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REGIONAL SEISMIC ARRAY IN CENTRAL BOHEMIA

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Abstract: An array of seismographs for recording strong-motion, near-focus seismic events was established during the second half of 1991 in the region of Central Bohemia. The purpose is to obtain data for the assessment of site-specified design accelerograms. The array consists of four seismographs operating in the triggered mode. The instruments are capable of recording earthquakes with intensities of 2 to 5° MSK-64.

Large blasting operations in surrounding quarries provide data for determining the seismic response function of the cretaceous layer underlying the building site.

Key words: seismic hazard; design basis earthquake; regional seismic array

1. INTRODUCTION

The possibility of constructing a nuclear power plant (NPP) is being appraised at the Tetov site in Central Bohemia. A seismic hazard prognosis of this building site has to be made. The antiseismic design is based on design accelerograms of the safe shutdown earthquake (SSE).

The size of the SSE is given on magnitude scale M_{SSE}, macroseismic intensity I_{SSE}, and also by the time histories of vibrations of the free surface. These depend on the maximum possible earthquakes $M_{\max}$, $I_{\max}$ in the near region of NPP, i.e. at epicentral distances $R \leq 200$ km.

2. SEISMOSTATISTICAL PROGNOSES OF $I_{\max}$

The prognosis is based on the macroseismic documentation of historical earthquakes and on the statistical analysis of their time-space distribution in the region. Statistical seismic prognoses are made according to the following rules:

(1) Marking the position of seismoactive zones.

(2) For each of these zones:

- determining the statistical dependence of the number $N(I_0)$ of earthquakes per year on epicentral intensity I_0 in the well-known form

$$\log N = a - bI_0 , \tag{1}$$

- determining the mean decrease of intensity $I_0 - I_R$ with epicentral distance R,

- determining the shakability of the building site as the aggregate of local intensities I_a of all earthquakes with foci in all active zones with regard to their maximum intensities, focal depths and distances from the building site,

$$\log N(I_a) = A - B(I_a), \tag{2}$$

- determining the most probable interoccurrence time $T(I_a)$ of events with intensity I_a as

$$T(I_a) = 1/N(I_a). \tag{3}$$

Now, the intensity I_a, whose interoccurrence time is $T(I_a) = 10^4$ years, is the prognostic value of seismic hazard.

The application of this procedure in the case of the NPP building site Tetov has yielded the following conclusions:

The locality is situated in the central part of the Bohemian Massif located in the vicinity of the northern margin of the Alpine orogene. Seismicity of this region is that of quiet, continental-plate type. According to Kárník and Schenková (1982), the documented earthquakes (period of 400 years) are distributed as follows:

$$\log N(I_0) = 2.06 - 0.78 I_0; \quad I_0 = 3, 4, 5. \tag{4}$$

This means that the most probable return period of epicentral intensity $I_0 = 4°$ MSK-64, for example, is 11.5 years.

Applying extrapolation to this relation in order to determine the seismic hazard (i.e. for return period of 10,000 years) does not yield sufficiently reliable results. This was verified by our numerical experiments.

The foci in the central part of the Bohemian Massif do not form well-defined lineaments and are more or less scattered. Their depths are shallow (about 5 km), and epicentral intensities larger than $I_0 = 5°$ MSK-64 have not occurred. It has been proved (Phillips, 1986) that under these assumptions only earthquakes with epicentral distances $R \leq 30$ km have the crucial effect on the seismic hazard.

To prescribe the site-specified assessment of seismic hazard, the two following problems have to be solved:

1. Determining the local increase in the intensity of seismic effects due to the resonance/attenuation characteristics of the shallow underlying geologic structure (seismic microzoning).

2. Assessing the maximum intensity I_{max} (the seismic potential) of earthquake source zones within 30 km of the building site. It is probable that these zones are related to tectonic faults. These relations can be assessed using seismotectonic methods.

