ACTA MONTANA IRSM AS CR (1996)
Series A, No.9 (100), 107–120

APPROACHES TO THE ENERGY CLASSIFICATION OF MINING–INDUCED SEISMIC EVENTS IN THE OSTRAVA–KARVINÁ COAL BASIN

KAREL HOLUB and VLASTA VESELÁ

Institute of Geonics, Academy of Sciences of Czech Republic
Studentská 1768, 708 00 Ostrava–Poruba, Czech Republic

ABSTRACT. Continuous monitoring of induced seismic events in the Ostrava–Karviná mining district is one of the necessary assumptions in investigation of the time dependent development of seismic activity in this region. Basic information concerning individual seismic events included in the database contains origin time, focus coordinates and appropriate class of energies. The present paper represents a special examination of individual approaches to the energy classification of induced seismic events recorded by individual monitoring systems operating in this mining area, and the seismic station Ostrava-Krásné Pole (OKC), as well. The resultant values of seismic energy and/or magnitude determined on the basis of accepted approaches of the parameter evaluation are being mutual correlated and the respective relations are established.

KEYWORDS: seismic energy, statistics, induced seismicity, Ostrava–Karviná Coal Basin

1. INTRODUCTION

Information concerning rockbursts and induced seismic events of lower intensity in a region can be acquired by the installation and operation of a seismographic network. The purpose of this network is a continuous recording and evaluation of these seismic events. The evaluation among other facilities is aimed to determine the foci coordinates and energy of induced seismic events quantification.

The released seismic energy is one of the most important parameter which has been usually implemented in quantification considerations during natural as well as induced seismicity investigations. The energy itself, besides the characterizing of individual events, should serve as directivity displaying of energy radiation at the moment of the rockburst origin accompanied with rupture of rock mass. However, this dynamic parameter represents also the basic input data in the rockburst prediction studies using, e.g. Benioff's graphs, frequency–energy distributions and Gumbel's asymptotic functions.

With respect to different types of used instrumentation, different suitable approaches in energy quantification were applied. The results of computations were then mutually correlated to find out possible linking of individual empirical relationships valid for the chosen data sets from long-term seismological observations. In principle, for released seismic energy and/or magnitude scale two methods are convenient. The first method is based solely on measurement of maximum ground motion, i.e. on displacement amplitudes, or particle velocities and appropriate period of vibrations. This method was proposed by Richter (1935) for estimation of local earthquakes and it became a basis for widely applicable method in quantification of earthquakes [Kárník 1956; Gutenberg, Richter 1956; Tobyáš, Mittag 1991] and also for seismic induced events [Gibowicz 1963; Dubinski, Wierzchowska 1973]. The latter mentioned approach assumes the determination of signal duration instead of maximum amplitude measurements and was described, e.g. by [Bisztricsany 1958; Kupras, Paszta 1980; Kiratzi, Papazachos 1985]. In practice the exact determination of seismic duration is not relatively so easy to reach the same value of signal duration by individual authors. Nevertheless, this method is more convenient the when prevailing part of recorded events exceeds the dynamic range of recording instrumentation either due to the intensity of events, or due to the short epicentral distance. Taking into account the knowledge of basic parameters, i.e.seismic event magnitude, the signal duration and epicentral and/or hypocentral distance, empirical relationships may be established.

The examination of results of induced seismic events quantification by using both approaches mentioned above and applied in processing of seismic monitoring systems data in the Ostrava–Karviná Coal Basin is the subject of the present paper. The resulting relationships between parameters, i.e. released seismic energy and magnitude, defined according to observations of individual systems are also introduced.

2. Calculation of Energy and Magnitude

The first seismic station in the eastern part of the Ostrava–Karviná Coal Basin was erected at the surface of the Darkov Mine (formerly 1st May Mine) in 1977 [Trávníček, Holečko 1980]. The purpose of this station was to start continuous observation of seismic activity induced by underground mining in this region. In accordance with the entire conception of local seismographic network construction, further surface as well as underground seismic stations were later put into operation. One of the basic tasks of the local network was to produce objective data estimating the released seismic energy of all recorded events reliably.

For the approximate estimate, a modified empirical formula was used to determine the released energy in a focus at small distance. This expression was based on Gutenberg's formula

$$E = 2\pi^3 \rho v D^2 A^2 T^{-2} \tau \,, \tag{1}$$

where ρ is the density [kg.m^{-3}], v is seismic wave propagation velocity [km.s^{-1}], D is epicentral and/or hypocentral distance [km], A is displacement amplitude [m], T is the period of the appropriate seismic wave oscillation [s] and τ is the duration of the corresponding wave group [s]. For the routine practice in the operational center of the local network was introduced the following simplified formula

$$E = kA^2D^2T^{-2}\tau \quad [\mathrm{J}], \tag{2}$$

where the factor $k = 2\pi^3\rho v V^{-2}$ [kg.m^{-2}.s^{-1}], V is the magnification of the seismograph, A is maximum trace amplitude measured from analogue seismogram in mm. The parameters ρ, v, D, T and τ have the same meaning as in Eq. (1).

As the first step in the source–observation site distance, the velocity of the fictitious velocity "S − P" wave was used [Holub 1986]. With respect to the different sensitivities of used galvanometers, the factor k reached prevailingly to the value of 200 [Trávníček, Holečko 1979], only at one station the value $k = 70$ was defined, if in both cases the parameters of a group of S–waves were involved in energy quantification. This type of instrumentation was in operation from 1977 to 1993. Approximately since 1979 a surface station in Dukla Mine was in operation being equipped with a delay–triggered velocigraph incorporating also analogue recording. When estimating the released seismic energy, the method based on signal duration was adopted and this can be expressed by the form

$$\log E_s = 3.1 \cdot \log\tau + 0.98 + 0.32 \cdot D\,, \tag{3}$$

where τ is the signal duration [s], D is the epicentral distance [km].

