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TYPICAL SOURCES OF VIBRATION GENERATED BY GEOTECHNICAL WORKS

TYPICKÉ ZDROJE VIBRACÍ VYVOLANÝCH PŘI GEOTECHNICKÝCH PRACÍCH

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Abstract

This contribution summarizes main information about technical seismicity generated by geotechnical works. These works can induce strong ground vibrations that produce negative disturbing of people and cause damage of sensitive instrumentation and structures in the vicinity of a working place. Seismological measurements are usually recommended to define the effect of this vibration. Three typical examples are presented in this paper: blasting operation, vibratory sheet pile driving, and the vibration generated by heavy trucks. Individual wave patterns have specific shapes that are briefly mentioned.

Abstrakt

Tento příspěvek shrnuje základní informace o technické seismicitě generované během geotechnických prací. Tyto práce mohou vybudit silné vibrace, které mají negativní vliv na osoby a mohou zapříčinit poškození citlivého vybavení v objektech nebo i staveb v okolí stavby. K definování projevu těchto vibrací jsou obvykle doporučena seismologická měření. V tomto článku jsou uvedeny tři typické příklady: trhací práce, beranění pilot a vibrace způsobené průjezdem těžkého kamionu. Jednotlivé vlnové vzory mají specifické tvary, které jsou stručně popsány.

Keywords

Vibration, technical seismicity, geotechnical works, blasting, sheet pile, traffic

Keywords

Vibrace, technická seismicita, geotechnické práce, trhací práce, beranění pilot, provoz

1 Introduction

Geotechnical works can be a source of several types of technical seismicity. The typical examples are construction activities such as blasting, pile-driving, operating heavy earth-moving equipment, and heavy trucks on rough roads. These vibrations have different manifestation, usually periodic or non-periodic vibration with different time duration, time limited shocks, isolated shock etc. (Lu, 2014, Tripathy et al., 2016, Kaláb, 2007, 2018). The intensity of induced vibrations depends on many parameters. Significant diversity of causes, influencing the intensity of a seismic event on the surface, is the reason why more creditable results cannot be obtained and simple relations cannot be derived without a larger number of measurements. Measurement request comes increasingly into operation if geotechnical works are carried out in urban areas and/or in the vicinity of historic structures.

This paper summarizes basic information about different types of vibrations generated by geotechnical works. Generally, the types of vibration can be classified as deterministic or random. Deterministic data are those that can be described by explicit mathematical functions (periodic, quasi-periodic, non-periodic). To evaluate measured seismological data from the structural response of buildings, the following factors need to be taken into account (e.g., Towhata, 2009):

- Resonant frequencies of basic structure and component parts (walls, floors, windows);
- Damping characteristics of basic structure and component parts;
- Type of construction, its condition and material properties;
- Spectral structural features;
- Characteristics of excitation;
- Deflected form;
- Non-linearity in amplitude response.

The vibration generated in the source excites adjacent ground, creating vibration waves that propagate through various soil and rock strata to the foundations of nearby buildings. The vibration propagates from the foundation throughout the remainder of the building structure. The maximum vibration amplitudes of the floors and walls of a building will often be at the resonance frequencies of various components of the building (according to Villaverde, 2009, Zeigler, 2018).

2 Measurement of vibration

Vibration is a dynamic quantity, it varies with time, and this demands care in its measurement. From the physical viewpoint, the most natural manifestation is the movement that occurs as the vibration passes the given location. This movement is possible to describe as displacement, velocity and/or acceleration in the time domain. Equivalent dual integral relationships may be used in the frequency (e.g. Doyle, 1995, Shearer, 1999). Rarely in justified cases, not only translational components of a particle are taken into consideration but rotational components are also measured (e.g. Lee et al., 2009, Knejzlík et al., 2012). The S-5-SR seismometer developed in the Institute of

Geonics was used for mining induced seismic events monitored in the Karviná Region. This modified seismometer enables to measure rotational velocity of vibration around vertical axis (Kaláb et al., 2013).

The instrumentation for these measurements has undergone a great technical innovation during last several decades, particularly by developing electronics and computer technology. Generally, a seismic channel has following basic parts: a sensor, a recording system, and an output system. The amount of stronger vibrations generated by geotechnical works (this is generally true) during these works and the level of common seismic noise on the surface establishes two types of recording and preprocessing of measured data:

- Apparatuses with triggering regime;
- Continuous record of „vibration situation“.

At present, permanent seismic monitoring with automatic data acquisition and primary interpretation of basic parameters is favoured in urban regions when significant vibrations are generated. It is supposed to install temporary seismic stations that will operate in some suitable buildings during the whole period of seismic loading (generally weeks or first months). Obtained results will be available to civil engineers, firefighters and also to custodians and occupants of influenced buildings. Web application is usually used with different access authority.

