A COMPARISON OF NUMERICAL MODELS RESULTS WITH IN-SITU MEASUREMENT OF GROUND VIBRATIONS CAUSED BY SHEET PILE DRIVING

Tomáš PETŘÍK *, Eva HRUBEŠOVÁ and Markéta LEDNICKÁ

VŠB – Technical university of Ostrava, the Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 33 Ostrava – Poruba
**Corresponding author's e-mail:* tomas.petrik@vsb.cz

(*Received* January 2012, *accepted* April 2012)

ABSTRACT
This paper pursues the effect of changes in distance and vibration frequency on the vibration velocity amplitude. As an example, we used the vibrating sheet piles at the construction of a new multi-functional FEI building on the premises of VŠB - TU Ostrava, at 17 listopadu street. The effect of these changes is monitored both in in-situ measurements and in a simulated real-life situation. The calculation software Plaxis 2D is used for creation of numerical models. At the close, the results from in-situ measurements are confronted with those achieved from the models.

KEYWORDS: numerical modelling, Plaxis 2D, sheet pile driving, vibration velocity amplitude, vibration frequency, vibratory hammer, dynamic analysis

INTRODUCTION

Nowadays, the building industry is focused on the most efficient utilization of open space. Primarily in larger cities, this leads to building new constructions in the vicinity of the existing facilities. During the construction of new facilities or during the reconstruction of the existing facilities, the adjacent areas are influenced by the construction machinery operations. This may lead to the occurrence of disturbances in the rock environment and in adjacent building structures. Among others, the duty of civil engineers is to predict these influences and minimize their actions in the early stage of design.

One of the options how to predict the influences of building operations is the utilization of models of the situation given (e.g. Bull, 2009). Various activities ranging from rock blasting (e.g. Stolárik, 2008) to vehicle traffic are simulated in these models. Thanks to the simulations in the models, it is possible to envisage some of the unfavourable effects on the given building structure and its surroundings.

One of the building activities influencing its surroundings is the construction of sheet pile walls that are used for the prevention of earth slide or water leaking into building pits. These walls are put together by vibrating the individual structural elements (sheet piles), mostly made of steel sections. When vibrating the sheet piles, seismic effects are generated among others (Athanasopoulos and Pelekis, 2000; Kim and Lee, 2000). The effects of technical seismicity are influenced by many factors, primarily by the magnitude of dynamic parameters (e.g. by centrifugal force, or vibration frequency), properties of the rock environment (e.g. by elastic parameters of the environment, unit weight of soils) and by the distance of the location under consideration from the one subject to vibrating action. During such seismic loading, elastic seismic waves are generated and disseminated that may result in the disturbance of the rock pillar and adjacent engineering constructions. That is why it is necessary to monitor the effects of technical seismicity and if required, to modify the technology in such a way that the seismic effect cannot exceed the permissible limit. For the assessment of the building damage degree we can find the limit values of oscillation velocity e.g. in the Czech standard CSN 730040; for the human health protection we can use e.g. the Collection of the Czech laws no. 272/2011.

CHARACTERISTICS OF BUILDING SITE

The construction of a new multi-functional building for Faculty of Electrical Engineering and Informatics (hereinafter the FEI only) was used for the purpose of this paper. This civil engineering project was initiated on the 7th February 2011 on the premises of the VŠB - Technical University of Ostrava (hereinafter the VŠB - TUO) at 17. listopadu street (see Fig. 1). The purpose of this building is to centralize the offices of pedagogues and PhD

