ELASTIC WAVE RADIATION IN A SOLID MEDIUM WHEN USING HE CHARGES WITH AIR SHELLS

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One of the effective methods of controlling an explosion is placement of the charge in an intermediate medium with a density significantly different from the density of the surrounding medium, which is the fundamental object of action of the explosive impulse. If a medium with low density and high compressibility as compared with the fundamental medium is taken as intermediate, then the rate of pressure growth diminishes and the impulse growth time increases. In particular an air shell around the HE charge can be used as intermediate medium [1, 2].

The presence of an air gap around the charge of a chemical HE substantially influences the characteristics of the initial pressure impulses acting on the surrounding medium. As the gap increases, the mode of shockwave propagation over the air shell and its interaction with the cavity wall become important.

Analysis of the wave processes for explosive charges with air shells in a medium is performed in [3] where it is shown that as the size of the air cavity increases the energy entrained by the shockwave in an underwater explosion decreases rapidly. Presented in [4] are results of an experiment to determine the influence of an air shell on the compression wave propagation process in a solid medium. Multiply remelted sodium thiosulfate, which is similar to rock salt in its mechanical properties, was used as medium. The source of the explosion was TEN microcharges. It is shown in [5] that the HE charge density, which can be altered by using porous HE or an air shell, also influences the parameter of explosive action.

A number of authors [1, 2, 5, 6] indicate that small air shells (from 0.5-1.5 HE volumes) increase the mechanical effect of an explosion and improve the rock fractionation parameters. This is associated with the fact that gas expansion within the cavity in the initial stage is distinct from the adiabatic mode and characterized by a small drop in the pressure as compared with the adiabatic expansion mode [7].

Moreover, because of the presence of the air shell the detonation products overtake and act on the cavity wall dynamically so that the peak pressure on the cavity can become even greater than the initial pressure of the detonation products. For large air shell dimensions strong energy dissipation in the air shell occurs, resulting in a significant reduction of the peak pressure on the cavity wall. The destruction zone in a solid medium gradually diminishes and shockwave interaction with the wall acquires a purely elastic nature. Almost all the energy here goes into raising the air temperature within the cavity. Therefore, by varying the dimension of the air shell, the pressure pulse acting on the solid medium can be altered substantially and the mechanical effect of the explosion can be controlled.

The parameter $\xi = R_i/R_c$ (R_i is the radius of the initial cavity, and R_c is the charge radius) was varied in experiments [4] and compression wave characteristics were studied when propagated in a solid medium. The question of the elastic energy being emitted here and its dependence on the parmaeter ξ remains urgent. From the viewpoint of seismic safety it is interesting to obtain the dependence of the maximal mass velocity, displacement and also the reduced potential of the elastic shifts (functions of the seismic source) on ξ which are studied by solving numerically the problem of a spherically symmetric underground explosion of a chemical HE charge surrounded by an air shell (Fig. 1). It is assumed that charge detonation occurs instantaneously. A two-member adiabat of trotyl [8] was taken as equation of state of the detonation products. The air between the charge and the medium was considered an ideal gas with adiabatic index $\gamma = 1.4$. The initial air parameters corresponded to normal

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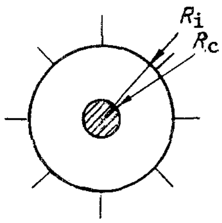

Fig. 1

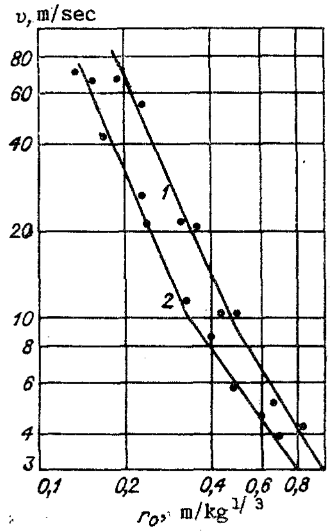

Fig. 2

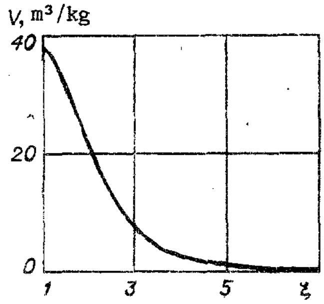

Fig. 3

conditions. Rock salt with mechanical characteristics taken from [5] was simulated as the surrounding medium.

