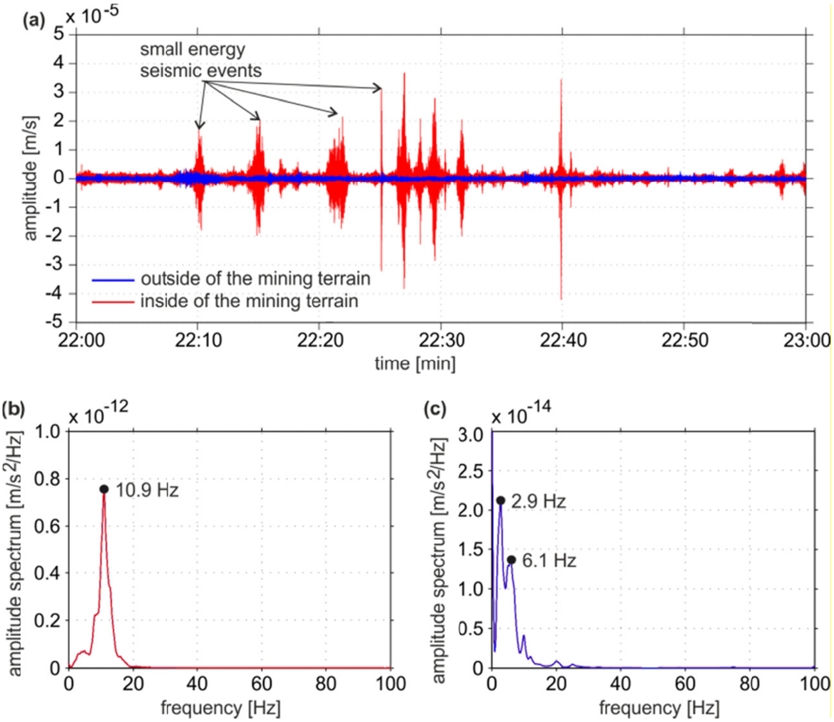


Fig. 1. Seismic noise recorded on a Sunday evening in the one hour period during mining operation terminated and its amplitude spectra. (a) Seismograms registered inside the mining terrain (red color) and outside the mining terrain (blue color); (b) Amplitude spectrum of seismic noise registered inside the mining terrain; (c) Amplitude spectrum of seismic noise registered outside the mining terrain

The microseismic activity induced by inelastic rock deformation under stress changes have been known for years (e.g. Gibowicz & Kijko, 1994; Hardy, 2003a, Barton, 2007). This understanding is based on empirical experiments performed in the laboratory (e.g., Goodman, 1963; Barron, 1971; Mogi, 1977; Khair, 1977; Gowd, 1980; Boyce et al., 1981) and in the field (e.g., Obert, 1941; Obert & Duvall 1942; Vinogradov, 1964; Gale et al., 2001). Microseismic activity, also called acoustic emission/seismoacoustic activity, is used in non-destructive methods of rock mass investigation. An interesting summary of the methods has been presented by Hardy (2003a, b).

Microseismic activity has been used to evaluate the risk of hazard burst occurrence in underground mines. Generally, microseismic activity and its energy change before a main shock occurs. Beginning in the 1960s, this phenomenon was studied in South Africa (Cook 1963) and in the US (Leighton & Blake, 1970; Leighton & Steblay, 1977). Later, investigations on this subject were conducted in most of the world's mining regions that were threatened by induced seismicity (Broz & Rocek, 1979; Mei & Lu, 1987; Spottiswoode, 1989). In Poland, the assessment of seismic threats was performed based on continuous observations of microseismic activity in underground hard coal and copper ore mines (Neyman & Zuberek, 1967; Zuberek & Chodyń, 1989; Lasocki, 1989; Glowacka & Pilecki, 1991; Pilecki, 1992, 1995, 1999; Marcak, 1998; Kornowski, 2003; Kornowski & Kurzeja, 2012).

Studies have shown that passive seismic tomography, based on microseismicity registration, is a useful tool to analyse the stress and deformation changes in rock mass in mines (Kormendi et al. 1986; Young & Maxwell 1992; Scott et al. 2004; Alcott et al. 1998; Li & Cai 2007; Hosseini et al. 2012, Czarny et al. 2016, 2018, 2019). Microseismicity has also been used to evaluate the deformation of rock mass due to the extraction of some of its volume (Obert & Duvall 1975; Maxwell and Young 1996). The statistical relationship between microseismicity and extracted volume in rock mass was also proposed by Kijko (1985) and Glowacka (1992).

