MATEC Web of Conferences **320**, 00003 (2020) https://doi.org/10.1051/matecconf/202032000003
ASO-2020

TRANSMISSION OF RAILWAY INDUCED VIBRATIONS IN BUILDINGS

Mariya Moskovets [1*] and *Nikolay* Kanev[2]

[1]BMSTU, Power Engineering Department, 105005, Moscow, Russia
[2]Andreyev Acoustic Institute, 117036, Moscow, Russia

Abstract. This paper presents the problem of vibration transmission in building structures, which is induced by rail transport, and it discusses the effect of acoustic isolation used at the foundation. The vibration sources generate acoustic waves which are transmitted to the foundation and propagate trough the floors and slabs of the building. The transmission coefficients of the acoustic waves induced by metro trains and trams were determined in the building foundation and slabs. It was shown that mechanical resonances have a significant influence on the vibrations of the slabs. The characteristics of vibration propagation through vibration-insulated floors were found. Using the data obtained in this study, vibration effects in buildings located near vibration sources can be estimated, vibration protection measures can be developed.

1 Introduction

Metro lines, tramways, and railways are sources of vibration impact in the buildings located near rail transport. Frequently, metro tunnels are laid at a shallow depth of a few meters and at a short distance from buildings, which leads to significant vibratory effects in the building structures. The motion of the trains generates ground vibration, which causes vibration in the building foundation and then spreads over the entire building structure [1].

The reduction of the vibration impact can be accomplished through various measures, by isolating the structure of the railway tracks or by protecting the buildings from vibrations [2, 3]. The most common solution for vibration isolation in buildings is accomplished by the insertion of a discrete or continuous elastic layer between the exterior walls of the foundation and the ground. The presence of such a layer significantly reduces the oscillations in the building. Measurement data of the vibration propagation in the buildings is required for predicting vibration effects and developing vibration protection solutions.

The parameters of the vibration in the building are evaluated from the measurement data using the frequency-dependent vibration transmission coefficients between the ground and the foundation and the coefficient for the rest of the building structure [4]. A reliable prediction requires a large amount of information which takes into account the coincident locations of the vibration sources and buildings, as well as the structural features of the buildings. This paper presents the results of full-scale vibration measurements of rail

* Corresponding author: ambernebula@icloud.ru

transport on the foundation and slabs of a monolithic frame building. It should be noted that this work is a continuation of experimental studies on the transmission of railway induced vibrations to buildings and their further propagation over the building structures [5, 6].

2 Method of measurement

The measured parameter is the vibration acceleration at the surface of the enclosing structure, a floor slab or foundation. Oscillations of structures in the vertical direction, i.e., normally to the surface, have much larger amplitudes compared to oscillations in horizontal directions, i.e., in two mutually perpendicular directions along the slab surface. Therefore, the oscillations of structures are only considered in the vertical direction for this study. According to [5], the parameter used to evaluate the vibrations in buildings is the logarithm of an average square value of the vibration acceleration calculated for the time interval of 1*s*. Modern measuring equipment is capable of recording this and other vibration parameters with a high sampling rate, which makes it possible to carry out a detailed analysis of vibration dynamics in the building when trains pass in its immediate vicinity. A clear illustration of this process is provided by vibration diagrams (vibrograms). The latter reflects the time dependency of the vibration acceleration level. Fig. 1 shows examples of vibrograms recorded at two locations for the vibration acceleration level in the octave band with an average geometric frequency of 63 Hz. The duration of those fragments was 20 minutes, during which 5 passages of metro trains were recorded. Each passage is manifested by a peak on the vibrogram. The background vibration acceleration level was about 60 dB while during the train passage, the vibration acceleration level reached 74-84 dB, so the influence of background vibration can be neglected. The maximum value of vibrational acceleration level recorded during each passage is the measured vibration parameter for that passage.

