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# Seismic impact of the railway on the geotechnical constructions

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**Abstract.** Nowadays, the focus on more ecological means of material and persons transport is still higher. Big loads can be transported on railways more effectively and with lower environment impact than on roads. The geotechnical structures are inherent parts of railway infrastructure, such as embankments, sides of notches and, of course, tunnels, foundation constructions of buildings or pillars of bridges and the others geotechnical constructions (e.g. retaining walls, culverts, transition area of bridges). By train pass, vibrations are caused and these vibrations are relayed to the soil. These vibrations can make adverse impact to surrounding objects and to technologies placed in. This so far uncared-for influence gets into the foreground by current trend of everyday life technical equipment increasing. The article introduces different kinds of geotechnical structures and the influence of by-passing railway transport on their constructions and surroundings. The data are evaluated in the amplitude and frequency domain.

## 1. Introduction

Nowadays there is emphasis on more environmentally-friendly ways to transport material and personnel than road transport. Rail can move large loads more effectively and with less environmental impact in particular. In the Czech and Slovak Republics there is a very dense railway network, which was started to be built in the mid-19th century and is still being modernized. An inseparable part of the transport routes also include geotechnical structures such as embankments, cuts, the transition zones of bridges, but of course also tunnels and foundation structures of the surrounding buildings.

Passing trains produce vibrations that are transmitted to the ground [1, 2, 3]. The vibrations propagate through the rock environment and decrease with increasing distance [4]. In the near-surface sediments the vibrations may even be amplified; resonant vibrations are induced here and the vibration period is extended as a result of free vibration of the near-surface sediments. The resulting vibrations, transmitted through natural ground or artificial soil body, may have an adverse effect on both the surrounding objects, on people living in these buildings, as well as on the technology located in them which can be very sensitive to vibration. With the current trend of the technical equipment of everyday life on the increase, this so far neglected effect comes to the fore. It is therefore important to realize the experimental measurements to obtain values representing these vibrations. The main task of these measurements is to determine the maximum velocity values (or acceleration), the parameters of waveforms and frequency spectra of the measured signals. The resulting data is then very important for civil engineers who, based on the measured values, can specify the effects on the existing technical



condition and possible susceptibility to damage [5]. The impact of such vibrations on buildings or on the population is then assessed by the relevant technical standards and regulations [6]. The effect of vibrations in the vicinity of the railway line can be also determined using numerical modelling of the actual geological structure, vibration and eventually buildings. The current models of the effects of vibrations on buildings are based on numerical methods such as FEM - "Finite Element Method", or BEM - "Boundary Element Method", while the building of relevant models is very often based on the results of experimental seismic measurements [7, 8].

This article presents the results of two experimental seismic measurements in the context of theoretical research on the dynamic impact of rail transport on various types of geotechnical structures. Specifically, it is the dynamic response of the secondary tunnel lining to the train's passing through the neighbouring tunnel tube and the response of the reinforced concrete walls. Subsequently a concrete example of a practical solution to the problem dealing with the same issues will be presented.

## 2. Instrumentation

All measurements were taken using Gaia2 and Gaia2T seismographs with ViGeo2 sensors (both of them are manufactured by Vistec Prague). The Gaia2 or Gaia2T seismograph is a three-channel seismic station with a dynamic range of 138dBp-ps and with the triggered and continuous digital data recording option. Time synchronization is provided by a GPS module. ViGeo2 is a compact, active, short-period, three-component and velocity seismometer for field and station applications. The seismometer includes three mechanical vibrating systems (sensors) with a natural frequency of 2 Hz and the frequency range is 2 Hz to 200 Hz. SWIP (Waves Seismic Interpretation Program), supplied as standard with Gaia seismometers by Vistec Prague, was used to process seismic data. This program enables to process a seismic signal both in the amplitude region and in the frequency domain. In the amplitude region, the processing software does not allow for the recalculation of vibration amplitude values to physical units [ $\text{mm}\cdot\text{s}^{-1}$ ], so the vertical axes are in quantizing levels [cnt] in all the wave pattern figures. Conversion formula:  $1 \text{ cnt} = 2.975 \cdot 10^{-6} \text{ mm}\cdot\text{s}^{-1}$ . Figures of all wave patterns show top down the vertical component, marked SHZ, the horizontal radial component SHN (directed in the direction in which the tunnel runs) and the transverse SHE; the horizontal axis is time in seconds (the axes are with the same amplitude and time scales).

