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The Design of Rail Tracks including the Influence of Vibration on People in Buildings

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Abstract

This paper concerns the situation where the proposed (or modernised) rail lines (railway, tramway, subway) will be located near buildings. Transport vibrations will be transferred to the foundations of this buildings (kinematic excitation). As a result of this additional dynamic forces arise loading the building structure. Vibrations are also affect people in the buildings. The design of vibroinsulation of the track (using simulation calculations) taking into account the requirements ensured the necessary vibration comfort for people in the buildings. In the final part of the paper an example of the application of this procedure in practice is presented.

Keywords: vibrations, railway, transport, influence on people, vibroinsulation.

1 Introduction

In the case of building or modernizing an existing line of rail transport (railway, metro or tram) in neighbourhood of existing buildings a problem arises of transport vibrations which will in future be transmitted onto these buildings as shown in Figure 1. There is also the problem of predicting the level of these vibrations [1, 2, 3]. Usually in the first moment the designers concentrate on influence of these vibrations on building structures. During further works connected with designing of vibroinsulation in the structure of railway route it proves that influence of vibrations on people residing in these buildings plays a decisive role. This results from the fact that the perception threshold of vibrations by people in building [4, 5] is considerably lower than the vibration level which may have a significant influence on the building structure [6]. Below, the problem of designing vibroinsulation in the structure of railway route – considering influence of transport vibrations on people in the neighbouring buildings – is presented.

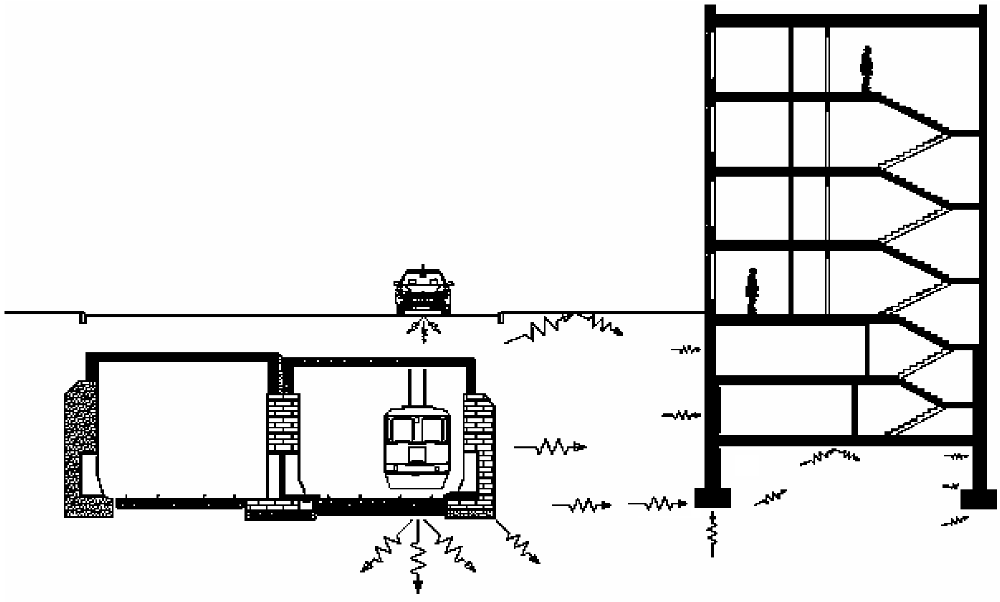

Figure 1: Scheme of the phenomenon

2 Simulative calculations and vibroinsulation designing

Application of vibroinsulation should be preceded by dynamic calculations (numerical simulation) confirming efficiency of the chosen vibroinsulation variant. For this purpose simulative calculation of vibrations of the building, predicted after execution vibroinsulation and then assessment of influence of these vibration on the building structure and people residing inside is performed according to the principles in two polish standards:

- PN-85/B-02170. Evaluation of the harmfulness of building vibrations due to ground motion. [6]
- PN-88/B-02171. Evaluation of vibration influence on people in buildings. [5]

As it was already mentioned efficiency of vibroinsulation is conditioned by fulfilment of assumed criteria in the range of vibration influence on people e.g. assumption of reduction of the level of influence below the human perception threshold.

