REDUCTION OF VIBRATIONS PRODUCED BY METRO TRAIN TRAFFIC

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ABSTRACT: The trench can act as a ground vibration barrier and is a potential mitigation measure for low frequency vibration caused by subway train traffic. The study addresses more practical aspects in which the sidewalls of the trench are at an angle to a vertical line. The study uses a finite element model. The results show that in all the conditions considered, open trenches located at an angle on both sides protrude in the best way.
KEY WORDS: *Vibrations, soil, subway, frequency, elasticity theory, trench, amplitude.*

I. INTRODUCTION

In the design of modern cities in the world, the development of transport communications with all types of means of transport: highways, tramways, subway lines at different depths and other means plays an important role. The construction of 37 metro stations and lines in the world in the last 10 years requires the study of the distribution of vibrations generated by the movement of trains at the ground level. At present, it is important to study the negative impact of vibrations generated by the movement of trucks on people, buildings and structures as a result of increasing weight and speed [1].

In recent years, the world is conducting research aimed at protecting buildings and the population from vibrations caused by the movement of metro trains as a result of the design and commissioning of shallow metro tunnels. In this regard, in developed countries, including the United States, Britain, Russia, Germany, India, China and other countries, to improve effective methods to protect buildings and structures from man-made impacts, primarily from vibrations generated by vehicles and reduce vibration levels, affect people, buildings and structures. special attention is paid to the development of technology to reduce the level of vibration.

Vibration from train traffic is one of the most serious environmental problems. It occurs in two forms: oscillations in the range 1-80 Gts, which belong to the group of low-frequency oscillations, and affect the population living near metro lines in the form of oscillations affecting the whole body. Vibrations in the range 16-250 Gts fall into the category of high-

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frequency oscillations and are manifested in the form of noise inside and outside the building [2,3]. Vibration range is less than 40 Gts when surface rail trains run, especially on soft ground, causing significant vibration. Typically, the amplitude of the ground point velocity varies in the range of 0.1–1 mm / s, depending on the type of soil.

There are a number of measures to reduce vibration in the vicinity of railways [2-4], which can be done by changing the design of vehicles, changing the road or ground, or adding barriers of various shapes.

A study by British scientists Miller and Pursey [5] examined the distribution of vibrational energy propagating from a source in an elastic, isotropic half-space along longitudinal, transverse, and surface waves. The researchers estimate that 67% of the energy share falls on relay waves, 26% on transverse waves, and only 7% on longitudinal waves. It can be seen that 3/2 of the dynamic excitation energy falls on the relay waves and fades significantly along the length of the ground surface relative to the volumetric waves. This is why it is important to protect structures from relay waves in the first place.

Open trenches have long been considered a possible solution to protect against vibrations generated during the movement of cars and rail trains. In a study by Woods [6,7], the results obtained from field experiments of open trenches were analyzed. Based on the results, the coefficient of reduction of the vibration amplitude is given. The decrease in vibration amplitude depends on the depth of the trench, which is effective only when the depth is greater than 0.6 of the relay wavelength, whereas the effect of trench width on the vibration reduction efficiency has not been studied.

Recently, Alzavi El Naggar [8] examined open and soft material-filled trenches through field experiments and determined that the conclusions given by Woods [6] were correct. Selebi [9] also conducted a series of field experiments using oblitsovkali concrete as a filler. In a study by Kim et al. [10], rubber grid pads were used as fillers in the trench. An analysis of the results obtained by Massarsh using gas pads [11] is given in the source.

[12] cited research data from the placement of trenches close to tram and rail lines, for example, measurements showed that vibrations were reduced by 10 dB when the trench depth was 3.5 m.

A study by O. Yoshima [13] presented the results of piled trenches formed around high-speed train lines. The depth of the trenches was 4-10 meters. A study by J. Lang [14] found the following findings, that trenches with a depth of 1.5 m reduced vibrations generated on tram lines by 10 dB. In a study conducted by Francois et al. [15], an 8-meter protective screen was studied, in which the screen material was made of polystyrene, concrete, and bentonite, and these screens could even be placed on tram lines. The results obtained are not positive, which is explained by the fact that the barrier material is harder than the ground material. The main conditions for the reduction of soil vibrations are, of course, the physical and mechanical properties of the soil and the means of transport.

