

Measurements of Vibrations and computer simulations in the design of vibroinsulation of railroads

Krzysztof Koziol^{1*}

¹ Cracow University of Technology, Warszawska 24 St., 31-155 Cracow, Poland

*corresponding author e-mail: kkoziol@pk.edu.pl

Abstract. Presented paper describes the problem of vibrations in buildings generated by rail transport. Dynamic analysis presented in this paper were based on two Polish standards developed at the Institute of Structural Mechanics at the Cracow University of Technology:

- PN-2016/B-02170. Evaluation of the harmfulness of building vibrations due to ground motion
- PN-2017/B-02171. Evaluation of vibration influence on people in buildings.

These standards define the rules, methods and criteria of the performed evaluations. Prepared computational model of the building as well as the way of propagation of vibrations generated by trains or trams often requires experimental verification. It could be done due to measurements. The results of field tests should be recorded in the databases containing information related to the geometry of the structure (building itself, track bed and tunnel-housing in case of the metro), propagation path (its length and nature of soil layers) and finally material properties. Presented examples of computer simulation application during designing of vibration isolation of railway tracks in the tunnel as well as tram line surface, showed that the basis of such calculations should be carried out vibration measurements in a given case or taken from proper measurement databases. Predictions may concern not only the impact of vibrations on surrounding buildings and people staying in them, but also reduction of expected vibrations of engineering structures. In order to verify correctness of adopted due to computer simulations solutions minimizing vibrations, it is necessary to perform post-implementation measurements, which should be a supplement to mentioned database. This approach to the design of vibroisolation allows to check used numerical procedures as well as implemented material constants describing materials used in the numerical model or in the case of constructing the building the quality of the materials used

1. Introduction

One of the inconveniences associated with regular operation of rail transportation are vibrations namely mechanical vibrations. They are emission of pollutants into the environment. According to ISO 14000

- pollution is emission that may be harmful to human health or the environment, may cause damage to property, may deteriorate the aesthetic value of the environment or may interfere with other, justified ways of using the environment

- emission - shall mean directly or indirectly introduced, as a result of human activity, into air, water, soil or land: substances and energy, such as heat, noise, vibrations or electromagnetic fields
- It follows from the ISO 14000 [1,2] provisions that the manager of the rail transport infrastructure (railway, tram, metro, etc.) is obliged to prevent or reduce vibrations.

As already mentioned, impact of such vibrations on the environment mainly concerns influence of vibrations on buildings as well as on people staying in buildings, and less often on vibrating devices. The legal basis for the assessment of these influences are two standards developed at the Institute of Structural Mechanics of the Cracow University of Technology [3, 4]:

- PN/B-02170:2016. Evaluation of the harmfulness of building vibrations due to ground motion.
- PN/B-02171:2017. Evaluation of vibration influence on people in buildings.

They specify the rules, methods and criteria for performing these assessments.

2. Measurements of vibrations in buildings and laboratory accreditation requirements in this field

The basis for performing all assessments and analyses of the impact of vibrations on buildings and people staying in them are vibration measurements carried out appropriately for this purpose. Moreover, predictions of such influences and assessment of impacts of dynamic investments on the environment depend on the results of measurements of vibrations obtained from measurements carried out in an ad hoc case or collected in measurements databases. Thus, the results of monitoring the impact of vibrations on the environment, results of the aforementioned assessments and analyses are significantly dependent on the reliability of the results obtained from vibration measurements.

Obtaining measurement results requires usage of specialized equipment to measure building vibrations in the low frequency range (from 1 to 100 Hz) of adequately high sensitivity (1 V/g). It is not enough, as it happens sometimes, a simple diagnostic device, which readout serves only to pre-determine the level of impact of vibrations on the building or people inside but the apparatus should enable recording of vibrations, which allows further dynamic analysis of the building structure. Persons performing such measurements should also have specialist knowledge and experience in the field of vibration measurements in buildings. It should be noted here the obligation clearly stated at the initial part of PN/B-02170:2016 „Vibration measurements are necessary to proper usage of this standard, especially for diagnostics purposes. Those measurements should be performed by scientific-research units or technical services equipped with measuring equipment and a specialists team including a structural engineer

3. Computer simulations as a tool for vibration prediction and design of vibration isolation of rail track superstructure

In addition to the control tests of the current level of vibration impact onto buildings or people inside buildings and having results of measurements, simulation calculations can be made to predict such influences. Most often it concerns predicting vibrations of neighbouring buildings caused by the future exploitation of the designed (or modernized) rail transport line or predicting vibrations of a building designed in the vicinity of an existing line. Sometimes, as it was in Warsaw, vibration prediction of a designed structure in the vicinity of the designed line (in this case it concerns the metro line) is needed.

