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STUDY OF SITE EFFECT USING MINING INDUCED SEISMIC EVENTS AND AMBIENT NOISE FROM KARVINÁ REGION

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ABSTRACT
Evaluation of seismic loading in urban areas is not a simple process. The horizontal to vertical spectral ratio method technique has been often used for determination of site effect recently. Results from the re-interpretation of mining induced seismic events from Karviná region in frequency domain using archival databases will be presented in this study material. Also, spectra of continuous records (about two days) and evolution of spectra within a moving time window of the length 10 seconds are presented. These continuous records were registered on two places with different geological conditions.

KEYWORDS: mining induced seismic event, ambient noise, spectral ratio, frequency analysis

INTRODUCTION

Mining induced seismicity does not only implicate number of problems in underground workings, but the most intensive seismic events have also significant macroseismic effect on the surface (e.g., Kwiatek, 1998; Kaláb, 2004). This seismic effect on surface structures in Karviná region, Czech part of the Upper Silesian Coal Basin, is monitored using solitaire seismic stations operated by the Institute of Geonics, v. v. i., ASCR, Ostrava (below IGN). At present, the influence of site effect on seismic manifestation in given position, especially on maximum velocity values and frequency content, is not documented. Therefore, we do not qualify the application of measured value validity for the surroundings of the operated seismic station.

The most popular seismological method for evaluation of seismic site response is based on Fourier transform of records and on horizontal to vertical spectral ratio method, so called HVSR method or Nakamura´s method. Principles and theoretical reasons of this method were described in details in many papers, e.g. Borcherdt (1970), Nakamura (1989) or Abott et al. (2001). Nakamura´s method is usually used with earthquakes. However, this method has number of modifications that were presented, for example, during 30th General Assembly of ESC in Geneva in 2006. Paper presented by Olszewska and Lasocki (2004) documents that the HVSR method can be successfully used to evaluate the local influence of the surface layer also for induced seismicity, in spite of the fact that in this case the conditions for application of the method essentially differ from the conditions met in natural seismicity.

The site response in Karviná region is very complicated by regional geological structure conditions. This fact was confirmed during field experimental measurement. Kaláb and Knejzlík (2006a, 2006b) published following results: stations without sedimentary layers (e.g. Orlová) have these spectral ratios about 1, other sites that are situated in area covered by sedimentary low velocity layers show spectral ratios with some significant local maxima. These peaks probably represent the resonant frequency of the surface layers at the measured position.

In this contribution, qualitative study of influence of site response on measured data will be presented. Velocity records of mining induced seismic events and ambient noise are used for presented paper.

DATA

Data from seismic stations located in Orlová and Stonava were used for this study. The first location is characterized by minimum thickness of sedimentary layer (so called "Carfoniferous window"). The Stonava region is covered with about 400 – 600 m of sedimentary rocks, in some areas with dramatic changes of the thickness (Kaláb and Knejzlík, 2005; Kaláb et al., 2006c). Generally, 2 – 8 m on the surface are represented by soils, sedimentary rocks above soil are represented by variation of Tertiary sediments (predominantly claystones, sandstones, limestones with different thicknesses and different degrees of consolidation).

Part of data used in this study is mining induced seismic events because mining induced seismicity is typical property of the Karviná region (e.g. Kaláb and Knejzlík, 2002; Holečko et al., 2006; Holub et al., 2007). Manifestation on surface of these events on selected positions is evaluated using solitaire seismic stations operated by the IGN since 1999. These stations are installed in big houses and digitally recorded wave patterns are applied to evaluate seismic load of given structures. The stations record from about 200 up to 500 events per year. Number of recorded events depends on preset trigger level on individual stations. Data acquisition system is based on apparatuses of PCM3-EPC type (e.g. Knejzlík and Kaláb, 2002). Seismometers SM-3 are anchored to the floo r in cellars, frequency range of seismic channels is 0.5 – 30 Hz, sampling frequency of digital data is 100 Hz. Periodic inspection and data transmission are performed through GSM network or telephone line.

