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A NOTE ON INVESTIGATION OF THE SEISMIC WAVES ATTENUATION

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ABSTRACT. Rockbursts and rockburst – l ke phenomena occurring in the Ostrava–Karviná Coalfield are usually recorded at seismic stations of the Frenštát Network which is a part of the Regional Seismic Polygon. Implemented software for data processing of this stations enables foci location and further investigation of the wave trains, e. g. polarization and/or spectral an
magnitude classification of the recorded seismic events have not been carried out yet. The present paper reports on the first step in derivation of basic relations for the released seismic energy determination of individual seismic events, i. e. investigation of P – waves attenuation within the approximate interval of epicentral distances 20 – 45 km. The law of attenuation of P – waves with distance depends on the wave front, on its geometrical spreading as well as on the absorption in geologic medium. Data set approximation was performed using the following power as well as exponential functions, i. e.

$$A = A_0 r^{-m} \quad \text{and} \quad A = A_0 r^{-n} e^{-\alpha r} .$$

KEYWORDS: induced seismicity, seismic waves attenuation, Ostrava–Karviná Coal Basin

1. INTRODUCTION

Based on the extent geological exploration in the broader region of the Ostrava–Karviná Basin, there was found a new hard coal deposit in the vicinity of the town Frenštát under Radhošť, recently. Considering this fact, there was made more detailed geological and geophysical exploration and also construction of a new mine has been started, i.e. of the Mine Frenštát–West. The approved coal reserves are relatively high. Nevertheless, the hard coal mining in the deposit has been evaluated as the very complicated one due to its natural conditions (depth of seams in the range of 1 000 up to 1 200 m, tectonic disturbances, complex structure of the overlying strata, etc.). Some deal of the overall complexity has been created also by the unfavourable primary stress field. The presently detected tectonical movements in the broader area of the mine have been detected also by repeatedly performed precise levelling and triangulation, made by [Vyskočil 1986].

There should be commonly stated that ore and/or coal mining is accompanied with induced seismicity in the given mining region. Considering the long–term experience with monitoring of the induced seismicity in the Ostrava–Karviná Basin, there has been confirmed the mutual linkage between the seismic and mining activities and, therefore, it was presupposed that the same increase of the seismic activity will be present also after starting of mining works in the mining field of the Mine Frenštát–West. Due to this presupposition, there was included seismic monitoring of this region in frame of the designed s.c. Regional Seismic Polygon (RSP). For the seismic activity monitoring prior the mining operation start, there was erected Frenštát Network of the RSP [Knejzlík, Zamazal 1992]. Recently, due to dramatic hard coal mining reduction, the further operation of the mine was stopped after dipping of all both main shafts and the mine has been conserved. Nevertheless, the operation of the Frenštát Network is going-on and rockbursts–like events (tremors) from Ostrava–Karviná Basin as well as from Polish mines and blasting operations in close quarries and/or natural earthquakes from the town Opava region or the ones originated in the tectonic contact of the Bohemian Massif and Western Carpathians are detected in the running manner.

The present kind of data processing is oriented mainly on detection and/or location of recorded seismic events and on various particular analyses described e.g. in [Kaláb 1992; Kaláb, Knejzlík 1996], as well. Temporarily, there is not made any energetic classification of these events. In the presented paper, preliminary results of methodical procedures aimed at testing of various approaches in determination of attenuation characteristics of P – waves in the area of interest using records of mining induced events in the Eastern part of the Ostrava–Karviná Basin are presented.

2. Observations

2.1. The Frenštát Network of the RSP

The above mentioned network consists of five three–component seismic stations, the location of them is in the broader area of the town Frenštát under Radhošť and could be seen in Fig. 1. All stations, equipped with seismometers WDS–202, have the frequency range of about 2 up to 30 Hz, the sampling frequency of 125 Hz and the dynamic range of 120 dB (MSB/LSB); the instrumentation was described by [Knejzlík, Zamazal 1992]. During the network construction, the basic aim
(RSP) at suppression of the noise background influence on the quality of the very records. Considering the necessity of filtration of the low–velocity layer situated close to the surface, in which the seismic noise is mostly propagated, seismometers were located in shallow boreholes ($h = 30$ m). The present experience from the network operation confirms suppression of the noise background, which guarantees the necessary quality of seismic records.