Obtained knowledge from experimental measurement is possible to summarize as follows:

- In short distances from the source of vibration, it is necessary to provide a high dynamic range of recorded apparatuses.
- Frequency range of seismic channel (i.e. both sensors and apparatus) should be as wide as possible, especially for higher frequencies.
- To record data of first quality, it is necessary to use high value of sampling frequency of a digital signal.
- A very good contact between sensor and basement is necessary to realize; the best solution is to anchor sensors to the basement with bolts or suitable additional load (it cannot vibrate).
- All demands are possible to reduce adequately if seismic station is located in larger distance.

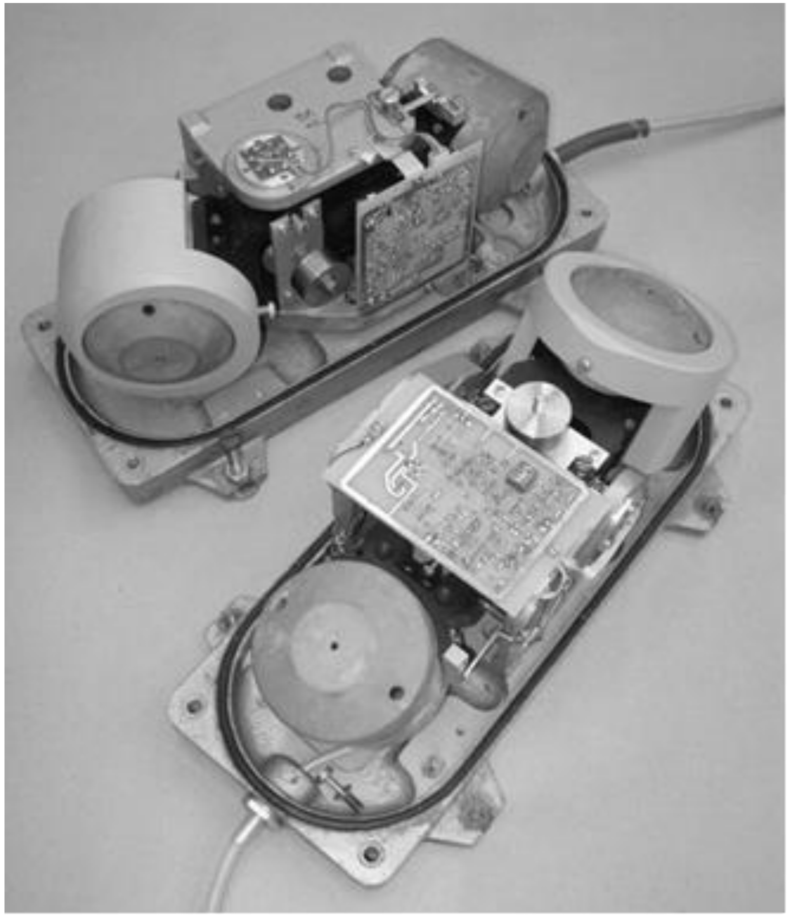

Fig. 1 The S-5-SR sensor recording rotational components of ground vibrations around the vertical axis (at the back) and around the horizontal axis (in the front); both sensors without cover (photo: Kaláb)

3 Selected examples of vibrations generated by geotechnical works

The presented case studies highlight the importance of monitoring structures in the context of technical seismicity effects. The problems concerning vibrations of structures due to technical seismicity generated during geotechnical works are current - and, not only due to blasting! The measurements should be performed in various locations at variable distances. It is also necessary to use suitable instrumentation and interpretation software.

3.1 Blasting operation

The first example usually represents the strongest effect of vibration generated by geotechnical works. Here, the results of

Fig. 2 Reconstruction of Jablunkov tunnel No. II (photo: Stolárik)