After erection of the seismic station Ostrava–Krásné Pole (OKC), which is situated at the outskirts of Ostrava, approximately 25 km from the center of the mining area, similar approach in energy estimate of induced seismic events was applied as described by Staňková et al. (1989). The basic empirical equation (3) was specified by the values of numerical constants having the form

$$\log E_s = A \cdot \log\tau + 0.33 + 0.03 \cdot D\,, \tag{4}$$

where $A = f(D)$ was tabulated.

Due to the insufficient capabilities of this instrumentation from the view of necessity of automation process in introduction of data acquisition and processing, development of a new generation of simple digital instrumentation was launched [Bigos et al. 1988]. For evaluation of the released seismic energy a special approach was applied. This approach was based on the assumption that the value of energy calculated from digital data is proportional to the area limited by the function $v^2(t)$ within the interval $(0;\tau)$, where τ represents body wave duration at the respective seismic station [Kalenda et al. 1991]. The evaluation of seismic energy E_{0i} released in the focus was performed using the formula

$$E_{0i} = E_i(r/R)^{k_1} \quad [\mathrm{J}], \tag{5}$$

where E_{0i} is related to the arbitrary distance R, E_i is energy of a seismic signal evaluated at the i–th station, r corresponds to the hypocentral distance and k_1 is the coefficient of energy attenuation. During the trial seismic experiments the values of parameters $k_1 = -3.4$ and $R = 7621.7$ m were derived. Since 1985 a new instrumentation was gradually installed at the seismic stations where it was operating together with the previous analogue instrumentation. In order to be kept with the continuation of long time series of observation before using the new recording system, the output data for energy quantification of both systems were correlated and resultant relation was derived

$$E_{0i} = \left[E_i(r/R)^{-3.4}\right]^{1.0756} \quad [\mathrm{J}]\,. \tag{6}$$

In the operational center where the final data processing of the local network is performed the resultant value of energy E_0 is expressed as a modus of the set of energies E_{0i} evaluated at individual seismic stations and this so–called "accepted energy" is stored in a database and it is used for further processing in investigation of induced seismic activity in the Ostrava–Karviná Coal Basin. This approach in determining the quantity of released seismic energy was applied till December 1991.

Starting from January 1992, a new approach in energy evaluation was introduced which was based on the following formula

$$\log E = A + B + C \cdot \log r \quad [\mathrm{J}]\,, \tag{7}$$

where: A and C are numerical constants, $B = A_i^2 \cdot S$, i.e. particle velocity $[\mathrm{m.s^{-1}}]\cdot$ sensitivity of the appropriate seismic channel, r is hypocentral distance [m].

The sensitivity S was being determined for each seismic channel within the microarray of the appropriate mine . When final data processing in the operational center in the Czechoslovak Army Mine is performed, then the numerical constants A, B and C in Eq. (7) are represented for individual mines by values the quantities of which are taking into account the values of parameters for individual seismic channel.

Besides the system of local seismographic network there has been since 1988 also in operation a regional seismic polygon (SP) consisting previously of five, and later, of ten stations [Kaláb 1991; Knotek 1991]. One of the principal tasks which had to be solved for reliable operation and ensuring results of high accuracy, was the investigation of a suitable model of medium which usually influences the focus determination and energetic quantification of individual seismic events as well. During the trial experiments there was determined the resultant model consisting of five layers upon the half–space. Applying the knowledge of velocity model enabled us to derive basic formulae for energy estimate as well as for application of magnitude scale. At present, the quantification of energy is being carried out by using the formula:

$$E = k \cdot A^2 \cdot d \cdot e^{2\alpha(d-1)} \quad [\mathrm{J}]\,, \tag{8}$$

where parameter $k = 1.633 \cdot 10^7$ [kg.m.s], ρ is density $[\mathrm{kg.m^{-3}}]$, v_P contained in parameter k corresponds to propagation velocity of P–waves $[\mathrm{km.s^{-1}}]$, A represents total vector of particle velocity $[\mathrm{m.s^{-1}}]$, d is epicentral distance [km], α is attenuation coefficient $[\mathrm{km^{-1}}]$. When comparing energy estimation by applying Eqs. (2), (6) in the system of local network and Eq. (7) for the seismic polygon, a relatively good agreement of calculated values was found there.

In the course of obtaining reliable results in energy quantification by another way, a formula for magnitude computation was derived. The magnitude is now calculated according to following relation

$$M = \log A_{\max} + \log d + \alpha \cdot (d - 1) \log e + K\,, \tag{9}$$

where parameters $A_{\max}$ and d correspond to parameters applied in Eq. (8), α is the attenuation coefficient ($\alpha = 0.04\,\mathrm{km}^{-1}$), K represents a fixation constant ($K = 5.202$).

3. INPUT DATA AND THEIR PROCESSING

Long-term seismological observations in the Ostrava-Karviná coal mine region have been performed by using local seismographic network and seismic polygon (SP) having the character of a regional network surrounding the whole region under investigation. A part of these monitoring systems is also the seismic station Ostrava-Krásné Pole (OKC) which was mentioned above. The layout of the observation sites in the region of coal mines and their adjacent area is given in Fig. 1. The instrumentation of individual monitoring systems and seismic station OKC as well as the methods of data processing were described, e.g. in Holub et al. (1993), Knotek (1991) and Staňková et al. (1989).