3. SEISMIC POTENTIAL OF FAULTS

The mapping of tectonic fault structures is based on surveying and quantifying geophysical and seismotectonic indications as well as the methods of remote sensing, and using a pattern detection device. Each tectonic active fault, provided it is related to stress concentrations in the core, has a certain seismic potential.

The following criteria are recommended in Bune *et al.* (1986) to estimate the seismic potential of faults:

- present (geodetically observable) vertical displacements of the surface presage only a very low potential;
- faults or flexures, not older than neotectonic (20 million years), have a small potential ($M_{max} = 3.5$), although they display quaternary or present tectonic activity;
- faults of proterozoic or palaeozoic age, active even recently (also disrupting quaternary layers) display seismic potential $M_{max} = 5.3$;
- very old structures, active recently, at points of intersection with other faults (neotectonic age, active recently), exhibit a considerable seismic potential ($M_{max} > > 5.3$).

As regards the faults in the Bohemian Massif, shown in Fig. 1, assessments of the seismic potential made by Šimůnek (1990) are based on the following geoscience data:

a) the tectonic map of the Bohemian Massif (geologically identified faults, quaternary tectonics);

b) repeated geodetic high-precision levelling;

c) satellite photography of the surface;

d) geophysical structural surveys, deep seismic sounding, seismic, gravimetric, aeromagnetic and geothermal maps.

Zones of possible earthquake foci and their seismic potentials are shown in Fig. 1. The assessments are based on the hypothesis that local seismicity is the manifestation of stick-slipping of segments of the upper crust or of its cymatogeny. It is caused by stress with predominating horizontal components acting roughly from N to S (perpendicular to the axis of the Alpine orogene). In view of a weak link of historical earthquakes to faults, it should be borne in mind that the seismic hazard of the locality is caused by earthquakes which are of moderate magnitude ($3.5 \leq M \leq 5.3$), but with foci occurring near the building site. Other earthquakes ($R > 200$ km) occurring in Central and East Europe make relative small contribution to the entire hazard.

4. DESIGN BASE ACCELEROGRAMS

No analytical methods, which have to be used in the near zone, have been available up to now. Application of empirical methods and relations is required. Because no strong-motion accelerograms have been recorded in the locality and region, there is no way out but making use of accelerograms recorded abroad.

However, assuming standard design spectra from abroad we may very likely come to unrealistic results which overestimate the actual seismic hazard.

The cause of this is that the standard response spectra are determined from strong motion accelerograms recorded in very active regions (USA, Japan, CIS). In such regions also strong regional earthquakes (with $R > 200$ km) contribute considerably to the seismic hazard. In these cases the surface waves with moderately low frequencies (below 1 Hz) are mainly effective in the phase of destructive oscillations. On the other hand, the response spectra of near, shallow, and relatively weak earthquakes, which is our case, contain considerable amount of oscillations with higher frequencies $2 \leq f \leq 8$ Hz and with short duration times $\tau \leq 10$ seconds.

To be able to revise this up to now compulsory, but evidently too conservative method, it is necessary to obtain a set of accelerograms of near and weak seismic events. As opposed to other European countries with quiet seismicity (FRG, Great Britain, France), no local strong-motion accelerographs have so far been established in our country. That is why accelerograms from abroad have to be used. In selecting such accelerograms, usable at least in the first approximation, it is, of course, necessary to observe the following conditions of similarity:

- magnitude M and focal depth H,
- epicentral distance R,
- the type of shallow geologic structure (the category of seismic properties of the subsoil).

The set of selected accelerograms is to be processed as realizations of a random process with the following characteristics:

- duration D of the phase of destructive oscillations,
- maximum amplitudes of acceleration $a_{\max}$ and velocity $v_{\max}$,
- response spectra (acceleration, velocity).

