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Site response investigation at the seismological station Ostrava-Krásné Pole (OKC)

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Vyšetřování odezvy podloží na dopadající seismické vlny na stanici Ostrava-Krásné Pole (OKC)

Práce je zaměřena na výzkum vlivu geologického podloží seismické stanice Ostrava-Krásné Pole (OKC) na dynamické parametry seismického neklidu pozorovaného na této stanici, a to: na amplitudy rychlosti kmitání u_i (m/s)a frekvenční obsah f (Hz) těchto kmitů. Při experimentu byl seismický neklid registrován současně v původním seismickém sklepě (OKC A) a v experimetální štole (OKC B). Výsledky zjišťování amplitud rychlosti ukázaly výrazné rozdíly mezi hodnotami měřenými během dne a v noci nejen na každém ze stanovišť, ale byly také zjištěny značné rozdíly amplitud rychlosti mati jednotlivými stanovišti v průběhu dne, či noci, jak ukazují následující rozmezí pozorovaných hodnot:.

stanoviště OKC A : $u_i \approx 30$ nm/s (noc) u_i up to 170 nm/s (den)
stanoviště OKC B: $u_i \approx 20$ nm/s (noc) u_i up to 70 nm/s (den).

Zesilující vliv podloží seismického sklepa (OKC A) byl vysvětlen asi 22 m mocnou vrstvou nezpevněných sedimentů s meším akustickým odporem (jílovité hlíny, písky a štěrky) ve srovnání s podložím štoly, která má v podloží výchozy kulmských břidlic.

Pro výpočet amplitudových spekter byla použita metoda FFT s tím, že byla byla zobrazena v intervalu frekvencí f ÷ 2-26 Hz a následně byla spektra normována. Zatímco spektra na stanovištích OKC A a OKC B mají na složkách Z a NS výrazná maxima na frekvencích f ≈ 10 Hz , u složky EW jsou maxima posunuta k vyšším frekvencím, a to f ÷ 12-16 Hz. V zasadě však průběhy normovaných spekter na odpovídajících složkách mají velmi podobný, téměř až identický, průběh.

Key words: *Czech Republic, Ostrava-Karviná region, seismic noise, particle velocity, spectral analysis.*

Introduction

Seismic waves generated by earthquakes, quarry blasts, ocean waves and various technological sources cause vibrations that spread through underlying strata into the broad vicinity of these sources. The aim of our experiments was to identify and characterize possible sources of seismic noise generated primarily by technical sources in the Ostrava-Karviná urban agglomeration, which is part of north-eastern Moravia (Czech Republic). The solution of this issue was initiated upon the demand for new knowledge of particle velocity amplitudes and spectral content of disturbing effects, using a newly developed data acquisition method and a system of digitized data processing. A detailed investigation of the influence of different seismogeological conditions at the two sites of observation was performed. While the seismic cellar (OKC A: $\varphi = 49.8375^{o}$ N, $\lambda = 18.1472^{o}$ E and $h = +272$ m) is underlain by glaciofluvial sediments (clay loams, sands and gravels), the thickness of which is approximately up to 22 m, the underlying beds in the nearby experimental gallery (OKC B: $\varphi = 49.8353^{o}$ N, $\lambda = 18.1423^{o}$ E, and $h = +250$ m) are represented by compact Culm-facies schists (Lower Carboniferous). The thickness of these Culm-facies that represent the underlying bed of the coal-bearing Upper Carboniferous (Namurian A) is about 1,200 m. The experimental gallery is situated at a distance of approximately 450 m from the original seismic cellar and about 22 m below its bottom. Different physical-mechanical properties of sub-surface layers at both sites result in different values of acoustic impedance, which naturally influences the particle velocity values, while the shape of calculated amplitude spectra displays a noticeable similarity. On the basis of experimental measurements, some results related to particle velocities and corresponding amplitude spectra of seismic noise are briefly discussed.