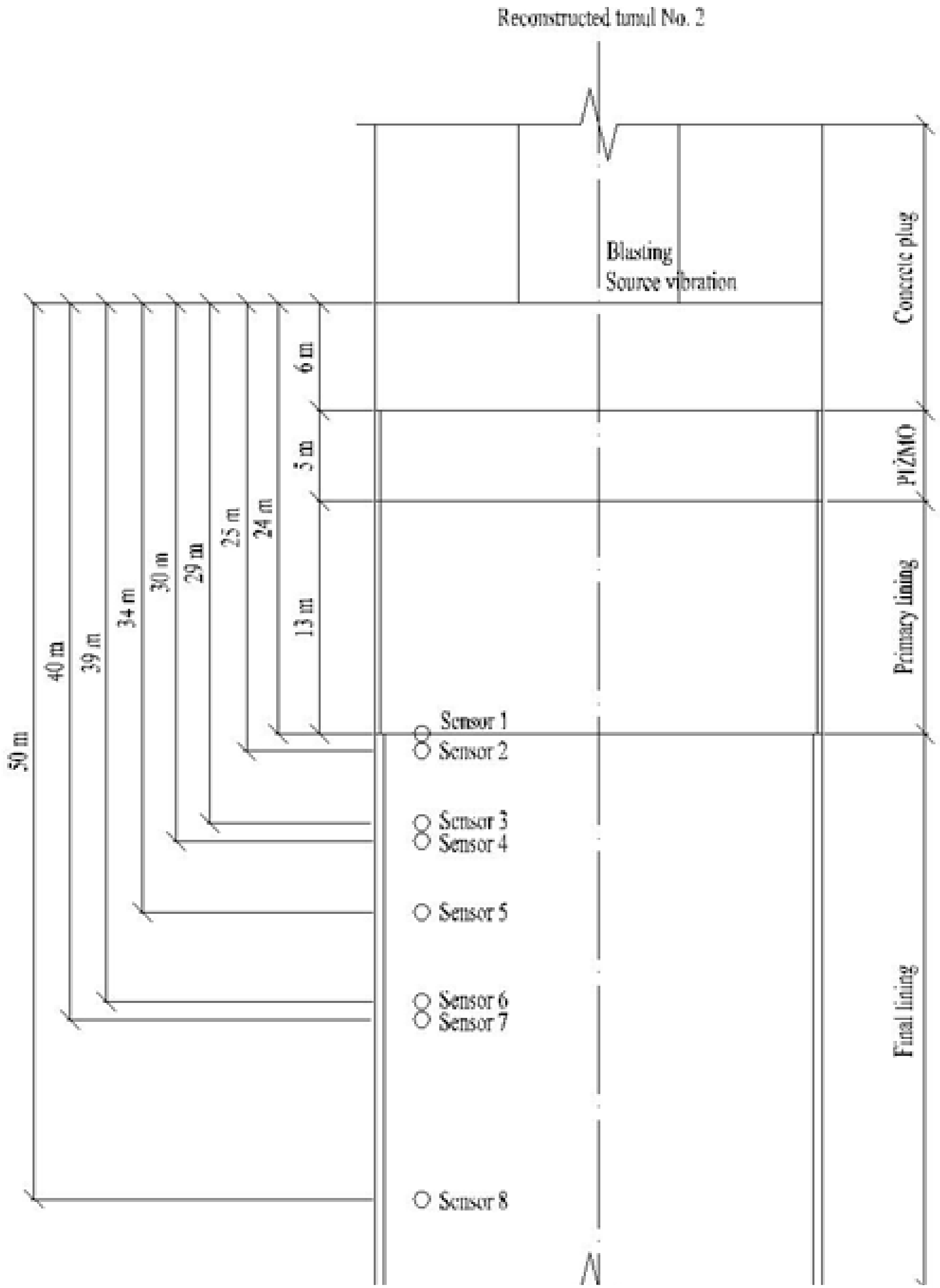

Fig. 3 Location of sensors used for evaluation of attenuation law of seismic waves

measurement, performed during the reconstruction of Jablunkov tunnel, are briefly depicted (Stolárik and Kaláb, 2010). Generally, the existing single-rail Jablunkov tunnel No. II was relined, round by round, and converted into a double-rail tunnel (Fig. 2). The measurement was carried out when the concrete plug was removed by using blasting operation. After the incident (November 2009), the tunnel was excavated and secured by the concrete plug.

The total charge of blasting operation used during geotechnical works is relatively small compared with production blasting in quarries (e.g., Pandula and Kondela, 2010, Kaláb et al., 2013, Pandula et al., 2013). In the Jablunkov tunnel, parameters of blasting were as follows: the charge in a borehole - 0.4 kg, the total charge – 12.5 kg, and total boreholes - 53 pieces. Results of 8 locations of sensors were used for evaluation of attenuation law of seismic waves (Fig. 3 - Fig. 5). Correlation of individual locations of sensors defined attenuation law; all correlation coefficients of individual components are very high (see Fig. 5). Obtained correlation is valid for distances between 20 – 50 m.

