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DOI: 10.35117/A_ENG_17_06_01

Optimization of the protection against railway vibrations on the example of railway control building in Biała Rawska

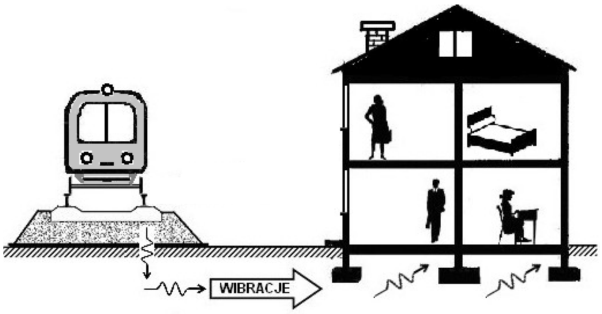
Abstract: The work presents the design process of vibration isolation for a building subjected to the influence of railway vibrations. This process is illustrated on the example of the railway control building in Biała Rawska, realized within the framework of the investment whose the general contractor was PORR Poland Construction S.A. Measurements of railway vibrations at the site of the planned building were made. The building calculation model was performed and then the vibration isolation parameters of the building were calculated based on the simulation calculations of this model. The purpose of the described design work was to limit the impact of vibration on the people and the equipment in the computer server room located in this building. The original design of the rail track vibration insulation was replaced by the building vibration project. This allowed to optimize work time, reduced railway traffic interruptions and the cost of vibration isolation.

Keywords: Railway vibrations; Design of vibroizolation; Vibroizolation of building.

Introduction

The need to meet the requirements to limit the adverse impact of investments on the environment is one of the important aspects of the modernization of railway infrastructure. Among the unfavourable impacts, apart from noise, the influence of railway vibrations on buildings and equipment as well as people staying in them should be seriously considered.

Railway vibrations are a paraseismic phenomenon, i.e. they relate to the transmission of vibrations from the source, i.e. track rails, through the ground to the building (Figure 1).



1. The scheme of vibration transmission from the railway track to the building and people staying in it.

Among the vibrations generated by rolling stock, various factors influencing the level of vibrations generated during journeys can be recognized: the type and condition of vehicle causing vibrations, mainly the condition of wheels wear, the type and condition of the rail surface, the way the vehicle moving, called driving conditions, the type and condition of the ground through which vibrations are propagated, the distance and location of the object receiving vibrations in relation to the source of vibrations, the type and condition of the object receiving vibrations and the type of vibration protection.

When designing and building rail transport lines and then using them, it is necessary to meet the requirements of relevant laws, regulations and standards [3, 4, 7, 8, 9, 10]. It is worth noting that each side of the investment process is obliged to take measures to protect against vibrations. The design process is presented below on the example of the control room building in Biała Rawska, being the part of the investment by PORR Poland Construction S.A. as the general contractor. It is also an example of the conscious approach to the aforementioned problem.

The genesis of the problem

As part of the modernization of the Central Railway Line No. 4 in Biała Rawska, a decision was made to build a new control room with four R-1200 turnouts with the substructure and with the adaptation of the traction network to the new speeds together with the control devices for the planned railway traffic.

