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DIGITAL SEISMIC STATION KLOKOČKOV IN NORTH MORAVIA

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Abstract: New local seismic station Klokočkov was established in North Moravia in June, 1991. It is equipped with three SM-3 seismometers ($T_0 = 1.5$ s, $D = 0.6$) and a digital, triggered recording unit, constructed by the author on the basis of a standard personal computer. The task of this station was to record microearthquakes at this locality, being considered as building site of a nuclear power plant. During the first three months of operation cca 300 seismic events were recorded. The results, based mainly on type analysis, indicated that none of them was of tectonic origin. Special pick-ups (microphone, photocell, geophone and antenna) are suggested to facilitate the discrimination between tectonic microearthquakes and all the other local seismic events.

Key words: seismic hazard; seismic zoning; microearthquakes; local seismic array; digital monitoring and processing

1. INTRODUCTION

Before choosing the building site for a nuclear power plant, it is first necessary to evaluate the hazard the building site is subject to as a result of extreme geodynamic processes. Of very considerable significance in this respect are the effects of earthquakes which are transmitted to the components of the primary reactor circuit via its foundation plate.

If the maximum Safe Shutdown Earthquake (SSE) calculated for the site involved exceeds intensity $I = 8°$ MSK–64, the nuclear power plant must not be built there. The following methods are used to determine the value of SSE:

- statistical evaluation of the macroseismic intensities of historically documented earthquakes,
- evaluation of the seismic potential of tectonic active fault structures in the region of the building site,
- evaluation of the seismic response of the geological structures underlying the foundations.

Intensity I_{SSE} is supplemented by site-specified accelerograms which the designer must take into account in safequarding the nuclear power plant against seismic hazard.

The results of the seismological surveys of the area, locality and building site of

Blahutovice (Šimůnek, 1977) were analyzed during the Czechoslovak-Soviet expertise in 1977, and the following conclusions were drawn.

2. SEISMIC HAZARD ON THE BLAHUTOVICE SITE

The Blahutovice site ($\lambda = 17.856°$ E, $\phi = 49.599°$ N) is located in a tectonic active region. A thin and nearly horizontal layer of the Carpathian range overlaps the Bohemian Massif here. The horizontal velocity gradients of the present-day relative vertical displacements at the locality amount to as much as 1 mm/(km.yr) in places. The seismic hazard determined by evaluating the reports on historical earthquakes in the relevant region is characterized by relation $\log N(I_0) = 1.55 - 0.61 I_0$. The mean annual frequency $N = 0.0001$, i.e. the extrapolation of this relation, indicates that an earthquake with intensity $I_0 = 9°$ MSK-64 has a repetition period $T = 10{,}000$ years.

The evaluation of the seismic potential of tectonic faults in the region yielded the conclusion that the largest hazard is due to two close tectonic faults:

(1) The Temanín fault. It is 75 km long, the smallest distance from the building site $R_{\rm min} = 10$ km, and seismic potential $M_{\rm max} = 5.5$.

(2) Fault at the margin of the Oderské vrchy Hills. Its smallest distance only 3 km, and seismic potential $M_{\rm max} = 5.0$.

These faults have recently not been (10^6 years) tectonically active and their geophysical indication is weak. In this seismotectonic situation it was necessary to carry out detailed seismic zoning. A local seismic array of five three-component seismographs with a detection capability from magnitude $M_{\rm L} = 1$ (Cidlinský *et al.*, 1985) was established for this purpose.

During the years 1984-1986 this array identified only two microearthquakes (Cidlinský, 1986):

on 8.8.1986, $\lambda = 17.740°$E, $\phi = 49.707°$N,

on 11.8.1986, $\lambda = 17.743°$E, $\phi = 49.708°$N.

Geomechanically the Blahutovice site is considered to be conditionally suitable. The foundation soils belong to the 2nd and 3rd categories (SNiP, 1982). Consequently, foundations on piles, or seismic resistance designed for 8° MSK-64 are being considered. The design accelerograms have maximum amplitudes of 0.32 g for frequencies of about 8 Hz. Building on this site would also present problems with groundwater which is carbonate-aggressive with respect to concrete structures. If technological water were to be supplied from the River Bečva, it would be necessary to build a new river dam at Teplice. However, this could be a source of induced seismicity.

3. BUILDING SITES NEWLY CONSIDERED AND THEIR SEISMIC HAZARDS

After the Soviet military left the area between the Nízký Jeseník Mts. and the Oderské vrchy Hills, it was possible to contemplate building in that area which is uninhabited and devastated. The following sites are up for preliminary consideration:

(1) Oldřůvky, a former village between the villages of Budišov nad Budišovkou and Klokočov, $\lambda = 17.670°\mathrm{E}$, $\phi = 49.7614°\mathrm{N}$.

(2) Luboměř pod Strážným, a former village 6 km north of the town of Potštát.

(3) Hájovna 5 km to the NW of the former village of Boškov and 5 km SE of the former village of Milovany.

The seismic hazard at these localities will probably prove to be more favourable than that on the Blahutovice site. However, it will be necessary to prove that no microseismic foci with magnitudes $M_L \geq 1$ occur there. Standard methodology requires establishing a local seismic array for this purpose (IAEA, TEC-DOC-343, 1985).

This practically involves providing proof that not one of the large number of events, recorded by a very sensitive seismograph over a period of several years, is a microearthquake of tectonic origin. It is therefore necessary to classify each recorded event. This includes shooting in surrounding quarries, atmospheric storms, aircraft overflights, traffic noise, machinery vibrations, and disturbances caused by the movement of local inhabitants, agricultural machines, and movement of game in the neighbourhood of the seismograph. It is also necessary to identify mine shocks, as well as weak tectonic events originating at regional focal distances, i.e. $R \geq$ ≥ 20 km.