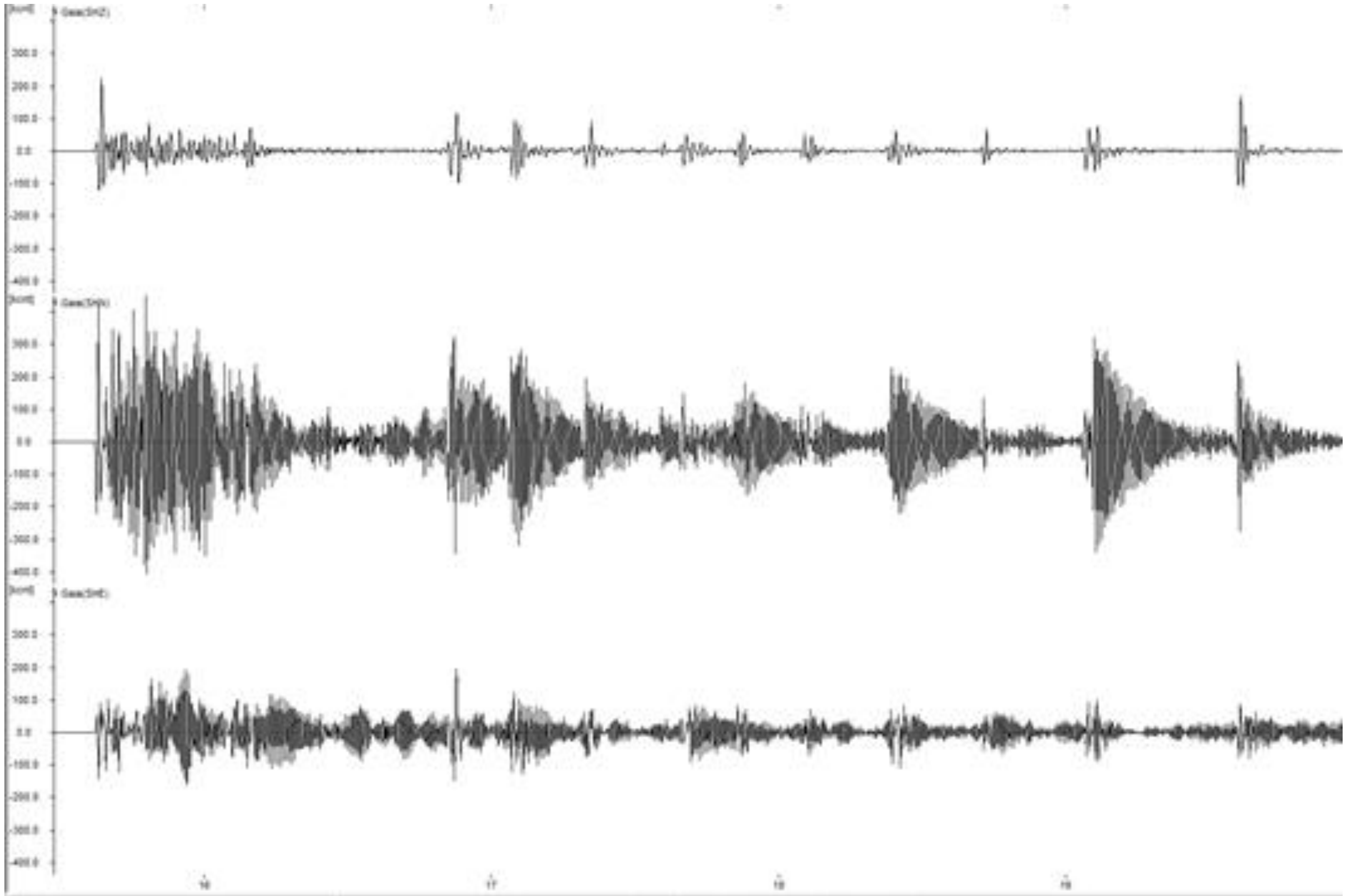

Fig. 4 Example of wave patterns of blasting operation measured in Jablunkov tunnel No. II

