NEW LOCAL SEISMOLOGICAL NETWORK IN SOUTHERN BOHEMIA

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ABSTRACT
A modern seismological network with telemetric data transfer has been constructed in southern Bohemia. The network is made up of 5 stations equipped with Reftek DAS (Data Acquistion System) 130-01 Broadband Seismic Recorders and GeoSIG VE-53 triaxial velocity sensors with a natural frequency of 1 Hz. The network works at a sample rate of 250 Hz. The main purpose of this network is to monitor local seismicity in southern Bohemia with a special focus on seismic activity in the vicinity of the Temelin NPP. The sensitivity in the central part of the network is at least 0.0 M_L. In addition to monitoring local tectonic movements it also monitors the effects of Alpine earthquakes in the area of southern Bohemia. For this reason one of the sites on the network is equipped with a GeoSIG AC-63 triaxial force balanced accelerometer.

KEYWORDS: microseismicity, nuclear power plant, southern Bohemia, local seismic network, data acquisition

1. INTRODUCTION

The construction of a sensitive local network in the southern part of the Bohemian Massif came about both from the need to keep the population informed about the seismic activity in a region where a nuclear power plant Temelín (NPP) is situated and equally from the necessity of measuring natural seismicity in the environs of the NPP (IAEA, 2002), for location of the network see Fig. 1. The previous seismological network consisted of five individual stations equipped with Lennartz 5800 broadband seismic recorders working in trigger mode with a sampling rate of 125 Hz. Mark triaxial seismometers were used as velocity sensors with a natural frequency of 2 Hz. The seismological data from these stations were recorded on a PC hard disk and could be transmitted in dial-up mode. The new network should allow the online transmission of data to a main processing centre, the increase of the sampling rate to 250 Hz and the transmission of a State of Health (SOH) channel. The enablement of remote configuration of the seismological stations is also an important consideration.

The local seismological network is situated in the Moldanubian Zone, which forms the southern part of the Bohemian Massif. The Bohemian Massif is the remnants of Variscan uplands formed up in the period from the Middle Devonian to Upper Carboniferous. Its cause is taken to be the collision of Gondwana and Laurussia (Chlupáč et al., 2002). The Bohemian Massif was not markedly deformed after the Variscan orogeny and become a firm consolidated basement. The rise of the Alps in the Mesozoic and Tertiary, which formed the Alpine-Carpathian region, created numerous faults in the Bohemian Massif. The recent activation of these faults can be caused by the movement of the African Plate and its satellite microplates in a north or north-westerly direction. The most important of these for the region in question is the Adriatic microplate, which is pushing the Alp complex to the north. The recorded seismicity reflects the geological situation in the area: local tectonic earthquakes with hypocentres in southern Bohemia are normally found as microquakes, whereas stronger ones are registered from the Alpine region.

2. SEISMOLOGICAL INSTRUMENTATION

Each seismological station is equipped with a seismmometer placed in a steel-lined shaft at a depth of 2 – 4 metres (according to the geological conditions of the location). The seismmometer is a triaxial velocity sensor VE-53 with a natural frequency of 1 Hz made by GeoSIG. The sensitivity of the sensor is 1000V/m/s. One of the stations on the network is also equipped with a GeoSIG AC-63 accelerometer. A diagram of the seismological station is given in Fig. 2.

Each seismological station is equipped by Reftek DAS 130-01 data acquisition system. This is a very precise high performance low power 24bit A-D converter having a dynamic range of more than 135 dB. The sample rate can be varied greatly, so the DAS

can register the required frequency spectrum. Amplifiers using software configured amplification mode allow the connection of various seismometers. The seismological data is synchronised using a GPS receiver time stamp. The data can be accessed either via the serial port or by Ethernet. Software setup allows the configuration of eight different measuring modes, recording concurrently in "streams" as follows:

0. SOH channel. This stream contains basic information about the state of the equipment, the GPS receiver and parameters set for the measurements.
1. Continuous record with choice of length of record and start of registering.
2. Event trigger – data is recorded when the ratio of the short time average (STA) and long time average (LTA) exceeds a specified ratio.
3. Level Trigger. Data will be recorded when the amplitude of the data exceeds a specified threshold.
4. Cross trigger. Cross triggering allows the start of data recording in the case that one of the other data streams is activated.
5. External trigger. External triggering allows the control of data registering by use of external tools including non-seismological equipment.
6. Time interval trigger. Time interval triggering at a planned time with a defined start point, length of data registering and number of repetitions.
7. Time list trigger. Time list triggering according to a list of time events, which define the beginning of registering and the length of the record.

The data from each stream is recorded on the DAS's internal memory. This memory comprises twin CompactFlash discs with a joint capacity of 2GB (twice as much – 4 GB – at the site with the accelerometer), which are in constant cyclical record mode, so the minimum period of data storage on-site is 7 days. Digital output is taken from the seismological equipment to an input HUB MSC-06. A Liebert PSI 700MT UPS (Uninterruptible Power Supply) is connected to another port via a SNMP card. This allows constant control over the power supply in the station. The data is transferred by radio link to a subcentre, where is processed along with the data from the other stations by Multilink 3.0 software. In the case of a power failure or any other faults, a message is sent by email to a control centre, which allows for almost instant reaction and servicing. The UPS is line interactive with an AVR(automatic voltage regulator) system, that guarantees stable power supply even in the case of long term weak or interrupted current flow. The predicted back-up period is about 5-6 hours. The seismic recorders are supplied for a further 48 hours by another UPS (type BZ 12EP) in order to minimise the loss of seismological data. In the case of a lengthier failure the data will not be transferred by radio to the subcentre, but will continue to be recorded in the memory of the seismological equipment and can be accessed after re-establishment of the signal for a minimum period of 7 days.