The new concept of power engineering has not been definitively established yet. Consequently, it is not necessary to conduct this survey in the shortest possible time, as was the custom earlier. On the other hand, it is necessary to keep the costs down to a minimum.

The present paper presents our attempts at solving the problems indicated, using a single seismograph installed close to the site being considered. We shall first describe the digital seismograph of our own patent (Babor and Buben, 1986), and the construction of the Klokočkov seismic station. Based on the available records of seismic events we shall then test known methods of identifying microearthquakes, and propose further necessary technical adjustments to the station and interpretation procedures.

4. KLOKOČKOV SEISMIC STATION

Locating the station in residential building the object of Klokočkov No. 85 is the result of our efforts to achieve maximum distance from sources of civilization noise while placing the recording instrument in a residential, heated room with electric mains, and having the possibility of servicing and safeguarding it. This location is at the very border of a military area, called Hadinkovo ($\lambda = 17.889°\mathrm{E}$, $\phi = 49.7417°\mathrm{N}$). Immediately under the seismometer pillar there are sediments at the confluence of the Budišovka River with the Odra River. The distance between the seismograph and the Oldřůvka site is 4.8 km. Standard SM-3-type electromagnetic seismometers were used as seismic pick-ups. MAC 524 amplifiers, with a voltage gain of 2500, were built into the seismometer boxes. The seismometers were installed on a pillar at a distance of 75 m from the residential building.

The digital recording instrument was designed on the basis of a PC. It operates in a triggered mode. The sampling frequency is 200 samples per second, the dynamic range is 4096 levels (12 bits). The frequency band of constant amplification for the seismic vibration velocity is limited by the natural frequency of the seismometer (0.3 Hz) and by the corner frequency of the input low passband filter (25 Hz).

The data sets are stored on a disk, duration 20 s (4000 samples), of which 4 s are reserved for the pretrigger time. The sets are stored if the following conditions are satisfied:

(1) the instantaneous absolute amplitude $P_1 \geq 32$ levels,

(2) the mean absolute amplitude per 1 s $P_2 \geq 1500$ levels.

The time coordinate of the records is derived from the frequency of the computer's clock. The absolute time and date are obtained by receiving time signals of station DCF 77. The local clock is corrected usually at intervals of 24 hours.

The transfer functions of the seismometers are tested daily by the operator. On commencing the calibration, the external resistors of damping coils are automatically disconnected. These coils are then automatically connected to a source of constant 15 μA current corresponding to the mechanical force which, applied at a jump to the pendula of seismometers, excites their free oscillations. These oscillations are recorded as a data set because they satisfy both the conditions for storing data sets on the disk.

A part of the recording instrument is a matrix printer. As the set is being stored on the disk, its designation is automatically printed: the date, time and amplitudes P_1 and P_2. Diagnostic data on the measurement are also printed. The station operator thus has an overview of the sets recorded and transfers them to floppy discs as required. The transfer is also automatic and is initiated by the operator. A special floppy disc is used to re-adjust the levels relevant to triggering conditions P_1 and P_2.

The seismometers are connected to the apparatus input by current loops. Shielded cables buried in the ground are used. The pre-amplifier offset drift is compensated automatically by the program based on the running averages of 36,000 samples.

The recording instrument has a program which enables continual single-channel recording on a monitor screen. This record, once the 33 lines of the monitor have been filled, is automatically erased, or automatically stopped and the screen is printed. The programs for interpreting the recorded events provide the following options:

a) display and printing of records of all components with optional time scale and amplitude normalization;

b) reading of the magnitudes (levels) of amplitudes with the aid of cursors;

c) reading of the time coordinate and time differences on the records using cursors.

The digital apparatus described was designed using a PC-XT. Its present purchasing price does not exceed 30,000 Kčs. So far Lennartz-Mars 8000 apparatuses, costing 30,000 DEM, have been imported.

Determination of the detection capability of a seismic station is based on the following deliberations. The input range of the A/D converters is ∓ 5 V. Considering their dynamic range of 4096 levels, one level corresponds to an input voltage value of 2.44 mV. Condition P_1 is exceeding 32 levels, i.e. an input voltage of $32 \times \times 2.44$ mV $= 78$ mV. The sensitivity of the seismometers with built-in amplifiers is 17 μV/(μm/s) $\times$ 2500 = 42.5 μV/(μm/s). Vibration amplitude velocity $v = = 78$ μV/42.5 μV/(μm/s) = 1.84 μm/s corresponds to the value of 78 μV. Assume that the frequency of the vibrations we are concerned with is in the neighbourhood of $f = 10$ Hz. As regards the displacement amplitude sufficient to satisfy the condition for storing data, $s = V/(2\pi f) = 0.029$ μm.

We require the seismograph to be able to record micro-earthquakes at epicentral distances $R \leq 20$ km. The smallest local magnitude M_L, which the seismograph is capable of recording, is

$$M_L = \log s + 1.4 \log R + 0.75 = 1.0\,. \tag{1}$$

5. DISCRIMINATION OF NON-TECTONIC EVENTS

The station began to operate at the beginning of the second half of 1991. About 300 events had been recorded by the end of the year. Their classification is based on the analysis of the following parameters.

5.1. Epicentral distance

An isolated station can only provide the difference between onset times, $t_S - t_P$. In the first approximation, local velocities V_P (determined in detailed seismic zoning using records of bursts and experimental explosions) at stations Malhotice (5.54 km/s), Partutovice (5.33 km/s) and Lučice (5.93 km/s) with epicentral distances of $3 \leq R \leq 20$ km, can be used. Assuming that the surface velocity in the neighbourhood of station Klokočkov is $V_P = 5.5$ km/s, and that $V_P = 1.7 V_S$, the velocity difference comes out as $V_F = R/(t_S - t_P = (V_P\, V_S)/(V_P - V_S) = 1.37 V_P = = 7.5$ km/s. Consequently, we excluded from further evaluation the events in which the onset time differences $t_S - t_P > 30$ km/7.5 km/s = 4 s.