The first two characteristics are determined as median value μ increased by the value of dispersion σ. The distribution functions of quantities log D, log $a_{\max}$, log $v_{\max}$ display a roughly normal pattern. Therefore value $\mu + \sigma$ seems to be sufficiently on the safe side.

It is well known that the response spectra always display a rather oscillating pattern. Design response spectra S are to be created by averaging the response spectra and by fitting the average curve by two or three linear regression segments.

The method described has enabled us to propose the revision of the previous design accelerograms of the Jaslovské Bohunice NPP. Safe shutdown earthquake SSE for this NPP is characterized by the quantities: $M = 6$, $R = 20$ km, $H = 15$ km. The standard method yielded peak acceleration amplitude of the design accelerogram $a_{\max} = 0.34$, whereas the proposed modification yields $a_{\max} = 0.22$ g (Buben and Pěč, 1990).

The acceptance or rejection of this method translates immediately not only into an economic impact of several thousand million Kčs but also into the possibility of future operation of this NPP. However, the research at the Institute of Geotechnics has been stopped by the grant agency due to the "lack of funds".

5. SITE-SPECIFIED DESIGN RESPONSE SPECTRA

The reliability of the design response spectra must be improved with regard to the characteristics of the seismic response of the geologic structure in the subsoil of NPP (the microzone).

According to the presently applicable regulations, the increments of intensity on the surface of sedimentary layers are evaluated using the method based on acoustic impedances. More reliable results can be obtained by investigating the seismic response function of the microzone. This function describes the resonance/attentuation effects of the subsoil geologic structure. The site-specified design accelerograms are then determined as the convolution of the incident seismic wave wih this response function.

Various methods of determining the seismic response function of a microzone exist. The most viable under conditions of the Tetov site is considered to be experimental seismic microzoning. It is based on processing the oscillations recorded at the building site and generated by blasting operations in the neighbouring quarries. This method is limited in that the shape of the general response function also depends on the nature of the incident waves (longitudinal, shear, surface) and on their angles of incidence (Barták and Zahradník, 1985). The outlined determination of site-specified design response spectra must thus be specified also for the largest possible number of records of local seismic events. Since most of them are too weak, the estimate of the desired seismic response for stronger local events must be attempted using analytical and physical modelling.

6. TOPOGRAPHY OF REGIONAL STRONG-MOTION ARRAY CENTRAL BOHEMIA

The purpose of this array is to obtain records of tectonic earthquakes as well as seismic events of technogenic origin occurring both at the locality ($R \leq 10$ km) and in the region ($R \geq 200$ km) of the NPP.

These events should be recorded simultaneously close to the focus, as well as on the building site (on the building foundation, and also close to the building site on the bedrock).

Table I. Designations and positions of stations

Designations	λ°E	φ°N
TET (Tetov)	15.44	50.08
ZAS (Zástava)	15.83	50.12
SOV (Sovenice)	14.98	50.56
ZLE (Žleby)	15.48	48.89

Four seismic stations were put into operation in 1991. Their designations and geographic coordinates are given in Table I and Fig. 1.

Seismic stations TET and ZLE are located at a distance of about 10 km from deep fault 2.3 (Železné hory) which disturbs the upper crust. The value of gradient of the vertical component of present slip (determined by repeated levelling) amounts to about 0.5 (mm/km)/year. One earthquake on this fault has been documented historically. The seismic potential assessment of this fault is 7° MSK-64. The stick-slipping of the southern block below the northern block is considered to be the cause of seismic activity. Therefore the horizontal component of motion, in the NW direction, may predominate.