Seismic apparatus PCM3-EPC3 was used for short time experimental measurement of ambient noise. Sensor Le3-D was installed on hardpacked earth and it was flattened for better contact. This measurement was realized along 500 m long profile in south-west part of Stonava area. Ten records were registered on each measured spot during afternoon of working day. Frequency range of seismic channel was the same as in previous measurements; sampling frequency of digital data was 250 Hz.

Seismic apparatus Vistec – GAIA2T was used for two-day experimental measurement of ambient noise. Sensor ViGeo was installed on concrete flat near our solitaire stations in Orlová and Stonava. Common "life" in the buildings was not limited during this measurement. Frequency range of seismic channels was 2 – 200 Hz, sampling frequency of digital data was 250 Hz.

METHOD

Amplitude spectra using fast Fourier transform were calculated from completely recorded seismic events. The matter is short epicentral distances and therefore individual phases cannot be identified, especially the S wave (as for spectral ratios with earthquakes). Also, wave patterns of mining induced seismic events have higher frequencies than earthquakes. As a result, the assumption of HVSR method that the vertical component of ground motion is amplification-free can be significantly violated in the case of induced seismicity (Olszewska and Lasocki, 2004).

Following methodology was applied using digital data of intensive mining induced seismic events or short-time (about 20 s) ambient noises (according to Nakamura, 1989, Abbott et al., 2001 and others):

- Velocity records with sampling frequency 100 Hz (for mining induced events) or 250 Hz (for ambient noise) were selected
- Spectra for vertical and booth horizontal components are calculated using the FFT algorithm
- The two horizontal spectra were averaged to form one horizontal spectrum
- The resulting vertical and horizontal spectra were smoothed with spline function
- Single station spectral ratios were calculated
- Individual spectral ratios for studied position are possible to summarize (it is calculated so called averaged ratio that occurs as sum of individual spectral ratios divided by number of used ratios)

Two places with different thickness of sedimentary cover were selected – Orlová and Stonava region. The following partial results can be stated:

- Very different shapes of spectral ratios of horizontal component to the vertical component are calculated in different places, when data from long-term monitoring in buildings are used.
- Usually, averaged spectral ratios are practically constant using 15 – 20 events (for a given place). Examples of the ratios are at Figures 1 and 2.
- Two or more maxima are often detected, which indicates complexity of the subsurface layers in the studied place.

Measurements and their interpretation based on the Nakamura´s method can be used also in urban areas. Many authors illustrate that good correlations appear between basic resonant frequencies and thicknesses of sedimentary layers (generally layers of defined geological age) that cover rock basement. For example, Mândrescu et al. (2006) describe the correlation mentioned above for Bucharest area. Amplification factor that was defined by Okamoto (1973) is in range 3.5 up to 4.1.

Records of ambient noises were used in areas with low natural seismicity. This topic is very popular now. The main reasons are (according Bonnefoy-Claudet et al., 2006):

- Registration of ambient noise is cheap and with easy tool-implementation and it does not need long term registration.
- However, H/V ratios of ambient noise are influenced by effect of source type, source distance and source depth (e.g. H/V ratio is slightly dependent on source function type; frequency of ambient noise is clearly independent, amplitude is slightly sensitive).
- The amplitude of H/V peak value is not able to give a good estimate of site amplification factor (H/V ratio is mainly controlled by local surface sources or the fundamental Rayleigh waves).

D´Amico et al. (2006) described following example: The measurement was performed in the Florence urban area. Records of seismic noise with duration of 20 min were interpreted and first or following peaks were used to evaluate resonant peaks in spectral ratios and amplification factor. These values were used for realization of detailed mapping of soft sediments thickness.

