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Technical note

THE EFFECT OF PENDOLINO HIGH-SPEED RAIL ON THE STRUCTURE OF BUILDINGS LOCATED IN THE PROXIMITY OF RAILWAY TRACKS

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The following research focuses on the dynamic analysis of impact of the high-speed train induced vibrations on the structures located near railway tracks. The office complex chosen as the subject of calculations is located in the northern part of Poland, in Gdańsk, in the proximity of Pendolino, the high speed train route. The high speed trains are the response for the growing needs for a more efficient railway system. However, with a higher speed of the train, the railway induced vibrations might cause more harmful resonance in the structures of the nearby buildings. The damage severity depends on many factors such as the duration of said resonance and the presence of additional loads. The studies and analyses helped to determinate the method of evaluating the impact of railway induced vibrations on any building structure. The dynamic analysis presented in the research is an example of a method which allows an effective calculation of the impact of vibrations via SOFISTIK program.

Key words: high-speed trains, FEM, dynamic analysis, railway tracks, structural damage.

1. Introduction

The railways were the first form of transportation system that made an enormous impact on nearly every aspect of human life. Over the years the main point of interest in developing the railways was the factor of speed, which transformed into more efficient shipment of goods and passengers. The growing preference for a more efficient railway system resulted in long-term engineering studies, which contributed to the emergence of the first high speed rail system. Despite many positive attributes high speed rail is not devoid of negative features. Negative parameters influence strongly all buildings constructed near railway tracks. Noise pollution caused by trains lowered the attractiveness of the nearby area for potential residential developments and reduced the value of existing housing. At the same time the proximity of an effective transportation system made the surrounding land attractive for warehouses, distribution centres, and other facilities, whose functioning does not depend on noise level. Additionally, noise pollution, as it has impact mostly on human and wildlife health, was the reason for implementing acoustic screens in railway areas. It strongly affected the aesthetic of urban landscape but on the other hand also reduced the noise level. While noise pollution can be relatively easily prevented, the other effects like vibrations, are rather difficult to counteract and can be harmful to nearby developments, regardless of the function.

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With higher speed, ground vibrations increase as well, and as a result the outcome of such resonances in buildings or their elements is more oppressive and noticeable. That depends on the vibrations level, their duration and the characteristic of a building that is subjected to resonance. The effect depends also on soil conditions of the subjected area, since it is the transmitting medium of vibrations. Usually, the level of vibrations that occur is not high enough to have an immediate effect on buildings. However, even a low level of vibrations that last for a longer period of time may cause fatigue damage, as a result of repeatedly applied loads. The consequences may vary. In historical buildings the damage might be more severe than in newer facilities. One of the most visible results of vibrations are cracks in walls, ceilings and individual parts of any structure. The damage is more severe if long term railway induced vibrations contribute to other, existing loads. In that case they may cause harm even to structural systems. Therefore, it is important to consider negative effects of high speed rail, especially while introducing this type of transportation system in new regions [1, 2].

In 2014 Poland joined a group of countries with high speed rail after implementing the Italian family of high speed trains, Pendolino. Their speed on the route oscillates currently around *200 km/h* (≈ *125 mph*), less than their maximum speed of *250 km/h* (≈ *155 mph*) and significantly more than the speed available for trains running up till then. The difference in those speeds and the fact that often closest areas to railway in Poland are densely populated, bring the problem of railway induced vibrations.

The research presents a method of dynamic analysis on the example of a project of Publishing Company Office, located in Gdańsk, in northern Poland. The purpose of the study is to evaluate the impact of railway induced vibrations, whose source might be Pendolino, the high speed train [3] the structural system of the buildings.

2. Publishing company office complex located near high-speed railway

The building analysed is the project of an office complex, located in northern Poland, in Gdansk. The building is ultimately situated in a proximity of railway tracks, the main rail route in Poland, which is connecting all major cities and is used by Pendolino, the high speed trains. The area is located in to Oliva district, with both valuable historical architecture and recently built modern, office developments.