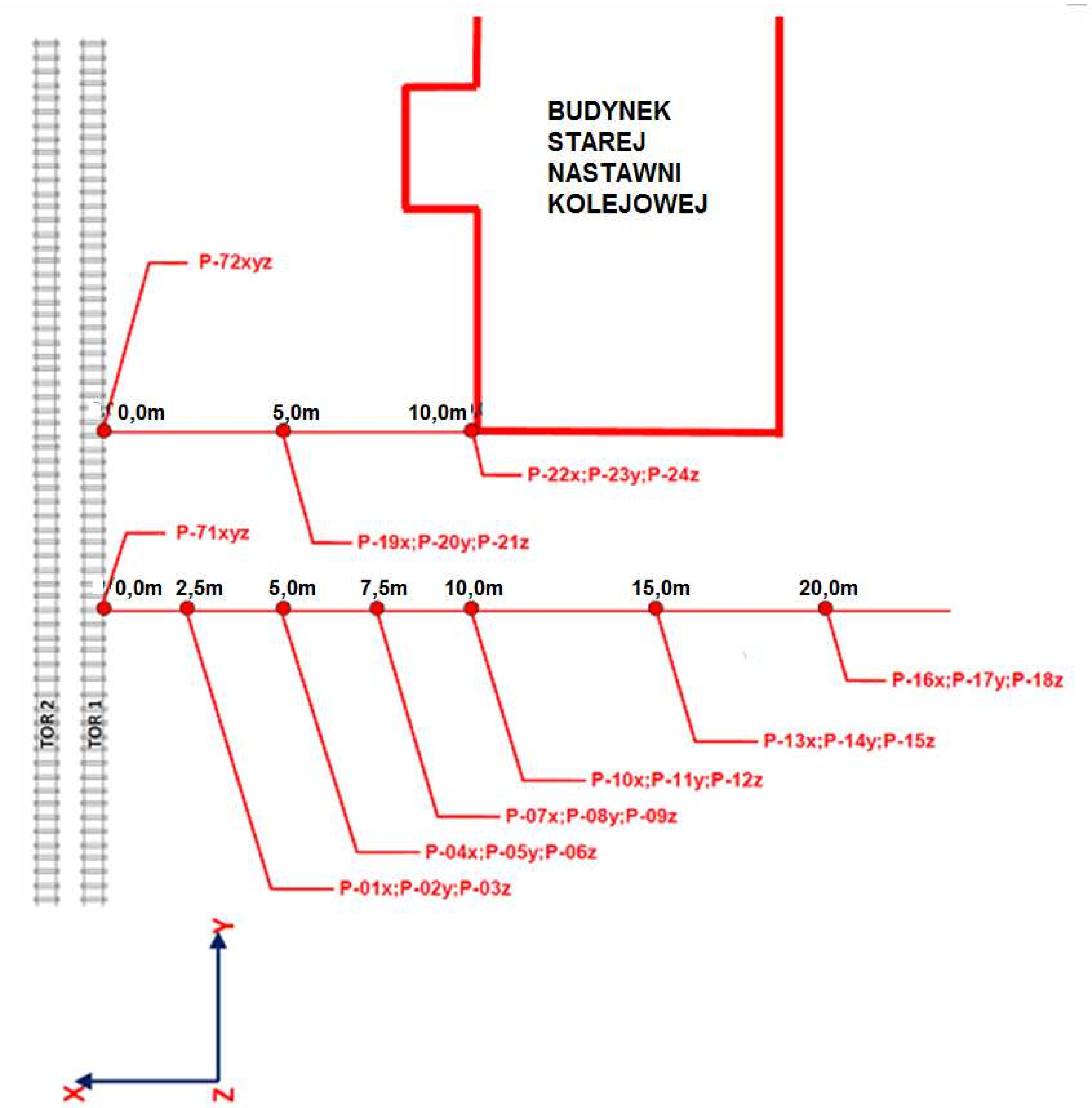
In order to reduce the impact of vibrations on the environment in the discussed construction project, the use of sub-ballast vibration mats in a large section was assumed in the construction to limit the impact of vibrations on computer devices and servers in the new control room of the building.

Among the main implementation requirements formulated by the investor at the tender stage was a significant limitation in the form of the maximum suspension of railway traffic for five days.

The paper presents the analysis of the possibility of protecting the building with the control room against vibrations through the use of a vibration isolation mat in the building construction. Such a solution can significantly shorten the time of excluding tracks from operation during the period of track works, with the equivalent protection of the future control room against vibrations.

In situ study

The tests included measurements of accelerations and vibrations frequencies at selected measuring points located on the ground by propagation of vibrations to the existing building of the old control room and on its foundation as well as on the ground in the planned location of the new control room (Figure 2).