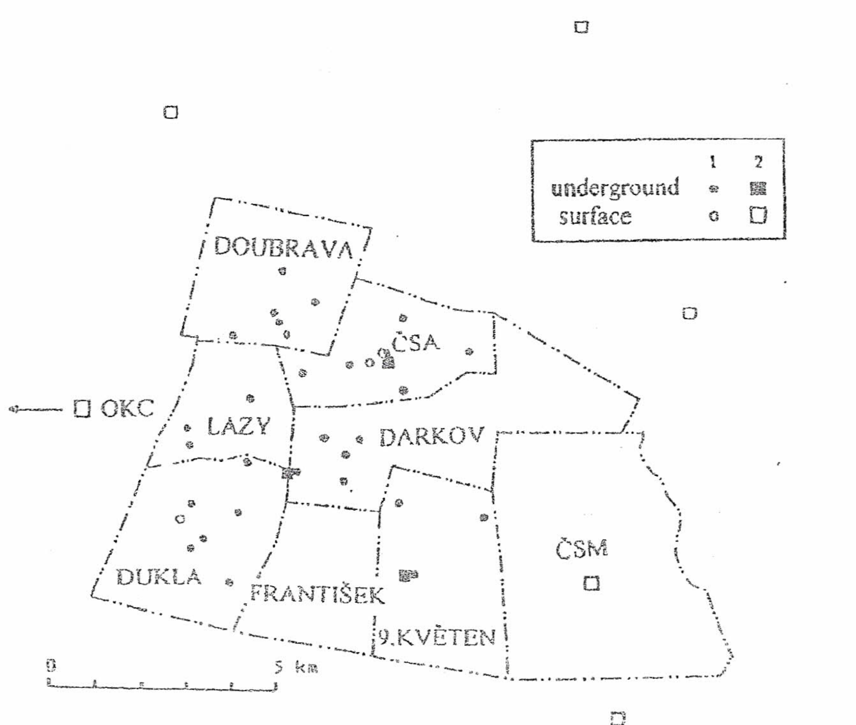

FIG. 1. Distribution of seismic monitoring systems in the Ostrava-Karviná Coal Basin: 1 – local seismographic network, 2 – seismic polygon (SP), OKC seismic station Ostrava-Krásné Pole.

For the determination of mutual correlations between individual data sets of random quantities represented either by the quantity of released seismic energy given in Joules or by local magnitude, the regression analysis is usually applied. These data have been contained in databases of individual monitoring systems and also in bulletins of local seismic events recorded at the OKC seismic station and they could be characterized as follows:

a) database of local seismographic network includes among others, the parameter of released seismic energy E [J] calculated till 1991 acc. to the Eq. (6), and since 1992 acc. to the Eq. (7),
b) database of seismic polygon with output parameters of released seismic energy E [J] defined by the Eq. (8) and/or local magnitude acc. to the Eq. (9),
c) database of local seismic events at the OKC seismic station, where released seismic energy is computed acc. to the Eq. (4).

The most frequent estimate of mutual correlation between two variables X and Y is so-called the coefficient of correlation. For correct application of this estimate, two basic assumptions are valid:

- regression line is a straight line
- basic data set is of 2–D standard distribution.

This 2–D standard distribution is characterized by the fact that for each value of the first random quantity the second random quantity has also random distribution with constant dispersion and vice versa. In accordance with Microsoft Excel application, basic formulae for calculation of the correlation coefficient R_{XY} are introduced which are described by the following relations

$$R_{XY} = \frac{\mathrm{cov}\,(X,Y)}{\sigma_X \cdot \sigma_Y}\,, \tag{10}$$

where σ_X and σ_Y are standard deviations of quantities X and Y, respectively. Covariance (X,Y) is defined as

$$\mathrm{cov}\,(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(X_i - \mu_X)(Y_i - \mu_Y)\,, \tag{11}$$

where μ_X and μ_Y represent mean values of random quantities X and Y, respectively. In the process of computation of R_{XY} dispersion variance (σ_X^2 and σ_Y^2) of both random quantities are determined using the expressions

$$\sigma_X^2 = \frac{1}{n}\sum_{i=1}^{n}(X_i - \mu_X)^2 \tag{12}$$

$$\sigma_Y^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \mu_Y)^2\,. \tag{13}$$

For mutual comparison of couples of chosen quantities, the linear regression analysis was applied which enables to approximate set of observations by the least squares method. The results of this approximation are described by numerical constants a and b in equation of a straight line the form of which is $y = a + bx$, all values defined for the confidence level of 95 %.

When determining mutual correlation between individual data sets, the following time series were analyzed:

- January 1991
- January – June 1991
- January – December 1991
- January – December 1992
- January – December 1993.

These time series from the viewpoint of energetic classification were limited by "accepted" value of released energy of 10^3 J computed on the basis of the local network data ($E_{\check{C}SA}$) and/or seismic polygon (E_{SP}). Using this limited value, the following correlations were investigated:

$$E_{OKC} \text{ vers. } E_{\check{C}SA} \qquad E_{OKC} \text{ vers. } E_{SP}$$
$$E_{\check{C}SA} \text{ vers. } E_{SP} \qquad E_{\check{C}SA} \text{ vers. } M_{SP}.$$

Special attention was paid to the detailed analysis of data sets $E_{\check{C}SA}$ vers. E_{SP} and $E_{\check{C}SA}$ vers. M_{SP} which comprised all available data from January 1991 regardless the low energetic limit. These calculations were aimed at finding out the influence of the a priori choice of the lower limit on the resulting equations of regression straight lines. For better and more objective display of calculated and expected quantities, there were prepared the histograms of the appropriate residua.