RESULTS

Karviná region is very populated and industrial site with many vibration sources. Individual sources have very variable intensities depending on their types, places and daytime. Experimental measurement along small road was realized to evaluate the applicability of the Nakamura´s method using records of ambient noises in this region. The experiment was realized on 10 positions in Stonava region, distance between two adjacent points was 50 m. Approximately 20 records were acquired on each point (duration of records about 30 s, sampling frequency 250 Hz). Methodology for calculation of spectral ratios was described above. Results from this experiment are presented in Figure 3. Thickness of sedimentary rock above the Carboniferrous massif ranged from 440 m (first graph) to 550 m (last graph).

Generally, differences between individual spectral ratios obtained on individual measured positions are not very significant, excluding last two points. At the first eight positions it is difficult to define predominant frequency on spectral ratio curves. Slight peaks can be found in range 1 – 2 Hz. Significant peaks exist on last two positions of set of spectral ratio curves with value about 1.4 Hz. The majority of the discussed curves notes significant frequency peak(s) round about 5 Hz (see also spectra of continuous records below). More detailed interpretation of these results has not been performed because of absence of more detailed information about shallow local geology.

To document differences in spectra at individual places, two figures present this initial result from two-day experimental measurement of ambient noise. Evolution of decimal logarithm of spectra for seismic record estimated within non-overlapping time interval of the length 10 seconds using autoregression spectral estimate of maximum entropy (Marple, 1987) of the 200-th order is calculated. Detailed description of this methodology is described in Lyubushin (2007). The results for vertical components of records from Orlová and Stonava seismic station are used as examples (Fig. 4 and Fig. 5). Spectra estimated from the mean of all time windows along the whole record are documented in Figure 6. The main differences that probably represent the effect of the local geology are detected in lower frequency band. Sharp maxima represent effect of mains (50 Hz and multiples).

CONCLUSION

Karviná region is very populated and industrial site with a lot of sources that are characterized by very variable intensities of individual sources depending on their types, places and day-time. The main results from this study can be summarized as follows:

- Spectral ratios of records of mining induced seismic events from different stations in Karviná region show individual shapes (related to sensor location and local geology)
- Character of spectral ratios is determined using about 15 – 20 events in elaborated set of events from given station (does not depend on parameters of events)
- Two or more maxima are detected, which indicates complexity of the subsurface layers in this place (due to natural conditions or situation after sinking due to mining)
- First results using ambient noise records document rather different shapes of spectral ratios (comparing with ratios of seismic events)