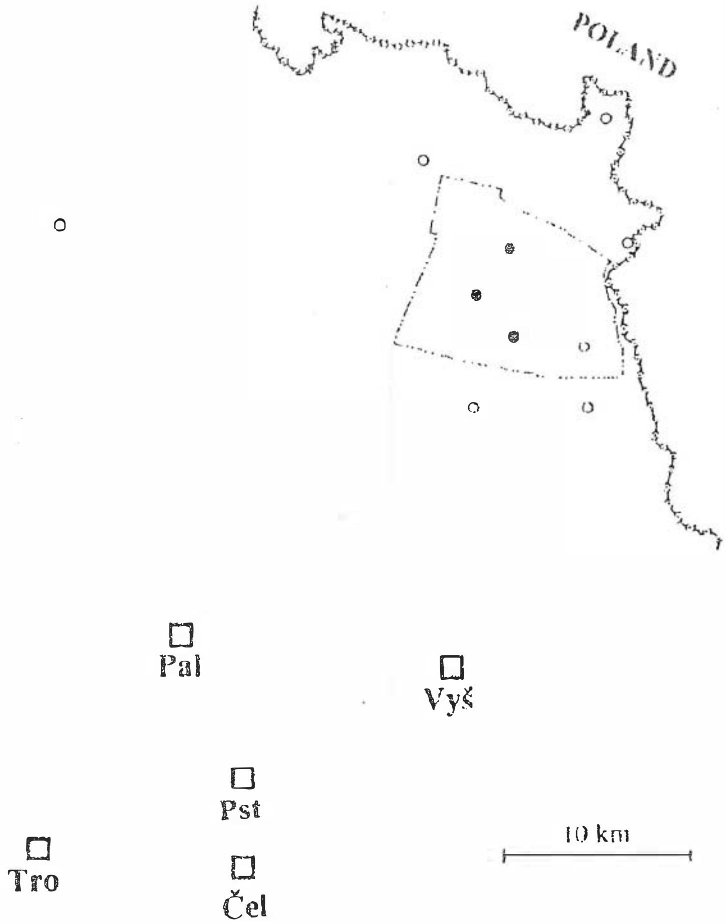

FIG. 1. The layout of seismic stations included into the Regional Seismic Polygon OKD surrounding the Ostrava–Karviná Coal Basin and Frenštát Network.

Seismic Polygon OKD: ● underground station
○ surface station
Frenštát Network: □ surface stations

2.2. Data Processing

For the data processing in the given time period, the mining induced seismic events from the Eastern part of the Ostrava-Karviná Basin for the time period 1993 – 1996 mostly within the energy order of $E = 10^5$ J were chosen. Only four events were energetically weaker ($6 \cdot 10^4 < E < 10^5$ J) and seven events had have an energy of $E \geq 10^6$ J. Altogether, 48 events were processed. Their frequency distribution within the range of energies could be seen in Fig. 2. From wave pattern of these events, for each of five stations of the Frenštát Network of the RSP of the Ostrava–Karviná District, there were detected on all three components particle velocity of the P – waves and according to these values, the complex particle velocity was determined. The found values of particle velocity and calculated epicentral

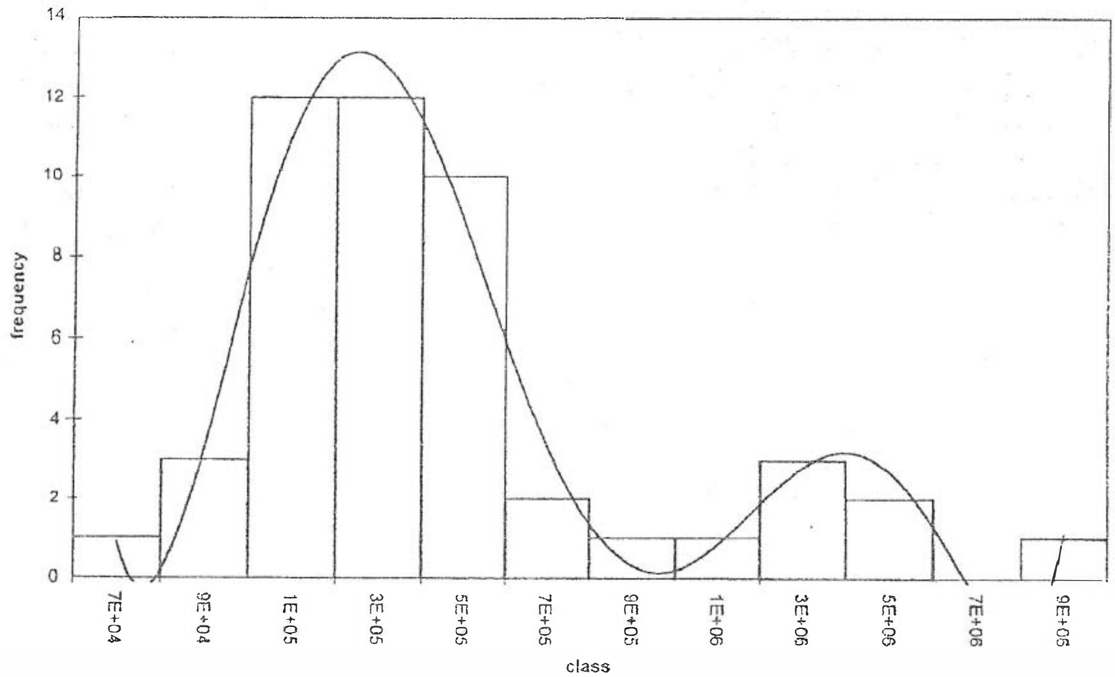

Fig. 2. Frequency–energy [J] distribution of seismic events used for interpretation.

distances of registration sites were graphically processed by means of the worksheet processor Microsoft Excel.

