EXCITATION OF LOW-FREQUENCY SEISMIC BODY WAVES IN AN UNDERGROUND EXPLOSION

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An underground explosion as a source of seismic waves has been well studied [1]. The mechanism of the formation of an elastic wave which is then transformed into seismic waves of various types consists in the following. The energy of the explosion is transferred to the surrounding medium by a compression wave which displaces a certain volume proportional to the energy of the explosion into the elastic region beyond the limits of the demolition zone. The linear dimensions of this zone depend on the properties of the medium, in particular on its compressibility and strength. For an explosion in rock salt the radius of the demolition zone is given approximately by $R_p = 100q^{1/3}$, if R_p is measured in meters and q is the weight of the TNT energy equivalent in kilotons (kton). The time of radial displacement of particles from an explosion in an elastic wave, which determines the frequency characteristic of the signal, is approximately equal to the diameter of the demolition zone divided by the velocity of longitudinal waves. The amplitude of the radial displacement u and the rate of displacement at the front of the compression wave can be determined from empirical relations. For example, for an explosion in rock salt

$$u = 0.135q^{1/3}\left(\frac{100q^{1/3}}{R}\right)^{1,6}, \quad v = 10\left(\frac{100q^{1/3}}{R}\right)^{1,6},$$

where u is the displacement amplitude of the wave (m), v is the displacement velocity at the front of the compression wave (m/sec), and q is the weight of the TNT energy equivalent (kton).

Because of the increase of the velocity of elastic waves with depth, waves at large distances are propagated along curvilinear rays deep in the mantle. These rays from the explosion emerge at large angles with the surface, so that the parameters of a longitudinal seismic wave are determined by the elastic wave formed beneath the explosion [2]. In an explosion at the surface of the ground the amplitudes of the compression wave and the longitudinal seismic wave decrease monotonically with decreasing depth of the explosion w, beginning with $w \simeq R_p$.

Let us now consider another mechanism of excitation of seismic waves. If the underground explosion is close enough to the surface so that an ejection crater is formed, or the mountain mass loses cohesion in the volume of the loosened cone as a result of large deformations, new forces appear which act on the elastic half-space. The inertial motion of large masses of rock within the ejection crater or loosened cone produces slowly varying forces. Romashov [3] showed that during explosions with ejection the volume of rock thrown up from the massif generates through cohesive and frictional forces a low-frequency rarefaction wave in the surrounding space. For a certain time the weight of rock ejected by the explosion is removed from the elastic half-space, and this generates an elastic unloading wave which close to the axis of symmetry under the explosion is obviously a longitudinal wave.

Let us estimate the maximum amplitude of the longitudinal elastic wave formed in the unloading of the elastic half-space. If we assume that the whole volume of rock contained in an inverted cone with its vertex at the center of the explosion and a radius equal to the depth of the explosion (ejection or loosened cone) is simultaneously separated from the massif, the effect on the elastic half-space can be represented as the action of a concentrated force $F = \rho g w^3$, where g is the acceleration due to gravity, ρ is the density of the rock, and w^3 is the volume of the cone.

The force F increases with increasing depth of the explosion. This increase stops when the explosion is not strong enough to separate the indicated volume from the massif, or when the time of fall in the gravitational field of the volume of rock separated from the massif becomes too small. It is believed that an explosion at a depth $w = R_p$ gives the largest amplitude of the unloading wave. Estimates show that in this case the initial velocity v_0 of the ejected rock will be sufficient (~10 m/sec) to ensure that the force acts for an appreciable time ($2v_0/g = 2$ sec).

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Remembering that the time to establish equilibrium after the concentrated force begins to act is related to the rearrangement of the fields of elastic deformations in a volume with linear dimensions much larger than the radius of the area of application of the "concentrated" force, the necessary minimum time the force acts is

$$\Theta \simeq 10R_p/c = 10w/c,$$

where c is the velocity of longitudinal waves.

Thus, the condition for effective excitation of an unloading wave is determined by the relation $2v_0/g \geq \Theta$.

At the boundary of the wave zone (the vertical distance from the surface $z = \Theta c$), the displacement along the axis of symmetry from the action of the concentrated force F on the surface can be calculated from the formulas for static equilibrium:

$$u_z = -\frac{(1-\sigma)(3-2\sigma)}{(1-2\sigma)\,2\pi\rho c^2}\frac{F}{z},$$

where σ is Poisson's ratio, ρ is the density of the medium, and z is the vertical distance from the surface.

Substituting $F = \rho g w^3$, $w = R_p = 100q^{1/3}$, $z = 10w$ for an explosion in rock salt ($c = 4.5$ km/sec, $\sigma = 0.25$), we obtain

$$u_z = -0.3 \cdot 10^{-3} q^{2/3}.$$

If q = 150 kton, $u_z = -0.85$ cm. We note that at this same distance for an explosion q = 150 kton the displacement in the compression wave given by the formula

$$u = 0.135\, q^{1/3}\left(\frac{100\, q^{1/3}}{z}\right)^{1.6}$$

is of the same order of magnitude, u = 2.1 cm.

However, while the displacement time in the compression wave is approximately $2R_p/c = 2w/c$, the displacement time in the unloading wave will be $\Theta = 10w/c$. Consequently, at large distances (~5000 km), because of the substantially slower absorption of energy of an elastic wave in the long wavelength part of the spectrum, the seismic wave excited by the unloading mechanism will play a decisive role.

It is important to note that at large distances the amplitudes of seismic vibrations which are excited in different ways depend differently on both the energy and the depth of the explosion. In particular, the dependence on the depth of the explosion of the amplitude of vibrations excited by an unloading wave has a maximum for $w = R_p = 100q^{1/3}$.

LITERATURE CITED

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