The main idea behind the whole project was to design a functional office complex, preferably for a small publishing company, which would fit into the diverse area. The form of the building was inspired by the contrast of the early XX century villas located in the area and the contemporary office developments, such as the Oliva Business Centre. The main architectural idea is reflected in the difference in the shape and height of individual parts of the building, as well as in the diversity of façade materials. The idea of contrast is also emphasized by angled axis, which divide the complex into two different, nearly separated wings and create the entrance to the facility and on the other end to the underground garage. The angled axis, and the semi-passage it creates define the asymmetric form of each part of the complex. The walls, which adjoin the axis, are similarly inclined, with the east wing widening in the north direction. Another characteristic feature, that is somehow a consequence of dividing the building, is the suspended, extended part of the south elevation of the east wing (Fig.1).

The entrance located on the axis is the main access point for pedestrians. It leads to a vast, open space of the lobby. Opposite site of the foyer is closed by a glass, curtain wall which separates the entrance area from open-roof atrium with greenery, that is located in the centre of the complex. The lobby is directly linked to the communication system which encircles the atrium. This kind of arrangement provides natural light to the corridors connecting the separate parts of the office building on the ground floor. On the first floor the connection is maintained by two glass connectors. Each part of the complex has its own communication core with staircases and elevators, that are also providing access to the underground garage and storerooms.

a) b)

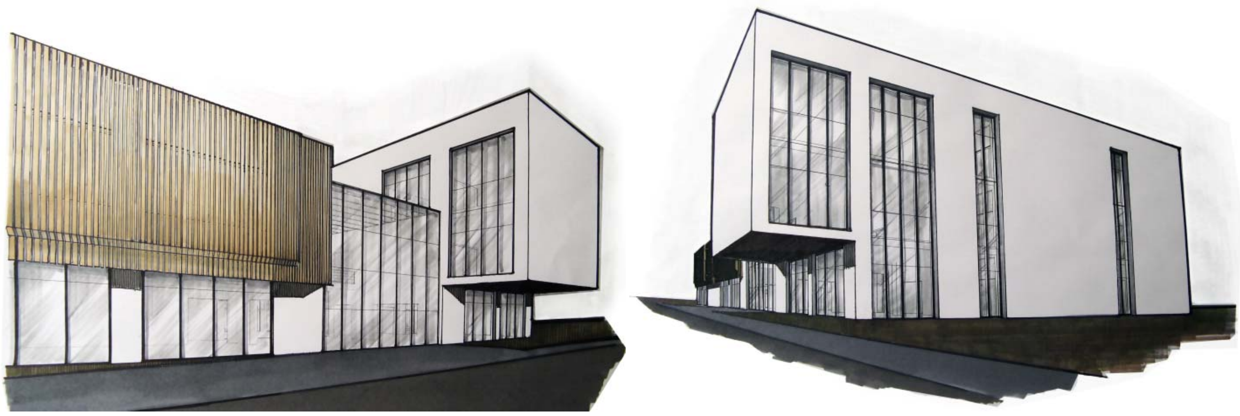

Fig.1. General view of building.

The ground floor of the east wing, beside the foyer, reception and the waiting area includes also administration section and restrooms. The remaining two upper levels have a similar layout and contain mainly offices and social rooms. On the ground floor of the west wing, shorter than its east counterpart by one floor, but relatively vaster, there are located server rooms, other restrooms, a spacious resting zone and a restaurant with its facilities. The upper floor of the west part of the complex is similar to the first floor of the east wing. It is mainly an office area with the exception of two conference rooms. Regardless of the function the interior design is very uniform terms of colours and materials. Its dominated by natural light and white, clear of any obstacles surfaces. Even the floor on each level, beside the underground garage, is covered by a few layers of white epoxy resin.

The basic façade material for the whole office complex is white plaster. Simple coating emphasizes the building form and serve as the background for the second openwork façade made of larch wood. The second façade covers only the west wing and underlines the difference and division of two wings of the office complex.