2.3. Wave trains

The basic information for determination of seismic waves attenuation were gained from records of rockburst–like events (tremors) particle velocity from the Ostrava–Karviná Basin, registered at seismic stations of the Frenštát Network of the RSP. Times of origin, co–ordinates of foci and values of seismic energy of chosen events were gained from the database of the seismic centre in the Mine ČSA. Based on known co–ordinates not only of seismic stations, but also of foci of individual tremors was deducted that the data set consists of events occurring approximately at the epicentral distance 20 up to 45 km. In course of detailed analysis of wave patterns of various seismic events, there was frequently presented a good coincidence of theirs character, i.e. a good reproducibility has been confirmed. This fact could be seen in the Fig. 3. Simultaneously, also some complexity of these wave patterns has been pronounced, mainly in the area of the first onsets of S – waves which could cause some troubles with their identification. Therefore, we paid our attention mainly to methodical issues joined with determination of attenuation characteristics of P – waves in the first stage of the solution. In the initial phase of records, these waves are featured by some stability of the wave pattern character, primarily at the location Pstruží (Pst), Čeladná (Čel) and Trojanovice (Tro), where the maximum particle velocity of P – waves are present within the time period of

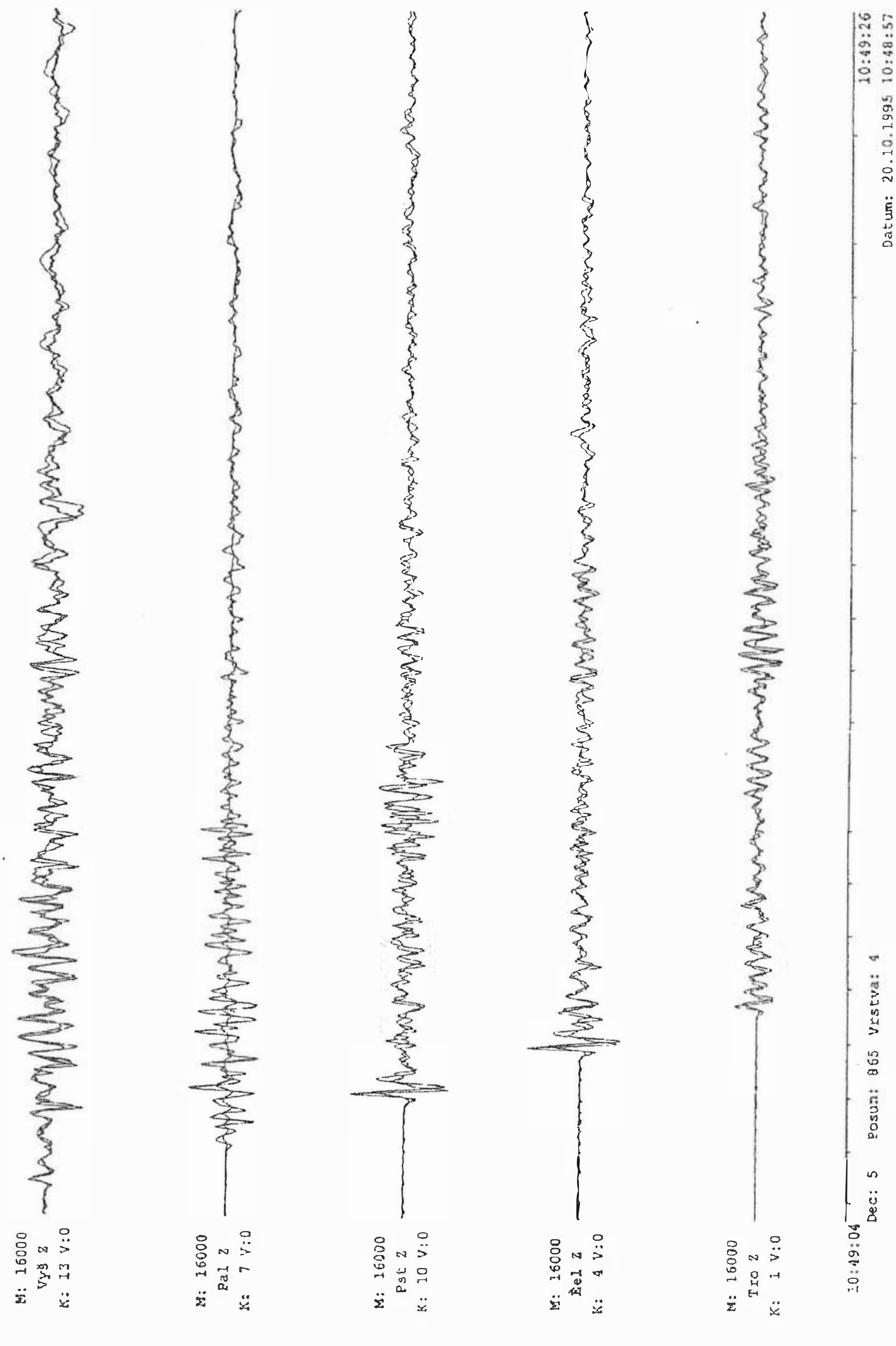

FIG. 3. Mutual comparison of wave patterns of two seismic events recorded at stations of the Frenštát Network.

the first cycle of the ground motion. In the contrary, the wave pattern of P-waves at locations situated at smaller epicentral distances, i.e. Vyšní Lhoty (Vyš) and Palkovické Hůrky (Pal), corresponds in a better way to the wave group of the interference character; the recorded particle velocity are lower in comparison to particle velocity detected at more distant sites