The below given example of vibroinsulation designing was performed according to the following algorithm:

- performance of investigations of the dynamic background i.e. measurements of building vibration before construction of the transport project,
- determination of forcing in the source of vibration on the basis of results of measurements of vibrations obtained from measurements performed at casually in the given case or collected in measurement data bases [7],
- creation of a propagation model using the finite elements method FEM with consideration of the given structure of the railway track and soil (ground) conditions (see Figure 2) and on this basis determination of predicted kinematics forcing in form of time traces of vibrations of building foundation,.

- construction of a model of a building for dynamic calculations using the finite elements method (FEM),
- performance of dynamic calculations by use of the time history analysis and obtaining of time traces of predicted vibrations in particular nods of the MES network,
- performance of analysis of vibration influence on people on particular building floors.

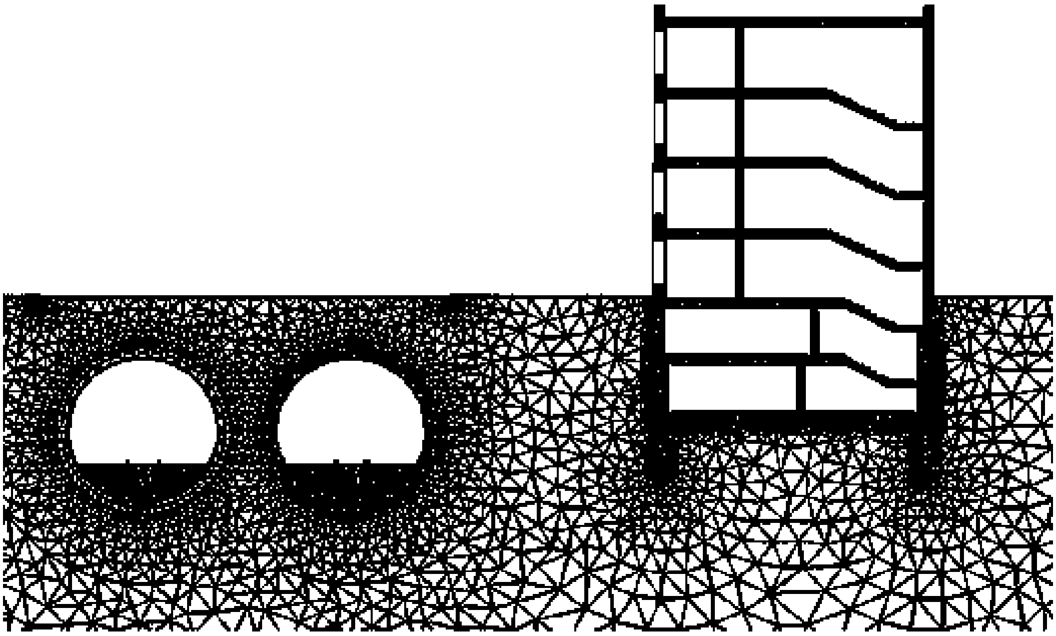

Figure 2: Model FEM (finite element method) for analyzing of vibration propagation from the track to the foundation of the building

The basis for simulative calculations is material data given by the producer of the vibroinsulating material and enclosing among other values: of the elastic modulus (tensile modulus, Young's modulus), shear modulus, Poison's ratio and vibration damping in particular frequency bands. Choosing vibroinsulation attention should be paid to its efficiency in low frequency bands (in dynamic diagnostics of the building the range from 1 to 100Hz) especially in the range 1 to 30Hz. As a rule, in higher frequency bands damping of vibrations is easier and more effective, hence the commercial information often relate mainly to this range of frequencies, or give only one damping coefficient which is not enough. Information is also important on aging of the vibroinsulation material i.e. to what a degree its properties change in time or how its properties change under external factors e.g. soaked with water.