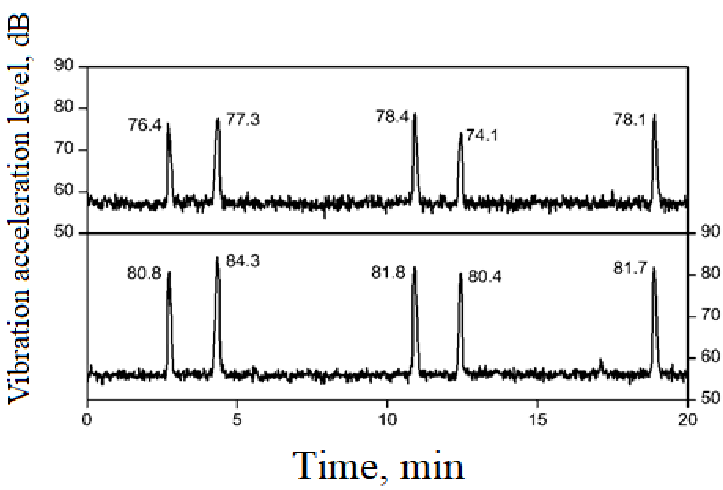

Fig. 1. Vibration diagrams demonstrating the dynamics of vibration acceleration level in the octave band of 63 Hz measured on the foundation plate (top graph) and on one of the floors (bottom graph).

Due to a series of unknown factors, the vibration acceleration levels for different passages have different peak values, therefore synchronous measurements are made at two or more points to correctly assess the vibration transmission. This reduces the influence of uncertainty associated with the vibration source. Fig. 1 shows the synchronous vibrograms recorded simultaneously on the foundation and on a slab. Further evaluation of the connection between the vibration measured on the foundation and the floor is carried out using the difference between the measured vibration acceleration levels in each passage.

3 Impact of slab resonances

Some structural elements of the building, primarily the inter-floor slabs, can amplify vibration due to natural resonances. Reinforced concrete slabs have the first resonant frequency of bending vibrations in the range between 10 to 30 Hz, depending on the length and bending stiffness. At these frequencies the vibration amplitude of the slabs is much higher than the vibration amplitude of the foundation.

In this study we consider an example of a building which is located adjacent to two types of rail transport: tram and metro trains with railways located on different sides of the building. The vibration sources are the tram lines (located on the ground surface) and the metro lines (near the ground surface) which excite superficial acoustic waves (vibrations) in the ground and the intensity of those vibrations decreases with the depth. The latter phenomenon was taken into account when designing the vibration isolation of the building. This dampening effect is significant because the foundation slab is approximately 10 m below the ground surface, therefore the vibration isolation layer was only applied along the perimeter of the walls below the surface level.

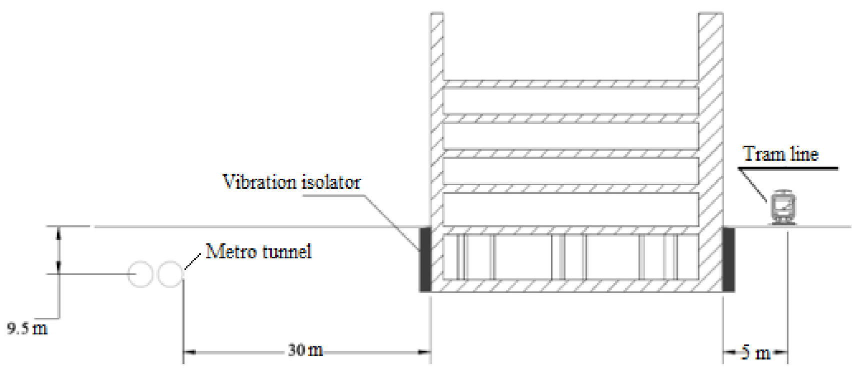

Fig. 2. Schematic diagram of a vibration-insulated building and the location of vibration sources.

We now consider the vibration transmission from the surface of the foundation to the second-floor slab of the building. To characterize the vibration transmission from the foundation to slabs, transmission coefficient K is introduced:

$$K = L_1 - L_2 \tag{1}$$

where L_1 is the vibration acceleration level on the floor slab and L_2 is the vibration acceleration level on the foundation. Figure 3 shows the vibration spectra caused by the passage of metro trains on the foundation and the second-floor slab, as well as the transmission coefficient K. The resulting graphs show an increase in the transmission coefficient, which reaches 16 dB at 20-25 Hz.

To evaluate the resonance frequencies of the slab, the response of the slab to the pulse load in the vertical direction was measured. Fig. 4a shows a record of the plate's reaction to the pulse action, while Fig. 4b shows the response spectrum. The maximums of the spectrum, i.e. the first resonant frequencies of bending oscillations are in the range of 20-30 Hz.