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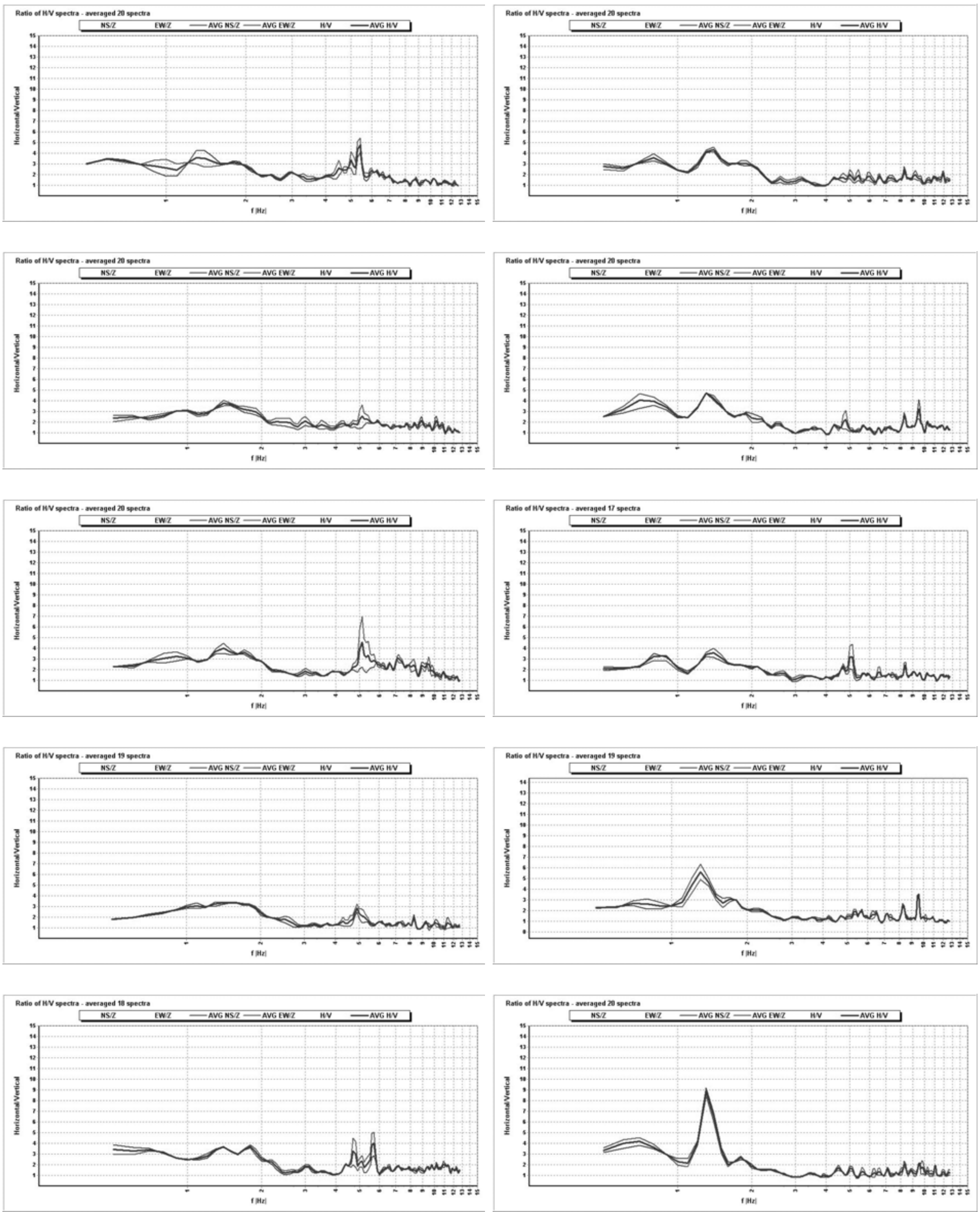

Fig. 3 Shapes of averaged spectral ratios of about 20 records of ambient noises obtained during experimental measurement in Stonava region (see text).