T.May and B.A.Bolt [16] studied the extinction efficiency of different waves falling into an open trench using a two-dimensional (2D) (ChEU) model. Ahmad and Al-Hussaini [17] also studied the efficiency of open trenches using the 2D model (ChEU-boundary element method) and extended the research to 3D. Research by R. Klein [18] has also focused on the study of the effectiveness of open trenches in 3D using the boundary element method. In the scientific work of S.D. Ekanayak [19], the efficiency of trenches filled with water and polystyrene fillers was studied using the finite element method.

It is known that the increase in the propagation velocity of the relay waves is caused by the non-uniformity of the soil and the pressure of the upper layer. It can be seen that the study of soil dynamics requires consideration of the displacement module, multilayer models, and the depth of location of the structure. The results of many published studies have been studied mainly in a single-layer environment. Homogeneous and layered soils have been studied by K.L. Leang [20-21]. It was found that in a soil where the first layer is softer and the next layer is harder, the efficiency of the trench is less than that of a homogeneous soil. Studies by Ahmad i Al-Husseini [17] also provide an analysis of the results obtained when using an open trench in layered soils.

By creating numerical models of the trench, many authors have studied the effects of vibration generated on the railway line. An open trench was studied by Yan and Hung [22] using a 2D model CHEU, which found that the Poisson's coefficient of the soil is important, and that the effectiveness of vibro protection depends on its size at depth.

Traditional methods of measures to reduce the seismic and external vibration effects of structures are mainly divided into two types:

1. Protection of objects from relay and lyav surface waves, which have a certain amount of energy;
2. Constructive solution, creation and application of seismic priority structures.

The aim of this study was to create a new direction of vibration barriers belonging to the first group. The following types of vibration barriers are mainly used:

1. Vertical barriers are designed to dissipate and reflect seismic wave energy on the ground surface. Includes open trenches or trenches filled with filler materials to protect against volumetric waves.
2. Horizontal barriers are mainly designed to protect against relay waves.
3. Discrete barriers are designed to reduce (scatter) seismic waves using pile fields. Large diameter circular piles are used to form such barriers. The main function of such a barrier is to dissipate seismic wave energy. For the first time, such barriers were used as a construction base in the construction of bridges in Vasco da Gama (Portugal) and Rion Antirion (Greece).

Most of the vibration energy is excited on the surface of the soil in the form of relay waves and propagated on the surface of the soil. Since these waves are weakened when moving away from the source in a horizontal direction, this can be done by placing the most effective vibration barriers between the vibration source and the protected object to reduce the vibration level in the ground.

When a trench is installed between a source and a protected object as a vibration barrier, the trench causes a certain part of the wave propagating from the source to return. This creates a split in its energy. Waves coming into the trench are divided into the following types of waves:

Relay waves, Relay waves passing through the trench, waves propagating back and forth through the body of the trench.
At present, much attention is paid in the world to the study of the distribution of vibrations generated by the movement of underground transport highways, ie metro trains, and to the improvement of their ecological condition. This is because the vibrations generated by the movement of trains on metro lines spread over sufficiently long distances, adversely affecting people living in areas close to the line and the devices located in that area.
Modern construction technology allows the application of the above-mentioned vibration load reduction measures.

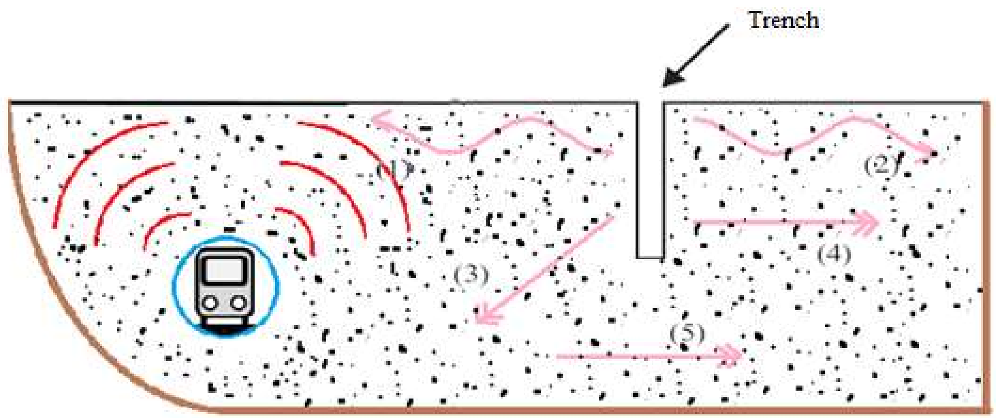

Figure 1. Waves coming into the trench, vibrations propagating through various rocks and soil under the trench

Measures to protect the building include:
- the use of vibration-reducing structures in the building and its foundation;
-Application of elastic elements-vibration insulation on the walls of the building, columns:
-vibration damping:
-use of vibrating screens (trenches) placed in the ground [23].