The relationship between mining subsidence and microseismicity, which is the aim of this study, was discussed by Pomeroy (1969). Pilecka (2008) presented the statistical relationship between discontinuous deformation of mining terrain surface in the form of lineaments on satellite images and seismic activity occurrence. Many mathematical models of terrain surface subsidence above exploited areas are available (Singh, 1985; Sroka et al., 2015a). They are based on the mathematical description of elastic and plastic processes occurring in rock mass. In Poland in almost all underground hard coal mines, the subsidence of terrain surface above exploited area is determined using Knothe's model (Knothe, 1953a; Sroka et al., 2015a, b; Polanin, 2015). This many years of experience has resulted in getting a high accuracy of the subsidence value of the terrain surface in the mining area. Knothe's subsidence model allows the prediction of the average displacements, strains, and the curvature of the subsidence trough resulting from mining.

In our study inelastic deformations, developed as the result of subsidence process in the rock mass disturbed by mining, can produce microseismicity. The subsidence process is complicated and can be faster or slower depending on the geological structure and physical and mechanical properties of the rock mass, changes in exploitation geometry, and changes in the rate of exploitation (Sroka et al., 2015a). The changes of the subsidence process velocity in the rock mass can induce the changes of microseismic activity.

We assumed that seismic noise with weak seismic events is a low-energy part of the microseismicity. The goal of this study is to establish a formula describing the energy distribution of seismic noise during subsidence process.

A test site for recording seismic noise above area of exploitation was chosen in the mining terrain of Jas-Mos underground coal mine. Continuously recording of the seismic noise was carried out for 42 days. The structure of recorded data showed a high seismic noise intensity from Monday to Friday and its decrease during weekend days, when mining operation was terminated. This observation has contributed to formulating in this work a wider theoretical justification for the relationship between seismic noise and subsidence process in the rock mass disturbed by mining.

2. Basic assumptions of Knothe′s subsidence model

Knothe's model is based on treating the rock mass as a stochastic medium, and it describes subsidence using stochastic equations (Bodziony et al., 1960; Litwiniszyn, 1964). In the case of longwall mining operations, the predicting formula is used in a two-dimensional version for the assessment of subsidence in the profile perpendicular to the front of the longwall.

Let $P(x, y)$ be the exploited area. Then, the final subsidence at the point (s, r), denoted $W(s, r)$, is approximated by the following equation (Knothe, 1953b), which can be interpreted as an empirical Green's function relating surface subsidence to surface deformation (Eshelby, 1961):

$$W(s,r) = \frac{W_{\max}}{R} \iint_P \exp\left[-\pi \frac{(s-x)^2 + (r-y)^2}{R^2} \right] dxdy \tag{1}$$

where $W_{\max}$ is the maximum subsidence approximated by the seam thickness, $R = \frac{H}{\tan \beta}$ is the radius of the main influence range, H is the depth of exploitation and β is a constant that is determined based on experience (Knothe, 1953b), which is the so-called angle of main influence.

In the case when subsidence is evaluated in time, instead of $W_{\max}$, the total compaction in all infinitely space elements of the plain should be multiplied by the integral function. The formula can be simplified by introducing an empirical exploitation parameter.

The second assumption on which the Knothe's theory is based is the proportionality of the subsidence process velocity to the difference between values of final subsidence W^k and temporary subsidence $W(t)$:

$$\frac{dW(t)}{dt} = c\left[W^k - W(t) \right] \tag{2}$$

where c – constant.

Both elements of Knothe's model can be encoded in a computer program, allowing the successful prediction of the subsidence in a new exploitation area. After terminating exploitation, subsidence should decline according to the formula:

$$W^k - W(t) = W^k \exp(-ct) \tag{3}$$

The surface subsidence resulting from stepwise underground volume changes can be obtained by convoluting equation (3) with the volume change steps as they occur over time.

3. Mechanism of subsidence process

The subsidence of mining terrain is not a rapid process but develops over time in a manner that is difficult to observe over a short period. It can be assumed that like many of the processes occurring on the surface of the earth, such as the movement of dunes, the movement of glaciers is the macroscopic result of microscopic processes occurring inside the medium. The stresses as a result of discontinuous appearances induce a series of displacements of different sizes, as it is shown schematically on the Fig. 2a.