The loads in the overhead part of the office complex are mainly transferred through the bearing wall system. The outer and inner structural walls, made of reinforced concrete, provide the needed vertical support and lateral forces resistance. In the underground part the structural loads are transmitted by reinforced, concrete columns, which created large openings and thereby the garage space. The ceilings structure is also made of reinforced concrete, with the exception of building connectors. Both bridges are constructed with the use of voided concrete slabs. This allows a much bigger span without any support. The extended, suspended part of the east wing, works as a suspended structure, and due to its significant size might be the most vulnerable element to railway inducted vibrations.

3. Dynamic modelling of Pendolino

There are two very important factors, which are considered while planning and constructing railway route. The railway tracks have to be constructed in a way that minimizes negative effects which might have an impact on the wellbeing of the passengers. Also, the exploitation and maintenance costs of the tracks must be as low as possible. During the designing process of railway infrastructure [ex. bridges], the dynamic analyses of facilities supporting safe runs of the trains are not performed.

The rails of the railway tracks are connected through joints. This type of connection allows the rails to change their length because of temperature shifts during the year. It also prevents axial force progression and thereby minimizes the risk of the rail buckling in high temperature. The disadvantage of such connection is the generation of high dynamic loads during the train passage. Dynamic loads might cause many problems such as rapid deterioration of the vertical geometry of rail tracks, yielding of the railhead material, dangerous cracks in elements and damage of the rail base and fastenings. The problems enhance with growing speed, because with higher speed the degradation of rail tracks is significantly faster .

To study the work of the tension force and the stress distribution it is required to determine the exact load-bearing function of each element of the rail tracks. The main task of the rail tracks is to transfer structural loads, caused by train, through discrete system of rails, rail bases and track ballasts (Fig.2) [4, 5].

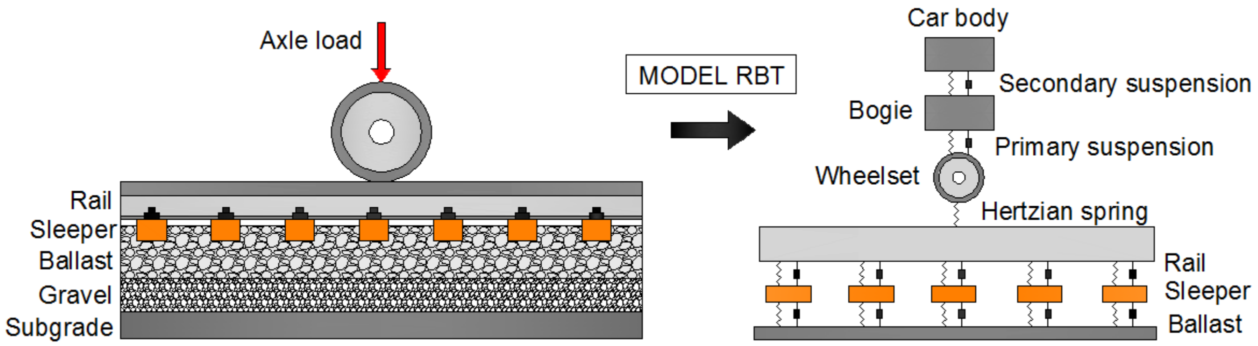

Fig.2. Scheme of relations between track-bridge-rolling stock.

Basing on the statics, transferring the structural loads, consists in the rule of reducing the stress “layer by layer”. The maximal stress occurs between the train wheel and the rail. Furthermore, as the surface area of the layers increases, the tension force between another elements declines. The minimal stress occurs between the sand bed and the soil.

The train, passing by with very high speed, causes a rapid increase of forces, tension forces, acceleration and vibrations. Because of that the dynamic modulus might not encompass the entire increase. Therefore, to accurately illustrate the exact response of the construction to changes of the dynamic load, it is required to analyse dynamics of the railway track [6, 7].

The output model of the structure is obtained by multiplying the output spectrum by the response function of the structure. Displacements and rotations at the contact point of wheels and rail tracks, and the occurring accelerations, which determine the comfort of passengers, are calculated in the time domain by the Fourier invert transform. The dynamic interaction between the train and the trail track can be adequately described in the vertical direction by a mathematic model (Fig.3).