3. TELEMETRIC TRANSFER OF DATA

One of the important requirements of the seismological network is the transfer of data to the control centre as quickly as possible so that the signal can be followed in an "on-line" mode. Connected to this apparently simple requirement are a whole host of problems including the choice of the most suitable method of data transfer not only to the subcentre but also on to the evaluation centre for further processing. The most suitable and easily achievable solution for the transfer of data from the individual sites is radio connection. Currently, with all low frequency radio bands (usually UHF and VHF bands) fully used, the solution is to use a radio band with a higher frequency in the GHz range. The 3.5 GHz band was therefore chosen, which, although it requires a telecom-munications payment unlike the more frequently used 2.4 GHz band, guarantees problem free service without interference that might cause data drop-out. The service offered by Alvarion was chosen from those offered in this frequency, as they provide very reliable equipment also used to a great extent by ISPs (internet service providers). The radio network is a point-multipoint one. The base radio unit is sited in the centre of the network with individual user radio units located at the seismological stations.

The radio network also fulfils the requirement for a duplex service based on the principle of separate frequencies for the data stream in the direction of the control unit and that in the opposite direction. The base radio unit found at the centre of the seismological network is comprised of an internal and external radio section. The external unit is located by the antenna system made up of various antennae with various gain levels and specific radiation pattern ensuring connection with the individual stations. The antenna system is based on an external unit of two splitters and directional couplers. These elements ensure optimal gain for the individual antenna and the correct impedance so that there is no reflection of the high frequency signal. The use of these state-of-the-art lightning protection ensures uninterrupted service even in the event of extreme power spikes. The external unit is connected to the internal unit by means of a low-loss coaxial cable, both units communicating at a frequency of 440 MHz. Ethernet data output from the internal unit is through a HUB connected to a SUN station storing data from all stations.

The units transferring data from the seismological stations are set up in a similar way. The external unit, in connection with a narrow directional antenna with a minimum gain of 24 dB, is placed on a mast in the vicinity of the seismological station. The internal unit is placed in the immediate vicinity of a

data acquisition system which processes the data from the seismometer. Its input is also surge protected. The data interface is equipped with Ethernet as in the case of the base station units.

All data recorded at the SUN workstation at the centre of the seismological network need to be further transmitted to the processing centre and that if possible in real time mode. The use of the internet and the services of certain ISPs was chosen as the most suitable option for the transfer of these data. The connection of our network to the ISP uses radio connection on the 3.5 GHz band, allowing all data to be transferred on line, immediately processed and visualised in the form of a seismic signal. In the opposite direction, i.e. from centrum in Brno, the whole network can be monitored, including all radio and seismic parameters, the state of the UPS, the temperature in the cases where the equipment is housed and other parameters. The parameters of the network can also be operationally configured depending on any given situation so that the information from the network answers to the most demanding criteria.

4. NETWORK CONFIGURATION

In choosing sites for the network it is necessary to take care to ensure that all criteria necessary for its functioning are fulfilled (IAEA, 1985). These requirements can be split into 6 groups:

1. a low level of interference from the surroundings (buildings, industry, transport)
2. a high quality radio connection to the subcentre
3. optimal cover by the stations of the area in question
4. relatively good access to the national grid (230 V)
5. minimal conflict with the activities of the landowners
6. access for the construction work.

The most important criteria are the choice of suitable sites from the point of view of geometric positioning around the area to be measured and ensuring the minimum seismic noise background and with it the sensitivity of the network for the detection and measurement of seismic events (Trnkoczy et al., 2002). In this situation the most suitable sites are those furthest from the influence of civilisation with the placement of the sensors at such a depth so that they are on a firm base and at the same time isolated as much as possible from the influence of surface noise sources such as trees, nearby roadways and so on.

The important criterion is the ability to transfer the data to the subcentre of the seismological network and the transmission of control codes connected with the functioning of the stations and in the opposite direction the ability to change the parameters directly from the processing centre. In order to establish a high quality radio signal regardless of the influence of negative climactic conditions (heavy snow or rain), it is necessary to choose positions from where there is a clear line of sight from the stations to the central radio unit based at the centre of the seismological network. This requirement is obviously best answered by the placement of measuring stations at a height to give terrain clearance. Another reason for the requirement of line of sight is the use of frequency bands using centimetre wavelengths.

Another important factor is access to the local power grid which will supply the technological equipment of the stations. The requirements of continuous functioning of the station and radio transmission of data cannot be supplied by sources such as solar panels, as at these latitudes the energy requirements of the station cannot be satisfied for long periods of the year from such a source. In addition it is necessary to ensure the supply of power to the stations in the event of a long term failure of the grid and have a back-up power supply available in this event usable at any time day or night.

Not to be overlooked are points 5 and 6, that is the minimalisation of conflict with the landowner, i.e. their granting of permission for such activity on their lands and access rights to the site for construction work. From these conflicting requirements it can be seen that great care must be taken in the choosing of the individual sites. Sitting also required numerous measurements of background noise in the surveyed sites, investigation of the accessibility to the power grid, measuring the level of radio signals with a view to maximum allowed emissions, and subsequent meetings with landholders and local government offices.

A reconnaissance of the terrain was carried out in the years 2003 – 2004 with the aim of finding sites for a subcentre and 5 measuring stations fulfilling the requirements for seismological stations in a local network. It was necessary to choose a central position for the subcentre with the assumption of good radio communications to the future stations. The CHMI (Czech Hydrometeorological Institute) observatory at Temelin with a 40 meter radio mast proved to be suitable as it could be equipped with antennae for radio transmission. After a survey of the area and drawing up of altitudinal cross-sectional profiles between the station and the subcentre, 3 – 7 potential positions were chosen for each station. A series of noise measurements were taken at each site over a period two days and 5 sites within a range of 6 – 23 km from the nuclear power station fulfilling the criteria were found.

