International Journal of Emerging Engineering Research and Technology
Volume 6, Issue 9, 2018, PP 1-10
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Vibrations of an Elastic Half-Space Containing a Pedagree with Account of Internal and Wave Dissipation of the Oscillation Energy

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ABSTRACT

The work deals with the vibrations of a half-space containing various barriers under the action of surface Rayleigh waves. The problem is solved by the finite element method. The aim of the paper is to substantiate the methods for studying the dynamic stress state of underground rectangular structures in a deformable massif.

Keywords: *oscillations, half-spaces, surface wave, finite element method, barrier*

INTRODUCTION

Underground structures of the system are one of the main components of oil and gas and petrochemical industries, therefore their safety depends to a large extent on the technical condition of the pipelines. Under the most unfavorable operating conditions are underground structures of the pump and compressor systems, because they experience significant vibrations, both from the side of machines and from the side of the transported environment. These effects are of a complex nature and are caused by pressure pulsation, flow failure, direction change and speed of its movement, acoustic resonances, interaction of flows at the pipeline branch points and other factors. In a number of cases, the vibration effect is transmitted to the supports by the construction through the ground [1,2].When designing underground pipeline systems, it is practically impossible to take into account the interaction of the factors listed above, to assess the level and parameters of the vibration effects on the constructed system and, consequently, to determine the resource of safe operation of pipelines.

The resource of underground structures experiencing vibratory action is determined by the level of cyclically changing stresses, which lead to accumulation of damages in the most stressed areas and subsequent fatigue failure or leakage of joints. Therefore, to predict the resource, it is necessary to be able to properly evaluate the stress-strain states of underground constructed systems, which simulates the body located in a deformable half-space. Various methods are used to solve dynamic problems. These are, of course, difference schemes, the method of generalizing relaxation, the method of integral relations, the method of splitting, cells, and others. In recent years, one of the most effective numerical methods for solving boundary value problems in continuous media mechanics, the finite element method [3,4], has become very popular. It has a simple physical interpretation of basic computing operations, as well as the presence of computer programs, which provides a high degree of automation of labor-intensive operations of drawing up and solving the system of equations. This method has a number of varieties. The choice of this or that version of the method is largely determined by the nature of the problem and, to a large extent, by the "taste" of the researcher, although some ideas have already been developed about these methods. For example, as pointed out in [5], the difference method leads to a large, memory loading of the machine memory, which is a certain disadvantage in solving large-scale systems. But the difference method gives the value of functions, which oscillates less. There are other features of this method. Many studies are based on the finite element method. It should be noted that with the development of the finite element method, its connection with other approximate methods became apparent. At present, it is believed that all the approximation processes used in solving problems described by differential equations are essentially a single whole [6]. However, when using these or other schemes, various computer algorithms of formation are realized that solve the system of equations. The problem in simple cases (when a cylindrical cavity or body) is analytically solved, but the numerical realization of the results obtained allows significant errors in the calculations [7].

THE APPLICATION OF THE FINITE ELEMENT METHOD

The problem is solved numerically, by the finite element method. The basic idea of the finite element method is that continuous quantities (displacements, stresses, pressures, etc.) are approximated by a discrete model on a finite number of subdomains. For this purpose, a design area is selected, which is discretized by a finite number of elements. These elements have common nodal points and in aggregate approximate the initial design area. A continuous value is approximated on each element through nodal values using interpolation polynomials. Interpolation polynomials approximate continuous functions in mathematical equations describing the physical process under study. Then the discrete model constructed in this way must satisfy the boundary (boundary and initial) conditions of the problem. Satisfaction of these conditions is carried out using various approaches known in the finite element method. Discretization of the computational domain Ω on the elements is the first step towards the solution of the problem. This step is very important, because a bad or imperfect discretization can lead to erroneous results. When choosing the sampling, the main attention is paid to the following rules: - smaller sampling should be performed in areas where large gradients of values are expected, and in places where the boundary of the computational domain changes; - to achieve rational numbering of elements and nodes of the sampled area, it is necessary to use sequential numeration of nodes when moving in the direction of the smallest body size. After the sample area has been sampled, the calculated parameters have been selected and entered into the program, it is possible to obtain a solution of the selected class of problems. It is necessary to test the problem on a model problem for this class of problems. After the task is tested, you can proceed to complicate the calculation area, boundary conditions, etc. The smaller the differences in the model problem and the specific technical task, the greater the reliability of the solution obtained. Therefore, the need for rigorous analytical solutions will always be relevant. Any calculation should be duplicated by a calculation with a smaller sampling area. Depending on the difference in the results of such comparative calculations with a continuous value, one can judge the ratio of the results of the calculation scheme used. For the numerical solution of the problem, an introduction Ω, which is a finite part of the half-space P; It is necessary to set and solve problems for the finite domain

$$\Omega = \Omega_1 + \Omega_2 + \Omega_3,$$

Where Ω_1 -cross-sectional area of buried building; Ω_2 - area of selections area, Ω_3 - internal surface of a buried structure.