4. RESULTS AND CONCLUSIONS

The standard least squares fit of the input data (energy quantification and time series) of individual monitoring systems described above, was performed using program modules of the Microsoft Excel. The importance of the applied statistical methods lies in their ability to estimate mutual relationships among individual energy quantifying parameters. This software permits different statistical approaches and resulting graphical displays suitable for objective presentation. The basic theoretical formulae used in present study were described in Chapt.3, the graphical and numerical outputs will be consequently discussed hereinafter.

From Figs. 2 – 6 one can see the graphs of the mutual relationships between the individual pairs of investigated data sets approximated by linear regression using the least squares method. These interrelations are characterized by the equations of corresponding straight lines and correlation coefficients R^2. The accuracy of linear dependence parameters is determined by their average values (μ_a, μ_b and μ_y), i.e. the numerical constant a, the slope of the approximation straight line b and the dependent variable y; above all, the number of observations N, is also given. The scatter of observed and expected values residua for the dependencies investigated during the period 1991 – 1993 is presented by the appropriate histograms.

Based on the presented results of the regression analysis it can be concluded that for our purposes the correlation coefficient R^2 offers the most complete information on the mutual dependencies among individual energetic parameters. By

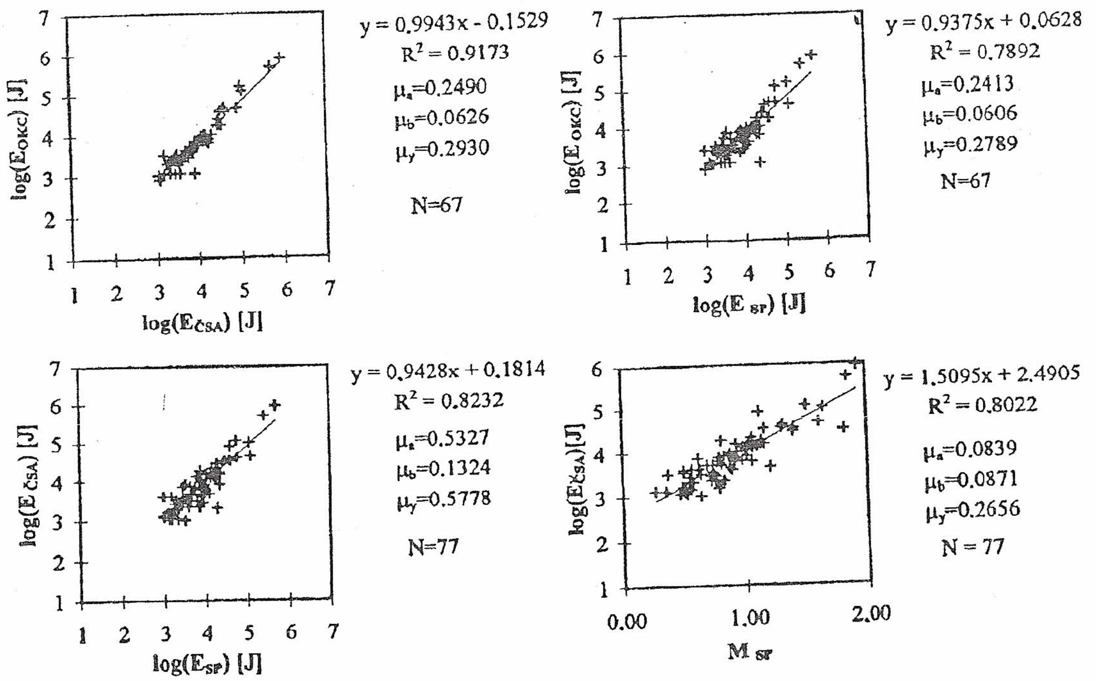

FIG. 2. Regression analysis of the energetic parameters defined during January 1991; lower threshold corresponds to the value of $E_{ČSA} \geq 10^3$ J.

