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Tram Type Influence on the Frequency Spectrum Character of the Subsoil Dynamic Response

***Abstract**. This article deals with the results of the experimental seismic measurement using a standard seismic in situ station on a rock mass where the influence of the type of the trams passing on the frequency spectrum characteristics, the bandwidth and the maximum peaks was monitored. The goal of presented experimental measurement was to verify whether it is possible to find common patterns for individual types of tram cars in the frequency spectra using standard equipment for seismic measurements. The results show that in the spectrums certain characteristics can be traced, which are common to both a particular type of tram and a common group of tram types historically or structurally derived from each other.*

Streszczenie.** W artykule przedstawiono badania sejsmiczne związane z przejazdem różnych typów tramwajów. Przedstawiono charakterystyki widmowe oraz monitorowano pasmo częstotliwości. Ekspeyment wykazał że każdy z pojazdów jak również każdy typ pojazdu ma typową dla siebie charakterystykę sejsmiczną.* ***Badania sejsmicznych charaterystyk widmowych różnych typów pojazdów szynowych

Keywords: seismic measurement, seismic station, frequency spectrum, tram cars.
Słowa kluczowe: badania sejsmiczne, trawaje, charakterystyka widmowa.

Introduction

Standard seismic stations equipped with speed or acceleration sensors are commonly used to measure the natural, induced and technical seismicity [1, 2, 3, 4]. Such a station, for example, monitors the dynamic response of buildings or the dynamic response of rock masses due to various sources [5, 6, 7] and, on the basis of such measurements, the possible damage to buildings or the influence of vibrations on humans is assessed according to the technical standards or the attenuation parameters of the rock environment are determined [8, 9, 10]. The obtained results of such seismic measurements are in the form of wave images and frequency spectra wherein maximum values or maximum frequency values are monitored in the wave images at a certain time interval, and the predominant frequency of the dynamic load source is determined from the frequency spectra [11]. The frequencies themselves then play a very significant role in the possible structural damage to buildings, especially if the resonance of the building's own frequency and the dynamic load source frequency occur. Long-term effects of vibrations to buildings may result in cracks in the plaster, masonry and, possibly, other faults, e.g. in vibration-sensitive equipment [12, 13, 14].

One of the most common sources of vibrations in the intravilan of large cities are the passing trams [15, 16, 17]. The intensity of these vibrations is mainly dependent on the type and age of the passing trams, but also on the structure and condition of the trackbed and the local geological structure [18, 19].

The range of maximum amplitudes of velocity, acceleration and frequency of the measured values for the rail transport in general are defined, for example, in International Standard ISO 4866:2010 [20]:

- the maximum range of the vibration velocity amplitude: 0.2-50 $mm.s^{-1}$
- the maximum range of the acceleration amplitude: 0.02-1 $m.s^{-2}$
- the frequency range: 1-80Hz

This paper reveals the findings and presents the results of the experimental seismic measurement using a standard seismic in situ station on a rock mass where the influence of the type of the trams passing on the frequency spectrum characteristics, the bandwidth and the maximum peaks was monitored.

Measuring device

The seismic measurements were performed using the Gaia2T device with the ViGeo2 sensor, both produced by the Czech company Vistec Praha (Fig. 1). The Gaia2T device is a three-channel seismic station with a 138dBp-p dynamic range with the ability to run both continuous and digital data recordings. Time synchronization is provided by the GPS module; data recording is performed on CompactFlash discs. ViGeo2 is a compact, active, short-period, three-part, speed seismometer for field as well as station use. The seismometer includes three mechanical oscillating systems (sensors) with a frequency of 2Hz and a frequency range of 2Hz to 200Hz.

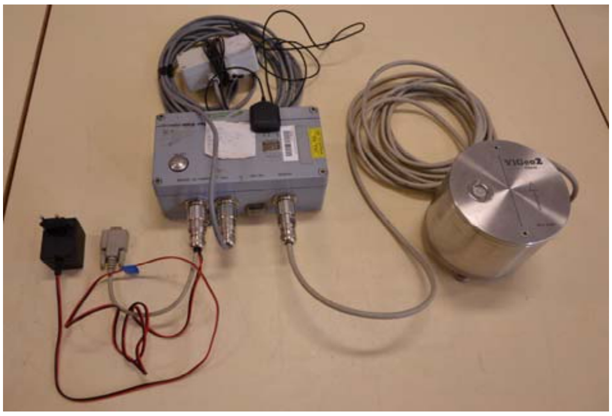


Fig.1. Seismic apparatus Gaia2T with seismometer ViGeo2

Seismic Wave Interpretation Program (SWIP), supplied by Vistec Praha as a standard to Gaia devices, was used to process the seismic data. In this program, the seismic signal can be processed in both the amplitude and the frequency domain. In the amplitude area, the processing software does not allow recalculation of the vibration amplitude values to physical units [$mm.s^{-1}$], therefore, the vertical axes are plotted in quantization levels in all figures of the wave images [cnt] (more information in [21]). Conversion formula for the ViGeo2 sensor:

$$1cnt = 2{,}975.10^{-6}\ mm.s^{-1} \quad (1)$$

Experimental measurement

The seismic measurement was carried out in the area of Silesian Ostrava (GPS coordinates 49.8288183N, 18.2988875E) in three days. The location for the experiment was chosen with respect to the remoteness from the possible interfering anthropogenic vibrational influences, with respect to the direct and zero elevation of the tramline, which meant a constant speed of the trams in both directions, and with regard to the simple geological structure, where, up to several meters, only anthropogenic sediments are found. The tramline is renovated here; new concrete sleepers are laid in the new gravel bed (Fig. 2). The seismic station was located at the nearest possible distance from the trackbed, as defined in ČSN 34 1500, ed. 2 [22], taking into account the traction lines (Fig. 3). The distance was also minimized due to the undesirable influence of the rock environment in which these vibrations are transmitted as well as attenuated, wherein, in the near-surface sediments, resonance vibrations may also be induced with the increasing distance, and the vibration times may be prolonged due to the free vibration of these sediments.

Fig.2. Location of the experiment with the tram ČKD T6A5

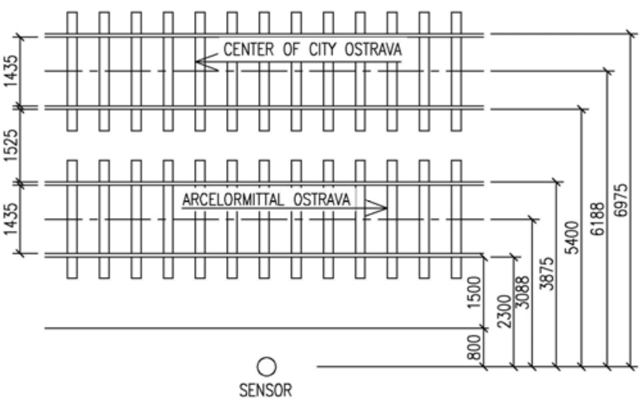
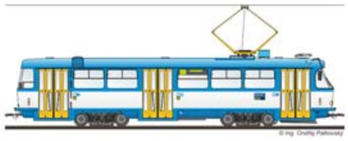


Fig.3. Measurement scheme

Types of trams in the monitored location

Table 1 shows the basic parameters of the tram cars that pass through the area of interest (measurement) at different time intervals. In the table, the trams are arranged from the oldest to the newest ones [23].

Table 1. Types of trams in the area of interest

ČKD T3	
	
Length [m]	14.000
Empty vehicle weight [kg]	16 300
Places to sit	31
Standing places	72
Model year	1962-1989
ČKD T6A5	
	
Length [m]	14.700
Empty vehicle weight [kg]	19 500
Places to sit	30
Standing places	85
Model year	1994
Inekon LTM 10.08	
	
Length [m]	19.790
Empty vehicle weight [kg]	26 000
Places to sit	41
Standing places	99
Model year	1998
Inekon 2001 TRIO	
	
Length [m]	20.130
Empty vehicle weight [kg]	24 200
Places to sit	41
Standing places	99
Model year	2001
Vario LFR	
	
Length [m]	15.100
Empty vehicle weight [kg]	21 200
Places to sit	33
Standing places	60
Model year	2005

Results

During the measurements, a total of 231 trams were captured. The length of the time records representing the passing trams ranged in the first seconds, depending on the type of the trams and the number of cars (one or two). Figure 4 illustrates a typical example of time records of the passing trams (the ČKD T3 type, two cars). The horizontal axis comprises the time [sec] while the vertical axis includes the amplitude [cnt]. The figure shows, top to bottom, the vertical component (SHZ), the horizontal radial component (SHN) (oriented perpendicular to the track) and the horizontal transversal component (SHE). For all-time records, the maximum values were always the highest for the vertical component, which corresponds to the dynamic load due to the passing trams. The digital data was transferred to the frequency domain using the Fast Fourier Analysis algorithm. An example of a frequency spectrum for a given time recording is illustrated in figure 5. It is obvious that the spectra of all three components are almost identical, only for the vertical component the maximum peak is significantly higher and is sharper, which corresponds to the measured data that represents the time record. This fact was found out for all evaluated spectra, so only the spectra obtained in the vertical component were processed for further analysis with respect to tram types.