## 3. Measurement 1 - seismic response of the secondary tunnel lining

During the reconstruction of the Jablunkov Tunnel II the operation of trains was diverted to tunnel I, which was temporarily operated. After an incident in 2009 that led to the collapse of the entire tunnel profile from the 70th to 160th tunnel meter (TM), a series of measures was taken [9]. In the blocked part mining was renewed, in the northern, unburdened part of the tunnel the secondary lining has already been installed. On this lining, seismic response measurement of the response of the invert of the secondary lining to a passing train in tunnel I was realized. Four velocity seismometers were set on the invert in a profile parallel to the longitudinal direction of the tunnel, and the radial horizontal axis (SHN) was oriented in the direction of the structure and the horizontal transverse axis (SHE) perpendicular to the axis of the temporarily operated tunnel I.

The largest response was observed from a passing freight train of thirty-four full four-axle wagons pulled by two locomotives. In Figure 1 the wave pattern of recording of the whole train can be seen, and in Figures 2 and 3 there is a detail of wave recording of the captured maximum amplitude on sensor 1 together with the corresponding frequency spectrum. Maximum velocity values captured on sensors 1 to 4 are shown in Table 1.

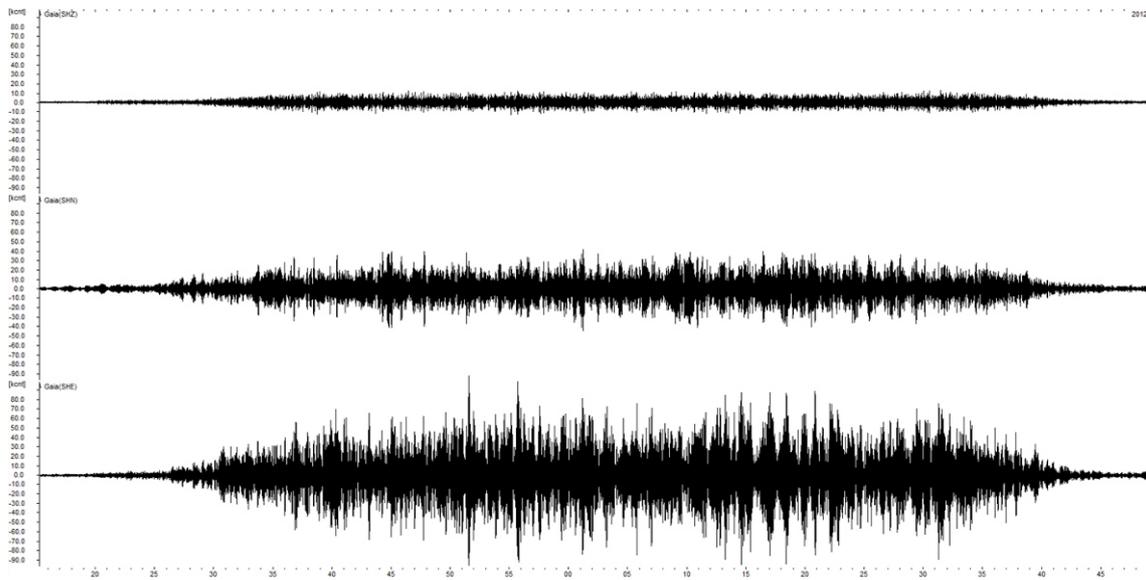


Figure 1. Wave pattern of recording of the whole train.

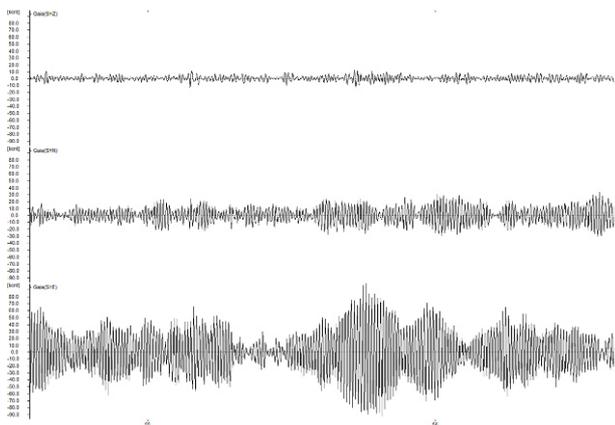


Figure 2. Detail of wave pattern of recording.