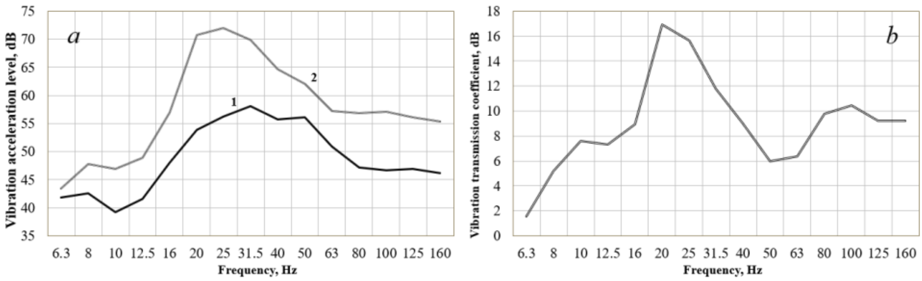

Fig. 3. Vibration acceleration levels in the building measured (a) on the foundation (1) and on the second-floor slab (2) from the movement of metro trains and vibration transmission coefficient (b).

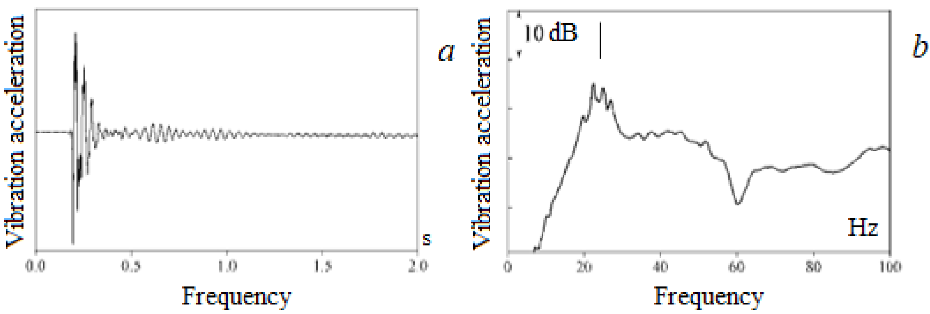

Fig. 4. Response of the second-floor slab to pulse impact (a) and corresponding response spectrum(b).

In addition to the effect of the metro line, the building is exposed to negative vibratory effects from the tram line located on the opposite side of the building (see Fig. 2). In this case, the obtained vibration spectra also indicate that the presence of slab resonance leads to amplification of the vibrations over the frequency range corresponding to the natural frequencies of the structure.

The obtained charts of vibration acceleration levels and transmission coefficients show (Fig. 5) that there is a significant increase in oscillation amplitude over the frequency range from 20 Hz to 31.5 Hz. To obtain a more complete picture, the response of the floor slab to the pulse action in the vertical axis was also measured in detail. Fig. 6a shows a record of the plate's reaction to impulse action and Fig.6b shows the response spectrum. The measured values allow us to establish a range of spectrum maxima that indicate the first resonant frequencies of bending vibrations. According to the response spectrum graph, the overlap resonance was achieved in the range from 20 to 30 Hz. At the same time, the quality (structural characteristics) of the fourth-floor slab was higher than the quality of the second-floor slab (compare Figs 4b and 6b).

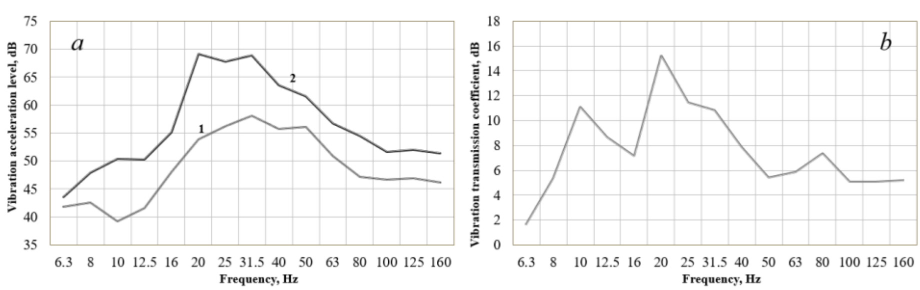

Fig. 5. Vibration acceleration levels in the building caused by the tram passage measured (a) on the foundation slab (1) and on the fourth-floor slab (2); (b) vibration transmission coefficient.