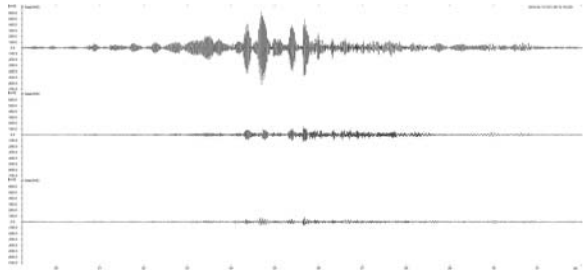


Fig.4. Example of time record of the passing tram

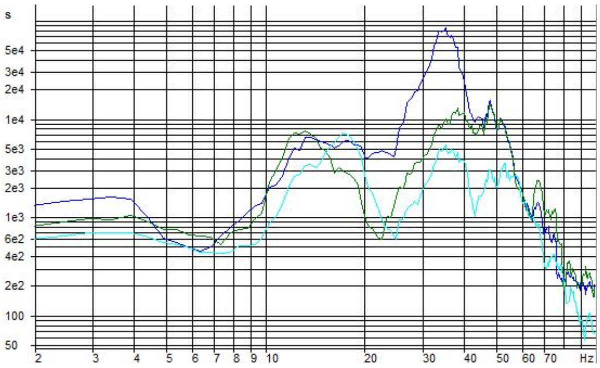


Fig.5. Example of a frequency spectrum for a given time record

The frequency spectra then differed with regard to the types of trams, which is represented by figures 6-10. The results are summarized in table 2. The driving direction, i.e. the difference between the closer or more distant track, did not have a more significant influence on the character of the spectrum. Only the maximum peak for the closer track was slightly lower, in the first units of Hz.

