Features of interaction of the construction works with a layered base under the influence of seismic loads

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Abstract. The paper considers the problem of dynamic joint work of a structure with a base during seismic actions propagating from the level of a mountain massif through a layered group medium in the direction of the structure. The main attention is focused on the extreme case of vertically propagating transverse seismic waves, their reflections and transitions through the layered medium of the soil. Wave equations of elasticity theory are used to describe dynamic processes.

1 Introduction

The problems of wave propagation in continuous multilayer systems attract the attention of numerous researchers in our country and abroad [1, 2]. This is due to the fact that in many fields of science and technology, it is increasingly necessary to face the need to calculate stress and strain fields that occur in layered bodies with different rheological properties when exposed to various kinds of dynamic loads. Dynamic problems of dissipative (viscoelastic) dynamical systems are solved by methods of mathematical physics [3, 4]. The complexity of their solution is explained by many reasons, for example, rheological properties of real media (anisotropy, viscosity, creep, plasticity, non-homogeneity, etc.), which causes a wide variety of schematized models to describe real phenomena in one or another approximation and does not allow creating a single mathematical model of a mechanical system [5-7]. Despite the large number of mathematical models of a mechanical system, mathematical methods for solving problems have been developed mainly for such systems as acoustic, whose elastic motions are described by linear differential equations [8-10].

2 Materials and methods

The problem of dynamic joint work of the structure with the base under seismic influences propagating from the level of the mountain massif through the layered group medium in the direction of the structure and transitions through the layered soil medium is considered (Figure 1).

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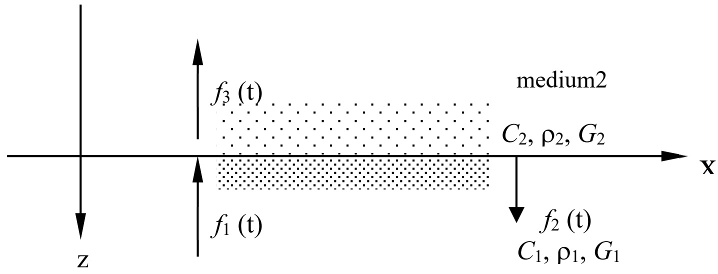

Fig. 1. The transition of transverse waves of the boundary of the soil layers.

Attention is focused on the extreme case of the action of vertically propagating transverse seismic waves, their reflection. The equations of motion of wave propagation have the following form:

$$\frac{\partial^2 \vartheta}{\partial t^2} - c^2 \frac{\partial^2 \vartheta}{\partial z^2} = 0, \; c = \sqrt{\frac{G}{\rho}} \tag{1}$$

Where G – shift modulus; ρ – the density of the material. The solution of the differential equation (1) is sought in the following form [11]

$$\vartheta(z,t) = f_1\left(t - \frac{z}{c}\right) + f_2\left(t + \frac{z}{c}\right) \tag{2}$$

On the border $z = 0$: $\vartheta(o,t) = f_1(t) + f_2(t)$, i.e. $f_1(t) = f_2(t)$, then $\vartheta(o,t) = 2f_1(t)$. Figure 2 shows that a transverse wave from one medium to another does not exactly pass, i.e.

$$f_2(t) = f_1(t)\beta_{21}; \; f_3(t) = f_1(t)\alpha_{21}$$

Or in the general case

$$\alpha_{ik} = \frac{2}{1 + \frac{\rho_k c_k}{\rho_i c_i}}; \; \alpha_{ki} = \frac{2}{1 + \frac{\rho_i c_i}{\rho_k c_k}} \quad \beta_{ik} = \frac{\frac{\rho_i c_i}{\rho_k c_k} - 1}{\frac{\rho_i c_i}{\rho_k c_k} + 1}; \; \beta_{ki} = \frac{\frac{\rho_k c_k}{\rho_i c_i} - 1}{\frac{\rho_k c_k}{\rho_i c_i} + 1}.$$

The solution is designed for an n – layer system. The changes in time of incoming and outgoing waves from the granule layers, on the rock and on the ground surface are investigated. For one and two-layer systems, the solution is adapted for the computational point of view of a less difficult version, in which changes in the time of oscillations at the level of the rock mass and on the ground surface are investigated.

