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Dynamic elastic properties of the hard coal seam at a depth of around 1260 m

Introduction

The knowledge of the dynamic elastic properties of the coal seam is important for (1) various types of calculations of the behavior of the coal seam under various stress-deformation conditions and (2) the implementation of seismic surveys in coal seams. In the first case, various types of numerical and analytical modelling are carried out related to maintaining the stability of workings and analyzing mechanisms, for example, related to the risk of rock bursts (Pilecki 1999, 2018; Dubiński and Konopko 2000). The second case concerns the calculation of relative stresses in various geological and mining conditions based on seismic profiling and seismic tomography in the coal seam (Dubiński et al. 2001; Szreder et al. 2008; Czarny et al. 2016; Wojtecki et al. 2016; Szreder and Barnaś 2017; Olechowski et al. 2018; Pilecki 2018; Chlebowski and Burtan 2021; Jarzyna et al. 2021).

The dynamic elastic properties of the coal seams can be determined using three basic parameters: P-wave velocity, S-wave velocity, and the volumetric density of coal. These parameters allow for the calculation of the subsequent quantities: the moduli of elasticity.

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The P-wave and S-wave velocities can be determined using the seismic method, e.g. by profiling along the sidewall of headings or by seismic tomography. The bulk density of coal is usually determined by the laboratory method.

The main task in the analysis of the dynamic elastic properties of the coal seam is to determine the velocity of the seismic waves of the P and S type, which depend on many factors. The most important ones include the physical properties and structure of coal seam, including the degree of fracture and filling with gases and liquids, the value of primary stresses in the coal seam related to its depth, and the impact of geological and mining factors such as geological disturbances (faults, flexures, washouts) and various types of edges and remnants of coal seams exploited in the vicinity and the impact of the excavations. In general, dynamic elasticity parameters are useful in various mathematical modeling of the stress-deformation state in various geological and mining conditions (e.g. Pilecki 1995; Kudyk and Pilecki 2009; Majcherczyk et al. 2012; Ślizowski et al. 2013; Marcak and Pilecki 2019).

The aim of the study is to calculate the dynamic elastic parameters of the coal seam located at a depth of 1,260 m in one of the hard coal mines in the Upper Silesian Coal Basin (USCB). In the condition of USCB there are only two coal mines that carry out exploitation at such levels. Basic measurements of the velocity of P- and S-waves were performed using the seismic profiling method. These surveys are unique due to the lack of measurements of the velocity waves in the coal seam at such depth. The existing mathematical relationships of changes in the velocity of the P-type seismic wave in the coal seam with depth were developed by Dubiński (Dubiński 1989) to a depth of approx. 900 m on the basis of several hundred measurements in the USCB coal mines. An attempt was also made to develop such a relationship up to approx. 1,200 m for the local conditions of the Jastrzębie mine (Kokowski et al. 2019). Measurements of the velocity of P- and S-waves at a depth of 1,260 m will allow for these relationships to be verified.

Measuring the velocity of seismic waves at such great depths is also important for assessing the relative changes in stress determined in the seismic profiling method. Dubiński (Dubiński 1989) assumed that with the increase of the depth and simultaneously with the increase of the primary stress, the increases in the P-wave velocity are smaller, but this requires verification for great depths.

The knowledge of the dynamic elastic properties of the coal seam may contribute to the improvement of the safety conditions of its exploitation through more accurate calculations of the degree of geodynamic hazard, and thus the management of mineral resources.

In the study, the results of wave velocity measurements in the coal seam in the area not disturbed by the influence of geological and mining factors such as geological disturbances or edges and remnants left in the adjacent seams were presented. Seismic profiling was performed along the sidewall of the new heading.

1. Methods and data

1.1. Theoretical background of seismic profiling in the coal seam

In the seismic profiling, following Szreder et al. (Szreder et al. 2008), refracted waves in the coal seam propagate along with an excavation in an elastic zone (not disturbed by excavation) on the border with a plastic zone (disturbed by excavation). The border between elastic and plastic zones may be illustrated using a Ladanyi (Ladanyi 1974) model in Figure 1.

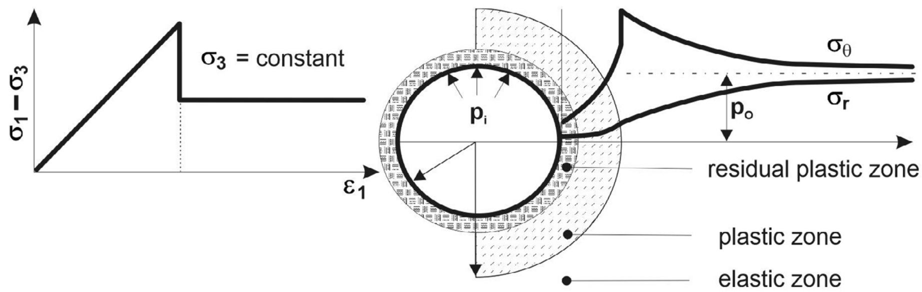

Fig. 1. Model of the behavior of a rock mass around an excavation (based on Szreder et al. 2008)
σ_1 – major principal stress, σ_3 – minor principal stress, σ_θ – tangential stress, σ_r – radial stress, ε_1 – major principal strain, p_o – virgin stress, p_i – lining load

