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Development of Road Infrastructure and The Legitimacy of Changing the Method of Assembly of Road Construction Elements With the Use of Vibration Isolation

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Abstract:

Purpose: *Due to the constantly progressing development of road infrastructure, which is very important in Poland, it is necessary to look at the possibilities of improving the quality of assembly of individual elements of the road structure. The main problem that negatively affects individual structures is the problem of vibrations transmitted from means of transport to the road. By performing specialized tests before assembly, we are able to assess the amount of vibrations in a specific area of the road. The paper presents the methods that were used in this type of research and the possibilities of using the above-mentioned methods. on-road assembly tests.*
Design/methodology/approach: *The authors conducted a series of tests using modern sensors allowing for precise indications of vibrations in the studied area. Then, taking into account the tests of vibro-isolating materials, they had the opportunity to properly select them for individual road construction elements.*
Findings: *As a result of the research, it is possible to minimize damage from means of transport to individual road construction elements and the roads themselves.*
Practical implications: *The proposed solutions are different from those available on the market, and make it possible to control damage to roads, and even prevent them to a fairly large extent, which has an impact on extending the quality of repairs. According to the authors, performing tests in individual areas is necessary before installing road structural elements, as it extends their service life.*
Originality value: The use of original solutions not available on the market. They allow you to fully assess the correctness of the work performed and prevent future damage caused by vibrations.

Keywords: *Transport, Logistics, Road infrastructure, Vibroisolation.*

JEL codes: *L91, L62.*

Research type: *Research article.*

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1. Introduction

The natural environment determines human life. The development of industry and the increase in the number of people in Poland (Adamczyk, 1979; Adamczyk *et al.*, 1991; 2003; Bednarz *et al.*, 2010) in the last century are the main reasons for the enormous transformation of our natural environment. In striving to improve the living conditions, the adaptation possibilities of the environment were often forgotten. This often led to irreversible changes or even damage. As a consequence, almost every element of the natural environment in Poland has been transformed.

One of the greatest threats has become broadly understood transport. Transport networks are an essential part of the supply chain and form the basis of the economy in all countries, allowing goods to be distributed and people to move around. Due to the development of transport, road transport, which is the most frequently used form of transport, also has the largest share in environmental pollution, and thus has become one of the greatest threats to civilization.

In addition to the well-known problems such as air and water pollution, road accidents or traffic congestion, the negative effect of road transport is vibrations (Ciesielski *et al.*,1973; 1979; 1990: 1993) which are associated with high costs that we all have to bear, not only transport users. The source of vibrations is also the constant expansion of the city infrastructure, which includes dynamic actions influencing buildings e.g., vibrations transmitted through the ground.

The problem of vibrations affects about 30-40% of the population of our society. Residents of large urban agglomerations, employees of industrial plants with high traffic of means of transport performing technological functions related to production, and the part of the population directly related to the place of residence in the vicinity of this type of industry are particularly vulnerable to them. Roads, especially expressways, have a negative impact on the environment. They unequivocally divide the area through which they run, occupy relatively large areas of land, and moreover, they are burdensome due to the intensity of traffic.

In the case of buildings, and more specifically building structures, vibrations can cause serious damage to them, and therefore the need for numerous renovations. In the worst case, if the relevant services do not react in time, a construction disaster may result. Particularly dangerous are vibrations caused by communications to buildings or historic buildings, which are usually located in narrow streets in the city center as a rule, built on low-strength soil.

As a result, the functionality of such public facilities as hospitals, schools and residential buildings (vibrations transmitted to the body of residents) decreases. An important aspect that should be noted is that vibrations are also a source of noise, which adversely affects the human body, causing psychological discomfort.

The civilization progress that we observe at the turn of the last century is enormous - both automotive and industrial, as well as road. Let us go back to the beginning of 1918, when the authorities of the reborn Poland faced the problem of reconstruction, expansion and, above all, adaptation of transport needs.

The problem of vibrations transferred to the environment by car communication has been functioning from the beginning of its existence. At the beginning, these vibrations were not taken into account, because the frequency of travel and loads were very low and their level did not differ from the level of vibrations from other means of transport, such as truck-mounted trucks with steel rims, driving on paved streets. As technical progress and the development of other means of communication began, attention began at the stage of designing cars on the possibility of reducing noise and vibration emissions from these vehicles on the environment.