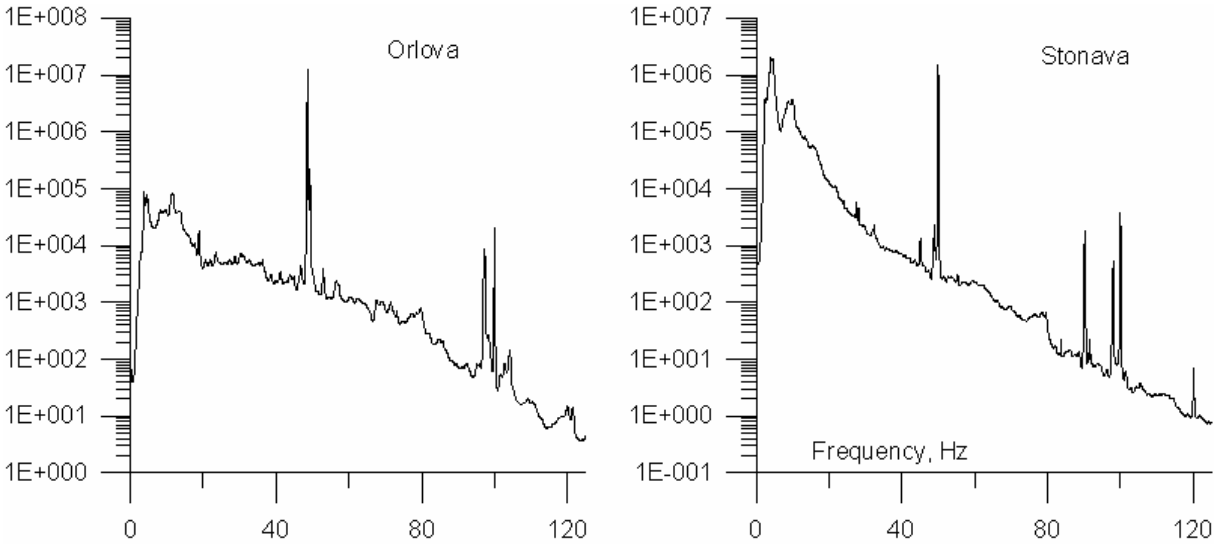

Fig. 6 Mean spectra estimates averaged over all time windows.

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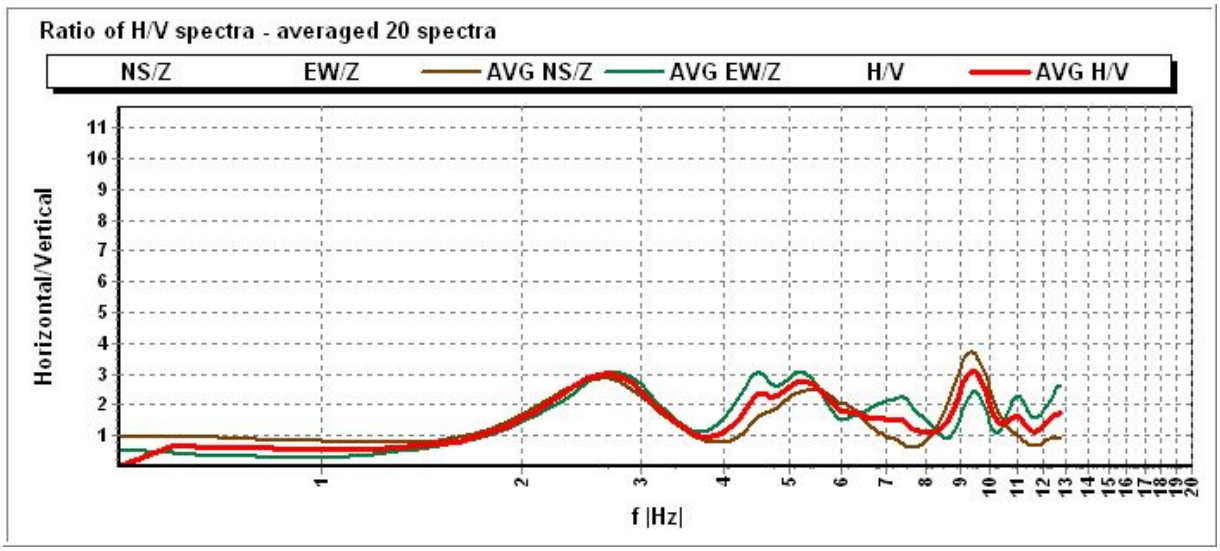

Fig. 1 Averaged spectral ratio of 20 seismic events in the analyzed place without sedimentary cover (station ORL1).