The following quarries are in operation in the neighbourhood of the Klokočkov station: Hranice-Skalka ($R = 23$ km), Hranice-Černotín ($R = 23$ km), Ústí ($R = = 24$ km), Hrabůvka ($R = 18$ km) and Jakubčovice ($R = 9$ km). Fig. 1 shows the record of event of 22.8.1991 at 14:50. In this record the P-waves are distinctly distinguishable from the S-waves, and the differences in onset times $(t_S - t_P) = = 2.3$ s, which corresponds to the epicentral distance of the Hrabůvka quarry. In other records (see Fig. 2) however, the onset of the S-waves is not quite distinct even in the horizontal components.

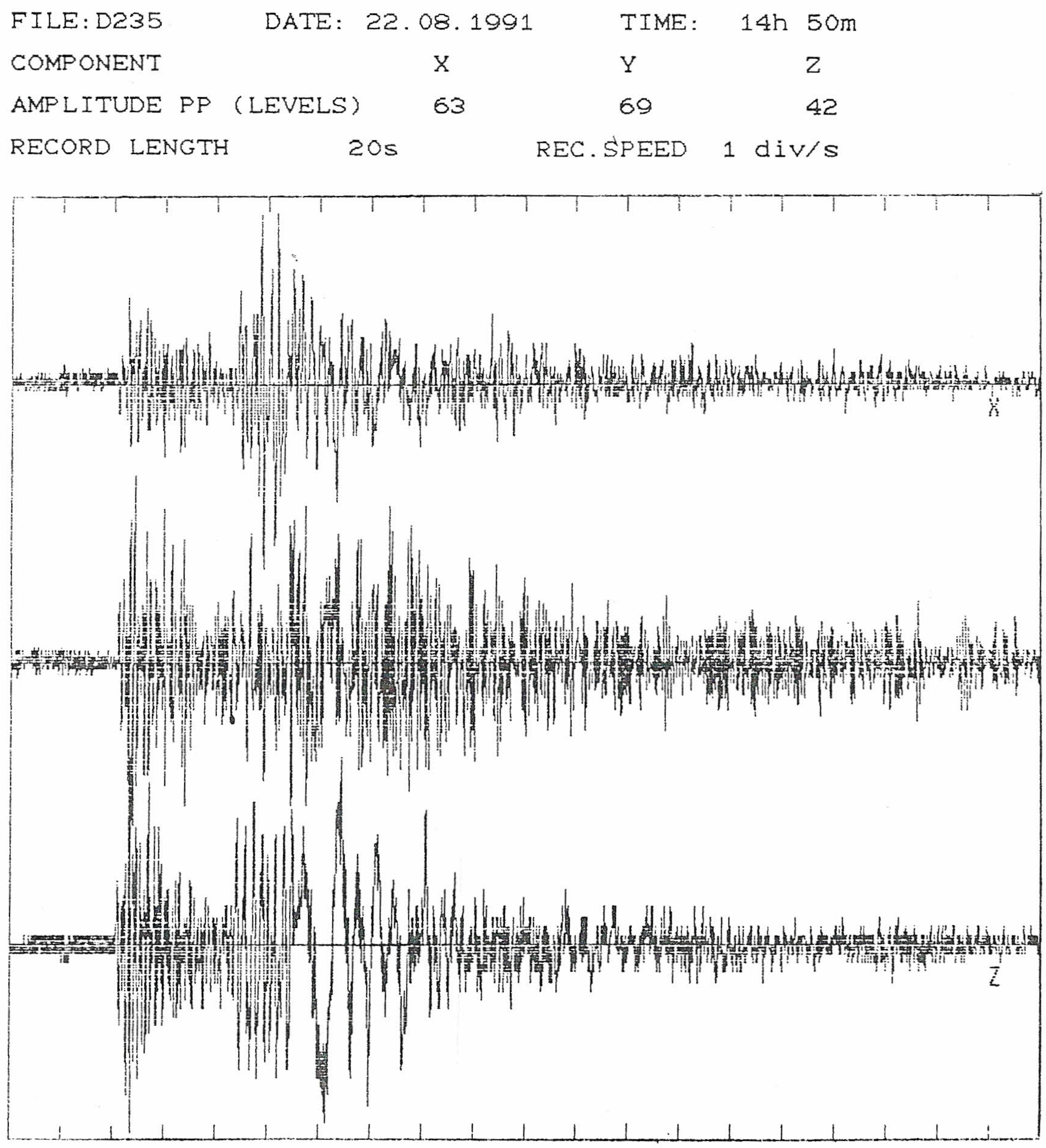

Fig. 1. Record of seismic event of 22.8.1991.

5.2. Quarry blast records

These records are very important for discrimination. For example, there were over 60 blasts in the Hranice-Skalka quarry in the years 1984–1985 which were recorded in the station array for detailed seismic zoning. About 40 of these had a local magnitude of $1 \leq M_L \leq 2.5$. Their epicentral time also contributes to classifying the events. For example, ten blasts were carried out between 10 and 11 a.m., and 34 betwen 12 and 2 p.m. at the Jakubčovice quarry. There were no other blasts outside these two intervals.