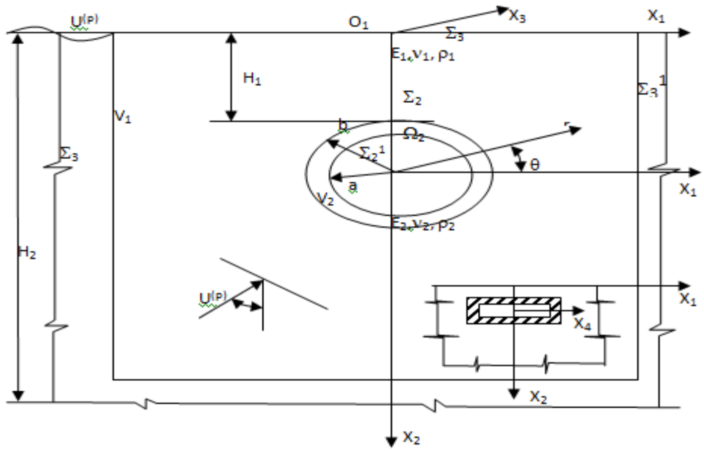

Fig1. *Calculation scheme*

Let us consider the linear vibrations of an elastic half-space containing a rectangular obstacle under the action of a harmonic wave. For non-stationary problems, the principle of causality is required as the study conditions: in a medium, there must be no displacements outside the region bounded by the leading edge of the waves coming from the oscillation sources. Boundary conditions on the boundary of the calculated region for fission dynamic (seismic) effects. When solving problems for infinite elements from an infinite half-plane, studies are made of the calculated domain of finite dimensions. The region under investigation is discretized and it becomes necessary to set up such conditions on the boundary that would not manifest itself on the results of the solution due to reflection, which occurs with long-term dynamic influences. Some researchers propose to consider solutions only a certain distance from the boundary of the region [8.9], considering that the reflection of the wave does not have time to reach this site in the considered period of time. Sometimes it is advisable to introduce additional artificial damping into the calculation area, increasing as we approach the boundary [10]. In Lismer's paper [11], boundary conditions were proposed for a finite computational domain, allowing one to simulate an infinite medium. These boundary conditions pass the wave through the boundary of the calculated region without reflection, that is, the so-called standard viscous boundary is obtained. The tasks of the standard viscous boundary are carried out by replacing the reaction of the parts of the half-plane that are not pressed into account by distributed loads σ and τ, calculated formulas:

$$\sigma=\alpha\rho C_p u; \qquad \tau=b\rho C_s \upsilon; \qquad (1)$$

where u and υ - the velocity of the points on the boundary of the body, respectively, along the coordinates X_1 and X_2 ,α and b - unlimited options; ρ- material density; $C_p$and C_s–the velocity of the longitudinal and transverse waves, respectively. Similar conditions can be considered as setting a viscous damper on the boundary. For solving non-stationary problems, it is applied to the stimulated parts of the region and to the conditions [12, 13]. To solve the problem, steady oscillations of cylindrical bodies, in the selected part, the Lismer conditions [11].

In the absence of external loads $\sigma_{01}=0$ The problems of natural oscillations of a mechanical system. External loads can be changed by harmonic law, i.e. $f(t)=P_0e^{i\omega t}; -\infty \prec t \prec \infty$. Then the problems of steady oscillations of the mechanical system are solved. The results for the action of an arbitrary load can be obtained using the Duhamel integral:

$$\sigma_k(t)=\frac{\partial}{\partial t}\int_0^1 P(T)\overline{\sigma_k}(t-T)dt; \qquad (2)$$

where P(t)-impact of an arbitrary kind; $\sigma_k(t-\tau)$- solution obtained by the action of (2). The problem is considered in the following statements.

- Investigation of the stress-strain state of a cylindrical body with an internal radius, and in external b (Figure 1), located in an unbounded elastic medium, under the action of elastic or non-stationary waves.
- Investigation of the proper oscillation of a cylindrical body with an internal radius a and an external b located at a distance H from the free surface of the half-space. Investigation of the stress-strain state of a cylindrical body with an internal radius a and with an external b (Figure 1) with the action of elastic harmonic waves.
- Find the stress - strain state of a cylindrical or rectangular body and its surrounding medium under the action of elastic non-stationary waves.

MATHEMATICAL FORMULATION OF PROBLEMS.