Rys. 1. Model zachowania się ośrodka skalnego wokół wyrobiska)
σ_1 – maksymalne naprężenie główne, σ_3 – minimalne naprężenie główne, σ_θ – naprężenie styczne, σ_r – naprężenie radialne, ε_1 – maksymalne odkształcenie główne, p_o – naprężenie pierwotne, p_i – obciążenie obudowy

In the elastic zone at the border with the plastic zone, the maximum hoop stress occurs (Figure 1). It should be assumed that in this part of the elastic zone, the most favorable conditions for the propagation of the refractive wave occur (Figure 2a). In practice, the boundary between the elastic and plastic zones is transient, and the propagation of the seismic wave is more complex. An additional problem is related to the fact that the velocity of the determined P-wave does not differ significantly from the velocity of the S-wave in shale layers in the roof and the bottom of the coal seam (Szreder and Barnaś 2017). At greater distances from the excitation point, the first breaks of the P-wave in the shale layers overtake or distort the first breaks of the P-wave in the coal seam. The complicated nature of the wavefield is visible in seismic recordings (Figure 3). The strongly variable width of the plastic zone along with the excavation also significantly influences the distortion of the wavefield (Figure 2b). It is often difficult to determine the input of the refractive wave and its amplitude in such conditions. The unrealistic results of inversion modeling indicate that this is often observed when interpreting seismic profiling measurements.

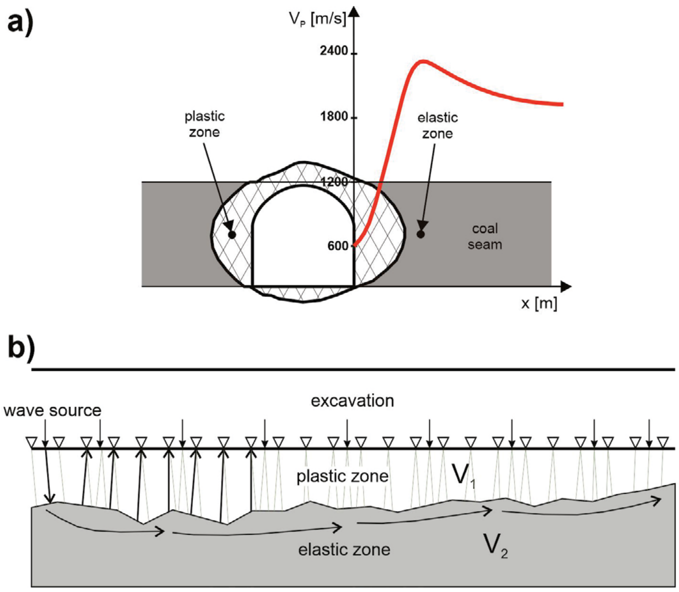

Fig. 2. (a) Model of P-wave velocity changes in the function of distance from excavation sidewall in coal seam; (b) Seismic profiling along excavation sidewall (based on Szreder et al. 2008)

Rys. 2. (a) Model zmian prędkości fali P w funkcji odległości od ściany wyrobiska w pokładzie węgla (b) Profilowanie sejsmiczne wzdłuż ściany wyrobiska

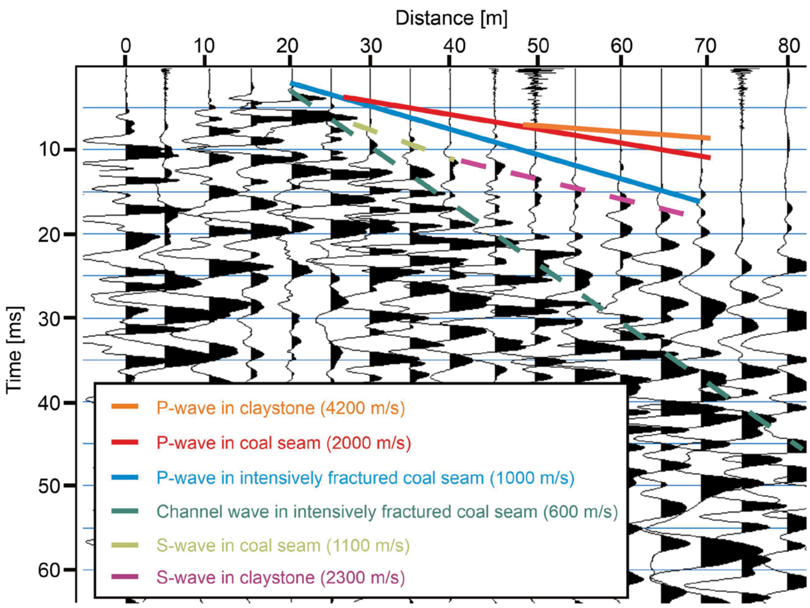

Fig. 3. Seismogram with a selected P-wave, S-wave and the channel wave (Kokowski et al. 2019)

Rys. 3. Sejsmogram z zaznaczeniem fali P, fali S i fali kanałowej

1.2. Methodology of seismic profiling

P-wave velocity profiling in coal seams used to be performed according to the Dubiński method (Dubiński 1989), updated in the work of Dubiński and Konopko (Dubiński and Konopko 2000). Moreover, Szreder et al. (Szreder et al. 2008) made significant progress in seismic data processing and its interpretation. This method enables a quantitative assessment of the impact of various factors responsible for stress and deformation conditions in the coal seam. This is the basic method that allows for the assessment of the influence of edges, remnants, faults etc., on the excavation made in the coal seam. It has an established and proven measurement and interpretation methodology. The results obtained by the seismic profiling method, especially when using the current measuring equipment with high dynamics and specialized interpretive software, are especially useful in assessing the state of a rock burst hazard.