of observations. In course of the qualitative evaluation of the wave pattern, there should be taken into account, at least, two important factors, which are affecting the wave pattern character, i.e. the seismogeological conditions of the environment site of measurement and the mechanism of the given seismic event origin. While the seismogeological conditions of seismic wave propagation through the medium between the focus and the site of observation, but also in the vicinity of the site could be considered from the viewpoint of their effects as nearly invariable, the seismic waves source character should be estimated as a variable parameter which could affect the record character.

In order to satisfactory identification of the wave group, the characteristics of which should be determined, there has been made a photomontage of seismic records with normalized particle velocity on the vertical component in the reduced time scale, as you can see in Fig. 4. In course of introduction of the reduced time scale, the seismic waves velocity of $v_r = 5.5\,\mathrm{km/s}$ was used in the calculation. From Fig. 4 follows that first interpreted onsets are arrayed into the line nearly parallel to the horizontal axis displaying epicentral distance. Therefore, there should be anticipated that P-waves velocity in the given region should be very close to the value of v_r.

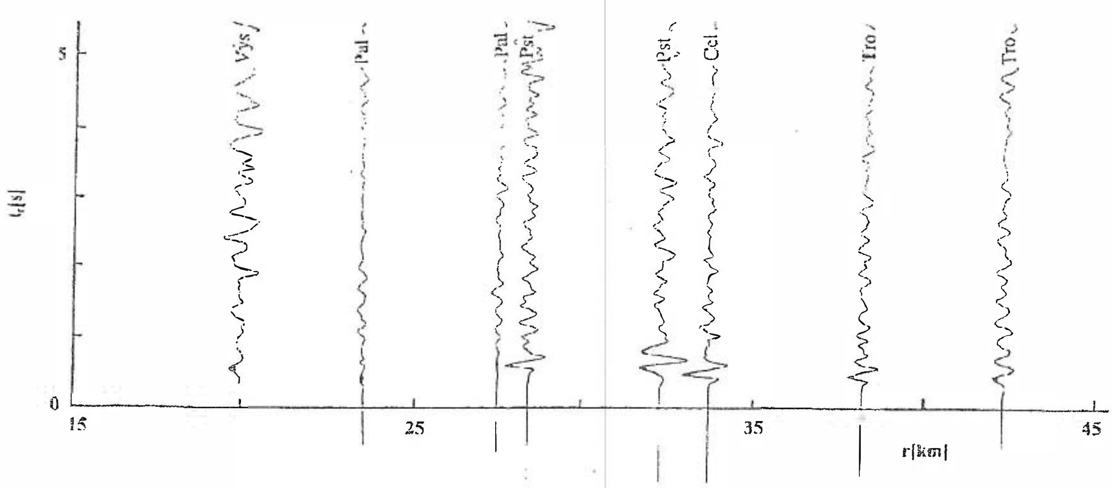

FIG. 4. Wave patterns recorded at different seismic stations displayed in the reduced time scale within the interval of epicentral distances $r = 20$ up to 45 km.

During the wave pattern analysis, there was evident that besides the good confidence of wave pattern character, sometimes the interchange of phases in case of seismic events with foci located in various parts of the Ostrava–Karviná Basin was observed probably due to different mechanism of the focus origin. Therefore, the measured–up particle velocity could cause some further inaccuracies in the seismic waves attenuation calculation.