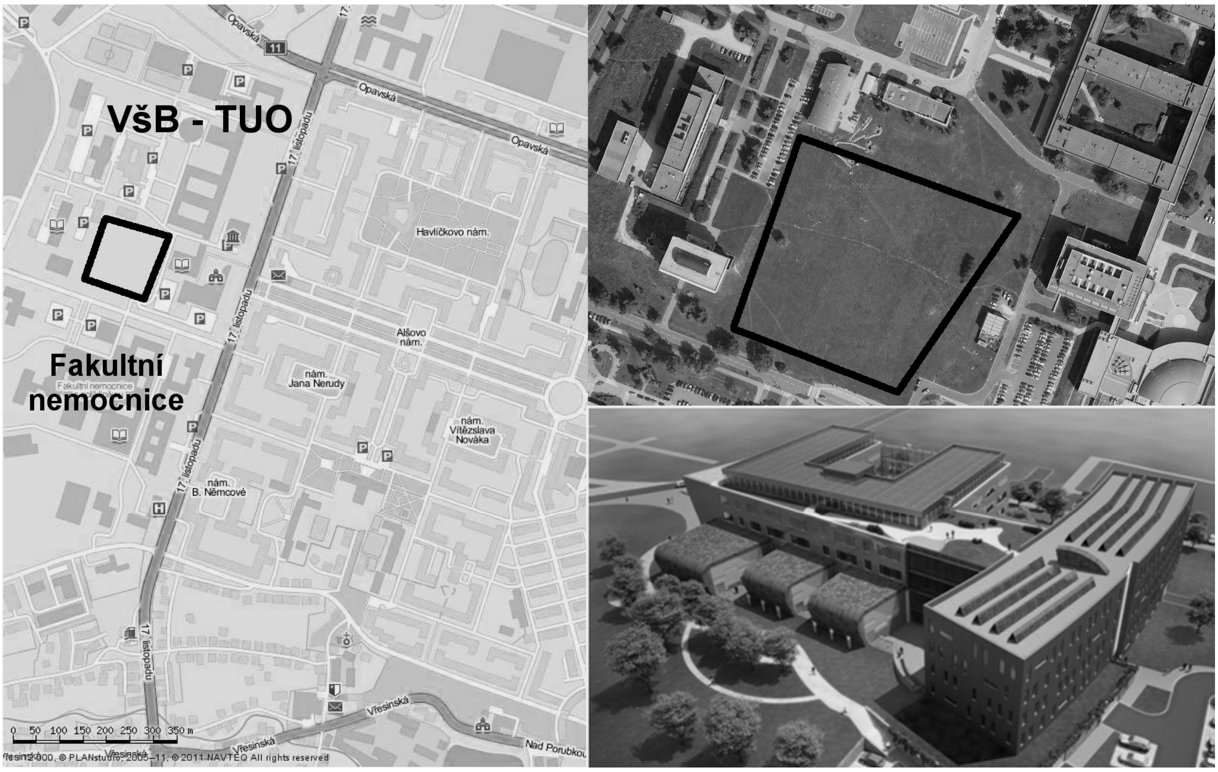

Fig. 1 Visualization of the FEI multi-functional building with a map and an air photograph of the location (the site is represented in the quadrangle (material:www.mapy.cz; www.fei.vsb.cz)).

Table 1 Soil parameters.

Parameter	Soil	1	2	3	4	5
	Units	CS1	SM	CS2	S-F	Slate
Thickness h	[m]	0 – 4.5	4.5 – 7	7 -12.5	12.5 – 20	20 – X
Bulk density γ	[kN/m^3]	18.5	18	18.5	17.5	24
Modulus of elasticity E	[MN/m^2]	4	15	4	25	60
Poisson number ν	[-]	0.35	0.3	0.35	0.3	0.25
Cohesion c	[kN/m^2]	14	5	14	1	100
Internal friction angle φ	[°]	24.5	29	24.5	31.5	28

graduates of the FEI into a single facility and provide sufficient room for lecture rooms and laboratories.

The sheet pile wall was implemented within the framework of earthmoving works prior to building the foundations of a new FEI building. This wall was installed by vibration at the north-east side of the building made of approx. 8 m long steel sheet piles (Fig. 2).

The soil environment in the given place consists of a layer of backfill under which there are Quaternary loamy up to sandy-clay sediments into a depth of approx. 12.5 m (CS1 and CS2). In the depth of 4.5 – 7 m below the surface there is a layer of sands, locally with crushed stone (SM). From the depth of 12.5 m down to approx. 20 m there are sands mixed with fine-grained soils (S-F). From the depth of approx. 20 m there is culm slate under these layers (according to in-house documentation, see Table 1).

For vibrating the sheet piles in situ, the resonance-free ram-hammer made by ICE Holland type 18 RF-ts with a separate driving unit (Fig. 3) carried by a wheeled crane was used. The selected parameters of the vibratory hammers indicated on the website by the ICE-Holland manufacturer in the company's regulations are given in Table 2.

CREATION OF A MODEL

The planar version of the Plaxis V8.2 calculation software developed for deformation and stability analysis of geotechnical problems was used for

Fig. 2 Part of sheet pile wall in the building pit (photo taken by: Lednická.).