Fig. 2a shows the influence of the random distribution of displacements on the measuring point on the terrain surface. As shown in Fig. 2b, there is almost steady growth in subsidence over a long period. It is important to evaluate the creation of large components in the displacement population. It can be assumed that the development of this process is described by the theory of cellular automata (Malamud & Turcotte, 2000) and the theory of self-organised criticality (Main, 1995). If the set of elements involved in the process of subsidence is linked to one another with springs, then the displacement is described by elastic theory. If, however, the springs are close to breaking and one of them fails, it will cause a further spread of these inelastic deformations in the form of displacement. Different sizes of avalanches of displacements occur, and the displacement at the measuring point is statistically dependent on their distribution. In general, the distribution is dependent on the exploitation rate, volume and properties of the disturbed rock mass.

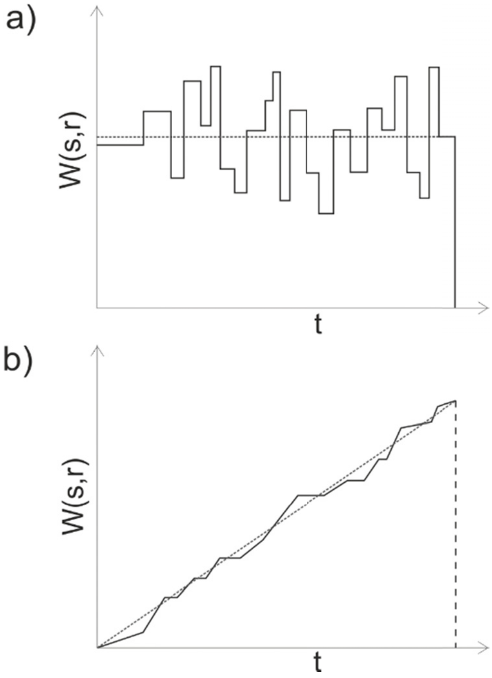


Fig. 2. The hypothetical subsidence model. (a) Subsidence velocity at the measuring point (s, r) on the terrain surface and (b) the total subsidence values over time

4. Stochastic process of creation and decay of displacements

As previously mentioned, the conventional seismic observations in mines are related to the seismic effects of fracturing in rock masses. From the physical point of view, we observe the effects of nucleation, propagation, and the fusion of cracks. The distribution $N(E)$ of seismic events with energy E in the population can be described with the following formula (Main et al., 2017):

$$N(E) = N_0 \left(\frac{E}{E_0} \right)^{-B} \exp\left(-\frac{E}{E^*} \right) \tag{4}$$

where the exponent $B > 0$ and subscript zero denote the correlation length of the population of seismic events E^* which is required to maintain a finite flux of strain energy as shown in publications of Kijko (1985), Lasocki (1989), Marcak (1998), and others. This formula is valid in the case of shocks induced by mining and registered by seismic arrays in the mine. The subject of investigations presented in this study is different. The seismic noise with weak seismic events is registered continuously from the rock mass disturbed by mining, while the high energy shocks appear rarely and only in some parts of rock mass. Frequency of recorded seismic noise and their amplitudes are significantly smaller from those recorded for shocks. The seismic noise is recorded in the band of up to dozen Hz, whereas frequency of shocks can achieve a few tens of Hz.

The subsidence process has plastic components with a random seeding (Molinari et al., 2014) of point defects (necking sites, micro-voiding) in ductile deformations, and number of defects per unit volume of the structure is proportional to the mean deformation in this unit (Dequiedt, 2015). In this conditions, the coalescence of defects has a different character due to fragility of rocks (Benzerga et al., 1999), which allows one to assume that the seismic sources are spatially independent. This is equivalent to the assumption of a constant fusion cross-section and an exponential distribution of the defects size (Czechowski, 1993).

Let the probability distribution of the displacements be described by $f(\varphi, t)$, where φ is the length of the element and t is time. The process of creating displacement avalanches at the time of subsidence can be described by the Smoluchowski equation (Filbert & Laurencot, 2004):

$$\frac{df(t,\varphi)}{dt} = \frac{1}{2}\int_0^{\kappa} K(\varphi-\kappa) f(t,\varphi-\kappa) f(t,\kappa) d\kappa - \int_0^{\infty} K(\varphi,\kappa) f((t,\kappa)\, d\kappa \tag{5}$$

where $K(\varphi, \kappa)$ is the probability of transition from state φ to state κ. Therefore, $K(\varphi, \kappa)$ is the probability of avalanche creation. If a kernel K depends only on time, then the solution to equation (5) has the exponential form (Czechowski, 1993):

$$f(\varphi,t) = A(t)\exp\left(-b(t)\varphi\right) \tag{6}$$

where $A(t)$ and $b(t)$ are constants over short periods.

