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# STUDY OF AN EXPLOSION IN BULK SOIL WHEN THE CHARGE IS SURROUNDED BY AN AIR-FILLED CAVITY

I. L. Zelmanov, et al

Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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I. L. Zel'manov, V. I. Kulikov, and A. F. Shatsukevich

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By: I. L. Zel'manov, V. I. Kulikov, and
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| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

# STUDY OF AN EXPLOSION IN BULK SOIL WHEN THE CHARGE IS SURROUNDED BY AN AIR-FILLED CAVITY

I. L. Zel'manov, V. I. Kulikov,
A. F. Shatsukevich

(Moscow)

Much theoretical and experimental material on the underground explosion in sandy ground has been recently published. Works [1-4] give experimental values for the mass velocities of soil during the explosion of PETN and 50/50 trotyl and hexogen charges and with an electric fusing. This article examines the effect of air-filled cavities surrounding the charge upon the mass velocity of soil particles in the compression wave and upon the parameters of craters during an ejection explosion.

Below are given the results of measuring the mass velocity of soil in a compression wave during the underground explosion of pressed charges made of PETN with a density of 1.4 g/cm$^3$ and a weight of 2.5 and 0.8 g.

The charges were placed on a solid-brass plate in the center of a gypsum half-sphere with a wall thickness of about 1 mm. The blast of the charges on the brass plate ensured obtaining a compression wave in the ground with parameters that correspond to the spherically symmetrical motion of the soil upon the explosion of a double-weight charge in the space. This was verified by setting up special experiments. Therefore, further on during the processing of experimental material, double weight was assigned to the charges during these experiments.

All experiments were conducted in a cylindrical tank 400 mm in diameter and 600 mm in height. The soil was dry sand with a poured density of 1.55 g/cm$^3$. The sand was not packed during the filling.

There were three series of experiments with ratios of air-filled cavity radius $R_1$ to charge radius $R_0$ equal to 3.16, 6.33 and 9.3. Furthermore, below we will cite some results for a common underground explosion which have been published in work [3]. This corresponds to a ratio of $(R_1/R_0) = 1$. Thanks to the use of the said gypsum sphere, the initial pressure in the cavity varied from 100,000 to 30 at.

In the experiments, whose procedure is stated in work [3], a recording was made of the rate of motion of soil particles with time at different distances in a vertical direction upward from the charge.

The processing of oscillograms made it possible to obtain the dependences of maximum mass velocity of the soil from a distance to the center of the charge. These dependences are presented in Fig. 1. Here, the dot-dash curve corresponds to the explosion in the cavity with $(R_1/R_0) = 3.16$ and to a common underground explosion; the continuous curve - $(R_1/R_0) = 6.33$, the dotted curve - $(R_1/R_0) = 9.3$. Let us emphasize that the dependences of maximum mass velocity from a distance for cavities with $(R_1/R_0) = 1$ and $(R_1/R_0) = 2.16$ coincide.

Processing the oscillograms also made it possible to obtain the dependences of the time of wave arrival upon the distance to the center of the explosion. Differentiation of these curves yields

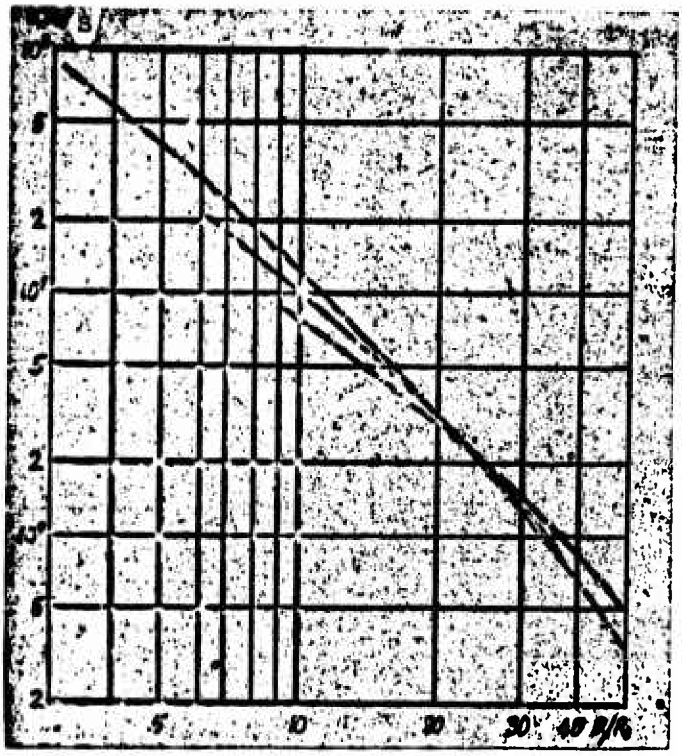

Fig. 1. Dependences of maximum mass velocity upon the initial distance to the center of the charge. The dot-dash curve is for an explosion without an air-filled cavity and for a cavity of radius $R_1 = 3.16\ R_0$; the continuous curve is for $R_1 = 6.33\ R_0$; the dotted curve for $R_1 = 9.3\ R_0$.