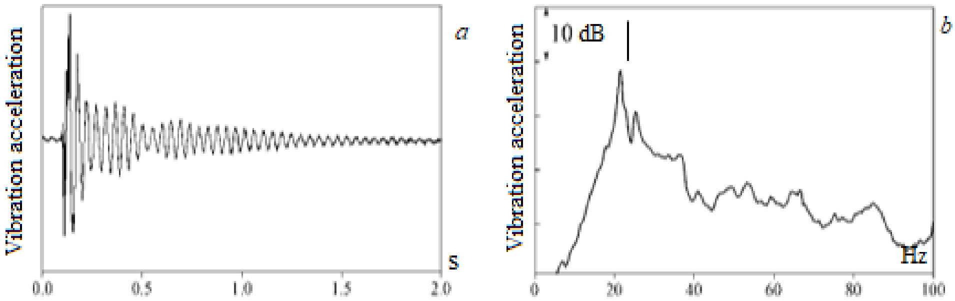

Fig. 6. Response of the fourth-floor slab to pulse effects (a) and corresponding response spectrum (b).

It should be noted that the vibration of rail transport in this example is transmitted through the foundation plate lying directly on the compacted ground. The interaction with the ground largely limits the oscillations of the plate, therefore there is a significant difference in the intensity of the foundation plate and the slab oscillations. This phenomenon corresponds well with known results [6, 8] and is used in standard documentation [4].

4 Vibration transmission in a vibration-insulated building

In another example, the underground part of the building is completely separated from the ground by a layer of elastic material (Fig. 7). The foundation plate is laid at a depth of 7 meters below the surface level. The vibration sources are the shallow tunnels of the underground at a depth of 10.9 m near the building: in terms of distance between the building and the tunnels, the distance is about 7 m.

Vibrations caused by the metro train movement measured at the foundation plate and lower level (-1st), 1st, 2nd floor slabs. The measurements were taken simultaneously on the foundation plate and each floor. The transmission coefficient (1) for each floor was calculated for one and the same transport passage. Fig. 8 shows the vibration acceleration spectra for different floors and the foundation slab, as well as transmission coefficients from the foundation plate to the floors.

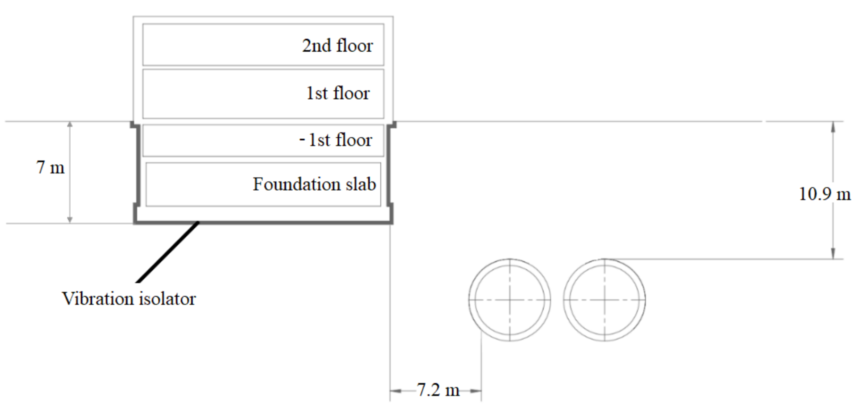

Fig. 7. Schematic diagram of the building vibration isolation.

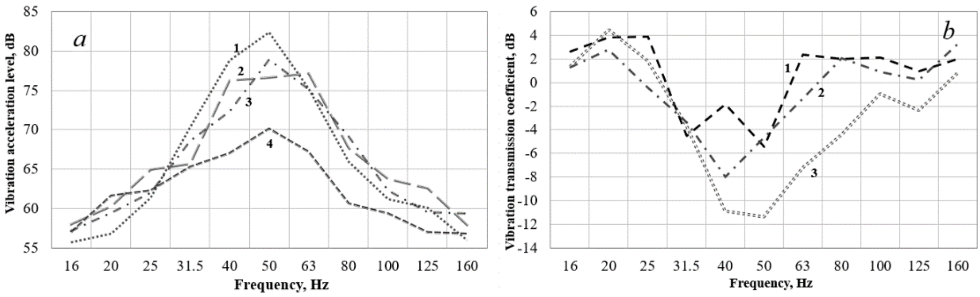

Fig. 8. Vibration acceleration levels measured (a) on the foundation (1), slabs of lower level (2), first (3) and second (4) floors and vibration transmission factors (b) for lower level(1), first (2) and second (3) floors.

