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Comparison of Profiling Results of Attenuation and Velocity of Refracted P-wave in Coal-seam

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SUMMARY

In the paper the problem of effectiveness of seismic profiling of attenuation and velocity of refracted P-wave in coal-seam along mining excavation in conditions of coal-seam edge impact has been presented. For practical use of seismic attenuation profiling, special measurement and interpretation methodology has been prepared. The measure of calculated attenuation is the value of attenuation coefficient based on determination of amplitude of refracted P-wave. In the paper examples of attenuation coefficient and velocity of refracted wave changes in the zones of exploitation seam edge in one of the Polish coal mines have been described. The usefulness of attenuation coefficient for such analysis has been underlined due to its greater sensitivity for changes of the state of stress and deformation in coal-seam comparing to changes of refracted P-wave velocity. It is shown that attenuation can be an interesting parameter complementary to refracted wave velocity in coal-seam, especially in high stress conditions.

1. Introduction

From a general view, the method of seismic refraction in coal mines is used to an assessment of relative state of stress in rock mass (Dubinski 1989). Generally, this method enables to assess in terms of quantity the influence effect of different factors forming state of stress and deformation. In principle, that is a fundamental method, which allows for assessing the influence effect of exploitation edges and remnants of coal-seams, active faults, and the like, on excavation support-rock mass system. The results achieved by seismic profiling are useful particularly in the assessments of rock bursts hazard.

From previous experiments with seismic profiling in coal-seams, it is known that an attenuation coefficient is more sensitive to changes of the state of stress and deformation than refracted P-wave velocity. A wider elaboration of that issue may find in paper of Szreder et al. (2008).

2. The methodological basis of profiling of attenuation and velocity of refracted P-wave in coal seam in underground excavation

The basic parameter used in a method of seismic profiling is a velocity of refracted P-wave. It is a velocity of propagating wave along excavation in an elasticity zone on the border with plasticity zone. The border between zones of elasticity and plasticity may illustrate with the use of a model of Ladanyi (1974) under conditions of long-term interaction of excavation support with the rock mass (Fig.1).

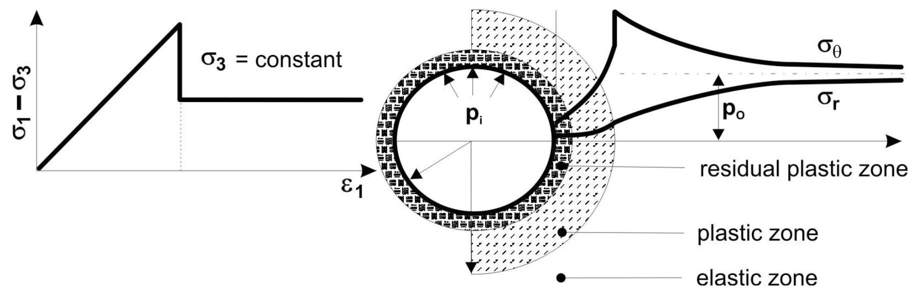

Fig. 1. Model of long-term behaviour of rock mass around excavation on the basis of Ladanyi (1974); σ_1 – major principal stress, σ_3 - minor principal stress, σ_θ – tangential stress, σ_r – radial stress, ε_1 – major principal strain, p_o – virgin stress, p_i – lining load

A maximum of tangential stresses occurs in an elasticity zone on the border with plasticity zone. It should be made an assumption that in this part of elasticity zone occur most favorable conditions of refracted wave propagation (Fig.2). In practice, the border between zones of elasticity and plasticity has a transitional character and seismic wave propagation is more complex. A complicated character of wave field is visible on seismic records (Fig.3b). A significant influence on distortion of wave pattern has an intensely variable width of a plasticity zone along excavation (Fig.3a). The determination of refracted wave onset and its amplitude is frequently complicated under these conditions. Often, the unreal results of inversion modeling observed at an interpretation of measurements of seismic profiling prove it.

