# CHARACTERISTICS OF WAVE PROCESSES IN EARTH UNDER THE ACTION OF EXPLOSIONS OF CHARGES WITH AIR SHEATHS

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Given here are the results of experimental investigations of wave processes in earth under the action of explosions of charges surrounded by sheaths of air, and some general laws are established.

One effective way of controlling an explosion is by placing the charge in some intermediate medium whose density is considerably different from that of the medium which is the main object being acted on by the explosive pulse. If a medium with small density and high compressibility, compared with those of the main medium, is employed as the intermediate medium, a decrease in the rate of growth of the pressure of the detonation products and an increase in the duration of their action are observed. Use of a sheath of air around charges as the intermediate medium was first proposed by N. V. Mel'nikov and developed in papers issuing from his school [1, 2].

The first analysis of wave processes in water under the action of explosions of charges with an envelope of air was made by B. D. Khristoforov [3]. This showed that the energy transferred to the water by the shock wave from the underwater explosion decreased rapidly with an increase in the dimensions of the air cavity. For a ratio $r_a$ of the radius of the air cavity to the reduced radius of the charge equal to 11.8 the energy becomes approximately one tenth of that without an air sheath. At the same time, with $\bar{r}_a = 2.65$ an increase of 15% in the size of the gas bubble and an increase in the usefully employed energy up to 59.9% were observed (as against 38.2% for explosions without an air sheath). Such a sharp decline in the energy of the pulse propagating into the medium when the dimensions of the air cavity are increased results from dissipation losses due to heating of the air.

A solution of the problem concerning the optimum air sheath under conditions where explosions take place in solid media has been proposed by V. N. Rodionov [4]. However, it was based only on thermodynamic relationships connected with the expansion of detonation products with no account taken of the wave processes in the solid medium, and satisfactory agreement with data from measurements was achieved only for cliff rock.

A study of the characteristics of wave processes in earth resulting from explosions of charges with air sheaths was made with concentrated charges exploding underground (charge weight 0.2 kg) and linearly distributed surge charges (running weight of explosive material 4 kg/m) in Kiev loam of density 1990 kg/m$^3$ and mean gravimetric moisture content 14.17%. The effect of the size of the air sheaths about the charges on the parameters of the explosion waves propagating in the ground as a result of the explosions was investigated.

As the explosive material in all the experiments, compressed trinitrotoluene of density 1600 kg/m$^3$, detonation rate 6 km/sec, and specific internal energy 1010 kcal/kg was used. The charge was placed in a special cardboard container whose volume exceeded that of the charge by the size of the air sheath. Measurements of parameters of the stress wave was made with a tensometric complex comprising a membrane-

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type pressure sensing element, 8 ANCh-7 m and UTS-1VT-12 amplifiers, and an N-700 loop oscilloscope. The stress sensors, calibrated in advance, were set in specially drilled bores, deep about the position of the charge, after which they were covered by earth removed from the bores with layered tamping. The stress sensors were positioned in such a way as to ensure the recording of the radial $\sigma_r$, the axial $\sigma_z$, and the peripheral $\sigma_\varphi$ components of the stress tensor.

Some results of these experiments, relating to general laws of explosions of charges with air sheaths, are given in [5]. Below we give results of the processing of oscillograms of the experiments.