FILE: D794 DATE: 21.11.1991 TIME: 01h 41m

COMPONENT X Y Z

AMPLITUDE PP (LEVELS) 44 34 19

RECORD LENGTH 20s REC.SPEED 1 div/s

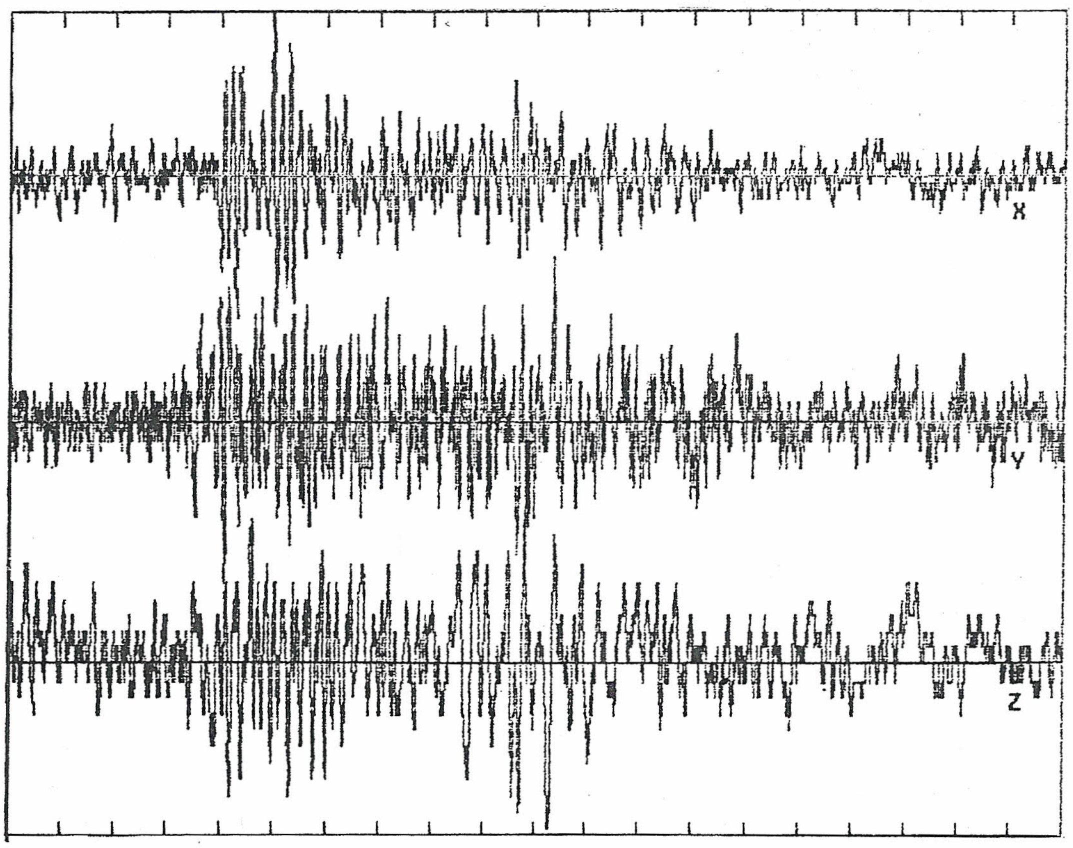

Fig. 2. Seismic event difficult to evalute.

5.3. Instrumental records of blasts

The records of vibrations in the near zone may add considerably to the information required to determine the dynamic and kinematic characteristics of the seismic waves at the locality. This would require about 15 epicentral vibrographs to be installed in the neighbouring quarries.

5.4. Atmospheric storms

Electric spike pulses get into the input seismograph circuits together with the vibrations which satisfy all the conditions for data set storage, during close storms. However, in this cases discrimination is easy at first glance (Fig. 3).

It is much more difficult to distinguish storm-generated vibrations when lightning is more distant and the electric spike pulse is lacking on the records, as shown in Fig. 4. It is, therefore, necessary to equip the seismic station with an electromagnetic antenna and a photocell. The lightning generates pulses in the sensors which excite the monostable circuit blocking the triggering.

FILE:D184	DATE: 17.08.1991	TIME:	16h 18m
COMPONENT	X	Y	Z
AMPLITUDE PP (LEVELS)	208	250	386
RECORD LENGTH	20s	REC.SPEED	1 div/s