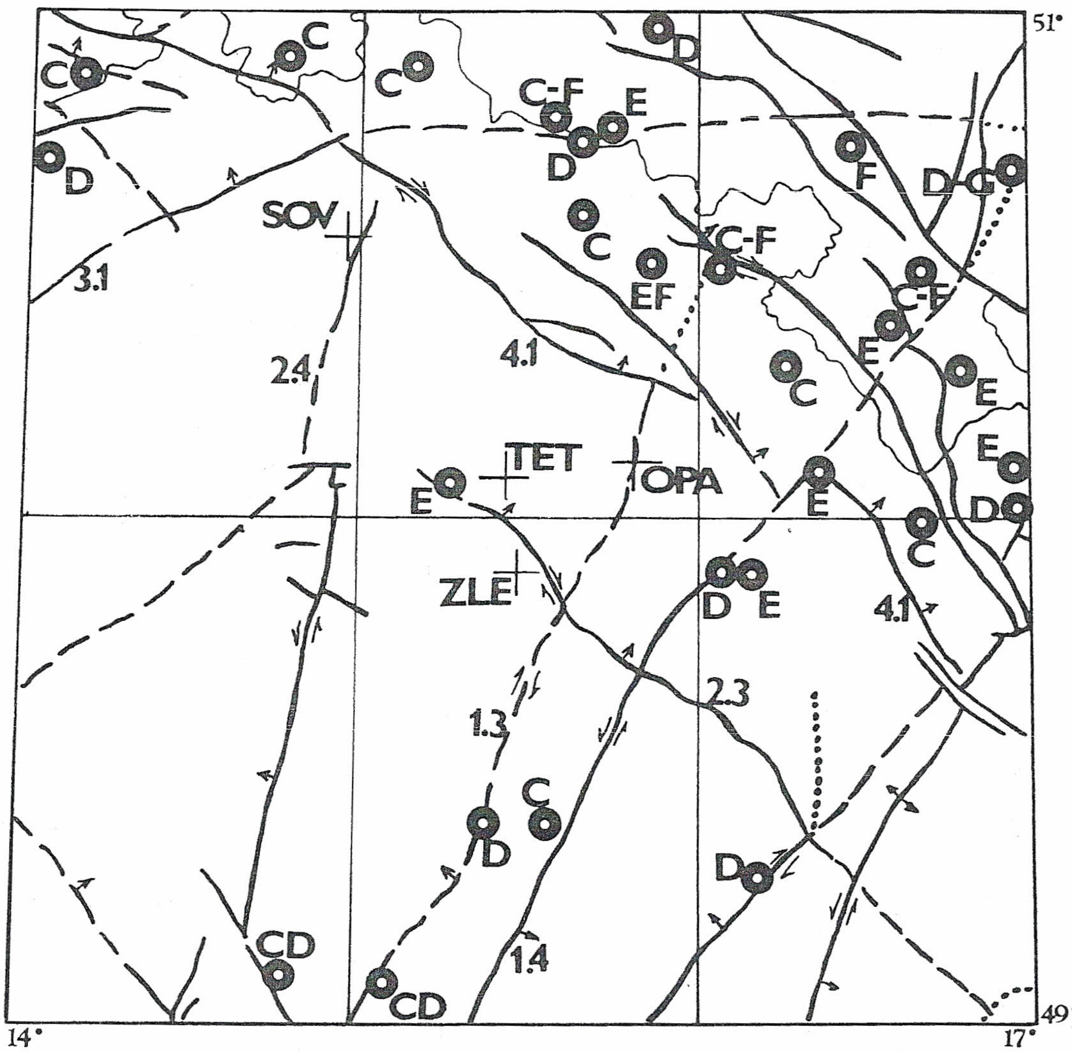

Fig. 1. Designations and positions of the array stations.

	C	D	E	F	G	H	I
I_0	III	IV	V	VI	VII	VIII	IX
M	2.5–2.9	3.0–3.5	3.6–4.0	4.1–4.6	4.7–5.1	5.2–5.6	5.7–6.1

Faults 2.3 (Železné hory) and 1.3 (Českomoravská vrchovina) intersect at distance $R = 12$ km from station ZLE. Isolated shallow foci with intensities up to $I_0 = 5°$ MSK-64 have been documented historically along fault 1.3. Fault 1.3 intersects deep fault 1.4 (Přibyslavský) at distance $R \geq 35$ km, $\alpha = 130°$ from station ZLE. Several foci with intensities $\leq 5°$ MSK-64 have been observed historically along fault 1.4. The slips probably displayed a well-defined horizontal component along the fault.