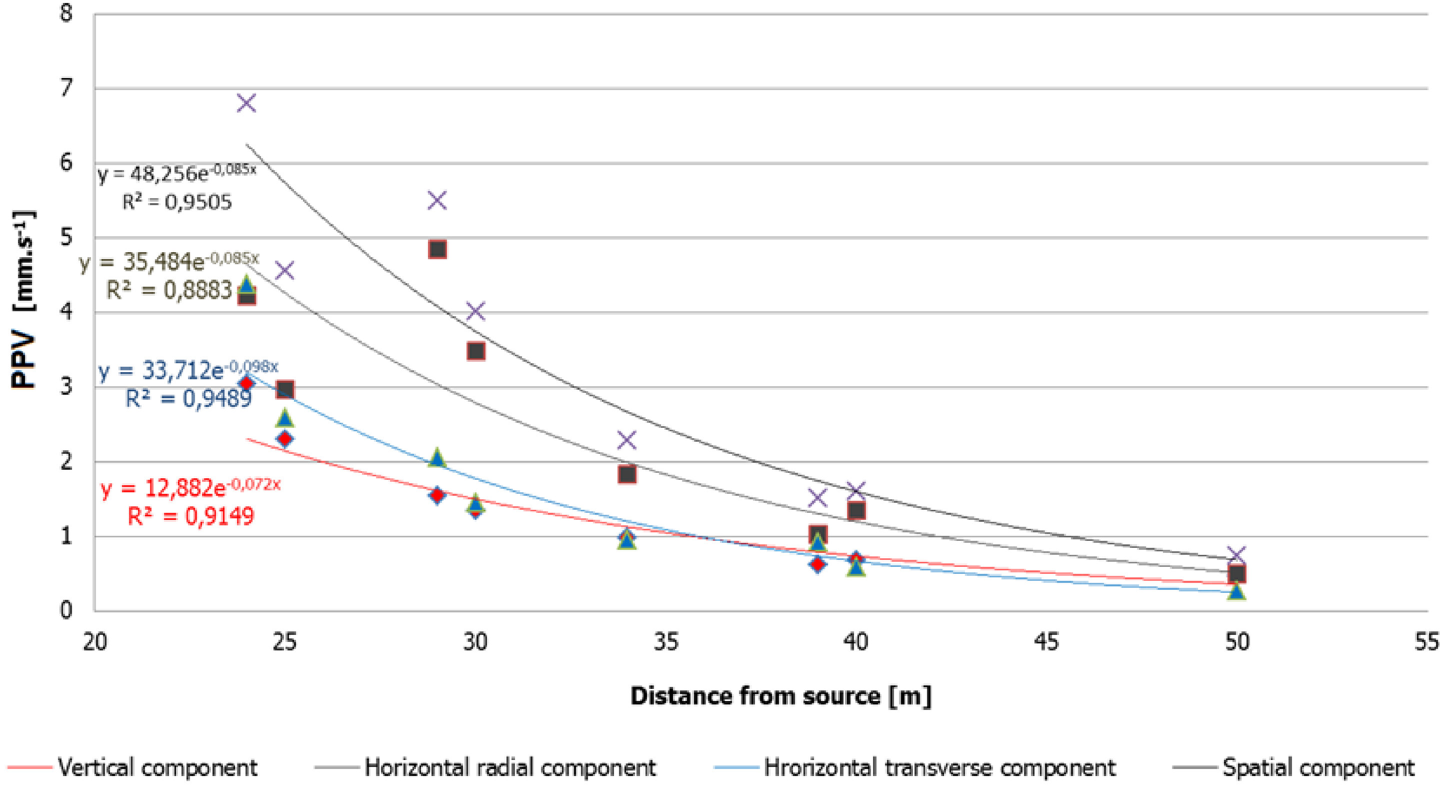

Fig. 5 Attenuation law of seismic waves for blasting operation in Jablunkov tunnel No. II (PPV – maximum velocity value)

3.2 Vibratory sheet pile driving

Vibratory driving is often used installation method of sheet piles. This method, however, can induce strong ground vibrations that produce negative disturbing of people and cause damage of sensitive instrumentation and structures in the vicinity of a working place. Presented seismological measurement was performed in the new VŠB – Technical University of Ostrava campus during the preparation of a foundation pit for the supercomputer centre (Fig. 6). The sheet pile wall was erected as a stabilization element.

Vibration of sheet piles generated significant harmonic vibrations with sharp frequency peak with the value of 12 Hz. This frequency value strictly depends on setting of a vibrating machine (Fig. 7 and Fig. 8). Maximum component value of the particle velocity was 5.82 mm.s^{-1} at the distance of 6 meters from the wall, and 5.09 mm.s^{-1} at the distance of 9 meters from the wall. If we discuss seismological measurement during vibration of gravel piles, we usually obtain much higher value of harmonic frequency (often about 50 Hz).

Main result, i.e. attenuation law of seismic waves, is presented in Fig. 9. Due to short distances and simple subsurface geology (soil sediments), correlation coefficients of individual components are very high.

Fig. 6 Workplace preparation of foundation pit for supercomputer centre (photo: Stolárik)