To describe the spherically symmetric gas motion within the cavity known gasdynamics equations were used

$$\begin{aligned} \partial V/\partial t + u\partial V/\partial r &= V(\partial u/\partial t + 2u/r), \\ \partial u/\partial t + u\partial u/\partial r &= -V\partial p/\partial r, \\ \partial e/\partial t + u\partial e/\partial r &= -p(\partial V/\partial t + u\partial V/\partial r). \end{aligned} \tag{1}$$

Here V and e are the specific volume and specific energy of the medium, u is the velocity, p is the pressure, t is the time, and r is the Euler coordinate.

Taken for the description of the motion of the solid medium surrounding the cavity are hydrodynamic equations taking account of the strength in Euler coordinates

$$\begin{aligned} \partial V/\partial t + u\partial V/\partial r &= V(\partial u/\partial r + 2u/r), \\ \partial u/\partial t + u\partial u/\partial r &= V(\partial \sigma_r/\partial r + 2\tau/r), \\ \partial e/\partial t + u\partial e/\partial r + p(\partial V/\partial t + u\partial V/\partial r) &= (2/3)\tau V(\partial u/\partial r - u/r), \end{aligned} \tag{2}$$

where σ_r and σ_θ are the radial and angular stress tensor components, $\tau = \sigma_r - \sigma_\theta$ is the shear stress and $p = -(\sigma_r + 2\sigma_\theta)/3$.

The elastic-plastic model with the dependence of the strength on the pressure [9]

$$|\tau| < Y(p),\ Y(p) = Y_0 + \mu p/(1 + \mu p/(Y_{pL} - Y_0)). \tag{3}$$

was used to describe the behavior of the medium. Here Y_0 is the adhesion, μ the friction coefficient, and Y_{pL} the limit value of the shear strength.

The equation of state of the medium was used in the known Tait form

$$p = \rho_0 c_0^2/n\,((\rho/\rho_0)^n - 1). \tag{4}$$

For a numerical computation the system (1), rewritten in Lagrange coordinates, was replaced by a system of finite-difference equations. A "cross" type difference scheme of second-order accuracy in a uniform Lagrange mesh was used and was completely conservative [10]. The system (2) describing the motion of the solid medium was solved by the difference method used in [11]. A combined linear-quadratic viscosity that assured the possibility of a through computation was taken to smooth the hydrodynamic discontinuities occurring in both schemes. Stability of the computation was achieved by an appropriate selection of the time spacing.

The numerical solution of the system (1) taken on the cavity boundary was the boundary condition for the numerical solution of the system (2) at each time. Therefore, a difference method was used that permitted solving the problem of an explosion in a solid medium with a complex gasdynamic pattern of detonation product behavior within the cavity taken into account. It was assumed that the rock salt is an ideally plastic material with a shear strength equal to Y_0 = 15 MPa.

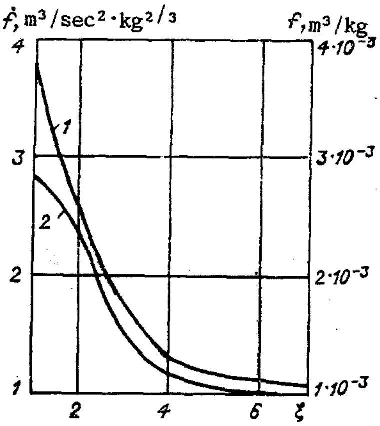

Fig. 4

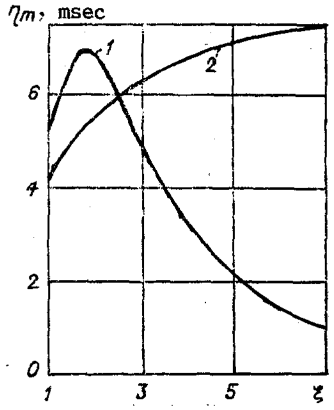

Fig. 5

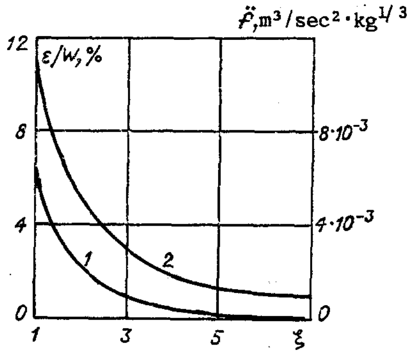

Fig. 6

To determine how much the selected computation scheme agrees with experiment, the computed dependence of the maximal mass velocity of the medium on the reduced distance is given in Fig. 2. The experimental points are taken from [4] (lines 1 and 2 correspond to $\xi = 1.5$ and 2). Good agreement between the computed and experimental results permits acceptance of the selected model to describe the process.