The basic quantity calculated in the Dubiński (Dubiński 1989) method is a seismic anomaly based on the measured V_P velocity with the reference velocity V_0 for a given depth and allows for a calculation of the according to the following formula:

$$A = \frac{V_P - V_0}{V_0} \cdot 100\ (\%) \tag{1}$$

Based on the size of the seismic anomaly calculated using the formula (1), Dubiński (Dubiński 1989) obtained a scale of relative stress changes in USCB conditions for depth range 500–900 m shown in Table 1.

Table 1. The seismic scale of relative stress changes in Upper Silesian Coal Basin conditions for depth range 500–900 m (Dubiński 1989)

Tabela 1. Sejsmiczna skala zmian naprężeń względnych w warunkach Górnośląskiego Zagłębia Węglowego dla zakresu głębokości 500–900 m

Degree of relative stress increase (decrease)	Positive (negative) seismic anomaly (%)	Scale of relative stress increase (decrease)	Probable increase (decrease) in relative stress (%)
0	< 5 (>–7.5)	Lack/very low	< 20 (<25)
1	5–15 (–15 – –7.5)	Low	20–60 (55–25)
2	15–25 (–25 – –15)	Medium	60–140 (80–55)
3	> 25 (< –25)	High	> 140 (>80)

The empirical formula for the reference velocity V_0 was determined on the basis of laboratory tests and several hundred seismic measurements carried out in the USCB coal mines (39 mines, 292 measurements) in 190–900 m depth range (Dubiński 1989):

$$V_0 = 1200 + 4.83h^{0.76} \tag{2}$$

where h is the depth of the measurement site.

Szreder and Barnaś (Szreder and Barnaś 2017) formulated the advantages and limitations of seismic profiling in coal seams (Table 2).

Table 2. Advantages and limitations of seismic profiling (Szreder and Barnaś 2017)

Tabela 2. Zalety i ograniczenia metody profilowania sejsmicznego

Advantages	Limitations
◆ Changes in the P-wave velocity in the coal seam correspond to changes in relative stress. ◆ Measurement is carried out on-site on the threatened section of the excavation. ◆ The survey is non-destructive. ◆ The acquired information may be considered continuous. ◆ According to the described methodology, the measurement is relatively short (2 h for 100 m profile). ◆ The measurement cost is relatively low.	◆ The high impact of mining disturbances on wavefield registration. ◆ Complicated wave image requiring experience in data processing and interpretation. ◆ The great influence of the disturbed zone in the sidewall of the excavation at the site of the sensor installation on the recording quality. ◆ Reduction of increments of the P-wave velocity with increasing stress (problem at greater depths). ◆ The necessity to maintain the seismic silence during the measurement in the research area (about 20 minutes per 100 m of the profile). ◆ Disturbances in the registration of seismic waves associated with complex tectonics and lithology (faults, seam thinning, washouts, rock partings, dirt bands). ◆ The use of non-intrinsically safe measuring equipment is possible in an atmosphere of up to 0.5% of methane under applicable regulations.

1.3. Measurement and interpretation methodology

Seismic profiling was performed on the I-I' profile in the eastern side of the longwall 1 in the coal seam 405/1 at a depth of 1,260 m (Figure 4). The location of the seismic profile was chosen in such an area that the stress-strain state in the coal seam is not disturbed by the significant influence of geological and mining factors. Measurements were made according to the scheme provided by Dubiński (Dubiński 1989). The basic measurement parameters were as follows:

- excitation of a seismic wave with a 4 kg hammer impact,
- the total length of the seismic profile: 80 m,
- geophones with a natural frequency of 40 Hz,
- distance between geophones: approx. 4–5 m,
- wave excitation points: every 10 m,
- sampling: 0.125 ms,