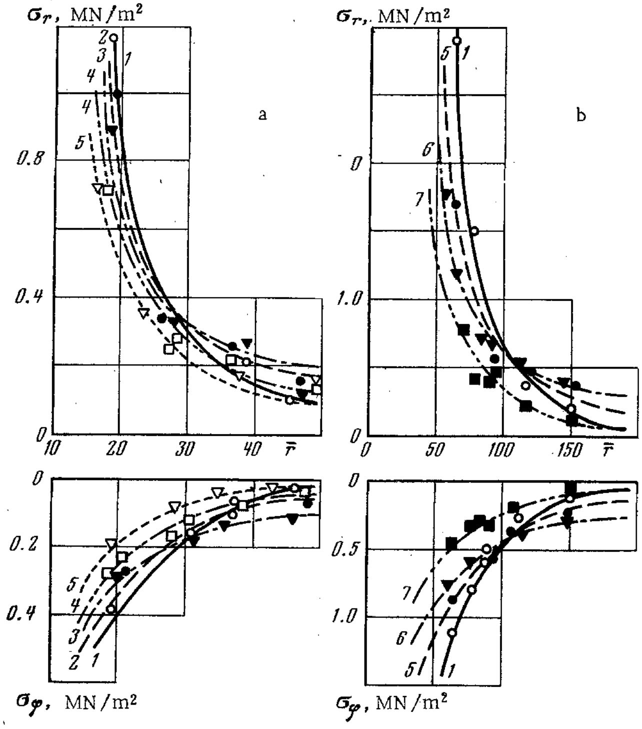

Fig. 1

In Fig. 1 the variation of the maxima of the radial and lateral stresses with distance, expressed in charge radii, is represented for various sizes of the air sheath in the cases of concentrated charges exploding underground (a) and linearly distributed surge charges (b). Curves 1-7 were obtained for cases when the ratios $\eta$ of the volume of the air sheath to the volume of explosive were respectively 0, 0.25, 0.50, 0.75, 1.00, 1.50, and 2.00. Analysis of the curves shows that, near the center of the explosion, increasing the air sheath leads to a significant decrease in the absolute magnitude of the pressure, this occurring up to a distance of (25-30) $r_3$ for concentrated charges and up to (90-100) $r_3$ for linearly distributed charges. At large distances from the center of the explosion the pressure in the explosion wave increases with increase in the volume of the air sheath from zero up to the optimum value $\eta_*$, and for $\eta > \eta_*$ it decreases. The variation of the maxima of radial and lateral pressures with $\eta$ that was established can evidently be explained by the redistribution of the energy of ground deformation in the presence of explosions of charges with air sheaths. The reduction of the maximum pressures in the near range is accompanied by a corresponding decrease in the expenditure of energy on plastic deformation. The portion of the energy that is released in the form of large-amplitude waves is transferred to more remote regions of the compaction zone, where it is expended primarily on volume strains of the earth. The overall decrease in the intensity of the explosion waves for $\eta > \eta_*$ is explained by the sharply increased dissipation losses in the air sheath itself [3].

The curves shown above can be approximated by a relationship of the form

$$\sigma = kr^{-\mu} \tag{1}$$

where k and $\mu$ are empirical constants, depending on the size of the air sheath of the charge. Calculations show that for optimum sizes of the air shells of the charges the exponent $\mu$ of the degree of attenuation of the waves with distance attains a minimum, which can be explained on the basis of minimum expenditure of energy on deformation of the ground when the charge is designed in this way.

The distribution of experimental points shown in Fig. 2, indicating the variation with distance of the arrival time $t_0(r)$ of the explosion disturbance at an arbitrary point of the ground in the case of explosions of concentrated (a) and distributed (b) charges, gives no possibility of establishing any significant influence of the air sheath of the charge on this parameter of the explosion disturbance. Therefore for various values of $\eta$ the dependence $t_0(r)$ must be assumed to be unchanged. For the conditions under which the experiments were performed and in the range covered by the measurements one can take

$$t_0(r) = m(r - 1) \tag{2}$$

as the form of an analytical expression for the function $t_0(r)$, where m is an empirical coefficient.

The arrival time $t_m(r)$ of the maximum pressure at a given point of the ground increases with an augmentation of the volume of the air sheath of the charge. The rate of this increase dies out and, starting with

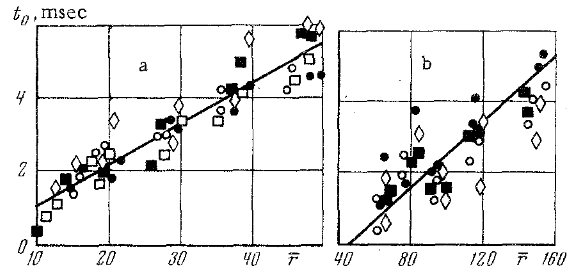

Fig. 2

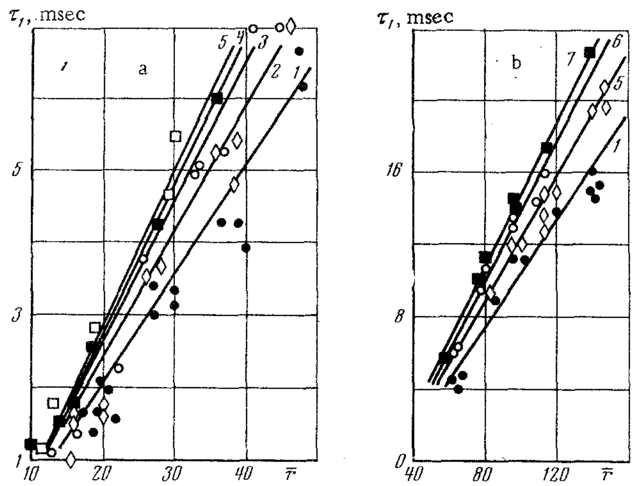

Fig. 3

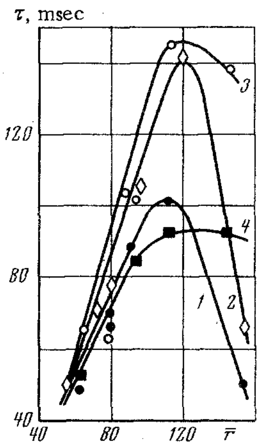

Fig. 4

a certain critical value $\eta'$, becomes insignificant. For explosions with central symmetry $\eta' = 1.0$, and for those with axial symmetry $\eta' = 2.0$.