2. Location of measuring sensors

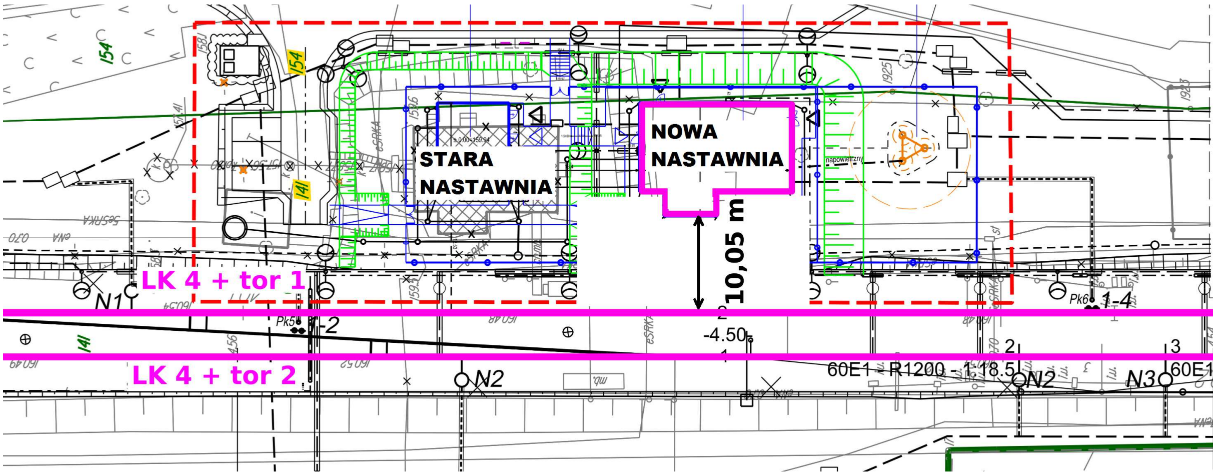
Measurements were made to determine the predicted kinematic extortion of the designed building. Each time, vibrations were measured in three directions: two horizontally perpendicular axes x and y, as well as z. The x and y directions were consistent with the horizontal projection axes of the planned building. The x direction was consistent with the direction of vibration propagation, i.e. was perpendicular to the axis of the railway line. Vibrations in the x-direction are called horizontal radial vibrations. The direction y, i.e. horizontal transversal oscillation, was parallel to the axis of the railway line. Using the accelerometers, the time courses of vibrations caused by the passage of individual trains were recorded. These trends were then subjected to the analysis in order to assess the impact of vibrations on the designed building, people stayed in it, and the operation of electro-technical machinery and apparatus placed in the building, in accordance with Polish PN-85 / B-02170 [3] and PN-88 / B-02171 standards [4].

The following specialist devices for measuring accelerations and ground vibrations were used in the research: 393B12 type accelerator PCBs, ESAM Traveler Plus digital data recording system, PA16000 signal conditioning system EC Electronics, analyzer recording and analysing system LMS SCADAS Mobile, measurement data analysis software (Matlab 7.3). The mentioned devices are adapted to the measurements of low frequency vibrations that occur in the case of transport vibrations. Measurement error was ± 11.6%.

The vibration measurements were performed by the Accredited Laboratory for Deformation and Building Vibration Studies of the Institute of Building Mechanics at the Cracow University of Technology. These measurements included vibrations transmitted through the ground generated by passing trains of various types, i.e. long-distance train of old type, long-distance train of a new type, long-distance train Pendolino and suburban train.

Simulation analysis of the impact of vibrations on the designed building

The location of the building in relation to the source of vibration is shown in Figure 3. In the design of the control room, a reinforced concrete frame structure with a wall filling is provided. In the simulation calculations, a spatial model based on the principles of finite element method (FEM) was adopted. All the components of the model were described with solid finite elements, tetrahedral finite elements with 3 degrees of freedom in each node. Geometrical dimensions were adopted in accordance with the provided design documentation. Partition walls with the technological floor in the calculation model were included as a substitute mass laid out on the reinforced concrete floor slab. The roof covering and the suspended ceiling together with the installations were assumed as a mass distributed in the level of the top model grate. The assumption is to mount the model in the ground.



3. The location of the designed building relative to the source of vibrations

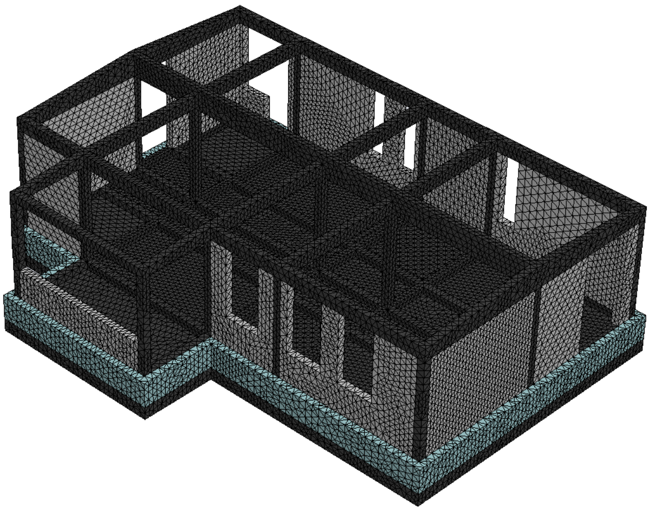
In the calculations, we included the specific gravity with usable loads in the standard dimension, reduced to 60% of characteristic values in accordance with PN-85 / B-02170 [3] distributed evenly on the floor slab. In the analysis, the characteristic values of loads and cross-sectional forces were applied.