Preventing the process of spreading dynamic effects through the ground on engineering structures (PN-88 / B-02171, 1993; Targosz, 2000; 2004; Thompson, 2009), the emission of sound or material vibrations requires the use of new solutions, both material and construction, that meet the conditions of vibration isolation between the source of vibration emission and the environment.

In order to assess the correctness of the selection of the method of limiting the impact of ground vibrations on engineering structures, preliminary tests of vibration wave propagation in the ground should be carried out, a model of wave propagation in the ground should be adopted, simulated for the physical parameters of the ground and then verified for real object. In highly developed countries, the currently used constructions allow for a significant reduction of the emitted noise to the environment.

One of the basic methods of reducing noise and vibrations in these countries is properly designed and made elements of roadways, both car and rail. This problem concerns not only car roads, intersections of single-level roads and intersections with rail transport roads, but also structural elements of road transport, such as e.g. manholes

Figure 1. *Sample photo of the road elements complex*

Source: *Own study.*

Repair or renovation (Figure 1) of shaft covers as part of the maintenance of sewage networks is immeasurably expensive. The experiences of many network users in Poland and EU countries show that damage often reappears within two years after modernization or renovation. They are the result of dynamic interactions of various types of motor vehicles.

Contrary to Germany, in the Republic of Poland there are no tests of the suitability of individual types of manholes and manholes installed on the road, and often in Poland various methods of modernization of manhole covers in relation to the time of failure-free operation of repaired, modernized or overhauled. Not only the condition of the roads at crossings affects the fluidity of road transport, failure rate, speed limits, dynamic effects (vibrations) transferred to the natural environment of man, but also the sequence of sewage, storm and drainage manholes built into the road, especially their construction and quality of buildings.

However, the problem of replacing old hatches with new ones is significant. For this purpose, the road element around the manhole should be exposed, which in our conditions is performed with the use of pneumatic hammers, at the same time severely damaging the road base structure and making it unusable for a longer period of time. The binder, which is then filled up with losses on the road, is placed by hand and of poor quality, making the newly replaced hatch, rigidly built into the road, suitable for renovation in a short period of time.

The dynamic effects of a manhole without an element of vibration isolation must sooner or later become noticeable. Based on literature research and conferences, e.g. IKT Seminar - Forum Schacht 2002 in Gelsenkirchen, it can be concluded that this problem is significant in all EU countries, e.g., in Germany, according to the information obtained at the conference, there are about 10 million manholes.

In connection with the above, a significant problem of our country is the minimization of dynamic impacts on the environment from elements that are an integral part of motorways, which can be achieved, among others, by the use of vibration isolation of these structural elements (manholes, manholes) of automotive communication routes, whose vibroinsulating, mechanical and rheological methods are selected by analyzing the dynamics of the correct models of the vibration isolation system.

Moreover, it would limit the impact of the vibration wave propagation in the ground and would limit its negative impact on other engineering structures (buildings, viaducts, etc.). It would also reduce the emission of nuisance noise, mainly impact noise. Currently, preliminary research works are carried out, which may have a positive impact on the design process of engineering structures, including roads, significantly accelerate it, as well as predict the propagation of the vibration wave and apply appropriate vertical or horizontal obstacles to limit e.g. the level of vibrations of road structures themselves, and thus their service life, as well as buildings in the vicinity of those roads where people are present.

Hence, the concept of limiting the dynamic effects of road construction elements, such as manholes and sewage chambers, was created.

2. Mode of Research Work

The main element of the work methodology is to determine the impact of any type of car forcing on one of the structural elements of a road, such as a sewerage well, or rather its cover (manhole) and the vibration wave caused by this extortion and its impact on the environment, in particular on engineering structures near this road. The implementation of this task requires the development of a mathematical model of a dynamic structural element of the road, which is a manhole, together with a model of the soil in which the manhole is embedded (mathematical and digital). Such a model required identification and verification on the site in real conditions.

The basis for these studies was the initiation of a research project on the topic: "Repair, modernization or renovation of damaged shaft covers", in which the first of all was the issue of how different methods of modernization of shaft covers differ in terms of transferring the dynamic load of car traffic. for the construction of the shaft. The result of these studies was the fact that, with certain limitations, the shaft cover repaired, modernized or refurbished according to generally accepted technical rules is structurally not able to permanently resist the dynamic loads caused by the load from road transport, which occurs in the street.

