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SEISMOLOGY MONITORING

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Abstract. Methods of induced seismic events registration in the deep coal mine Mayrau (near Kladno town 20 km westwards from Prague) by means of a local seismic network and consecutive data processing are described. This network yields some thousands seismograms per year. Some results of data processing are submitted in this paper.

Keywords: seismic network, induced events, location, magnitude.

1. Introduction

The main purpose of the Mayrau seismic network is monitoring of local seismic events. First of all there occur rockbursts induced by excavation of coal, of course, but also seismic waves excited by mine blasting are recorded. Explosions in near carriers and local or regional earthquakes are detected, too. The design of seismic network and the interpretation methods are chosen in such a manner, that characteristics and parameters of induced seismic events may be obtained and further studied. This research shall solve the following tasks:

- velocity model determination
- location of foci
- determination of seismic energy
- continuous monitoring both space and time distribution of seismic activity.

Obtained results are saved in a central database together with data of another research methods used in this mine (see another chapters of this issue).

2. Morphology of the Seismic Network

The network has been built gradually, but at present it may be considered as finished. It consists from 7 seismic stations. Three of them are underground, the remaining four are at the surface. Underground seismic stations occupies two vertical levels, while the vertical coordinates of all surface stations are practically equal. The characteristic inter–stations distances are about 200 m. Two underground stations at the 7th floor are about 400 m under the surface and one underground station is located at the 10th floor in the depth about 500 m. It is clear, that our network has quite small dimensions. Exact coordinates of all seismic stations are given in

Tab. 1. Both geographic coordinates λ, ϕ and Cartesian orthogonal coordinates X, Y (national system JTSK) are given there. The X coordinate goes form North to South and the Y coordinate from East to West.

TABLE 1

Station code	latitude ϕ	longitude λ	X	Y	altitude Z
DES	50.167	14.083	765663	1031013	−167
SED	50.166	14.084	765548	1031095	−49
KAM	50.165	14.084	765582	1031162	−48
KRY	50.165	14.083	765675	1031139	352
GAR	50.166	14.086	765438	1031126	348
BYT	50.168	14.084	765578	1030927	358
CEN	50.166	14.084	765539	1031079	350

The geographic coordinates are less convenient because of small characteristic distances of seismographs.

3. Instrumental Equipment

Standard seismometers of SM–3 type are solely used at all seismic stations. They are velocigraphs in fact and have following parameters:

sensitivity	17 mV.s/mm
dumping factor	0.7
self period	1.5 s

All surface stations record the NS, EW and Z spatial components of ground motion but all underground ones record the Z component only.

Each seismometer is supplied by a low–pass amplifier in order to suppress the noise induced on cable traces. The characteristics are Bessel's type of 6th order with the cut–off frequency 50 Hz and the gain 100. The preamplified analog signals are lead to the central recording site via mine telephone cables.

The final recording of seismic signals is enabled by a PC 386 completed with two 12 bit/16 channels ADC. The analog signals coming from mine cables are connected through flash fuses and anti–alias Bessel's filters with appropriate inputs of both ADCs. Correct sampling and all other time services are supported by an additional PC card containing DCF 77 receiver. In the case of fading, time code is substituted by internal PC clock. Anti–alias filter enables splitting of selected input analog signals into two corresponding channels with two different gains. Registration software automatically selects only that channel, in which the data are well sampled due to the 12 bit resolution. In such a way, the effective dynamic range is broadened nearly to 16 bits using only 12 bit conversion.

The recording software is written in C++. It can be used in a resident mode, because all substantial functions are activated by HW interrupts. Beside the data recording itself it is also possible to run suitable application in the foreground. The recording module follows continuously the state of all input signals and realizes necessary operations:

- reconstruction of channels with splitted dynamics
- removing offset by means of high–pass filtering
- STA/LTA refresh
- trigger test at selected channels and testing the coincidence
- generation of data blocks with headers in cyclic buffers in memory
- writing of triggered data with pre– and post–time on HD