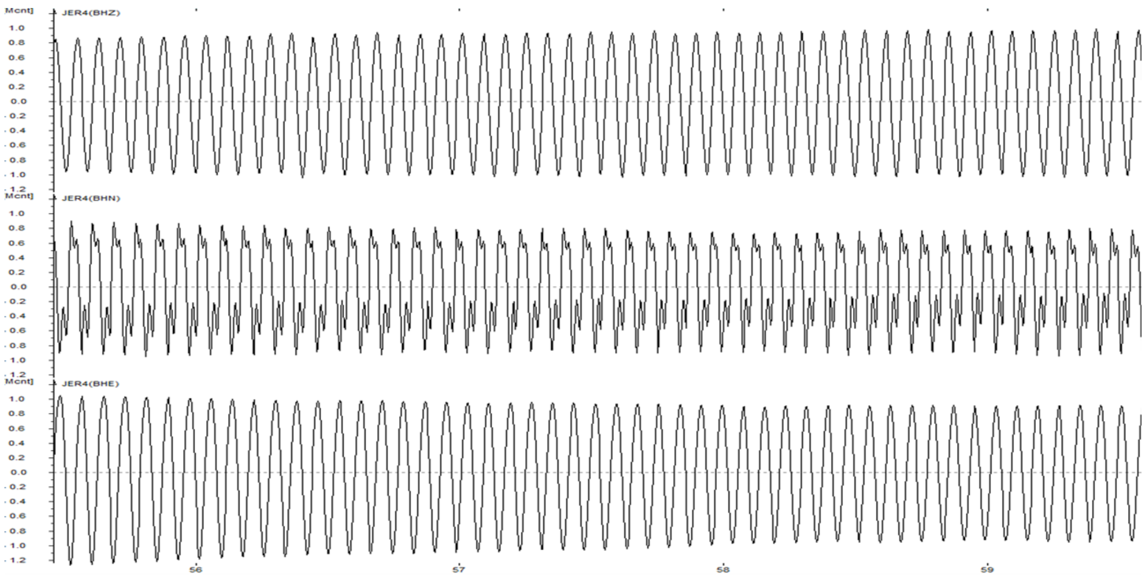

Fig. 7 Example of wave pattern generated during vibration of sheet piles

3.3 Vibration generated by heavy trucks

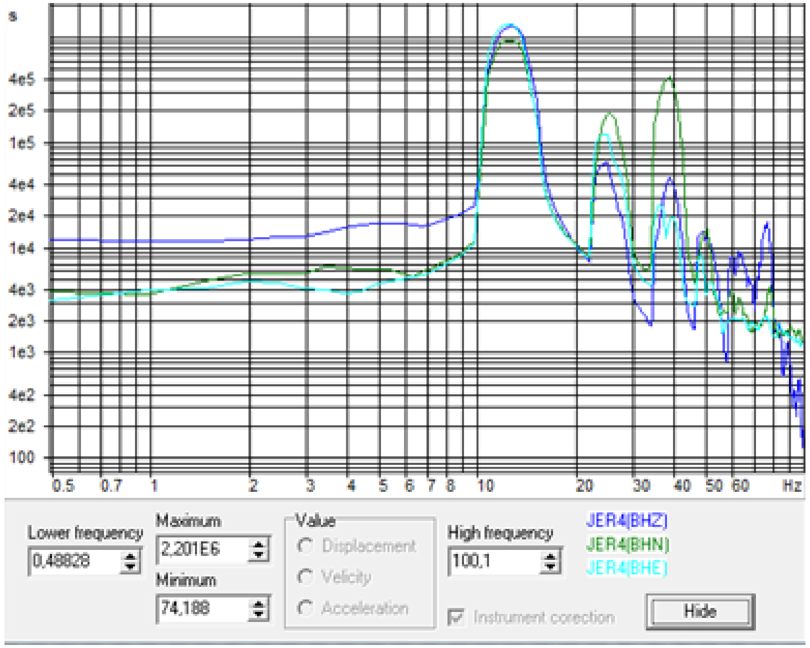

Fig. 8 Example of frequency spectra of recorded wave pattern generated during vibration of sheet piles

This seismological measurement was performed in a new outbuilding of a small house located in the village of Zelinkovice near the main road from Frýdek-Místek. During the measurement irregularities on the road surface, like potholes or cracks, were identified. This vibration occurs as part of geotechnical works because the amount of material is necessary to transport.

Traffic vibrations were mainly generated by heavy trucks. Passenger cars rarely generated perceptible vibrations in this outbuilding; it means that maximum velocity vibration did not exceed level of 0.10 $mm.s^{-1}$ (not felt) or 1.15 $mm.s^{-1}$ (threshold of perception). Heavy traffic generated significant harmonic vibrations with prevailing harmonic frequency in the range of about 9 – 11 Hz (Fig. 10), maximum component value of particle velocity was 0.32 $mm.s^{-1}$ on the ground floor of the outbuilding. On the first floor of the evaluated building, velocity values reached up to 0.65 $mm.s^{-1}$. In this locality, consolidated sedimentary rocks are covered by only small thickness of soils, however, the outbuilding was constructed on infilling of waste rocks.