3. Approaches Applied in the Estimation of the Seismic Waves Attenuation

During investigation of the seismic waves attenuation as a function of the epicentral distance, various approaches in calculating amplitude decrease could be applied. In case of an approximate solution, the power function $A(r) = A_0 r^{-m}$ has been often used, where m achieved values of 1.5 up to 3.1 as was reported by [Kuzmina et all. 1962; Butler, van Aswegen 1993]. On the other hand, it is generally known, that the process of the amplitudes attenuation is a very complicated one. In principle, there should be taken into account that this attenuation is defined essentially by two prime parameters, i.e. by absorption and by geometrical spreading of the wave front. The later mentioned factor characterizes the decrease of seismic wave particle velocity with regard to increasing distance (hypocentral and/or epicentral) due to geometrical spreading which does not depend on the frequency content of the seismic wave and could be commonly described by the function $f(r)$ defined by the type of the investigated seismic wave, medium properties and the source character. Except for this factor, which is independent on the frequency, absorption coefficient α (distance^{-1}) depends on the frequency and the complex phenomenon of the particle velocity decrease should be described by the exponential function having the following form:

$$A_2 = A_1 \cdot \mathrm{e}^{-\alpha(r_2 - r_1)}\,, \tag{1}$$

where A_1 and A_2 are the amplitudes observed in epicentral distances r_1 and r_2.

The approaches applied for simultaneous determination of n and α (distance^{-1}) are based on the approximation of measured–up data $A = f(r)$ using the exponential function $A = A_0 r^{-n} \mathrm{e}^{-\alpha r}$, similar approaches in solving of the particle velocity attenuation were described by [Riznitchenko 1956; Khalturin, Urusova (Mrs.) 1962; Dubinski, Wierzchowska (Mrs.) 1973]. This method relies upon the assumption that there are at disposal pairs of measurements, i.e. measurements of particle velocity at two different epicentral distances. This function could be written in the form of equations

$$\begin{aligned} A_1 &= A_0 \cdot r_1^{-n} \cdot \mathrm{e}^{-\alpha r_1} \\ A_2 &= A_0 \cdot r_2^{-n} \cdot \mathrm{e}^{-\alpha r_2} \end{aligned} \tag{2}$$

and their ratio could be expressed by equation

$$\frac{A_1}{A_2} = \left(\frac{r_1}{r_2}\right)^{-n} \cdot \mathrm{e}^{-\alpha(r_1 - r_2)} \tag{3}$$

which get after taking the logarithm the form

$$\frac{\log(A_1/A_2)}{\log(r_2} = n + \alpha \frac{0.43 \cdot (r_2 - r_1)}{\log(r_2/r_1)}\,. \tag{4}$$

In the case of greater number of measurements, there is possible to create from these pairs of values a graph of linear relation

$$\varphi = n + \alpha\psi\,, \tag{5}$$

where α is the slope of the regression straight line and n is the point of its intersection on the vertical axis φ. All both transformed co-ordinates are defined by following relations

$$\varphi = \frac{\log(A_1/A_2)}{\log(r_2/r_1)} \qquad \text{and} \qquad \psi = \frac{0.43\cdot(r_2 - r_1)}{\log(r_2/r_1)}\,. \tag{6}$$

4. Graphs of the Particle Velocity Attenuation

The results interpretation comes out from the solution of the problem of particle velocity attenuation as a function of the increasing epicentral distance described in the Chapter 3. The sets of analysed relations of experimental values are, for better conception, showed in relevant graphs along with equations of regression lines, which were calculated according to given data sets.

a) *particle velocity vs. epicentral distance*

In Fig. 5, the dependence of complex particle velocity prepared on basis of measurements on all five sites of measurements is depicted. Measurements on individual sites are mutually distinguished by relevant symbols. With regard to epicentral distances of sites from the foci of analysed seismic events, these measurements are for individual sites grouped approximately in the distance interval of 5 up to 6 km with respect to the fact that as a whole, the measurements (observations) cover the epicentral distances interval of 20 up to 45 km. The graph includes all measurements without any distinguishing of the wave pattern type and value of released seismic energy of individual events. This fact simultaneously affects in a specified manner also the scatter of values of particle velocity depicted in Fig. 5. In Fig. 6, there could be seen the differentiation of all measurements into two subgroups of experimental values of measured particle velocity. At sites Palkovické Hůrky (Pal) and Vyšní Lhoty (Vyš), which are located in shorter epicentral distances, the measured particle velocity are relatively smaller. In the contrary, at sites Pstruží (Pst), Čeladná (Čel) and Trojanovice (Tro) being situated in greater epicentral distances, the measured values are relatively greater. In all both cases, the data sets are featured by the decreasing trends with mutual ratio of particle velocity level at closer sites being approximately of one order lower. As was mentioned in the Chapter 2.3, the reduction of particle velocity at sites Palkovické Hůrky and Vyšní Lhoty could be caused by various factors, but some explicit explanation which of them is the dominant one, could be defined from the experimental document only in a very difficult way. In this case, only wave patterns of the same type were introduced into the processed data set and also events in the energy interval $1\cdot10^5$ up to $4\cdot10^5$ J were chosen. In all both subgroups given in Fig. 6, the trends of particle velocity decrease are described by power functions.