Fig. 3 Demonstration of the overhead vibrator (photo: www.ice-holland.com.)

Table 2 Parameters of ICE type 18 RF-ts vibratory hammer (www.ice-holland.com).

18 RF-ts specifications		
Eccentric moment	0 – 18	kgm
Max. centrifugal force	1015	kN
Max. frequency	2300	rpm
Max. amplitude including clamp	11.6	mm
Total weight including clamp	4120	kg

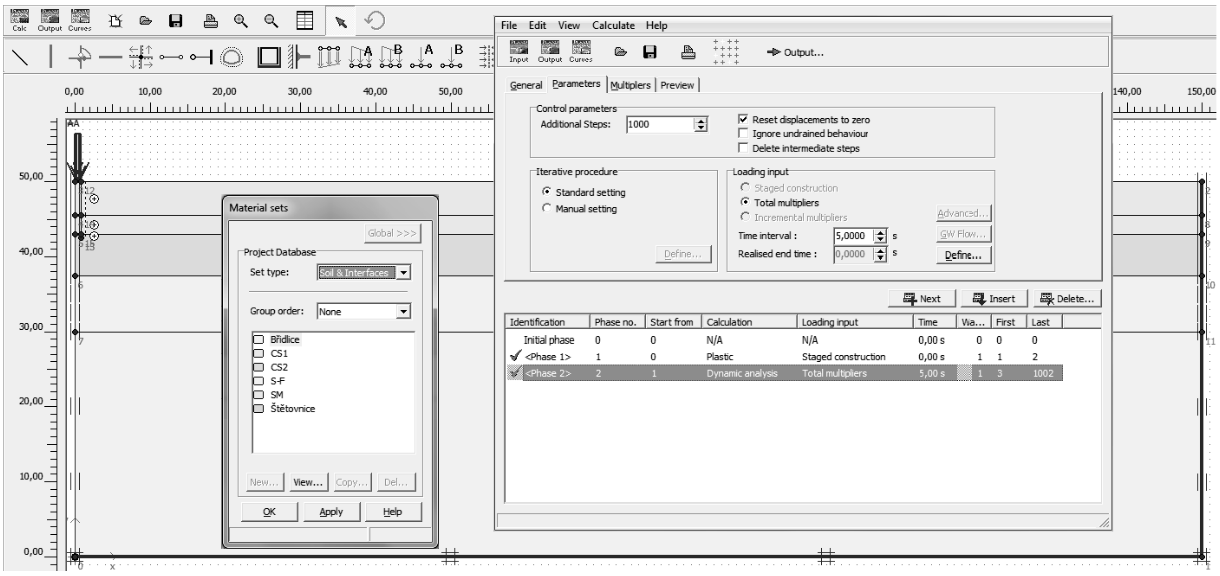

Fig. 4 Example of numerical model in Plaxis 2D.

creation of mathematical models. This calculation software is based on the finite element numerical method (hereinafter the FEM only). Plaxis V8.2 2D has a calculation dynamic module that makes it possible to solve dynamic problems using the FEM. The dynamic analysis results from Newton's law of motion. The elementary equation for calculation of time-dependent deformation changes under dynamic loading a matrix notation for the entire area under consideration as follows (Brinkgreve, 2002):

$$M\,a + C\,v + K\,u = F \qquad (1)$$

Where: u, v, a – vector of displacements, velocities and acceleration
M – mass matrix
C – damping matrix
K – stiffness matrix
F – load matrix

The mathematical models were selected as axisymmetric ones within the range of 150 x 50 m (length x width) (see Fig. 4). Conventional geometrical boundary conditions are set up in the models to limit displacements in the appropriate direction and supplemented with absorption conditions at the lower and right vertical boundaries of the model. By the absorption conditions, the absorption of increments of stress at the boundaries of the model caused by dynamic loading and which would otherwise be bounced back into the model, are achieved.

The rock environment was made up of five layers with a simple horizontal interface. Physical and mechanical properties of the soils were set up according to Table 1. The effect of water in the models was neglected due to simplification. The transversal and longitudinal velocities of propagation of seismic waves are automatically determined in the calculation software (Brinkgreve, 2002) for individual soils from the input parameters (elastic parameters and unit weight) according to relations 2 and 3 (Towhata, 2008).

$$V_P = \sqrt{\frac{E_{oed}}{\rho}} = \sqrt{\frac{E \cdot (1-\upsilon)}{\rho \cdot (1+\upsilon) \cdot (1-2 \cdot \upsilon)}} \; m/s \qquad (2)$$

$$V_S = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{E}{2 \cdot \rho \cdot (1+\upsilon)}} \; m/s \qquad (3)$$

Where: E ... Young's modulus;
ρ ... bulk weight of environment;
υ ... Poisson number.