For the purposes of digital filtering, the low–pass recursive filters are used [Kanasewich, 1975]. If the input data are expressed by a vector x_i and their transform are denoted by y_i, $i = \cdots -2, -1, 0, 1, 2, \ldots$ the following relation holds

$$y_i = y_{i-1}a + x_i(1-a) \tag{1}$$

where a is a weighting factor. It may be shown, that the simple one–point convolution (1) may be expressed in the frequency domain as (ω is angular frequency, $\triangle t$ sampling period)

$$Y(\omega) = K(\omega).X(\omega) \tag{2}$$

$K(\omega)$ is the frequency response of the filter (1). DC component equals 1 and its high–frequency asymptotic is ω^{-2}. The corner frequency f_c can be determined as follows:

$$f_c = (1-a)/(2\pi\triangle t) \tag{3}$$

The band pass of the filter can be easily tuned by a suitable choice of the weighting factor a. Under given circumstances, the value STA is generated as an output signal of a low pass filter (1) with a corner frequency $f_{\mathrm{STA}} = 0.25\,\mathrm{Hz}$. The value LTA is generated by another filter with $f_{\mathrm{LTA}} = 1/200\,\mathrm{Hz}$. The offsets of all channels are refreshed by filters with the corner frequency equal also to $f_{\mathrm{OFF}} = 1/200\,\mathrm{Hz}$. The critical value of the short–time to long–time average has the optimum value STA/LTA = 4. The data are recorded in the case of coincident triggering at least 4 seismic stations of the network.

The used computer PC 386/33 MHz enables synchronous sampling of 18 analog channels (splitted signals included) with frequency 250 Hz. The system is exploited by this recording function to about 65 %. In the periods of writing to disk, the data flow is so high that this system cannot be used as continuous recorder. It is possible to run programs not too exhaustive to conventional memory in the foreground (up to now, utilizing of programs in protected mode or running programs under Windows are not possible).

4. METHODS OF DATA PROCESSING

Data structures are in accordance with the internal norm of our institute. Binary seismograms are saved in directories whose nodes express time information of the event origin. Disk structure for saving data contains independent directories for every month of the year and on a deeper level for every calendar day. Data itself representing waveforms are multiplexed in blocks 1 kB in length containing small header holding status information and the time. A report about measured and evaluated data is kept in the database "Paradox". This database involves corresponding files containing:

- list of recorded events
- list of phase onsets and their amplitudes
- list of located events
- comments

The work with data and with the database is realized above all by means of an interactive program Seisbase [Fischer, 1992]. This program enables a preliminary view of seismograms and their selection. Further step is usually manual picking of P wave onsets (alternatively also S waves onsets). Events with defined onsets are located. Determination of local magnitude follows the location. The catalog of located events may be visualized like maps of foci, magnitude–frequency relations and bulletins may be printed, too.

The location is realized by an algorithm which minimizes the differences between calculated and measured onsets of P and—or S phases [Geiger, 1912; Klein, 1978; Lee and Lahr, 1972; Lienert et.al.1986]. The minimalisation uses the simplex method [Tarantola, 1987; Menke, 1989]. Up to now, theoretical onsets (the direct problem) are calculated for a homogeneous velocity model or for the 1D half-space with vertical gradient. Magnitude is determined automatically from the maximum amplitude $A_{\max}$ detected on the vertical component of ground motion velocity. The used relation is

$$M_L = \log(A_{\max}.r/100/2\pi) \tag{4}$$

where r is the hypocentral distance in km. The factor 2π follows from using velocity records while magnitude formula supposes displacement to be measured. Resulting magnitude is averaged for all available stations.

5. Practical Examples

Epicentres of induced seismic events which occurred in the time period June – December 1993 are shown in Fig. 1. Corresponding vertical cross–section is in Fig. 2. On the basis of obtained results, the following statements can be deduced:

- foci do occur mainly within a near top wall of the coal seam in the layers of total thickness about 80 m. The overburden of the seam is generally formed alternatively by sandstone, conglomerate or mudstone in layers with various thicknesses. According to the results of geological investigation, seismic events occur in nearly pure sandstone horizons with negligible contribution of clayey elements. For more details, see the article of Brož and Živor, this issue.
- positions of foci appear no evident correlation with tectonic faults passing through the investigated safety pillar. On the other hand, seismic source zones correlate with sites of instantaneous mining.