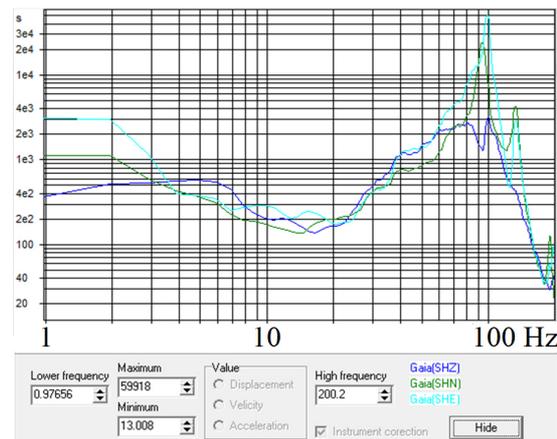


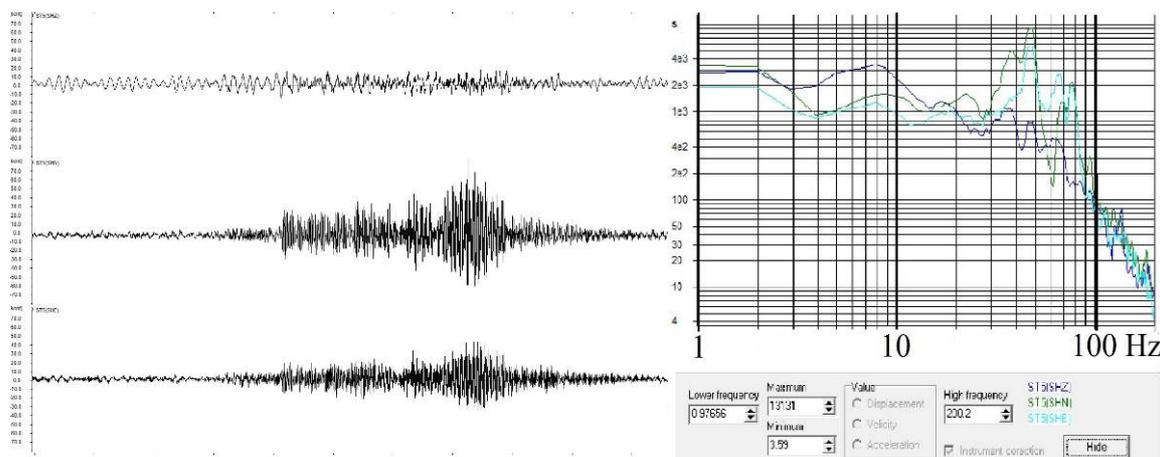
Figure 3. The corresponding frequency spectrum.

Table 1. Maximum amplitudes of velocity – measurement 1.

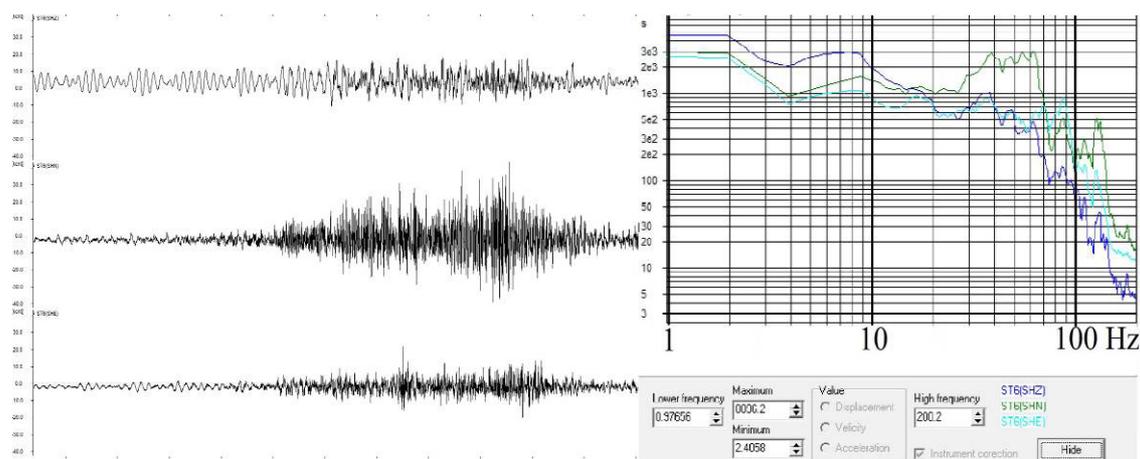
Sensor	Maximum velocity amplitude of oscillation [mm.s <sup>-1</sup> ]		
	SHZ	SHN	SHE
1	0.037	0.135	0.312
2	0.025	0.112	0.174
3	0.031	0.146	0.157
4	0.054	0.224	0.250