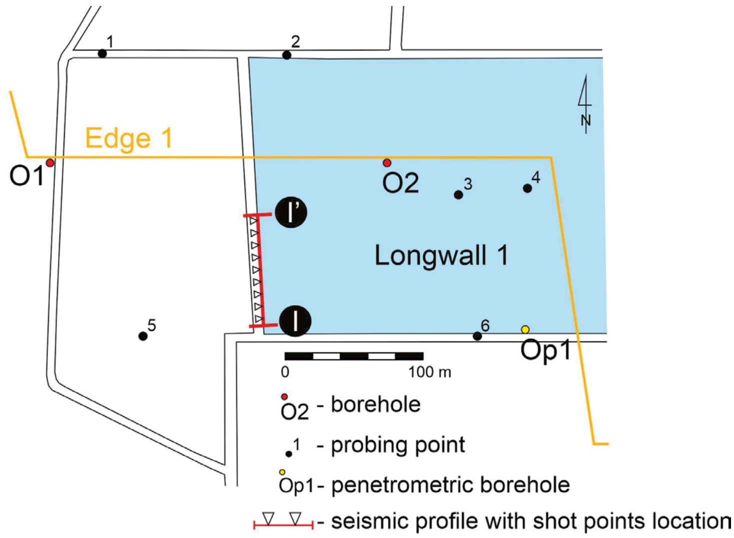

Fig. 4. Location of the I-I' profile in the area of longwall 1 in coal seam 405/1
along with the location of test boreholes O1, O2 and Op1

Rys. 4. Lokalizacja profilu I-I' w rejonie ściany 1 w pokładzie 405/1
wraz z położeniem otworów badawczych O1, O2 i Op1

- recording time: 0.5 s,
- stacking: 7 times.

The geophones were installed on short bolts, about 4 cm long, in the unloosened zone. The time of recording and sampling of the signal was selected before taking the measurement.

Seismic measurements were carried out with the use of Geode 24-channel seismic equipment. The apparatus is characterized by system dynamics of 144 dB and a resolution of 24 bits. The measurements were performed with geophones with a natural frequency of 40 Hz, manufactured by Geospace, USA. The measurement system was operated using the MGOS (Multiple Geode Operation System) software by Geometrics. The data was registered in the SEG-2 seismic format.

The velocities of the P-wave and the S-wave were calculated from the hodograph of recording on the first three or four geophones closest to the wave's excitation point. Such a methodology of calculations resulted from the high interference of various waves appearing at a short distance from the wave excitation point. Then, the calculated velocities were compared with the velocity model developed by the standard reciprocal traveltimes method (Figure 5).

For this purpose, a two-layer model of the medium was adopted, consisting of the fracture and solid zones. The model was adjusted using the inverse analysis method. The accuracy of the calculations was verified by minimizing the mean square error. The Seisimager2D

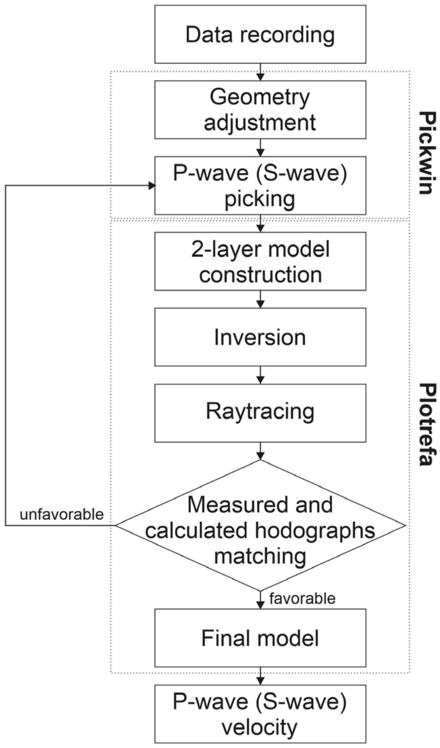

Fig. 5. A generalized scheme for processing and interpretation of seismic data (based on Szreder and Barnaś 2017)

Rys. 5. Uogólniony schemat przetwarzania i interpretacji sejsmicznych danych

software package by Geometrics was used to process seismic data, particularly its two modules: *Pickwin* and *Plotrefa*.

1.4. Calculation of modulus of elasticity

The dynamic modulus of elasticity E_d and the dynamic Poisson's ratio υ_d were determined on the basis of the measured velocity of the longitudinal wave P and transverse wave S and the density of hard coal from the following formulas (e.g. Pilecki 2018):

$$E_d = \rho (V_S)^2 \frac{3\left(\frac{V_P}{V_S}\right)^2 - 4}{\left(\frac{V_P}{V_S}\right)^2 - 1} \tag{3}$$

$$\vartheta_d = \frac{1}{2}\frac{\left(\frac{V_P}{V_S}\right)^2 - 2}{\left(\frac{V_P}{V_S}\right)^2 - 1} \tag{4}$$

↳ V_P – P-wave velocity,
V_S – S-wave velocity,
ρ – bulk density.

To calculate the dynamic modulus of elasticity, the hard coal bulk density was assumed to be equal to 1,330 kg/m^3. The remaining dynamic bulk modulus K_d and dynamic shear modulus G_d were determined from the following formulas:

$$K_d = \rho\left(V_P^2 - \frac{4(V_S)^2}{3}\right) \tag{5}$$

$$G_d = \rho(V_S)^2 \tag{6}$$

2. Geological conditions

The measurements were conducted in the 405/1 coal seam. The coal seam on the I-I' profile had a thickness of around 3.0 m. The quality parameters of coal in the measurement area allow it to be classified as type 35.1 orthocoking coals (PN-G-97002:2018-11, ISO 349:2020). The mean value of the uniaxial compressive strength R_c of the coal measured in penetrometer Op1 (Figure 4) is 16.6 MPa. The average bulk density of coal calculated on the basis of tests carried out on samples taken from 6 points in seam 405/1 (Table 3) in the area of the I-I' profile (Figure 4) is 1,327 kg/m^3.