Altogether 40 noise measurements were carried out, each of them over a minimal period of 48 hours. The site selection was very difficult because of the rugged topography, high population density, local industry, and communications. The final selection of the five sites is therefore a way of a compromise in meeting the requirements 1 – 6 given at the beginning

of this subchapter. The positions of the 5 seismological stations comprising the final measuring network are marked on the schematic map in Fig. 1.

On the basis of the results of noise measurement and using a formula for the calculation of local magnitude the sensitivity of the network was calculated. The requirement for the sensitivity calculation was the registration of the sesimic event on a minimum of four stations with the signal-to-noise-ratio four. The area of interest was divided into a grid of points with the grid cell size of 1 km in both horizontal directions. At each point we supposed the local earthquake at a depth of 10 km and then we calculated the magnitude at all five stations for this earthquake. The starting value of the amplitude was the mean level of the noise measured at the station. In the calculation we entered this value multipled by four into the formula for the local magnitude calculation (Scherbaum and Stoll, 1983) with other earthquake parameters:

$$M_L = (2800 \cdot \log_{10}(U))/0.6325 + 1.4 \cdot \log_{10}(H) + 0.1$$

where U is the amplitude of the signal (displacement in mm) and H is the hypocentral distance from the supposed earthquake to the station in km. We got five magnitude values for each point of the grid. The requirement for the localisation is the event occurence at a minimum of four stations: we took the four best values of magnitudes and selected the worst of these four. This value is the sensitivity at the point in question. We calculated these values stepwise for each point of the grid (600 points together) and generated the contour map. The result is in Fig. 3. It is evident that the network fulfils conditions to record seismic events with minimum magnitude $M_L = 1.0$. In the area close to power plant the sensitivity is $M_L = 0.0$ and better.

5. ACQUISITION AND EVALUATION OF DATA

The data from all five stations is continually transmitted by radio to the subcentre for further evaluation. Up to eight data streams with various sampling and acquisition parameters for seismological signals can be defined for transmission. In view of the expected frequency of the signals a sampling rate of 250 Hz was chosen. For the transfer of seismic signals three streams are used: stream 0 carries State of Health, stream 1 with continuous data and stream 2 selecting data from the individual stations based on the STA/LTA event trigger algorithm. The extent for the measured frequencies is within the bandwidth 1 – 100 Hz.

The subcentre equipment is located at Temelín meteorological station, in a dedicated room with cable access and the possibility to site a case containing communications technology and a SUN work station. The SUN workstation runs *rtpd* software in an uninterrupted mode which compiles the database of seismological data in Reftek format. Running on this platform is *rtptrig*, which compiles records on seismic events in all measured channels based on the coincidence of seismic events from several stations of the network (a minimum number of stations within a selected time frame). The SUN work station transmits this data to the data centre over the internet at a speed of 256 kb/s. The link and its attached radio connection allow two-way access to the computer subcentre and the individual seismological station. This allows input and changes to the parameters of both data measurement and recording. All levels of the equipment's operation are controlled by a monitoring programme and any drop-out in measurements or acquisition of data is flagged by email. The data acquisition and processing flow chart is in Fig. 4.

The data is stored at the processing data centre in Brno on a SUN 1500 Blade computer. Streams 0, 1 and 2 are transferred from all stations, i.e. information about the state and monitoring activity of each of the stations, continuous seismological data and data clusters chosen by the STA/LTA algorithm from each individual DAS. Data selected by the *rtptrig* software run at the subcentre is transmitted independently of the previous data flow. The SUN 1500 Blade runs *snda* at the data centre, which performs its own analysis of the continuous data. *Snda* analyses the individual data streams, organises them into potential seismic events and localises them. All data is stored for further analysis.

A test was run on data acquisition during the period from 7.10. to 7.11. 2005. The data selected by *rtptrig* at the subcentre, data files from *snda* and additional continuous data was used for analysis. Data analysis methods were the standard used at IPE Insitute. First the data was converted from Reftek format to the css3.0 format commonly used by

Table 1 Table of measurement parameters.

Equipment	Parameter	Value
Seismometer VE-53	natural frequency	1 Hz
Seismometer VE-53	sensitivity	1000V/m/s
Accelerometer AC-63	sensitivity	1g/10V
Reftek DAS 130	LSB	49 nV
Reftek DAS 130	sample rate	250 Hz
Seismic channel	frequency band	1 – 100 Hz

Table 2 Categorization of events based on epicentral distance.

Type of event	Epicentral distance	Number
local	to 50 km	17
near	50 – 200 km	192
regional	200 – 2000 km	51
teleseismic	more than 2000 km	32
total		292

analysis programmes. Seismic events were visualised and further analysed using *geotool*. After seismic phase identification and arrival time and amplitude reading, events were separated into four categories according to predicted distance from the centre of the network:

- local to 50 km from the network centre

- near at a distance of 50 – 200 km

- regional at a distance of 200 – 2000 km

- teleseismic at a distance of greater than 2000 km

In view of the fact that emphasis was placed on seismicity in the vicinity of Temelín, attention was focussed mainly on registering the first two groups, with special emphasis on local events. Arrival times, type and amplitude of the phases taken from *geotool* were used as input for the *hypo3d* programme, which performs three-dimensional localisation of seismic events and calculates local magnitude

6. RESULTS OF THE TESTING PERIOD

During the period from 7.10. to 7.11. 2005, 292 seismic events were registered. An overview of registered events is shown in Table 2. Of the total number, 17 events were explosions from local quarries at a distance of up to 50 km from the network centre, 192 events at a distance of 50 – 200 km from the centre of the network (without closer investigation it is impossible to tell whether these were blasts or quakes); 51 regional events were recorded and 32 teleseismic ones.

Using the localisation of 17 local explosions, confirmation at the quarries verified the fact that the localisation error was no greater than 500 meters. The local magnitude of these blasts was in the range of $M_L= 0.0 – 0.8$. This proved that the network is sensitive enough to measure local seismic events with $M_L=0.0$.