The size of the elements $\zeta_1, \zeta_2, \ldots, \zeta_n$ in the set of displacements can be divided into several classes, m_1, m_2,..., m_n, and the initial conditions have the form ζ_0. Then, the following set of equations describes the probability distribution:

$$f_1(\zeta_1) = m_1, f_1(\zeta_2) = m_2, ...f_1(\zeta_n) = m_n, f_1(\zeta_0) = m_0 \tag{7}$$

According to Knothe's theory, the number of elements that are created per unit time (Formula 1) is proportional to the rate of exploitation and is distributed according to formula (5). In contrast, the decay of these elements has a complex characteristic.

By adopting Knothe's model, it can be assumed that in short periods, the distribution of the displacements is described by the formula (5) however, for the long lapse time it also decreases exponentially:

$$g(\varphi_i, t) = f(\varphi_i)\exp(-c_i t) \tag{8}$$

We assumed that the distribution of the displacements (8) also describes the population of seismic noise energy. The energy of the seismic signal E is proportional to the rupture surface according to the following formula (Koyama 1997):

$$E = \frac{1}{2}\iint_S d\sigma(\varsigma) dS(\varsigma) d\varsigma \tag{9}$$

where $d\sigma$ is the stress drop on the S surface, and $d\sigma$ is constant during quasi-stationary subsidence process, and $d\sigma$ is proportional to the displacement. This relation between displacements in rock mass and microseismicity is also shown by Wells et al. (1994) and Glowacka (1993).

Let according to formula (7) set of displacements $\zeta_1, \zeta_2, \ldots, \zeta_n$ is converted into set of energies in seismic noise populations $\varphi_1, \varphi_2, \ldots, \varphi_n$, and classes $m_1, m_2, \ldots, m_n$ into energetic classes $n_1, n_2, \ldots, n_n$, and function f_1 into function f.

Let according to formula (6):

$$f(\varphi_i) = B(\varphi_i)\exp(-h\varphi_i t) \tag{10}$$

where φ_i is the distribution of seismic energies in seismic noise populations, and B and h are parameters.

Then,

$$g(\varphi_i, t) = B(\varphi_i)\exp(-h\varphi_i t)\exp(-ct) \tag{11}$$

where c is parameter.

Further considerations are related to the local distribution of parameter φ_i rather than the time t in the distribution $g(\varphi_i, t)$. Interpretation of formula (11) leads to the conclusion that the number of elements causing seismic noise should decay with time.

However, the structure of seismic noise is complicated, and the local distribution of parameter φ_i, related to the subsidence process, is used in further estimations.

According to the exponential function in formula (11), large amplitudes decay more rapidly with increasing time compared with small amplitudes, as shown in Fig. 3a, where the lines fit the function $g(\varphi_i, t)$.

The variability of the parameter $\frac{\partial \ln g(\varphi_i, t)}{\partial \varphi}$ in time, can be described by the function $a_x \ln(t) + b_x$, where a_x and b_x are constants (Fig. 3b). The values of $\frac{\partial \ln g(\varphi_i, t)}{\partial \varphi}$ calculated from the measured data change in time according the same function as ratio be shown on Fig. 3c. This indicates that the proposed model may correspond to empirical distributions.

If we assume that square of the seismic noise amplitude A^2 is proportional to its energy, then formula (11) has form:

$$g(A_{ei}, t) = B(A_{ei}^2)\exp(-hA_{ei}^2 t)\exp(-ct) \tag{12}$$

For the Gaussian curve of the form $e^{-\mu^2 x^2}$, the length is x_i for which the function is greater than $1/A$, where $A > 1$ and A equals to $x_i = \frac{1}{\mu}\sqrt{\ln(A)}$. Then the linear relationship is obtained for the interval of the record in which amplitude is greater than A. This method of describing of the seismic noise amplitude distribution is equivalent to formula:

$$N(t, A) = N_0(t, A_0)\ \exp(-b_e(t)A) \tag{13}$$

where $N(t, A)$ denotes the total length of time intervals in which the seismic noise amplitude