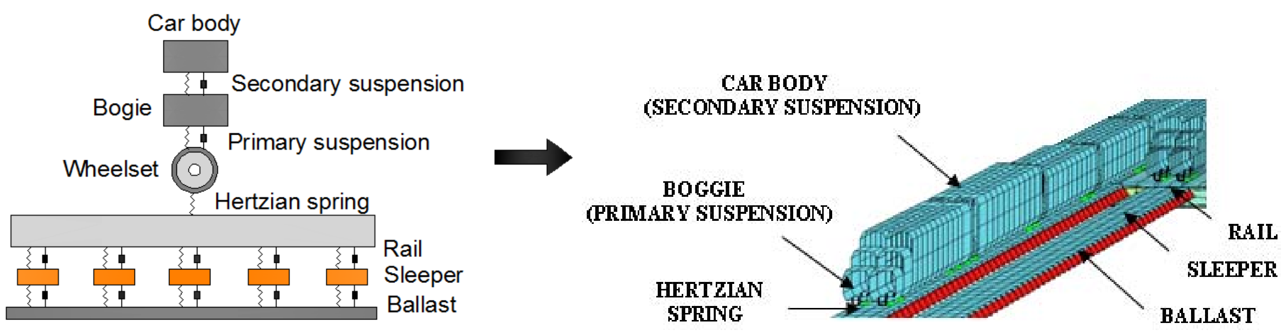

Fig.3. Scheme of relations between track-bridge-rolling stock in Sofistik.

The model consists of a discrete system, which acts on the basis of mass and spring. The system of suspension between the wheel and the wagon of the train is the first spring type connection. A damper between this connection make in possible to decrease vibrations caused by reciprocal influence of the wheel and track rail. Therefore this type of suspension is called a simple connection. Reduction of vibrations for lower frequency is considered at the second stage between the spring wagon and the mass of the rolling stock. It is called secondary suspension. For the needs of calculations the railway track is working as the infinitely stiff structure and along with the rolling stock is one collaborative structure [8, 9, 10].

In order to implement data it is required to specify the dimension, in which the dynamic analysis is made. For the purpose of the research individual, vertical loads of each elements of the system are replaced by one load of the rolling stock, which is transmitted on the track through a set of leaf springs. Mathematical and physical modelling of the structure is divided into secondary structures, which are considered in the equations of motion, implemented into SOFISTIK program. The equations create a simplified function which, after implementing into SOFISTIK, renders it possible to reflect the dynamic effects caused by Pendolino train [11, 12].

4. Dynamic analysis of the train's influence on the building

The dynamic analysis of the train's influence on the building construction was performed in the SOFISTIK software. The calculations were carried out for two instances of a passing rolling stock. The first case "without dilatation" and the other case "with dilatation" between the track and the building. The dilatation is a membrane in the soil with the waves' and ground vibrations' absorption properties (Fig.4) [13].

a) b)

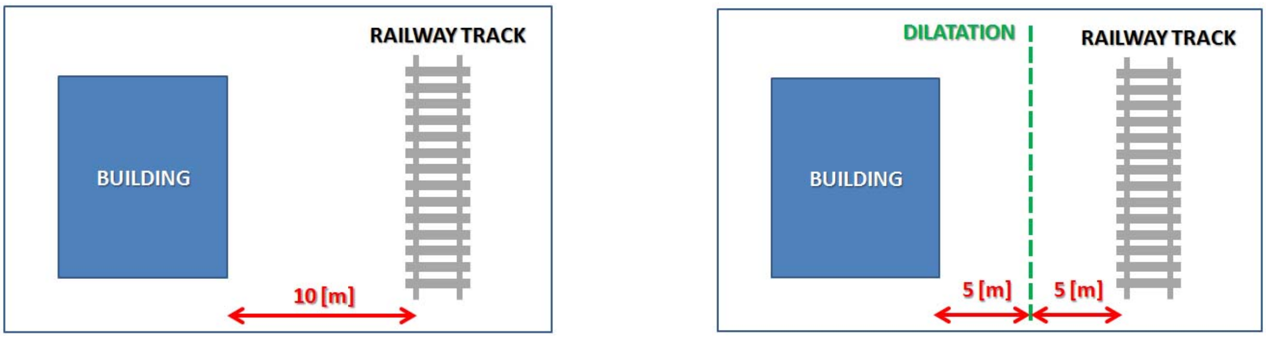

Fig.4. Schemes of the systems for which the dynamic analysis was performed: a) without dilatation, b) with dilatation