The research conducted for many years also confirmed that the factors that had a negative impact on the durability of the shaft hatch structure include:

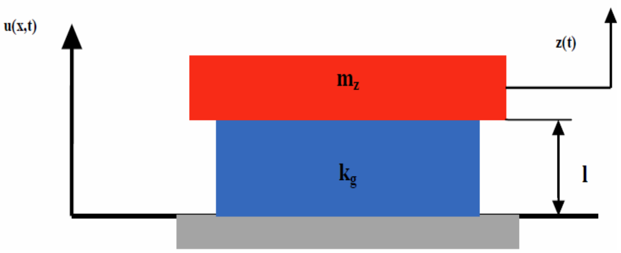
- weather factors (temperature, rainfall) during the construction and modernization process,
- corrosion due to the action of brine in winter,
- temperature differences,
- humidity differences,
- loads resulting from changes in frost / dew.

The main purpose of the research, however, is to determine the process of destroying shaft covers in real conditions and, based on laboratory tests of various types of models, to compare the effectiveness of various repair, modernization and repair methods depending on actual conditions. Such solutions extend the life of manholes, but do not limit the dynamic impact on the glass and do not ensure continuous passage through road transport. The continuity of the passage in this issue is understood as the structure of the road and the channel shaft. Apart from examining the state of the modernization technique, important elements of the research are tests of modernized shaft covers, i.e .:

- vibration tests (vibration isolation coefficient) on a sample directly after modernization,
- vibration tests (vibration isolation coefficient) on samples produced as part of the modernization,
- production and testing of samples in the laboratory,
- settlement measurements for modernized shaft covers for at least one year,
- laboratory tests on damaged glass covers,
- material tests (dynamic tests of damping parameters, vibration isolation, tensile strength, compression, fatigue).

Figure 2 shows a discrete-continuous model of the vibration isolation system in which the mass mz symbolizes the mass of the manhole plate together with the mass of the motor vehicle, which in the model acts as a pressure plate, and the k_g coefficient characterizes the stiffness of the vibration isolation system.

Figure 1. *Computational model*



Source: *Own study.*

The differential equation describing this model was derived with the assumption that the elastic elements characterizing the rubber k_g have linear characteristics, then it takes the following form (1):

$$\frac{\partial^2 u}{\partial t^2} = a^2 \frac{\partial^2 y}{\partial x^2} \tag{1}$$

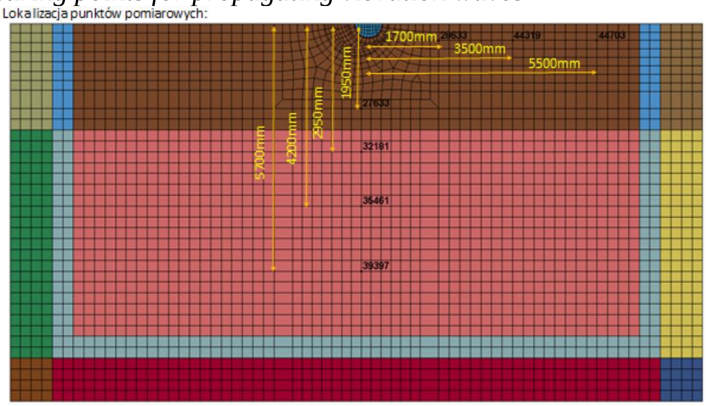
Then we introduce the boundary conditions in the form:

E - dynamic Young's modulus,
ρ - rubber material density,
F - rubber cross-sectional area,
m_z - weight of the pressure plate
k_g - elasticity coefficient of the vibro-isolating element

$$tan\frac{\omega}{a}l - \frac{EF}{m_z a\omega} = 0 \tag{2}$$

After applying the above boundary conditions, we obtain a formula thanks (2) to which we determine ωi, which are the eigenfrequencies of the model of the vibration isolation system, machines and vibration devices, presented in Figure 2. It allows us to calculate after substituting the actual values, knowing that the frequency range of excitations of road transport is contained in the range f = 30 ÷ 50 (Hz) (f = ω / 2π) so choose the parameters of the vibration isolation element and the mass of the manhole so that they do not coincide with the natural frequencies of the vibration isolation system and, moreover, meet the condition of vibration isolation (Figure 3).

