ACTION OF AN EXPLOSION IN TRANSPARENT PLASTIC

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Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 8, No. 3, pp. 90–92, 1967

To test theoretical schemes* for explosions in rocks, we consider explosions in transparent plastic and compare the calculated results with the available experimental evidence [1, 2] for this case.

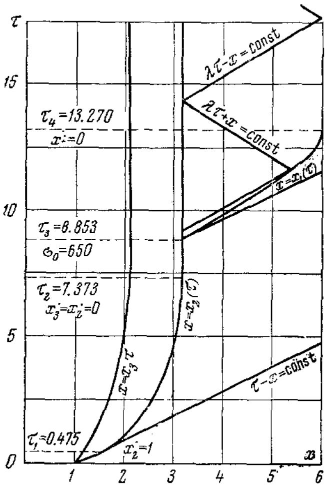

Fig. 1

Measurements have been made [1, 2] of the propagation of the stress wave near the explosion, i. e., the change in front speed and stress-wave parameters with distance, as well as the details of the fracture of the material. Our calculations give these characteristics, which can be compared with experiment.

We took the initial data for the calculation from [1], and namely: density ρ_0 = 119.5 kg/sec^{2}m^4, speed of longitudinal waves c = 2700 m/sec, speed of transverse waves b = 1344 m/sec, strength in static uniaxial stress 650 kg/cm^2, strength in compression 900 kg/cm^2, initial pressure of explosion products (mean over initial volume) p_0 = = $8 \cdot 10^4$ kg/cm^2, hydrostatic pressure p_n = 1 kg/cm^2, and adiabatic exponent γ = 3 for the explosive (pressed PETN).

The parameters of the explosion wave directly adjoining the cavity were calculated on the assumption that the material is compressed to a constant density at the shock-wave front, on account of the very high pressures, with ρ_1/ρ_0 = 1.3. It was also assumed that the medium behind the shock-wave front was incompressible and was in a state of plastic flow. The plasticity condition was taken as $\sigma_\vartheta = \alpha\sigma_r$, in which α was taken as 0.51, i. e., the value $\sigma_\vartheta/\sigma_r$ = $= 1 - 2\gamma^2$ (γ = b/c) given in [1] for a plane elastic wave.

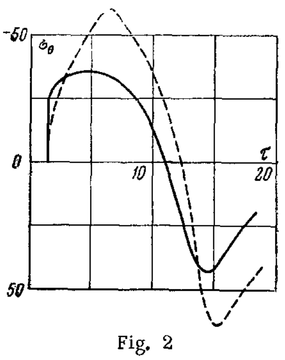

Fig. 2

The shock wave is initially supersonic, so the above data are sufficient for calculating the motion, but the speed of the shock wave at some point comes to equal that of longitudinal waves, after which the wave becomes subsonic. For this second stage we have to formulate a condition for the emission of elastic waves from the shock-wave front to solve the problem. For this condition we took p = $= -(\sigma_r + 2\sigma_\vartheta)/2$ = constant = 600 kg/cm^2, which corresponds to an idealized condition for failure of a porous brittle material produced by hydrostatic pressure alone. Physically speaking, it is very doubtful whether this condition applies for transparent plastic, but numerous calculations for various failure conditions show that the form of this condition has no marked effect on the solution at the stage of subsonic propagation of the shock wave, so we adopted this as one of the possible conditions for transparent plastic. Also, we took as the failure condition for the stage where radial cracks are formed σ_ϑ = constant = 650 kg/cm^2.

The above scheme gives as the following successive stages for wave propagation and failure in transparent plastic.

1. A supersonic compressive shock wave propagates into the unperturbed medium, while the material between the front and the explosion cavity undergoes plastic flow.
2. The shock-wave front propagates subsonically and radiates an elastic wave, while the plastic flow behind the shock wave continues.
3. The shock wave degenerates into a contact break, behind which plastic flow continues, but without involving fresh compression, and the break radiates an elastic wave. This stage continues until σ_ϑ at the break reaches the value σ_* = 650 kg/cm^2.

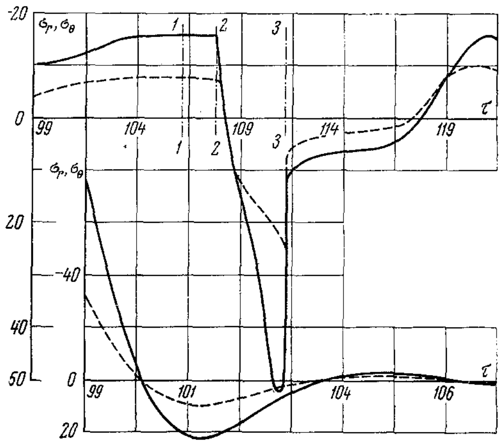

Fig. 3

4. A shock front propagates outward from the break and produces radial cracks; plastic flow continues behind the break. This shock from radiates an eleastic wave, and $\sigma_\vartheta = \sigma_*$ at the leading side of the front.
5. The failure cracks cease to propagate, no new fractures are produced, but the elastic wave is still emitted and the plastic flow around the cavity continues. This stage lasts until the motion around the cavity ceases and the elastic wave emitted in the previous stages has receded to infinity.