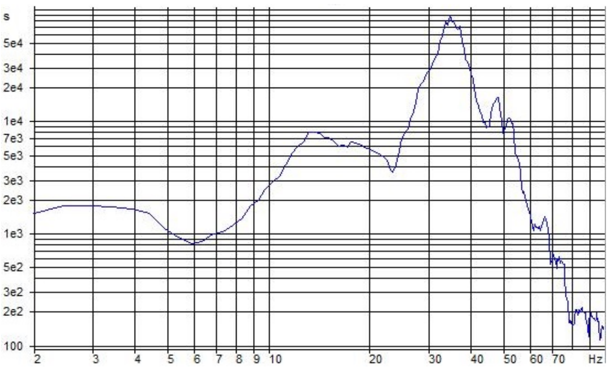


Fig.6. Characteristic frequency spectrum of the tram type ČKD T3

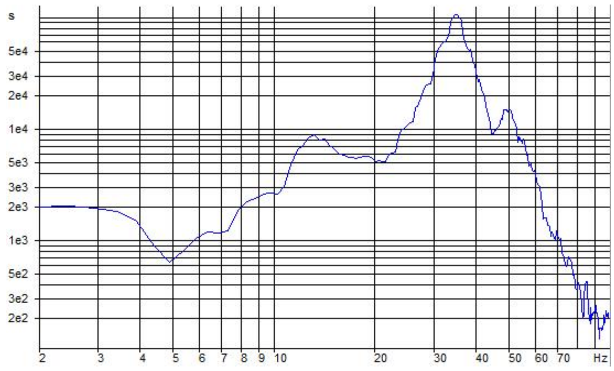


Fig.7. Characteristic frequency spectrum of the tram type ČKD T6A5

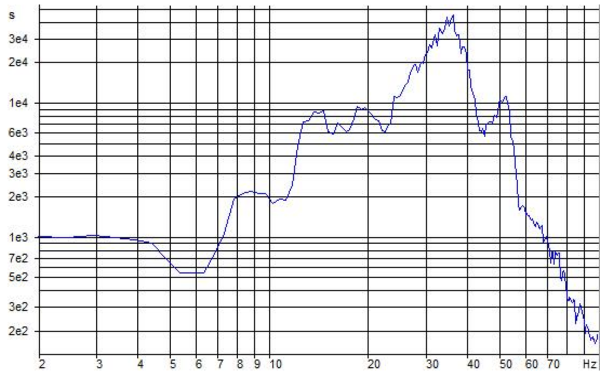


Fig.8. Characteristic frequency spectrum of the tram type Vario LFR

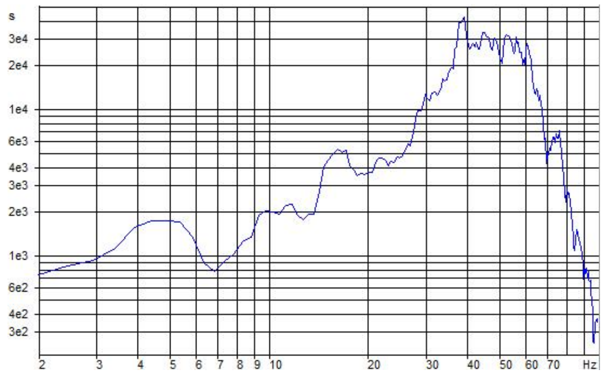


Fig.9. Characteristic frequency spectrum of the tram type Inekon LTM 10.08

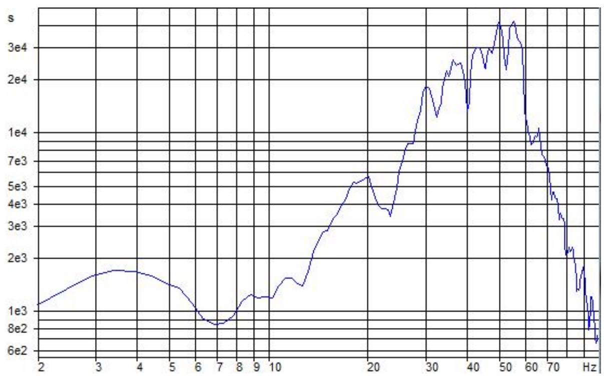


Fig.10. Characteristic frequency spectrum of the tram type Inekon 2001 TRIO

Table 2. Summarized results of measured frequencies

Tram type	Number of passes	Bandwidth [Hz]	Maximum peak [Hz]
ČKD T3	49	22-48	34-35
ČKD T6A5	38	20-45	35-36
Inekon LTM 10.08	47	20-70	38-62
Inekon 2001 TRIO	44	22-65	48-58
Vario LFR	53	20-45	35-36

In the spectra, we can observe a strong match in the two oldest types of trams, ČKD T3 and ČKD T6A5, both in the frequency bandwidth, in the location of the maximum peak and in the character of the whole frequency image. ČKD T6A5 was the direct successor to ČKD T3, which is, inter alia, the most widely produced tram car in the world. Some consistency with the previous two types can be seen, especially at the maximum peak position, in the significantly newer Vario LFR type, which came to existence by means of complete reconstruction and modernization in the operation of the proven T3 trams. All three types were captured in a set of two cars. In contrast to these three types, the spectra of the Inekon LTM 10.08 and Inekon 2001 TRIO types, which are trams of a new structure, differ more markedly, wherein TRIO is the successor to the LTM type. In both spectra, a broader frequency band is traceable instead of a prominent and sharp peak, wherein the maxima are shifted to higher frequencies compared to the previous tram types. The character of both of the frequency images is also similar.

Discussion

A standard seismic station is primarily designed to measure seismic effects for the purpose of assessing seismic loads. To obtain accurate frequency spectra of the individual passing trams and their possible identification, it would be useful to use, for example, resistance strain gauges glued directly to the rail [24, 25] because measurements on a rock mass, even in close proximity to the trackbed, will already be burdened with a certain error, which is due to the transmission properties of the railway bed and the rock subsoil [26, 27]. However, strain gauge measurements bring a number of pitfalls during the implementation of the experiment itself, such as rail traffic constraints and favourable climatic conditions for glueing the strain gauges, cabling and other equipment in close proximity to the track, etc. Therefore, the goal of our experimental measurement was to verify whether it is possible to find certain common patterns for individual types of tram cars in the frequency spectra using standard equipment for seismic measurements. The results show that despite the imperfection of the scheme of such a measurement with respect to the location of the measuring device, certain characteristics can be traced, which are common to both a particular type of tram and a common group of tram types historically or structurally derived from each other.

Measurement in the location where the railway bed is concrete is a logical continuation of the experiment, wherein the measurement scheme is identical, i.e. in close proximity, and a seismic station will be placed directly on the concrete base. Under these conditions, the results should be much more accurate, assuming that the concrete base should not resonate in such a near zone.

Conclusion

The paper presents the results of experimental seismic measurement of dynamic effects of passing trams using a standard seismic station equipped with a three-part, speed seismometer. The measurement was conducted on a rock mass, in close proximity to the tramline. The goal of this measurement was to show the alternative use of such a station for the possible identification of individual types or, possibly, groups of tram types, which have, for example, the age or structure of the tram in common, specifically on the basis of characteristic features in the frequency spectra. Despite the undesirable effects of the surrounding rock environment, the results of five types of trams have shown that it is possible to find identical patterns in the spectra that would allow the spectra to be assigned. The benefit of tram identification based on such spectra, in cases where, for example, it is not possible to use recording audio-visual equipment at the same time, may be produced in the case of long-term seismic monitoring of buildings, where, besides information on the size of the dynamic load, its number and frequencies, we can also obtain, from the analysis of the measured data, the information on the source, which is, in this particular case, the tram type. Similar identical patterns should also be identified in the frequency spectra for railway transport with regard, for example, to passenger and cargo units.

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