BASED ON THE SOLUTION OF THE THREE-DIMENSIONAL DYNAMIC PROBLEM IN THE THEORY OF ELASTICITY, THE OPTIMIZATION OF GEOMETRIC DIMENSIONS FOR PASSIVE VIBRATION PROTECTION SYSTEMS IS PRESENTED

Mirsaidov Mirziyod[1], Yuldashev Fakhriddin Sharafitdin ugli[2]
[1] "Tashkent institute of irrigation and agricultural mechanization engineers" NRU
[2]Namangan Engineering and Construction Institute
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Abstract. *The problem of vibration propagation in soils caused by vehicle movement has been addressed. The finite element method has been employed, and radiation conditions have been applied at the boundaries. The effectiveness of passive vibration mitigation systems placed between the vehicle source and the protected structure has been investigated. Optimization of the geometric parameters of the screening trench has also been undertaken.*
Keywords: *theory of elasticity, vibration, soil, transport structure, vibration protection, trench, amplitude of vibrations.*

Introduction. The paper discusses the issue of vibrations propagating through soils during vehicle motion, using the finite element method and boundary conditions for radiation. It also considers the use of passive vibration protection systems between the vibration source and the protected object and optimizes the dimensions of a trench that can be used as a barrier. Elasticity and vibration theory are important considerations for the design of structures built on soil. The theories of elasticity and vibration play an important role in the design of structures, especially those built on soils. This is particularly relevant in Uzbekistan, where the rapid development of transportation infrastructure has led to an increased amplitude of vibrations caused by passing vehicles. These vibrations typically range between 5 and 100 Hz and can be noticeable to humans.

It is essential to consider measures such as deepening and vibration-proofing to protect buildings from such vibrations. Residential buildings should not be located closer than 40 meters to transportation facilities. If the buildings are located closer, it is necessary to calculate the level of vibration and develop vibration-reducing devices if necessary.

There are various methods to reduce vibrations propagating through soils from transportation structures. One solution to combat noise and vibration caused by vehicles in residential areas is the installation of ground screens. Vibration protection systems need to meet specific requirements, depending on their operational conditions. These include small overall dimensions, consistent vibration protection properties, easy manufacturing, reliable operation, and cost-effectiveness.

The vibration protection systems must maintain their elastic and damping capabilities despite changes in environmental factors such as temperature, humidity, and atmospheric conditions.

Requirements set maximum permissible vibration limits that must not be exceeded, as this would violate social, domestic, or environmental standards. These limits are determined without consideration of current feasibility.

Standards define the permissible vibration levels based on static methods, and compliance with these standards ensures the safety of personnel and equipment's proper operation and performance. This paper focuses on the theoretical investigation of ground vibrations induced by vehicle movement. Various vibration mitigation systems are proposed, including arrangements of obstacles between the source of disturbance and the protected structure. Passive vibration isolation techniques employ various types of barrier solutions, and the effectiveness of these systems has been examined. The analysis centers on the maximum displacement, velocity, and acceleration amplitudes caused by ground vibrations. The efficacy of the proposed trench is determined through a comparative analysis of its depth.

It is assumed that the dynamic forces transmitted through the railway tracks affect the underlying ground. In this regard, the impact of axle loads moving at a particular speed along the track axis is considered. We aim to determine the displacement and velocity of nodes in the soil, taking into account the physical and mechanical properties of the material.

To solve this problem, we will use the finite element method. A dynamic model of the area under consideration is depicted in Figure 1.

Methodology: To achieve this objective, a model has been developed using the Plaxis 3D software. The dimensions of the model are 100 meters wide, 100 meters long, and 20 meters deep. For this study, a lightly colored clay loam with a macroporous structure and high density was selected as the underlying soil. This soil also has low humidity and includes coarse-grained particles.