#### 4. Measurement 2 - seismic response of a reinforced concrete angled wall

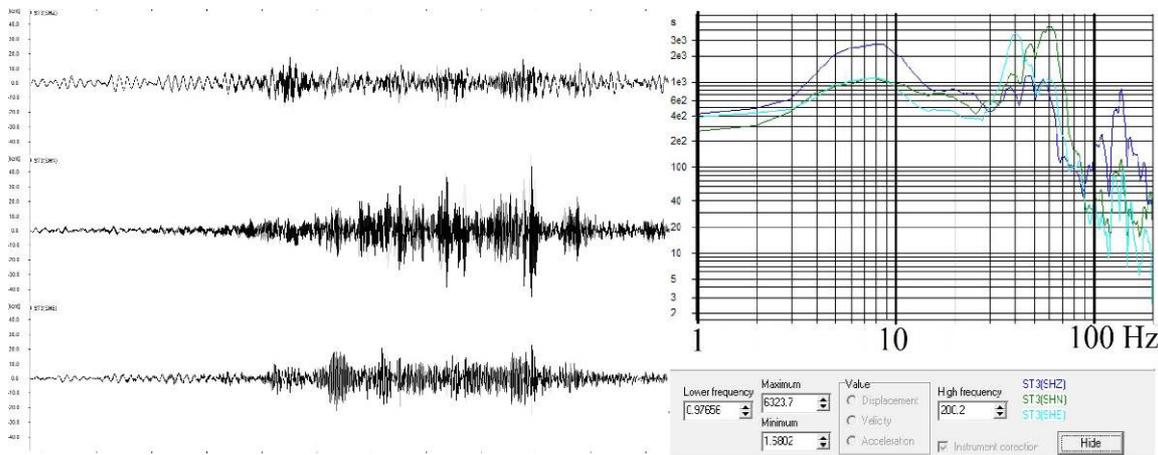
The second presented measurement is the response of a reinforced concrete angled wall in Ostrava - Svinov, Prodloužená Bílovecká. At a distance of fifteen metres from the nearest operated rail, measurements were realized both in the foot of the wall (sensor 1) and in its crown (sensor 2) and another station was also located on the far side of the road (sensor 3, distance from the nearest operated rail around thirty-four metres), which is built on an artificial ground body stabilized by the angled walls. All velocity seismometers are oriented with their radial horizontal axis (SHN) perpendicular to the track axis and horizontal transverse axis (SHE) horizontally with the axis of the track. From the recorded train sets (closest rail - CityElefant, electric unit series 460, and rail at a distance of twenty-two or twenty-six metres - RegioJet, SC Pendolino, express train, an empty freight train) the largest response observed against all expectations, was from the CityElefant. Figures 4-6 present wave patterns or records of CityElefant and frequency spectra obtained from individual stations. The maximum amplitudes of velocity are shown in Table 2.