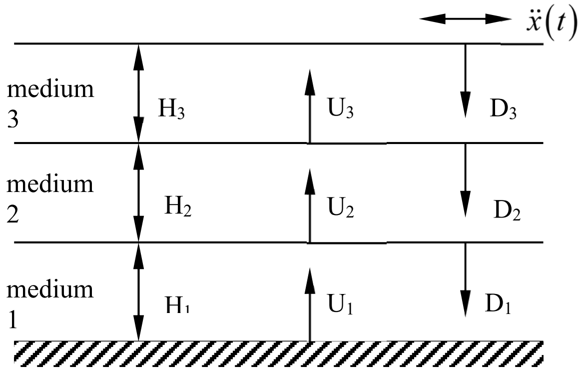

Fig. 2. The transition of transverse waves of a multilayer medium.

The construction structure is a rigid foundation with horizontally acting seismic movement, designed for two versions. In the first case, the vibrations of a rigid foundation are solved in the classical way, i.e. separately when loaded by seismic acceleration on the ground surface $\ddot{x}(t)$

$$\ddot{x}(t)=\alpha_{01}\sum_{j=1}^{j_{\max}}2\beta_{01}^{j-1}e^{-\varepsilon H_1(2j-1)}\ddot{x}_0\left(t-\frac{H_1(2j-1)}{C_1}\right)$$

The second version is that the loading seismic acceleration $\ddot{x}(t)$ also takes into account the actions of secondary reflected disturbances in the ground environment caused by the oscillation of the structure. The solution of foundation vibrations is carried out using the equations

$$\begin{gathered} m\ddot{u}(t)+k_{11}\dot{u}(t)+k_{12}\dot{\phi}(t)+C_{11}u(t)+C_{12}\phi(t)=-m\ddot{\alpha}(t) \\ I\ddot{u}(t)+k_{21}\dot{u}(t)+k_{22}\dot{\phi}(t)+C_{21}u(t)+C_{22}\phi(t)=0 \end{gathered} \tag{3}$$

where $k_{11},k_{12},k_{21},k_{22}$ – damping coefficients; $C_{11},C_{12},C_{21},C_{22}$ – the coefficient of rigidity.

3 Results and analysis

Equations (3) are linear equations and are easily solved analytically. The calculation results are presented in Table 1.

Table 1. Change of movement, speed and acceleration depending on.

ξ	$u\ m\cdot 10^{-3}$	$\dot{u}\ m/s\cdot 10^{-1}$	$\ddot{u}\ m/s^2$	$\phi\ grad\cdot 10^{-4}$
0.30	0.206	0.047	0.238	0.128
0.15	0.198	0.058	0.256	0.136
0.0	0.210	0.079	0.288	0.146

The following initial data were used for numerical calculations: $\Delta t=0.005s$; $\varepsilon=0.005$; $j_{\max}=5.$ Thus, the paper has developed a method for calculating a multilayer foundation under the influence of seismic waves.

Vibrations of the base are one of the main tasks that have a comprehensive technical application, such as: foundations for walls, various types of construction of road surfaces and airfields, etc. The vertical and torsional vibrations of the elastic half-space were considered in [1-3]. In this paper, solutions of vertical and torsional vibrations of a viscoelastic half-space are proposed when applying the idea of complex elastic modules. For a vertical dynamic load uniformly distributed over a circular contact cavity with radius a, i.e. for boundary conditions on the surface of a half-space at $z=0$:

$$\mathrm{P_z = P_0e^{iwt}},\ 0<r<a;$$

$$\sigma_z=0;\sigma_{rz}=0,\ r<a.$$

Assume that the vertical normal load P_1 is distributed over a circular cavity according to the static contact problem, hence the boundary conditions:

$$\sigma_z=\frac{Pe^{iwt}}{2\pi a(a^2-r^2)^{1/2}}\ \text{for}\ 0<r<a,$$

$$s_z=0;s_{rz}=0;\ \text{for}\ r>a.$$

The vertical dynamic deflection w on the surface of the half - space has the following form:

$$\frac{wG_a}{P} = \frac{1}{2\pi}\int_0^\infty \frac{\sin\eta J_0(\eta\frac{r}{a})}{f_1(\eta_1\Omega_1\delta_1\xi)} d\eta e^{iwt}. \tag{4}$$

In equations (4)

$$f_1(\eta,\Omega,\delta,\xi) = \frac{-(1+i\delta)^2\left[\left(2\eta^2 - \frac{\Omega^2}{1+i\delta}\right)^2 - 4\eta\sqrt{\eta^2 - \frac{\Omega^2}{1+i\delta}}\right]}{\Omega^2\sqrt{\eta^2 - \frac{\Omega^2\xi}{1+i\delta}}}$$

$\Omega = wa/c_s$; $\xi = \frac{1-2\nu}{2(1-\nu)}$; $C_s = \sqrt{\frac{G}{S}}$; $J_1(\eta)$ *and* $J_0\left(\eta\frac{r}{a}\right)$- Bessel functions of the first and zero order.

