Evaluation of Seismic Effect of Traffic-Induced Vibrations

Zdeněk Kaláb[1] *and* ***Eva Hrubešová***[1]

Vibrations caused by moving vehicles are necessary to take into account if roads are situated in populated areas. The vibration of ground induced by moving vehicles is a complicated problem. Values of induced vibrations depend on several parameters, i.e. the parameters of vehicles, quality of roads or railroad tracks, and subsurface geological patterns. It is possible to derive initial information about the vibration effect from experimental measurements. Four individual phases are usually studied in the surroundings of roads or railroads: generation of vibrations, propagation of seismic waves through soils, influence of vibrations on the nearest structures, and a reduction of vibrations using wave barriers.

This paper presents a methodology of seismological measurements in the surroundings of the road or railway and a detailed interpretation of digital data from seismological viewpoint. Frequency range of seismic channel was 2 – 200 Hz, so that the detailed interpretation may be performed in the time-frequency domain. Relations between the distance and maximum amplitude of vibration velocity were compiled. The relations are relatively complicated, especially in the distance of more than 7 – 10 m. We suppose that described effect is induced by local surface and subsurface geological pattern.

Key words: *traffic-induced vibration, seismological measurement, interpretation of wave pattern*

Introduction

An important phenomenon of present time is the transport of people and various materials. Vibrations expanding to the surroundings of road or tread road are one of the consequences of increasing traffic. In extreme cases, the vibration affects people or causes damage of buildings. Effects of vibrations on buildings and their occupants are both a technical and complex subject. Vibrations can be caused by passing road traffic, by railways, both surface and underground, by users of buildings and by numerous other sources. Generally, accepted influences (limit values) solve hygienic and construction standards. Geotechnical earthquake engineering deals with, among others, spreading of vibrations in different types of natural and artificial environments (Towhata 2008). Generation of vibrations could be reduced by modified design of vehicles, by improving the quality of tracks, by determining the optimum speed etc., and also by putting into practice suitable structures called vibration barriers. Barrier parameters are established by using numerical modelling (e.g., Ju 2009, Yang and Hung 2009). Obtained properties of numerical models (based on BEM - "boundary element method" or FIEM - "finite/infinite element method") are verified using physical models or analysis of experimental seismological measurement results.

Reliable evaluation of dynamic loading of both transport structures and its subsoil is one of the important factors determining the safety and serviceability of transport structures and contributing to the decrease of life cycle cost (LCC). Several examples of seismological measurements of vibrations induced by moving vehicles are presented in this paper. Our initial study was presented in the paper by Kaláb et al. (2012). That paper described some examples of experimental measurements.

Technical seismicity

The structural response of buildings depends on the excitation, as defined, e.g. in International Standards ISO 4866:1990. Different sources of vibrations might be taken into consideration such as earthquakes, explosions, wind effects, sonic booms, internal machinery, traffic, construction activities and others. With the exception of earthquakes, all sources belong to the technical seismicity. 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). Random data are stationary or non-stationary.

To evaluate measured seismological data from the structural response of buildings, the following factors need to be taken into account (according to ISO 4866:1990):

- 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;

[1]*prof. RNDr. Zdeněk Kaláb, CSc., doc. RNDr. Eva Hrubešová, PhD.*, VŠB – TU Ostrava, Faculty of Civil Engineering, Department of Geotechnics and Underground Engineering, Ludvíka Podéště 875/17, 70833 Ostrava - Poruba, Czech Republic, zdenek.kalab@vsb.cz, eva.hrubesova@vsb.cz

- Spectral structural features;
- Characteristics of excitation;
- Deflected form;
- Non-linearity in amplitude response.

Most available guidelines are based on frequency-velocity control bounds. Studies have shown that velocity seems to correlate closely with observed damage. Frequency plays a large role in vibration related to structural damage. Common structures have a low natural frequency, typically less than 30 Hz. Structural vibration exponentially increases if the vibration frequency falls within the bounds of the natural frequency of the structure. This phenomenon is commonly known as resonance. Thus, low frequency vibrations are potentially more of a concern than their high frequency counterparts (Henwood and Haramy 2015). Evaluating the influence and/or damage of buildings due to vibration, National (e.g. DIN 4150 - German, CSN 73 0040 – Czech, STN 73 0036 – Slovak) or International Standards are used (ISO 4866:1990).