Necessity of performance of calculations (and/or experimental studies) confirming efficiency of vibroinsulation in the case of its particular application results from the dependence of vibration – insulation effects on many factors, among others on:

- damping properties of the vibroinsulating material (stiffness of the vibroinsulation mass in block supports and coating of the embedded rail, stiffness of vibroinsulating mats and dimensions of the applied elements e.g.

vibroinsulating mats thickness (considering rail track deformation)

- spacing of supports e.g. block supports and the resulting of it deflection of the rail and in consequence change of forcing characteristics
- structure and dimensions mass of the track plates
- stiffness of the foundation
- structure of the tunnel housing in the case of underground traffic
- different spectrum of vibration frequency in the case of various kinds of vehicles (tram, underground, railway carriages)
- ground – water conditions on the way of vibration propagation from the rail line to the building
- structure and technical condition of the building receiving vibrations
- differences in vibration receipt by the same building in dependence whether the vibration are excited by underground or surfaces traffic.

In consequence of simulative calculations vibroinsulating parameters adequate in the given situation are chosen (e.g. thickness of the vibroinsulating mats, their stiffness etc) so as to obtain the assumed vibroinsulation efficiency (assumed level of vibration influence on people).

3 An example of the design of the track vibroinsulation

In 2006 designing and building of the end section of first underground line in Warsaw was undertaken. The range of the zone of dynamic effects of the metro was in Warsaw (shallow metro) determined as 40m (in horizontal projection) from the outer walls of the tunnel. In mentioned section (about 3,9 km long) in this zone there were 129 buildings. It resulted from the experience the Warsaw Metro gained during the earlier executed sections of this metro line that one of the crucial problems is designing of the metro track structure so as to satisfy the standards requirements concerning influence of vibrations excited by metro train passages on the buildings structure and people residing in them.

Making use of the listing of the technical state of the structure (including photographic documentation of damages) performed in all buildings 36 buildings were chosen as representative with regard to future dynamic effects of the metro. In these buildings consequent measurements of the dynamic background and prognosis of influence of vibrations generated by metro train passages on the building and people in them were performed. Since in a big number of buildings the forecasted level of vibration influence on people was too high (exceeding considerably the human sensitivity threshold of vibration) a new ballastless track with application of the embedded block system EBS EDILON and there where it was necessary also vibroinsulation mats were used as shown in Figure 3. After choosing mats of determined parameter of damping and stiffness (basing on simulative calculations of vibration influence on people in particular buildings) it was determine which of the three preliminary chosen mat thickness: 12mm, 25mm or 37mm may be applied in particular sections.

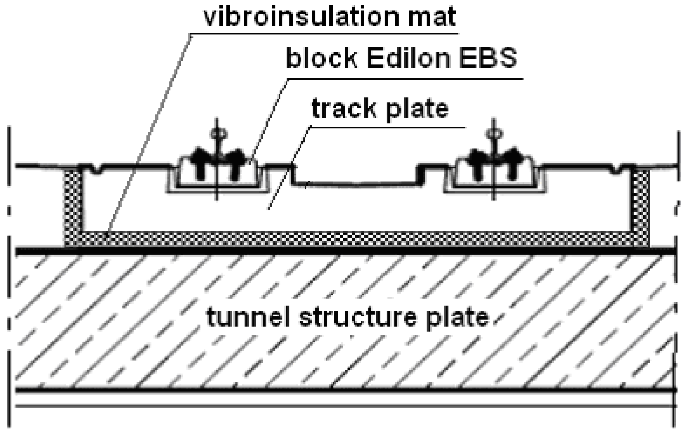

Figure 3: Construction of analyzed track with vibroinsulation mat

The algorithm of procedure may be traced on one of the buildings marked K. This is a residential building with cellar and four floors over ground with a not used attic. This building has brick walls. The distance of the building K from the tunnel equals 31,5m.

To perform dynamic calculations of the building a computational spatial model of the finite elements method FEM was made whose visualization is presented in Figure 4.