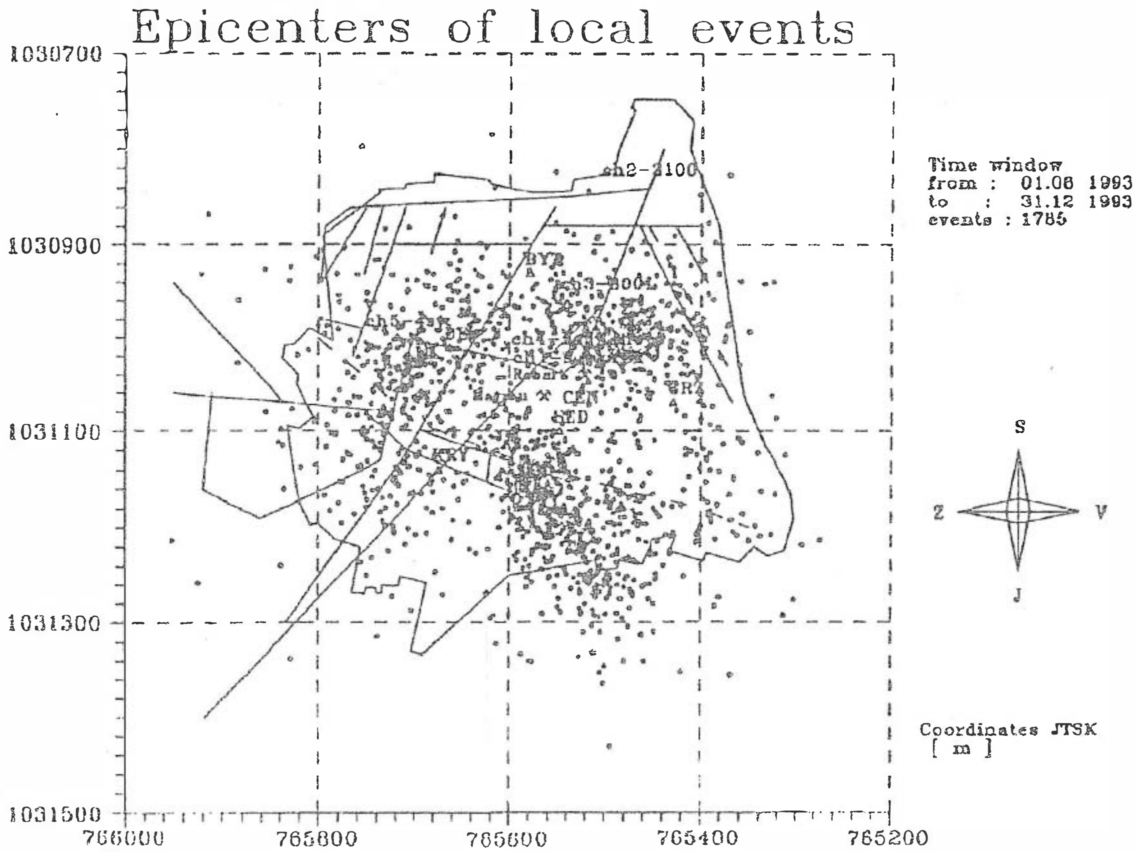

FIG. 1. Schematic map of induced seismic events originating during a half year period. Straight lines express mine corridors, closed curves is contour of safety pillar being currently exploited.

A convincing evidence about the induced mechanism of seismic events give Figs. 3 and 4. Fig. 3 shows the number of events occurring in various days of a week. Deep minimum on Saturday and Sunday is evident, while a clear maximum of seismic activity happens on Wednesday. The mining activity has similar periodicity. From Mondays to Fridays, the exploitation runs continuously 24 hours per day, but on Saturdays and Sundays it happens only exceptionally. The mean magnitudes of seismic events for various days of a week are shown in Fig. 4. This shape contrasts with that of Fig. 3. As a rule, on Saturdays and Sundays one can expect slightly stronger events as those in the middle of the week.

Though this correlation between mining and seismic activity, the latter has also its own regime, caused by natural conditions. Mean number of events per day during the year 1993 is given in the Fig. 5 as a function of time. The activity increases in periods from the beginning of July to the end of September and then during December. This changes are very remarkable, even if the quality and extent of exploitation remains practically the same. Variability of the mean number of events in both periods is followed by a weak increase of the mean magnitude, too.

