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Propagation of Vibrations Created by the Movement of Trains on Parallel Railway Tracks, in the Ground and in Buildings

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Abstract--- The article considers the state of vibrations created on two parallel railway tracks by freight trains moving simultaneously in opposite directions, in buildings and ground located in proximity to it. The loads created by the train cars are presented in the form of dynamic force. The problem is solved by the finite element method. The speeds and accelerations of ground and building vibrations were checked at various points remote from the railway.

Keywords--- Railway, Finite Element Method, Soil, Theory of Elasticity, Elastic Waves, Vibration, Boundary Conditions, Infinite Plane, Velocity.

I. Introduction

Currently, as a result of an increase in the population, the construction of buildings and structures, and production processes in industry are increasing dramatically. This leads to an increase in demand for vehicles carrying people and goods.

Railway transport is a convenient means of transport for servicing people and transporting various types of cargo. Therefore, the need for them increases, the number of trains increases from year to year, and modern types appear, that is, there is an increase in power and speed.

Deposits in the soil under the influence of fluctuations created by the movement of vehicles on the ground near the main streets, the tracks on which high-speed trains run, lead to changes in their structure. Rail transport and road transport developed in the process of urbanization due to their advantages, which facilitated the movement of people, as well as created harmful environmental fluctuations.

Fluctuations occurring in buildings and soil near transport facilities lead to changes in the structure of the building and the structure of the soil. Especially negative changes are more common in buildings that are subject to fluctuations caused by the continuous movement of vehicles. Taking this into account, this article studied the vibrations created by two freight trains located in parallel and simultaneously moving in opposite directions in nearby buildings and ground [11, 17].

Railway sleepers are the main part of the railway composition. Its function is to transfer railway cargo to the ground. Sleepers are a means of countering the repetitive force of the impact of dynamic noise and vibrations of the train. In the study [3] it was shown that the addition of rubber to the edge of the concrete screed significantly increases its damping ability. It is established that the use of rubber increases the resistance of the traverse to cracking under the action of forces.

The influence of vibration emitted by moving vehicles on people, buildings, and industries located in the vicinity of the source was studied in the work of G.R. Watts [4]. In the first section, based on surveys conducted among the population, the essence of the problem was described in detail, methods for predicting the degree of irritation when exposed to vibrations and noise. The second section examines the effect of vibration generated by the movement of vehicles on buildings and provides data from several studies. Studies have shown the disadvantages of buildings subject to constant vibrations.

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P. Fiala and G. Degrande researched digital modeling of noise and vibrations created in buildings due to the movement of ground rail transport [5]. In their articles, they are engaged in the digital calculation of the structural and acoustic response of a building to an incoming wave field created by high-speed rail traffic. The article studies the structural and acoustic response of a multistory frame building to the frequency of movement at a constant speed of the high-speed train "Talis". The insulating effectiveness of several anti-vibration measures was tested, and conclusions were drawn.

Aires Colaço and Pedro Alves Costa experimentally tested vibrations caused by the movement of railway trains in buildings using the 3D finite element method based on the subsystem technique [6]. In this paper, the authors presented a general and effective modeling methodology for solving fluctuations that occur during railway traffic. The main feature of this technique is its ability to effectively solve any common road and ground properties, i.e., it allows you to model large areas in a short time. With the dynamic evaluation of the response for an observation point located 35 m from the railway center for the analyzed specific case, a reduction in the calculation time by almost 50% was achieved.

This research work is aimed at determining the level of vibrations occurring in buildings and on the ground located near a double-track railway structure.

The results of the study show that numerous works were carried out to reduce the fluctuations created by the movement of railway transport, in most of which satisfactory solutions were obtained. But the implementation of the results of the research work in practice is very difficult or requires significant funds from an economic point of view. For example, from reinforced concrete structures, it was found that their ability to dampen vibrations was not high when using various materials. In this study, the velocities, accelerations, and displacements of vibrations created by transport structures in the ground and the structure of the building were compared.