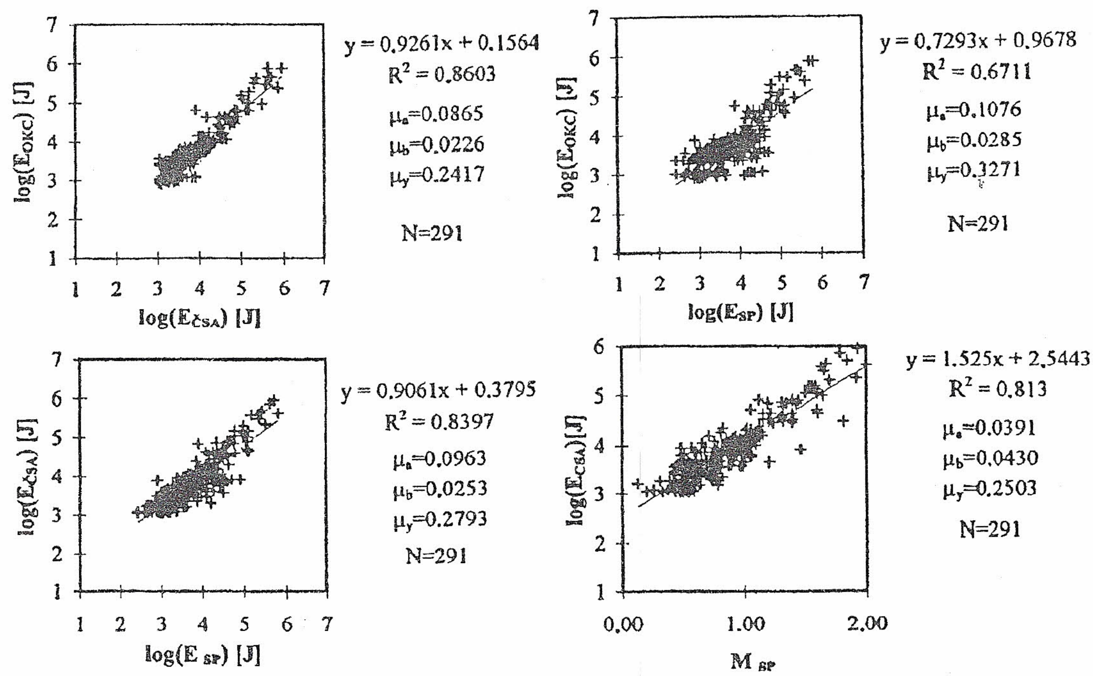

FIG. 3. Regression analysis of the energetic parameters defined from January to June 1991; lower threshold corresponds to the value of $E_{ČSA} \geq 10^3$ J.

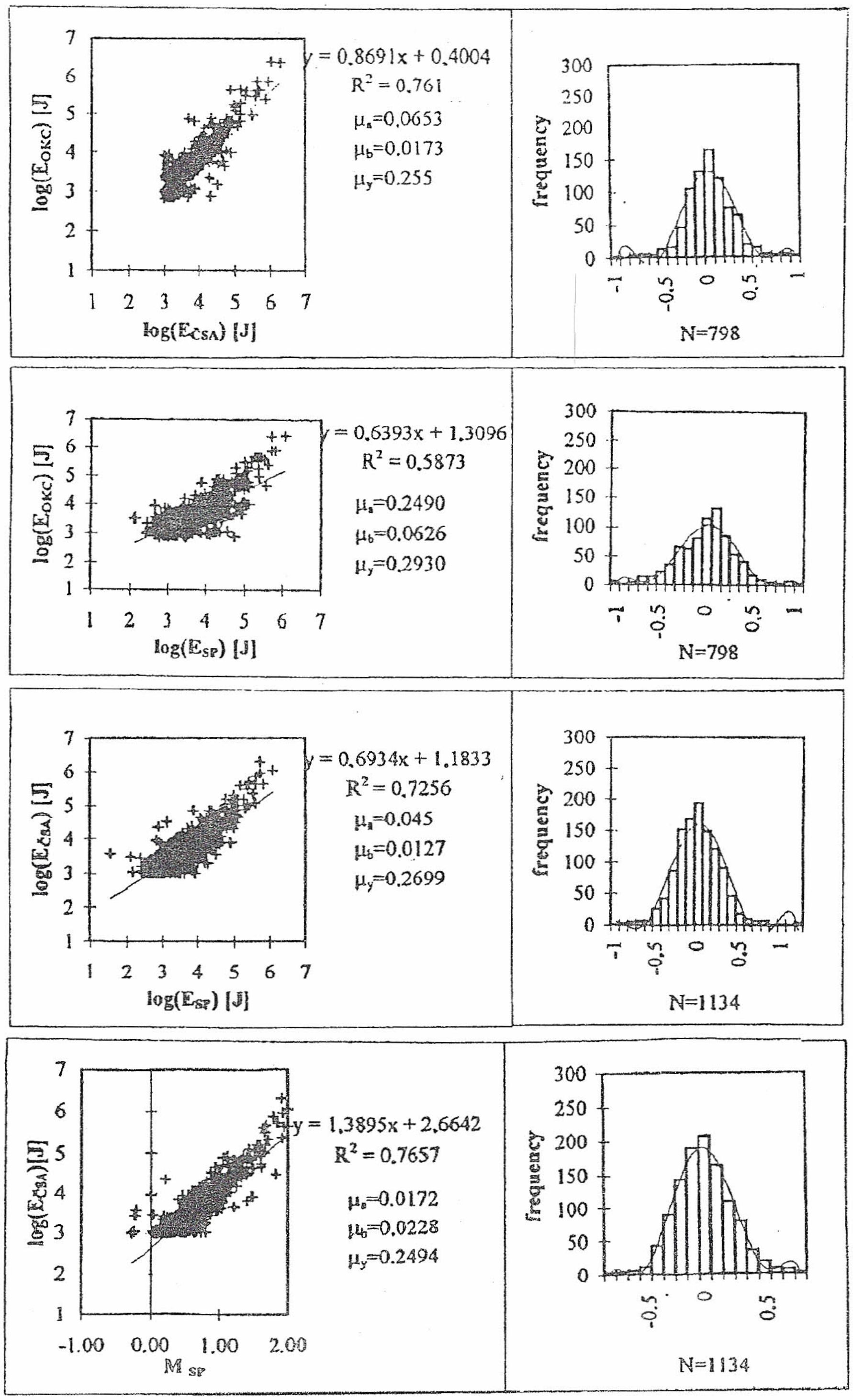

FIG. 4. Regression analysis of the energetic parameters and appropriate residua histograms defined during 1991; lower threshold corresponds to the value of $E_{\check{C}SA} \geq 10^3$ J.