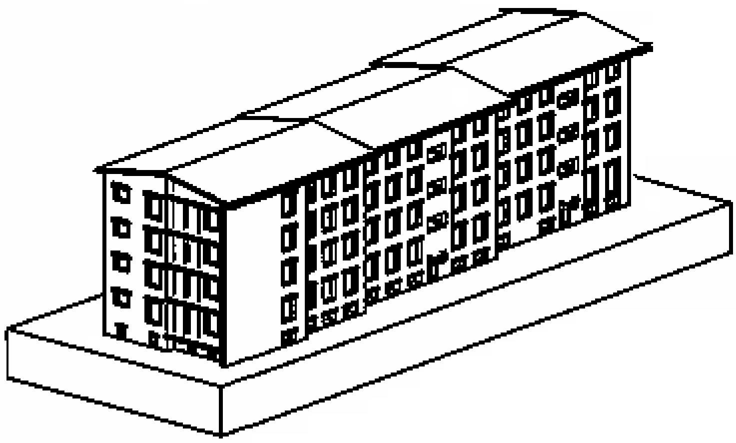
Figure 4: Visualization of the computational model of building K

This model was then verified comparing the results of assessment of vibration influence on people obtained directly from measurements of the dynamic background with results of simulative calculations on the building model subject to kinematic excitation (vibrations of building foundations) measured during the same time of dynamic background measurements. An example of the effect of such a comparison is shown in Figure 5.

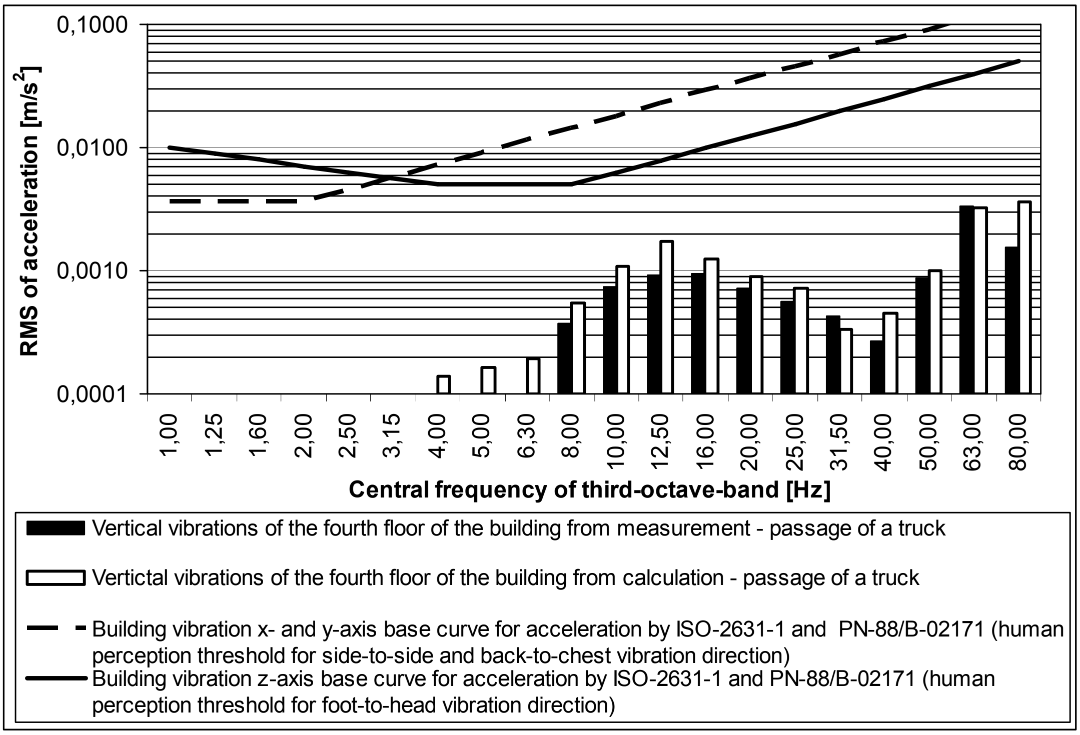

Figure 5: Verification of the model - a comparison of measured and calculated RMS (root mean square) values of acceleration of vertical vibrations on the fourth floor of building K caused by passage of a truck

In the next step, using the model of vibration propagation from the tunnel to the foundations of the building (compare Figure 2) kinematic excitation (time traces of three components of vibration of the building foundation caused by metro) in the case of lack of vibroinsulation was determined. Results of these calculations for component x, y and z are presented in Figures 6, 7 and 8 respectively.