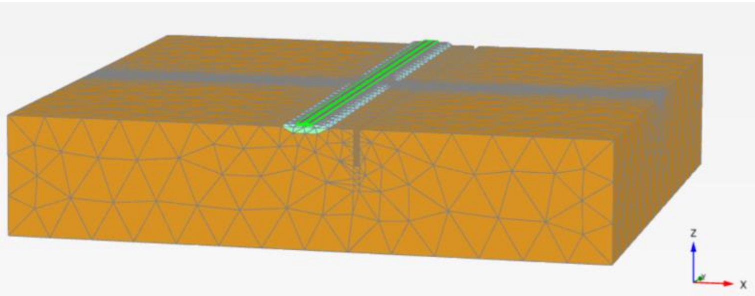


Figure 1. Dividing the Model into Finite Elements

The study area was discretized into 45071 finite elements and 79443 nodal points. The shape of the finite elements was chosen to be irregular tetrahedrons. The total number of equations in the system of second-order linear differential equations for the "soil-railway" system was 238329.

On the faces of the selected box, where there is no continuation of the medium, the corresponding boundary conditions are set [1, 2, 3, 4]:

$$\left.\begin{aligned}\sigma_x &= a\rho V_p\dot{u}\\ \tau_{yz} &= b\rho V_s\dot{u}\\ \tau_{zy} &= b\rho V_s\dot{w}\end{aligned}\right\}\quad \left.\begin{aligned}\sigma_y &= a\rho V_p\dot{v}\\ \tau_{xz} &= b\rho V_s\dot{w}\\ \tau_{zx} &= b\rho V_s\dot{u}\end{aligned}\right\}\quad \left.\begin{aligned}\sigma_z &= a\rho V_p\dot{w}\\ \tau_{xy} &= b\rho V_s\dot{u}\\ \tau_{yx} &= b\rho V_s\dot{v}\end{aligned}\right\}\qquad (1)$$

The basic equations of motion of a discrete system, under the action of a dynamic load obtained after dividing into finite elements, are expressed as follows:

$$[M]\{\ddot{u}(t)\} + [C]\{\dot{u}(t)\} + [K]\{u(t)\} = \{F(t)\} \qquad (2)$$

where the mass matrix, the damping matrix, which also takes into account the boundary conditions, the stiffness matrix, the load vector, the displacement vector, the velocity, the acceleration vector can change over time. $[M] - [C] - [K] - \{F\} - \{u(t)\} - \{\dot{u}(t)\} -$ вектор $\{\ddot{u}(t)\} -$ вектор

In numerical terms, the formation of an iteration over time is an important factor in the stability and accuracy of the computational process. Step-by-step integration of the system of equations is carried out according to the Newmark scheme [5]. The characteristics of the soil and the base of the ballast layer are given in Tables 1, 2 and 3.(2)

Table 1

Physical and Mechanical Properties of Materials

Parameter	Unit	Designation	Loam, light-brown, macroporous, dense, low-moist, with the inclusion of coarse-grained soils
General Properties			
Ground model	–	–	Linear-elastic
Material Behavior Type	–	–	Drained
The specific gravity of the soil is above the groundwater level	кН/м^3	γ_{unsat}	16
Specific gravity of the soil below the water table	кН/м^3	γ_{sat}	17
Mechanical Parameters			
Young's modulus (constant)	кН/м^2	E'_{ref}	60000
Poisson's ratio	–	$v/\ v_{ur}$	0,35

Table 2

Features of the ballast layer

Ballast layer / Features Laying	Protective layer	Balast
№	1	3
Ground model	Linear-elastic	Linear-elastic
Material Behavior Type	Drained	Drained
Specific gravity of soil above groundwater level - γ_{unsat} [kN/m3]	20	16
Specific gravity of soil below groundwater level - γ_{sat} [kN/m3]	22	17
Young's modulus - E [kN/m2]	70000	130000
Poisson's ratio - ν	0,3	0,15