METHODS

In this study, the effectiveness of a trench, which is one of the measures aimed at reducing vibrations in the ground using a numerical modeling method, was studied, depending on its geometric parameters, location. The object of research was a circular metropolitan tunnel and the surrounding soil mass, the studied area was mathematically modeled by the method of finite elements. We have considered the problem of reducing the vibration generated in subway tunnels through shallow trenches.
The traditional view of open trenches used as vibration protection has been suggested in all literature in the form of a right rectangle, i.e. the side walls are at an angle of 90°. The main disadvantage of these trenches is their predominance when used for a long time, i.e. the inability of the side walls to maintain their condition. It is also much more difficult to create

such barriers. Therefore, in this study, non-traditional types of trenches were studied and their effectiveness in reducing the vibrations propagating on the soil surface was studied. In this study, the results of a trench with a normal sidewall of 90^0 were compared with the results of a vibration barrier with a sidewall of 45^0 and 60^0. In these three cases, the trench is located 8 meters from the axis of metropolitan symmetry, with a depth of 7 meters. We bring the issue to the flat problem of the theory of elasticity. When choosing an accounting scheme, we follow the following. Based on the results of many years of experiments, it is considered that the impact of vehicles is subject to the harmonic law, and since the vibration amplitude is very small, we consider the problem to be linear.

It should be noted that since the train is long enough and larger than the length of the building under consideration, and assuming that oscillations along the length of the tunnel occur in a single phase, the problem can be brought to the flat problem of the theory of elasticity. We determine the displacements formed by the action of a harmonic load pair placed on the bottom of a cavity bounded by a ring in a half-plane, taking into account the physical and mechanical characteristics of the material.

We adopt a right-angled coordinate system. We orient the X axis to the right along the free boundary of the half-plane. The Y-axis is directed downwards to the elastic medium (Fig. 2), the physical and mechanical properties of the medium are characterized by the elasticity constant, E - Yung modulus, $\boldsymbol{\nu}$ - Poisson's ratio, $\boldsymbol{\rho}$ - density. If the **Y** axis is passed through the center of the separated rectangular sphere, the problem becomes symmetric with respect to the **Y** axis. We use this property of the issue because the memory of computers is limited.

In this case, we replace the infinite half-plane with a finite sphere. At the boundaries of $\boldsymbol{AB}$, $\boldsymbol{BC}$ and $\boldsymbol{CD}$ (Figure 2), the following conditions are set to ensure that the waves tend to infinity.

From the condition of symmetry at the $\boldsymbol{AB}$ boundary,

when $\boldsymbol{x} = \boldsymbol{0} \quad \boldsymbol{u} = \boldsymbol{0}$ (1)

The boundary conditions at the $\boldsymbol{BC}$ and $\boldsymbol{CD}$ boundaries are respectively

$$\text{in } \boldsymbol{BC} \quad \left.\begin{array}{l} \boldsymbol{\sigma} = \boldsymbol{a}\cdot\boldsymbol{\rho}\cdot\boldsymbol{V_P}\cdot\dot{\boldsymbol{v}} \\ \boldsymbol{\tau} = \boldsymbol{b}\cdot\boldsymbol{\rho}\cdot\boldsymbol{V_S}\cdot\dot{\boldsymbol{u}} \end{array}\right\}, \qquad \text{in } \boldsymbol{CD} \quad \left.\begin{array}{l} \boldsymbol{\sigma} = \boldsymbol{a}\cdot\boldsymbol{\rho}\cdot\boldsymbol{V_P}\cdot\dot{\boldsymbol{v}} \\ \boldsymbol{\tau} = \boldsymbol{b}\cdot\boldsymbol{\rho}\cdot\boldsymbol{V_S}\cdot\dot{\boldsymbol{u}} \end{array}\right\}$$

In this case, $\boldsymbol{\sigma}$ and $\boldsymbol{\tau}$ are normal and experimental voltages; $\boldsymbol{u}$ and $\dot{\boldsymbol{v}}$ are projections of the velocities of the boundary points on the axes; $\boldsymbol{V_P}$ and $\boldsymbol{V_S}$ – are the velocities of the P and S waves; $\boldsymbol{a}$ and $\boldsymbol{b}$ are dimensionless parameters; $\boldsymbol{\rho}$ is the density of the material.