The problem defines the vibration levels in the ground and the building as a result of the movement of two parallel rails. A 60 m wide, 200 m long, and 20 m deep dirt plot was taken as a model. The question also took into account the influence of groundwater to a depth of up to 15 m from the earth's surface. As an example, the characteristics of the soil with the high plasticity of clay materials given in Table 1 were selected. When forming the ballast layer, the drawing shown in Figure 1 was used, based on the norms of railway construction. On it, 20 cm of sand and 30-40 cm of compacted crushed stone are laid on the ground, on which a traverse is designed. In both trains, wagons are moving, each of which has its weight of 23 tons on its wheels (Fig.2). Freight trains move at a speed of 60 km/ h. The building was also designed near the intersection point of two freight trains. Since the selected limit area has a length of 200 m, the time of vibration affecting the building continues until both freight trains pass completely.

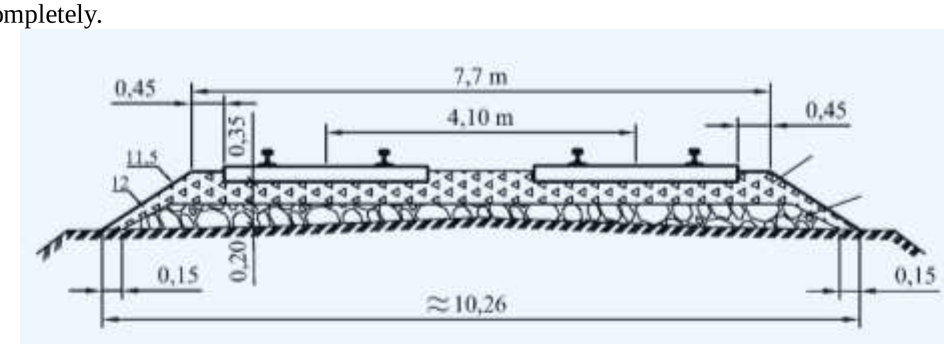

Figure 1: A Cross-section of the Ballast Part for the Design of a Railway Structure

II. Method

It is believed that dynamic loads through the wheels of the train affect the rails. We will determine the movements and speeds of the obtained nodes in the soil, taking into account the physical and mechanical characteristics of the material. In this problem, we will replace the infinite plane with a finite rectangle [1, 8, 12, 15]. At the same time, the following conditions are set at the boundaries (Fig. 2), ensuring the tendency of waves to infinity [2, 7, 9, 10, 14].

$$\left.\begin{aligned}\boldsymbol{\sigma} &= \boldsymbol{\alpha}\,\boldsymbol{\rho}\,\boldsymbol{V_p}\dot{\boldsymbol{v}}\\ \boldsymbol{\tau} &= \boldsymbol{\beta}\,\boldsymbol{\rho}\,\boldsymbol{V_S}\,\dot{\boldsymbol{u}}\end{aligned}\right\}\ (1)$$

The static equilibrium of a continuous medium can be represented as:

$$\underline{\underline{\boldsymbol{L}}}^{\boldsymbol{T}} \cdot \underline{\boldsymbol{\sigma}} + \underline{\boldsymbol{b}} = \underline{\boldsymbol{0}}\ (2)$$

This equation relates the spatial derivatives of the six stressed components collected in the vector $\boldsymbol{\sigma}$ to the three parts of the grounding forces collected in the vector $\boldsymbol{b}$. $\boldsymbol{L^T}$ is the transfer of the differential operator, which is defined as [13, 16, 18].

$$\underline{\underline{L}}^T = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix} (3)$$

In addition to the equilibrium equation, the kinematic relation can be formulated as follows:

$$\underline{\boldsymbol{\varepsilon}} = \underline{\underline{\boldsymbol{L}}}\underline{\boldsymbol{u}} (4)$$