On the basis of the data from the O1 and O2 boreholes (Figure 6), it was found that directly above the coal seam 405/1, there is a layer of clay shale locally sanded with a thickness of approx. 1.5–7.2 m, and above, a sandstone layer with a thickness of 6.6–9.7 m. In the 405/1 seam, there is a shale layer with coal with a thickness of up to approx. 1.55 m. Below the coal seam 405/1, there is clay shale with coal intergrowth and locally according to the O1 borehole with approximately 2.5 m of fine-grained sandstone. The total thickness of these layers is approx. 19.8–22.7 m.

Assuming the average value of the bulk density $\rho = 2{,}550$ kg/m^3 (Gustkiewicz 1999; Majcherczyk et al. 2002; Małkowski et al. 2021) for Carboniferous formation, it was calculated

Table 3. The bulk density of coal in the research area

Tabela 3. Gęstość objętościowa węgla w rejonie badań

Sample no.	Bulk density (kg/m^3)		
	value	mean value	std. deviation
1	1,360	1,327	32.04 (2.4 %)
2	1,340		
3	1,270		
4	1,340		
5	1,310		
6	1,340		

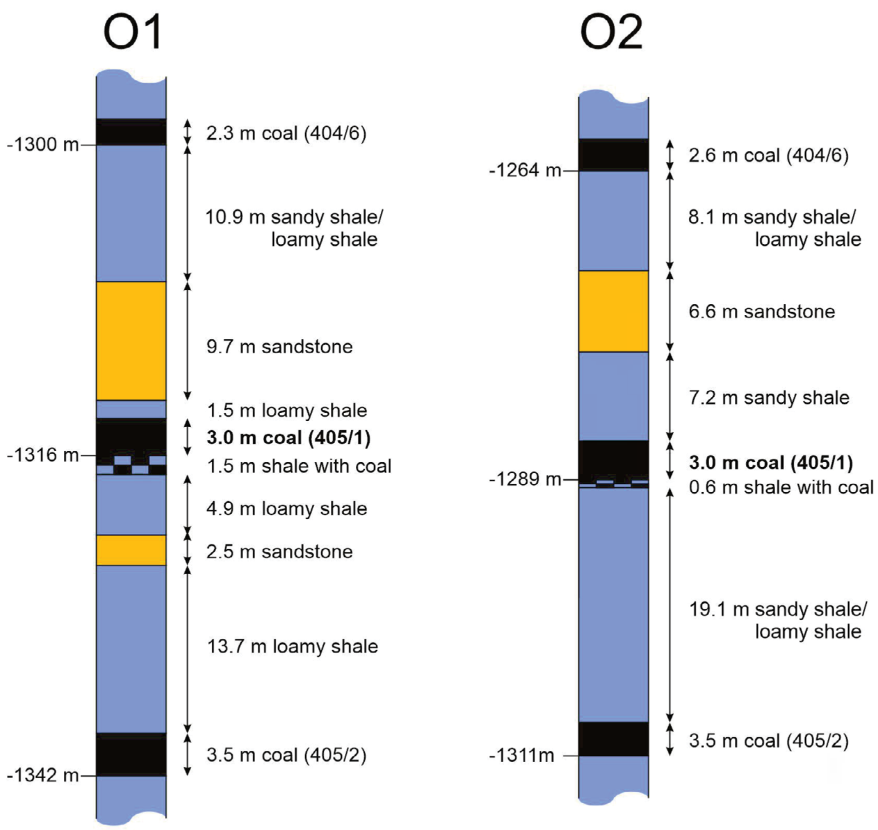

Fig. 6. Geological profiles from the research area

Rys. 6. Profile geologiczne z rejonu badań that the value of virgin vertical stress in the research area is around 32 MPa. However, the original horizontal stress, assuming the coefficient of earth pressure λ = 0.42, is around 13 MPa (Brown and Hoek 1978).

3. Results and discussion

The calculation results for the P-wave are presented in Figure 7a and for the S-wave in Figure 7b. There is a slight monotonic increase in the velocity towards the northern end of the I-I' profile in both cases. This may mean a slight change in the stress-deformation conditions, but the change is relatively small on this length of the profile.

Finally, arithmetic mean wave velocities were calculated along the entire length of the 80 m profile. Based on the knowledge of the average values of the P-wave and S-wave velocities, the dynamic elasticity parameters were calculated, which are presented in Table 4. The values of the calculated parameters have minor standard deviations from 1.44 to 4.31%.