Figure 3. *Measuring points for propagating vibration waves*

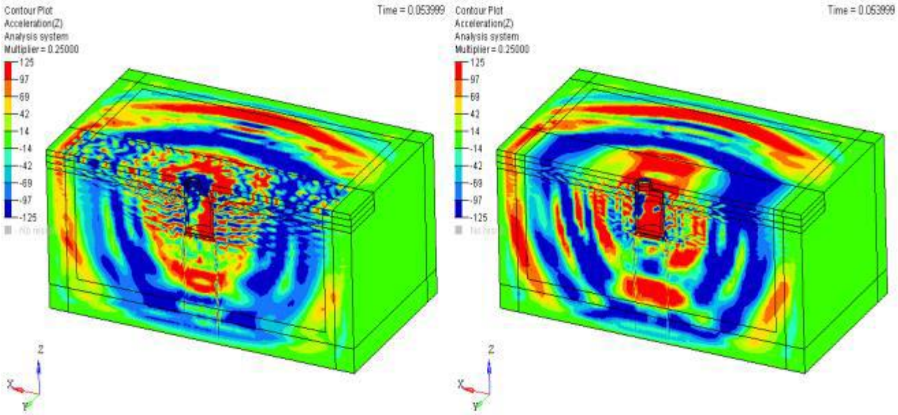


Source: *Own study.*

3. Results of Numerical Calculations

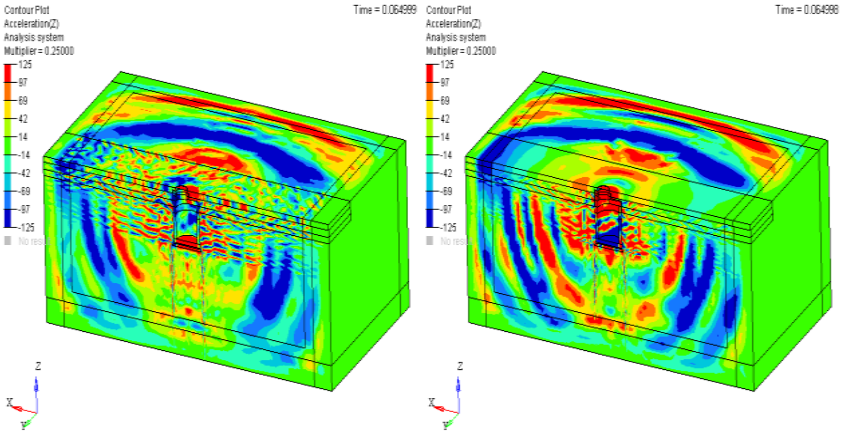
The simulation results of the numerical models are presented in the form of acceleration distribution maps for different time moments, which are shown in Figure 4-6.

Figure 4. *Distribution of accelerations for the time moment t = 0.054 s (the drawing on the left with the channel vibration isolation system)*



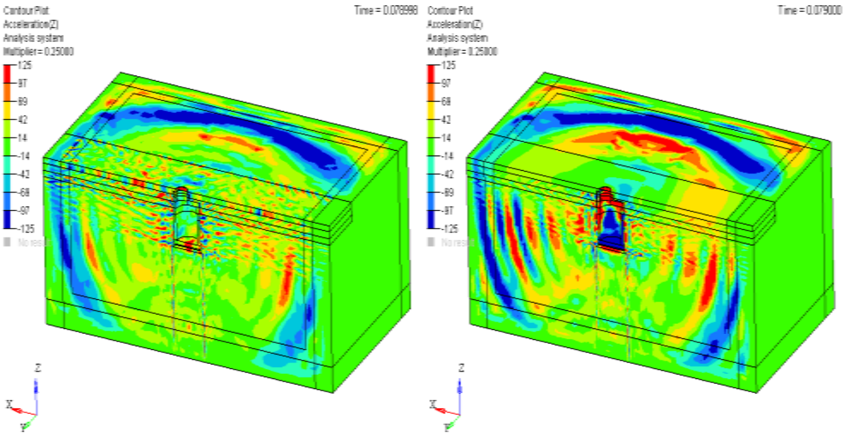
Source: *Own study.*

Figure 5. *Distribution of accelerations for the time moment t = 0.065 s (the drawing on the left with the channel vibration isolation system*



Source: *Own study.*

Figure 6. *The acceleration distribution for the time moment t = 0.079 s (the drawing on the left with the channel vibration isolation system*



