EFFECT OF THE CASING ON THE INITIAL PARAMETERS OF THE UNDERWATER EXPLOSION OF A CYLINDRICAL CHARGE OF EXPLOSIVE

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An experimental determination was made of the initial parameters of shock waves in water with the explosion of cylindrical charges of TNT in casings. It is shown that these parameters depend mainly on the dynamic rigidity of the material and the relative weight of the shell. It is established that during the process of the expansion of the casing of the charge with an explosion in limited volumes of water there is formed a region of extremely rapid expansion, whose boundary can be identified with the boundary between the detonation products and the water after destruction of the casing, coinciding in time with the arrival of the cavitation front.

The question of the underwater explosion of cylindrical (elongated) charges of explosive has been discussed in [1-5]. In [1, 4, 5] data are presented on pressures at the front of shock waves P_f for open charges at relatively great distances from their surfaces, which does not permit evaluating the value of the initial pressure at the front of the shock wave P_{f_0}. In [2], for open charges of PETN (density $\rho = 1.67$ g/cm^3, detonation velocity $D = 8.4$ km/sec), the value of P_{f_0} at the surface of the charge was $195 \cdot 10^3$ kg/cm^2. The underwater explosion of elongated charges in casings (saturated charges of TNT in paper casings, $\rho = 1$ g/cm^3, $D = 5.5$ km/sec, as well as detonating fuses made of TNT and hexogen) was studied in [3]; there the initial pressure at the front of the shock wave P_{f_0} was found equal to $35 \cdot 10^3$ kg/cm^2. However, the substantial change in the detonation parameters in comparison with [2] does not permit forming a judgment with respect to the effect of the casing of the charge on the initial parameters of an underwater shock wave.

The experiments on the study of the effect of the casing on the initial parameters of a shock wave in water were carried out in transparent plane-parallel aquariums measuring $100 \times 100 \times 150$ mm^3. The explosives used were cylindrical charges of TNT ($\rho = 1.55$ g/cm^3, $D = 6.7$ km/sec) with a diameter of $2R_0 = 12$ mm and a length of 42 mm. The charges of explosive were exploded in casings made of Plexiglas and Duralumin with a wall thickness of 1 mm, and of steel (St.3) with wall thicknesses of 0.5, 1, and 2 mm. Ignition was from one end, using lagless detonators. The internal radius of all the samples was equal to 6.5 mm. The explosion was recorded with an SFR-2 camera using a pulsed light source.

The photography was done using a variant of slit scanning. In all cases, the charges were mounted horizontally in the middle part of one of the walls of the aquarium. The width of the slit was 0.2 mm, and the scanning rate was 2 km/sec.

Figures 1-3 give photograms of the scanning of the process of the explosion of charges of explosives in water, where I is the casing of the charge before the explosion, II is a shock wave in water, III is the expanding casing of the charge, IV is the region of very rapid expansion. The time scale (along a horizontal) is 3 mm = 1 μsec.

Figure 1 relates to the explosion of a charge in a steel casing, Fig. 2 in a Duralumin casing, and Fig. 3 in a Plexiglas casing. The presence of light bands in section III of the photogram (Fig. 2) is evidence of the formation of cracks in the Duralumin casing with the passage of a detonation wave from the charge of explosive. The white spot at the boundary between sections I and II of the photogram (Fig. 3) is

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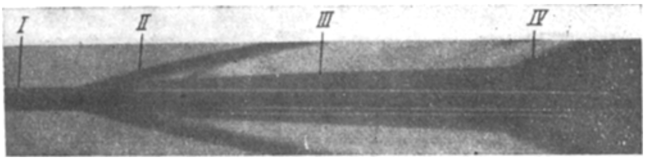