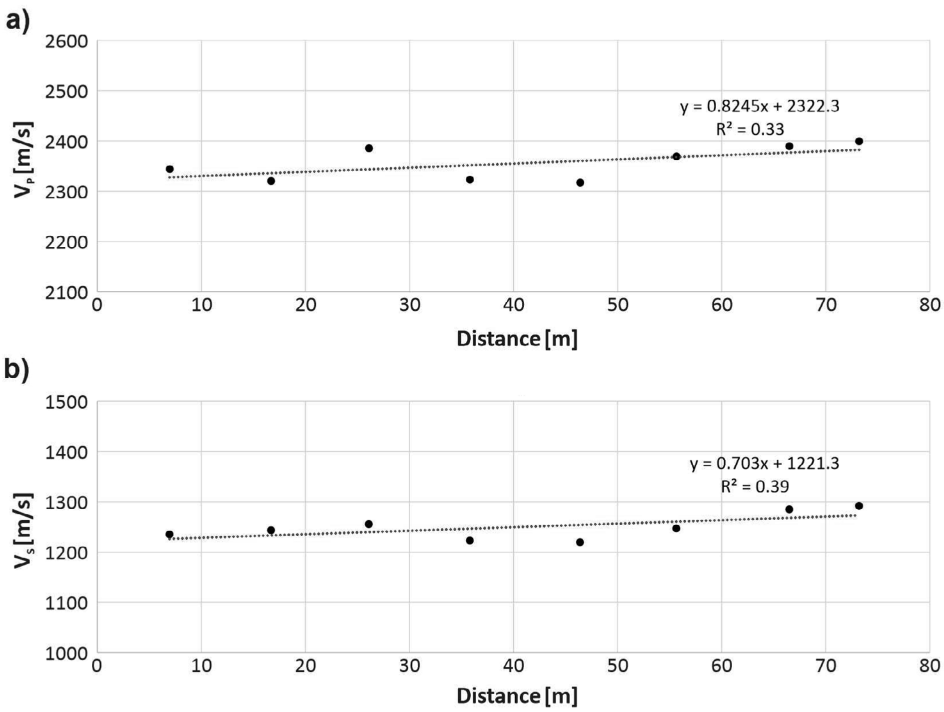

Fig. 7. Graphs of (a) P-wave velocity P changes and (b) S-wave velocity changes in coal seam 405/1 along with the I-I' profile at a depth of 1,260 m

Rys. 7. Wykresy (a) prędkości fali podłużnej P i (b) poprzecznej S w pokładzie 405/1 na głębokości 1260 m wzdłuż profilu I-I'

Table 4. Dynamic elastic parameters of the 405/1 coal seam at a depth of approx. 1,260 m

Tabela 4. Parametry dynamiczne sprężyste pokładu węgla 405/1 na głębokości około 1260 m

Parameter	Unit	Mean value	Range	Standard deviation (%)
P-wave velocity V_P	m/s	2,356	2,317–2,399	33.8/(1.44%)
S-wave velocity V_S	m/s	1,250	1,220–1,292	26.6/(2.14%)
V_P/V_S	–	1.88	1.86–1.90	0.02/(1.06%)
Dynamic elastic Young modulus E_d	GPa	5.41	5.17–5.74	0.21/(3.95%)
Dynamic bulk modulus K_d	GPa	4.60	4.41–4.76	0.12/(2.59%)
Dynamic shear modulus G_d	GPa	2.07	1.97–2.22	0.09/(4.31%)
Dynamic Poisson ratio – υ_d	–	0.30	0.295–0.308	0.006/(1.92%)

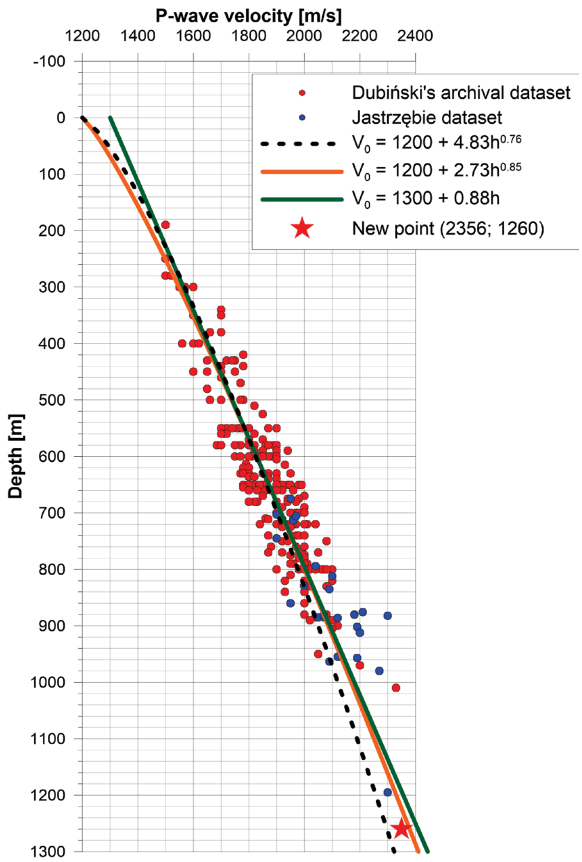

Fig. 8. The plot of the Dubinski (1989) model with data from Jastrzebie coal mine (Kokowski et al. 2019) – new P-wave velocity value on the depth of 1,260 m denoted by red star

Rys. 8. Wykres zależności Dubińskiego (1989) wraz z danymi z KWK Jastrzębie (Kokowski i in. 2019) – nowa wartość prędkości fali P na 1260 m oznaczona czerwoną gwiazdką