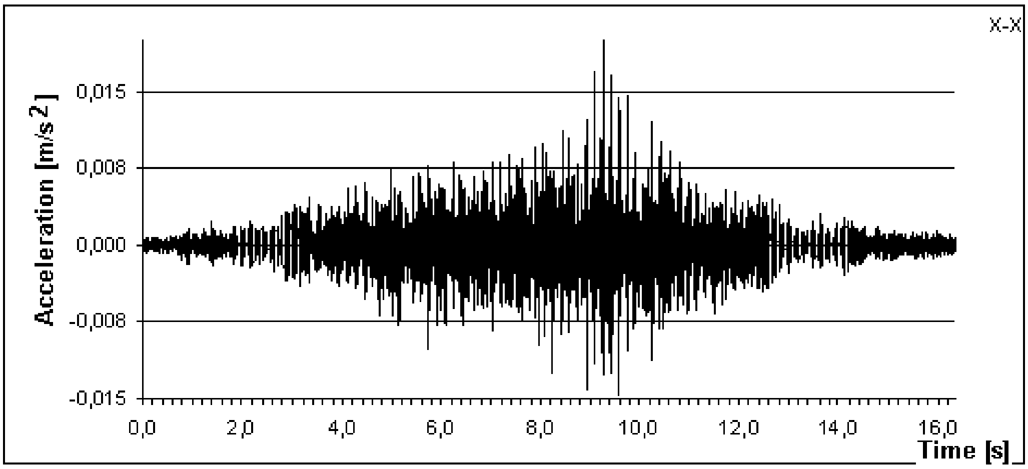

Figure 6: Predicted kinematic excitation of the building K (acceleration of vibrations of the building foundation) in the case of metro track without vibroinsulation – the radial horizontal component x (direction perpendicular to the axis of a metro tunnel)

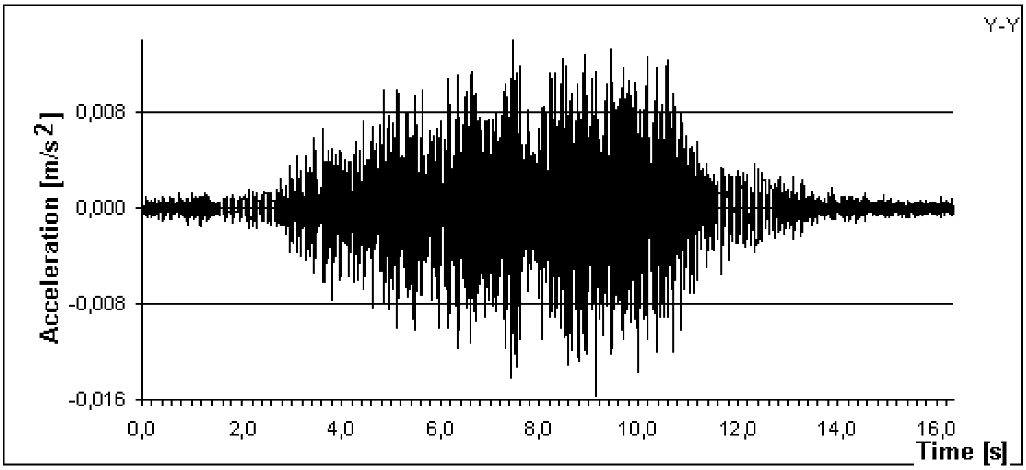

Figure 7: Predicted kinematic excitation of the building K (acceleration of vibrations of the building foundation) in the case of metro track without vibroinsulation – the transverse horizontal component y (direction parallel to the axis of a metro tunnel)