A blast from the quarry at Slavětice is shown in Figure 5. The blast was carried out at 11:26 UTC on 12.10 2005, with a charge of 6810 kg. Two earthquakes occurred in the area of Hronov in the Czech Republic of local magnitudes 3.3 and 1.5 on 25.10.2005 and 7.11.2005. The strongest was macroseismically observed by people in north-eastern Bohemia. Figure 6 shows the weaker of the two on 7.11.2005 at 19:24 UTC to document the sensitivity of the network. Figure 7 shows a record of a $M_L=2.7$

earthquake from the Austrian Alps, on 23.10 2005, the spectrum of registered signals is shown in Figure 8. In the regional and teleseismic category further events were registered from France, Greece, India, Pakistan and Japan, among others were recorded. Measuring these earthquakes is not the aim of the local network, however.

7. CONCLUSION

The newly built seismic network in southern Bohemia equipped with telemetric data transfer represents a marked technological improvement for operational evaluation of seismic monitoring. Duplex operation of a point-multipoint radio network allows the transmission of seismological data and a State of Health channel to the subcentre and control commands in the direction of the seismic equipment. The subcentre of the network is telemetrically joined to the internet, thus allowing data to be transferred to the processing centre.

During the month testing the local seismological network registered almost 300 seismic events. The majority of these events were near seismic events with an epicentre at a distance of between 50 and 200 km from the centre of the network. All local events with an epicentre at less than 50 km were identified as quarry blasts. In view of the fact that the hypocentres of these blasts are known it was possible to determine that the margin of error in the localisation of local blasts is not greater than 500 meters. The magnitude of the quarry blasts shows that the sensitivity of the network at its centre is $M_L=0.0$ at least.

Because of the large dynamic range of the seismological equipment, which is more than 135 dB, it is possible to register both very weak local tectonic events as well as strong Alpine earthquakes.