We use the finite element method to solve the problem. After dividing the given $\boldsymbol{ABCD}$ field into finite elements, we write the equation of motion as follows:

$$[\boldsymbol{M}]\{\ddot{\boldsymbol{u}}(\boldsymbol{t})\} + [\boldsymbol{C}]\{\dot{\boldsymbol{u}}(\boldsymbol{t})\} + [\boldsymbol{K}]\{\boldsymbol{u}(\boldsymbol{t})\} = \{\boldsymbol{P}(\boldsymbol{t})\} - [\Gamma]\{\dot{\boldsymbol{u}}\} \quad (2)$$

In this place: $[M]$, $[C]$и$[K]$- mass, damper and virginity matrices of the system, respectively, $\{u(t)\},\{P(t)\}$- vectors of node displacement and impact forces, $[\Gamma]$- matrix that takes into account the viscosity of the boundaries. The computational model of the problem-solving area is shown in Figure 2.

Suppose that the external force is given in the form of a harmonic function with frequency $\boldsymbol{\omega}$

$$\{\boldsymbol{P(t)}\} = \{\boldsymbol{P_0}\}\boldsymbol{e^{i\omega t}} \tag{3}$$

The reaction of the system for a stable process is as follows

$$\left.\begin{aligned} \{\boldsymbol{u(t)}\} &= \{\boldsymbol{\overline{u}}\}\cdot \boldsymbol{e^{i\omega t}} \\ \{\boldsymbol{\dot{u}(t)}\} &= \boldsymbol{i\omega}\,\{\boldsymbol{\overline{u}}\}\cdot \boldsymbol{e^{i\omega t}} \\ \{\boldsymbol{\ddot{u}(t)}\} &= -\boldsymbol{\omega^2}\{\boldsymbol{\overline{u}}\}\cdot \boldsymbol{e^{i\omega t}} \end{aligned}\right\} \tag{4}$$

Now if we put (3) and (4) in the equation of motion (2), we have a system of complex algebraic equations independent of time.:

$$[\boldsymbol{K}]\cdot\{\boldsymbol{\overline{u}}\} = \{\boldsymbol{P_0}\} \tag{5}$$

Where $\{\boldsymbol{\overline{u}}\}$ is the vector of oscillation amplitude; $\{\boldsymbol{P_0}\}$ is the amplitude vector of the acting force

We divide the allocated area into finite elements. As a result of the correct numbering of element nodes and field elements, the mass, virginity matrices in the problem are formed using the algorithm proposed by O. Zenkevich. Because the deformable system is symmetrical, they have a symmetrical and tapered appearance.

By solving the equation (5) by Gaussian method, the coordinates of the constant complex amplitude vector of the system are determined.

$$\{\boldsymbol{\overline{u}}\} = \{\boldsymbol{\overline{u}_1},\ \boldsymbol{\overline{u}_2}, \boldsymbol{\overline{u}_3}, \dots, \boldsymbol{\overline{u}_N}\} \tag{6}$$

In this case, $\boldsymbol{N}$ is the degree of freedom of the industry. Real displacements are determined by the following formula.

$$\{\boldsymbol{u(t)}\} = \boldsymbol{Re}\{\boldsymbol{\overline{u}}\}\,\boldsymbol{\cos\overline{\omega}t} + \boldsymbol{Im}\{\boldsymbol{\overline{u}}\}\,\boldsymbol{\sin\overline{\omega}t} \tag{7}$$

The amplitude of oscillations on the surface of the ground is fading and non-monotonous as the winding moves away from the axis of canvas or metropolitan symmetry.

The problem-solving algorithm and computational program were compared with the experimental results presented in the study.