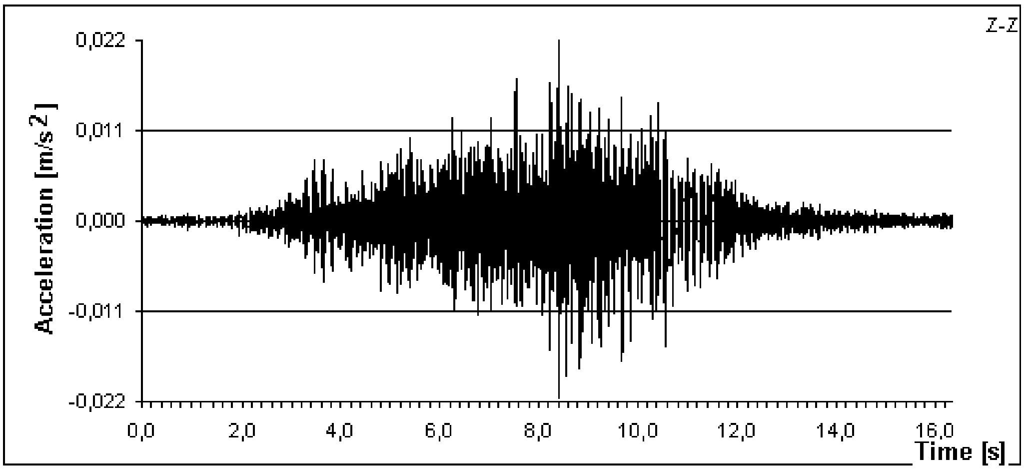

Figure 8: Predicted kinematic excitation of the building K (acceleration of vibrations of the building foundation) in the case of metro track without vibroinsulation – the vertical component z

Calculation results of vibration influence on people on the ground floor of the building referring this case are presented in Figure 9.

Since the human perception threshold was exceeded calculations were repeated adopting a vibroinsulating mat 12mm thick. Their results are shown in Figure 10. The result was still not satisfactory, hence consequent calculations for a mat 25mm thick were performed and the assumed reduction of the vibration level below the human perception threshold was obtained as illustrated in Figure 11.

Control measurements performed after construction of discussed here section of metro line confirmed efficiency of applied solution as shown in Figure 12.

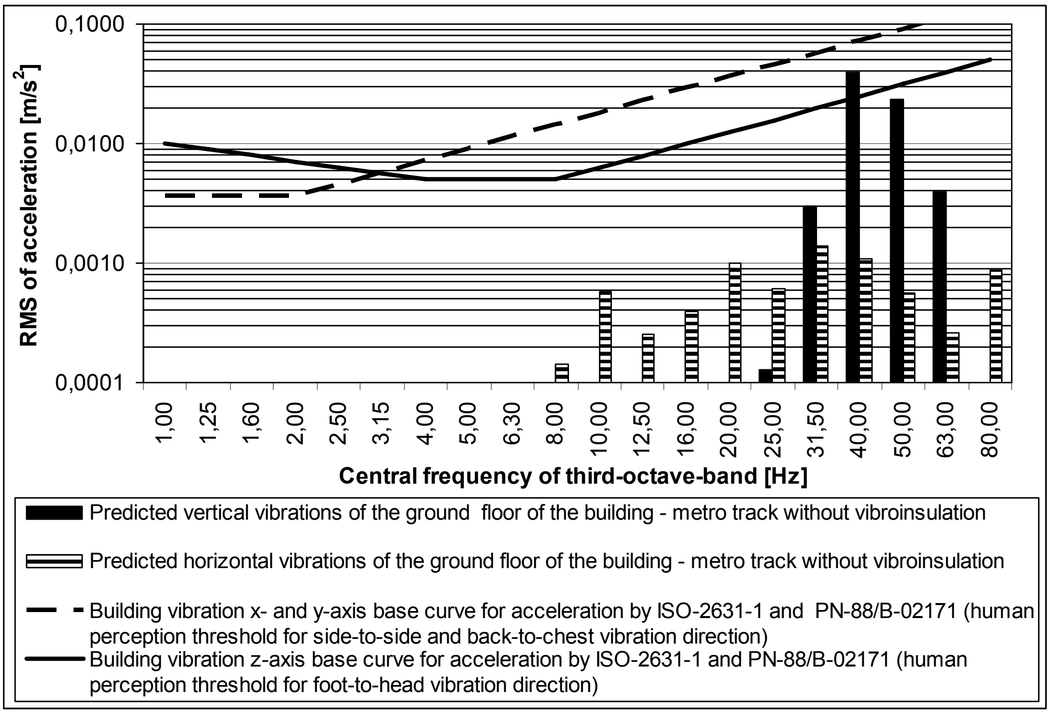

Figure 9: Predicted influence of vibrations caused by metro on people on the ground floor of building K in the case of metro track without vibroinsulation

