EXPERIMENTAL DATA ON STRESS-WAVE PARAMETERS IN THE EARTH DUE TO UNDERGROUND AND SURFACE EXPLOSIONS

V. D. Alekseenko and G. V. Rykov

Experimental data on the parameters of stress waves in sandstone and clay ground are compared when charges of from 0.2 kg to 200 kg of TNT are exploded.

1. It is shown in [1] that in the neighborhood of the axis of symmetry at angles $\alpha \leq 30°$ (the angle α is measured from the axis of symmetry) the stress field for a surface explosion preserves the qualitative characteristics of the centrally symmetric stress field which occurs for an underground explosion, although in a surface explosion only a certain part of the energy E_0 of the total energy of the explosion E is exciting the stress wave in the ground. Hence, the wave parameters excited in a surface explosion in the region close to the axis of symmetry can be calculated from the wave parameters excited in underground explosions if we use in the latter the fraction of the explosion energy E_0. To verify these considerations we carried out a series of experimental investigations of wave parameters excited by surface and underground explosions in the same types of ground, namely sandstone and clay. The method of investigation is described in [1-3]. To determine the maximum radial stresses σ_r^m, the specific impulses I_r, and the time of action τ for the underground explosions we obtained the following empirical formulas:

$$\sigma_r^m(R) = K_1 R^{-\mu_1}\ \text{kg/cm}^2,\quad I_r{}^\circ(R) = K_2 R^{-\mu_2}\ \text{kg}^{2/3}\text{sec/cm}^2,\quad \tau_r{}^\circ(R) = a + \eta R\ \text{sec/kg}^{1/3}$$
$$R = r/r_0,\qquad r_0 = 0.054\ C^{1/3},\qquad I_r{}^\circ = I/C^{1/3},\qquad \tau^\circ = \tau/C^{1/3}\cdot 10^3, \tag{1.1}$$

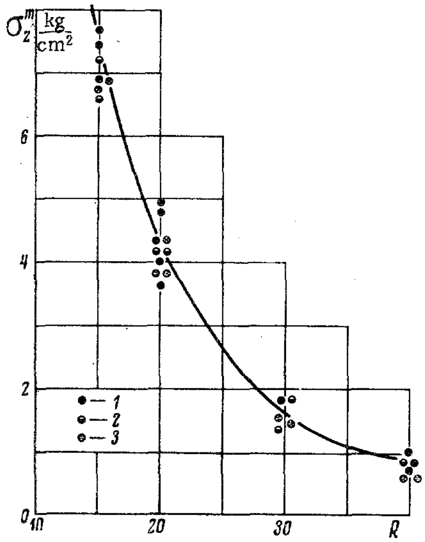

Fig. 1

Here r is the distance from the explosion center in meters; r_0 is the charge radius in meters; C is the weight of the explosive charge in kilograms; $I_r{}^\circ$ and τ° are the specific impulse and the total time of action, relative to the scale of the effect; K_1, K_2, μ_1, μ_2, a, η are experimental coefficients which depend on the properties of the ground.

	K_1	μ_1	K_2	μ_2	a	η	λ
(1)	$11.5\cdot10^3$	2.36	4.85	1.53	17.5	0.57	0.35
(2)	$42.6\cdot10^3$	2.81	—	—	—	—	0.33
(3)	$2.8\cdot10^6$	3.45	525	2.73	8.8	0.09	0.23

Here row (1) relates to sandstone ground with a specific gravity of the frame of γ_0=1.50-1.52 g/cm³ and a moisture content by weight of ω=10-12%; row (2) refers to loam with γ_0=1.65-1.70 g/cm³ and ω=10-15%; row (3) refers to clay with γ_0=1.70-1.75 g/cm³ and ω=20-22%.

The parameters of the waves excited by a surface explosion with $\alpha \leq 30°$ can be determined from (1.1) if we replace the charge C by

$$C = \lambda C_0,\qquad \lambda = E_0/E. \tag{1.2}$$

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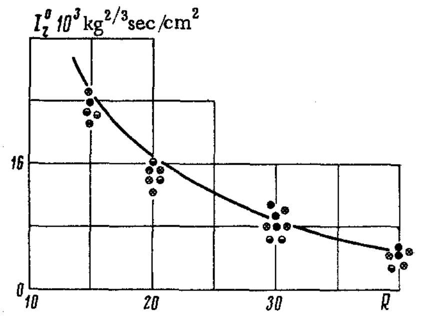

Fig. 2

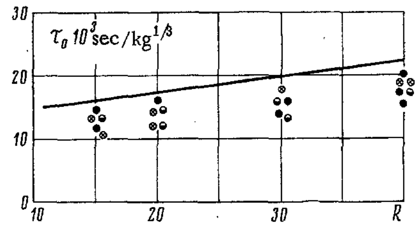

Fig. 3

Here C_0 is the weight of the explosive charge in the surface explosion and λ is a coefficient which represents the energy fraction radiated into the ground by the surface explosion.