The basic equation of the time - dependent motion of a volume under the action of a dynamic load is expressed as follows:

$$\underline{\underline{\boldsymbol{M}}}\ddot{\boldsymbol{u}} + \underline{\underline{\boldsymbol{C}}}\dot{\boldsymbol{u}} + \underline{\underline{\boldsymbol{K}}}\boldsymbol{u} = \boldsymbol{F} \ (5)$$

Here $\boldsymbol{M}$ is the mass matrix, $\boldsymbol{u}$ is the displacement vector, $\boldsymbol{C}$ is the absorption matrix, $\boldsymbol{K}$ is the stiffness matrix, and $\boldsymbol{F}$ is the load vector. The displacement $\boldsymbol{u}$, the velocity$\dot{\boldsymbol{u}}$, and the acceleration $\ddot{\boldsymbol{u}}$, can change over time. The last two terms in Equation (5) $\left(\underline{\underline{\boldsymbol{K}}}\boldsymbol{u} = \boldsymbol{F}\right)$correspond to static deformation [19, 20].

Here, the theory is described in terms of linear elasticity. However, it can mainly be used for dynamic analysis on all models. Soil conditions may or may not be dry. In the latter case, a large amount of groundwater hardness is added to the stiffness matrix $\boldsymbol{K}$, as in the case of static calculations.

The matrix $\boldsymbol{M}$ takes into account the mass of materials (soil + water + any structure).

The formation of time integration in the numerical representation of dynamics is an important factor in the stability and accuracy of the computational process. Explicit and implicit integration are two widely used temporal integration schemes. The advantage of explicit integration is that it is relatively easy to set up. But the computational process is not very strong and imposes serious restrictions on the time step. The indefinite integration method is more complex, but it provides a more reliable (more stable) computational process and, as a rule, a more accurate solution (**Sluys,** 1992).

The Newmark integration scheme with indefinite time is a commonly used method. When using this method, the displacement and speed at time $\boldsymbol{t} + \Delta\boldsymbol{t}$ are expressed as follows:

$$\boldsymbol{u}^{t+\Delta t} = \boldsymbol{u}^t + \boldsymbol{u}^t\Delta^t + \left(\left(\frac{\mathbf{1}}{\mathbf{2}} - \boldsymbol{\alpha}\right)\boldsymbol{u}^t + \boldsymbol{\alpha}\boldsymbol{u}^{t+\Delta t}\right)\Delta\boldsymbol{t}^2 (6)$$

$$\boldsymbol{u}^{t+\Delta t} = \boldsymbol{u}^t + \left((\mathbf{1} - \boldsymbol{\beta})\boldsymbol{u}^t + \boldsymbol{\beta}\boldsymbol{u}^{t+\Delta t}\right)\boldsymbol{t}\Delta \ (7)$$

In the equations above, $\Delta\boldsymbol{t}$ represents the time scale. Coefficients $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$characterize the accuracy of digital time integration.

With unlimited time integration, equation 5 is taken at the end of the time step $(\boldsymbol{t} + \Delta\boldsymbol{t})$:

$$\underline{\underline{\boldsymbol{M}}}\ddot{\boldsymbol{u}}^{t+\Delta t} + \underline{\underline{\boldsymbol{C}}}\dot{\boldsymbol{u}}^{t+\Delta t} + \underline{\underline{\boldsymbol{K}}}\boldsymbol{u}^{t+\Delta t} = \underline{\boldsymbol{F}}^{t+\Delta t} (8)$$

We use the finite element method to solve the problem.

A finite dynamic model of the problem-solving area is shown in Figure 1.