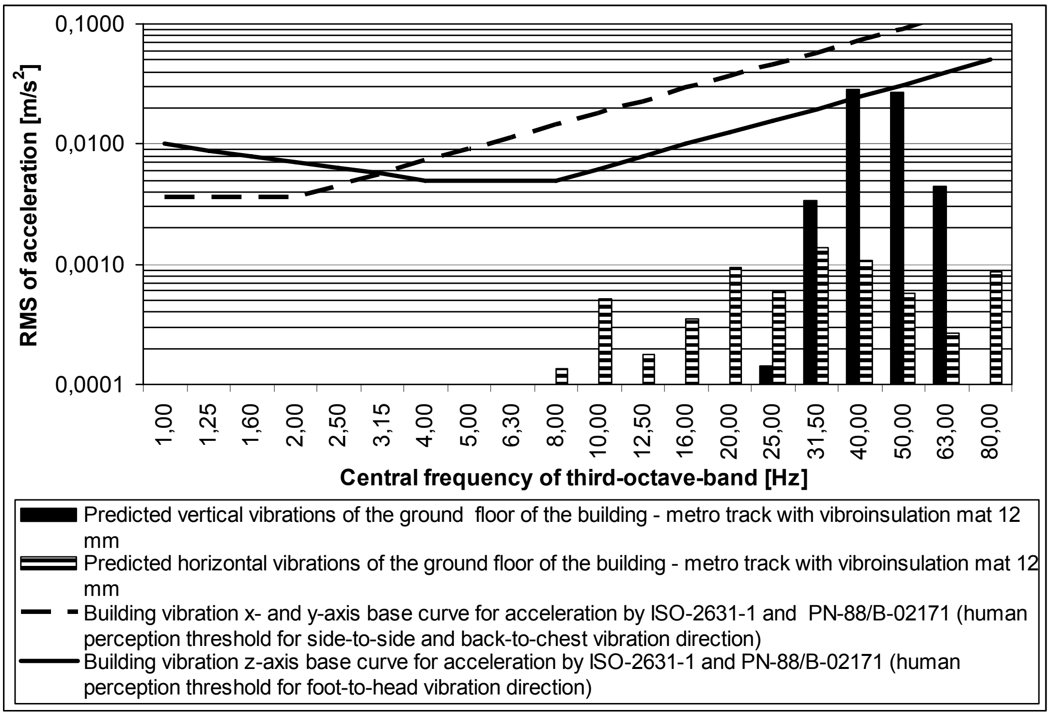

Figure 10: Predicted influence of vibrations caused by metro on people on the ground floor of building K in the case of metro track with 12 mm thick vibroinsulation mat