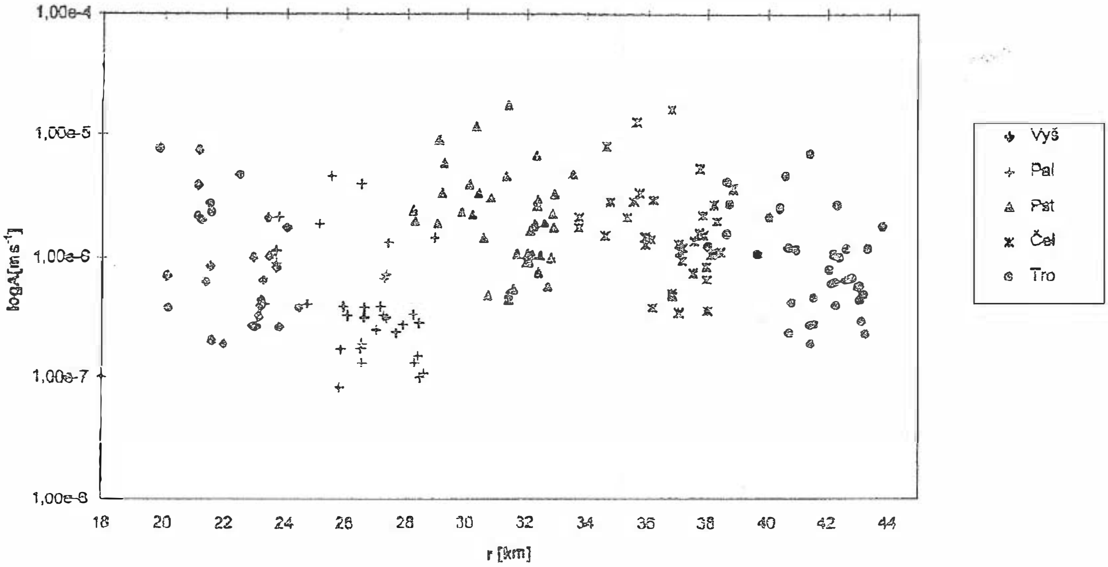

FIG. 5. Dependence of complex particle velocity vs. epicentral distance of individual seismic stations.

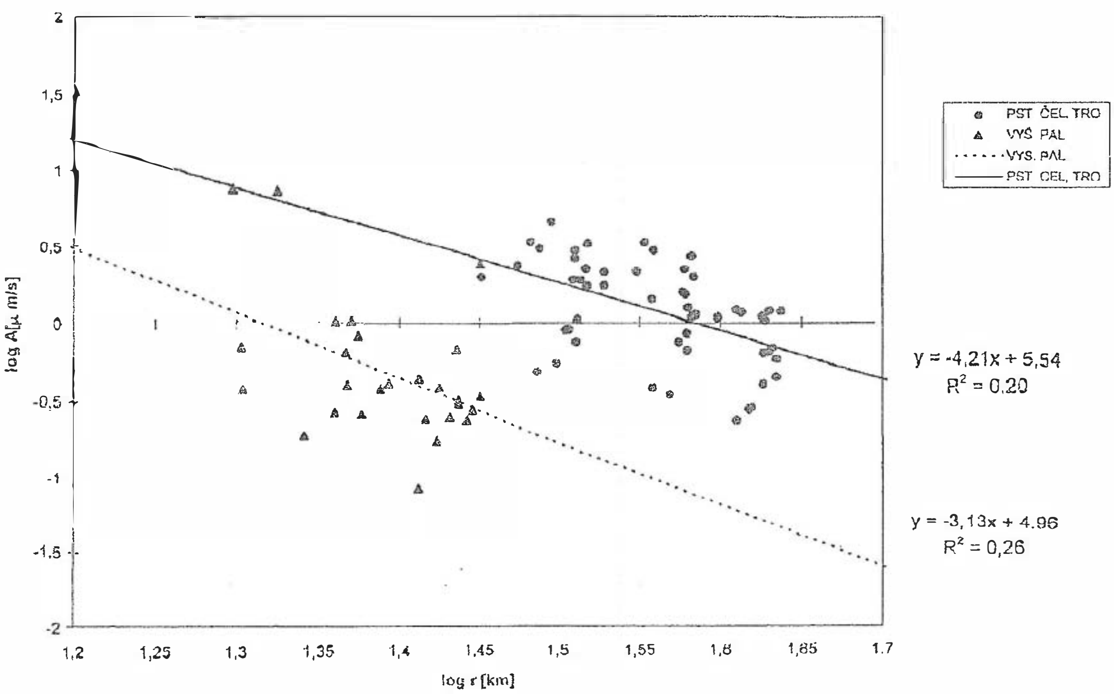

FIG. 6. Dependence of complex particle velocity vs. epicentral distance of two data subsets, including seismic events of the similar type of wave pattern and interval of energy 10^5 up to $4 \cdot 10^5$ J. The sequence of all equations corresponds to the legend.