Integral functions in the relations are complex functions of the real variable η, and have no discontinuities in the domain of integration, and improper integrals converge. Vertical oscillations of mass m with a circular contact plane – diameter a on a viscoelastic half-space are described by differential equations of motion.

$$m\frac{d^2w}{dt^2} + R(t) = P_0 e^{iwt} \tag{5}$$

Where $R(t)$- the reaction of the viscoelastic half-space and w, in the case of a rigid foundation block, represents the average dynamic deflection at the contact of the cavity. The average dynamic deflection from the load and reactions of the base has the following form.

$$|W| = \frac{P_0}{G_a}\sqrt{\frac{W_R^2 + W_j^2}{(1+b\Omega^2 W_R)^2(b\Omega^2 W_I)^2}}$$

Phase angle

$$\psi_w = arctg\frac{W_I}{W_R + b\Omega^2(W_R^2 + W_I^2)},$$

$$b = m/\rho a^3, \qquad \Omega = wa/C_S.$$

In a similar way, with torsional oscillations of a viscoelastic half-space with a linear distribution of shear stresses on a circular cavity of radius a, a conclusion is made for the tangential displacement u_0 on the surface of the half-space in the form of the following relation

$$U_0 = -\frac{\tau_0 a}{G}\int_0^\infty \frac{J_2(\eta)J_1(\eta\frac{r}{a})}{f_1(\eta,\Omega,\delta)} d\eta e^{iwt},$$

where τ_0 - the amplitude of dynamic shear stresses on the surface at $r=a$, af_1 is

$$f_1(\eta,\Omega,\delta) = \sqrt{\eta^2(1+i\delta)^2 - \Omega^2(1+i\delta)}.$$

Figure 3 shows the amplitude-frequency characteristic of the vertical mass $|W^*| = \frac{|W|Ga}{P_0}$ oscillation on a viscoelastic half-space for the value of the Poisson's ratio of the base material $v = 0.25$ and the attenuation parameter $\delta = 0.2$. The real part of the elastic modulus of the base material G was assumed to be constant, independent of frequency. A replacement system with one degree of freedom, equivalent to the action of mass on a viscoelastic half-space, can be determined in the same way as in [12, 13] from the conditions of equality of the coordinates of the resonant extreme of both systems.

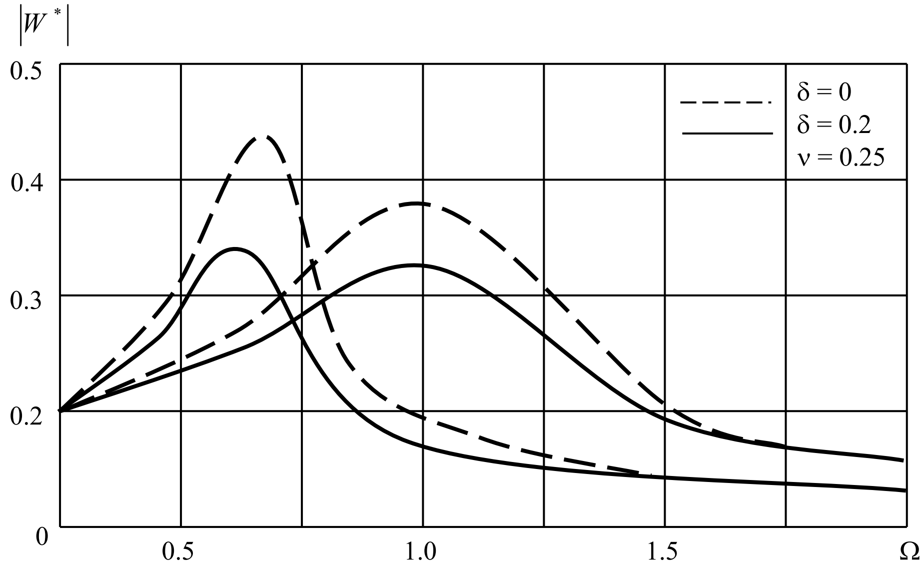

Fig. 3. Amplitude –frequency characteristic of vertical mass oscillation on a viscoelastic half-space.

4 Conclusion

The change of the parameter on which the amplitude of the half-space displacements so significantly depends is investigated. A methodology and algorithm for studying the dynamic characteristics of a half-space have been developed.

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