Shown in Fig. 3 is the dependence of the volume of the zone enclosed by plastic flow on the parameter ξ. It is seen that as ξ changes in the range between 1.0 and 3.5 an abrupt diminution occurs in the size of the plastic flow domain, associated with a significant attenuation of the action of the shock wave by the air shell. To determine the motion occurring in the elastic zone, the potential $f(\eta)$ of elastic shifts was computed by the method of [12]. A condition for the beginning of radiation is diminution of the front velocity to the elastic wave velocity in the medium. The dependences $f(\eta)$ are obtained for different air shells cases. Here $\eta = t - (r - R_e)/c$ (r is the radial coordinate, R_e is the elastic radius, c is the longitudinal speed of sound in the medium, and t is the time).

For the computations $c = 4500$ m/sec. As ξ increases a diminution in the potential and reconstruction of its shape occur, associated with displacement of the characteristic elastic signal frequency towards higher frequencies. Represented in Fig. 4 is the dependence of the maximum of the seismic source function (SSF) on the reduced cavity radius ξ (curve 2), curve 1 is the change in the maximum of the SSF derivative with respect to ξ, that by its definition corresponds to a change in the maximal displacements in the medium. The shift of the signal frequency is seen well in Fig. 5 (curve 1), where η_m is given as a function of ξ which is the value of η for which the potential reaches the maximum. This dependence is not monotonic and can characterize the change in the period of the elastic signal radiated in the medium for a variation of ξ since $\eta_m \sim T$. For small air shell sizes an increase occurs in the characteristic period of the signal, where an abrupt drop starts after the maximum is reached, which is associated with the competition between the two mechanisms. As is known, the characteristic period of the signal is proportional to the radius of the elastic radiator which diminishes as ξ grows. Meanwhile, if it is taken into account that the impulse acting on the elastic radius has a finite time of action T_0, then it is easy to obtain from a solution of the Sharp problem that η_m will increase smoothly with the lapse of time from $(1/\omega_0)\arctan(1/\sqrt{1 - 2\nu})$ (for $T_0 = 0$ which corresponds to a δ-shaped pulse) to π/ω_0 (for $T_0 = \infty$ which corresponds to a constant stress on the elastic radius). Here ω_0 is the characteristic frequency from the Sharp problem ($\omega_0 = 2c_t/R\sqrt{2(1 - \nu)}$, c_t is the transverse wave velocity, ν is the Poisson ratio). Therefore, an increase in η_m for $1 < \xi < 2$ is related to the growth of the time of detonation product action on the cavity wall (Fig. 5, curve 2).

The question of the fraction of explosion energy radiated in the form of elastic waves is quite important in studying the mechanical effect. Shown in Fig. 6 is how the radiated seismic energy depends on ξ (curve 1). This dependence can be approximated by the formula $\varepsilon/W = 7/\xi^{1.9}$ that satisfactorily describes the radiated energy curve up to $\xi \sim 3$. The line 2 is the dependence of the maximum of the second derivative of the SSF with respect to ξ, this corresponds to a change in the maximal mass velocity. The mentioned dependences yield a representation of the seismic effect on the explosion of a charge surrounded by an air shell.

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FEATURES OF ELASTIC WAVE PROPAGATION IN A SYSTEM PLATE–LAYER–HALF-SPACE

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When solving questions for protecting supply-line engineering structures from the action of moving loads, information about the features of harmonic wave propagation in systems simulating real objects with their interaction with substructures and foundations taken into account can turn out to be useful. One of the models permitting clarification of the feature of dynamic interaction of structural elements is the system plate–layer–half-space. This latter (sometimes called a foundation) is considered rigid or deformable. Approximate methods for taking account of the pliability of the foundation in static problems are presented in [1].

Investigated below are the waveguide properties of the elastic systems plate–half-space, plate–layer, and plate–layer–half-space. Sliding contact is realized between the plate and the layer (half-space), while the layer and half-space are rigidly connected. Two foundation models are examined, exact (within the framework of elasticity theory) and approximation, the model of an elastic medium with one vertical displacement. Apparently, Rakhmatulin [2] first used this model in a problem not related to questions of structure interaction with a medium. Approximate equations are used in [3] to analyze the static and a number of dynamic problems. The dynamics of piecewise-homogeneous media was investigated in [4-6] by using this model and similar modifications. Information about the dispersion of harmonic waves in composite systems, obtained in [7-9], has a direct application to problems of geophysics, acoustodiagnostics, but leaves aside questions of strength and carrying capacity of the structures subjected to the action of waves being propagated in the surrounding medium. This is explained by the fact that the correspondence between the nature of free wave propagation and nonstationary processes under moving loads was not clarified. The fundamental merit in

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