magnitudes for rate of wave propagation which on the boundary with the cavities proved to be equal to 360, 300 and 250 m/s with $R_1/R_0$ equal to 3.16, 6.33 and 9.3 respectively. The values for the maximum mass velocity of soil particles adjoining the air-filled cavity are correspondingly equal to 100, 20 and 8.9 m/s (Fig. 1). In view of the fact that the wave fronts near from the cavities are comparatively abrupt, it is possible to estimate the pressure in the soil at the initial moment on the boundary with the cavity using the formula $\Delta p = \rho . uD$. This estimation yields the following values: 560, 93, 34.5 at respectively for $R_1/R_0$ equal to 3.16, 6.33 and 9.3.

An estimation of the frontal parameters of a wave in the soil that are generated upon the impact of the air shock wave onto the boundary of the cavity was made. Thus, in the case of an initial air-filled cavity with a radius of $R_1 = 6.33\ R_0$, the incoming air wave has an amplitude of about 120 at and a mass velocity of 2.9 km/s on the front. The air's adiabatic index calculated by the formula of maximum compression equals 1.27. Hence, the pressure in the reflected air shock wave will be about 1400 at, and the mass velocity in the compression wave which begins to propagate into the soil equals 110 m/s. It is evident from Fig. 1 that the experiment yields a value of 20 m/s. Similar divergences of 5-6 times are also obtained for other air-filled cavities. It follows from these estimations that the compression wave in the soil is not determined by the air shock wave coming into the cavity boundary. Apparently, this is connected with the fact that the pressure in the air shock wave drops very quickly behind the wave front.

Thus, it is essential now to examine the explosion of explosives in an air-filled cavity as instantaneous, and the products of the explosion are considered uniformly distributed throughout the cavity, i.e., the blast of the charges in the air-filled cavities are examined as an explosion of explosives with a density corresponding to the volume of the cavity, and the pressure at the front of the wave emitted into the soil is correspondingly estimated.

An examination of the dependences of maximum mass velocity upon distance in Fig. 1 shows that deviation from the law of energetic similarity is observed near from the cavities where the wave in the soil is determined by the initial pressure of the explosion products. At distances on the order of 2-3 radii of air-filled cavity from the center of the charge, the values of maximum mass velocities during an explosion in the cavities coincide with the maximum mass velocities during a common underground explosion, i.e., the law of energetic similarity is satisfied, and the effect of the initial pressure of the explosion products is unsubstantial. Only for a very large air-filled cavity with radius $R_1 = 9.3\ R_0$, in which the pressure of the products differs by almost four orders of magnitude from the initial pressure during a common underground explosion, and the mass of the charge becomes comparable with the mass of air in the cavity, do the maximum mass velocities of the soil at distances of 20-50 radii of the charge differ from the maximum mass velocities during a common underground explosion.

It is interesting to also compare the beyond-frontal motion of the soil during a common explosion and during an explosion in cavities. Analysis of a large number of oscillograms showed the practical coincidence of mass velocities of soil particles with time to the moment of arrival of the waves reflected from the walls of the tank, meaning also displacements of particles for this time.

Let us now examine the effect of the initial air-filled cavity upon the parameters of the blow-out crater in dry bulk sand. The experiments were conducted in a tank 800 × 800 mm in size and 500 mm in depth. Charges made of PETN and weighing 0.8 g were used. During the processing of the experimental data, the radius of the charge was considered equal to 5.13 mm, which corresponds to a compression density of the charges of 1.4 $g/cm^3$, and the weight C of the charges was expressed in the weight of the trotyl charge, which is equivalent in terms of explosive energy to the above-mentioned charge of PETN, i.e., it was considered equal to $1.12 \times 10^{-3}$ kg (the trotyl equivalent of PETN was assumed equal to 1.4). The charges were hung out on wires in the center of the gypsum spheres. The depth W of embedding the charges was considered from the bottom surface to the center of the sphere. The experiments included recording the profiles of the blow-out craters in the axial cross-section by the method indicated in work [7]. This made it possible with accuracy of to 1 mm to determine the radii r of the craters on the bottom surface, their depths H and volumes V.

Several series of experiments was conducted with spheres of different sizes in a rather large range of depths, which showed that an explosion in an air-filled cavity can be considered similar to a common ejection explosion, if some great energy or great weight $\eta C$ is added to charge C laid into the cavity. Coefficient $\eta$ will be called the trotyl equivalent of an explosion in an air-filled cavity. One of the methods for finding quantity $\eta$ consists of computing the ratio of magnitudes of maximum given volumes for craters during an explosion in a cavity and during a common explosion:

$$n = \frac{(V/C)_{max}}{(V/C)_{max}} \qquad (1)$$

This quantity for the series of radius $R_1 = 3.5\ R_0$ proved to be equal to 1.29 when $R_1 = 7.8\ R_0$ $n = 1.44$. However, here it follows to note that for large air-filled cavities (i.e., when the radius of the cavity is of the same order of magnitude with the depth of laying, at which the blow-out crater is observed), there is a deviation from the law of similarity. This deviation is almost on an order of magnitude less than the size of the cavity, and it has a greater effect on the depth of the crater than on the other parameters.