The distance from the nearest building to the railway track rails, on which the Pendolino train passes is *10*[*m*]. In the second instance the dilatation aiming at a reduction of vibrations reaching the building is applied. The dilatation was made at a 5 meters distance from the railway tracks and 5 meters from the wall of the building. The depth of the dilatation is equal to the depth of the substructure of the track and made of a material absorbing the vibrations coming from the moving rolling stock. The first stage of the analysis was to investigate and calculate the amount of waves reaching the building after using the dilatation in relation to the system without dilatation. In the subsequent stage, the results of the accelerations and displacements on the very structure of the building for the two defined instances were read and compared (Fig.5) [14, 15].

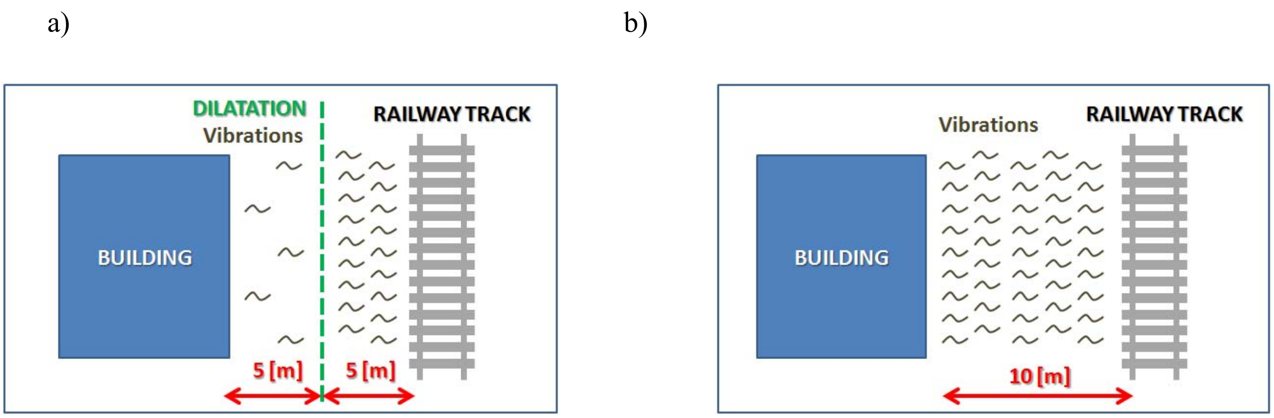

Fig.5. Distribution of vibrations resulting from a passing train: a) without dilatation, b) with dilatation

On the basis of the performed numerical simulations the results of the accelerations at the selected point of the structure were read. The places where the most common failures and damages of the building resulting from the cyclic train passages occur were chosen. The failures and the damages occur in the form of cracks on the windows and on the walls from the side of the railroad tracks. FEM models of the building and the train, as well as the simulations of the train passage were conducted in the Sofistik software (Fig.6). The speed of the rolling stock was equal to *250km/h*, as much as the maximum speed reached by the Pendolino train. In the simulation of the passage, an RBT model that precisely renders the performance of all the rolling stock's elements that transfer the vibrations to the subsoil was used. Then, after reading the acceleration of soil that emerged during the train's passage at the speed of *250 km/h*, the obtained values were applied to all nodes of the building's construction and the integration of equations of motion in the real time of the passage time was performed [16].