For the mathematical formulation of problems, the principle of possible displacements is used, according to which the sum of the work of the active and mass forces acting on the system, with possible displacements is zero

$$\begin{aligned}\delta A = &-\int_{\Omega_0}\sigma_{ij}\delta\varepsilon_{ij}d\Omega-\int_{\Omega_1}\sigma_{ij}\delta\varepsilon_{ij}d\Omega-\int_{\Omega_2}\sigma_{ij}\delta\varepsilon_{ij}d\Omega-\\ &-\int_{\Omega_0}\rho_0\ddot{\vec{U}}\delta\vec{U}d\Omega-\int_{\Omega_1}\rho_1\ddot{\vec{U}}\delta\vec{U}d\Omega-\int_{\Omega_2}\rho_2\ddot{\vec{U}}\delta\vec{U}d\Omega+\\ &+\int_{\Sigma_1^1+\Sigma_2+\Sigma_3}\sigma_{ij}v_j\delta u d\sum+\int_{\Omega 2}\vec{f}\delta\vec{v}d\Omega+\int_{\Sigma_2}\vec{p}\delta\vec{U}d\sum=0\end{aligned} \qquad (3)$$

Here $\vec{U}$, $\sigma_{ij}, \varepsilon_{ij}$ - displacement vectors, components of stress and strain tensors; $\delta\vec{U}$; $\delta\varepsilon_{ij}$-variations of displacements and deformations; ρ_1, ρ_2, ρ_3 – density of the material of the elements of the system under consideration, ν_J –direction cosines of the outer normal; $\vec{f}$ -mass force vector; $\vec{p}_1$-vector of external forces applied to the area $\sum_2$. To solve the problem (3), we need boundary and initial conditions that are automatically satisfied for the variation formulation. The mathematical formulation of the Eigen vibration problem involves the variation equations (1), which are written in the form

$$\delta A = -\int_{\Omega} \sigma_{ij}\delta\varepsilon_{ij}\, d\,\Omega - \int_{\Omega} \rho_n \ddot{\vec{U}}\delta\vec{U}\, d\,\Omega = 0 \,. \qquad (4)$$

Need to find w and the corresponding own form $\vec{U}^*$, satisfying the equation (4) for any $\delta\vec{U}^*$.

In the absence of external influences, the natural oscillations of the mechanical system are considered. In this case, solutions (3) are sought in the form

$$\vec{U}(\vec{x},t) = \vec{U}^{*}(\vec{x})\exp(-i\omega t) \qquad (5)$$

where $\omega = \omega_R - i\omega_I$ и $\vec{U}^* = \vec{U}_R^* - iU_I^*$ - complex quantities.

If a hole is acted upon by a harmonic wave, then the displacements $\vec{U}$ points (the selected region) is searched as a sum [8,9].

$$\vec{U}(\vec{x},t) = \vec{U}_0(\vec{x},t) + \vec{U}^*(\vec{x},t), \qquad (6)$$

Where $\vec{U}_0(\vec{x},t)$ - which you want to define.

The formulation of the problem for the desired function includes the variational equation

$$-\int_{\Omega} \sigma^*_{ij}\delta\varepsilon_{ij}\delta\Omega_1 \; -\int_{\Omega_1} \sigma_{ij}\delta\varepsilon_{ij}\delta\,\Omega \; -\int_{\Omega_2} \sigma_{ij}\delta\varepsilon_{ij} d\Omega \; +\omega^2 \int_{\Omega_1} \rho_1{}^{11}U^*\delta U d\Omega \; +\omega^2 \int_{\Omega_2} \rho_2{}^{11}U\delta U d\Omega -$$

$$-i\omega \int_{x+\sum_3+\sum_3^1+\sum_1} \sigma^*_{ij}\nu_j\delta u^*_j d\sum \; + \; \int_{\sum_3} \vec{p}_1\delta\vec{U} d\sum = 0 , \qquad (7)$$

radiation conditions at

$$\vec{x} \in \sum\nolimits_3 \text{ и } \sum\nolimits_3^1: \quad \frac{d\vec{U}^*}{dx_1} \pm \frac{i\vec{U}^*}{c} = 0 \qquad (8)$$

$$\vec{x} \in \sum\nolimits_1^1 \quad ; \quad \vec{U} = 0 \quad .$$

It is necessary to determine the time-periodic solution of the variational problem (8), which satisfies the boundary conditions for any $\delta\bar{U}^*$. To solve the initial-boundary value problem (3) - (8), we use the method of finite elites formed in displacements.

OF COURSE - THE ELEMENTAL EQUATIONS OF THE MECHANICAL SYSTEM.