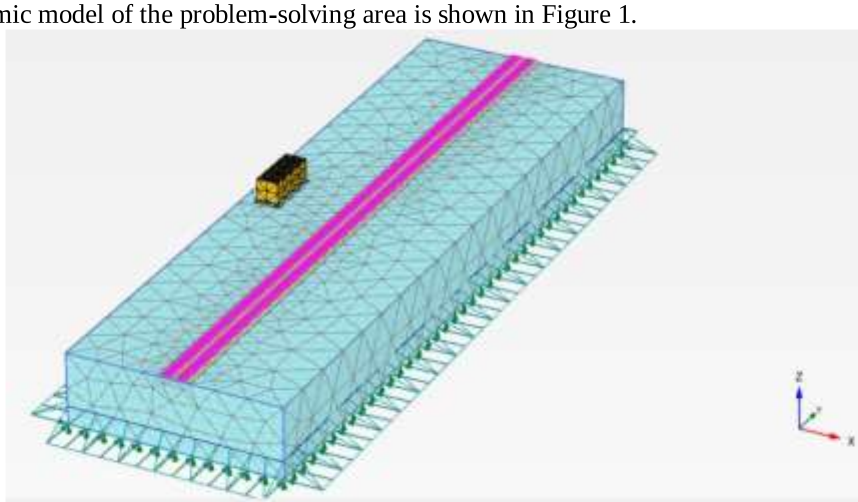

Figure 2: Model in Which the Task is Divided Into Finite Elements

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The properties of the soil and materials in this matter are given in Tables 1, 2, and 3.

Table 1: Physical and Mechanical Properties of Materials

Ground type **Ground properties**	**Clay-soils [soils of light brown color, with low humidity, medium-hard plastic consistency]**	**Sandy-soils [light brown loam, with medium humidity, hard-plastic soils]**	**Clay [light brown, loess-like, coarse-pored, medium-hard, moist and with low soil moisture]**	**Gravel-soil [pebbles from 10% to 20%, mixed sand, medium density stones]**
№	1	2	3	4
The type of model used	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit weight above phreatic level- γ_{unsat}[kN/m^3]	14,9	14,7	16,9	19,5
Unit weight when saturated with water - γ_{sat}[kN/m^3]	17,5	17,0	18,2	20,5
Deformation modulus - Ed [кN/м^2] -at naturalhumidity -when saturated with water				
	8,0	9,0	7,5	55
	4,7	4,78	4,5	50
Internal friction angle – φ [º]	25	27	25	38
Dilatancy angle – ψ [º]	4	1	2	14
Cohesion- c_{ref} [kN/m^2]	14,0	8,3	12	-
Young's modulus - E [kN/m^2]	55	50	200	100
Poisson's ratio - ν	0,3	0,35	0,3	0,25

Table 2

№	**Material Properties**	**Designation and unit of measurement**	**Rail**	**Sleeper**
1	Cross-sectional surface	*A*- [m^2]	7,7x10^{-3}	5.13x10^{-2}
2	Volumetric weight	*γ*-[kN/m^3]	78	25
3	Modulus of elasticity	*E*-[kN/m^2]	200x10^4	36x10^4
4	Moment of inertia on the X axis	I_x-[m^4]	3,055x10$^{-5$}	2.53x10^{-2}
5	Moment of inertia on the Y axis	I_y-[m^4]	5,13x10^{-4}	2.45x10^{-4}

Table 3: Features of the Ballast Layer

Ballast layer **Features of laying**	**Crushed stone (rubble)**	**Sand**
№	1	2
The type of model used	Mohr-Coulomb	Mohr-Coulomb
Unit weight above phreatic level- γ_{unsat}[kN/m^3]	19	14,7
Unit weight when saturated with water - γ_{sat}[kN/m^3]	17,5	17,0
Internal friction angle – φ [º]	25	27
Dilatancy angle – ψ [º]	4	1
Cohesion- c_{ref} [kN/m^2]	14,0	8,3
Young's modulus - E [kN/m^2]	55	50