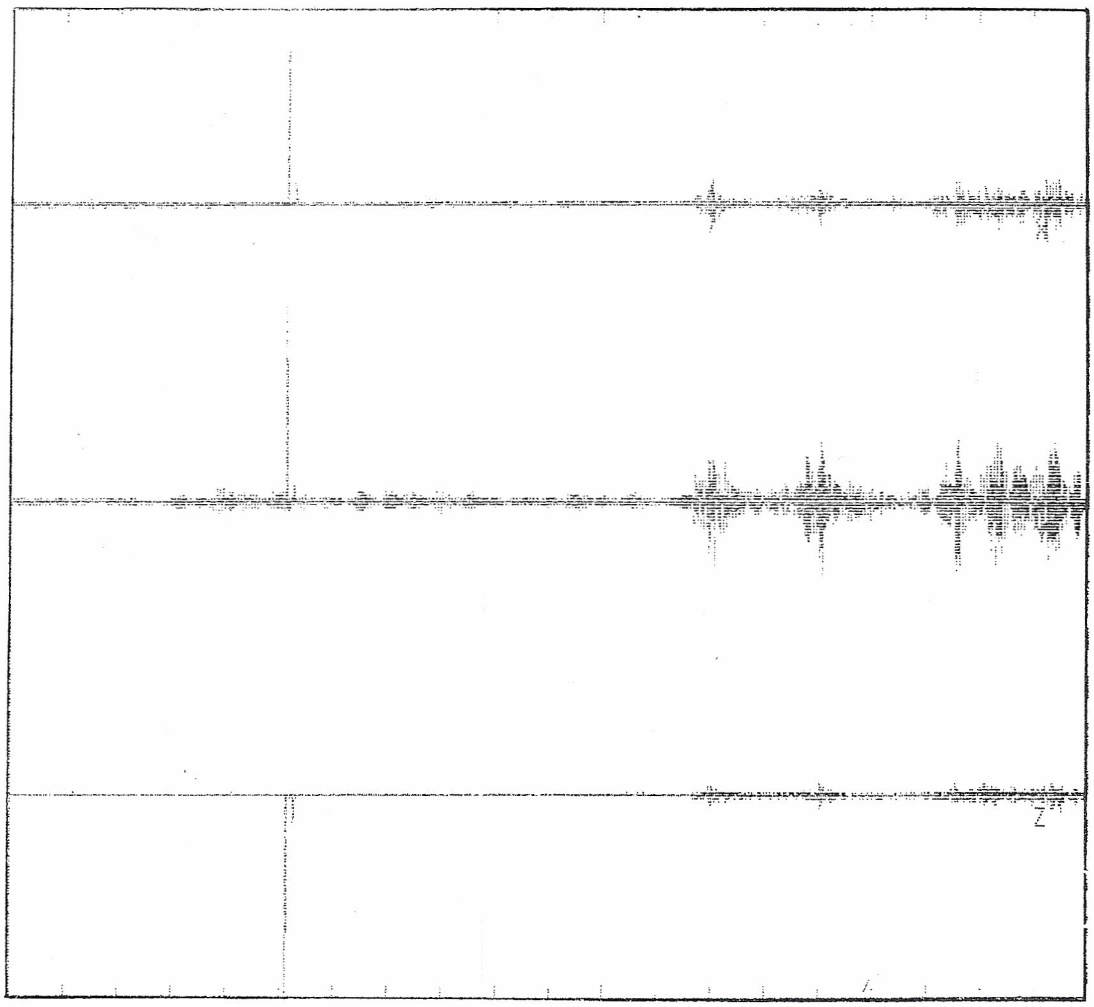

Fig. 3. Electric pulse and mechanical vibrations generated by a near atmospheric storm.

FILE:D241	DATE: 28.08.1991	TIME:	14h 46m
COMPONENT	X	Y	Z
AMPLITUDE PP (LEVELS)	152	342	176
RECORD LENGTH 7.510s		REC.SPEED	2 div/s

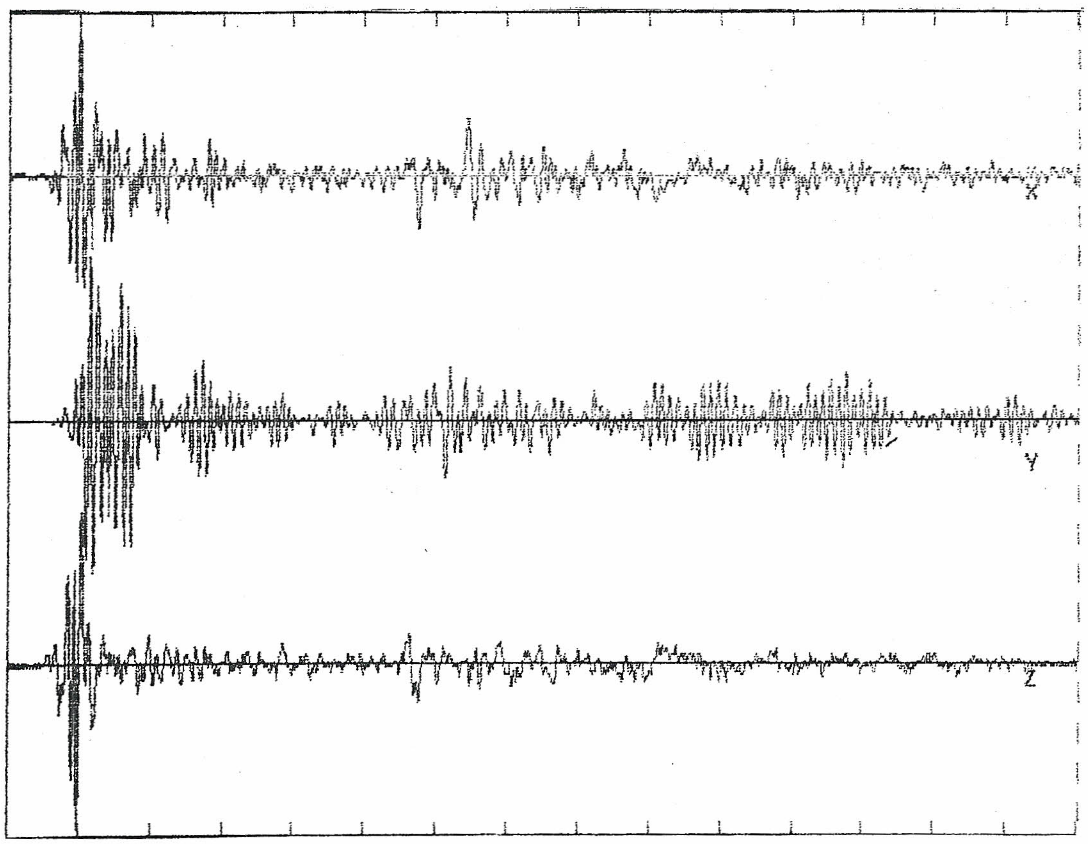

Fig. 4. Seismic vibrations generated by a distant atmospheric storm.

5.5. Mechanical vibrations of local origin

These vibrations are excited by the movement of vehicles, operation of agricultural machines, work in workshops, agricultural work, and by the movement of domestic animals and animals living out in the open. Examples are shown in Fig. 5 (tractor engine) and Fig. 6 (tractor pulling a trailer). Fig. 7 shows pulses generated in a mechanical workshop at a distance of about 70 from the pillar of the seismic station.