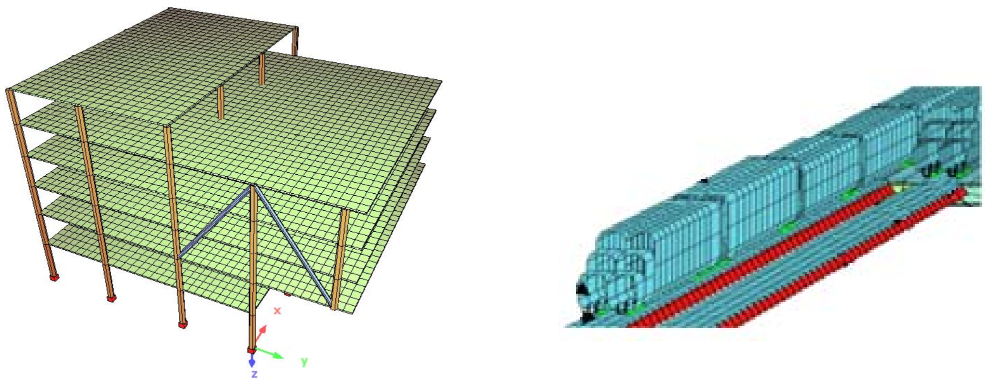

Fig.6. FEM model of the building and the Pendolino train performed in the Sofistik software.

After the performed numerical analyses, the results of the accelerations and displacements for the system "with dilatation" and "without dilatation" were obtained. One of the main obstacles in dynamic analysis of high-speed trains' load is not a simulation of a single passage, but the cyclical nature of the passages that result in construction's fatigue. When analyzing only a single passage one may obtain misleading results for it is important if the structure is able to absorb the rapid increase in loads, accelerations and deflections following one after another (Fig.7).

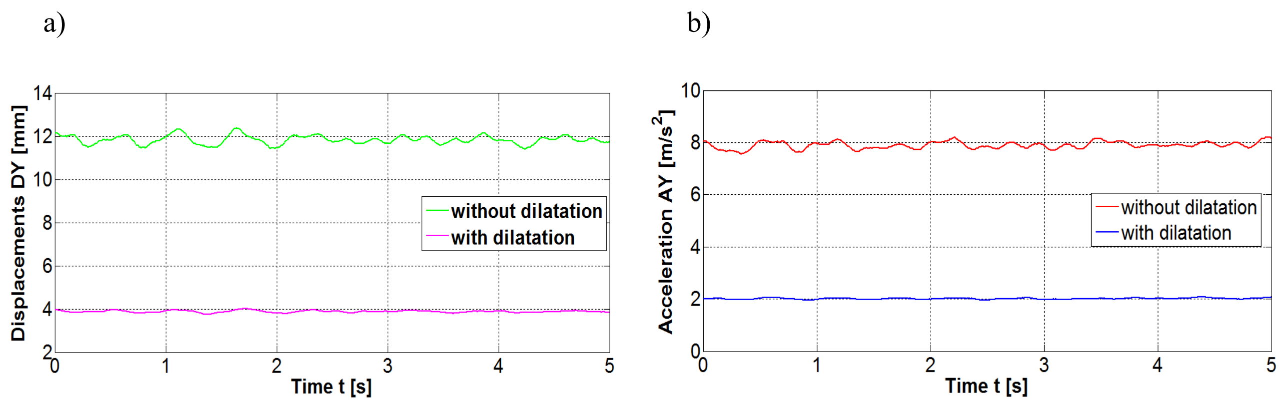

Fig.7. FEM model of the building and the Pendolino train performed in the Sofistik software.

5. Conclusions

On the basis of the analysis, a vibrations' distribution resulting from a passage of a high-speed train was developed. Numerical simulations proved that the vibrations in the system with dilatation between the track and the building have decreased by about *80%* in comparison to the system "without dilatation". The results of the analysis were obtained at the speed of *250 km/h* Pendolino train. The accelerations after the application of the system "with dilatation" decreased by four times, while the displacement decreased by three times. Thanks to the created dynamic model and the concept of using the dilatations between the railway track and the nearby buildings, already at the design and construction stage it will be possible to take into account the influence of the by-passing train's vibrations as a negative factor interacting with the buildings. Thereby, it will allow a faster and more effective elimination of errors and mistakes.

The design process lacks procedures that take into account the dynamic loads caused by passing high-speed trains. The use of the dilatations that absorb the vibrations will render it possible already at the design or modernization stage to increase the safety of buildings constructed nearby the railway lines usage.

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