From a general view, an observation in seismic measurements of wave amplitude decay with offset increases is related with geometric propagation of wave and with the losses of seismic energy as a result of absorption and dissipation. It could be made an assumption that wave amplitude decay for plane waves in coal-seam is a total effect of absorption and dissipation of seismic energy and has an exponential character in the function of a distance:

$$A(r) = A_0\, e^{-\alpha r} \tag{1}$$

where:
A – amplitude in the distance **r** from a source,
A_0 – source amplitude,
α – attenuation coefficient (has a dimension 1/m).

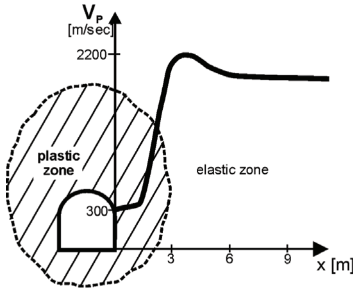

Fig. 2. Exemplary characteristic of P-wave velocity in function of distance from excavation sidewall (Szreder et al. 2008)

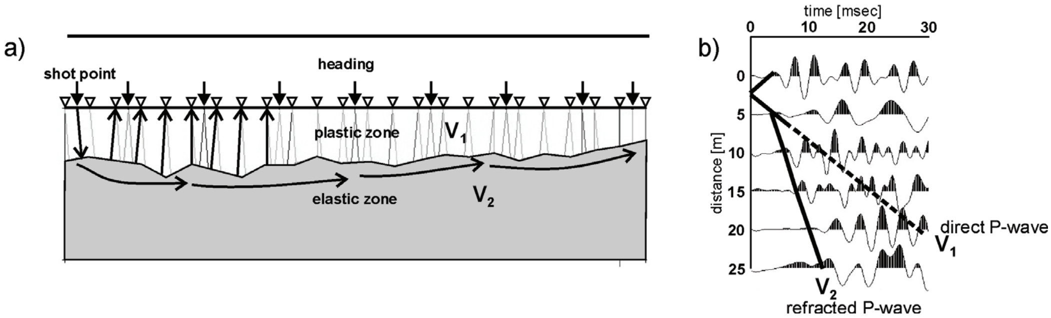

Fig. 3. Seismic profiling along excavation sidewall: (a) refraction wave propagation; (b) exemplary wave pattern (Szreder et al. 2008)

3. Methodical assumptions of seismic attenuation profiling

Measurement methodology

Depending on conditions of refracted P-wave propagation in coal-seam the length of spread for 24 geophones may reach up to 115 meters in adjustment to energy of wave source. The geophone interval should be made an assumption from 2 to 5 meters depending on possibility of refracted P-wave identification. The seismic wave is excited with the use of stroke with sledgehammer. For improvement of signal quality, it should be applied sevenfold stacking, at least. The seismic records are legible even in longer sections in case of low seismic noise level and high amplifications of test equipment of the order of over 100 dB. The geophone may be installed in a different way, in addition to which the contact with rock mass is to secure the distinct and non-deformed onsets of refracted waves. The geophones fixed on short, about 40 cm long anchors in not separated rock mass, ensure wave images that are enough useful to an interpretation. The recording time and signal sampling have to be always tested in specific investigation site. There is some suggestion to select a sample interval with 0.125 ms and record length with 0.5 sec.

Methodology of interpretation

The calculations of attenuation coefficient consist in:

- reading of maximum value of refracted wave amplitude on consecutive traces on selected profiling section so-called reference section. On the basis of experience, the amplitudes for calculations should be made an assumption a reference section up to 15 meters in length from a point of wave source, excluding recording point located closest to the wave source,
- normalizing the amplitudes relative to the biggest value A_{Pmax} – closest to the wave source,
- graphic data presentation arranged in a natural logarithm of normalized amplitude of refracted P-wave A_P in a function of the distance from a source i.e. $\ln(A_P/A_{Pmax})$,
- calculating the slope coefficient of a line as a result of approximation of survey points, which is an attenuation coefficient α,
- assignation the value of calculated attenuation coefficient α to the mid-point of a reference section.