Fig. 1

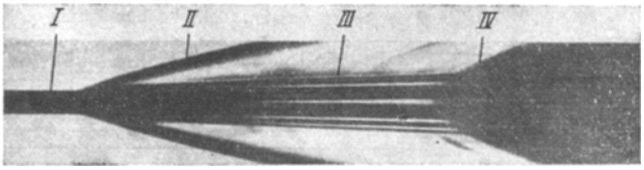

Fig. 2

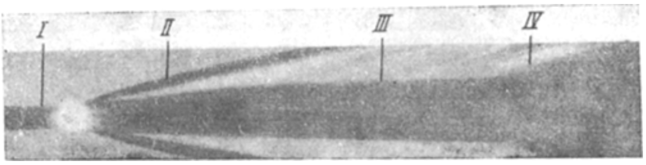

Fig. 3

obviously due to luminescence of the air in the gap between the explosive and the casing with the emergence of the detonation wave to the surface of the charge; in the present case, this is observed as a result of the transparence of the Plexiglas casing.

Analysis of the photograms obtained came down to measurement of the distances ΔR of the front of the shock wave from the surface of the casing, at determined intervals of time $\Delta \tau$. The mean (from two experiments) values of $\Delta R = \Delta R(\Delta \tau)$ mm are given in Table 1.

The data given in Table 1 were approximated by the following dependence with an error not greater than 3-5%, in the range $0 \leq \Delta R^* \leq 2.3$, $0 \leq \Delta \tau^* \leq 4.5$

$$\Delta R^* = V_0^* (1 + \Delta\tau^*)^m \ln (1 + \Delta\tau^*) \tag{1}$$

where

$$\Delta R^* = \Delta R / R_0, \ \Delta\tau^* = \Delta\tau D / R_0$$

V_0^* are experimental constants.

In its physical sense the constant V_0^* is the dimensionless initial rate of propagation of the shock wave along a normal to the surface of the casing. Actually,

$$\frac{d(\Delta R^*)}{d(\Delta\tau^*)} = \frac{1}{D} \frac{d(\Delta R)}{d(\Delta\tau)} = \frac{V_0}{D} = V_0^* \frac{m \ln (1 + \Delta\tau^*) + 1}{(1 + \Delta\tau^*)^{1-m}} \tag{2}$$

whence, with $\Delta \tau^* = 0$ we have $V_0/D = V_0^*$.

The true dimensionless initial velocity of the front of the shock wave $N_{f0}^* = N_{f0}/D$ with slipping of the detonation wave was found in accordance with [3] from the expression

$$N_{fc}^* = V_{f0}^* (1 + V^{*2}{}_0)^{-1/2} \tag{3}$$

Further, using known hydrodynamic relationships, calculations were made of the initial pressures P_{f0} and the mass velocities U_{f0} at the front of the shock wave; these are given in Table 2.

It follows from Table 2 that the initial parameters of a shock wave in water depend mainly on the dynamic rigidity of the material of the casing and the ratio of the weights of the casing and the charge of explosive; the other characteristics do not exert any substantial effect (within the limits of the accuracy of

TABLE 1

Casing mater., exter. radius R_1, mm	$\Delta\tau$, μsec							
	0.333	0.667	1.000	1.333	1.667	2.000	3.000	4.000
Plexiglas $R_1 = 7.65$	2.15	3.20	4.41	5.39	6.55	7.65	10.70	13.45
Duralumin $R_1 = 7.60$	1.35	2.54	3.80	4.68	5.98	7.15	10.09	12.95
St. 3, $R_1 = 7.00$	1.44	2.46	3.64	4.85	5.96	6.87	10.00	12.66
St. 3, $R_1 = 7.50$	1.12	2.04	2.73	3.81	4.66	5.59	8.71	11.15
St. 3, $R_1 = 8.50$	0.90	1.76	2.60	3.50	4.40	5.26	7.58	10.20

TABLE 2

Casing material, dynamic rigidity, $\rho C_0 \cdot 10^{-4}$, g/(cm^2·sec)	Wt. of casing: wt. of charge	V_0^*	m	N_{f0}^*	N_{f0}, km/sec	$P_{f0} \cdot 10^{-3}$, kg/cm^3	U_{f0}, km/sec
Plexiglas $\rho C_0 = 3.4$	0.30	0.880	0.202	0.664	4.45	63.0	1.40
Duralumin $\rho C_0 = 14$	0.64	0.586	0.463	0.506	3.39	28.5	0.82
	1.0	0.613	0.407	0.523	3.50	31.0	—
St. 3 $\rho C_0 = 43$	2.0	0.456	0.496	0.415	2.78	14.5	0.51
	4.0	0.447	0.502	0.412	2.76	13.3	—