The FEM procedure involves a transition from differential dependencies, for individual finite elements, to a global system of equations for the entire array. For linear problems of non-stationary interaction, this global system in the matrix form usually has the form:

$$[M]\{q''\} + [S]\{q'\} + [K]\{q\} = \{F\}, \qquad (9)$$

Here [M],[K],[S] – respectively, the mass, damping and stiffness matrix of the system; $\{q''\}$, $\{q'\}$, $\{q\}$ - acceleration, velocity and displacement vectors; {F} – vector of external loads; [p] – matrix of external damping. Matrices of masses, damping and stiffness of the finite element system composed of the corresponding matrices of elements

$$[M] = \sum_{i,j=1}^{n}[M_{i,j}];\; [S] = \sum_{i,j=1}^{n}[S_{i,j}];\; [K] = \sum_{i,j=1}^{n}[K_{i,j}].$$

The stiffness matrix of an element has the form

$$[K_{i,j}] = \int_S [B]^T[D][B]dxdy \,,$$

where

$$[B]=\lfloor B_i, B_j, B_m \rfloor; [B_i]=\begin{Bmatrix} b_i, 0, \\ 0, c_i \\ c_i, b_i \end{Bmatrix} |2\Delta,$$

$$[D]=\frac{E(1-\nu)}{(1+\nu)(1-2\nu)}\begin{vmatrix} 1 & \frac{\nu}{1-\nu} & 0 \\ \frac{\nu}{1-\nu} & 1 & 0 \\ 0 & 0 & \frac{1-2\nu}{2(1-\nu)} \end{vmatrix}$$

The matrix of masses of an element is defined by the relation

$$[M_{i,j}]=\int_S \rho[N_i]^T[N_j]dxdy \cdot$$

A matrix damping element - the ratio

$$[S_{i,j}]=\int_S \nu[N_i]^T[N_j]dxdy,$$

Where: ν – coefficient of damping. The mass matrix for a triangular element can be represented in the following form

$$[M_{ij}]=\rho Ah\begin{vmatrix} \frac{1}{6} & 0 & \frac{1}{12} & 0 & \frac{1}{12} & 0 \\ 0 & \frac{1}{6} & 0 & \frac{1}{12} & 0 & \frac{1}{12} \\ \frac{1}{12} & 0 & \frac{1}{6} & 0 & \frac{1}{12} & 0 \\ \frac{1}{12} & 0 & \frac{1}{12} & 0 & \frac{1}{6} & 0 \\ 0 & \frac{1}{12} & 0 & \frac{1}{12} & 0 & \frac{1}{6} \end{vmatrix},$$

Where ρ – the density of the material; A is the area of the element; ћ – thickness of the element.

Analytical methods for solving linear systems of ordinary differential equations (9) are well known. However, because of the high order of the matrices, their practical implementation is possible in large part only by approximate numerical methods. The most popular are the finite-difference relations of one or another modification. Dimension of the matrix [ρ] corresponds to the dimension of the matrix of the system [M], [S], [K], nonzero terms which refers to the established viscous boundary and for points located on the vertical boundary and are equal to

$$P_{2i}=\rho_i \cdot C_{Si} \cdot l_i; \quad P_{2i-1}=\rho_i \cdot C_{pi} \cdot l_i, \quad (10)$$

where ρ_i – the density of the material near the i-point under consideration, C_{si},C_{pi}– the velocity of transmission respectively of the transverse and longitudinal waves in the material at about í–ů points;l_i-the average distance between the dampers are installed around í–ů points. For the points of the horizontal boundary in equation (9), the indices need to be interchanged. The discretization of the considered region is carried out with the help of triangular elements [14].

METHOD OF DISCRETIZATION IN TIME IN PROBLEMS OF ELASTIC WAVES ON HOLES

In the problems of nonstationary action of elastic waves on the hole, the duration of the process is sufficiently small and direct integration is the most effective method for solving them. Equations of equilibrium (9) for direct integration are satisfied not at any time, but at some given (sufficiently small) time interval Δt. The study of the accelerations, velocities, and displacements of the system is considered within a given time interval. The transition from differential equations with time-dependent coefficients to equations with constant coefficients is carried out by using the approximation of speed and acceleration by finite-difference expressions in displacements or velocities. The method of direct integration is divided into methods of explicit integration, where the velocities, accelerations and displacements are calculated from the equilibrium equation at the time (the method of central differences).