Fault 1.4 runs at distance $R \geq 35$ km, $\alpha = 13°$ from station ZAS. Foci with intensities $I_0 \leq 5°$ MSK-64 and depths about 7 km have been macroseismically documented along it in the past.

Seismic station SOV is located a few kilometres from fault 2.4 (Jizerský). This fault disturbs the underlying palaeozoic block. No earthquake foci were observed here in the past. Deep fault 3.1 (Litoměřický) and fault 4.1 (Jílovecký) intersect at a distance of 20 km and azimuth $\alpha = 350°$ from the station. Seismotectonic evaluation indicates seismic potential of this zone as $I_{0\,\max} = 6°$ MSK-64. Isolated foci with intensities up to $I_0 = 5°$ MSK-64 and depth of 5 km have been observed here in the history. These earthquakes may be related to the folding of the upper soil level in the Quaternary.

7. SEISMIC APPARATURES

Seismic instruments of our own design have been installed at the stations. Two horizontal (NS and EW) components are recorded synchronously with the time marks (station DCF 77). The records are made in the form of frequency modulation (seismic signals) and amplitude modulation (time marks) using a commercial stereophonic tape-recorder in the triggering mode. The triggering condition is exceeding the preset amplitude level within the frequency range ($1 \leq f \leq 30$ Hz). This condition is supported by protection against undesirable triggering due to noise. The most frequent disturbing signals are single spikes of electromagnetic origin. Triggering is thus blocked unless the amplitude level is exceeded again after a short time interval (e.g. of 1 s). This involves the testing of the time history which is characteristic of the seismic vibrations being recorded.

After frequency and amplitude demodulation, the recorded data are processed on a PC with the corresponding software (Málek and Růžek, 1991).

Type SM-3 standard electromagnetic seismometers ($T_0 = 2$, $D = 0.6$) are used to pick up the vibrations. The dynamic range of these instruments is limited from above by the maximum possible displacement of the pick-up coil ($s_{\max} = 5$ mm). At frequencies of $5 \leq f \leq 10$ Hz, it is therefore possible to pick up maximum oscillation velocities $v_{\max} = 2\pi f s_{\max} = 15$ cm/$< v_{\max} < 30$ cm/s. It is known that this velocity occurs during earthquakes with intensity of 5° MSK-64.

The recording device used has a dynamic range of at least 40 dB, so that the instrument is also capable of recording local earthquakes with intensity $I_0 \geq 2°$ MSK-64 which are already beneath the threshold of macroseismic events.

8. RESULTS

The events listed in Table II have been recorded simultaneously at three of the stations at least.

t is the absolute time of triggering the record (hr.min.s); τ is the duration of the oscillations (s), v_m is the maximum oscillation velocity (μm/s), and f_m is the frequency at which v_m was recorded (Hz).

Table II. Events recorded simultaneously at three stations at least

Date	Desig.	t	τ	f_m	v_m	Note
10. 8. 91	TET	07:24:39	20	5	41/25	
	ZAS	07:24:??	20	5	49/56	breakdown DCF
	SOV	07:24:31	20	6	99/55	
5. 10. 91	TET	06:17:12	25	1	48/35	
	ZLE	06:17:07	25	1.5	15/10	
	ZAS	06:17:17	25	1.5	71/58	
	SOV	06:17:31	25	1	20/27	