The calculated values of an attenuation coefficient along profile's entire length for every wave source point are graphically presented the most favorable with allowance for potential geological and mining factors disturbing the state of stress and deformation in investigation site.

4. An example of profiling of an attenuation and velocity of refracted P-wave in conditions of influence of exploitation edge

Location and scope of research

The seismic surveys in headings of a longwall 23 in coal-seam 505/2 at a depth 680-780 meters have been made on December 2007 in Jas-Mos coal mine. The profiles 115 meters in length in total 230 running meters of seismic profiles have been done in two longwall's headings. The profiles were located in a zone of an influence of overlying exploitation edge in coal-seam 505/1 generated in 2003 (about 2.3 meters in thickness) within the vertical distance from 8.0 to 12.0 meters.

The results of seismic profiling and its analysis

A diagram for changes of refracted P-wave velocity as well as of an attenuation coefficient on both profiles I – I' and II – II' together with mining situation in a region of a longwall 23 in coal-seam 505/2 was presented on Fig.4.

Profile I- I'

An attenuation coefficient of seismic wave preserves values from 0.09 m^{-1} to 0.17 m^{-1} (Fig. 4a). The relative variations of the values of that coefficient is A_A^1 = 89%. The attenuation coefficient preserves highest values under goaf of coal-seam 505/1 in a profile section from 0 up to 45 meters. Whereas it preserves the lowest values in a section under unmined coal-seam 505/1, from the edge of this coal-seam (45 – 115 meters in profile).