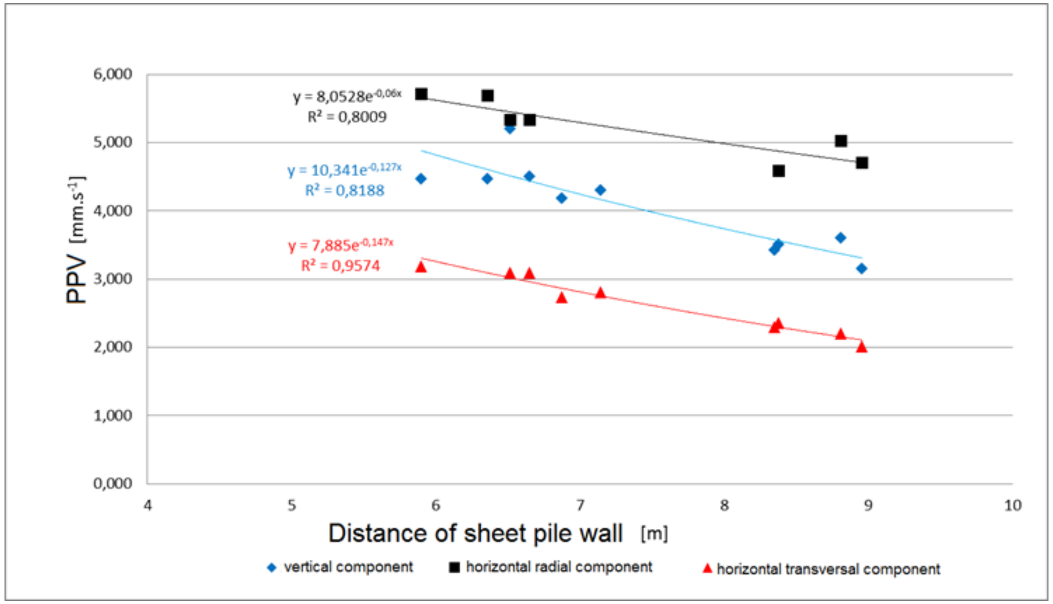

Fig. 9 Attenuation law of seismic waves for vibration of sheet piles (PPV – peak particle velocity)