Different vibration instrumentations consisting of a sensor and a recorder were used for our experimental measurements. All used sensors (Le-3D, ViGeo2) have three independent components; one in the vertical direction, and the other two in orthogonal horizontal directions. Measured seismological data were interpreted in time and frequency domains. Methodology of seismological measurements of technical vibrations and interpretations of these data were presented in many papers, e.g. Hradil et al. 2009, Kaláb et al. 2013, 2014, Henwood and Haramy 2015.

Damage of church

The first example presents seismological measurements at Světí near Hradec Králové (Eastern Bohemia). Measurements were performed in St. Andrew's church founded in the Middle Ages (14th century); the church was declared the National Heritage Site. Today, less and more significant cracks are detected in its walls and ceiling (Fig. 1).

Seismological measurement was performed using four seismic stations installed inside the church anchored to the floor. All sensors were located near the walls with the most significant cracks (crack up to 3 cm). An example of wave pattern is presented in Fig. 2, the minimum distance between this sensor and road was 14 m. Duration of seismic effect was up to 7 s, the maximum component value of velocity was 0.44 mm.s^{-1}, and harmonic vibrations were in the range of about 8-12 Hz. Nevertheless, the main cause of failures is probably the instability of soils under the basement of the church, partly located on a gentle slope. Vibrations induced by traffic (especially heavy agricultural vehicles) increase loading of the church. This often repeated loading has a highly negative impact on the technical conditions of the church.

Fig. 1. Church at Světí near Hradec Králové, on the right: examples of failures in the church (photo: Kaláb).

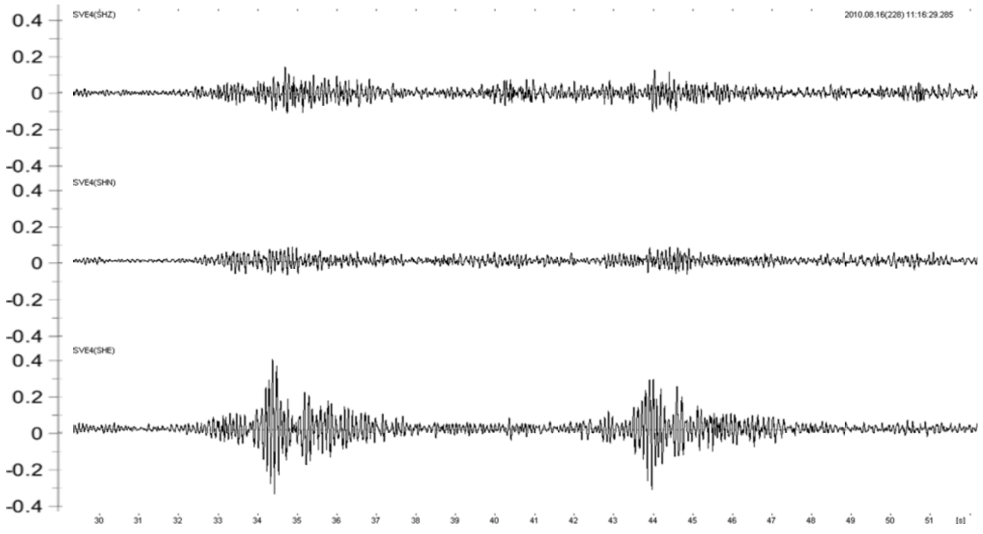

Fig. 2. Example of wave pattern of vibration induced by truck (distance about 17 m; top-down vertical, longitudinal and transversal components [mm.s^{-1}], vertical axis – relative time [s]).

Harmonic vibration in outbuilding

This seismological measurement was performed in a new outbuilding of small house located in the village of Zelinkovice, near the main road from Frýdek-Místek (Northern Moravia). Irregularities in the road surface, like potholes or cracks were identified during the measurement. Traffic vibrations were mainly generated by heavy trucks. Cars rarely generated perceptible vibrations in this outbuilding; it means that maximum particle velocity vibration did not exceed level of 0.10 mm.s^{-1} (not felt) or 1.15 mm.s^{-1} (threshold of perception), e.g. Hanaidy (2000).

Heavy traffic generated significant harmonic vibrations with prevailing harmonic frequency in the range of about 9 – 11 Hz; maximum component value of velocity was 0.32 mm.s^{-1} on the ground of the outbuilding (Fig. 3). On the first storey of the building, velocity values reached up to 0.65 mm.s^{-1}. Consolidated sedimentary rocks are covered by only the small thickness of soils in this, however the outbuilding was constructed on the infilling of waste rocks.