The calculations were made using the load history (THA) method, taking the integration step $\Delta t=0.002s$ and obtaining the model's response in the time.

Kinematic loads were assumed in the form of recorded waveforms of vibration accelerations applied at the base of the model, at the building contact with the ground, as a uniform force.

The calculations were made in two variants:

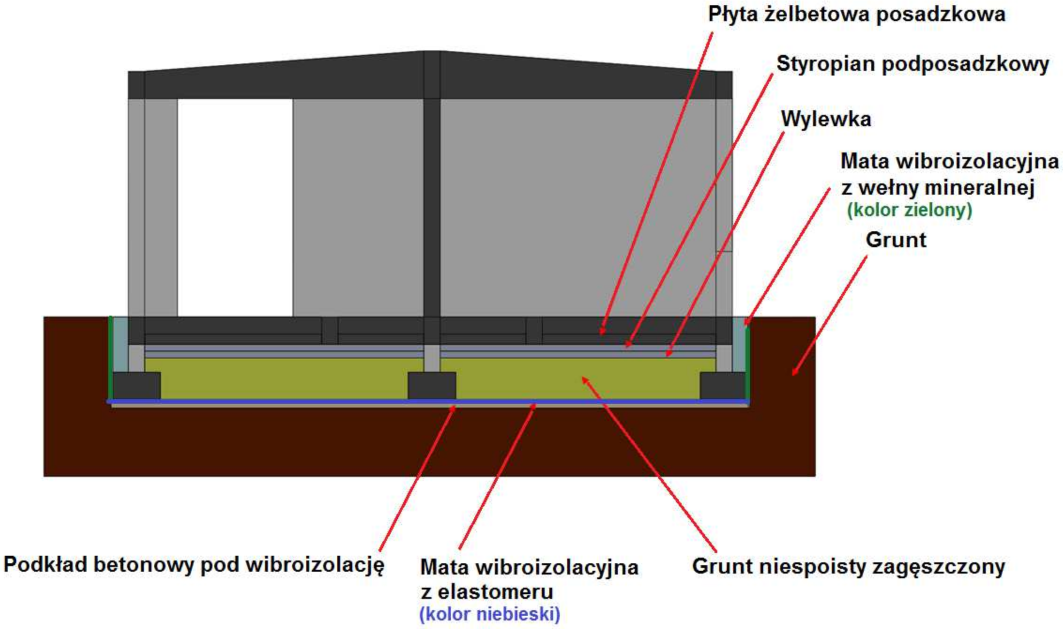
- In the first variant, calculations were made for the model without vibroisolation. The geometric model adopted in the calculations together with discretization using finite elements is shown in Figure 4.



4. Discretization of the computational model, a variant without vibroisolation

- In the second variant, vibroinsulation was introduced in the form of mats on the entire horizontal surface under the foundations with elastomer mats and vertically on elements embedded in the ground with mineral wool mats, see Figure 5.

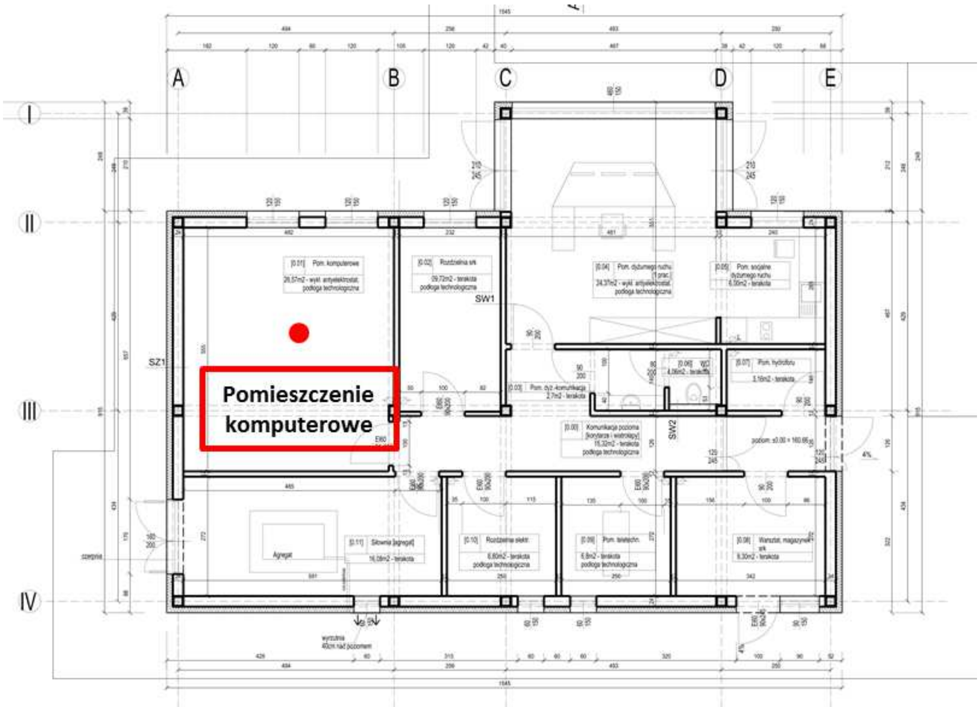
Standard parameters of the building's structure and characteristics of vibroinsulating materials provided by their manufacturers were adopted in the calculations.