The material parameters of damping were defined in the model using Rayleigh damping coefficients. For the given geological composition, the coefficient values were selected pursuant to previous experience, i.e. for $\alpha_R = 0.001$ and $\beta_R = 0.001$. The primary state of stress was generated by the software system automatically pursuant to the properties of soils under consideration and the depth. The steel sheet piles in the models reached the depth of approx. 7.5 m.

The dynamic force of the vibratory hammer was defined from the manufacturer's data (see Table 2), i.e. from the centrifugal force of 1015 kN at various frequencies of the vibrating action (up to 38 Hz) (see Fig. 5). For the calculation, the dynamic loading was not under consideration in the entire time span of its action but for the first 5 seconds only. The calculation and the model-based analysis were carried out in two stages. The values of velocity of vibration for creation of the attenuation curve were read out at 10 different distances from the centre of the sheet pile. Disturbing frequency was not considered.

EXPERIMENTAL IN-SITU MEASUREMENTS

In February 2011, short-term measurements of seismic effects of vibrations in the surrounding of the vibrating sheet pile wall were taken. During these measurements, several experiments were carried out in order to make attenuation curves of the velocity of vibrations in the given environment and assess the seismic loading of close building objects according to Czech technical standard ČSN 73 0040 (Lednická and Kaláb, 2011a, 2011b).

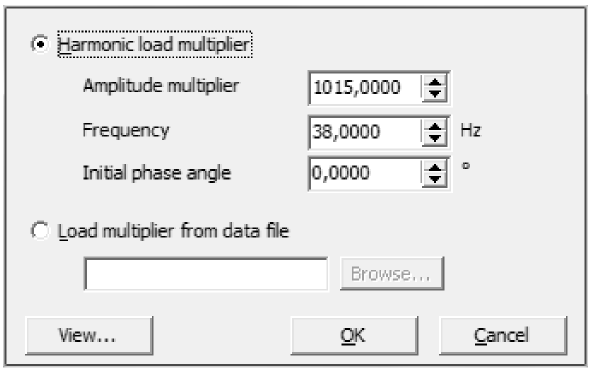

Fig. 5 Example of setting dynamic load in Plaxis.

The solitary GAIA seismic stations made by VISTEC Praha were used for the measurements (see Fig. 6). These stations provide digital records of three-component data. The dynamic range of the apparatus is up to 138 dB, the sampling frequency of the digital signal is up to 500 Hz. The time of the station control system can be synchronized with the GPS system (Universal Time) via an active antenna. The short-period sensors of ViGeo2 (see Fig. 6) and LE3D were used. The orientation of the horizontal components of the sensors was radial during the measurement mentioned, which meant that the component N of a sensor was always oriented towards the source of vibrations at each point, i.e. towards the place of the sheet pile wall; the component E is perpendicular to the component N.

Fig. 6 Seismic station GAIA by VISTEC Praha with ViGeo2 sensor

During the short single-day measurement, there were three seismic stations altogether available which were installed in several selected locations in the field subsequently.

RESULTS

The waveform records of vibration velocities in two directions (horizontal component v_x, vertical component v_y) were the outcome of the mathematical modelling. Analogous to measurements in the field, the prevailing vibration velocities occurred mostly on the vertical component and therefore, the vertical component was only used as a resource for other analyses.

The sustained values of the vibration velocity amplitude for preselected distances from the source of seismic loading were subtracted from the waveform records. The damping curve for the given frequency of the vibratory hammer and for the given rock environment was plotted from these vibration velocity amplitudes. This step was repeated also for other models with different vibration frequencies of the vibratory hammer. The graph in Figure 7 indicates four simulated damping curves with different vibration frequencies of the vibratory hammer.