**Figure 4.** Wave pattern and frequency spectrum of recording at the foot of the angled wall (sensor 1).



**Figure 5.** Wave pattern and frequency spectrum of recording at the crown of the angled wall (sensor 2).



**Figure 6.** Wave pattern and frequency spectrum of recording at the remote side of the communication (sensor 3).

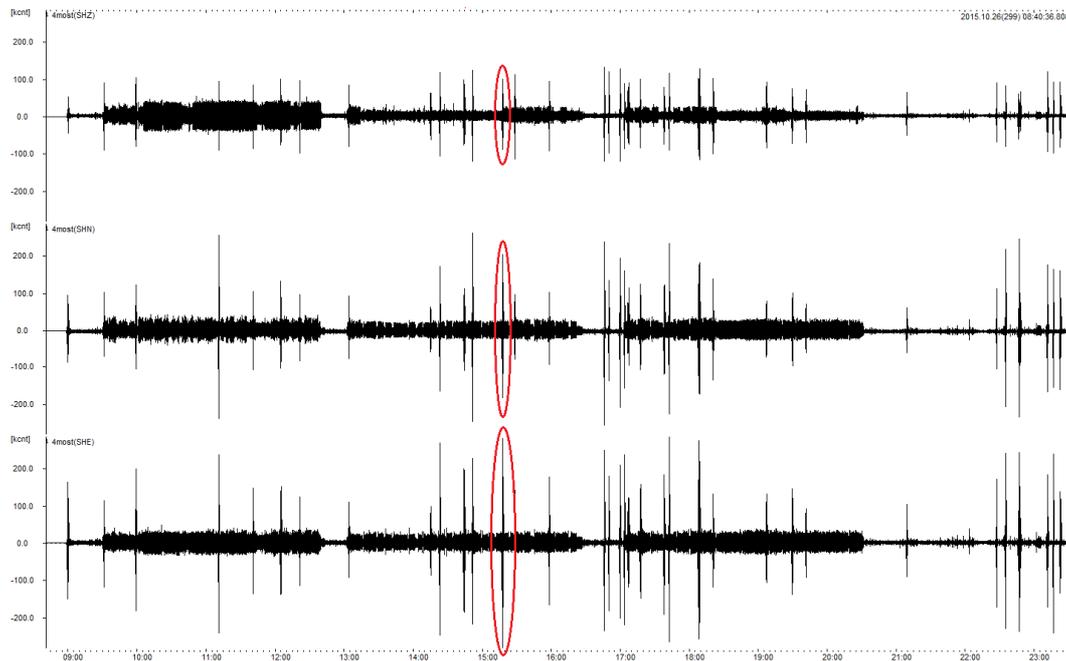
**Table 2.** Maximum amplitudes of velocity – measurement 2.

Sensor	Maximum velocity amplitude of oscillation [ $\text{mm}\cdot\text{s}^{-1}$ ]		
	SHZ	SHN	SHE
<b>1</b>	0.060	0.243	0.131
<b>2</b>	0.052	0.128	0.062
<b>3</b>	0.056	0.146	0.073

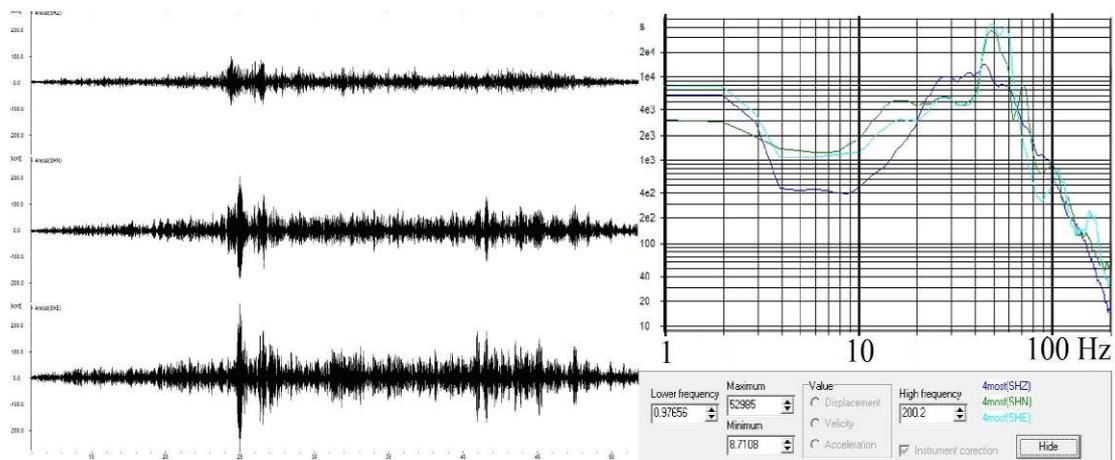
### 5. Measurement 3 - seismic response of a reinforced concrete floor

In the following section, seismic measurements are presented which dealt with the specific practical task when a technology very sensitive to vibrations should be located in a production hall, and in close proximity outside the hall works a railway was operated at a distance of twenty metres. The aim of the measurements was to assess the maximum possible seismic load and frequency of journeys per twenty-four hours. A velocity seismometer was placed on the concrete floor of the empty hall at the location where the equipment should be installed in the future, with the radial horizontal axis (SHN) being orientated perpendicular to the axis of the railway. Figure 7 is a wave pattern of recording at the time from 9 am to 11 pm with distinct peaks representing various passages of trains. In the background among others, the noise caused by the technology in the next production hall can be traced. The following figure shows the wave pattern of the phenomenon with the maximum captured velocity amplitude and the corresponding frequency spectrum, where a significant peak in the 50-55 Hz region represents the just mentioned technological background process.