5. Cross section of the calculation model of the control room building, a variant with vibroinsulation.

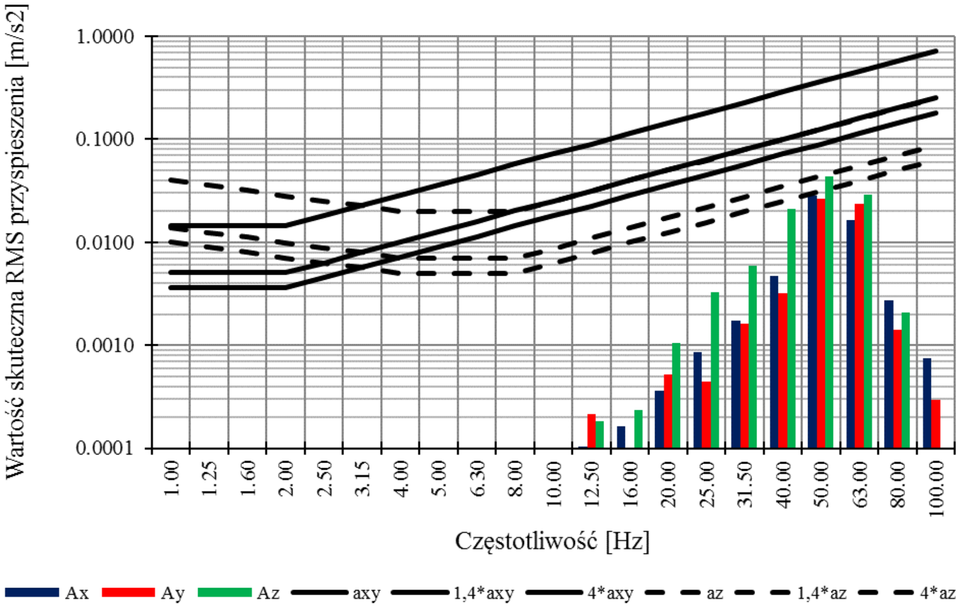
Analysis of the impact of vibrations on people and equipment in a building without vibroinsulation

The impact of vibrations on people was exceeded for the planned building with the control room without the use of vibration isolation. The calculations were carried out for the finite element mesh control node located on the reinforced concrete floor in the computer room (see Figure 6).



6. Location of the control node for simulation of the impact of vibrations on people and devices in the building.

Subsequently, Figure 7 presents the selected results of the impact of vibrations on people in the building. These calculations used the dynamic model for the control node. The analyses show that without the use of vibroinsulation, the predicted impact of vibrations on humans reaches the values of WODL> 1.0.



7. Simulation of the impact of vibrations on people in the building with the control room without vibroisolation, a control node with WODL> 1.0.

In the designed object, before applying vibroisolation, it was also found that the impact of vibrations on the computer equipment was exceeded. Below, in Figure 8, selected vibration speed patterns calculated using a dynamic model in a computer room are presented. The analyzes show that without the use of vibration isolation, the predicted impact of vibrations on the devices exceed the admissible values. Impact of vibrations on very sensitive devices according to PN-85 / B-02170 [3]:

Vibration analysis in the "x" direction

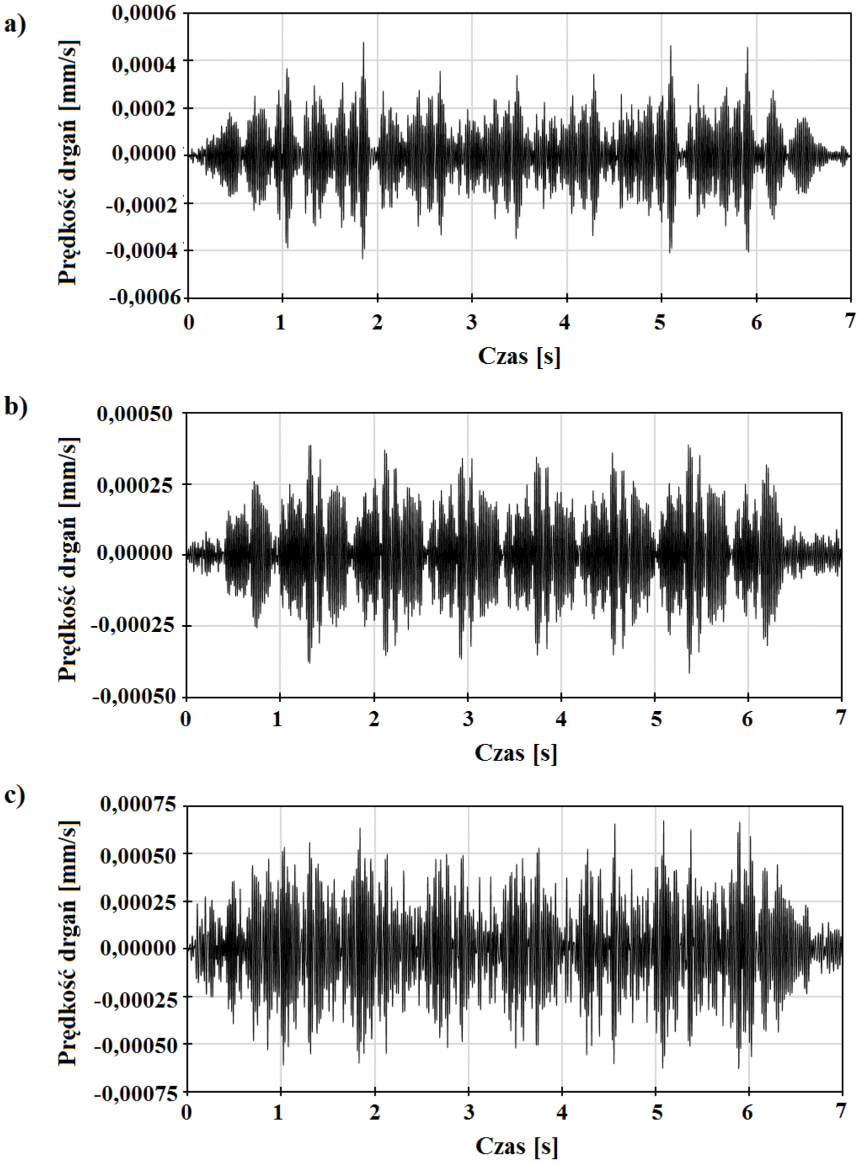
$V^{x}_{RMS} = 0{,}0001 m/s = V_u = 0{,}0001 m/s$ *condition fulfilled*

Vibration analysis in the "y" direction

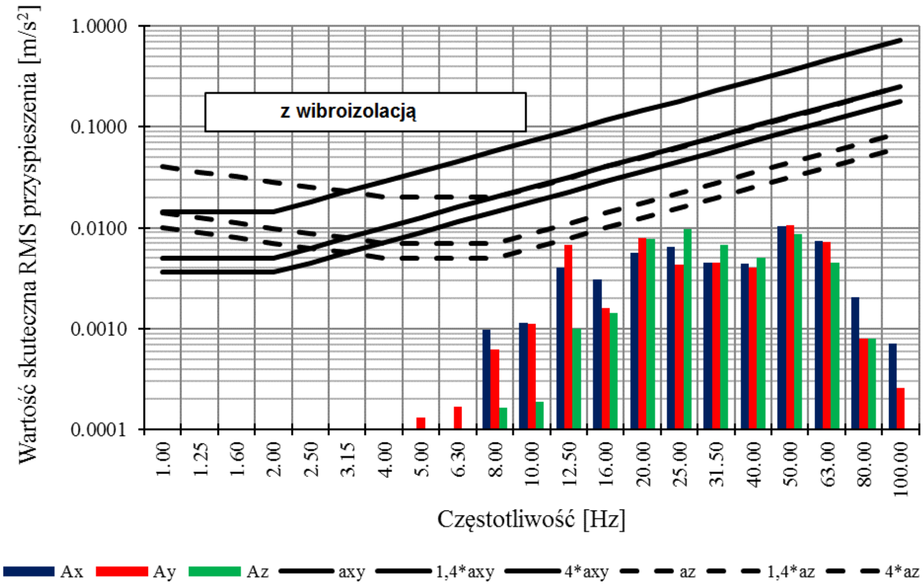
$V^{y}_{RMS} = 0{,}0001 m/s = V_u = 0{,}0001 m/s$ *condition fulfilled*