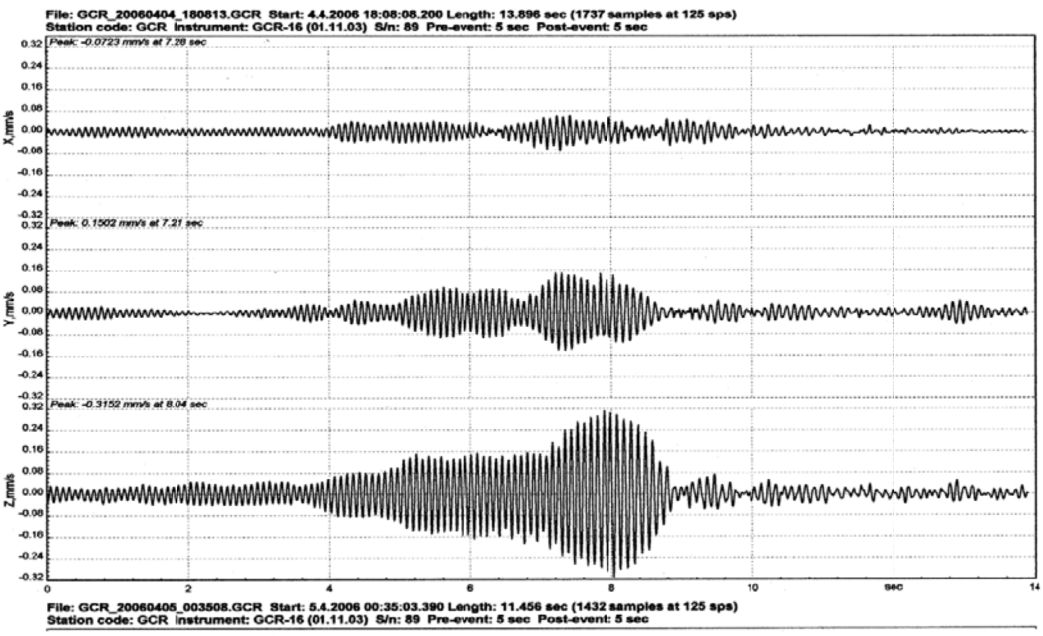

Fig. 3. Wave pattern with significant harmonic vibration generated by heavy truck in outbuilding (distance 5.5 m; top-down longitudinal, transversal and vertical components [mm.s^{-1}], the horizontal axis is relative time [s]).

Vibrations generated by train

A possible influence of vibrations generated by trains is a frequent question in discussions with the general public and also professionals (e.g. Hanaidy 2000). There are usually studied four individual phases in the surroundings of railways (and also roads): a generation of vibrations, a propagation of seismic waves through soils, an influence of vibrations on the nearest structures, and a reduction of vibrations using wave barriers (e.g. Yang and Hung 2009). In order to get some more detailed information, we realized experimental measurements near the railway from Ostrava – Svinov to Studénka (Moravia). This railway has been modernized in recent years and trains pass through this section with a speed up to 160 $km.h^{-1}$; maximum speed during experimental measurements was about 130 $km.h^{-1}$. Sensors were installed at distances of 3, 6, 9, 12, 15 m from the outer railway tie.

Wave patterns generated by trains have a typical character with gradually increasing and decreasing amplitudes depending on a number of wagons. In accordance with the presumption, maximum generated vibration velocity amplitude has clear correlation with the distance between the sensor and the railway tie. The results of this case study were presented by Kaláb (2015). Conclusions have been compiled as follows: Maximum measured value of vertical velocity was almost 20 $mm.s^{-1}$ on the railway tie; values of horizontal components were significantly lower here. Sensors located out of railway tie have higher values on the horizontal components; up to 2 $mm.s^{-1}$ at a distance of 5.5 m. Prevailing maximum frequencies in wave patterns were in the range from 7 – 15 Hz. Obtained relations between the distance and maximum amplitude of vibration velocity are relatively complicated, especially at a distance of more than 7 – 10 m. We suppose that described effect is induced by local surface and subsurface geological pattern. Differences in measured values are probably a result of different weight of vehicles and their speed. An example of attenuation curves are in Fig. 4. It is possible to document that type of train (it means especially the weight of a vehicle) has a significant influence on the maximum vibration value in only the nearest distances.