The following figures show a graph of the change in the modulus of amplitude at the free surface of the soil under the influence of the kinematic load applied in the direction of the Y axis to the tunnel with a circular cross section. Here the abscissa represents the distance of the tunnel to the axis of symmetry. The ordinate, on the other hand, shows the change in the amplitude values at the free boundary of the half-plane. In obtaining these results, the value of the modulus of elasticity of the half-space was assumed to be $E = 2{,}85\cdot 10^8\ Pa$, the Poisson's ratio $\nu = 0.35$. In this study, the tunnel was located at a depth h = 8 m above the free surface level of the soil.

The separated rectangular sphere is divided into 1164 triangles, which are connected by 640 nodes. This allows the allocated finite half-space to be replaced by a system with 1280 degrees of freedom. The finite element sizes were selected based on the findings of the study [24].

Analysis of the obtained results shows that the vibration amplitude disappears without monotony at all frequencies as it moves away from the axis of tunnel symmetry along the free surface of the soil.

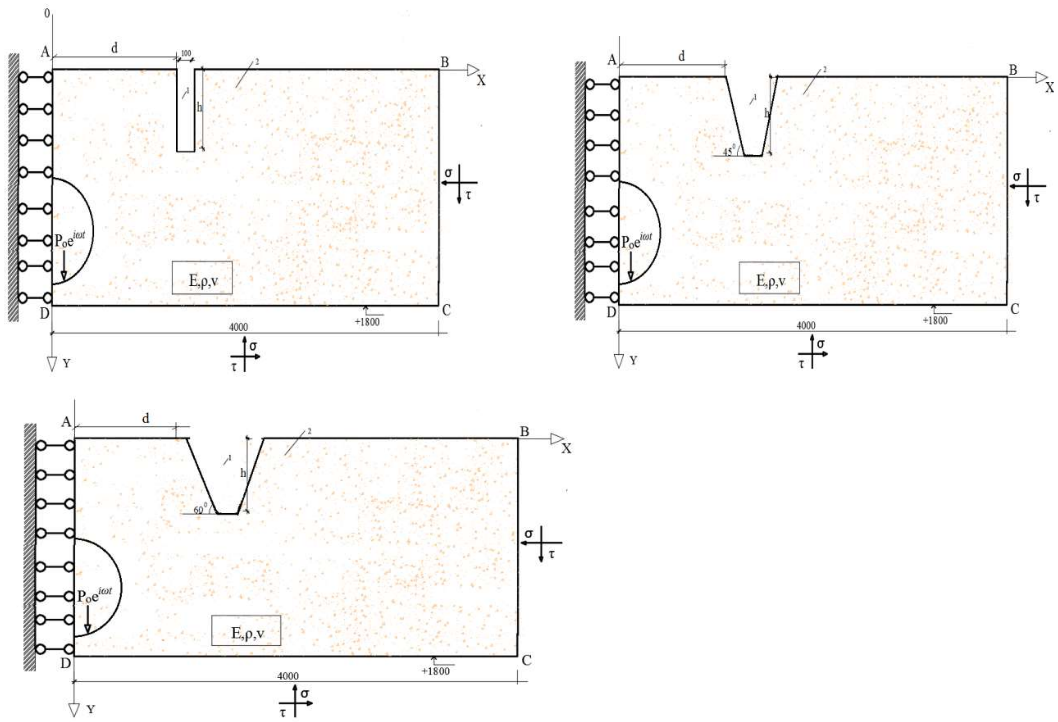

Figure 2. Computational schemes of trenches with side walls at different angles

RESULTS AND DISCUSSION

The winding of the amplitudes of vibrations on the surface of the ground has a fading and non-monotonous character as it moves away from the axis of metropolitan symmetry. The results of the study are presented in tabular and graphical form below.

Table 1

The propagation of vibration taking into account the trenches where the side walls are at different angles

Frequency	Length of the area under inspection, m	Vertical displacement of characteristic points in the	Vertical displacement of characteristic points in a trench with	Vertical displacement of characteristic points in a trench with	Vertical displacement of characteristic points in a trench with