Over 90% of all events recorded are of this origin. Their useless storing can be prevented by three additional sensors, i.e. microphone, geophone and antenna. The geophone is placed as close as possible to known sources of local vibrations (workshop, garage, road), and the antenna and the microphone are placed, for example, under the roof of the house. The suitable sensitivity of these sensors is then adjusted by means of amplifiers. The amplifier outputs are connected to blocking circuits. This prevents data from being stored even if generated by local perturbing vibrations or storms.

FILE: D343	DATE: 26.09.1991	TIME:	19h 05m
COMPONENT	X	Y	Z
AMPLITUDE PP (LEVELS)	71	59	24
FILE LENGTH 20s		REC. SPEED	1 div/s

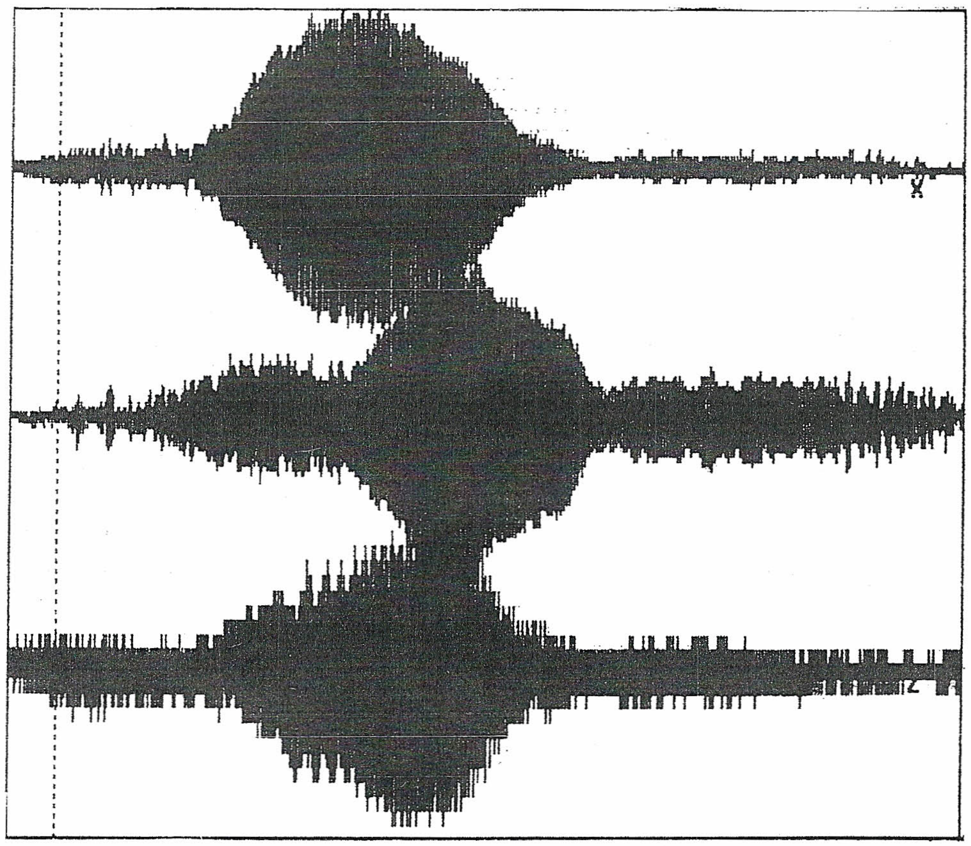

Fig. 5. Vibrations generated by running tractor engine at a distance of 50 m from the pillar.

5.6. Fourier spectrum

Discrimination is based on the experience that blasts, as a rule, display more developed surface waves. The spectrograms of blasts occurring at a shallow depth thus contain more local extremes for $T \geq 0.3$ s.

Distinguishing microearthquakes by epicentral depth, determined from the records of just one seismograph, is not very hopeful in this case. The pillar has been sunk into a low-velocity sedimentary layer which increases the emergence angle by values which are difficult to determine. Due to the complicated structure of the subsoil, the method of polarization analysis does not seem to be particularly hopeful, either, although this method has proved itself very well with seismograph on a rock base (Sekereš, 1991).

FILE: D275	DATE: 04.09.1991	TIME:	17h 28m
COMPONENT	X	Y	Z
AMPLITUDE PP (LEVELS)	64	172	19
RECORD LENGTH 20s		REC.SPEED	1 div/s