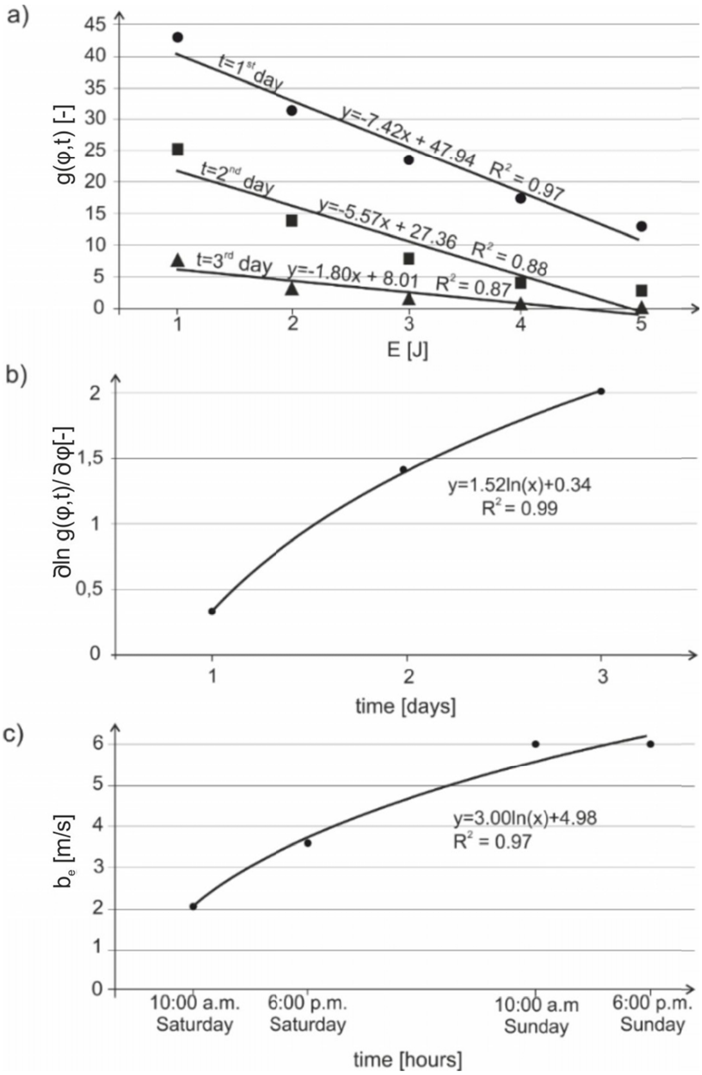


Fig. 3. (a) Distributions $g(\varphi_i, t)$ described by formula (11) for the following parameters: $B = 100$ J, $h = 0.3$ 1/J day, $c = 0.5$ 1/day; (b) the changes of the parameter $\dfrac{\partial \ln g(\varphi_i, t)}{\partial \varphi}$ calculated for the same parameters as in the case (a) in time $t = 1,2,3$ day; (c) change of the ratio b_e over the period of 32 hours of the test in the Jas-Mos coal mine

exceeds the value of $A(t)$ and $N_0(t, A_0)$ denotes the total length of intervals in which the amplitude exceeds the minimal amplitude A_0.

The assumption that energy of seismic noise is related to the inelastic deformation of the rock mass during the subsidence process according to formula (9) and that A^2 represents the energy of the seismic noise leads to conclusion that parameter b_e is the measure of the changes of seismic noise energy distribution during the subsidence process within the rock mass. In result the b_e can be written:

$$b_e = \frac{1}{A} \ln \frac{N(t, A)}{N_0(t, A_0)} \tag{14}$$

where ratio b_e is estimated for time interval for which seismic noise amplitude distribution does not depend on time. If parameter b_e is independent of A and it is estimated in time interval for