In this case, the highest level of vibration acceleration (Fig. 8a) is recorded at the foundation plate (1). In this case, the vibration level is attenuated over the main frequency range from 31.5 to 63 Hz when the vibration propagates upwards the building through the floors. The lowest vibration acceleration level was measured on the second floor of the building.

The vibration transmission coefficient (Fig. 8b) makes it possible to assess the reduction of vibration as it spreads through the building. The values of the transmission factor at the main frequencies are negative in contrast to the first example (compare Fig. 3b and 5b). This is due to the fact that the foundation plate lies on the vibration isolation layer, i.e. on a more elastic media compared to the ground in the first example, thus the amplitude of its vibration is much higher. For this reason, the vibration transmission coefficients between the foundation and the slabs in buildings with vibration-insulated foundations differ from those recommended in the literature on the established technical standards [4], which should be taken into account when looking for vibration isolation solutions.

Furthermore, the obtained transmission coefficients allow one to estimate the degree of vibration attenuation during the vibration transmission from floor to floor. The maximum vibration spectrum was found to be over the range of 40-63 Hz (Fig. 8a). At these frequencies, the difference of vibration acceleration levels between the -1st and the 2nd floors is 6-9 dB, which means that the attenuation for each floor is 3-4.5 dB and it is within the recommendations given in [9].

5 Vibrations of the floor slab

The vibration of the slabs is not uniform across the surface since the vibration spectrum generated by the rail transport is over the frequency range of the first resonance of the slab bending vibrations. As a rule, external vibrations excite several first resonances of the floor slabs, while the amplitude of excited vibrations at the resonant frequency is inversely proportional to the square of resonance number [10]. Vibrations with the highest amplitude are observed at the first resonant frequency, which is indirectly confirmed by the results of measurements given above (compare Fig. 4b and 6b). In this connection, the maximum amplitude of the slab oscillation is observed in the area of its geometric centre, with the minimum amplitude along the edges.

To assess the non-uniformity of vibrations measured on the surface of the inter-floor slab, vibration acceleration measurements were performed in the slab centre and near the supporting column shown in Fig. 7. Figure 8 shows the difference between the inter-floor slabs for the first and second floors. The first resonant frequency of the slab was found to be in the third-octave band of 31.5 Hz, the difference at this frequency reaches 14 dB. It should also be noted that the ground floor also showed resonance vibrations at higher frequencies.

Outside the resonance frequencies, the difference in vibration levels measured on the slab surface was found to be approximately 3 dB.

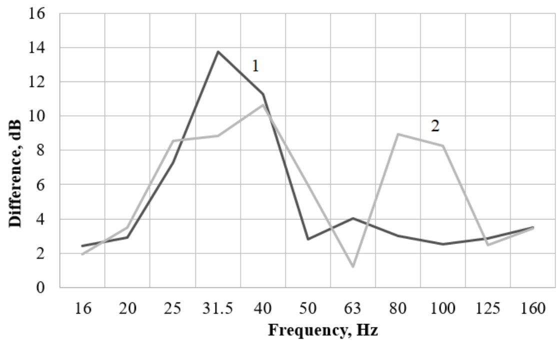

Fig. 9. The difference between the vibration acceleration levels measured at the centre of the slab and near the supporting column on the first (1) and second (2) floors.

6 Conclusion

Field measurements of vibration excited by rail transport in the buildings were analysed. The vibration transmission coefficients from the building foundation to the inter-floor slabs were obtained. A special feature of this study was the synchronous measurement of vibrations on foundations and inter-floor slabs, which eliminated the uncertainty associated with the variation of vibration parameters for different train passages.