A detailed analysis of wave pattern is possible to realize using spectral or wavelet analysis. For example, using software named "Spectra_Analyzer" made by prof. Lyubushin (e.g. Lyubushin 2007, Kaláb et al. 2011) recorded a signal that could be decomposed into a defined number of levels with subsequent frequency ranges. The orthogonal wavelet order is found automatically by using the minimum entropy criterion. After plotting each sub-level in scale we can see the most important parts of the original signal depending on the time period.

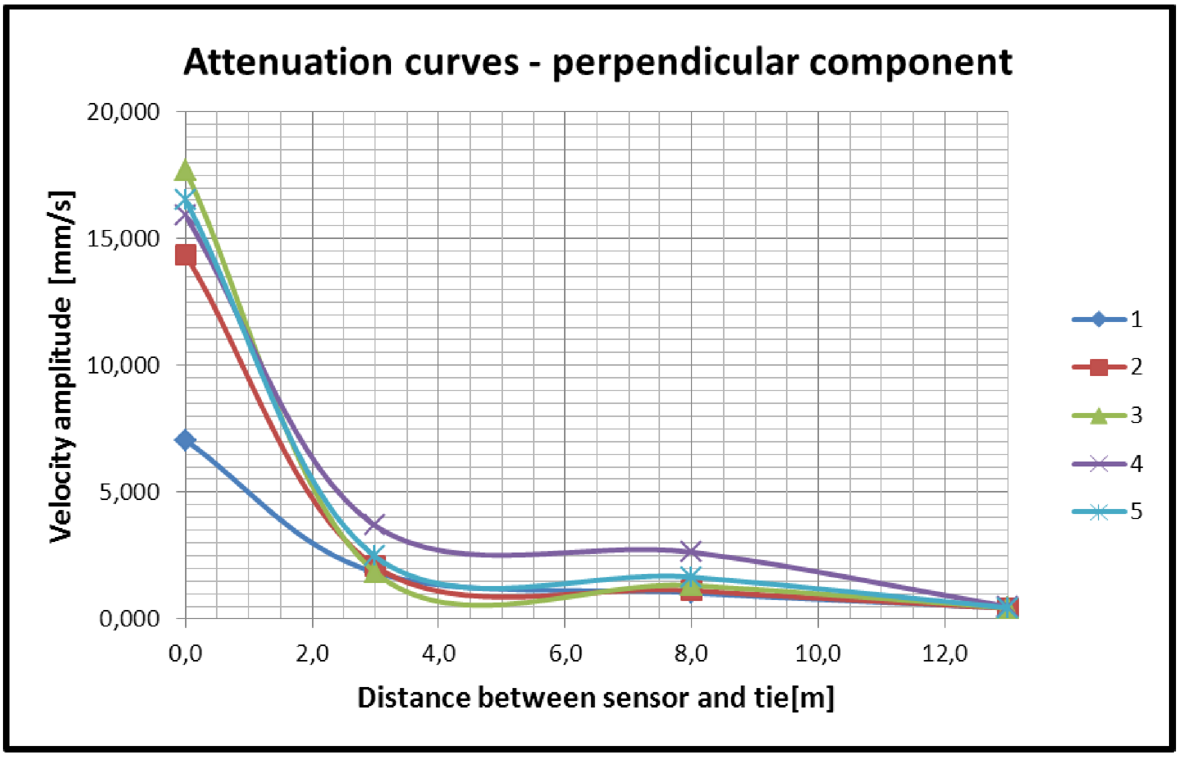

Fig. 4. Attenuation curves (perpendicular component to railway tie). Note: 1 – freight locomotive, 2 - wagon trail, 3 – 5 – fast trains (according to Čejka 2009).

Conclusion

This paper has summarized three examples of experimental measurements of vibrations generated by traffic. Generally, these vibrations do not evoke damages of structures in the surroundings of roads and roadways. However, first of all, they provoke very unpleasant perception of people. The specific attention is necessary to pay to road traffic vibrations on historic buildings (e.g. Hume 20xx). Due to the particular geological structure and/or particular construction, substantial vibrations could be generated. Three main parts are necessary to take into account; it means - source, path and receiver. Physical parameters and characteristics of the soil/rock environment (represented path) are usually not available. However, these geological characteristics of the environment between the source of vibrations and a studied place, usually structures or buildings, have an important influence on the values and other parameters of the generated vibrations. In order for us to evaluate reasons of these vibrations the interpretation in both time and frequency domains is necessary. Modern numerical methods, for example, fuzzy sets, fractal analysis and wavelet analysis (e.g. Lyubushin et al. 2004, Telesca et al. 2011) may have provided some new information.

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