If prepared prediction concerns a designed building located in the vicinity of an existing communication artery (a road or a rail transport line), so then during measurements at the site of the future structure foundation and / or having results from the measurement database one should determine kinematic excitation of the building (vibrations in the level of foundations); make a building model for

simulation calculations (Fig. 1); calculate dynamic forces (inertia forces) additionally loading building elements and check its structure in terms of strength and determine the predicted level of vibration impact on people in the building.

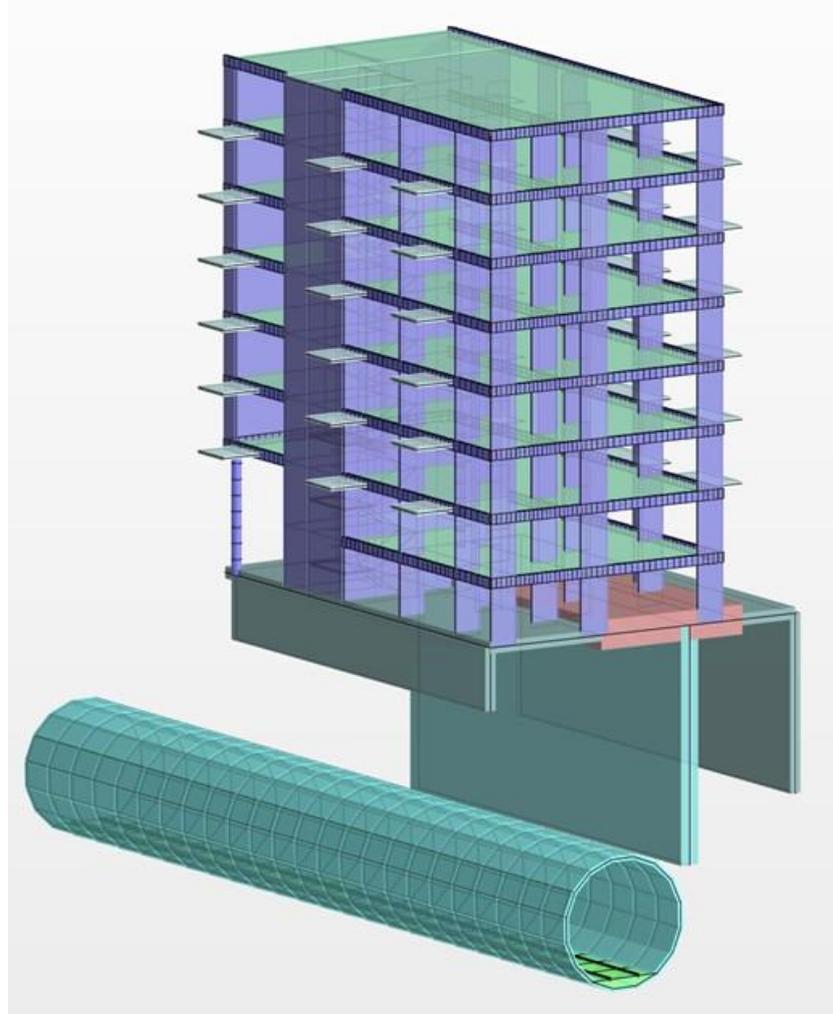


Fig. 1. Spatial model of the building used for FEM calculations

In case of predicting impact on neighbouring buildings of the communication artery, which is to be built or modernized, it is usually necessary to perform simulation calculations of vibration propagation from a new source to an existing or planned building (Fig. 1).