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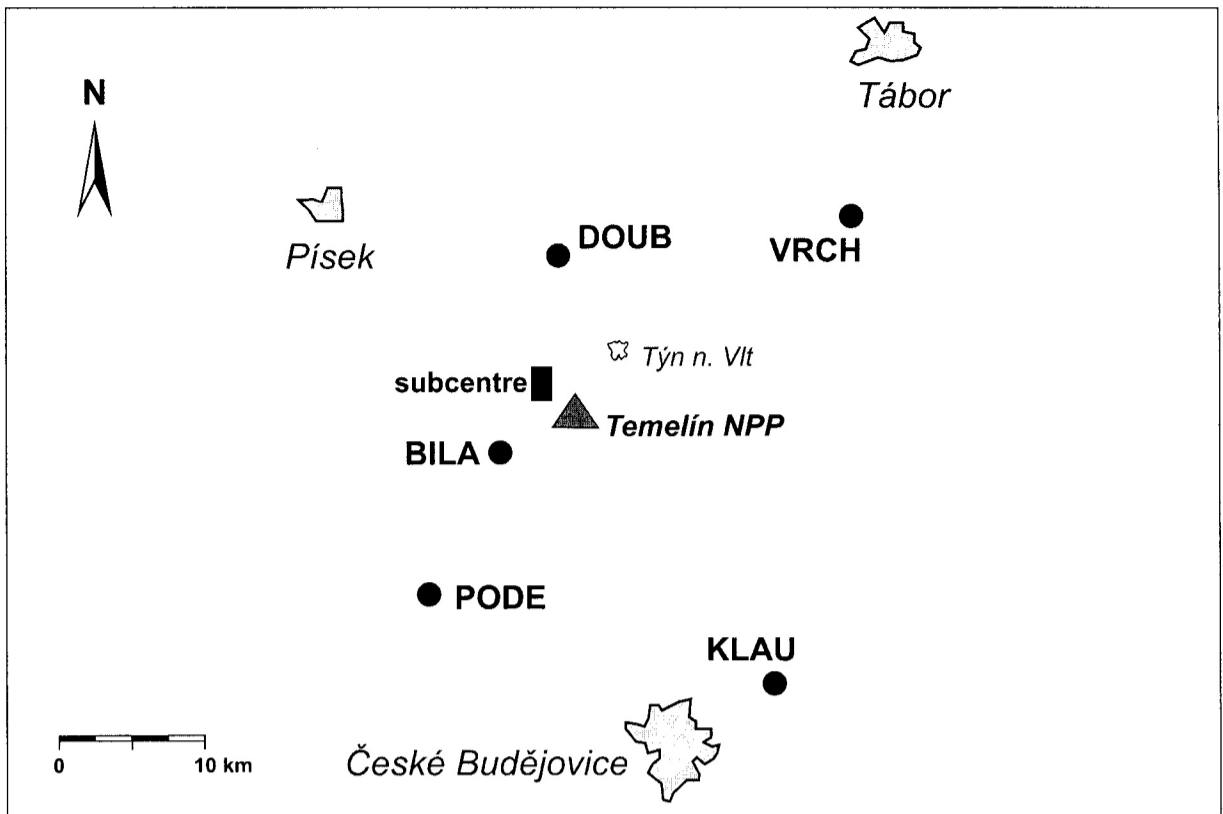
Fig. 1 Schematic map of the seismological network in southern Bohemia. Monitoring sites – black circles, network subcentre – black rectangle, Temelín NPP – grey triangle.
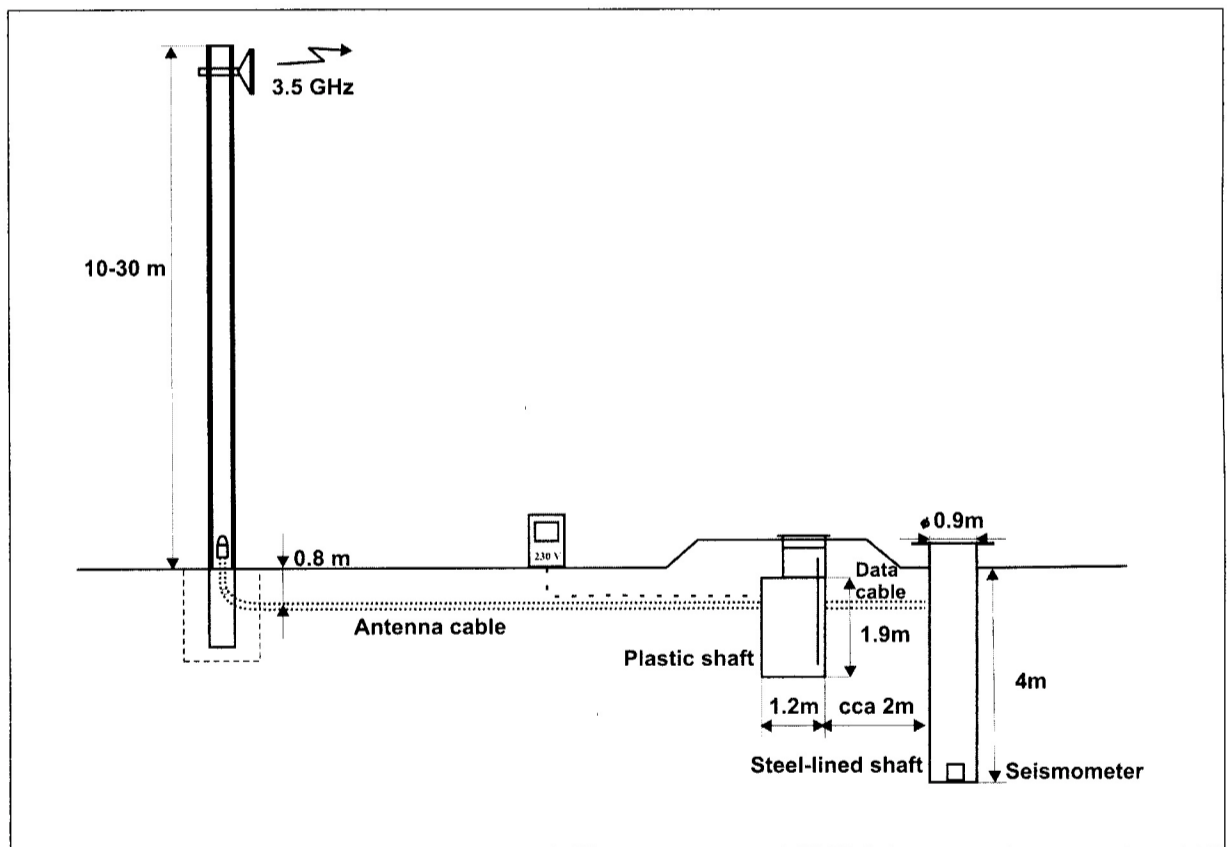
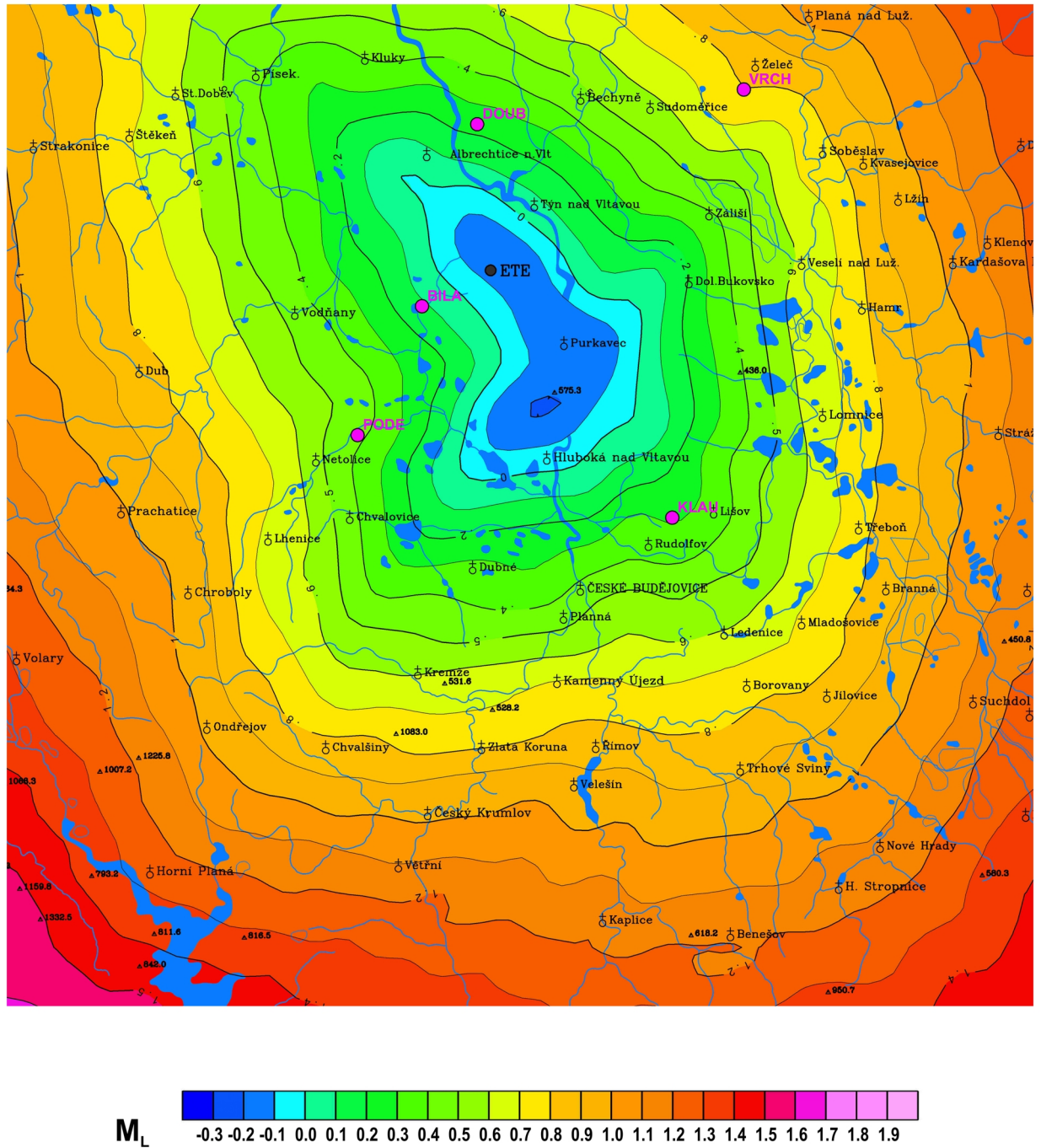