The point with the new calculated P-wave velocity at a depth of 1,260 m was introduced on a graph of velocity V_P changes with depth given by Kokowski et al. (2019) (Figure 8). Figure 8 shows the relationship of Dubiński (Dubiński 1989) with a black dashed line and the relationships given by Kokowski et al. (Kokowski et al. 2019) marked with orange (exponential) and green (linear). The dependence of Kokowski et al. (Kokowski et al. 2019) was calculated to supplement the data provided by Dubiński (Dubiński 1989) with data gathered at the Jastrzębie coal mine. As shown in Figure 8, the new point location corresponds to the analytical extension of relationships of the Dubiński (Dubiński 1989) and Kokowski et al. (Kokowski et al. 2019). Based on the measurements of the P-wave velocity, it is difficult to unequivocally confirm whether the increases in the P-wave velocity are smaller with the

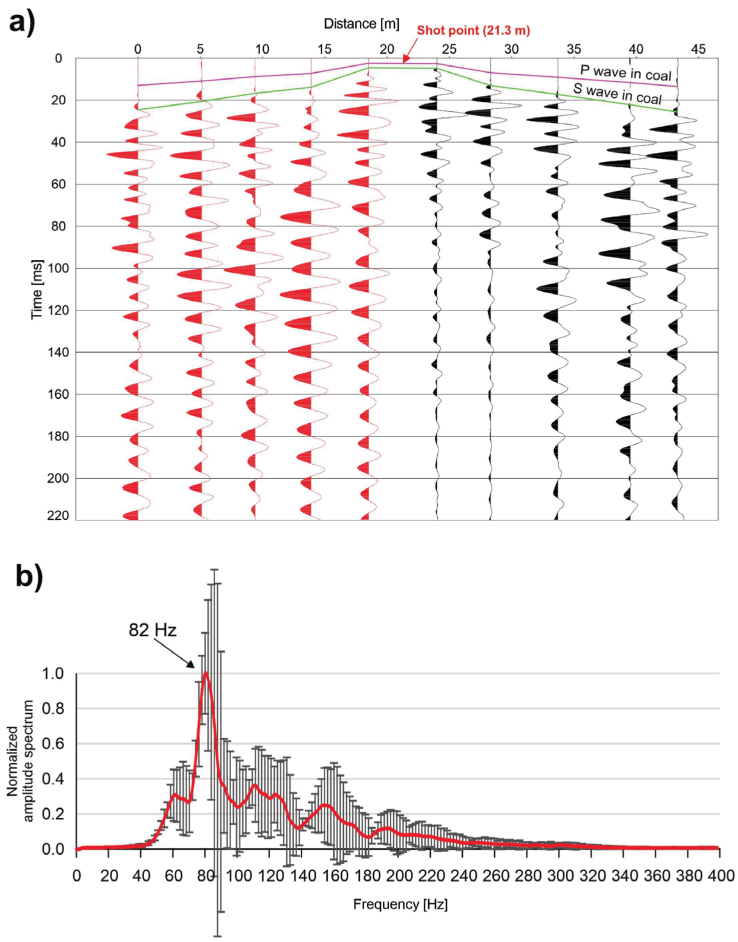

Fig. 9. (a) An example of a wave field recording for a wave excitation point located at 21.3 m of the I-I 'profile; (b) with an averaged spectrum

Rys. 9. (a) Przykład rejestracji pola falowego dla punktu wzbudzenia fali położonego na 21,3 m profilu I-I'; (b) wraz z uśrednionym widmem increase in depth and the increase in the primary stress. This problem requires additional measurements of the P-wave velocity at various depths below 1,000 m.

The source of the wave in the seismic profiling was a 4 kg hammer impact. Figure 9a shows an example of a wave field recording on 40 Hz geophones, and Figure 9b shows the spectrum calculated for recording on five geophones in a 220-millisecond window (red color).

The spectrum shows that there is a central frequency in the wave field of approx. 82 Hz and the signal energy broadly range from 40 Hz to approx. 240 Hz. It should be emphasized that the spectrum was cut off from the lower frequencies as a result of recording with a 40 Hz geophone. The main reason for the use of 40 Hz geophones is interference from mine noise. The errors in the spectrum calculation, marked with the shaded area in Figure 9b, are relatively large, especially for the frequencies of 90, 110 and 160 Hz. This is mainly related to the disturbances caused by the mining equipment, e.g. fans, conveyor belts, power cables, etc. The results of the calculated spectrum confirm the results obtained so far for the hammer impact in the coal seam (e.g. Pilecki 2018).

Conclusions

In this study, the dynamic elastic parameters of the 405/1 seam located at great depth in one of the mines of the Upper Silesian Coal Basin were measured and calculated. Based on the study results, the following conclusions can be drawn:

1. The P-wave and S-wave velocities in the coal seam were measured at the greatest depth of 1,260 m, at which the seismic profiling measurements were conducted in the Upper Silesian Coal Basin. The average velocity V_P in the 405/1 coal seam is 2,356 m/s, and the average velocity V_S is 1,259 m/s. It should be emphasized that the measurements were made in difficult mine conditions, in which the wave field is strongly disturbed by mine noise.
2. Measurements of the P-wave and S-wave velocity using the seismic profiling method allowed for the calculation of the dynamic moduli of elasticity of the 405/1 coal seam at a depth of 1,260 m. The results of the calculations are presented in Table 4. The modules were calculated for the average volumetric density of coal in this seam $\rho = 1{,}327$ kg/m^3.