Such models, taking into account propagation of vibrations from the rail through the ground into the building, allow to predict the effects of application different vibroisolation solutions of the rail structure. It could be only done if characteristics (stiffness, vibration damping in different frequency bands, etc.) of the used materials are known. Simulation calculations are an efficient tool in designing effective and optimal vibroinsulating solutions. Figures 3-5 present results of calculations of the predicted impact on people of the ground floor vibrations of the analysed building caused by the trains passing through the tunnel in relation to the three variants of the proposed vibroisolation (Fig. 2):

- EBS system
- EBS system + 15 mm thick vibration insulating mat under the track plate,
- EBS system + 30 mm thick vibration insulating mat under the track plate,

It should be noted that the previously completed simulation calculations allowed to choose proper stiffness of the mats, because too soft mat despite the theoretically greater attenuation caused an increase in vibrations as a result of the formation of excessive rail distortions.

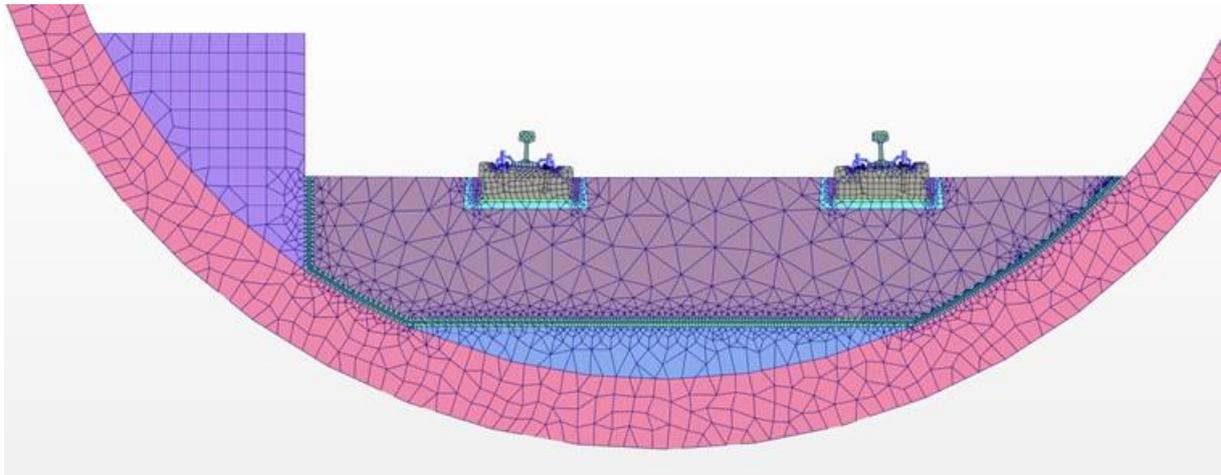


Fig. 2. Model used for simulation calculations of vibration propagation from the railway tunnel to the building