Fig. 2 Seismological station diagram.

Fig. 3 Sensitivity of the seismological network plotted in local magnitude M_L. Based on noise background measured at sites of the seismological stations. Signal to noise ratio SNR 4:1 required at four stations at least as localisation condition.
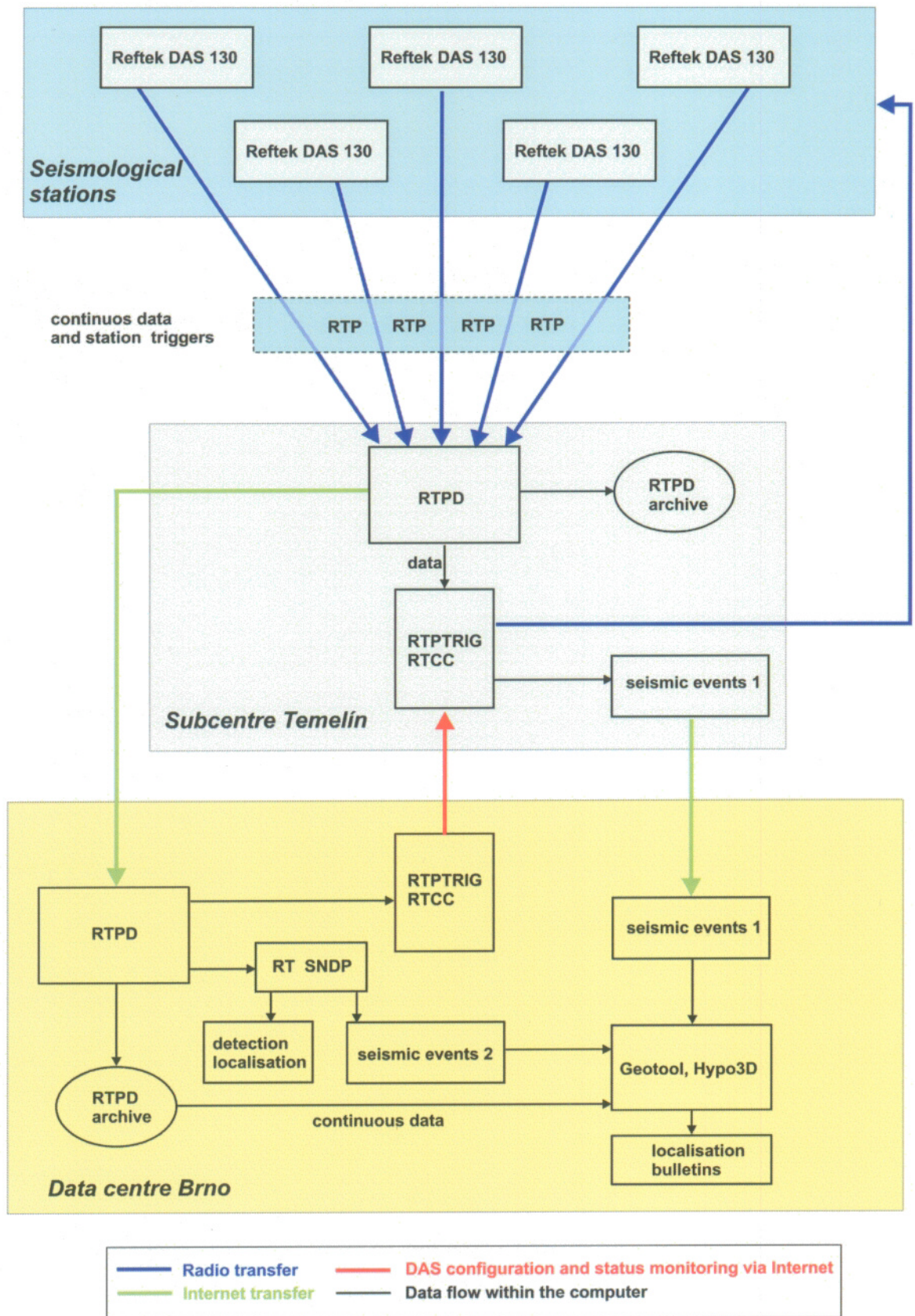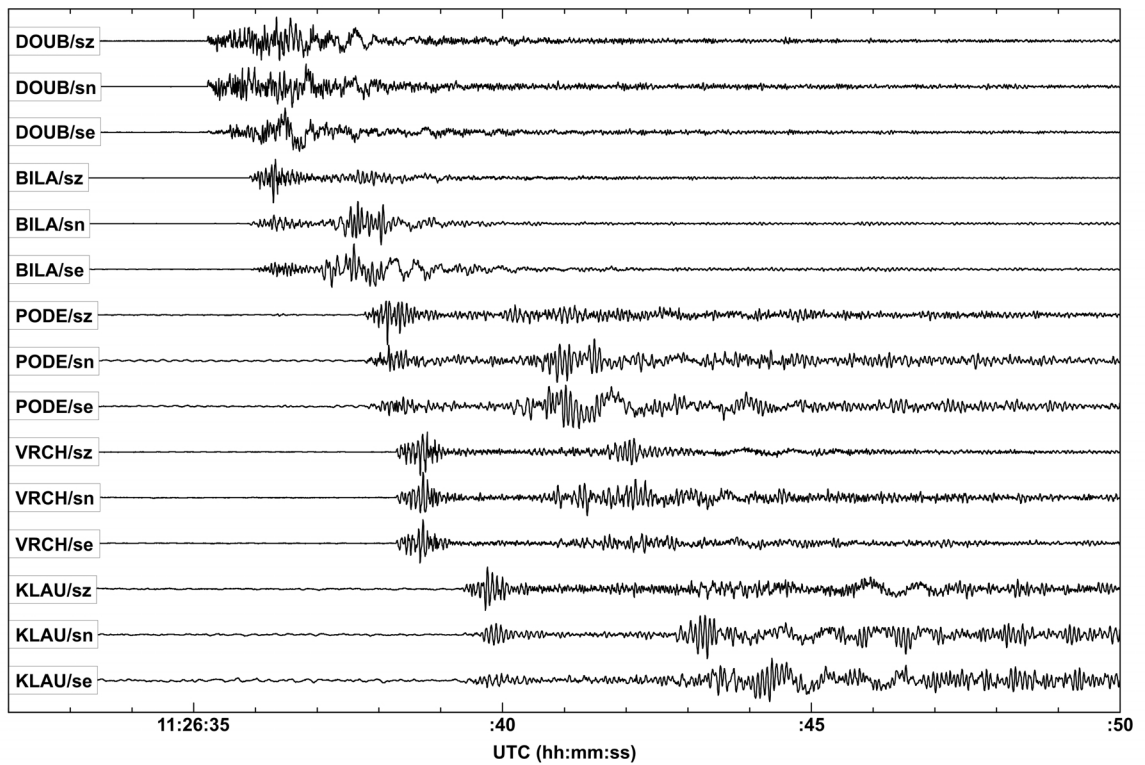
Fig. 4 Data processing flow chart.