b) graphs of dependence φ vs. ψ

In correspondence with the selected method of simultaneous determination of parameters n and α, there was solved the equation set of the type (4). Aimed at the solution, the measured values of particle velocity in given epicentral distances were transformed into the co-ordinate system φ and ψ, defined by equations (5). In the given case, as the reference site, the most distant one was chosen, i.e. Trojanovice (Tro) station. The solution results in the transformed co-ordinate system φ and ψ for individual sites are graphically depicted in Figs. 7 and 8 along with equations of relevant regression straight lines. While complex particle velocity of the same wave pattern type are considered in Fig. 7, in Fig. 8, the data sets of amplitudes derived only from the vertical component of the seismic records are analyzed.

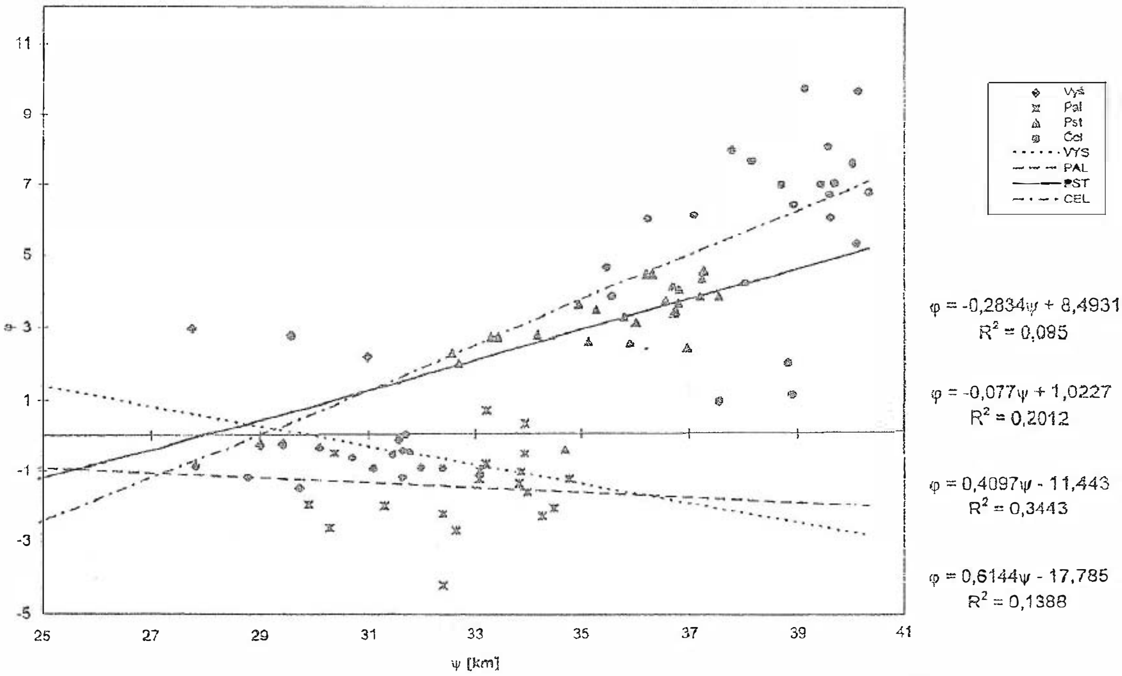

FIG. 7. Graph of values ψ and φ calculated for individual seismic stations using complex values of particle velocity determined for one type of wave pattern only. The sequence of all equations corresponds to the legend.

In all both figures mentioned above, the considerable scatter of observed values is obvious. This scatter is characterized by relatively small values of squares of correlation coefficients R^2. The diagrams are also characterized by different slopes of regression straight lines in the system of co-ordinates φ and ψ. The resulting values of coefficients of particle velocity attenuation and squares of correlation coefficients are given in Table 1.