Computing was done for 1020 triangular finite elements. The system of inhomogeneous complex algebraic equations was solved by the Gauss method, with the following initial data: υ_1=0.20, υ_2=0.33, H/R=2.10, 15. E_1/E_2= 0.1. The results of the calculations are shown in Fig. 2. Fig. 2 shows the results of calculations for H/α= 3 (curve 1) and 4 (curve 2). It can be seen that with increasing depth, the voltage decreases noticeably. With increasing depth of deposit (H/α→∝) the values of the numerical results tend to the result of solving the problem of diffraction of waves on a body located in an infinite medium (Fig. 2). Thus, the numerical solutions obtained show that the depths of the deposit (H/α) when the stress is deformed under the action of elastic waves, depends on the parameters H /*a*and 2*a*/λ. The oscillation of the elastic half-space of the rectangular contour containing the barriers under the action of harmonic waves is investigated. It is established that the depth of the deposit affects the stress-strain state of the body. Concentration of voltage with increasing depth of deposition and wavelength approaches the static value of voltage. The developed calculation technique allows one to study the natural oscillations of piecewise homogeneous deformable systems in an elastic medium with allowance for internal and wave dissipation of energy. The dimension of the matrix [p] corresponds to the dimensionality of matrices of the system [M], [S], [K] whose zero terms belong to the established standard viscous grenade and for points on the vertical boundary are equal

$P_{2i}=\rho_i*C_{si}*l_i$; $P_{2i-1}=\rho_i*C_{pi}*l_i$;

Where ρ_i – the density of the material near the considered i - μ' points; C_{si}, C_{pi} – the velocity of transmission respectively of the transverse and longitudinal waves in the material in the vicinity of i - u points; l_i – the average distance between the damped by about i - u points. For the points of the horizontal boundary in equation (10), the indices need to be interchanged. The matrix differential equation (9) can be written out in finite-difference form using the Newmark method [15]

$$(\frac{1}{\Delta t})^2[m](q^{j+2}-2q^{j+2}+q^j)+(\frac{1}{2\Delta t})[S](q^{j+2}-q^j)+[k][\beta q^{j+2}+(1-2\beta)q^{j+2}+\beta q^j]= \\ =\beta F^{j+2}+(1-2\beta)F^{j+2}+\beta Fq^j \tag{11}$$

Where j, j+1, j+2 – past, present and future values of variables; β-parameter chosen from the conditions of numerical stability and accuracy.

In this example, it is adopted β=1/3;

Thus we obtain a system of linear algebraic equations, which is solved by a time step.

From Newmark's Proposition [15], the following relations were used to determine the displacement and velocity:

$$\{\dot q\}^{j+1}=\{\dot q\}^j+\tau[(1-\gamma)\{\ddot q\}^j+\gamma\{\ddot q\}^{j+1}]; \\ \{q\}^{j+1}=\{q\}^j+\tau\{\dot q\}^j+\tau^2[(\frac{1}{2}-\beta)\{\ddot q\}^j+\beta\{\ddot q\}^{j+1}]; \tag{12}$$

Where γ characterizes the circuit damping γ=1/2 at which there is no attenuation.

The relation (10) can be represented in the form of an algebraic system

$$[A]\{q\}^{j+1}=\{R\}^j\ ,$$

where $$\{R\}^j=\{F\}^j+(\frac{2}{(\Delta t)^2}[M]=[K])\{q\}^j-\frac{1}{(\Delta t)^2}\{q\}^{j-1} \tag{13}$$

implement a typical procedure for computing the variable vector {q(t)}.

Then, in the case of diagonal matrixes of elements' masses, the matrix of the system is also diagonal. The time integration step is assumed to be equal to $0{,}125\cdot10^{-4}$ with a minimum period of free oscillations of the element $6{,}28\cdot10^{-4}$ s. Time stepped out of the condition that its change to a change in voltage and speed in the nodes.

The written technique allows to effectively solve equation (13) through the Gaussian elimination procedure at each time step. This path is more effective than iterative methods. When implementing the account, the basic properties of the system's stiffness matrix are used: symmetry, positive definiteness, ribbon. All this contributes to the minimum use of main memory and computer time. When solving the problem of natural oscillations, a combination of MCE and the Mueller method is used. The reliability of the constructed algorithm demonstrates, for example, the solution of the problem of the diffraction of harmonic waves on a cylindrical cavity, for which there is an analytical solution (test). The initial data for solving the problem using the program contain the following information: the applied impact in the form of accelerations (an accelerogram) or (instantaneous, impulsive or time-dependent); elastic and dynamic characteristics of the structure and the environment; The parameters describing the sampling of the chosen calculation area are presented in a special way. As a result of solving the problem, using these programs, we obtain vertical and horizontal accelerations, velocities and displacements, stress and strain tensor components for elements of the finite element grid of the computational domain. Of course, elemental discretization of the computational domain is carried out by triangular elements.

NATURAL OSCILLATIONS OF PIECEWISE HOMOGENEOUS DEFORMABLE SYSTEMS WITH ALLOWANCE FOR INTERNAL AND WAVE DISSIPATION OF ENERGY

Let us consider the natural oscillations of the medium in the presence of a cylindrical hole.