Fig. 5   Example of a seismogram – explosion from Slavětice quarry on 12.10.2005, 11:26 UTC, charge 6810 kg. Signal at all five stations, components sz – vertical, sn – horizontal N-S, se – horizontal E-W.
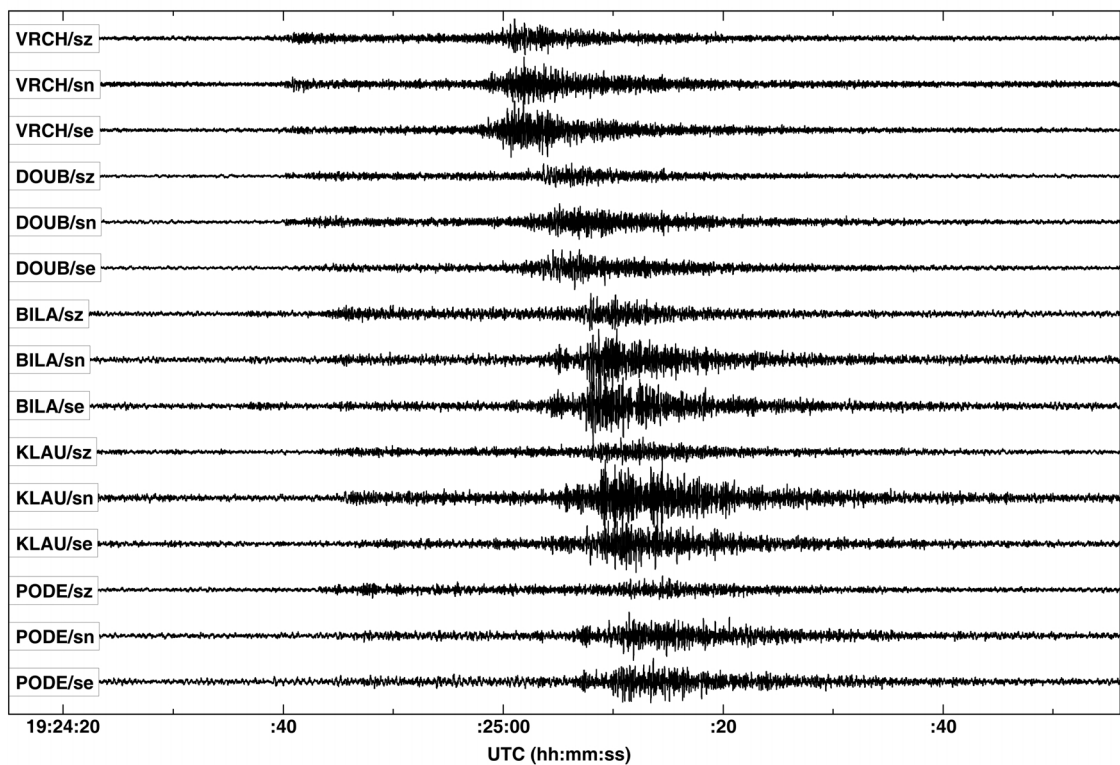