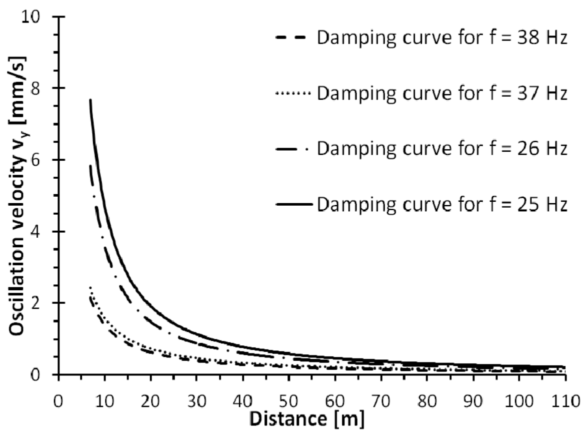

Fig. 7 Selected model-based damping curves

The maximum values of vibration velocity for two selected frequency intervals were subtracted at all measuring sites for total assessment of the vibration velocities measured in-situ and their damping in the given environment. The graph in Figure 8 indicates the plotted values of vibration velocities versus distance from the vibration source, separately for the frequency ranges of 20-29 Hz (grey quadrangles) and 30-38 Hz (black triangles). It is evident from the results that the vibration velocity reaches higher values in all measuring locations for the amplitudes on lower frequencies. The resulting model-based damping curve for 20 Hz frequency (unbroken curve) or for 38 Hz frequency (broken curve) was then plotted in the same graph.

The location at a distance of approx. 64 m from the vibration source was used for the comparison of the model (unbroken line) with real values of in situ measurements (broken line) – the values in the model correspond with the response of the rock environment, the monitored values were measured on the surface of a parking lot (the graph in Figure 9).

The differences in graphs between real-life and model-based situations are caused by a number of assumptions. For instance, it means simplifying the model via homogenization of the environment with similar parameters or determination of Rayleigh coefficients with insufficient reliability. With more precise entries in the model the results might achieve more comparable values with real-life situation but the demands on input data would be increased disproportionately, the duration of calculation would be extended and the size of output data would be increased.

CONCLUSIONS

The objective of this paper is to prove the possibility of utilization of the numerical modelling as a means for preliminary determination of propagation of seismicity in the rock environment.

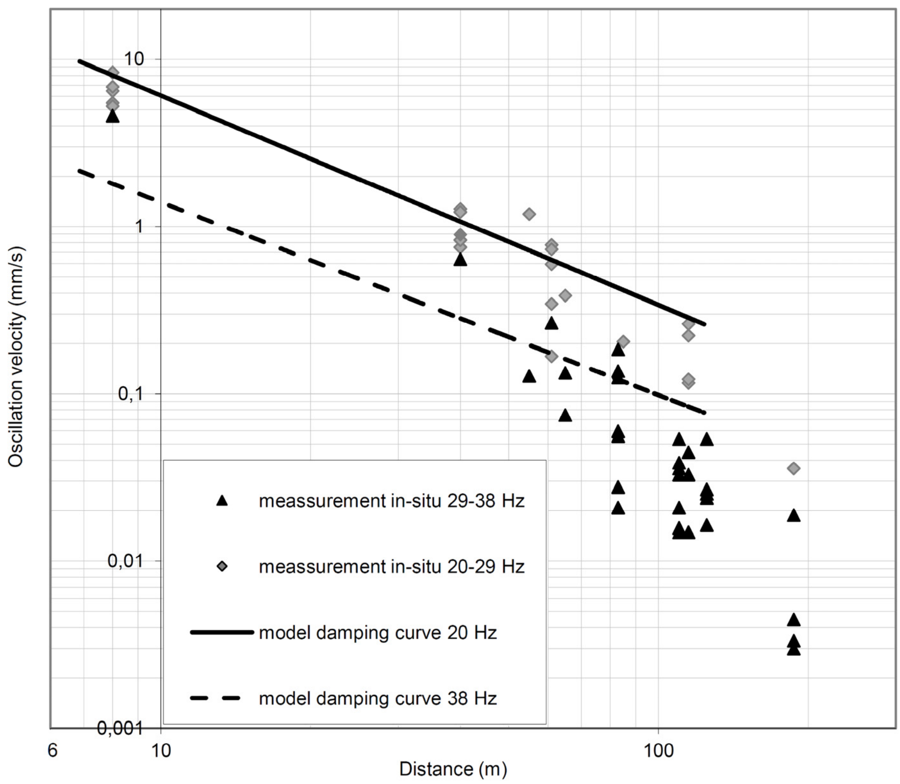

Fig. 8 Comparison of the model-based damping curves with the data measured in the field.