The calculated average P-wave velocity, equal to 2,356 m/s for the depth of 1,260 m/s, is approximately consistent with the empirical dependence of Dubiński (Dubiński 1989) (Figure 9). Therefore, the dependence of Dubiński (Dubiński 1989) probably describes changes in the P-wave velocity even to a depth of about 1,300 m. However, this requires confirmation with a more significant number of measurements.

3. The calculated average of the P-wave velocity, equal to 2,356 m/s, is also approximately consistent with the empirical relationship given by Kokowski et al. (Kokowski et al. 2019).

4. The measured average velocity of the P wave equal to 2,356 m/s can be taken as the reference velocity at a depth of approx. 1,260 m in the calculation of the seismic anomaly in the seismic profiling method.
5. The calculated dynamic elasticity parameters may be useful in mathematical modeling of the stress deformation state in the coal seam under various geological and mining conditions.

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DYNAMIC ELASTIC PROPERTIES OF THE HARD COAL SEAM AT A DEPTH OF AROUND 1260 m

Keywords

dynamic elastic parameters, coal seam, P-wave velocity, S-wave velocity, seismic profiling

Abstract

The knowledge of the dynamic elastic properties of a coal seam is important in the context of various types of calculations of the seam behavior under various stress-strain conditions. These properties are often used in numerical and analytical modeling related to maintaining the stability of excavations and the analysis of mechanisms, e.g. related to the risk of rock bursts. Additionally, during the implementation of seismic surveys, e.g. seismic profiling and seismic tomography in coal seams, the reference values of the elastic properties of coal are used in the calculation of relative stresses in various geological and mining conditions.

The study aims to calculate the dynamic elastic parameters of the coal seam located at a depth of 1,260 m in one of the hard coal mines in the Upper Silesian Coal Basin (USCB). Basic measurements of the velocity of P- and S-waves were conducted using the seismic profiling method. These surveys are unique due to the lack of the velocity wave values in the coal seam at such a great depth in the USBC and difficult measurement conditions in a coal mine. As a result, dynamic modulus of elasticity was calculated, such as Young's modulus, volumetric strain modulus, shear modulus and Poisson's ratio. The volumetric density of coal used for calculations was determined on the basis of laboratory tests on samples taken in the area of the study. The research results showed that the calculated mean P-wave velocity of 2,356 m/s for the depth of 1,260 m is approximately consistent with the empirical relationship obtained by an earlier study. The P-wave velocity can be taken as the reference velocity at a depth of approx. 1,260 m in the calculation of the seismic anomaly in the seismic profiling method.

DYNAMICZNE SPRĘŻYSTE WŁAŚCIWOŚCI POKŁADU WĘGLA NA GŁĘBOKOŚCI OKOŁO 1260 m

Słowa kluczowe

dynamiczne parametry sprężyste, pokład węgla, prędkość fali P,
prędkość fali S, profilowanie sejsmiczne

Streszczenie

Znajomość dynamicznych właściwości sprężystych pokładu węgla jest istotna w kontekście różnego rodzaju obliczeń zachowania się pokładu w różnorakich warunkach naprężeniowo-odkształceniowych. Właściwości te są często wykorzystywane w modelowaniach numerycznych i analitycznych związanych z utrzymaniem stateczności wyrobisk oraz analizą mechanizmów, np. związanych z zagrożeniem tąpaniami. Dodatkowo w trakcie realizacji badań sejsmicznych np. profilowań sejsmicznych i tomografii sejsmicznej w pokładach węgla referencyjne wartości właściwości sprężyste węgla wykorzystywane są w obliczaniach naprężeń względnych w różnych warunkach geologiczno-górniczych.

Celem badań jest obliczenie dynamicznych sprężystych parametrów pokładu węgla, położonego na głębokości około 1260 m, w jednej z kopalń węgla kamiennego w Górnośląskim Zagłębiu Węglowym. Podstawowe pomiary prędkości fal sejsmicznych wykonano metodą profilowania sejsmicznego. Te pomiary są unikatowe ze względu na dużą głębokość położenia profilu pomiarowego oraz trudne warunki pomiarowe w kopalni. W efekcie obliczono dynamiczne moduły sprężystości takie jak: moduł Younga, moduł odkształcenia objętościowego, moduł odkształcenia postaciowego oraz współczynnik Poissona. Gęstość objętościową węgla przyjętą do obliczeń wyznaczono na podstawie testów laboratoryjnych na próbach pobranych w rejonie badań. Wyniki badań pokazały, że obliczona średnia prędkość fali P równa 2356 m/s dla głębokości 1260 m jest w przybliżeniu zgodna z empirycznymi zależnościami określonymi we wcześniejszych badaniach. Prędkość fali P może być przyjęta jako prędkość odniesienia na głębokości około 1260 m w obliczeniach anomalii sejsmicznej w metodzie profilowania sejsmicznego.