5. CONCLUSIONS

Based on interpretation of seismograms, recorded at seismic stations of the

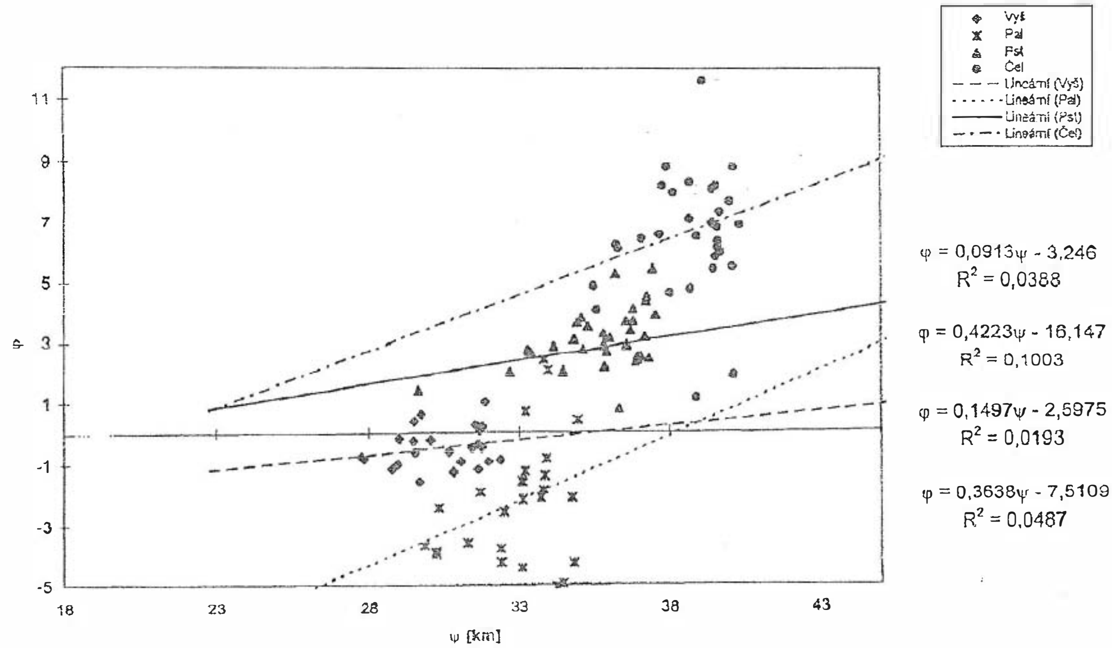

FIG. 8. Graph of values ψ and φ calculated for individual seismic stations using values of vertical component of seismic records. The sequence of all equations corresponds to the legend.

TABLE 1. The parameters α [km^{-1}] and n calculated using Eq. (4).

	complex amplitudes			Z – component amplitudes		
	α [km^{-1}]	n	R^2	α [km^{-1}]	n	R^2
VYŠ–TRO	−0.3	−8.5	0.1	0.1	3.2	0.04
PAL–TRO	−0.1	−1	0.2	0.4	16.1	0.1
PST–TRO	0.4	11.4	0.3	0.2	5.8	0.2
ČEL–TRO	0.6	17.8	0.1	0.4	7.5	0.05

Frenštát Network of the RSP, and also after some mathematical analysis of these data, partial conclusions which could be briefly characterized as follows, were derived:

- The set of particle velocity values measured at all five seismic stations with epicentral distance within the interval of 20 up to 45 km (see Fig. 5), could not be approximated by unique function. With regard to the investigated values, the original data set could be divided into two partial subsets, each of them being in bilogarithmic scale approximated by the power function having different exponent m. At sites Palkovické Hůrky (Pal) and Vyšní Lhoty (Vyš) which are located in smaller epicentral distances from seismic events foci, the relatively smaller particle velocity were detected and their decrease trend could be characterized by the equation of the form given in Fig. 6. Measurements at sites Pstruží

(Pst), Čeladná (Čel) and Trojanovice (Tro) create the second partial subset of data enabling approximation by means of a function given also in Fig. 6. In all both above mentioned cases, the m values are in relatively good agreement with the results described by [Kuzmina et all. 1962] ($m = 1.5-2.2$) and [Butler, van Aswegen 1993] ($m = 3.1$),

- the utilization of the method of simultaneous determination of the parameter n characterizing geometrical spreading of the wave front and attenuation coefficient α according to the Eq. (4) could not bring us any reasonable values of all both parameters due to large scatter of values. In Tab. 1 there are given the resulting values of coefficients which are quite different from results reported, e.g. by [Berzon et all. 1962] (n = 2–4, $\alpha = 1.10^{-4}$–$1.10^{-1}\,\mathrm{m}^{-1}$) and [Knotek 1991] ($\alpha = 0.006\,\mathrm{km}^{-1}$). The input data after transformation into the co-ordinate system φ and ψ, regression straight lines and the resulting equations for individual sites of observation are given in Figs. 7 and 8. From above mentioned facts follows that determination of parameters φ and ψ is in a substantial manner affected by small extent of epicentral distances, in which these measurements were made. Therefore, the method of simultaneous determination of parameters φ and ψ could not be used during processing of our measurements. There has been left as not solved the problem, if the primary data processing in the frequency domain could contribute by some more pronounced manner to the solution of the problem, because as had been presented in the Fig. 3, the selected wave patterns of individual seismic events are very similar ones and could be anticipated that also results of the spectral analysis should be also very similar, too,
- in accordance with our results of data interpretation, it seems, that for the energy classification of the mining induced seismic events recorded at seismic stations of the Frenštát Network only one of more distant stations could be applied as a reference one, e. g. site of observation Trojanovice.

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