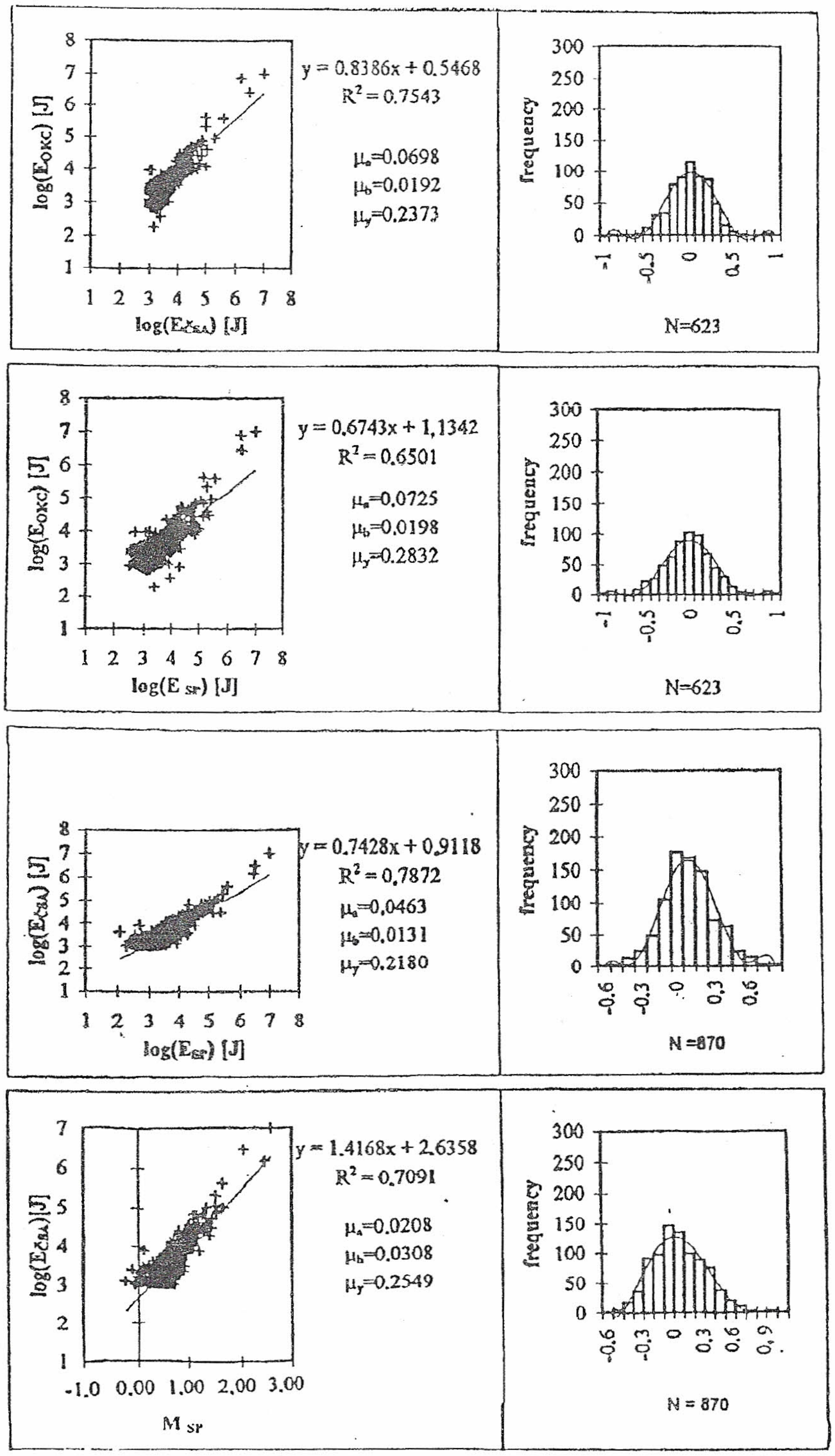

FIG. 5. Regression analysis of the energetic parameters and appropriate residua histograms defined during 1992; lower threshold corresponds to the value of $E_{\text{ČSA}} \geq 10^3$ J.