		trenchless state, cm	side walls 45^0, cm	side walls 60^0, cm	side walls 90^0, cm
1	2	3	4	5	6
frequency at 20 Gts	10.00000	0.27255	0.00408	0.00176	0.16730
	20.00000	0.18135	0.00118	0.16982	0.11417
	30.00000	0.04262	0.06290	0.07078	0.02097
	40.00000	0.00924	0.04577	0.04297	0.00668
frequency at 25 Gts	10.00000	0.26298	0.00753	0.00201	0.22902
	20.00000	0.08476	0.00064	0.06597	0.05014
	30.00000	0.03055	0.03281	0.05411	0.03642
	40.00000	0.01266	0.00672	0.01161	0.01412
frequency at 30 Gts	10.00000	0.20455	0.00619	0.00230	0.14766
	20.00000	0.03108	0.00051	0.02455	0.01765
	30.00000	0.04995	0.02130	0.04545	0.03227
	40.00000	0.00887	0.01482	0.00735	0.00748
frequency at 35 Gts	10.00000	0.13716	0.00475	0.00163	0.07606
	20.00000	0.04066	0.00031	0.00939	0.03699
	30.00000	0.03249	0.02005	0.02273	0.01408
	40.00000	0.01119	0.00266	0.00864	0.00693
frequency at 40 Gts	10.00000	0.08141	0.00318	0.00104	0.06291
	20.00000	0.04774	0.00016	0.01613	0.04295
	30.00000	0.00906	0.00818	0.00342	0.00602
	40.00000	0.00534	0.00236	0.00381	0.00383
frequency at 45 Gts	10.00000	0.06960	0.00233	0.00085	0.05225
	20.00000	0.03392	0.00015	0.00943	0.03069
	30.00000	0.00728	0.00077	0.00339	0.00817
	40.00000	0.00162	0.00139	0.00077	0.00169
frequency at 50 Gts	10.00000	0.07156	0.00187	0.00064	0.03996
	20.00000	0.02232	0.00015	0.00475	0.01908
	30.00000	0.00667	0.00207	0.00388	0.00632
	40.00000	0.00150	0.00088	0.00097	0.00143

Figures 3-8 show graphs constructed based on the results obtained when three different trenches were used. The graph shows a graph of the results obtained when the trench is not used by a continuous line, and a graph of the results obtained when the trench is used by a dotted line.

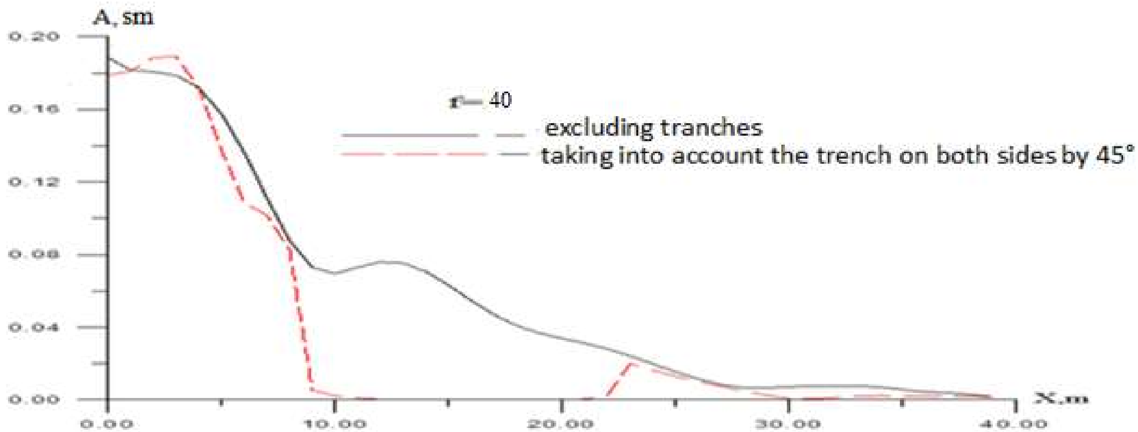

Figure 3. Variation of vibration amplitudes on the surface of a trench with a side slope of 45^0 inclination at a frequency of f = 40 Gts