The mathematical formulation of the problem of natural oscillations involves variation equations, which are written in the form

$$\delta A = -\int_{\Omega} \sigma_{ij}\delta\varepsilon_{ij}dv + \omega^2 \int_{\Omega} \rho_1 u'' \delta U d\Omega = 0 \qquad (14)$$

With the help of the developed FEM algorithm, the variation problem (14) reduces to the complex algebraic eigen value problem

$$([k] - i\omega[c] - \omega^2[M])\{q\} = 0, \qquad (15)$$

where $[M],[c],[k]$ – respectively, the mass matrix, the damping of the stiffness of the system; $\{q\}$ – displacement vectors; To determine the natural frequencies of oscillations, it is necessary to find the eigen values, which are the roots of the frequency equations (15). All eigen values can be determined using Mueller's iterative method [16].

Researcher	Number of nodes	Frequency ω_i(rad / s)					
		1	2	3	4	5	6
I.A. Konstantinov	25	29,73	68,42	79,94	124,21	156,14	173,52
	36	29,1	68,01	75,33	122,21	152,43	176,00
	144	1441	68,43	73,61	114,23	161,47	168,83
L.A. Rozin	144	27,53	68,45	73,67	114,4	161,47	168,63
Author of the work	144	27,45	64,88	73,87	125,37	161,41	173,41
	78	28,56	66,75	77,79	121,72	187,8	188,22
	45	28,67	69,39	76,17	131,8	166,4	207,11

The Mueller iterative method is a quadratic interpolation scheme that gives fast convergence in the neighborhood of the solution root even for a rough first approximation. The reliability of the approach adopted in the work for finding the natural frequencies is shown in the example of the problem of oscillations of a plate in the form of a rectangular triangle of 100 m and a base of 75 m, considered by IA Konstantinov and LA Rozin (table). It is also shown that the values of the vibration frequencies become stable with the number of nodes 60-80; further entrainment the number of nodes does not lead to a significant refinement of frequencies, although considerable computer time is expended.

As an example, let us consider the natural oscillations of a cylindrical layer in an elastic medium. The problem reduces to solving a system of homogeneous algebraic equations (15). From the condition for the existence of a solution of homogeneous algebraic equations, it is necessary to determine the equations (15) must be equal to zero. The frequency equation is solved by the Mueller method, and the value of the left-hand side of (15) for each iteration is determined by the Gauss method with the separation of the principal element. If we assume that $\upsilon_1=\upsilon_2$, $\rho_1=\rho_2$, $E_1=E_2$.We obtain the results of calculating the natural vibration frequencies of a cylindrical hole in an elastic medium. The results obtained coincide with the results obtained in [12] with a difference of up to 10% (N = 150, v = 0.20). Now we study the process of propagation of vibration in deformable media from the rectangular body of Figure 2. To a rectangular body we apply a harmonic load, then we obtain an algebraic system of complex equations.

$$([k] + 2\pi i\omega[c] - 4\pi^2\omega^2[M])\{U\} = \{P\} \ . \qquad (16)$$

Here $\{U\}$ - vector of complex amplitudes of oscillations of the system; $\{P\}$ is a vector of external load amplitudes, ω-frequency of external load. A computer calculation was made for 1020 triangular finite elements. In Figure 2. Curves-modules of the displacement amplitudes of the body's vertical oscillations are presented under the action of a load with a unit amplitude. The following initial data were accepted

υ_1=0.36, υ_2=0.20, ρ_1/ρ_2 =0.85, E_1/E_2= 0.01, H/α= 2.0

It can be seen from Figure 2. That as the frequency and distance increase, the displacement amplitudes decrease. Consequently, in the case of diffraction of plane harmonic waves in a half-space, there are always surface surface waves. Their amplitude on the surface X_2=0 depends on the depth of the tunnel. With increasing H, it decays exponentially. An analysis of this solution allows us to draw a practical conclusion. Extensive underground structures in seismically hazardous areas are like generators of surface waves in earthquakes, transforming partially falling seismic waves into secondary surface waves. The presence of such in homogeneities on the path of a seismic wave affects the formation of the surface Rayleigh wave. The shape of the cross-section of cylindrical bodies is of no fundamental importance for this phenomenon. The obtained numerical results (Figures 3, 4, 5) show that the depth of the deposit H/α noticeably on the stress-strain state of the body. Under the action of surface Rayleigh waves, as the depth of deposition increases, the value of the dynamic stressed-deformed state approaches the static result (Figure 6). In the region of long waves, the depth of deposition has a particularly strong effect on the stress-strain state. With increasing depth of deposit $(H/a \to \infty)$ the values of the numerical results tend to the result of solving the problem of diffraction of waves on a body located in an infinite medium (Figure 7). Thus, the numerical solutions obtained show that the depths of the deposit (H/a) when the stress is deformed under the action of elastic waves, depends on the parameters H/a and $2a/\lambda$