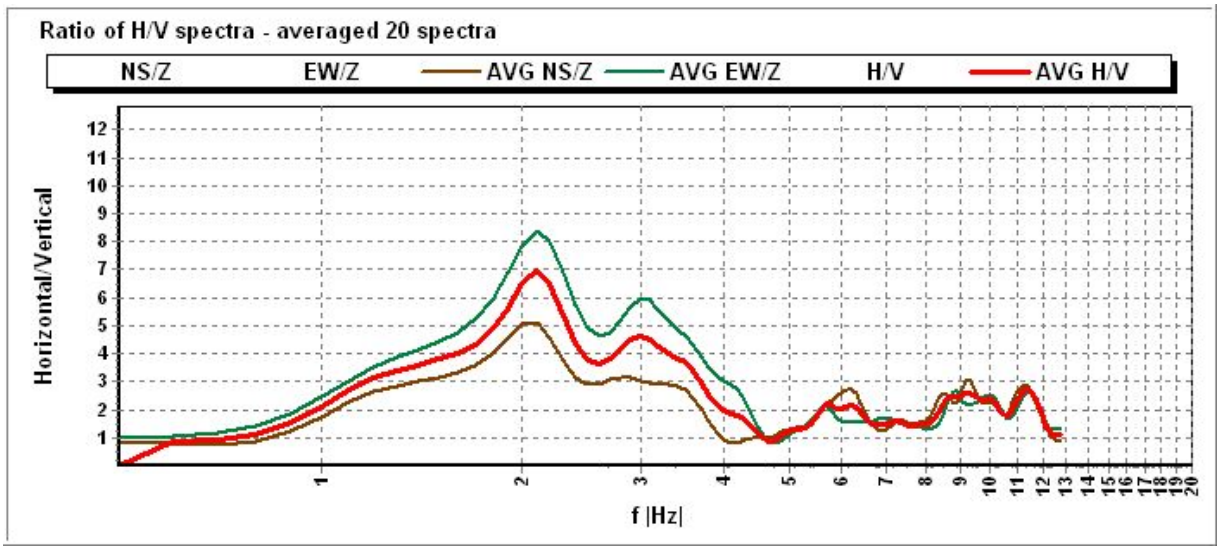

Fig. 2 Averaged spectral ratio of 20 seismic events in the analyzed place with about 550 m of sedimentary cover (station STO1).