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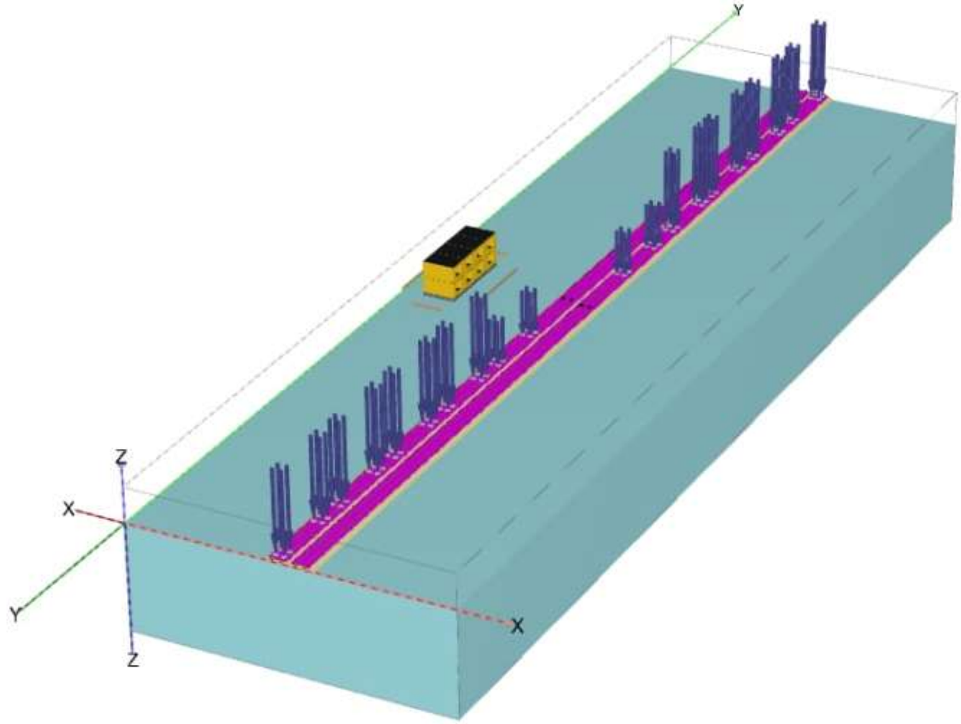
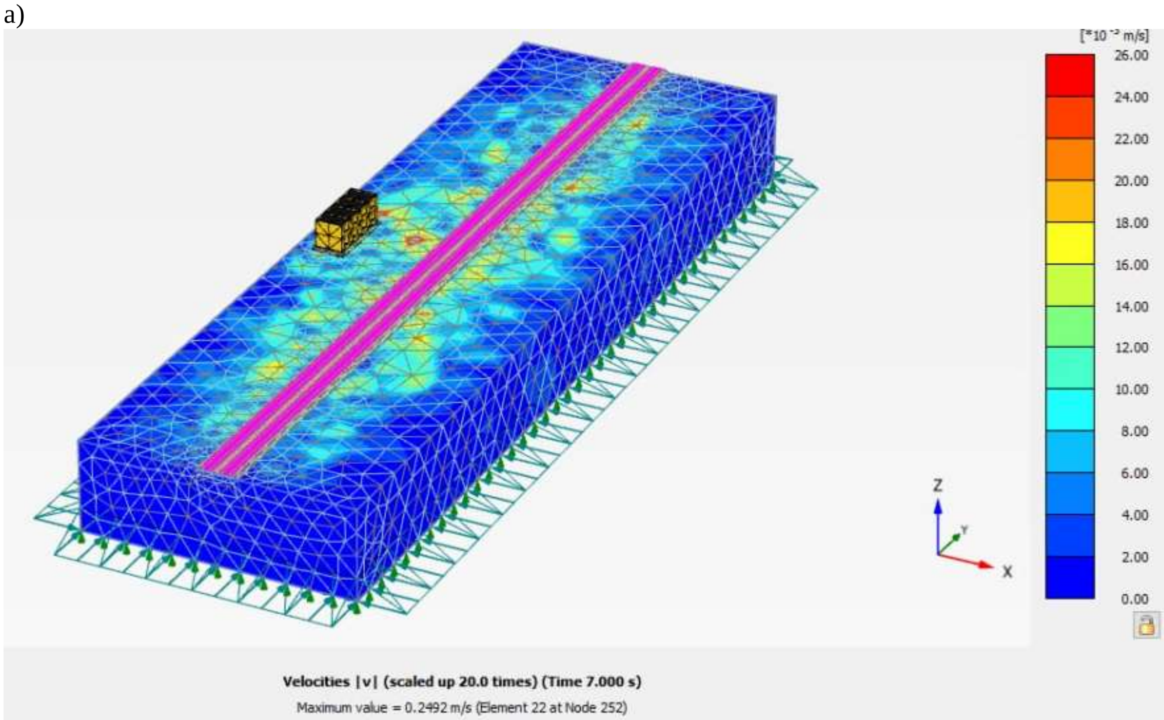
Poisson's ratio - ν	0,3	0,35