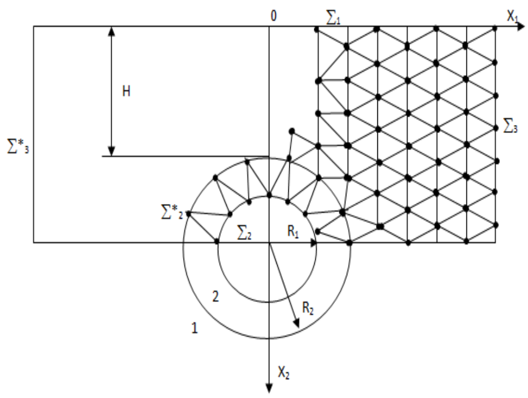

Fig2. *Calculation scheme.*

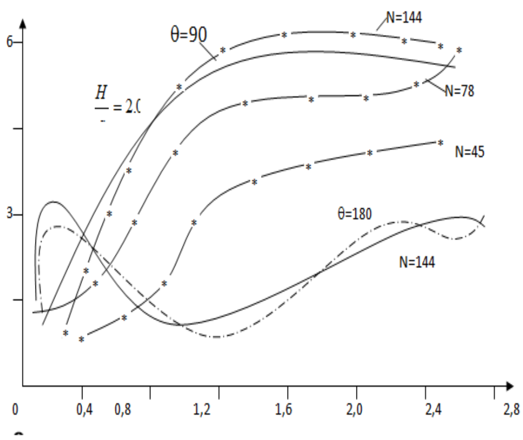

Fig3. *Changing the ring voltage as a function of the frequency of external disturbances.*

------ N=288 -·-·-·- N=160

—— Mao,Pao

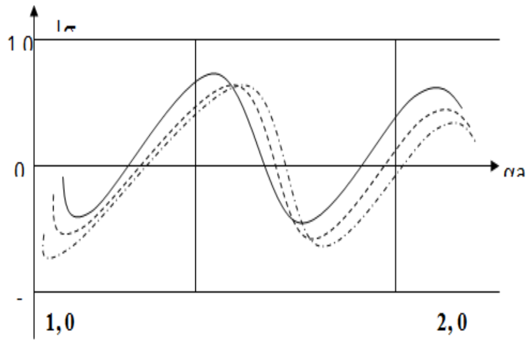

Fig4. *The change in the ring voltage as a function of the frequency of external perturbations.*

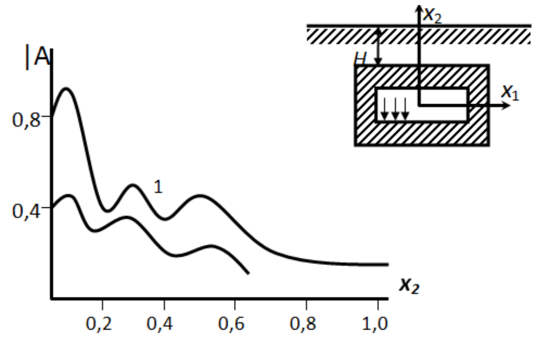

Fig5. *Measurement of displacements as a function of distance x2 at 1.w=0.2, 2.w=0.8.*

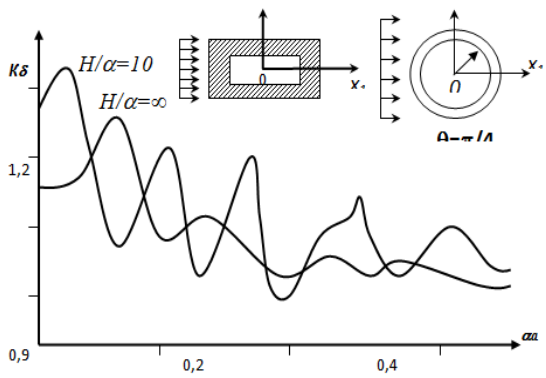

Fig6. *Addiction σ0* on a free body contour from the values of the parameter α/λ.*

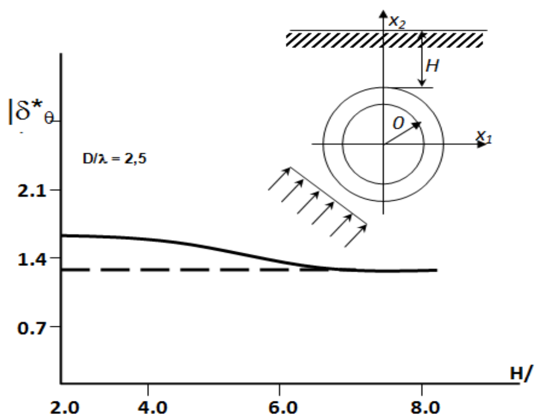

Fig7.