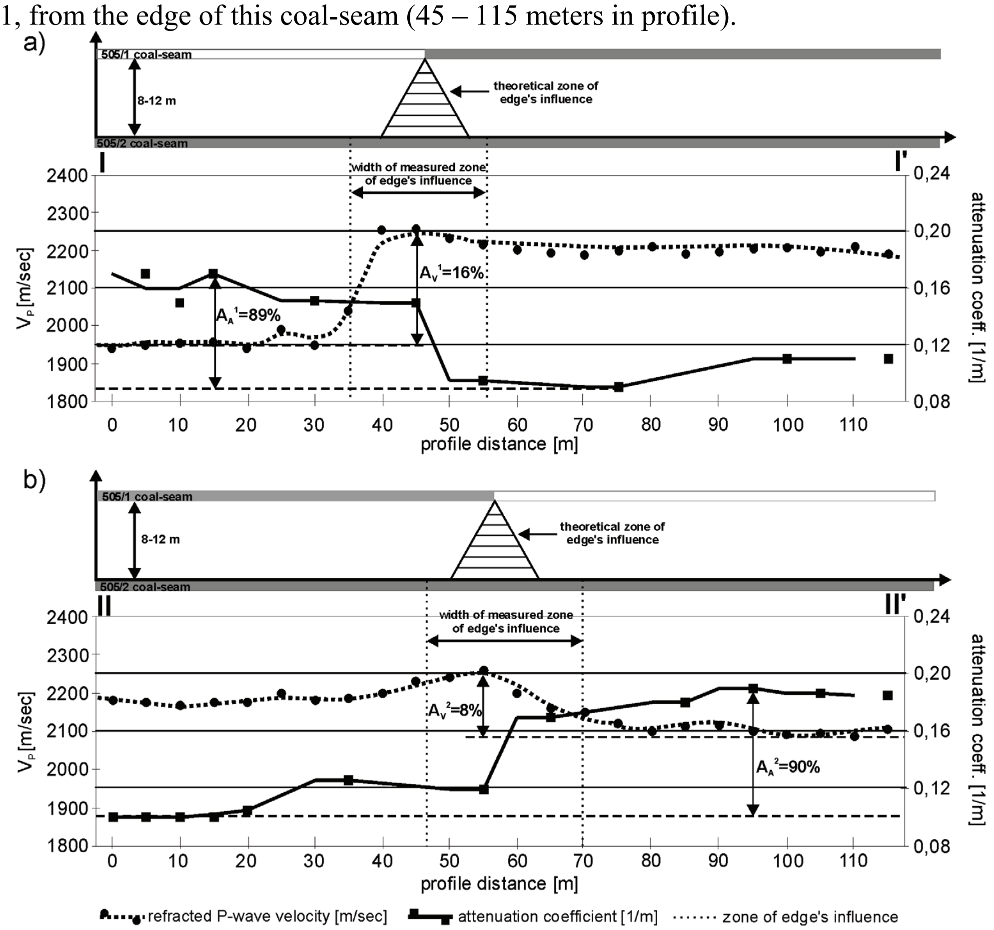

Fig. 4. Seismic profiling of changes of refracted P-wave velocity and attenuation coefficient in the influence zone of coal seam 505/1 edge in headings for longwall no 23 in coal seam 505/2 in Jas-Mos coal mine: a) seismic profile I – I', b) seismic profile II – II' (Szreder et al. 2008)

The refracted P-wave velocities change from 1940 m/s to 2260 m/s. The relative variations of values of the measured velocities is A_V^1 = 16%. The seismic wave velocity preserves the highest values under unmined coal-seam 505/1, and the lowest values under goaf of that coal-seam. In both cases of wave velocity and attenuation coefficient they undergo relatively sudden changes of gradient of its value in a zone of edge's influence. A width of this zone is about 20 meters in a section from about 35 up to 55 meters. The range of the zone of measured edge's influence 505/1 is wider than a range of the theoretical zone of this edge's influence. That is probably an effect of a decay of magnitude of edge's influence upon increasing its range with the lapse of time.

Profile II- II'

A character of variations of refracted P-wave velocity and attenuation coefficient is analogous as on a profile I – I' (Fig. 4b). The variation of attenuation coefficient is almost identical from 0.10 m^{-1} to 0.19 m^{-1} (A_A^2 = 90%). Whereas in case of wave velocity the variation is smaller from 2090 m/s to 2260 m/s (A_V^2 = 8%). A measured range of edge's influence is about 20 meters in a section of profile from around 45 up to 65 meters. This range is also wider than a theoretical range of edge's influence 505/1.

Summarizing, it should be found that an attenuation coefficient preserves comparatively high values under distressing conditions of mined overlying coal-seam. This distressing causes in the end an opening of different type of fracture systems as well as greater degree of freedom of fluid and gas motion in a porous texture of coal-seam. It causes an increase of plastic behaviour in an elasticity zone. The velocity of seismic wave is going to decrease under these conditions.

An impact zone of edge's coal-seam causes sudden changes in value of wave velocity and attenuation coefficient. The gradient of these changes depends on magnitude of static load from the edge and is dependent on many parameters such as distance from coal-seam in which a survey was carried out, coal-seam thickness "with an edge" and the lapse of time from its exploitation or strength and deformation properties of rock mass.

5. Summary

A profiling of seismic attenuation similarly as and seismic wave velocity in coal-seams describes the state of stress and deformation in the rock mass. Based on experience, it should be found that the relative variation of an attenuation coefficient is definitely greater than the relative variation of refracted P-wave velocity. This is due to the higher sensitivity of refracted P-wave amplitude to changes of stress and deformation in the rock mass compared to refracted P-wave velocity.

The profiling of seismic attenuation requires a careful installing the geophones in such a manner that the recording conditions of seismic wave be comparable in every survey point. One should avoid influence of a near field in vicinity of wave source in calculations of an attenuation coefficient.

The presented issue requires further researches, and especially gathering of experience in different geological and mining conditions.

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