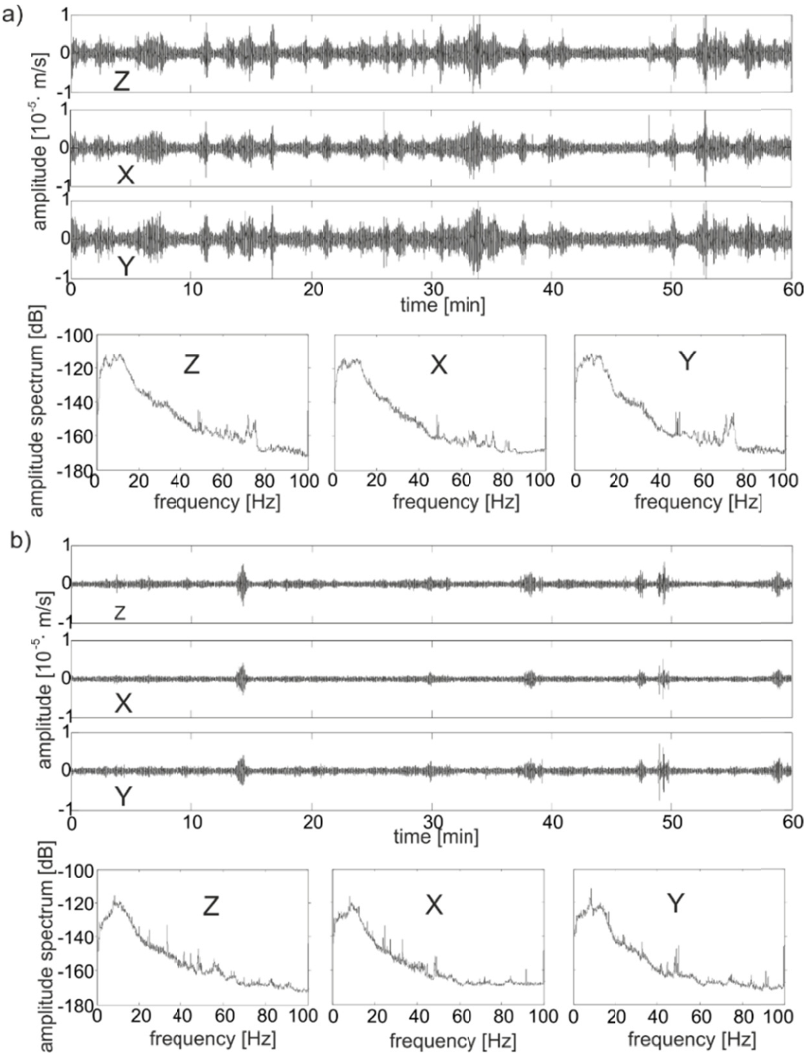


Fig. 4. (a) Record of one hour of the Z (vertical), X (horizontal N-S), and Y (horizontal E-W) components of the seismic noise in the Jas-Mos mine and its amplitude spectra on the day with mining operation and (b) without mining operation

which seismic noise amplitude distribution does not depend on time then it will represent the tangent of the plot $N(t,A)/N_0(t,A_0)$ versus A.

5. Calculation example

A six-week registration of the measured seismic noise in the Jas-Mos coal mine was performed in August and September 2013. A digital CMG-6TD Güralp broadband seismometer of 0.03-100 Hz with three components and with a sensitivity of 2×1200 V/m/s was used for the measurements. The Jas-Mos mine at that time was operated with three longwalls at a depth of 600-800 meters. Mining operations influence the intensity of recorded seismic noise, almost doubling the amplitude values (Fig. 4a,b).

In Fig. 5a, the records of one hour of the horizontal and vertical components of seismic noise are presented, and in Fig. 5b, the ratio of vertical to horizontal amplitudes of the measured seismic noise. It can be concluded that a large part of the strong noise signals is the result of vertical displacement associated with the process of subsidence in the rock mass, as indicated in Fig. 5b above level 1 and below –1.