Vibration analysis in the "z" direction

$V^{z}_{RMS} = 0{,}0002 m/s > V_u = 0{,}0001 m/s$ *condition not met*



8. Vibration speed on the floor in the computer room (a) direction x, (b) direction y, (c) direction z.



9. Simulation of the impact of vibrations on people in the control room building with a vibration isolation mat, a control node.

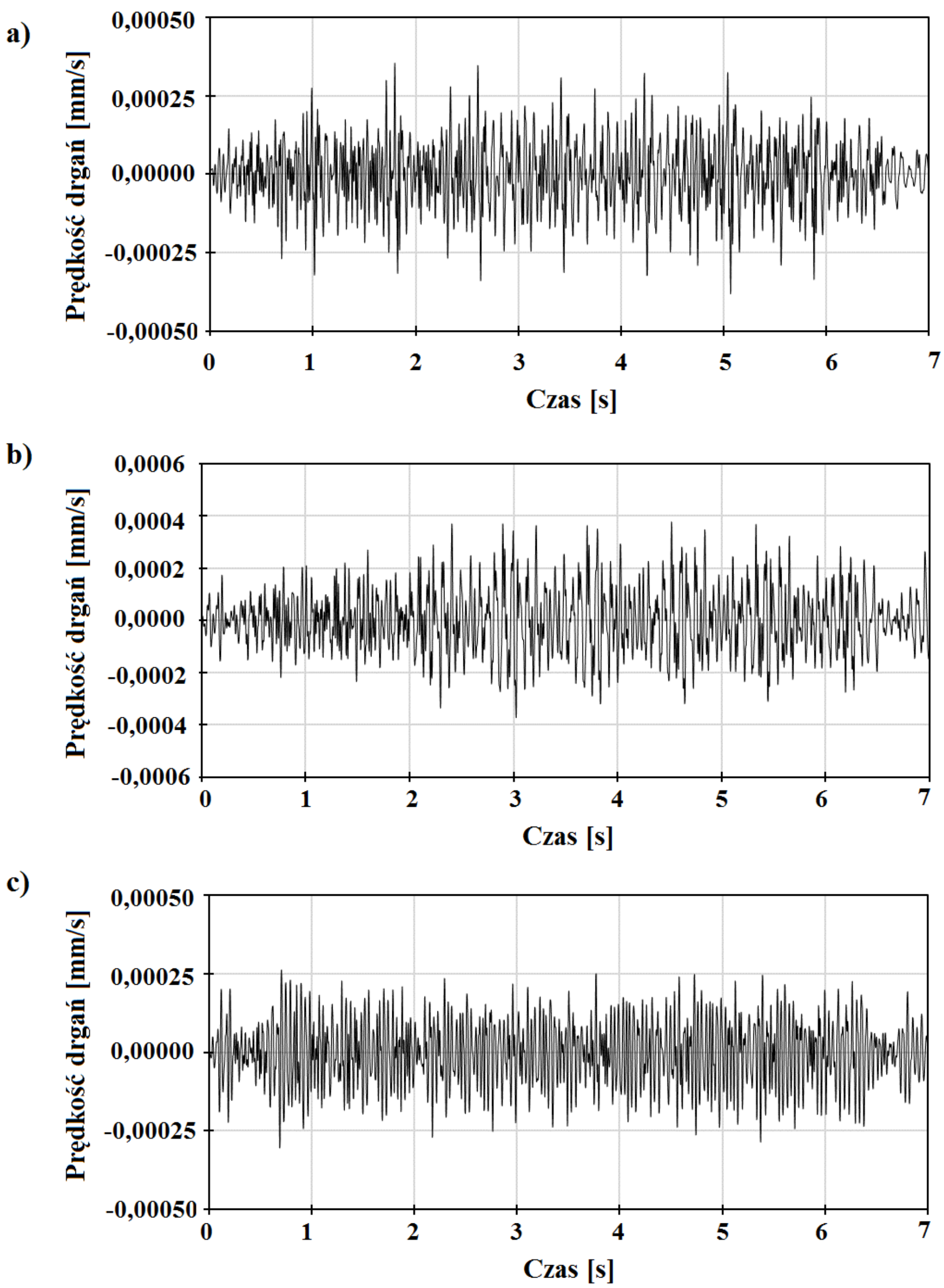
Analysis of the possibility of using vibroinsulation in a building

Due to exceeding the impact of vibrations on people and equipment in the building, the using vibroinsulation under the building has been proposed in this study. As a criterion of vibro-isolation, it was assumed that the level of impact of vibrations on people in the building below the vibration perception threshold and on the devices in the building is below the limit values specified in the PN-85 / B-02170 standard [3].