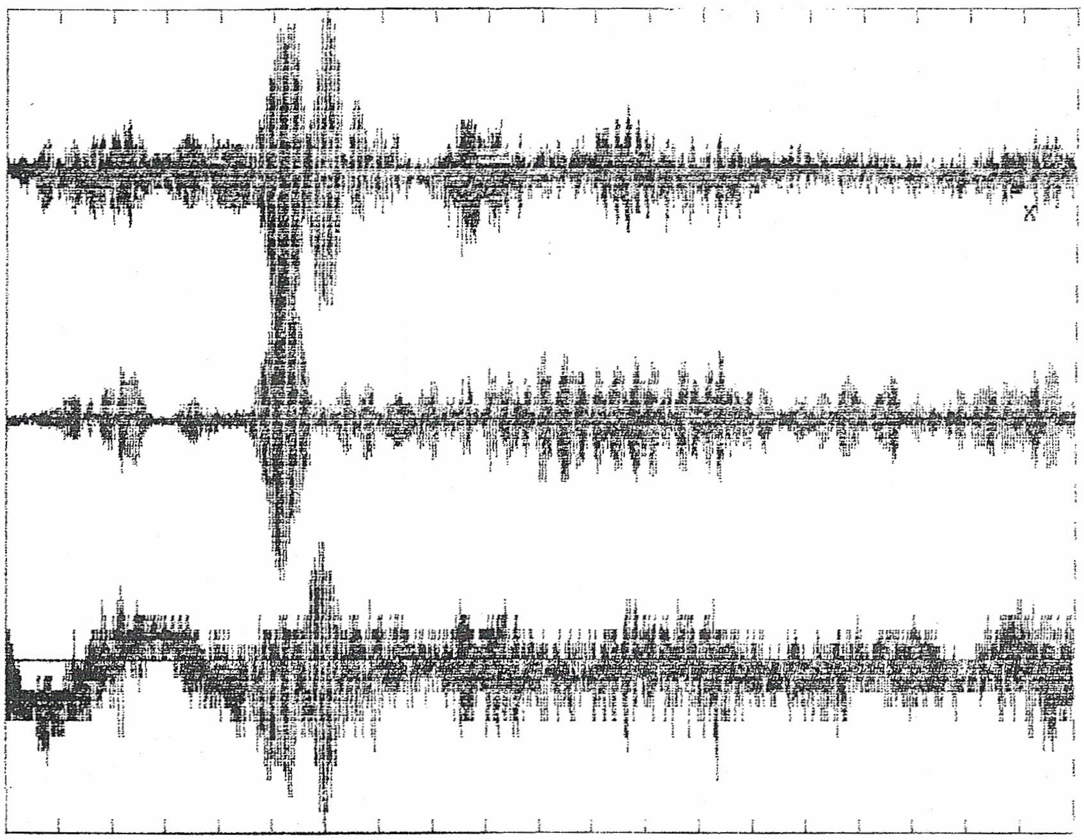

Fig. 6. Vibrations generated by transport of lumber along a forest road using tractor and trailer at a distance of about 100 m from the seismometer.

5.7. Differential magnitude

The different force mechanism of man-made surface events and tectonic microearthquakes may also be reflected in different integral record characteristics. The local magnitude is one of these characteristics. This quantity is determined either from the maximum displacement amplitudes s, or from the overall duration τ of all oscillations. To determine magnitude M_τ we shall use the relation (IAEA, 1985)

$$M_\tau = 2 \log \tau + 0.0035R - 0.87\,, \qquad (2)$$

and to determine magnitude M_V from the maximum amplitude V_{max} of the vibration velocity the following relation (Scherbaum and Stoll, 1983)

$$M_V = \log\, v_{max} + \log\, T_{V_{max}} + 1.4\, \log\,(t_S - t_P) + 1.2 \qquad (3)$$

FILE: D185	DATE: 17.08.1991	TIME:	16h 19m
COMPONENT	X	Y	Z
AMPLITUDE PP (LEVELS)	152	297	48
RECORD LENGTH 20s		REC. SPEED	1 div/s

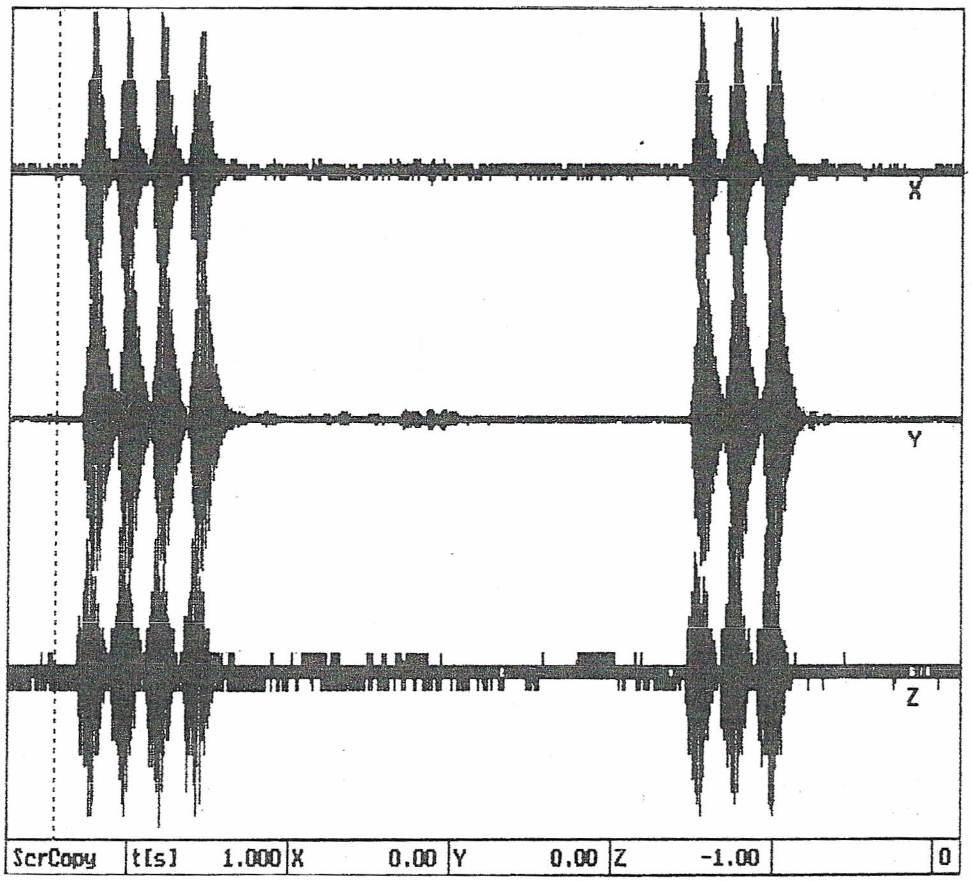

Fig. 7. Pulses generated in a workshop at a distance of about 70 m from the seismometer.

is used. The difference $(M_\tau - M_V)$ may be used as a very simple discrimination criterion. The symbol $T_{V_{max}}$ is used to designate the "visible" period in the group of vibrations which display the maximum displacement amplitude (according to the interpreter's estimate). The vibrations from epicentres at the surface should have positive differential magnitudes.