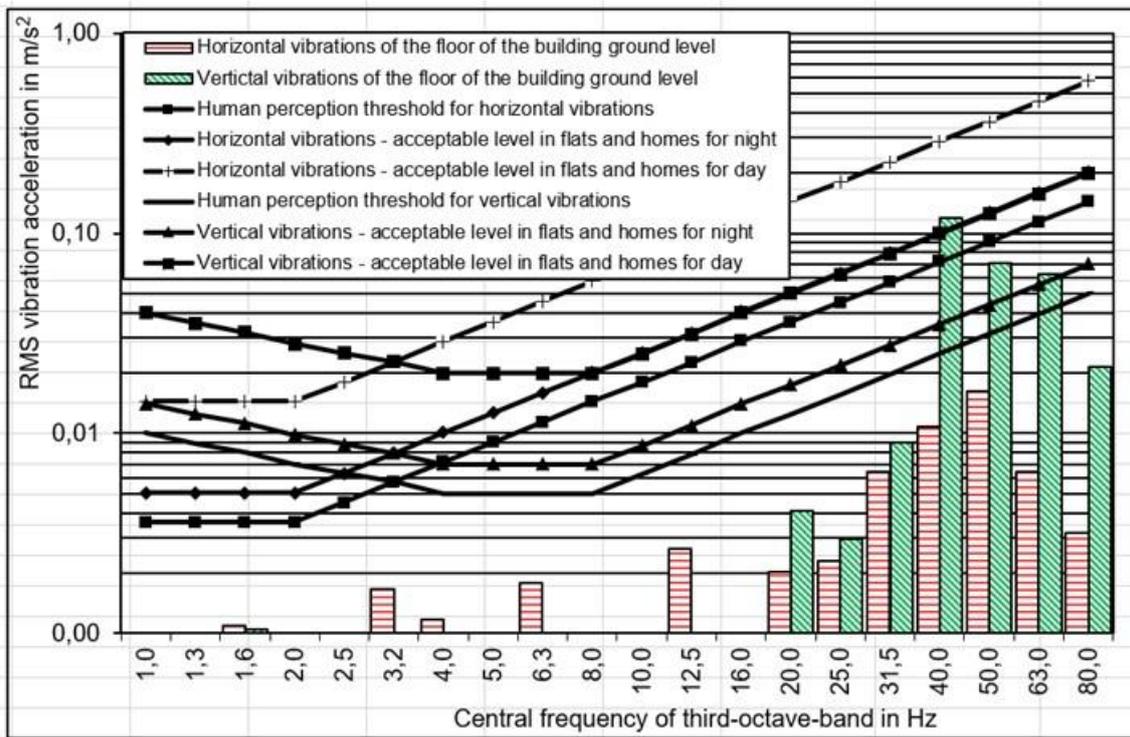


Fig. 3. Impact of vibrations on people staying on the ground floor of the "S" building in case of a rail superstructure with EBS system in the tunnel

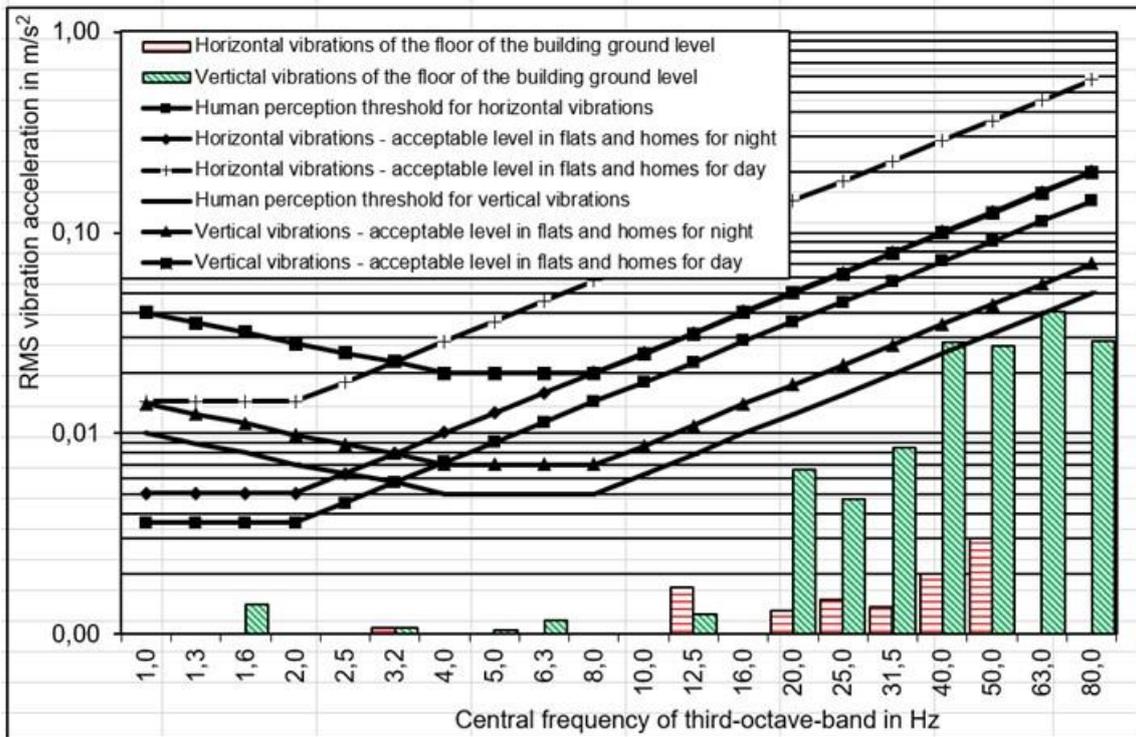


Fig. 4. Impact of vibrations on people staying on the ground floor of the "S" building in case of a rail superstructure with EBS system and vibration involvement mat with a thickness of 15 mm in the tunnel