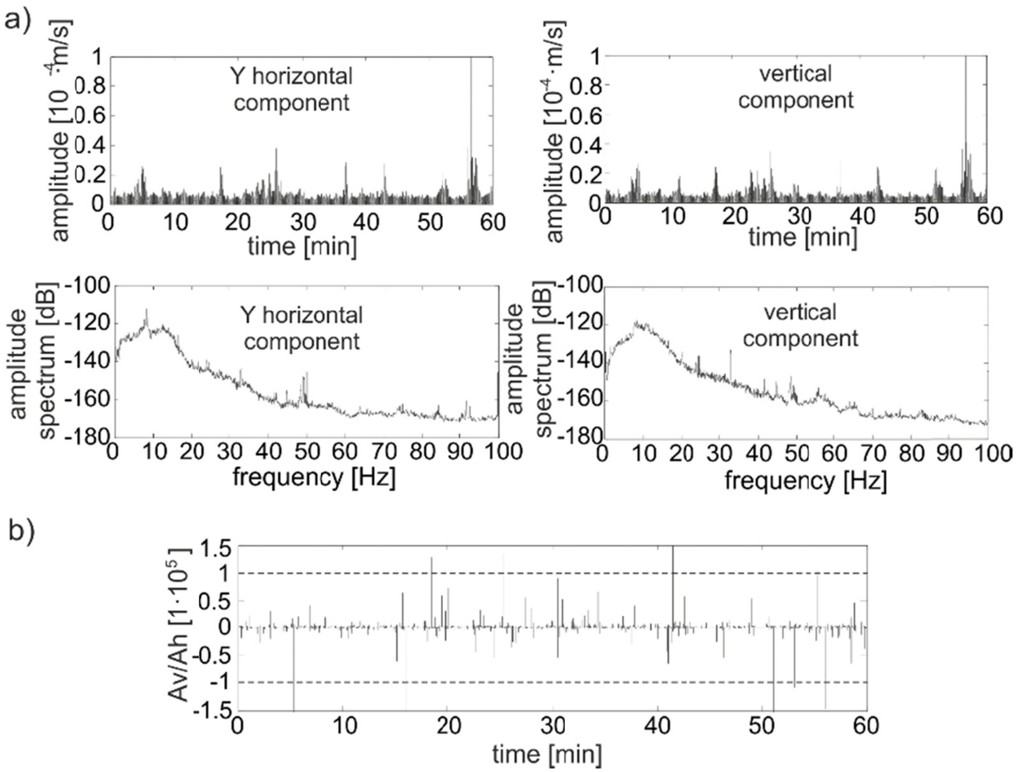
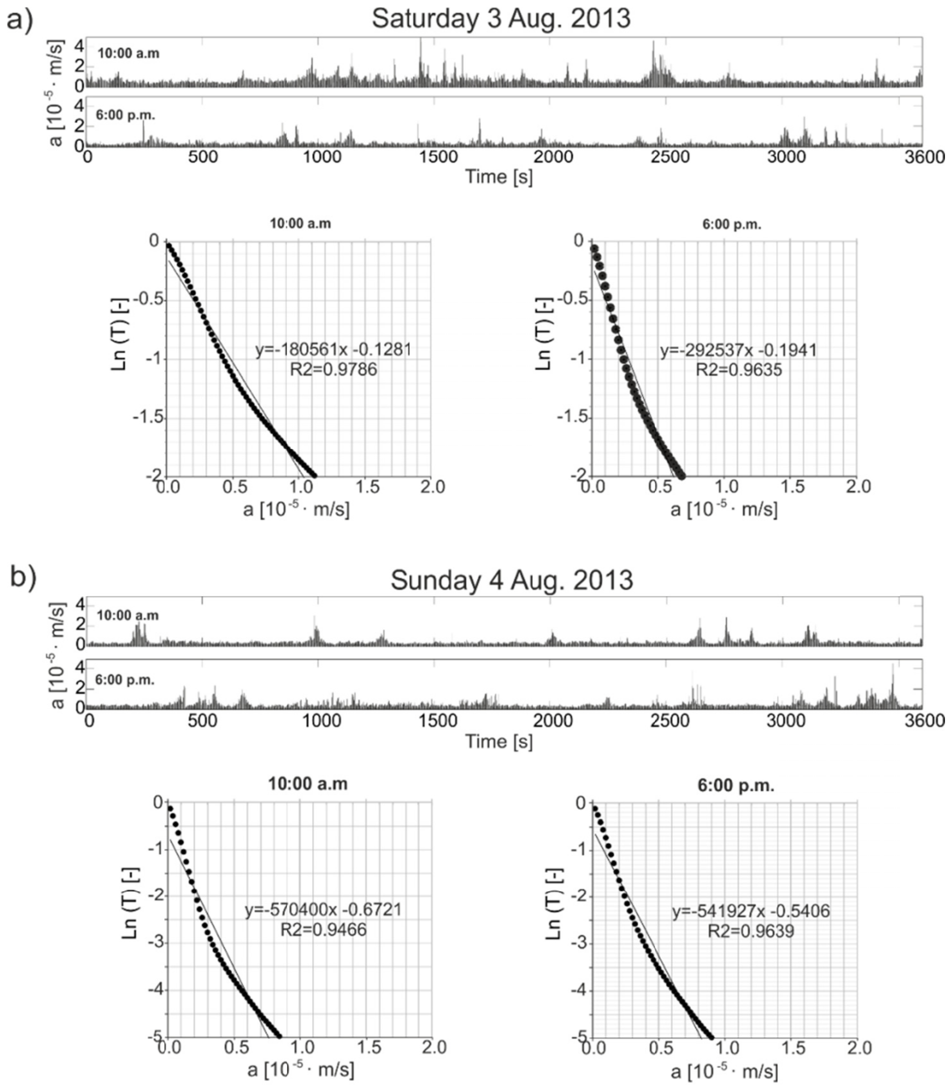