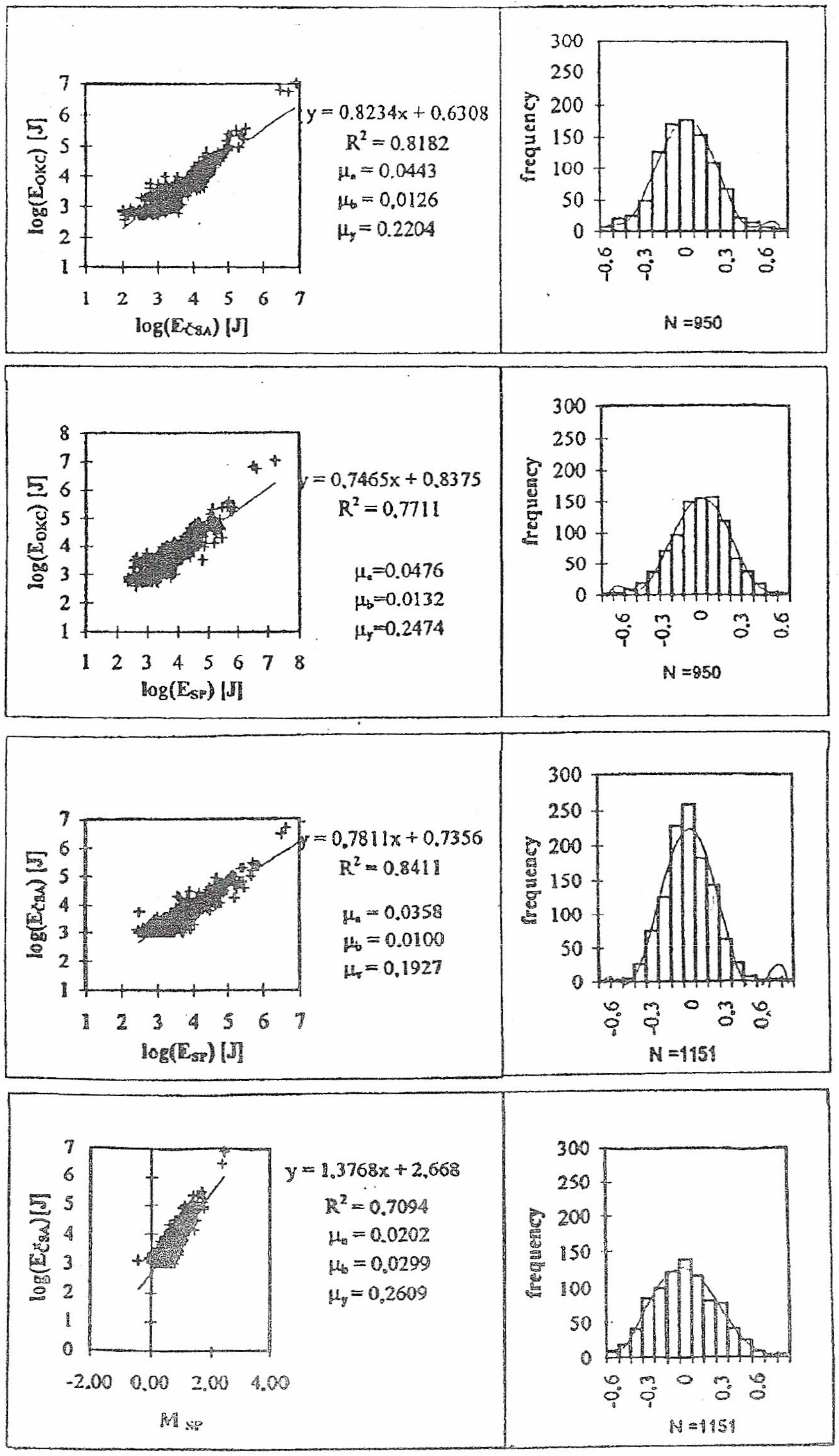

FIG. 6. Regression analysis of the energetic parameters and appropriate residua histograms defined during 1993; lower threshold corresponds to the value of $E_{\check{C}SA} \geq 10^3$ J.

TABLE 1. Average values of linear regression coefficients a and b within the time period 1991 – 1993.

E_{OKC} vers. $E_{\mathrm{ČSA}}$	$\varnothing a = 0.62 \pm 0.21$
	$\varnothing b = 0.84 \pm 0.03$
E_{OKC} vers. E_{SP}	$\varnothing a = 1.09 \pm 0.22$
	$\varnothing b = 0.69 \pm 0.05$
$E_{\mathrm{ČSA}}$ vers. E_{SP}	$\varnothing a = 0.94 \pm 0.24$
	$\varnothing b = 0.74 \pm 0.04$
$E_{\mathrm{ČSA}}$ vers. M_{SP}	$\varnothing a = 2.65 \pm 0.01$
	$\varnothing b = 1.39 \pm 0.02$

discussing the appropriate relationships, all the parameters and their mean values characterizing the scattering in the data sets, have similar values for different time series investigated. When computing the average values of parameters a and b, calculated according to observations in 1991 – 1993, one can find out that the value b displays a smaller scatter than the parameter a. Only for the dependence $E_{\mathrm{ČSA}}$ vers. M_{SP} the scatter of the parameter a is characterized by a minimum value (see Table 1). Nevertheless, it can be stated that both parameters in linear regression (a and b) during the time of observation the duration of which is approximately a year at minimum, are relatively stable. The present findings of approximation straight line equation (13), for example

$$\log E_{\mathrm{ČSA}} = 1.39 \cdot M_{\mathrm{SP}} + 2.65 \tag{13}$$

agrees very well with previous results reported by other authors, e.g.

Dubinski & Wierzchowska (1973)	$\log E = 1.9 \cdot M_L + 1.8$	(14)
Syrek & Wcislo (1981)	$\log E = 1.9 \cdot M + 1.65$	(15)
Klíma et al. (1991)	$\log E = 2.825 \cdot M_{\mathrm{SP}} + 1.19$	(16)
Konečný (1994)	$\log E_{\mathrm{SP}} = 1.66 \cdot M_{\mathrm{SP}} + 2.29\,.$	(17)

Taking into account the data from January 1991 whose energetic span was lower than the released energy of 10^3 J, a linear equation (17)

$$\log E_{\mathrm{ČSA}} = 1.93 \cdot M_{\mathrm{SP}} + 2.05 \tag{18}$$

was derived which is similar to the Eqs. (14) and (15).

As it was also proposed by Klíma et al. (1989) and Staňková et al. (1987), similar approach could be performed in determining the interrelations between seismic energy and local magnitude scale of seismic events using the data of local seismographic network, seismic stations Průhonice (PRU), Kašperské Hory (KHC) and seismic station OKC, as well.

On the other hand, it was ascertained from the present analysis that the lower values of energetic parameters are taken into account, the higher scatter of data in mutual relationships can be expected. The evidence of this statement is seen from Figs. 2 – 6, where the lower threshold of released seismic energy of 10^3 J is introduced. It is obvious that the greater scatter of calculated data from weak seismic events is caused by a relatively greater inaccuracies in primary data determination at individual seismic stations, and consequently, within the appropriate monitoring systems and at the seismic station OKC, as well.

Finally, the histograms representing residua of the differences between calculated and expected values of energetic parameters correspond to the normal distribution, the smoothing curves of these histograms display more or less expressive maximum.

In summary, the method of linear regression applied in present study seems to be a suitable one for the estimating mutual dependeces of energetic parameters defined on the basis of different computation approaches. Our preliminary results confirmed further continuation in detailed analysis leading to determination of generally valid relations, namely in their linking to the magnitude scale of the seismic stations Průhonice (PRU) and Kašperské Hory (KHC), as well.

