Attenuation of plane shocks in solids

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INTRODUCTION

Study of propagation of shock waves in solids is of considerable importance, because of its applications in engineering and also for the calculation of the equation of state of the solids.

Drummond [3] studied attenuation of plane explosive shocks in aluminium by the methods of characteristics, by using an explosive whose equation of state is $P=A\rho^{\gamma}$.

We have used here an altogether different method, i.e. based on the energy hypothesis deviced by Thomas [6] and developed by Bhutani [1] and Singh [4, 5]. In his paper Singh has extended the energy hypothesis to find the attenuation of shock waves in water produced by spherical charge. In this paper, we have applied this method to plane shocks produced by plane wave generator.

Attenuation is calculated for plane shock wave in aluminium. Results are compared with those of Drummond and also with experimental data generated by us at TBRL and also by Yadav [7].

It is found that by Drummond's method, attenuation is a little less as compared to that of ours. It is perhaps due to different method of calculation which we have used. At very high pressures our results match well with the experimental data produced by us and Yadav [7]. Due to experimental difficulties more points could not be obtained. Actually at later distances, attenuation is still higher as compared to our theoretical predictions. This is because as shock becomes weaker, the actual situation deviates from the assumption of hydrodynamic flow.

BASIC EQUATIONS OF THE PROBLEM

Let PQ be an explosive device which generates plane wave in the explosive pad QR of length X_0 and cross sectional area A. Let RS be cylinder of some solid material whose cross sectional area is A' which is greater than the area A of explosive pad, and is of semi-infinite length. We initiate the explosive

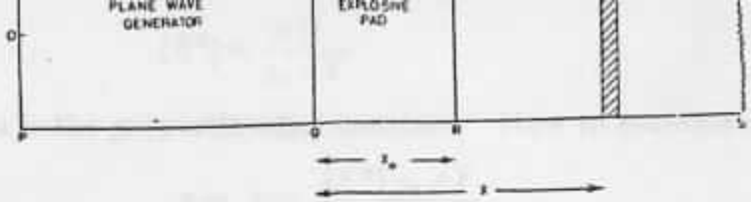

Figure 1 Setup of the model.

device PQ at O, which gives a plane detonation wave in the explosive Q
Plane detonation wave when strikes the face R of the solid cylinder, a pl
shock is induced in the solid material which (shock) moves in the directi
of RS.

Let the equation of state of the solid material be given by

$$U = a + bu_2 \quad (1$$

where U is the shock velocity in the material and u_2 is the particle velo
behind the shock and a, b are the constants of the material. If p, ρ, E are
pressure, density and internal energy per unit mass and subscripts 2 an
respectively denote the state behind and in front of shock, the jump conditi
across the shock are

$$p_2 = \frac{\rho_1 a^2 \delta (\delta - 1)}{\{b \quad \delta (b-1)\}^2} \quad (1$$

$$U = \frac{a \delta}{\{b - \delta (b-1)\}} \quad (1$$

$$E_2^* = E_1^* + \left\{ \frac{(\delta - 1)a}{b - \delta (b-1)} \right\}^2 \quad (1$$

where $\delta = \rho_2 / \rho_1$, $E^* = E + \frac{1}{2} u^2$ (1

Equations (1.2–1.4) are the jump conditions relating four unknowns p_2,
and E_2^*. To solve for these parameters one more relation is required.

If we know the variation of one of these parameters in terms of dist
X, where X is the distance measured from the surface Q, we can know al
parameters.

FORMULATION OF THE PROBLEM

Let $\tilde{Q}$ be the total energy released by the explosive pad QR when deton
Let at any time t, X be the position of the shock and $V\,(= AX)$ be the vo
of the medium perturbed by the shock. Following Singh and Bola [4]
Bhutani [1], one gets jump in energy E^* as (see appendix),

$$[E^*] = \frac{\alpha Q}{\rho_2 AX}$$

where α is the proportionality constant. Now to evaluate α we have

$$\alpha = \lim_{X \to X_0} \frac{[E^*] \rho_2 AX}{J\bar{Q}}$$

where J is the mechanical equivalent of heat and X_0 is the leng explosive charge.

Substituting the value of $[E^*]$ from the relations (1.4) and (2.2)

$$\alpha = \left\{ \frac{a(\delta^* - 1)}{\delta^* - b(\delta^* - 1)} \right\}^2 \frac{\rho_1 \delta^* AX_0}{J\bar{Q}}$$

where $\delta = \delta^*$ when $X = X_0$.

To find δ^* we use mismatch method due to Buchnan and Jame at the solid explosive boundary, we have

$$\frac{p_2}{p_D} = \frac{2\rho_1 U}{\rho_D U_D + \rho_1 U}$$

where $p_D = \frac{1}{4} \rho_D U_D^2$ and U_D, ρ_D are the detonation velocity and dens explosive. In (2.4), p_2, U are functions of δ^* and p_D, ρ_D, U_D a quantities of any explosive. Thus we can evaluate the values c (2.4). In the present case for which we use a RDX/TNT pad, valu 1.26025. Knowing δ^* we know α from equation (2.3). Equation be written as

$$\left\{ \frac{(\delta - 1)}{b - \delta(b-1)} \right\}^2 = \frac{\alpha \bar{Q} / \bar{X}^{-1}}{\rho_1 \delta}$$

where $\bar{X} = X/X_0$ and $\bar{Q}$ is the heat energy per unit volume and i quantity for any explosive. Equation (2.5) enables determination function of $\bar{X}$ and hence p and U.