Table 3

Physical and Mechanical Properties of Rail and Sleeper

Name		Unit	Rail	Sleepers
Share		[kN/m3]	78	25
Cross-section type			User – defined	Defined
Cross-sectional area		m2	0,0077	0,0513
Moment of inertia	I_2	m^4	0,00000513	0,000245
	I_3	m^4	0,00003005	0,02530
Young's modulus		ν	200 000 000	360 000

As part of our study, we simulate the motion of a train using harmonic force [6, 7, 8]. The phase of this harmonic force is 27.78 and the amplitude is 10 *m/s*, at a frequency of 10 *Hz*. The initial speed of the train on the section is set at 27.78 *m/s*.

We also introduce a time notation with a duration of 4 seconds.

Figure – 2. Characteristics for Train Movement

Results: Observation points were distributed at intervals of 5 meters to analyze the level of vibrations penetrating the ground.

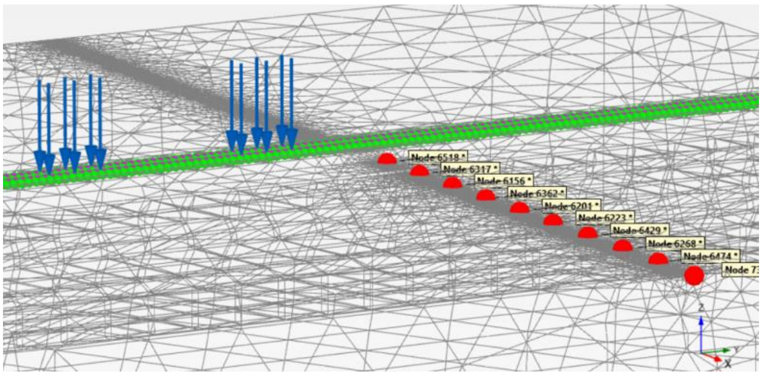


Figure – 3. Observation Points

The presented graphs demonstrate the effect of trench depth in the interval from 1 to 10 meters on the displacement, velocity and acceleration in the ground at a distance of 20 meters from the axis of the railway track.

The two scenarios are presented for comparison: the blue line represents the case where the observation point is at coordinates, with a trench located 8 meters after the railroad track, while the $x = 20,\ y = 50,\ z = 0$ red line depicts the situation without the trench.

Trench depth 2m

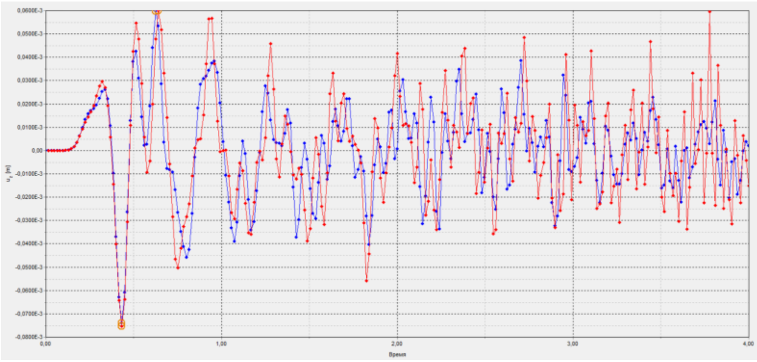
To analyze the dynamics of changes, two coordinate points were chosen: the first with coordinates, and the second, in the absence of a trench, with coordinates.