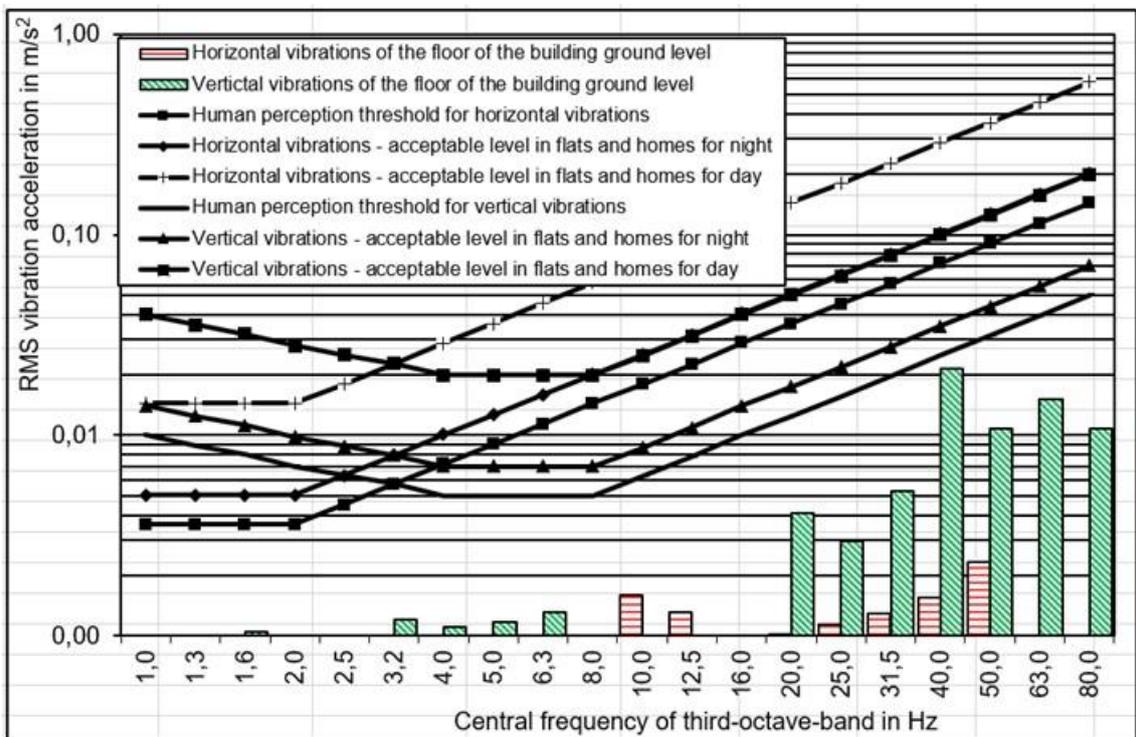


Fig. 4. Impact of vibrations on people staying on the ground floor of the "S" building in case of a rail superstructure with EBS system and vibration involvement mat with a thickness of 30 mm in the tunnel

Similar calculations made by the author - as part of the last section design of the first metro line in Warsaw - allowed not only to select the construction of vibroisolation, but also to optimize the solution by designating route sections of varying thickness of vibration isolation mats depending on the required efficiency. Achievement of such effectiveness was confirmed by control measurements after the project was completed.

4. Summary

If it is necessary to carry out measurements of vibrations in buildings whether directly related to the assessment of vibration impacts on the environment or for use in designing isolations against these impacts, the contractor of such measurements should be required to have accreditation for vibration measurements in buildings, more strictly in the range of PN/B-02170:2016 and PN/B-02171:2017 standards. During designing vibroisolation in rail structure one should include implementation of computer simulations, which result in predicting of the effectiveness of the proposed solutions. The basis for simulation calculations should be reliable results of vibration measurements carried out in a given case or taken from measurement databases. Predictions may concern not only the impact of vibrations on neighboring buildings and people staying in them, but also reduction of expected vibrations of engineering structures (bridges, viaducts).

References

- [1] ISO 14031: Environmental management - Assessment of environmental performance - Guidelines
- [2] ISO 14032: Environmental management - Examples of evaluation of environmental performance
- [3] PN/B-02170:2016: Evaluation of the harmfulness of building vibrations due to ground motion.
- [4] PN-B-02171:2017, Evaluation of vibrations influence on people in buildings, (2017) Polish Standard (in Polish)