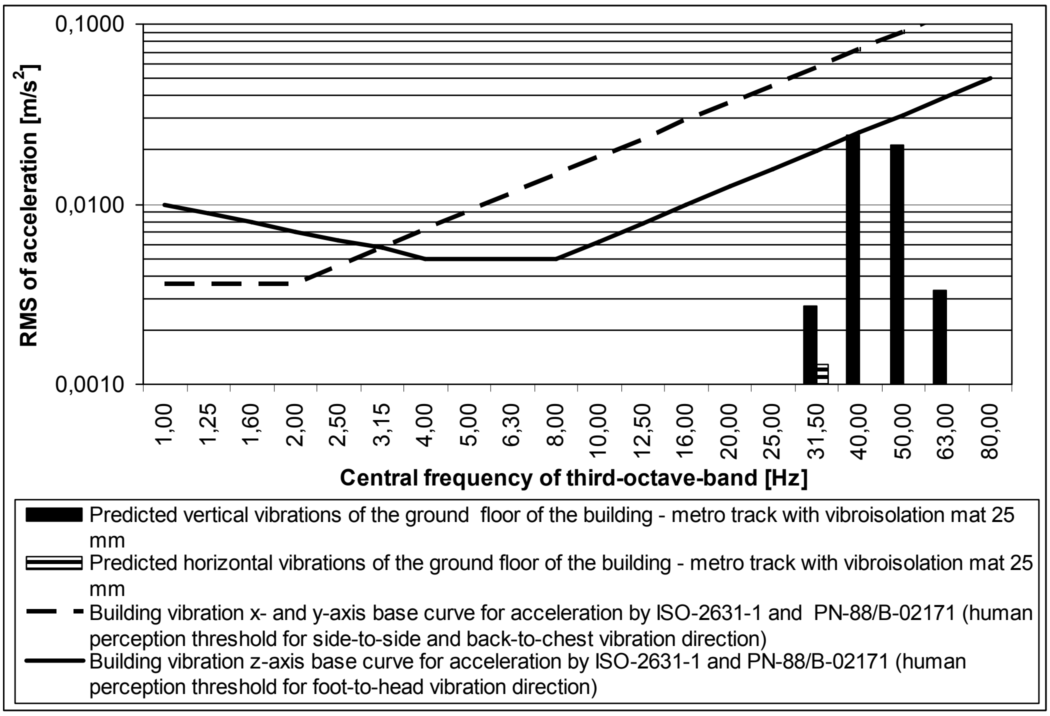

Figure 11: Predicted influence of vibrations caused by metro on people on the ground floor of building K in the case of metro track with 25 mm thick vibroinsulation mat

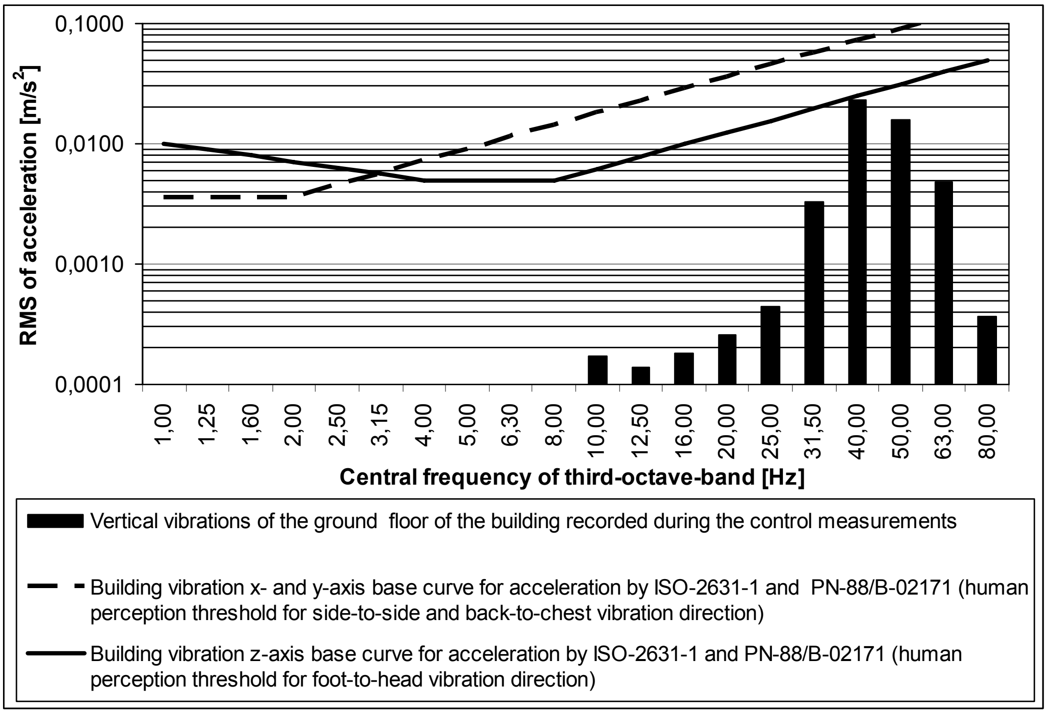

Figure 12: Results of control measurements - influence of vertical vibrations caused by metro on people on the ground floor of building K (metro track with 25 mm thick vibroinsulation mat)

4 Conclusions

In the case of building or modernization of rail transport line located close to buildings assessment of vibration influence on people in these buildings should be the measure of efficiency of the designed vibroinsulation. Making use of simulative calculations (prediction of vibration influence on people) in designing solutions of vibroinsulation of the rail track permits to obtain the required efficiency of vibroinsulation at optimalization of the costs of the applied solution.

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