Table III. List of quarries in the zone and their positions

			R_E [km]				α[°]			
Desig.	λE°	φN°	ZLE	ZAS	TET	SOV	ZLE	ZAS	TET	SOV
ZBRA	14.33	49.09	84	110	82	85	272	260	258	215
KLEC	14.46	50.18	83	106	75	61	293	274	278	224
MRAC	14.69	49.76	57	88	61	86	264	249	243	195
MILI	14.67	49.57	70	102	80	114	329	235	225	193
PLAN	15.03	50.61	37	57	30	57	118	264	265	179
BERN	15.11	40.67	37	72	52	100	228	227	209	175
ZUMB	15.87	49.74	26	27	38	99	274	175	307	322
CHVA	15.39	50.03	18	33	7	67	157	253	210	335
BUDI	16.18	49.80	50	43	61	119	281	325	301	316
ZELH	15.75	49.63	33	54	54	117	147	187	157	153
MAST	16.22	50.23	65	31	59	95	233	243	252	293
BELI	14.47	49.77	74	101	78	97	259	248	244	203
LITI	16.31	50.08	66	37	66	111	252	274	270	299
CHOL	15.79	49.98	15	21	16	78	40	227	128	225

Two long-period events (0.6 Hz) with amplitudes of 30 to 40 μm/s were recorded on 12.7.91 at 12:46 and on 18.7.91 at 14:00 at all the four stations of the network.

Figs. 2 and 3 show examples of the event velocigrams and amplitude spectra which were recorded simultaneously at stations SOV, TET and ZAS at 7:24 on 10.8.1991.