III. Results

Migrations and their levels in each node of the model being tested are shown in the figures below.



a)



b)

Figure 3: a-b.The Speed of Vibrations the Ground and on the Floors of Buildings

The graphs in the figures below detail and compare the fluctuations resulting from the movement of a freight train on the ground and in a building located at the same distance from the railway track, that is, at a distance of 20 m.

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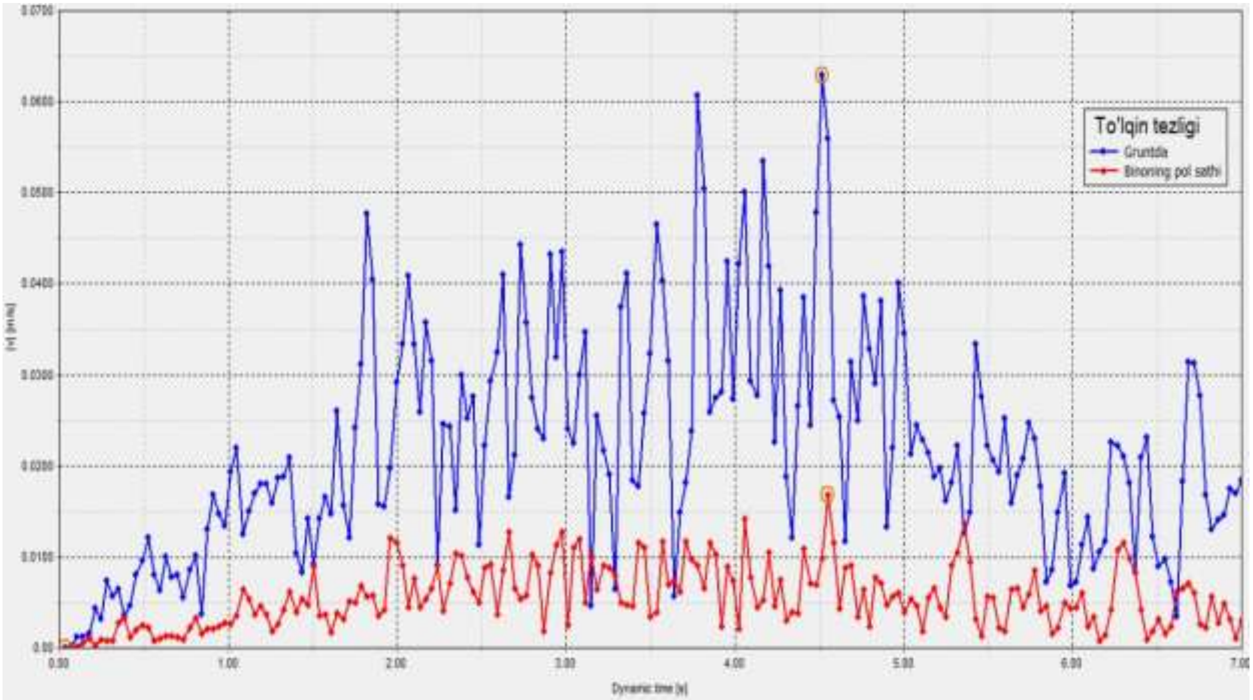