Instrumentation

Two identical three-component sets oriented in Z, NS and EW directions were installed at both sites. Modified electrodynamic seismometers of the S5S type with eigen-frequency of $f \approx 0.25$ Hz were used as sensors. The modification of those seismometers consisted in substitution of the original low-resistance signal coil ($R \approx 100\ \Omega$) with a high-resistance one ($R \approx 3.6$ kΩ). After the substitution, the sensitivity of seismometers was about 60 V.s.m^{-1}, as opposed to the original sensitivity of 10 V.s.m^{-1}. The damping constant $D_S \approx 0.7$ was reached using a negative feedback in preamplifier circuits. The frequency responses $^{-1}$of all seismic channels presented in Fig. 1 were almost flat, having been limited by high- and low-cutoffs $^{-1-}$

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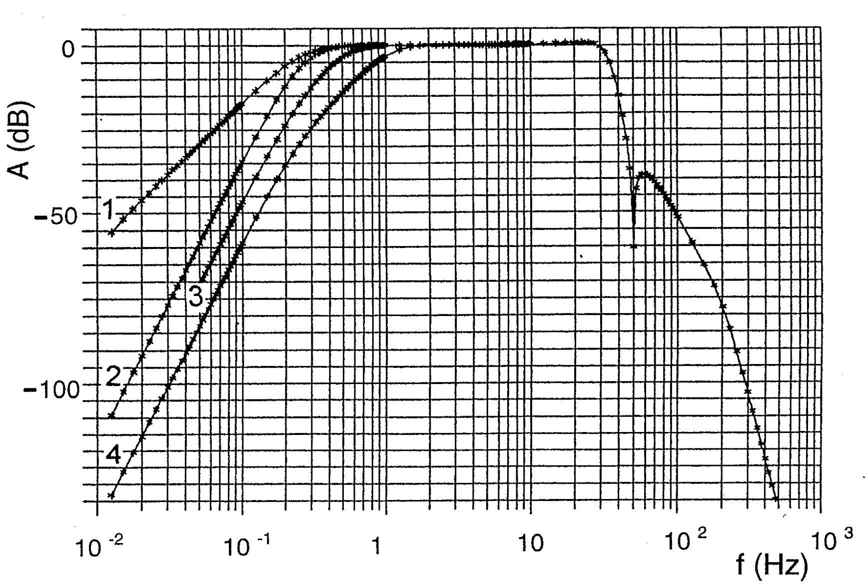
at 30 Hz and 0.5 Hz, respectively. The relevant measurements of the seismic noise level were performed using seismic channels with the frequency response of No. 2.



Obr. 1. Frekvenční charakteristiky seismického kanálu pro lineární přenos (1), a pro hornofrekvenční propust 0.5 Hz (2), 1 Hz (3) a 1.875 Hz (4).

Fig. 1. Frequency characteristics of seismic channel for linear transfer (1), and for high-cut off 0.5 Hz (2), 1 Hz (3) and 1.875 Hz (4).

Signals from both sites were transmitted by a current loop into the seismic laboratory situated in a local planetarium, where the data acquisition system was installed. Such a way of signal transmission assured great resistance to various interferences. The digital recording system was represented by a PC equipped with an A/D converter card with the resolution capability of 12 bits. The ONLINE software module, parameters of which were recorded into the configuration set, was implemented in the system. This system enables to set up the number of seismic channels (1 to 16), the sampling frequency (1 Hz to 1 kHz) and the input voltage range of the A/D converter (0.1, 1 and/or 10 V). Recording of seismic data can be activated manually and/or in a triggered regime, taking the appropriate STA/LTA algorithm into account. During our experiments, recording was activated only manually.

Analysis of seismograms

The recorded digital data was, after decoding, ready for processing by the special interpretation program „WAVE“ (Toth, 1991). The first step of the data processing was the transformation of recorded data into particle velocity waveforms. If the character of the waveform display was not predefined, individual channels could be displayed in the normalized form, e.g. against their maximum amplitude and/or against the so-called „global“ amplitude. The „global“ amplitude represented in this case is the maximum amplitude of the whole processed waveform. Various approaches were applied in order to determine seismic signals, e.g. calculation of the ground velocity amplitude, calculation of the Fast Fourier Transform (FFT) and the polarization analysis, which are integral parts of the abovementioned „WAVE“ program.

Identical instrumentation was installed at both sites in order to reach reliable and mutually comparable output data. According to our experience, unavoidable vibrations are predominantly caused by railroad and roadway freight traffic, local urban heavy industry, agricultural activities in the vicinity of both sites and the effects of the wind that causes motion of trees in the surrounding forest.