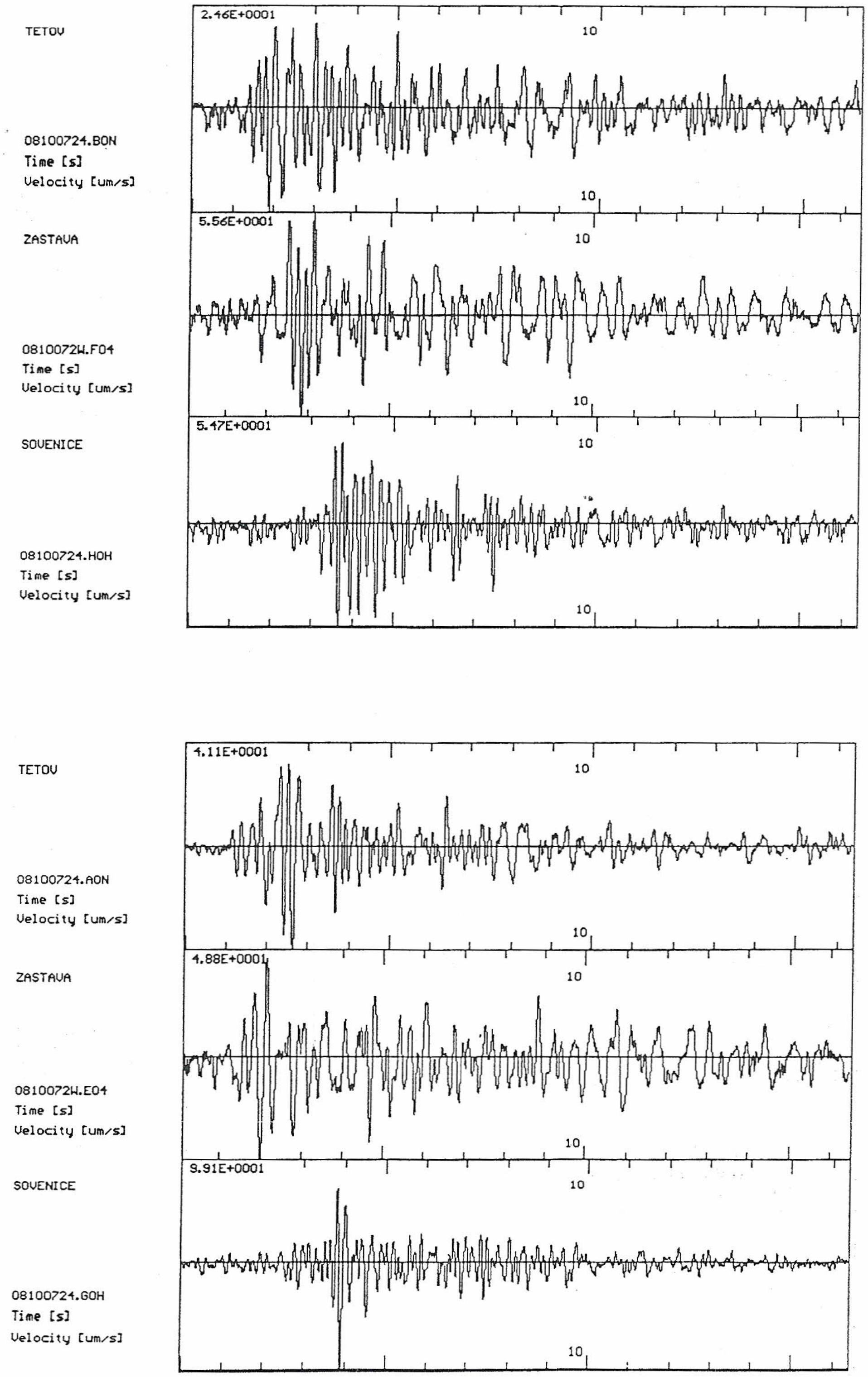

Fig. 2. Velocigrams of the event of 10. 8. 1991.