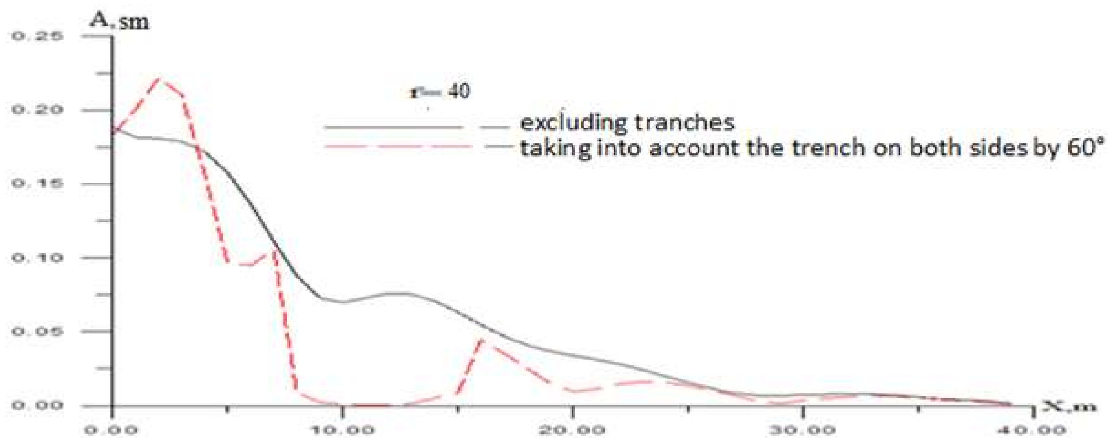

Figure 4. Variation of vibration amplitudes on the surface of a trench soil with side slopes of 60^0 inclination at a frequency of f = 40 Gts

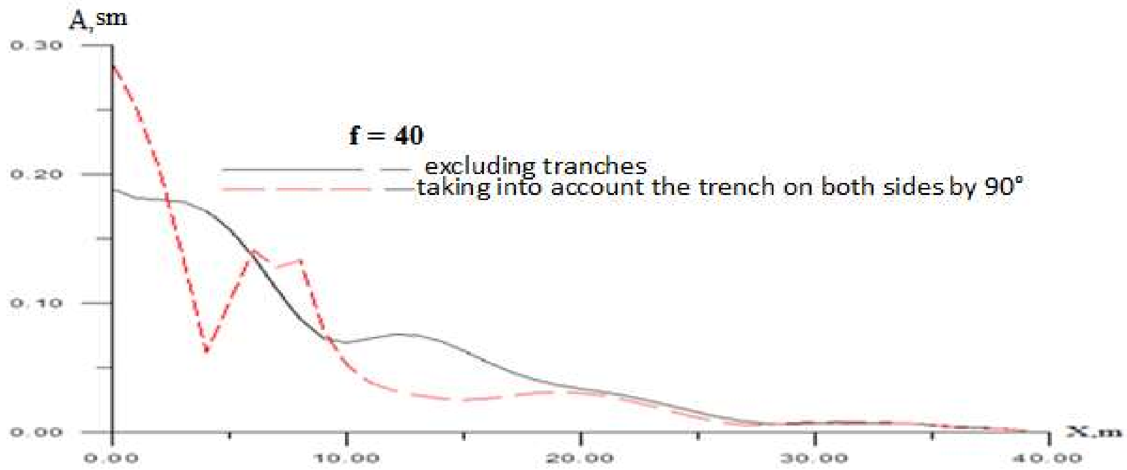

Figure 5. Variation of vibration amplitudes on the surface of a trench soil with side slopes of 90^0 inclination at a frequency of f = 40 Gts

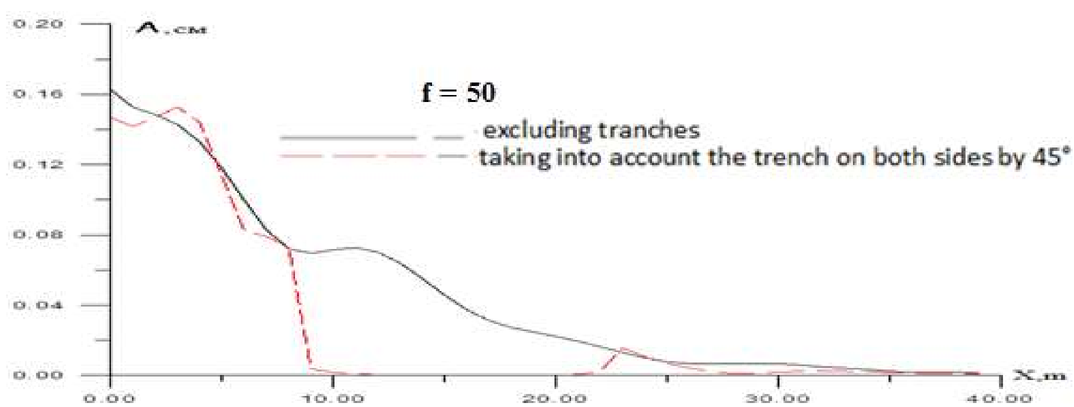

Figure 6. Variation of vibration amplitudes on the surface of a trench with a side slope of 45^0 inclination at a frequency of f = 50 Gts