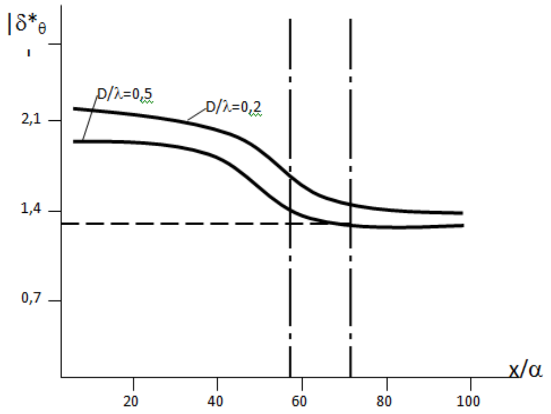

Fig8. *The results of theoretical studies*

In the static theory of underground structures, the effect of aridity is more or less, the experimental was investigated [1, 2, 3].In the dynamic case, the effect of the arch is experimentally almost not investigated. The main published works are of a theoretical nature. Conducted a series of experimental studies to assess the distribution and effects of arches, found that the pressure acting on the length of the rate does not depend on the structure of the distribution of stress in a layer of soil located above its surface at a distance of two or three of its width results from one of the experiments presented in Fig. 8. the vertical component of the pressure, σ_v depth Z = H without effect of strength (ie hydrostatic load) was $\sigma_{vh.}$ As can be seen from the figure, for a layer of soil thick in Z<0,4(Z_b>2s) on the stress distribution diagram, there is no decrease in the vertical component due to the absence of a lasting effect. But with Z = H, i.e. in the area of the soil located outside the mediocre proximity to the rectangular insert, □v is not less than 10% σ_{vh}.

On some problems of dynamic arch arches of buried underground structures.

In the static theory of underground structures, the effect of archedness more or less, was experimentally investigated in [13]. In the dynamic case, the arch effect is almost not investigated by experimental means.

The main published works are of a theoretical nature. In [14], we present a number of experimental results, studies with the aim of estimating the distribution and effects of parchedness. It was found that the pressure acting on the length of the bet does not depend on the structure of the distribution of stress in a layer of soil located above its surface for a distance of two or three of its width. Solving the equilibrium equations for the distribution of the vertical component of the pressure forces per unit length of the section, we obtain:

$$\sigma_v = \frac{b(\gamma - 2c/b)}{2k_r tg\varphi}[1 - e^{-2k_r(z/b)tg\varphi} + qe^{-k_r(2z/b)tg\varphi}]$$

Where φ- angle of internal friction; c-angle of cohesion of soil; b- geometrically parameter; γ - constant parameter (0<γ<1), k_r-empirical coefficient.

For soil type dry sand, which does not have the forces of adhesion (c = 0), the vertical component of the pressure σ_{vw} on the elastic strip for the section at a large depth of the soil approaches its maximum value. At a thickness of a ground more 2,5b , σ_{vw}=by/(2k,tgθ) mixing of the rectangular insert does not affect the structure of the voltage distribution for a given depth of soil. Until now, the phenomenon of archedness, which arise when loads acting on the upper surface of an elastic structure, has been considered. With the dynamic calculation of the arched appearance, different degrees of dependence on the wavelength and the properties of the soil, the existence of an arched phenomenon for bodies in a half-space is numerically determined. The analysis of numerical results (Fig. 2) will estimate, to the phenomenon of arcs, the following inequalities

$$\frac{Z}{D} > \gamma(0{,}5e)^{\lambda/b} + Z_0 \qquad (22)$$

Where Z_0 – the value of the arched effect in the static problem; D is the geometric parameter (internal surface diameter),λ - wavelength.

Expression (22) is the ratio of the dynamic arctic effect of "Safarov". If relations (22) are satisfied in the calculation of subterranean constructions, methods for calculating the deep foundation of structures are applied. Thus, the following conclusions are drawn:

- On the basis of the variational method (MCE), the stress-strain state of a cylindrical layer (aperture) under the action of harmonic waves was investigated. It is established that the maximum concentration of stress is allowed for long waves. The effects of dispersion become dominant as the wavelength decreases;

- The arch effect is established under the dynamic influence of underground structures.

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Citation: *Safarov Ismail Ibrahimovich, Kuldoshev Nasriddin Urinovich, Marasulov Abdurahim Mustafoevich. (2018). "Vibrations of an Elastic Half-Space Containing A Pedagree With Account of Internal and Wave Dissipation of the Oscillation Energy". International Journal of Emerging Engineering Research and Technology, 6(9), pp.1-10*