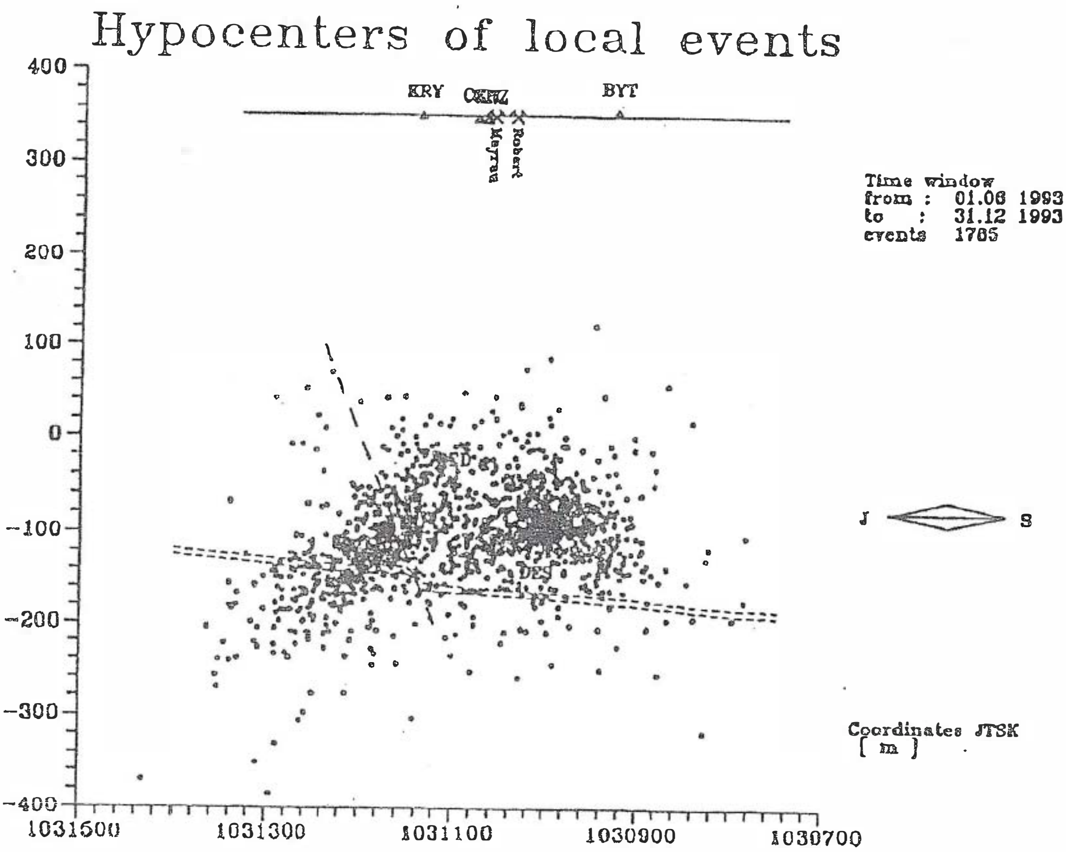

FIG. 2. The same as in Fig. 1 in vertical cross–section. Note the coal seam disturbed by a fault and seismic foci lying in the overburden of the seam.

6. SUPPOSED FURTHER DEVELOPMENT

Further development of interpretation methods is supposed, first of all a combined search for P– and—or S– waves onsets simultaneously complemented with kinematic location. The improvement of the reliability of location is expected from a complex application of both methods operating in automatic way [Roberts et al. 1989; Ruud and Hosebye, 1992; Cichowicz, 1993; Baer and Kraldorfer, 1987]. Some known or modified procedures of onsets determination will be controlled by spatial geometry of seismic stations.

Improvement of the seismic model of the medium will be reached by parallel tomographic location of seismic events [Jech, 1986; Pavlis and Booker, 1980; Spencer and Gubbins, 1980; Šílený, 1987 and 1989; Scarpa, 1993; Mao and Suhadolc; 1992]. Implementation of some up to now less obvious optimalisation methods is supposed to be introduced into tomographic location (e.g. the genetic algorithm of Sambridge and Drijkoningen 1991, Goldberg 1989). A development of a general tomographic location method is considered in connection with a grant application offering to the Grant Agency of Czech Republic.

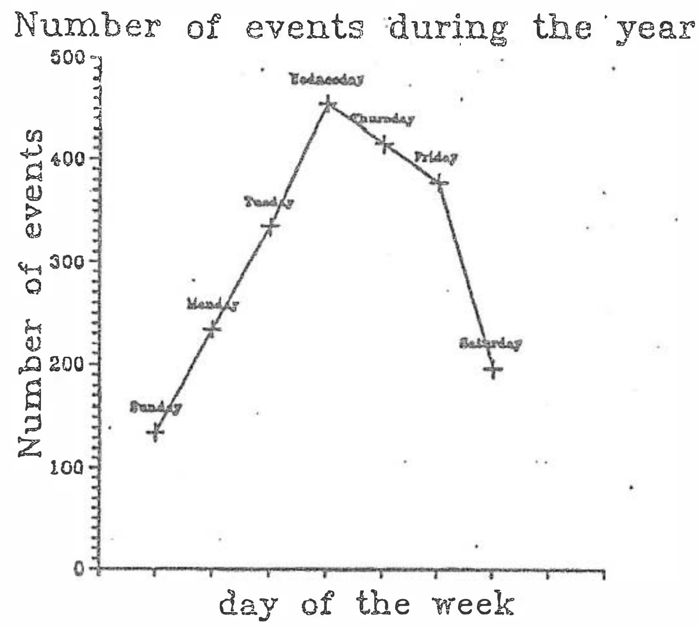

FIG. 3. Simple statistic expressing time occurrence of induced events: Most events originate in the middle of the week.