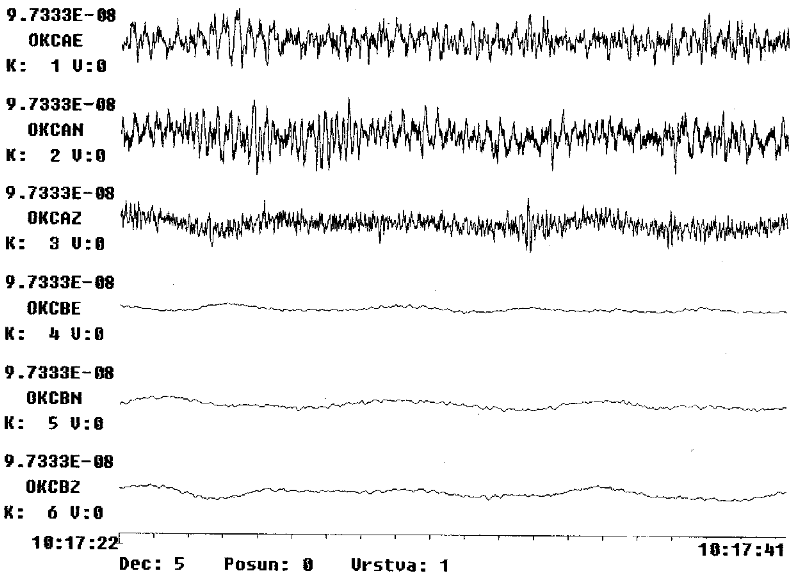
Particle velocities

A detailed analysis of the noise level was performed at the observation sites OKC A and OKC B, where particle velocities of seismic noise were recorded with the sampling frequency of 100 Hz. The amplitudes of seismic noise were unambiguously characterized by the measurements. In general, the mutual ratio of amplitudes was characterized by values of the order of 10^{-8} m.s^{-1} up to 10^{-7} m.s^{-1} (OKC A), as opposed to 10^{-9} up to 10^{-8} m.s^{-1} (OKC B). One example of the difference between both observation sites is shown in Fig. 2**.** In addition to the effects of roadway transportation on the amplitude level, especially at the site (OKC A), further interference sources were also observed, e.g. rotary motion of the astronomic cupola during the astronomical observatuions or low-frequency oscillations induced by the interaction of wind and trees in the forest., the speed of which was checked up by anemomete.

Long-term experience along with the investigation of seismic noise properties proved that the wide spreading microseismic noise is relatively low, having frequencies f ≈ 2 Hz (Holub 1976, Plešinger & Wielandt 1974). It appears to be almost monochromatic in the records of short-period seismographs.

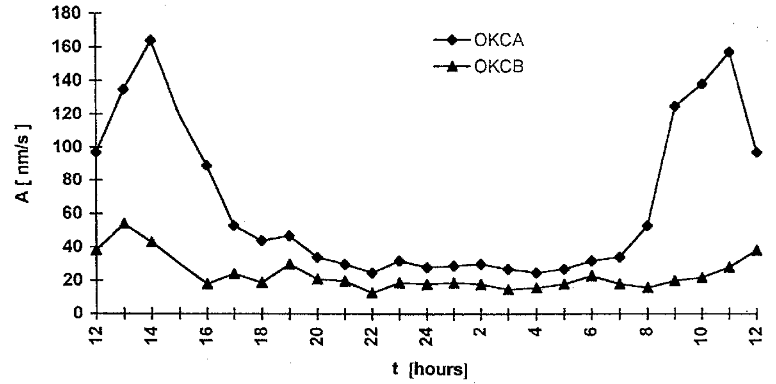
Therefore, the noise amplitudes are more distinct during the nights and weekends, when the level of cultural noise is low. On the other hand, its variations during the daytime are worse perceivable due to a higher level of cultural noise. These phenomena were also documented in papers (Fyen, 1990; Tiira et al., 1995).

A detailed analysis of the seismic noise level was carried out at both observation sites during a workday; the graph illustrating daily changes of particle velocity is shown in Fig. 3.