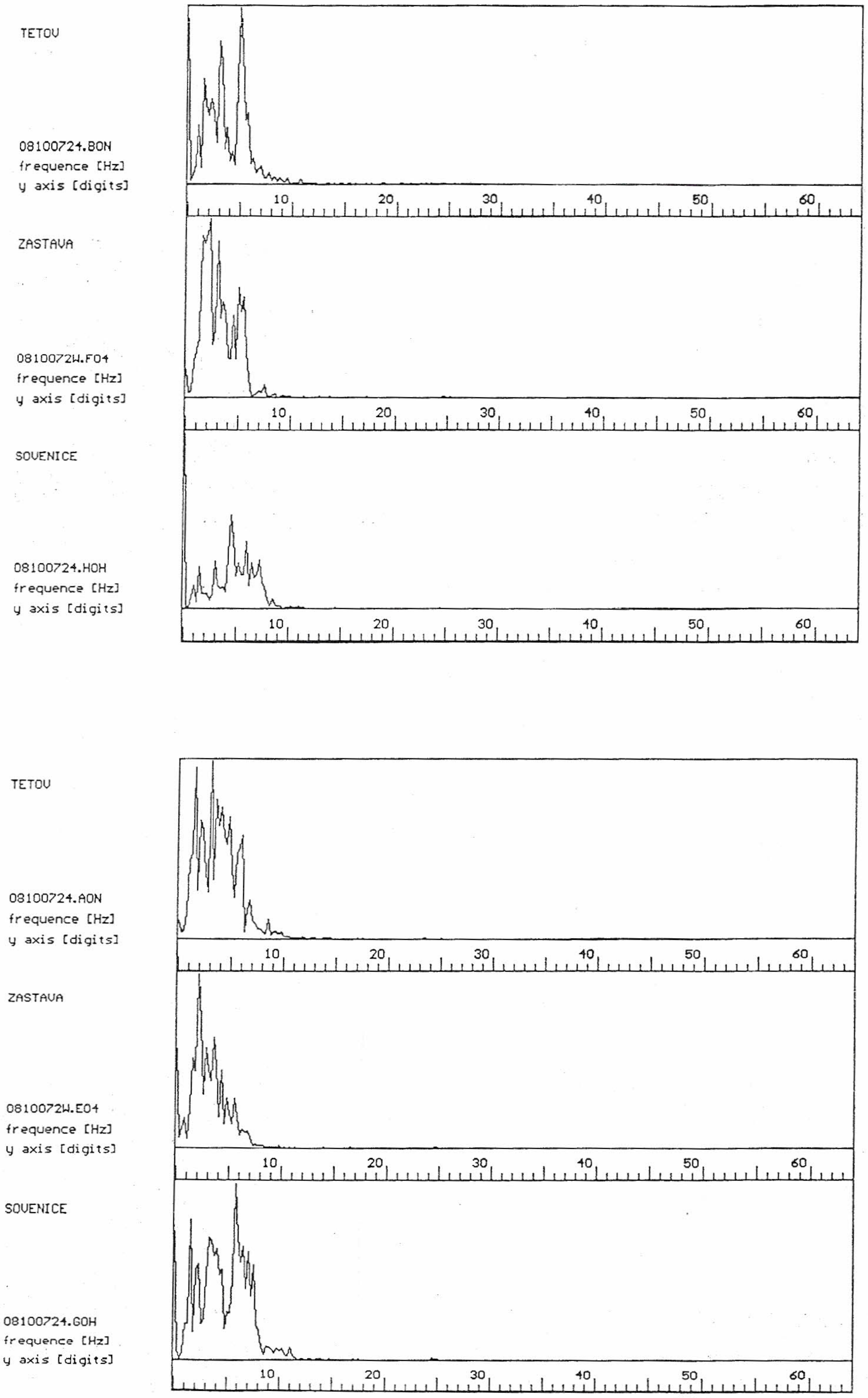

Fig. 3. Amplitude spectra of the event of 10. 8. 1991.

The classification of the recorded events, i.e. mainly discrimination between tectonic and technogenic events, is based on the registration of blasting operations carried out in quarries. A list of the quarries operating in the zone is given in Table III.

After accumulating a larger number of records we shall be able to distinguish between the blasts in the separate quarries applying type analysis to their records. Table II indicates that blast records from various distances and azimuths will be available from each of the stations.

The records of blasts can also be used to check experimentally the seismic transfer functions of the geologic structure (microzone) underlying the seismograph. Figs. 2. and 3 illustrate this method. Records shown in the time domain (velocigram) as well as frequency domain (power spectrum) were made simultaneously at stations TET, SOV and ZAS. Local maxima at frequencies of 2 to 6 Hz can be seen at station TET, the underlying layer of which is a 200 m thick sedimentary (cretaceous) layer; this agrees with the results of site microzoning which we have carried out here earlier using the method of spectral analysis of continual microvibrations.

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REGIONÁLNÍ SEISMICKÁ SÍŤ STŘEDNÍ ČECHY

Jiří Buben

V regionu Střední Čechy byla vybudována síť seismografů pro záznam silných blízkých seismických jevů. Účelem této sítě je získání empirických podkladů pro konstrukce místně specifikovaných akcelerogramů maximálních výpočtových zemětřesení. Seismografy sítě Střední Čechy pracují v čekacím režimu, mohou zaznamenávat průběhy rychlosti kmitání ve frekvenčním pásmu 0,5 až 30 Hz a v amplitudovém rozsahu do 3 m/s. Dynamický rozsah aparatur je 40 dB.

Stanice jsou postaveny jednak v blízkosti místních tektonických zlomů (Žleby, Sovenice), jednak v uvažovaných místech výstavby JE Střední Čechy.

Ve druhém pololetí r. 1991 bylo již zaznamenáno několik jevů. Jejich počítačová interpretace je zajištěna přístrojovým a programovým vybavením vyvinutým v ÚGt. Umožňuje stanovení spektrální odezvy oscilátorů, výpočet lokálního magnituda a průběžné vyhodnocování polohy ohnisek regionálních jevů. Jsou sledovány velké trhací práce v okolních lomech, které poskytují dostatečně dlouhý pozorovací materiál i pro stanovení lokální kinematické a dynamické charakteristiky podloží místa výstavby JE.

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