5.8. Pattern identification

Classification of records by similar oscillation pattern proved to be very effective in the seismic research into mine shocks (Buben, 1967). Model patterns, drawn on a transparent foil, were fitted to the seismograms being studied. For example, mine shocks generated in about ten different places were reliably identified in this way on records of seismic station Kladno. The experienced interpreter was then able to identify these mine shock at a cursory glance at the analogue record of the local seismograph.

The subjective factor of interpreting pattern similarity can be eliminated by using cross-correlation functions. The degree of similarity of the records is then objectively expressed in terms of the maximum value of the smoothed cross-correlation function. However, this method can only be used if the model records have been previously classified. This must be done in some other way.

5.9. Locations of epicentres

If only an isolated seismograph is available, the accurate location is not possible. The problem is to determine epicentral distance R and epicentre azimuth α. Instead of measuring the amplitudes of onsets on a three-component record, it is more convenient to use three closely spaced vertical-component pick-ups instead of the usual three orthogonally adjusted components at a single location, and to measure the time differences of the first onsets.

The use of a three-component seismograph is justified by the need to determine the onset times of shear waves, which can be distinguished better on horizontal component records. Programs for polarization analysis can then be used to identify these onsets objectively (Sekereš, 1991). If only records of the vertical component are available, programs for Wiener optimum predictive filtration can be used (Robinson, 1967). The sudden increase in prediction errors indicates the onset of the S-phase. This method of detecting S-wave onsets does not require the use of horizontal components. However, the records of three spaced-out vertical components can be used for three-channel filtration.

The determination of azimuth α from the ratios of the first amplitudes of the horizontal components is subject to errors caused by the anisotropy of the elastic characteristics of the layers underlying the station. It is therefore better to use three identical pick-ups of the vertical component installed in boreholes which reach down to the layers underlying the low-velocity layer.

These pick-ups should be placed at the apexes of an equilateral triangle, which we shall denote S_1, S_2, S_3. Epicentre azimuth α is the angle between the lines connecting CS_i and CE, C being the centre of the triangle and E the epicentre, $i = 1, 2, 3$.

The distance of the pick-ups D should be such that the measurable phase shifts between records can be distinguished clearly. However, these records should be coherent, but this is only the case if distance D is very small as compared to wavelength $L = c/f = 550$ m.

For example, if the surface velocity of the first phase $V_P = 5.5$ km/s, the distance between the pick-ups $D = 175$ m, and the sampling interval of the recorder is 0.005 s, the time shift on the records of pick-ups S_1, S_2, S_3, expressed as the number of sampling intervals $k_{1,2}$, $k_{1,3}$ and $k_{2,3}$, will take the values, depending on azimuth α

$$\begin{aligned} k_{1,2} &= 10(0.866 \ \cos\alpha - 0.5 \ \sin\alpha)\,, \\ k_{1,3} &= 10(0.866 \ \cos\alpha + 0.5 \ \sin\alpha)\,, \\ k_{2,3} &= 10 \ \sin\alpha\,. \end{aligned} \tag{4}$$

These time lags can be determined as the time shifts between the corresponding maxima of the cross-correlation functions of the records. Azimuth α is determined by solving Eqs. (4). Overdetermination enables severe errors to be eliminated.

The correlation methods of interpreting make better use of the information contained in records than methods based on reading the onset times. The possibility of automating the evaluation of α, R and M_L is self-evident.

It is technically convenient to place the dislocated pick-ups in boreholes (there is no need to build a cell and pillar). If NS-2 geophones ($f_0 = 2$ Hz) are used in connection with radio UHF data transmission, this technical setup can be realized very easily.

6. CONCLUSIONS AND DISCUSSION

At the beginning of the 2nd half of 1991, the new digital seismic station Klokočkov, designed on the basis of a PC-XT, was put into operation. The purpose of the station is to prove the absence of local microearthquakes in the neighbourhood of the building site of nuclear power plant North Moravia over a period of at least three years.

The seismograph operates in the triggered mode. The triggering criteria are based on the value of the instantaneous amplitude, as well as on the values of short-term and long-term average amplitudes.

The recorded events are clasified according to the type of foci. Master record patterns of quarry blasts, atmospheric storm vibrations, and vibrations due to local traffic and works in the building have been established.

It has been suggested that devices to pick up noise (microphone), lightning (photocell), local vibrations (geophone), and electromagnetic pulses (antenna) be added to the station's equipment. Instead of the present three orthogonal components of the SM-3 seismometers, it has been suggested that three pick-ups of the vertical component (borehole seismometers) be used, located at distances of about 200 m from one another. The classification of the recorded events and discrimination of microearthquakes is based on spectral and correlation analysis, as well as on predictive filtration and polarization analysis of records.

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DIGITÁLNÍ SEISMICKÁ STANICE KLOKOČKOV NA SEVERNÍ MORAVĚ

Jiří Buben

V červnu 1991 byla zřízena nová lokální seismická stanice Klokočkov. Je vybavena třemi seismometry typu SM-3 ($T_0 = 1{,}5$ s, $D = 0{,}6$) a digitální automaticky spouštěnou aparaturou sestrojenou autory s použitím běžného osobního počítače. Úkolem stanice bylo registrovat mikrozemětřesení v místě uvažovaného staveniště jaderné elektrárny Severní Morava. Během prvních tří měsíců provozu bylo zaregistrováno zhruba 300 lokálních seismických dějů. Výsledky získané hlavně pomocí typové analýzy ukázaly, že žádný z nich nebyl tektonického původu. Pro snadnější rozlišení tektonických zemětřesení od všech ostatních lokálních seismických dějů jsou doporučeny snímače (mikrofon, geofon, fotočlánek, elektromagnetická anténa). Signály těchto snímačů zablokují ukládání datových souborů při výskytu místních rušivých jevů, které nejsou tektonického původu (lokální mikrozemětřesení).

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