Obr. 2. Ukázka třísložkových záznamů ze stanovišť OKC A (seismický skleo) a OKC B (experimentální štola). Amplitudy byly normovány maximální amplitudou zaznamenanou na složce E na stanovišti OKC A.
Fig. 2. Three-component seismograms recorded at the sites OKC A (seismic cellar) and OKC B (experimental gallery).
The amplitudes were normalized by the maximum amplitude of the component E at the site OKC A..

The influence of underlying strata on the amplitude of ground velocities at relevant sites is quite apparent.



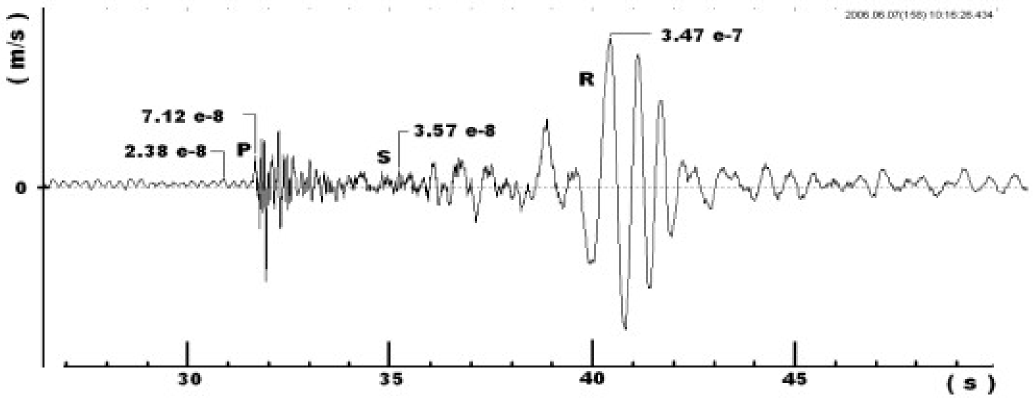
Obr. 3. Diagram amplitud rychlosti kmitání seismického neklidu na stanovištích OKC A a OKC B v průběhu pracovního dne.
Fig. 3. Diagram of particle velocities of seismic noise at the sites OKC A and OKC B during a whole working day.

Seismic signal detection is mostly concentrated to the 0.5-20 Hz frequency band, where the properties of man-made noise quite often vary considerably due to changing properties of the noise sources and the site-source distance. Records from vertical seismographs are most frequently used to detect the first arrivals of P waves, especially when relatively weak seismic signals are expected. Moreover, the detection reliability also depends on the noise/signal ratio.

On the basis of the graphs shown in Fig. 3, the following levels of the seismic noise ground amplitudes were determined:

site A: $u_i \approx 30$ nm/s (night) u_i up to 170 nm/s (day)
site B: $u_i \approx 20$ nm.s^{-1} (night) u_i up to 70 nm/s (day).