In the study of a trench located at a distance of 8 meters from the axis of the railway track and having a depth of 2 meters, the following values of displacement, velocity and acceleration at the specified point were obtained:$x = 20,\ y = 50,\ z = 0 x = -20,\ y = 50,\ z = 0$

Displacement – efficiency 1.79%; Speed – efficiency 62.13%;

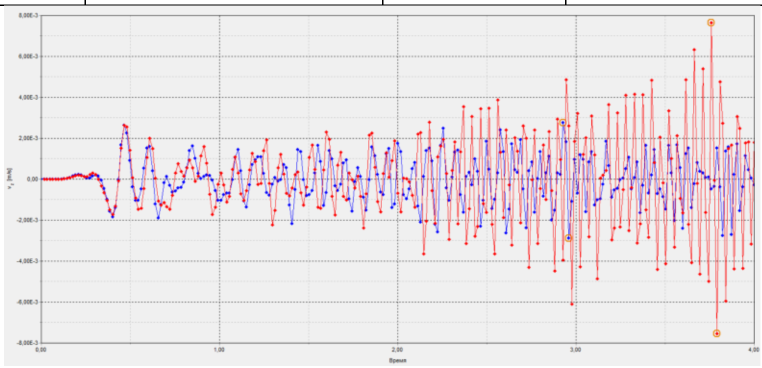
Displacement

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	u_z [m]	Time (s)	u_z [m]
0,432	0,00007411675	0,432	0,00007544359
0,624	0,00005977821	0,640	0,00005992758



Speed

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	v_z [m/s]	Time (s)	v_z [m/s]
2,928	0,00275768946	3,760	0,00764219044
2,960	0,00289379799	3,792	,00755099067



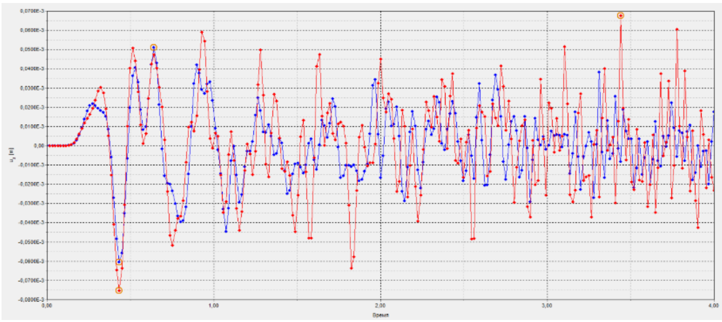
Trench depth 4m

To analyze the dynamics of changes, two coordinate points were chosen: the first with coordinates, and the second, in the absence of a trench, with coordinates. When examining a trench located at a distance of 8 meters from the axis of the railway track and having a depth of 4 meters, the following values of displacement, velocity and acceleration at the specified point were obtained:$x = 20,\ y = 50,\ z = 0x = -20,\ y = 50,\ z = 0$

Displacement – efficiency 19.75%; Speed – efficiency 35.33%;

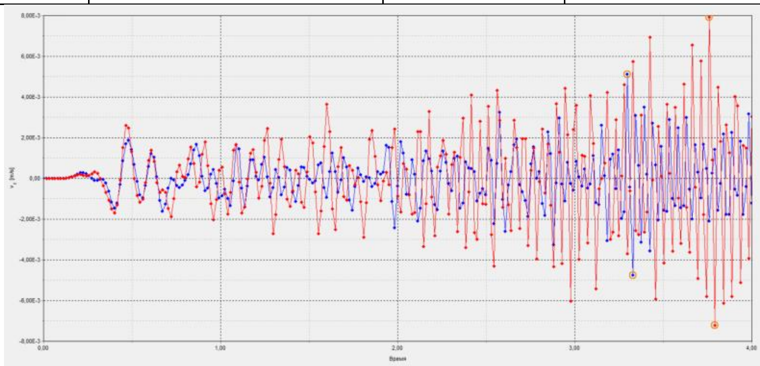
Displacement

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	u_z [m]	Time (s)	u_z [m]
0,432	0,00006045035	0,432	0,00007533396
0,640	0,00005108257	3,440	0,00006757169



Speed

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	v_z [m/s]	Time (s)	v_z [m/s]
3,296	0,00511898756	3,760	0,00791601930
3,328	0,00476976577	3,792	0,00720440783