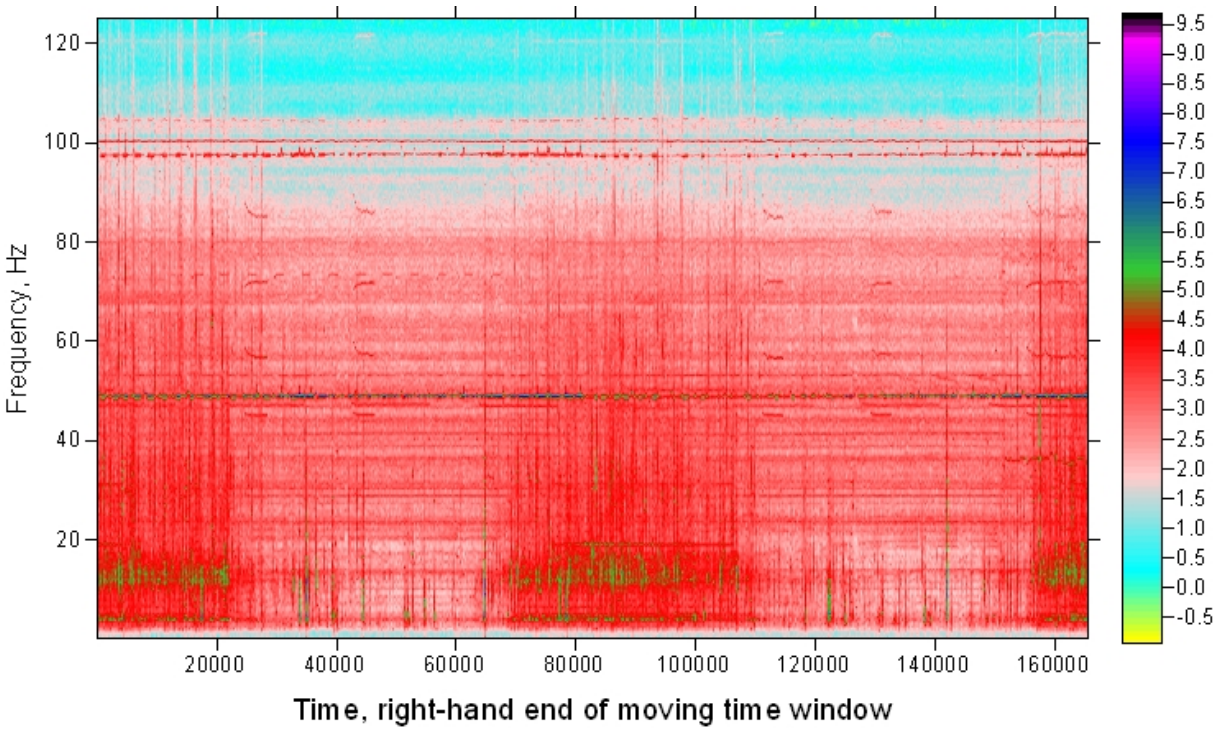

Fig. 4 Evolution of decimal logarithm of spectra for seismic record from Orlová.

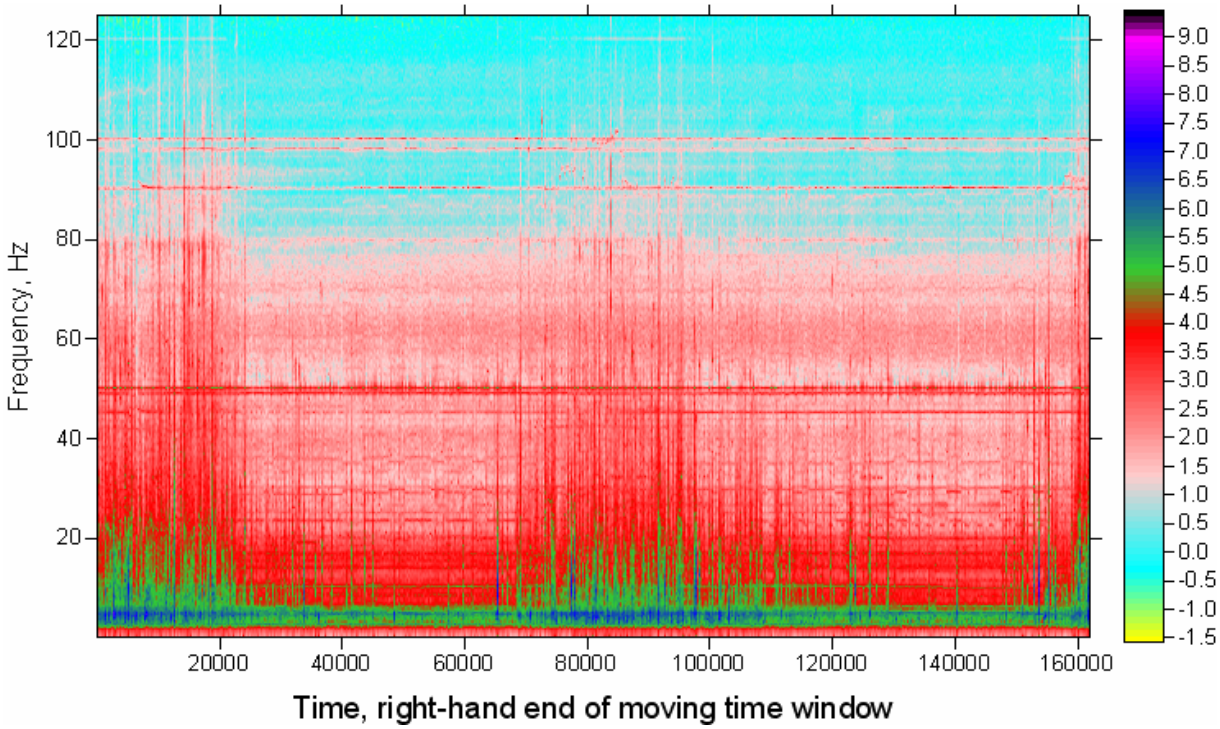

Fig. 5 Evolution of decimal logarithm of spectra for seismic record from Stonava.