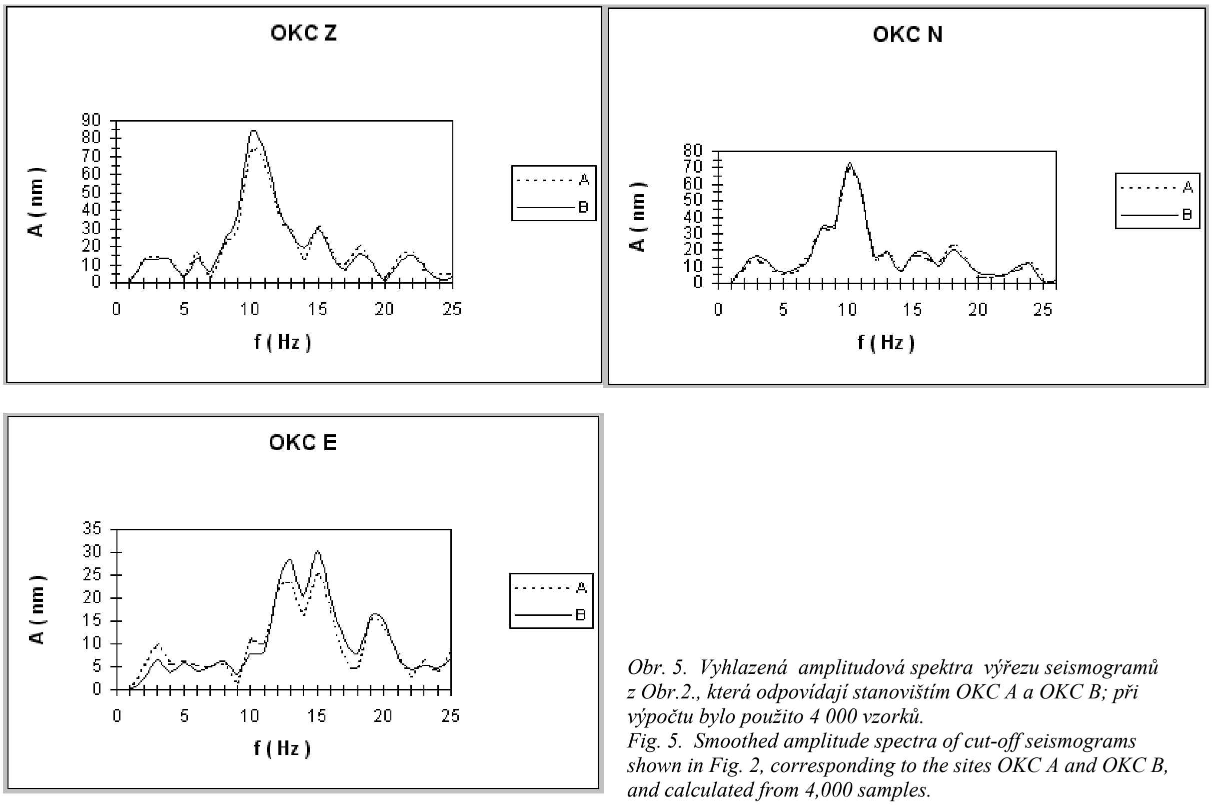
At present, we are dealing with the detection and analysis of mining-induced and tectonic events, as well as events generated by quarry blasts, which are used as seismic sources for the investigation of the structure of the uppermost part of the Earth crust. As an example of the comparison of the background noise level and levels of useful seismic signals (body and surface waves), a seismogram of a quarry blast recorded at the seismic station OKC (site B) situated in the nearby gallery is shown in Fig. 4.



Obr. 4. Porovnání úrovně seismického neklidu s amplitudami užitečných vln při odstřelu v lomu, který byl zaznamenán vertikálním seismografem v experimentální štole (OKC B); d ≈ 30 km, Q = 14 425 kg.
Fig. 4. Comparison of seismic noise level with amplitudes of some useful signals during a quarry blast recorded by vertical seismograph in the experimental gallery (OKC B ; d ≈ 30 km, Q = 14 425 kg.

Amplitude spectra

As usual, the noise characteristics are recalculated into noise amplitude spectra, which will probably reveal much more information on the type and importance of various seismic noise sources around the site than corresponding time domain records. For the purpose mentioned above, the records of ground velocities were spectrally analyzed using the Fast Fourier Transform method. It is well known that the records of seismic noise are not periodic functions, while their amplitude spectra are continuous ones. Considering that we were dealing with the original digital data sampled by the frequency f = 100 Hz, an analytical solution of the integrals was adopted and up to 7,000 samples could be applied. The numerical integration was performed and measured data was, after the recalculation, displayed in a smoothed form. The resulting smoothed Fourier amplitude spectra are shown in the scale of nm.



Obr. 5. Vyhlazená amplitudová spektra výřezu seismogramů z Obr.2., která odpovídají stanovištím OKC A a OKC B; při výpočtu bylo použito 4 000 vzorků.
Fig. 5. Smoothed amplitude spectra of cut-off seismograms shown in Fig. 2, corresponding to the sites OKC A and OKC B, and calculated from 4,000 samples.

Fig. 5. shows basic shapes for the chosen samples of data. The respective smoothed amplitude spectra for individual components were calculated at both observation sites within the frequency interval f ÷ 2-26 Hz. According to the previous experience (e.g. Holub 1996 and 1998), the predominant part of the frequencies of seimic noise induced by man-made sources was expected within this frequency band. It is interesting that amplitude spectra corresponding to localities A and B, with qualitatively diverse physical-mechanical properties of the underlying bed, have almost identical shape, while the values of ground amplitudes at the same sites differ.