For a more detailed study of the dependence of effectiveness in using air-filled cavities upon their dimensions, a series of experiments was conducted with spheres of different radius at given depth $(W/C^{1/3}) = 0.48\ m/kg^{1/3}$, which is optimal for a sphere with $R_1 = 7.8\ R_0$ and close to optimum depth for a sphere with $R_1 = 3.5\ R_0$ equal to 0.44. Therefore, the crater volumes obtained during the experiments could have beeen considered maximum. The results of these experiments are presented in Fig. 2, where we have given the dependences of V/C of the maximum volumes of blow-out craters upon the dimensions of spheres in which the charge is exploded (in the radii of the charge). The blackened disc corresponds to the maximum volume of the blow-out crater during a common explosion. The continuous curve illustrates the change in blow-out crater volumes, and the dash curve - the volumes of blown-out soil. Then the trotyl equivalent for the cavities were computed using formula (1). The dependence of the trotyl equivalent of a spherical air-filled cavity upon its radius $R_1$, expressed in charge radii, is presented in this same figure (the dot-dash curve).

The experimental results presented in Fig. 2 show what kind of effectiveness there is in using spherical air-filled cavities during an ejection explosion in loose soil. These results are in

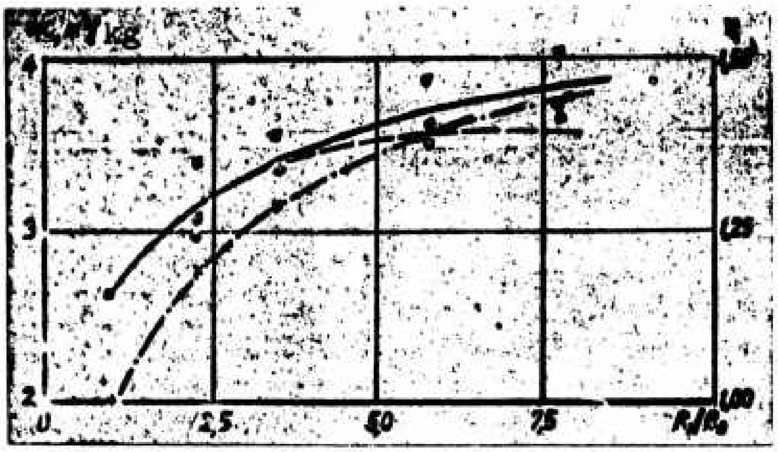

Fig. 2. Dependence of blow-out crater volume and trotyl equivalent upon the radius of the air-filled cavity.

satisfactory agreement with the Tangan-Say experiment conducted under actual conditions [8] and do not contradict the results of works [5, 6]. However, regardless of the works known to us, this article proposes to evaluate the effectiveness of air-filled cavities during an ejection explosion by coefficient η, defined as the trotyl equivalent. This makes it possible to clearly predict the parameters of blow-out craters for an explosion in an air-filled cavity with an arbitrary depth of charge, if the crater parameters are known during a common explosion without a cavity.

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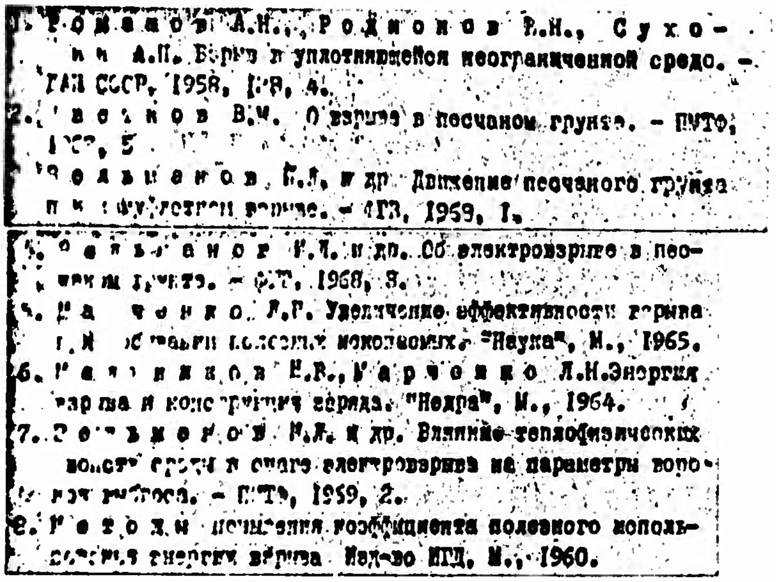
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