The calculations were made for different variants of solutions, assuming different vibro-isolating mats, changing their thickness, as well as stiffness and damping properties to obtain the assumed effectiveness. The calculations were carried out on the adopted FEM model, defining the necessary parameters of vibroinsulating materials. On the basis of these findings, the contractor held trade talks as a result of which a solution was adopted in the form of an elastomer vibroinsulating mat, Sylomer SR 28 with the thickness of 25 mm produced by Getzner company, under the building, and the 50 mm thick mineral wool insulation mat from Rock Delta on the side walls. The results of the evaluation of the impact of vibrations on people after applying this solution are presented below. The results relate to simulation analysis in the control node of the computational model.

As a result of the process of choosing the right vibroisolation, the WODL index was reduced below the threshold vibration sensation (WODL <1.0).

Figure 10 presents selected vibration speed patterns calculated using a dynamic model for a computer room, and a verified result of vibration effects on the equipment.



10. Vibration speed on the floor in the computer room after applying vibroisolation, (a) direction x, (b) direction y, (c) direction z.

The calculations were carried out assuming boundary conditions as for very sensitive devices. The use of vibroinsulation has reduced the impact of vibrations on the equipment below the limit values. Impact of vibrations on very sensitive devices according to PN-85 / B-02170 [3]:

Vibration analysis in the "x" direction

$V^{x}_{RMS} = 0{,}0001 m/s = V_u = 0{,}0001 m/s$ *condition fulfilled*

Vibration analysis in the "y" direction

$V^{y}_{RMS} = 0{,}0001 m/s = V_u = 0{,}0001 m/s$ *condition fulfilled*

Vibration analysis in the "z" direction

$V^{z}_{RMS} = 0{,}0001 m/s = V_u = 0{,}0001 m/s$ *condition fulfilled*

Analysis of the impact of vibrations on the building structure

For the assumed kinematic constraints, calculations were made on the adopted building model with vibroinsulation in order to determine the impact of vibrations on the structure. On this basis, the maximum values of substitute stresses were obtained according to HMH were obtained, i.e. the Huber-Mises-Hencky effort hypothesis, in all structural elements. Then, they were compared with the strength of these elements. As a criterion for assessing the impact on the construction of the building, it was assumed that if the extreme share of substitute stress induced by the kinematic constraint is less than 5% of the strength of the material then this impact on the construction of the building is considered negligible.

The analyses show that in the model with introduced vibroinsulation, the maximum value of HMH stresses did not exceed 5% in no analysed kinematic inputs. In the worst case, the value of these stresses in structural elements is 3.4% of the strength value of the material. Based on the simulation calculations of the impact of vibrations on the building, it is stated that for all considered cases of dynamic actions, the predicted vibrations are imperceptible to the building structure and harmless.

Below are three pictures from the implementation of the control room regarding the implementation of vibroisolation.

11. Concreting the underlay for vibration isolation mats (photo provided by PORR Poland Construction S.A.)

12. Elastomeric vibroinsulation mats arranged under the building (photo provided by PORR Poland Construction S.A.)

13. Vibro-insulating mats made of mineral wool (Rock Delta company) arranged at the interface between the side walls and the ground (photo provided by PORR Poland Construction S.A.)

Conclusions

The analyses presented in the above work concerned a substitute solution to the protection of the control room building against the negative impact of vibrations generated by the operation of the railway line. Awareness of the general contractor, i.e. PORR Poland Construction S.A. and experience in implementing similar investments were the basis for commissioning field studies, their analysis and implementation of optimization of the vibroisolation project.

They made possible to significantly shorten the time of excluding tracks from operation during the period of performed works, at an equivalent, or even better than the original design, protecting the building with a new control room against vibrations.

The economic aspect of the new concept of vibroisolation should not to be missed, because it resulted in a reduction in costs both in the amount of necessary vibroinsulating materials as well as in the shortening of track work time. A wide range of professional vibroisolation solutions existing on the market allowed to choose the optimal solution for a given situation.

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