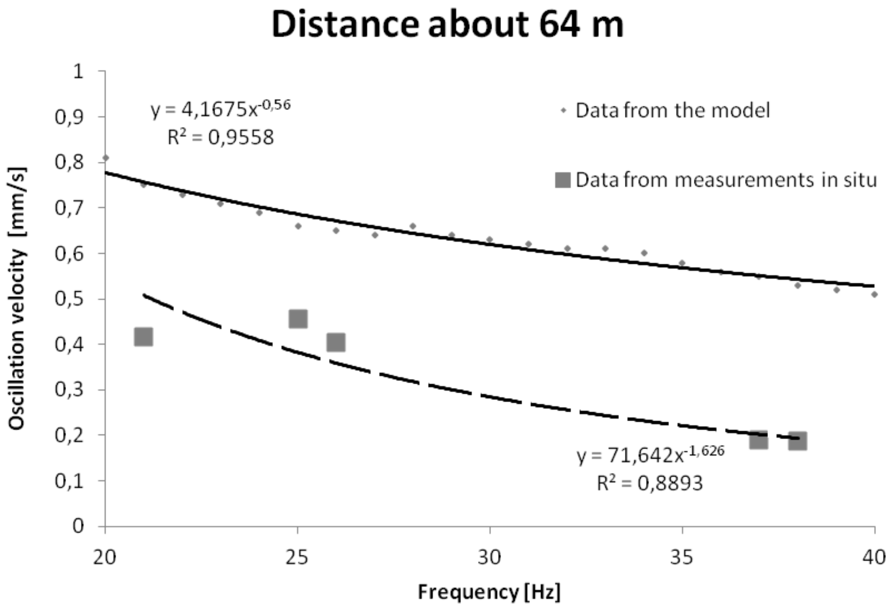

Fig. 9 Maximum magnitude of vibration velocity versus frequency at a distance of about 64 m.

The paper monitored the influence of change in frequency and distance on the amplitude of vibration velocity in the case of installation of the sheet pile by vibration using the vibratory hammer for the construction of the new FEI building in Ostrava-Poruba. Numerical models for the given locality of the site were created and technical seismicity measurements were carried out in situ and in the vicinity at the same time. Based on these numerical models and measurements carried out, comparison and evaluation of the influence of the sheet pile driving on the surrounding rock environment were presented. In light of quality, the results of numerical models corresponded with the situation in situ, in light of quantity, the conformity between the model-based results and the monitored values was not achieved, which can be primarily explained by necessary simplifying assumptions of the model (e.g. homogenization of the rock environment) and due to not quite reliable input data (damping parameters).

ACKNOWLEDGEMENT

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No. 1M0579, within activities of the CIDEAS research centre.

REFERENCES

Athanasopoulos, G.A. and Pelekis, P.C.: 2000, Ground vibrations from sheetpile driving in urban environment: Measurements, analysis and effects on buildings and ocupants. Soil Dynamisc and Earthquake Engineering, 19 (5), 371–387.

Brinkgreve, R.B.J.: 2002, PLAXIS 2D - version 8 (manual), Delf University of Technology & PLAXIS b.v., A.A. Balkema Publisher.

Bull, J.W.: 2009, Linear and non-linear numerical analysis of foundations [online]. [s.l.] : [s.n.], 2009 [cit. 2011-11-25]. In WWW: <http://books.google.cz>.

Czech Technical Standard: CSN 73 0040: 1996, Loads of technical structures by technical seismicity. (in Czech).

Kim, D.S. and Lee, J.S.: 2000, Propagation and attenuation characteristics of various ground vibrations. Soil dynamics and earthquake engineering, 19 (2), 115–126.

Lednická, M. and Kaláb, Z.: 2011a, Evaluation of ground vibrations generated by sheet-pile driving. 6th Congress of the Balkan Geophysical Society, Conference proceedings and exhibitors´ catalogue [CD-ROM], Budapest, Hungary.

Lednická, M. and Kaláb, Z.: 2011b, Evaluation of ground vibration during sheet-pile driving in urban areas. Geotechnika, roč. 14, č. 3, 16–21, (in Czech).

Stolárik, M.: 2008, Modeling of vibration effect within small distances. Acta Geodyn. Geomater., 5, No. 2 (150), 137–146.

Towhata, I.: 2008, Geotechnical earthquake engineering. Springer Verlag- Berlin Heidelberg, 684 pp.