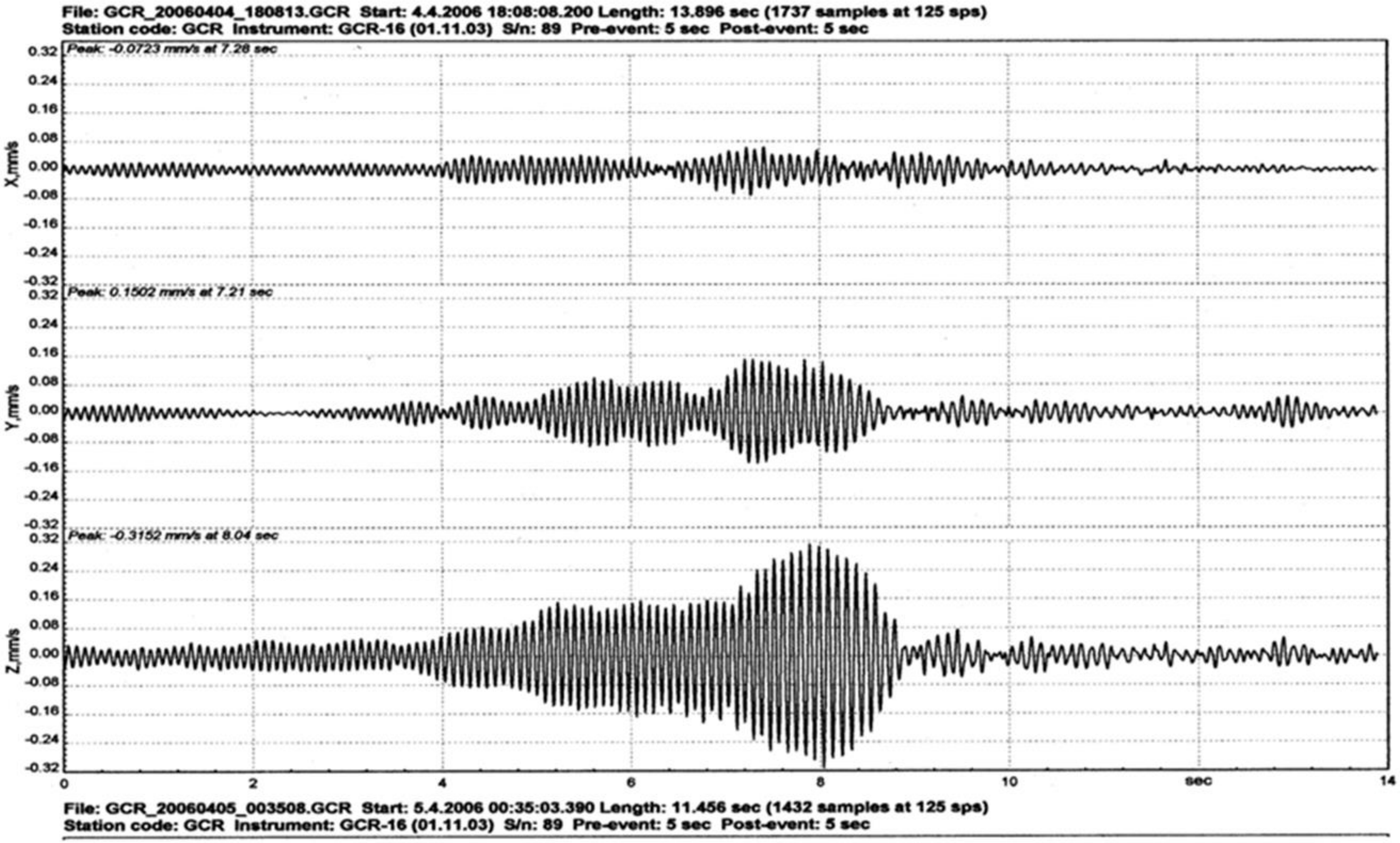

Fig. 10 Example of wave pattern generated by heavy truck in building in the village of Zelinkovice

4 Conclusion

The current problems are vibrations of structures due to technical seismicity generated during geotechnical works - and not only due to blasting! The measurements are necessary to perform in various locations at variable distances; suitable instrumentation and interpretation software are necessary to use. The presented case studies highlight the importance of monitoring of structures in the context of the effects of technical seismicity generated during geotechnical works. Factors that influence levels of vibration and noise in the surroundings of building site were summarized in Basic Ground-Borne Vibration Concepts (WEB1) – see Tab. 1.

Factors Related to Vibration Source	
Factors	**Influence**
Vehicle Suspension	If the suspension is stiff in the vertical direction, the effective vibration forces will be higher. On transit cars, only the primary suspension affects the vibration levels, the secondary suspension that supports the car body has no apparent effect.
Wheel Type and Condition	Use of pneumatic tires is one of the best methods of controlling ground-borne vibration. Normal resilient wheels on rail transit systems are usually too stiff to provide significant vibration reduction. Wheel flats and general wheel roughness are the major cause of vibration from steel wheel/steel rail systems.
Track/Roadway Surface	Rough track or rough roads are often the cause of vibration problems. Maintaining a smooth surface will reduce vibration levels.
Track Support System	On rail systems, the track support system is one of the major components in determining the levels of ground-borne vibration. The highest vibration levels are created by track that is rigidly attached to a concrete trackbed (e.g. track on wood half ties embedded in the concrete). The vibration levels are much lower when special vibration control track systems such as resilient fasteners, ballast mats and floating slabs are used.
Speed	As intuitively expected, higher speeds result in higher vibration levels. Doubling speed usually results in vibration levels 4 to 6 decibels higher.
Transit Structure	The general rule-of-thumb is that the heavier the transit structure, the lower the vibration levels. The vibration levels from a lightweight bored tunnel will usually be higher than from a poured concrete box subway.
Depth of Vibration Source	There are significant differences in the vibration characteristics when the source is underground compared to at the ground surface.
Factors Related to Vibration Path	
Factor	**Influence**
Soil Type	It is generally expected that vibration levels will be higher in stiff clay type soils than in loose sandy soils.
Rock Layers	Vibration levels often seem to be high near at-grade track when the depth to bedrock is 30 ft or less. Subways founded in rock will result in lower vibration amplitudes close to the subway. Because of efficient propagation, the vibration level does not attenuate as rapidly in rock as it does in soil.
Soil Layering	Soil layering will have a substantial, but unpredictable, effect on the vibration levels since each stratum can have significantly different dynamic characteristics.
Depth to Water Table	The presence of the water table is often expected to have a significant effect on ground-borne vibration, but evidence to date cannot be expressed with a definite relationship.
Frost Depth	There is some indication that vibration propagation is more efficient when the ground is frozen.
Factors Related to Vibration Receiver	
Factor	**Influence**
Foundation Type	The general rule-of-thumb is that the heavier the building foundation, the greater the coupling loss as the vibration propagates from the ground into the building.
Building Construction	Since ground-borne vibration and noise are almost always evaluated in terms of indoor receivers, the propagation of the vibration through the building must be considered. Each building has different characteristics relative to structureborne vibration, although the general rule-of-thumb is that the more massive a building is, the lower the levels of ground-borne vibration will be.
Acoustical Absorption	The amount of acoustical absorption in the receiver room affects the levels of ground-borne noise.

Tab. 1 Factors that influence levels of vibration and noise (according https://pdfs.semanticscholar.org/c94d/b9c98d85dc9049f9c5f9b86b88c816819061.pdf)

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