Two types of buildings have been considered: (i) with a foundation slab lying on the ground and (ii) with a vibration isolation layer placed between the foundation and ground. The interaction of the foundation with the ground limiting the vibrations of the foundation slab led to a significant difference in the intensity of the vibration of the foundation and the slab in the two buildings. In both cases, an increase in the amplitude of oscillations at the resonance frequencies of bending oscillations was found. The latter was determined by measuring the response of the slab to the pulse load in the vertical direction.

It was also found that the vibration was attenuated when it propagated up the floors by 3-4 dB per floor. The difference in the vibration levels measured at different locations over the surface of the floor slabs could reach up to 14 dB, depending on the bending vibrations of the inter-floor slab.

The obtained data can be used to predict the propagation of vibrations over the structure of the building [11-15], and to find vibration protection solutions for buildings of similar construction raised in the proximity of rail transport.

References

1. A. Mecke, I. Lee, J.R. Baker jr., M.M. Banaszak Holl, B.G. Orr, Eur. Phys. J. E **14**, 7 (2004)
2. M. Ben Rabha, M.F. Boujmil, M. Saadoun, B. Bessaïs, Eur. Phys. J. Appl. Phys. (to be published)
3. F. De Lillo, F. Cecconi, G. Lacorata, A. Vulpiani, EPL, **84** (2008)
4. L. T. De Luca, Propulsion physics (EDP Sciences, Les Ulis, 2009)
5. G. Plancque, D. You, E. Blanchard, V. Mertens, C. Lamouroux, *Role of chemistry in the phenomena occurring in nuclear power plants circuits*, in Proceedings of the

International Congress on Advances in Nuclear power Plants, ICAPP, 2-5 May 2011, Nice, France (2011)

6. GOST R ISO 14837-1-2007, *Mechanical vibration. Ground-borne noise and vibration arising from rail systems*, Part 1, General guidance.
7. SP 23-105-2004, *Vibration assessement for design, construction and operation of metro units*.
8. N.G. Kanev, *Optimization of building protection solutions against subway vibrations*, Subway levels, **22**, 33-35 (2019)
9. SP 441.1325800.2019, *Protection of buildings against vibration generated by railway transport*. Design rules.
10. GOST 31191.1-2004, *Vibration and shock. Measurement and evaluation of human exposure to whole-body vibration.* Part 1. General requirements.
11. M.E. Moskovets, N.G. Kanev, *Evaluation of the transfer of vibration of rail transport from the ground to the foundation of a building*, in Proceedings of the IV All-Russian conference of young scientists and specialists "Habitat Acoustics", 24th of May 2019, Moscow, Russia (2019)
12. M.E. Moskovets, N.G. Kanev, *Negative effect of floating floor construction on buildings due to vibrations*, Compendium of Studies of the XXXII session of the Russian Acoustic Society, 14-18 October 2019, Moscow, Russia (2019)
13. C. E. Hanson, D. A. Towers, L. D. Meister, *Transit Noise and Vibration Impact Assessment,* U.S. Department of Transportation Federal Transit Administration (2006)
14. N.I. Ivanov, Engineering acoustics. *Noise control theory and practice*. Logos (2016)
15. S.P. Timoshenko, D. H. Young, Engineering Mechanics (1964)
16. N. D. Chaynov, V. A. Markov, A. A. Savastenko, *Structural Noise and Acoustic Characteristics Improvement of Transport Power Plants*, IOP Conference Series: Materials Science and Engineering, **327(**2), 022069 (2018)
17. O. A. Logvinov, A. A. Malashin, *Resonance phenomena in a channel with oscillating walls*, European Journal of Mechanics-B/Fluids. (2020)
18. A. Petrov, V. Rumyantseva, *The acoustic waves propagation in a cylindrical waveguide with the laminar flow*, MATEC Web of Conferences. – EDP Sciences, 2018, **211,** 04005 (2018)
19. V. S. Vanaev, *Bench Tests for Jackhammers: A Review*, Russian Engineering Research, **40**(6), 458-462 (2020)
20. V. Shekhovtsov, M. Lyashenko, P. Potapov, A. Diakov, K. Evseev, *Calculated and experimental tests of dynamic vibration isolators for use in the suspension system of the traction vehicle* cabin, IOP Conference Series: Materials Science and Engineering. 2020. Vol. 820. No. 012022 (2020)