From the wave pattern of the entire twenty-four hour recording the maximum velocity amplitude of oscillation was deduced for the six largest phenomena (Table 3). Note: the time indicated in the tables is CET. The end result was a chart showing the time distribution of the seismic load for a given location (Fig. 9).



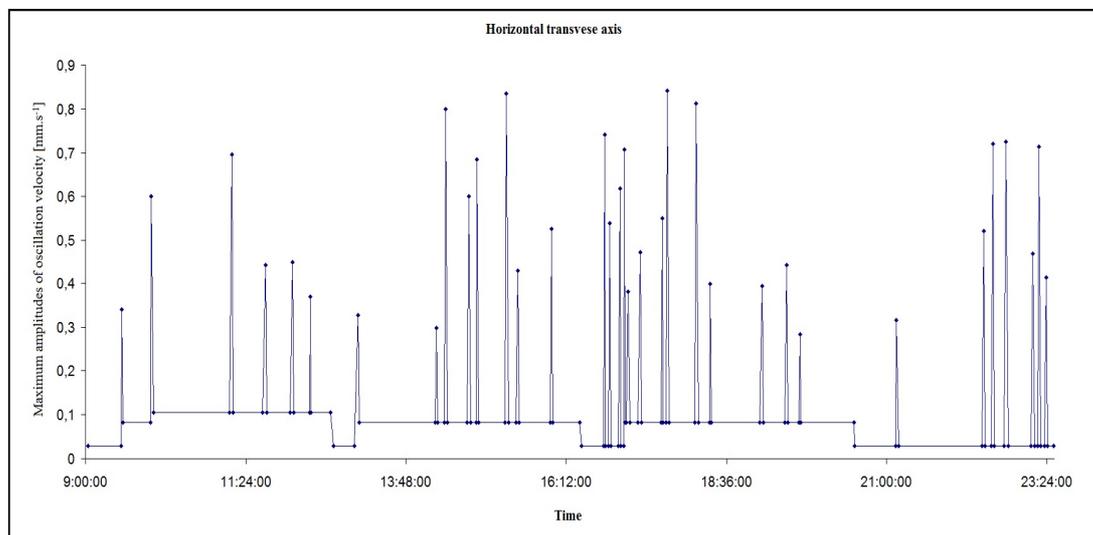
**Figure 7.** Wave pattern of recording at the time from 9 am to 11 pm with recorded maximum amplitude – red color.



**Figure 8.** Wave pattern and frequency spectrum of recording of the phenomena 3.

**Table 3.** Maximum amplitudes of velocity – measurement 3.

Evaluation phenomena number	Time captured of the phenomena	Maximum velocity amplitude of oscillation [ $\text{mm}\cdot\text{s}^{-1}$ ]		
		SHZ	SHN	SHE
<b>1</b>	11:11 am	0.279	0.756	0.714
<b>2</b>	2:51 pm	0.366	0.768	0.672
<b>3</b>	3:18 pm	0.339	0.601	0.848
<b>4</b>	4:47 pm	0.387	0.762	0.741
<b>5</b>	5:42 pm	0.342	0.693	0.827
<b>6</b>	7:27 am	0.202	0.726	0.720

**Figure 9.** Distribution of the seismic load for a given location in the time period from 9 am to 11 pm – horizontal transverse axis (SHE).

## 6. Conclusion

In this paper we presented the results of two experimental seismic measurements carried out in the framework of theoretical research on the dynamic influence of rail transport (and transport in general) on various types of geotechnical structures. Specifically, the dynamic response of the secondary lining of the train's passing through a side tunnel tube and the response of the reinforced concrete angled wall loaded with dynamic effects of rail traffic were mentioned. Following this a specific example of the problem in practice of dealing with seismic loads was presented, which could jeopardize the smooth operation of industrial technology very sensitive to vibration. The results of this measurement ultimately proved the unsuitability of the location selected for the location of the equipment.

The research interest is obviously much broader. Within this extensive study dealing in general with the dynamic effects of traffic, some results both in terms of seismic experimental measurements [10] and in terms of mathematical modelling of seismic effects [11] were already presented within the workplace. The issue is solved comprehensively and as shown by the results of measurements three (response of reinforced concrete floors in the production hall) in the article, it is necessary to monitor and analyse not only vibrations with stronger intensity which can lead to damage to buildings, but also vibrations with an intensity that is significantly lower.

### Acknowledgements

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