Fig. 5. (a) The absolute values of seismic noise with their amplitude spectra and (b) the ratio of the vertical to horizontal amplitude, registered during mining operation from the Jas-Mos coal mine



c)

Date	b_e value			
	Sat. 10am	Sat. 6pm	Sun. 10am	Sun. 6pm
3-4 Aug. 2013	-180561	-292537	-570400	-541927
10-11 Aug. 2013	-226466	-218101	-662812	-525303
17-18 Aug. 2013	-178631	-450291	-499402	-699721
24-25 Aug. 2013	-162968	-489684	-989423	-813452
31 Aug. - 1 Sept. 2013	-198747	-306296	-291577	-601260
7-8 Sept. 2013	-209956	-346702	-643775	-456915

Fig. 6. Absolute values of the vertical amplitude of seismic noise and b_e values estimated from these data recorded for one hour periods in the Jas-Mos coal mine on (a) Saturday and (b) Sunday August 3, 2013, at 10 a.m. and 6 p.m., (c) the values of b_e estimated for one hour periods during weekends of six subsequent weeks

Similar subsidence periods should be identified in the recorded noise to analyse the b_e ratio changes during weekend (Saturday and Sunday) when subsidence process decayed (Fig. 6). The overnight operation terminated on Saturday before 10 a.m., followed by a break in mining for Saturday and Sunday. The b_e ratio was estimated from four periods of one hour of seismic noise (vertical component) starting at 10 a.m. and 6 p.m. on Saturday and Sunday in the six subsequent weeks in August and September 2013 (Fig. 6c).

The estimation process occurs in the following stages:

- Maximal amplitude of the one hour of noise was appointed such that only approximately 1% of the amplitude population was greater than this value.
- The range from 0 to the maximum value was divided into ten equal levels. The length of the time intervals D_i in which the value of the noise amplitude exceeds the limit of A_i is calculated.
- The parameter $T_i = D_i / D_{hour}$ was calculated.
- The graph of the function of $\ln(T_i)$ versus A_i was drawn, and a linear approximation was calculated to determine its slope, which is an estimator of b_e.

The estimated value of the b_e ratio varies depending on the week (Fig. 6c) but with significantly less variation than for the one hour periods starting at 10 a.m. and 6 p.m. on Saturdays and Sundays (Fig. 6a,b). Both recorded seismic signals (Fig. 6a and 6b) and the statistically estimated b_e ratio confirmed that the seismic noise can be correlated with the process of subsidence described by Knothe model. The average value of b_e (Fig. 3c) is similar to that calculated directly from formula (11) (Fig. 3b), which confirms that the proposed model is valid.

6. Conclusions

In the study, we present a conceptual to explain the phenomenon of microseismicity (seismic noise) recorded on the terrain surface during exploitation of the underground coal seam. We assume that the phenomenon of microseismicity is associated with the subsidence process within rock mass. This subsidence process runs throughout the rock mass from the level of exploitation to the terrain surface. The fact that we register microseismicity on the terrain surface with the help of sensitive seismometers is the effect of displacements occurring within the rock mass. The increase in registered microseismic activity is related mainly to the increase in the intensity of displacements, i.e. irreversible small deformations within the rock mass. This intensity of deformation is described by the b_e ratio.

Finally, it can be concluded, that:

- the changes of subsidence process velocity in rock mass disturbed by mining, which are the changes of inelastic deformation in rock mass, are correlated with changes of seismic noise energy, and
- the ratio b_e is the measure of the changes of seismic noise energy distribution, and
- monitoring of the changes of ratio b_e can be used as a qualitative description of the subsidence process development within the rock mass.

Presented approach requires further research and the obtained conclusions should be confirm in other geological and mining conditions.

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