Source: *Own study.*

Summarizing the analysis of the discrete-continuous model, based on the selection of parameters and elements of vibration isolation, and then simulation of the numerical model of a vibration-insulated manhole mounted in the ground (substrate) of the road, it can be concluded that:

1. Vibration isolation elements used in manholes allow to reduce the propagation of vibrations transmitted through the ground to building structures adjacent to the road and to the road itself.
2. The analysis of spectrograms, examples of which are shown in Figures 4-6, showed that both for the road and possibly buildings located in its vicinity, the use of vibro-isolating elements ensures reduction of vibrations in a wide spectrum of frequencies.

3. It can also be concluded that, according to spectrograms and time courses, the decisive parameters for the quality of ducts with elastic elements are the rigidity of the vibro-isolation elements and correct assembly.
4. After installing the hatch, knowing its mass and elastic parameters, it is possible to determine the natural frequencies of this engineering structure and limit the speed of motor vehicles, especially on residential roads.

5. Conclusive Remarks

Vibrations are a common social nuisance and occur in all areas of human activity. The analyzes of the literature on the subject show that they concern about 30-40% of the population of our society, one of their greatest sources is road communication. It is also characteristic that the occurrence of this type of vibrations is associated with high costs that must be borne by everyone, not only the users of transport.

Residents of large urban agglomerations, employees of industrial plants with high traffic of means of transport performing technological functions related to production, and the part of the population directly related to the place of residence in the vicinity of this type of industry are particularly vulnerable to them. The same cities are additionally burdened by vibrations from public transport and individual vehicles.

Existing not only in Poland, but also in other EU countries, the problem of the negative impact of road transport on engineering structures (buildings, bridges, viaducts, etc.) in the vicinity of roads continues to worsen as a result of the expansion of the road network. That's why, in particular at the stage of planning or designing roads, efforts should be made to avoid errors that may have a negative impact on the natural environment and, as far as possible, to minimize the adverse effects of road transport. A very important aspect is that a well-designed and constructed road structure means that road transport is less of a threat to the environment.

Therefore, the construction industry should be required to own and the use of objective tools for assessing and forecasting the impact of vibrations on building structures. It is very important both at the design stage and in the diagnostics of existing building structures, as well as the land on which the buildings will be erected.

On the basis of material tests and the results of the simulations of the vibration-insulated sewage sump and the threshold, it was found that in both considered cases, the use of vibro-isolation elements allows to reduce the propagation of vibrations transmitted through the ground to building structures adjacent to the road and to the road itself. Additionally, the analyzes of spectrograms and graphs of acceleration amplitude, frequency, propagation time and damping parameters as a function of soil type and weather conditions showed that both for the road and buildings located in its vicinity, the use of vibro-isolating elements ensures reduction of vibrations in a wide spectrum of frequencies.

Thus, the obtained results of the work confirm the thesis that vibration isolation reduces the impact of dynamic effects from motor vehicles on infrastructure elements. The necessary condition, however, is the appropriate selection of vibrosiolation, its design and initial verification in model conditions.

It was found that the decisive parameters about the quality of the channels and speed bumps with elastic elements is the rigidity of the vibration isolation elements and their correct assembly. In addition, based on the simulation of speed bumps and the procedures for their production and operation presented in the paper, it was found that, regardless of their design, their use on Polish roads is not an optimal solution, and in many cases even unfavorable.

A desirable solution to the road infrastructure limiting the speed of a car may be a combination of a structural element responsible for recording the car speed (e.g. a photocell) with an active element responsible for effectively enforcing a car speed limit by the driver (e.g., an automatic moving threshold) operating only when the speed limit is exceeded. Additional equipment increasing safety may be horizontal light marking of the threshold (e.g., signaling diodes). Solutions of this type, the so-called smart thresholds are proven and work in some EU countries. However, the transfer of these solutions to national conditions will require adaptation to the conditions prevailing on our roads (including climatic conditions, road type, traffic intensity, etc.).

In addition, it was found that in order to eliminate the negative impact of vibrations generated by road transport, it is of key importance to make an appropriate forecast of this impact prior to the implementation of this type of investment, using appropriate measurement bases for this purpose. If the result of the forecast requires the use of vibration isolation, it should be designed using structure modeling and simulation calculations.

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