Acknowledgement: The research presented in this paper is being performed with the financial support of the Grant Agency of the Czech Republic (Grant No.105/95/0474). The authors are thankful to the staffs from the Operational Center in the Czechoslovak Army Mine in Karviná, the Seismic Polygon at Paskov and seismic station Ostrava–Krásné Pole (OKC) for their assistance in data completion.

REFERENCES

Bigos R., Holub K., Štverka V. (1988), *New generation of measuring instruments for the network of mine seismologic stations in the Ostrava–Karviná Coal Field*, Publs. Inst. Geophys. Pol. Acad. Sc., **M–10** (213), 393–401.

Bisztricsány E. (1959), *On the determination of earthquake magnitudes*, Ann. Univ. Sc. Budap., Section geol., Budapest, p. 39–51.

Dubinski J., Wierzchowska Z. (1973), *Metody obliczen energii wstrzasow gorotworu na Gornym Slasku*, Prace GIG Katowice, komunikat nr 591, pp. 23.

Gibowicz S.J. (1963), *Magnitude and energy of subterrane shocks in Upper Silesia*, Studia geoph. et geod. **7**, 1–19.

Gutenberg B., Richter C.F. (1956), *Earthquake magnitude, intensity, energy and acceleration*, Bull. Seism. Soc. Am. **46**, 105.

Holub K. (1986), *Preliminary results of determination of the S–P wave velocity in Ostrava–Karviná Coal Basin*, Acta Montana **71**, 129–133. (in Czech)

Holub K., Slavík J., Kalenda P. (1993), *Current state of seismographic network in Ostrava–Karviná Coal District*, Uhlí–Rudy **41**, no. 9, 286–293. (in Czech)

Kaláb Z. (1991), *Regional diagnostic polygon in the Ostrava–Karviná Coal Field*, Publs. Inst. Geophys. Pol. Acad. Sc., **M–15** (235), 189–196.

Kalenda P., Slavík J., Holub K., Sglunda R. (1991), *Determination of energy of seismic events from records of apparatus DSLA*, Publs. Inst. Geophys. Pol. Acad. Sc., **M–15** (235), 183–187.

Kárník V. (1956), *Magnitudenbestimmung europaischer Nahbeben*, Travaux Inst. Géophys. Tché-cosl. Acad. Sci. **47**, 399.

Kiratzi A.A., Papazachos B.C. (1985), *Local Richter magnitude and total signal duration in Greece*, Annales Geophysicae **3**, no. 4, 531–538.

Klíma K., Pros Z., Vaněk J., Vajter Z., Kozák J. (1989), *Magnitudová klasifikace seismických jevů na základě pozorování důlních stanic*, Proc. 6th Czechoslovak national workshop on seismic data acquisition and computer processing, Geophys. Inst. SAS, Bratislava, p. 63–77.

Klíma K., Janatková Z., Ruprechtová L., Mořkovská E. (1991), *Energetická klasifikace indukovaných otřesů z OKR.*, Proc. 7th Czechoslovak national workshop on seismic data acquisition and computer processing, Geophys. Inst. SAS, Bratislava, p. 74–78.

Knotek S. (1991), *Realizace RDP - Optimalizace provozu RDP, dílčí rozšíření interpretace seismických dat na počítačích PC-AT-386, vč. zavedení archivace dat*, Etapová zpráva OKD – BVZ a.s. Ostrava.

Konečný P. (1994), *Mining induced seismicity in the Czech part of Upper Silesian Coal Basin depending on mining conditions*, In: Geomechanics 93, Z.Rakowski (ed.), A.A.Balkema, Rotterdam/Brookfield, p. 63–68.

Kupras M., Paszta E. (1980), *Determination of the mining tremors energy in the "Szombierki" coal mine from duration of their record*, Publs. Inst. Geophys. Pol. Acad. Sc., M–**3** (134), 67–72.

Microsoft Excel (1993), *Uživatelská příručka, Verze 5.0*, Microsoft Corporation.

Richter C.F. (1935), *An instrumental earthquake magnitude scale*, Bull. Seism. Soc. Am. **25**, 1–32.

Staňková E., Holečko J., Arlethová H. (1987), *Relation between the magnitude and energy of seismic events from Ostrava–Karviná Coal District (OKR) for Ostrava–Krásné Pole (OKP) station*, Proc. 5th Czechoslovak national workshop on seismic data acquisition and computer processing, Geophys. Inst. SAS, Bratislava, p. 27–32.

Staňková E., Arlethová H., Holečko J., Trávníček L. (1989), *Úloha a postavení seizmické stanice Báňské měřické základny Ostrava–Krásné Pole při sledování seizmické aktivity*, Uhlí **37**, no. 4, SNTL, Praha, 149–155.

Syrek B., Wcislo A. (1981), *Przydatnosc magnitudy dla okreslenia parametrow wstrzasow rejestrowanych w kopalnianych stacjach sejsmicznych Gornego Slaska*, Prz. Gor. **6**.

Tobyáš V., Mittag R. (1991), *Local magnitude, surface wave magnitude and seismic energy*, Studia geoph. et geod. **35**, 354–357.

Trávníček L., Holečko J. (1979), *Seismologická registrace horských otřesů v OKR*, Zpráva OKR – DPB Paskov.

Trávníček L., Holečko J. (1980), *First results of the seismic recording of rock bursts in the Ostrava–Karviná Coal District*, Publ. Inst. Geophys. Pol. Acad. Sc., M–**3** (134), 73–83. (in Czech)