Figure 4: Graph of the Dependence of the Speed of Vibrations Occurring in the Ground and Building on the Movement of Freight Trains on Time

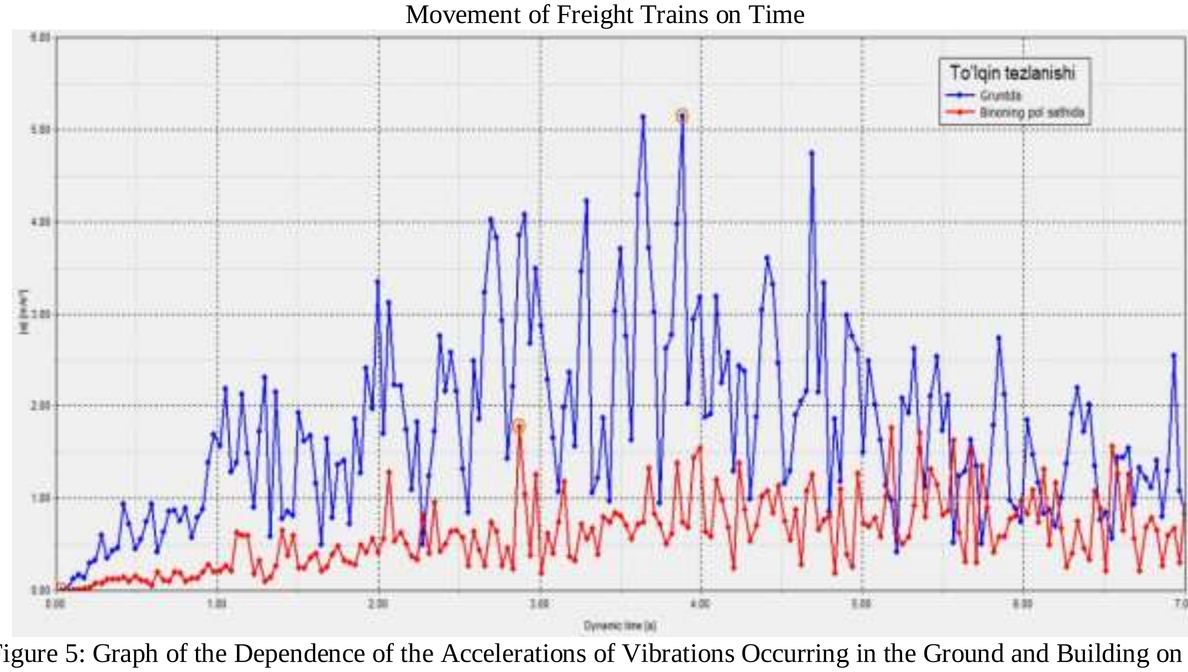

Figure 5: Graph of the Dependence of the Accelerations of Vibrations Occurring in the Ground and Building on the Movement of Freight Trains on Time

IV. Conclusion

The maximum value of the vibration velocity generated by the ground located at a distance of 20 m from the movement of freight trains, in accordance with the considered issue (Fig.4) reached 6.4 cm/s. At the same time, at the floor level of the building located at the same distance, the maximum wave velocity was 1.6 cm/s. That is, we can see that the vibration level in the ground created by the movement of two freight trains in parallel and in opposite directions is 4 times greater than in the building. Almost the same situation was observed on the wave acceleration graph (Fig.5).

Thus, from the results obtained, it can be said that the degree of vibration resulting from the movement of vehicles due to the connection of the ground environment with the foundation part of the building, i.e. due to the fact that the foundation of the building and the ground are heterogeneous, in the building structure is significantly less than in the ground.

The distribution of vibrations in soils and structures depends on their properties (modulus of elasticity, Poisson's ratio, density, etc.) the dependence is revealed. From this question, it can be said that studying and preventing the vibrations created by multi-lane motorways and the damage they cause is necessary.

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