Using the dependences $t_m(r)$ and $t_0(r)$ that have been obtained, we can find the variation with distance of the rise time $\tau_1(r)$ of the pressure in an explosion wave, since

$$\tau_1(r) = t_m(r) - t_0(r) \tag{3}$$

A graphical interpretation of this dependence for explosions with central (a) and with axial (b) symmetry is shown in Fig. 3, where the various curves correspond to the same sizes of air sheath as those cited above. Analysis of the curves shows that the rise time of the pressure in an explosion wave varies in a way similar to that of the arrival time of the maximum pressure. Analytically the dependence in question can be represented by a linear function of the form

$$\tau_1(r) = k_1 r - q \tag{4}$$

where $k_1$ and q are empirical coefficients.

The increase in the loading time in the pressure pulse and the simultaneous decrease in maximum stress, occurring with an increase in the size of the air sheath of the charge, have a considerable influence in decreasing the loading rate in an explosion wave. The general character of the variation of this parameter of the wave disturbance is similar in qualitative respects to that considered above for the dependences $\sigma_r(r)$ and $\sigma_\varphi(r)$.

Analysis of results of the experiments shows that for volumes of the air sheaths about the charges that are close to optimal one should expect an increase in the duration of the action of the explosion pulses in the region of low pressures. This is traced more sharply in the case of explosions of linearly distributed charges (Fig. 4). Here the relative sizes of the air sheaths (corresponding to the number attached to the curves) are 0, 1.0, 1.5, and 2.0 respectively. The scatter of experimental points obtained by processing results of underground explosions of concentrated charges made it impossible to arrive at any definite conclusions.

Significantly, the variation of the parameters of the stress waves resulting from explosions of charges with air sheaths, discussed above, has an influence on the distribution of the magnitude of the pressure pulses.

Figure 5 shows dependences illustrating the variation with distance of magnitudes of radial impulses on part of the loading

$$I_r' = \int_0^{\tau_1} \sigma_r(\tau)\, d\tau$$

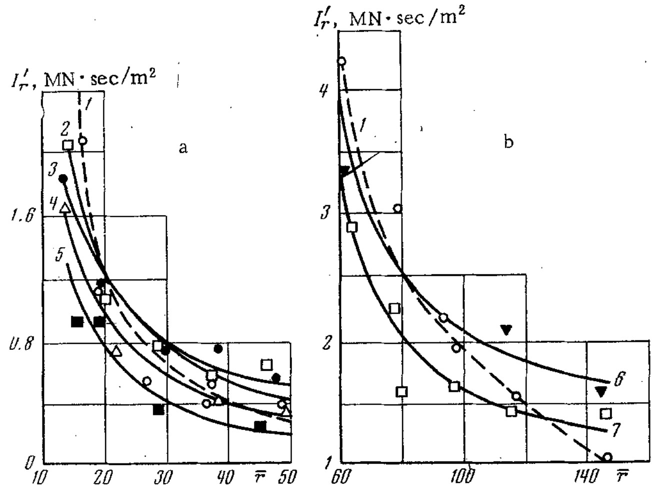

Fig. 5

for various relative volumes of the air sheath, resulting from explosions of charges with central (a) and axial (b) symmetry (for sizes of the air sheath corresponding to each curve, see the explanation of Fig. 1).

These curves show that for the optimum size of the air sheath of the charge, one should expect a decrease in the absolute magnitude of the radial impulse near the center of the explosion (at r < ~ 20 for concentrated and r < ~80 for elongated charges) with some increase in it at large distances. This confirms the thesis, propounded above, concerning the redistribution of deformation energy with a change in the design of the charge.

The above discussion enables one to state that the air sheath of a charge has a substantial influence on practically all parameters of the wave disturbance propagating into the earth from an explosion.

The characteristics of wave processes in earth resulting from explosions of charges with air sheaths that we have established can be used for the calculation of the action of an explosion [6, 7] during cutting in open-pit mining and in other underground operations in compressible earth.

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