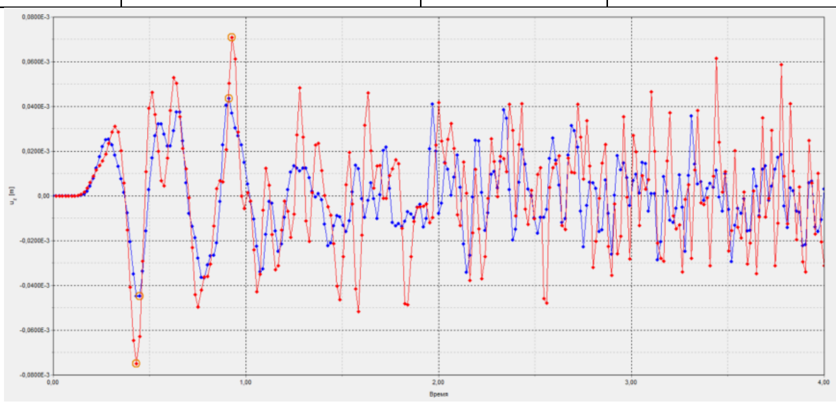
Trench 6m

To analyze the dynamics of changes, two coordinate points were chosen: the first with coordinates and the second, in the absence of a trench, with coordinates. In the study of a trench located at a distance of 8 meters from the axis of the railway track and having a depth of 6 meters, the following values of displacement, velocity and acceleration at the specified point were obtained:$x = 20,\ y = 50,\ z = 0x = -20,\ y = 50,\ z = 0$

Displacement – efficiency 40.24%; Speed – efficiency 49.75%;

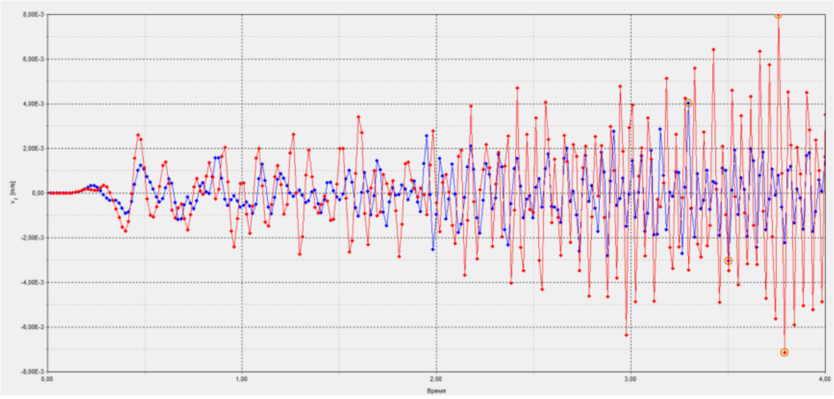
Displacement

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	u_z [m]	Time (s)	u_z [m]
0,448	0,00004480830	0,432	0,00007498244
0,912	0,00004364501	0,928	0,00007088215



Speed

There is a trench		Trench No	
20/50/0		-20/50/0	
Time (s)	v_z [m/s]	Time (s)	v_z [m/s]
3,296	0,00401495672	3,760	0,00799117051
3,504	0,00303548246	3,792	0,00714988541



Conclusion: Based on the facts provided, trenches are a very efficient protection device against surface waves caused by a variety of sources of vibration, particularly transportation infrastructure. It has been discovered that a trench between the vibration source and the protected item may absorb and diffuse vibrational energy. This ability is related to the depth of the trench, with deeper trenches resulting in greater absorption efficiency.

It is advised that trenches be actively included, in various configurations, while developing vibration-resistant systems. This strategy would considerably improve object protection while also providing increased comfort for surrounding settings and humans.

It is important to note that within sanitary norms and regulations, measurements and comparisons are predominantly conducted based on velocity parameters. This is because velocity serves as one of the primary indicators of vibrational impact, and evaluating its values allows for a proper assessment of potential risks to the environment and individuals.

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