Discussion of results and conclusions

The interpretation of digital records of particle velocities proved that different levels of seismic noise exist at both observation sites. In connection with this statement, two problems had to be solved. The first one was to find a respective source or sources of disturbing vibrations, while the second one involved finding out the reasons of the significant particle velocities amplification, which was observed in the original seismic cellar (site OKC A).

To fulfill these targets, daytime passages of vehicles were monitored along the nearby main road, which lies about 1.2 km from the observation sites. According to rough correlation of time domain between the passages of lorries and buses and the occurrence of pronounced disturbing vibrations on seismograms, their influence was determined and heavy road traffic was, in general, considered a candidate to explain the increased daytime noise level. On the other hand, the passage of cars was indistinct. As seen in Fig. 3, these local disturbances within the frequency band $f \approx 7\text{-}20$ Hz were mostly observed during the day (7 A.M. – 8 P.M.), while the course of particle velocity amplitude levels during the night (8 P.M. – 7 A.M.) represents an integral response of „cultural noise background“ without any pronounced influence of individual sources of disturbing vibrations. One part of this cultural noise background is also the wide spreading seismic noise in the frequency band 1.5-2.5 Hz, which has a regional character. In principle, the mutual ratio of observed amplitudes was characterized by values of the order of 10^{-8} m.s^{-1} up to 10^{-7} m.s^{-1} (OKC A), as opposed to 10^{-9} up to 10^{-8} m.s^{-1} (OKC B). The lower level of seismic noise at the station situated in the experimental gallery helped create qualitatively better site conditions, and therefore even weak seismic signals were reliably recorded (see Fig. 4).

The significant amplification of seismic noise ground amplitudes at the site OKC A was explained by different seismogeological conditions, as opposed to the site OKC B. On the one hand, the seismic cellar was situated in a place where underlying beds were represented by 22-metres-thick layers of glaciofluvial sediments, while the seismometers in the experimental gallery were placed on the outcrops of compact Culm-facies schists. The difference between both underlying beds manifested itself in different acoustic impedances caused by different velocities of seismic wave propagation. Similar results of observations or computations that concerned the determination of the amplification factor were described, e.g., by Darragh and Shakal (1991), Safak (1991), Field et al. (1992), Malagnini et al. (1993) and Zaslavsky et al. (1998). In all the abovementioned experiments, the resulting effects of amplification were usually influenced by the quality of underlying beds, where mostly unconsolidated sediments were preserved to a large extent.

Spectral properties of site responses displayed in Fig. 5 were calculated for all three components (Z, NS and EW) using the FFT, and the spectra were subsequently smoothed and normalized. The similarity of normalized spectra on both sites is obvious at the first glance and only slight deviations from the basic shape were evident. While the spectra of seismic noise recorded by vertical and horizontal (component NS) seismographs display almost identical shape with an expressive spike at the frequency of about 10 Hz, spectra obtained by another horizontal seismograph (component EW) differ substantially from both the previous ones. Moreover, the peak or peaks of spectral amplitudes are shifted towards higher frequencies between 13-15 Hz. One can easily see the high contamination of the sites by man-made seismic noise, the frequencies of which appear to be within the range of about 10-20 Hz. It is assumed that the corresponding spectral spikes apparent in these spectra were caused mainly by heavy traffic on the main road. The similarity of spectra presented in Fig. 5 also shows that the relatively thin layer of glaciofluvial sediments did not affect the spectral content of disturbing vibrations propagating from the surface source towards both observation sites. However, a plausible explanation of differences between noise spectra calculated from the records of the vertical and horizontal (NS) components and the horizontal (EW) component was not found.

In general, our results proved that the site response to ground motion observed at the two test sites was significantly affected by their different subsurface geological conditions. It can be concluded that the higher the acoustic impedance of the bedrock, the less seismic noise is observed, and vice versa. On the other hand, these seismic experiments proved that the spectral content of ground motions remained the same after the passage of seismic waves through both the thin soft-soil layer and the compact Culm-facies schists.

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