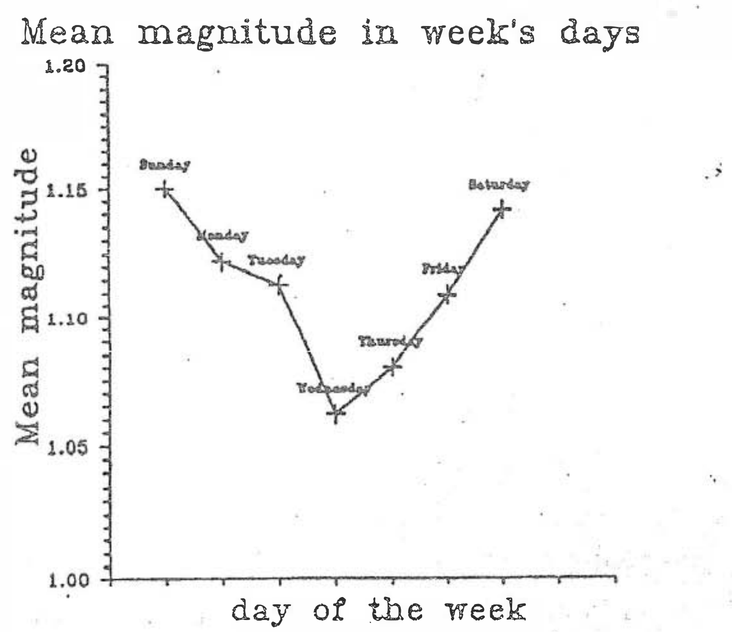

FIG. 4. The same as in Fig. 3 for mean magnitudes: Strongest events are expected in week–end days.

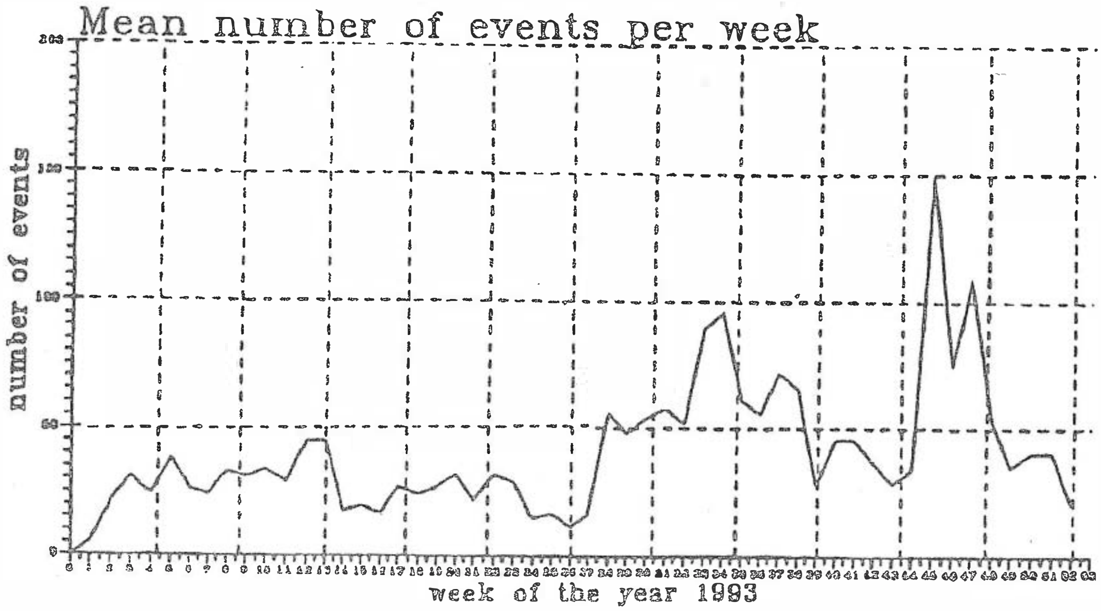

FIG. 5. Substantial changes in the seismic activity were obtained during the year 1993.

Promising research of long term temporal and spatial variations of the Q–factor showed [Růžek, 1994] its correlation with the stress state of the massif and possibly with the destructive processes in the mine. Beside of the continuous monitoring of this parameter further improvement of the computation method is presumed.

7. Conclusion

Seismological methods introduce a substantial component of the complex monitoring system. The continuous monitoring and its results are used for the operative managing of mining exploitation as well as all other necessary works. Data describing induced seismic events are stored in a central database and will be utilized in the future as a time sequence in finding suitable prognosis algorithm.

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