This division into five stages is confirmed by high-speed cinematography. The persistent shock waves are indicated by the variable speed of the failure front. Experiments [1, 2] confirm that there is a front and a zone of radial cracks. The material in plastic flow is taken as incompressible to obtain expressions for the stresses and other dynamic quantities as a function of the distance r from the center. Two unknown functions of time are involved.

The stresses and speeds in the zone of radial cracks are expressed via two unknown functions each in one variable; only one known function is involved for the unfractured region where the elastic wave propagates.

*S. S. Grigoryan, Doctoral dissertation, Research on Soil Mechanics, Moscow State University, 1965.

The problem for each stage is to determine the unknown functions and the laws of motion of the boundaries of the cavity, shock wave, and failure front. These laws must satisfy certain equations derived from the conditions at the various boundaries.

In each of stages 1–3, the problem reduces to a Cauchy problem for a system of ordinary differential equations; for stage 4, we get a system of functional differential equations. Stage 5 gives a system of differential equations with a deviant argument. Generally speaking, only a numerical (computer) solution is possible. The initial data for each stage are taken from the solution for the previous stage.

Some results are given below, which were obtained with the Strela-4 computer at the Moscow University Computer Center.

Figure 1 shows the pattern in the plane $x = r/r_0$, $\tau = ct/r_0$. The line $x = x_3(\tau)$ represents the expansion of the cavity; $x = x_2(\tau)$ represents the propagation of the shock-wave front; and $x = x_1(\tau)$ represents the propagation of the failure front. Here r_0 is the radius of the charge chamber, t is time, and r is distance from the center of the charge.

The results agree well with experiment [1], namely a plastic region spreading from r_0 to $2r_0$, and a shatter region extending out to $5r_0$ or $6r_0$ (here allowance must be made for expansion of the charge chamber to $2r_0$ and subsequent contraction almost to the initial size after the shattering [2]). The speed of the shock-wave front ranges from 6000–2700 m/sec and then falls to zero, while the speed of the shatter front is 2500–3000 m/sec [1].

Figure 2 shows σ_ϑ at x = 18 as calculated (solid line) and as deduced from the single reliable oscillogram [1] (dashed line). It is clear from this that the calculated values are only about half of the observed ones, evidently because the static critical stresses for transparent plastic are less than the dynamic values [1] (it has been stated [1] that the static strength is half the dynamic strength). However, Fig. 2 shows good qualitative agreement between theory and experiment.

The calculations show that the stress at a given x increases up to the time when the stress in the elastic wave attains the value for onset of radial cracking, after which the stress decreases and oscillates about the asymptotic (static) value.

Figure 3 (upper part) shows σ_r and σ_ϑ in kg/cm^2 at x = 100 as functions of time, while Fig. 4 (upper part) shows V as a function of τ. Section 1-1 shows the instant when x = 100 is reached by the elastic wave emitted at the moment when $x_2 = 0$ (shock-wave front stops); 2-2 shows the instant when this point is reached by the elastic wave emitted at the instant when the failure front is produced; and 3-3 shows the same for the wave emitted when that front stops.

The lower parts of Figs. 3 and 4 show relationships analogous to those in the upper parts, but constructed for the elastic solution to the problem (without allowance for plasticity, compression, and

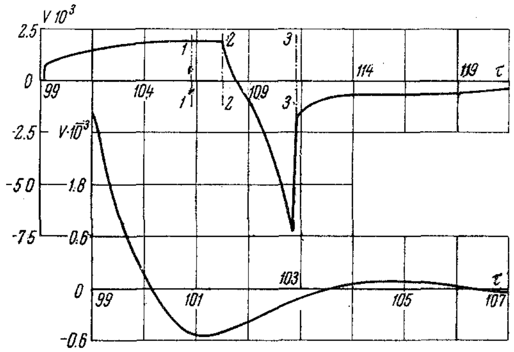

Fig. 4

failure). The differences are very pronounced. The decay of the amplitudes in the first case is much more rapid than in the second (the first maximum in σ_r at x = 100 is 15 kg/cm^2 in the first case, as against 800 kg/cm^2 in the second). The lengths of the first prolonged phase in the two cases are $10r_0/c$ and $1.3r_0/c$. Plasticity and failure near the charge thus produce very great changes in the elastic wave in all respects. These major differences extend out to a large distance from the center on account of effects localized in a small volume around the charge. The results indicate that: 1) our theoretical model agrees well with experiment, 2) it is essential to include the plasticity and brittleness in the immediate region of the charge in considering problems concerning explosions in real brittle solids (e. g., rocks).

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