TABLE 3

Material of casing	$P_{f0} \cdot 10^{-3}$, kg/cm^2		U_{f0}, km/sec	
	expt.	calc.	expt.	calc.
Plexiglas	63.0	60.0	1.40	1.43
Duralumin	28.5	37.8	0.82	1.06
St. 3	14.5	18.9	0.51	0.66

the experiment). It must be noted that the value of P_{f_0} determined in the present experiments for an open charge of TNT, using the above method, is equal to $62.5 \cdot 10^3$ kg/cm^2, which practically coincides with the corresponding value of P_{f_0} for a charge in a Plexiglas casing.

In [2], for an open charge of TNT, $P_{f_0} = 195 \cdot 10^3$ kg/cm^2. It can be postulated that this result was obtained for the propagation of the front of the shock wave along a normal, i.e., without taking account of the true direction of the velocity of the front of a shock wave with slipping of the detonation. In the present experiments, for TNT in a Plexiglas casing, which practically corresponds to an open charge, with an explosive heat of explosion $Q_{vm} = 1200$ kcal/kg, the normal velocity of the front of the shock wave $V_0 = 5.89$ km/sec; in accordance with [5], such a velocity corresponds to $P_{f_0} = 160 \cdot 10^3$ kg/cm^2. For PETN ($Q_{vm} = 1460$ kcal/kg) we have $P_{f_0} = 160 \cdot 10^3\ (1460/1200) \approx 195 \cdot 10^3$ kg/cm^2, which coincides with the value of P_{f_0} from [2].

It is of interest to compare the experimental values of the initial parameters of a shock wave at the boundary between the casing and the water with the calculated values. Table 3 shows such a comparison for casings made of Plexiglas, Duralumin, and steel with a thickness of 1 mm. Methods for calculating the initial parameters of a shock wave at the boundary between the different media are set forth in [6, 7].

If we take into consideration the degree of approximation of the calculating methods, as well as the assumption made in the calculations with respect to the invariability of the parameters of the shock wave in the casings, the agreement of the results must be recognized as satisfactory.

An interesting fact is the presence of section IV on the photograms (Figs. 1-3), characterized by a sharp point of inflection of the boundary of the image, i.e., by a discontinuity in the velocity. This phenomenon may be due to water cavitation in the rarefaction wave. This assumption is confirmed by the fact, established in special experiments, that the time of the appearance of section IV on the photograms depends on the volume (linear dimensions) of the aquarium in which the explosion takes place.

The indirect linking on the photograms of sections III and IV is evidence of the fact that the cavitation zone has arrived at the casing of the charge. Taking into consideration that, in this case, ahead of the expanding (deforming) casing there is a sharp drop in the pressure, the moment of the appearance of section IV on the photograms may obviously be connected with the moment of the destruction of the casing.

In a consideration of the photograms presented, the following proposition may arise: Is not the appearance of section IV connected with the arrival of the shock wave at the walls of the aquarium and their destruction, leading to a loss of transparency? However, in the experiments under consideration the loss of the transparency of the walls set in later than the start of the recording of section IV, and therefore could not affect its appearance in any way.

Analysis of sections IV on Figs. 1-3 yields the following values of the initial velocities of the motion of the boundary of the rapidly expanding region: in the case of a Plexiglas casing, 5.47 km/sec; in the case of a Duralumin casing, 5.60 km/sec; in the case of a steel casing, 7.02 km/sec.

As can be seen from the data presented, this velocity is considerably greater than the velocity of the front of the shock wave in section II, N_{f0}. If the identity holds between the boundary of the image in section IV of the photograms and the boundary of a gas bubble after destruction of the casing, such a discontinuity in the velocity may be explained by a sharp lowering of the density of the cavitating water [4, 8].

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