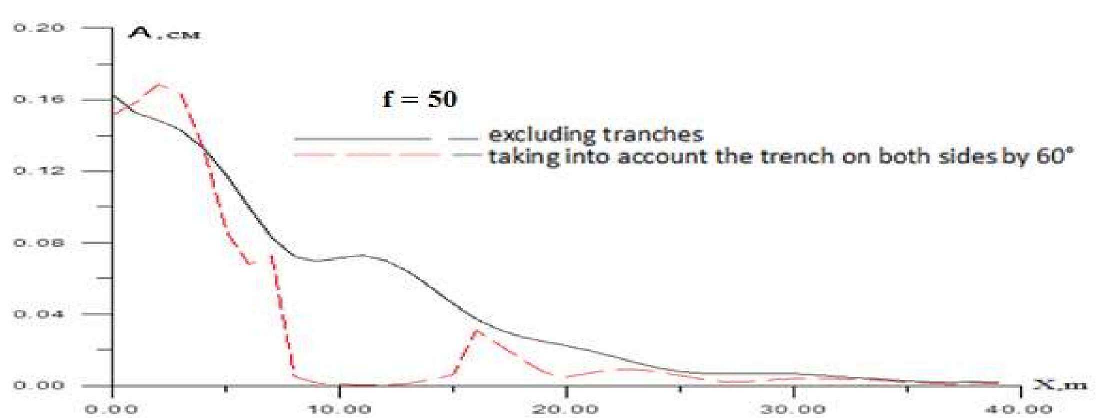

Figure 7. Variation of vibration amplitudes on the surface of a trench soil with side slopes of 60^0 inclination at a frequency of f = 50 Gts

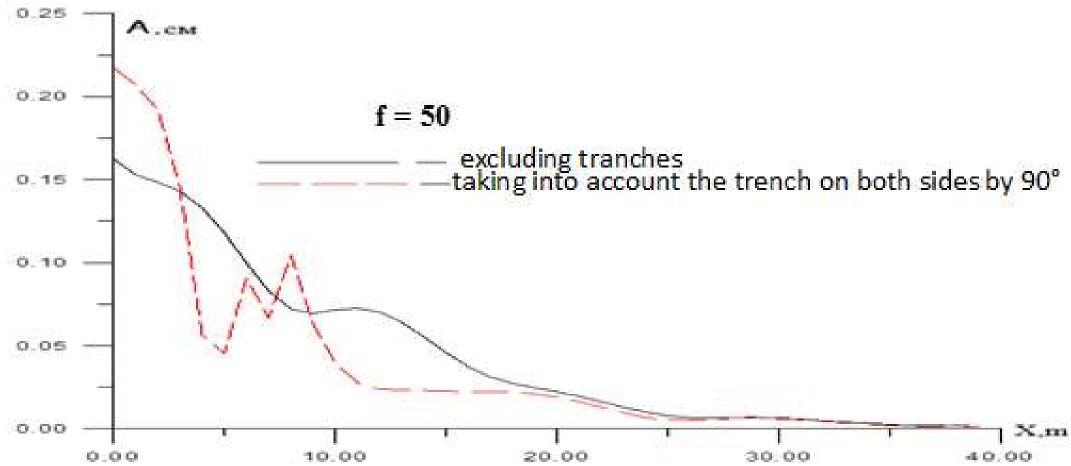

Figure 8. Variation of vibration amplitudes on the surface of a trench soil with side slopes of 90^0 inclination at a frequency of f = 50 Gts

CONCLUSIONS

1. The use of an open trench has a good effect in reducing vibrations;
2. As a result of increasing the distance between the open trench and the axis of metropolitan symmetry, its efficiency decreases;
3. When open trenches are used, the attenuation rate of vibrations at the ground level is found to be reduced by 20-50% compared to the case without trenches. Open trenches (45^0 and 60^0) with side walls at different angles have been shown to be more efficient than vibro-barriers with side walls that are vertical, i.e. 90^0.
4. Vibration reduction will create favorable conditions for people from the areas around the metropolitan tunnel, defined by sanitary norms..

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