Fig. 6   Example of a seismogram – earthquake near Hronov in the Czech Republic, 7.11.2005 at 19:24 UTC, M_L=1.5. Signal at all five stations, components sz – vertical, sn – horizontal N-S, se – horizontal E-W.
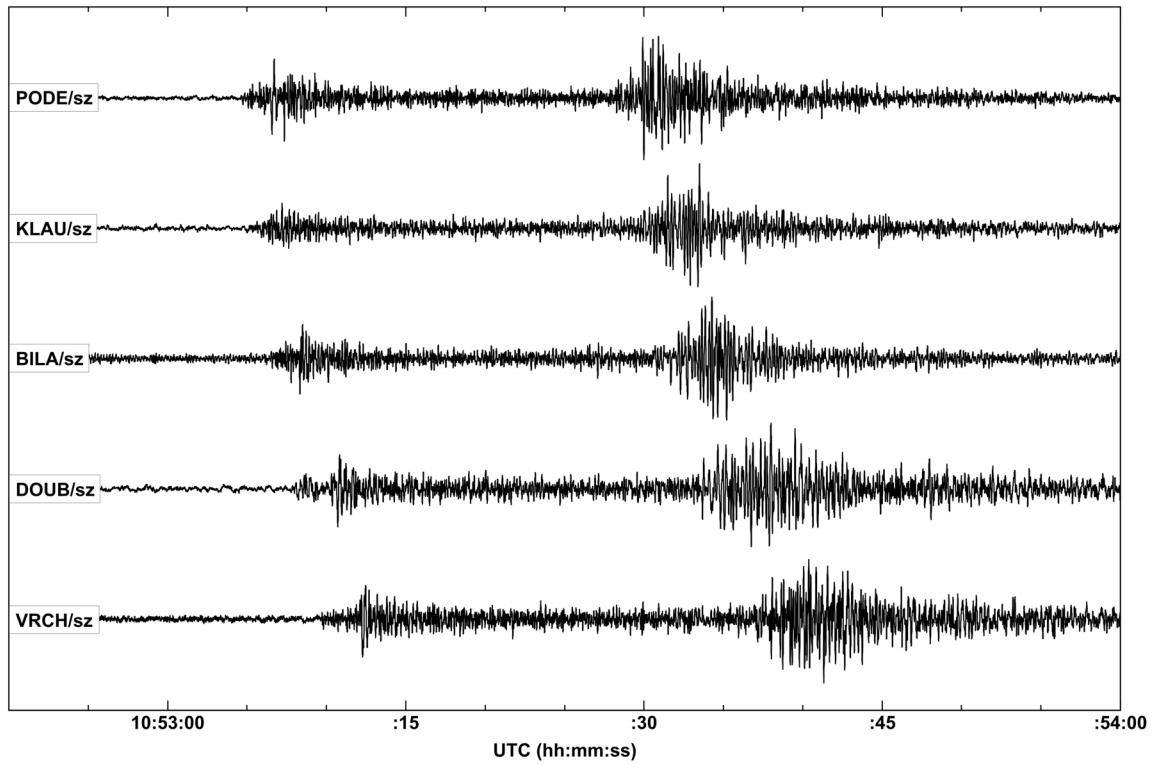
Fig. 7   Example of a seismogram – earthquake from Austria, Salzburg on 23.10.2005 at 10:53 UTC, M_L= 2.7. Signal at all five stations, vertical components.
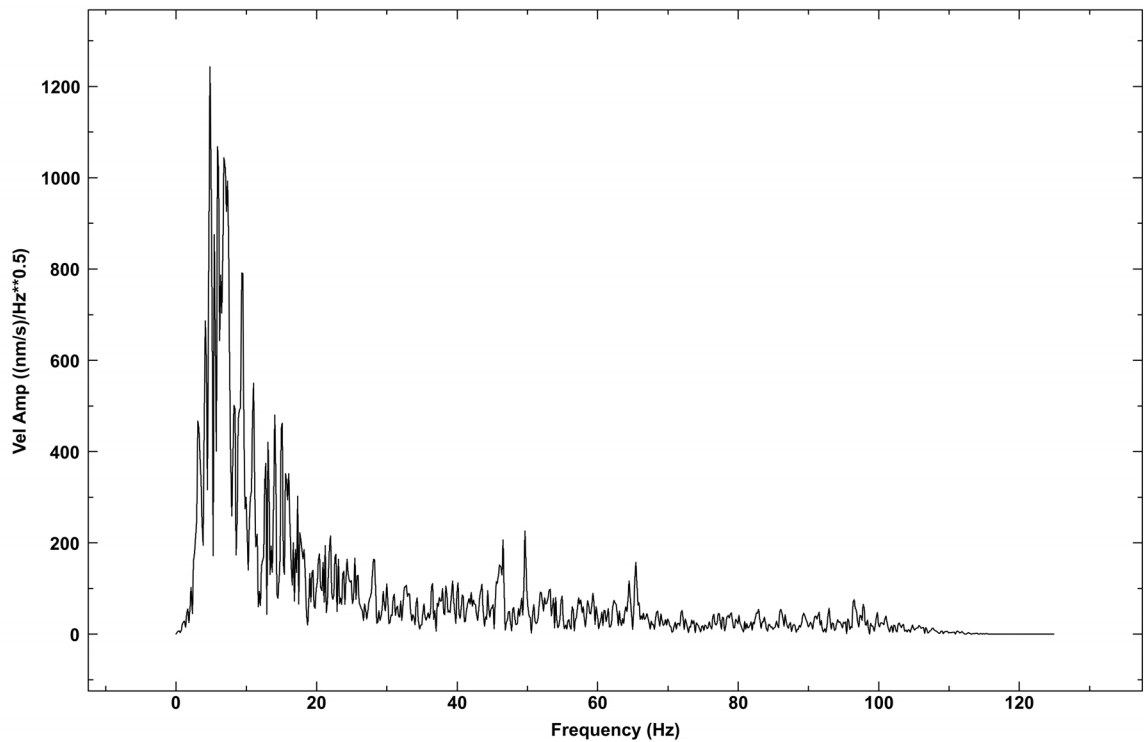

Fig. 8   The amplitude spectrum of seismic signal, earthquake from the Austrian Alps on 23.10.2005 at 10:53 UTC, M_L=2.7 recorded by station BILA, vertical component, Sg phase.