EXPERIMENTAL SETUP

To find the attenuation of shock velocity in aluminium block expe a streak camera was used. RDX/TNT 60 : 40 pad (thickness X_0) along with a plane wave generator. An aluminium block with a sl for recording the shock attenuation at various thicknesses. Refle intense light, derived from an argon flash bomb, from a mirror st the cut surface of the aluminium block was used in the streak camera Both the event and the argon flash bomb were synchronized and using an electric detonator. In case of no event the argon light from the mirror can be recorded in the streak camera uninterrupt the event is fired in synchronization with the argon flash bomb, sh as shown in Fig. 3. ... streak camera record thus obtained is

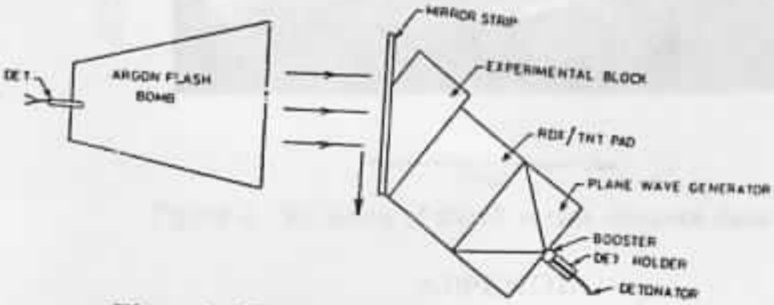

Figure 2 Experimental setup before firing.

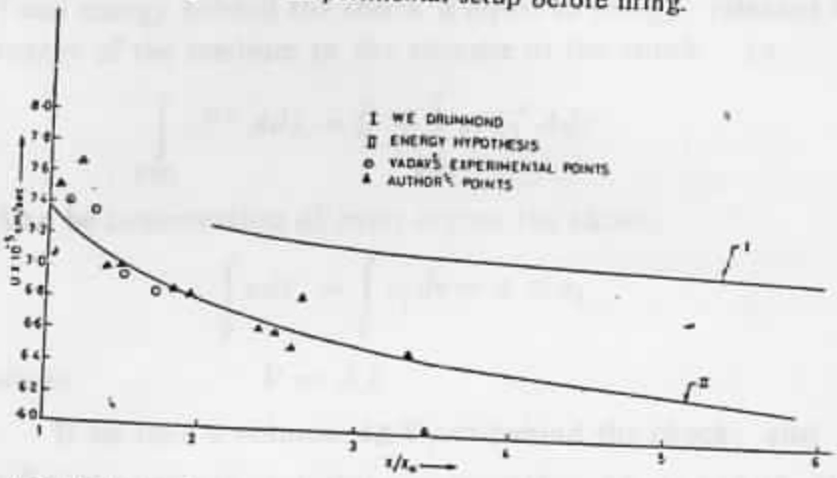

Figure 3 A typical streak record, showing attenuation of shock waves in aluminium.

RESULTS

Equation (2.5) is computed for aluminium. Variation of δ and thus shock velocity is evaluated versus X. Following data are used for numerical computations.

$$a = 5.328 \times 10^5 \text{ cm/s}$$

$$b = 1.338$$

$$\rho_1 = 2.785 \text{ gm/cc}$$

$$\rho_D = 1.68 \text{ gm/cc}$$

$$U_D = 7.8 \times 10^4 \text{ cm/s}$$

$$\bar{Q} = 2476 \text{ cal/cc}$$

Thus

$$\alpha = 0.78256$$

It is found that δ and U decrease as X increases. Results are compared with experimental data produced by us and shown in Fig. 4. It is found that at very high pressure our theory gives very good matching with the experiments. But while comparing our results with those of Drummond we find, in our case attenuation is little more.

The present method can be applied to all the solids which behave like nonviscous, nonheat ...

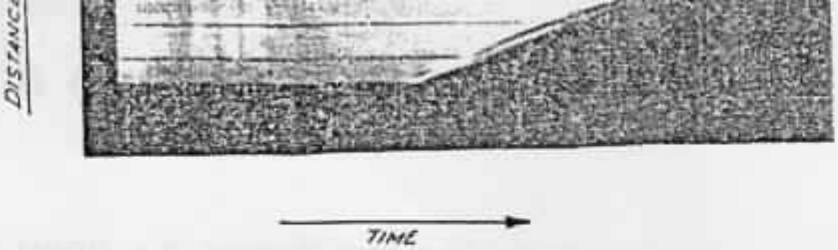

Figure 4 Variation of shock versus distance ratio X/X_0.

APPENDIX

Total energy behind the shock is equal to energy released by explosi energy of the medium in the absence of the shock, i.e.

$$\int_{V(t)} \rho E^* \, A dx = \tilde{Q} + \int_{V(t)} \rho_1 E_1^* \, A dx$$

Also be conservation of mass across the shock,

$$\int_V \rho \, dV = \int_V \rho_1 \, dv = A \times \rho_1$$

where $\qquad V = AX$

If we take a volume $A\Delta X$ just behind the shock, and if in this $\Delta\tilde{Q}$ is the heat of explosion, we have from (A.1) and (A.2)

$$\rho_2 E_2^* \, A.\Delta X = \Delta\tilde{Q} + \rho_1 E_1^* A.\Delta X$$
$$\rho_2 A.\Delta X = \rho_1 A.\Delta X$$

which gives

$$\Delta\tilde{Q} = \rho_2 (E_2^* - E_1^*) \, A.\Delta X$$

Also by energy hypothesis (Bhutani [1])

$$\Delta\tilde{Q} = \alpha\tilde{Q} \, \frac{\Delta X}{X}$$

where α is the proportionality constant. (A.5) and (A.6) give

$$[E^*] = \frac{\alpha\tilde{Q}}{\rho_2 AX}$$

which is same as (2.1).

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