The values of λ have been given earlier for the above types of ground for explosive charges whose centers are at the level of the free surface.

The determination of λ for different grounds by fixing the wave fronts of the excited shock waves of the surface explosion has been described in [1].

Figures 1-3 show curves of $\sigma_z{}^m(R)$, $I_z{}^\circ(R)$ and $\tau^\circ(R)$ for a surface explosion, constructed using (1.1) and taking relations (1.2) into account for sandstone ground (1).

The different points in Figs. 1-3 show experimental data obtained in independent experiments with surface explosions in the same ground with $\alpha=0°$ (points 1), $\alpha=15°$ (points 2), and $\alpha=30°$ (points 3). Consideration of the data in the figures indicates the fairly good agreement between the curves calculated using (1.1)-(1.2) and the corresponding experimental data. Some difference in determining the time of action τ° is due to the fact that the end of the compression wave cannot always be accurately determined due to the different pickup sensitivities. However, as can be seen from Fig. 2, this has practically no effect on the valueof the specific impulse $I_z{}^\circ$, since the stresses at the end of the wave action are small. Similar results were obtained in loam and clay. Figure 4 shows, in particular, data on stresses calculated using formulas (1.1) and (1.2) for loam (2) (curve 2) and clay (3) (curve 1), and also experimental data obtained for $\alpha=0°$.

Therefore, if we know the energy fraction of the surface explosion radiated into the ground and the wave parameters $\sigma_r{}^m(R)$, $I_r{}^\circ(R)$, and $\tau^\circ(R)$ for an underground explosion, the corresponding stress-wave parameters in the axial region of the surface explosion can be determined from (1.1) by introducing the parameter λ according to (1.2). Conversely, if we know from an experiment the relationships which describe the stress-wave parameters in a surface explosion in the neighborhood of the axis of symmetry then, by multiplying the value of the charge C by the coefficient $1/\lambda$, we can obtain the wave parameters of an underground explosion for the same type of ground.

2. The above data also enables us to determine the energy distribution in a surface explosion when the charge surface is at ground level and the method of wave front fixing [1] is not applicable. Figure 5 shows hodographs of the front of the excited shock wave for different positions of the charge center relative to the surface of loamy ground (2). Curve 1 relates to the charge placed directly on the free surface, curve 2 relates to the center of the charge coinciding with the surface, and curve 3 relates to the charge center situated at a depth of the charge radius from the surface. As can be seen from Fig. 5, curve 3 is considerably higher than curves 1 and 2. The value of λ determined from curve 3 (Fig. 5) according to [1] is 0.97, which is physically almost equivalent to a camouflet explosion for a depth of the charge center $H_0=30\text{-}40\ r_0$ and does not correspond to reality. The latter is due to the fact that when such a charge is exploded the ground surrounding it forms a circular "collar" near the center. As a result the air shock wave which occurs initially propagates mainly upwards, taking the shape of a semielipsoid of revolution with the major axis directed normal to the surface. Subsequently the shape of the air shock-wave front becomes semispherical and the wave propagates along the free surface according to the usual laws. However, the peculiarities of the initial stage of the motion have an effect up to R=50. Hence, another method of determining λ is proposed for such cases.

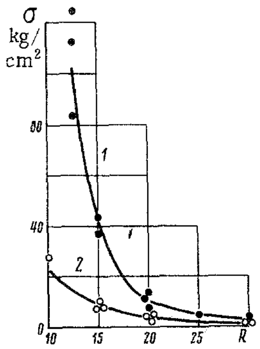

Fig. 4

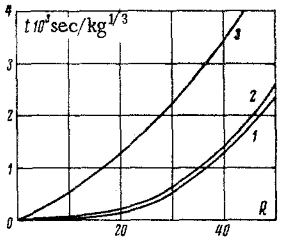

Fig. 5

It follows from the above that the maximum radial stresses $\sigma_r{}^m(R)$ for an underground explosion and the maximum main normal stress $\sigma_z{}^m(R)$ in the neighborhood of the axis of symmetry for a surface explosion are given by the formulas

$$\sigma_r{}^m(R) = K_1 R^{-\mu_1}, \qquad \sigma_z{}^m(R) = K_1 R^{-\mu_1} \lambda^{1/3\mu_1}. \tag{2.1}$$

Dividing the second equation by the first and solving the result we obtain

$$\lambda = \left[\frac{\sigma_z{}^m(R)}{\sigma_r{}^m(R)}\right]^{3/\mu_1}. \tag{2.2}$$

Hence, for an experimental determination of the energy fraction of a surface explosion radiated into the ground, it is necessary to measure the stresses $\sigma_z{}^m(R)$ and $\sigma_r{}^m(R)$, and also to determine the coefficient μ_1. The value of λ determined in this way for loam when the charge center is at a depth of one charge radius $(H_0 = r_0)$ is 0.56. The value of λ for clay (3) was found in a similar way.

LITERATURE CITED

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