Pramāṇa – J. Phys., Vol. 32, No. 1, January 1989, pp. 39–45. © Printed in India.

Simulation of pressure-space-time history in underwater explosions

V P SINGH and A M N YOGI

Centre for Aeronautical Systems Studies and Analyses, C V Raman Nagar, Bangalore 560 093, India

MS received 24 February 1988; revised 2 October 1988

Abstract. Pressure-space-time history of shock waves due to the detonation of explosive charge in water is obtained by simulating the numerical integration of shock trajectory with the variation of fluid parameters behind the shock front. Results are compared with those obtained experimentally elsewhere.

Keywords. Simulation; underwater explosion; pressure-space-time.

PACS No. 52·35

1. Introduction

Evaluation of pressure space time history of shock wave due to underwater explosion is the first requirement for the estimation of damage to targets in the medium. Pressure-space-time history is obtained experimentally by using pressure transducers (Bjarnholt 1980). The theoretical evaluation of shock attenuation with time has not so far been studied completely by analytical methods. Brode (1959) who tried to solve this problem in air by making use of the artificial viscosity method did not compare his results with those obtained experimentally. Bjarnholt (1980) showed that pressure time curve is of exponential shape. To study the attenuation of shock with respect to time, knowledge of variation of fluid parameter behind the shock is estimated. Singh and Yogi (1988) evaluated the variation of pressure inside the shock envelope as a function of scaled distance r/R, where r is the spatial distance and R the shock radius. Since R is a function of time, we have simulated the pressure-time history at a fixed point as the shock envelope expands to infinity by fixing r and allowing the time to increase.

The theoretical pressure time history thus obtained has been compared with that obtained experimentally by Singh *et al* (1986) for the case of a spherical charge of a typical explosive (composition-*B*), and good agreement is obtained.

2. Formulation of the problem

The aim of the present study is to find the pressure-space-time history of shock profile as it propagates in water medium. Various theories have been suggested to find the space attenuation of shock waves. In this connection, the names of Whitham (1958), Brinkley and Kirkwood (1947) and Thomas (1957) are worth mentioning. Later Singh *et al* (1980) modified the energy hypothesis of Thomas (1957) for the case of the explosion of a finite charge in water. We have used the energy hypothesis of Thomas (1957) to evaluate space attenuation of shock waves in water.

But attenuation of shock parameters due to time has not been studied completely in water medium (Brode 1959). In the present paper, we have tried to solve this problem by combining three different problems as follows:

(a) space attenuation of shock wave produced by underwater explosion;
(b) variation of pressure with time at a fixed point inside the shock envelope where R is an increasing function of time;
(c) to determine the time interval between explosion and the current time, using shock trajectory $dR/dt = U(t)$.

It is assumed that at time $t = 0$ there is an explosion in water medium and a spherical shock starts from the surface of the charge of radius R_0 along the radial direction. Conditions at the water-explosive boundary are known (Buchanan and James 1959). Our aim is to find the pressure-time history attained at a fixed point in space due to this explosion. We assume that all the distances are scaled with respect to R_0, and all velocities are scaled with respect to the sound velocity in water. Let the radial distance r, at which the variation of fluid parameters with respect to time is to be studied, be denoted by ξ.

As shock propagates from the explosive surface to the medium the attenuation law is given by (Singh *et al* 1980)

$$F(U) = F(U_T)/R^3, \tag{1}$$

where

$$F(U) = U(U-a)^2/(a+(b-1)U),$$

R, U, U_T respectively are the scaled radial distance, scaled shock velocity and transmitted shock velocity at the explosive water boundary, a and b are the parameters of the equation of state of water given as,

$$U = a + bu_2,$$

where a has the dimensions of velocity and is the same as the sound velocity in water (Madan *et al* 1983). Equation (1) gives the variation of shock velocity versus R. The value of U_T transmitted from the explosive to water can be evaluated by the shock impedance method (Buchanan and James 1959; see also Singh *et al* 1980).

The time taken by the shock to cover the distance from $R = 1$ (surface of explosive) to R is given by

$$t = (R_0/a)\int_1^R (dR/U), \tag{2}$$

where $R = 1$ at the explosive-water boundary. As the shock crosses the point $r = \xi$, the pressure at that point rises sharply, which subsequently attenuates as t passes. Now our aim is to find the pressure-time history at $r = \xi$ which is fixed in space, r being the particle path and the flow being radial. If the shock front crosses this point at time $t = t_1$, then

$$t = t_1; \quad r = R = \xi. \tag{3}$$

t_1 can be evaluated from (2), where the limits for integral vary from 1 to ξ. Let at this point $U(t_1)$ be the shock velocity, P the pressure and ρ the density. We denote these values with subscript 2, immediately after the shock has crossed the point $R = \xi$. Flow behind this shock was studied by Singh and Yogi (1988). In that study, variation of fluid parameters behind the shock was studied as a function of $\lambda(=r/R)$. Thus we find that $\lambda = 1$ at $t = t_1$.

At time t_1 the value of pressure and density at point ξ is governed by the Rankine Hugoniot (R-H) jump conditions. But after a small interval of time (Δt), i.e. at time $t_1 + \Delta t$, R becomes $\xi + \Delta R$. Thus the value of λ at a fixed point ξ at time $t_1 + \Delta t$ becomes $\xi/(R + \Delta R)$, which is less than the earlier value of λ which was equal to one. The value of fluid parameters at new λ can be determined by integrating the following equations from $\lambda = 1$ to $\lambda = \xi/(R + \Delta R)$, by Runge-Kutta method

$$\mathrm{d}f_0/\mathrm{d}\lambda = \frac{2f_0}{[\lambda\{(f_0 - \lambda)^2 - 1\}]}, \tag{4a}$$

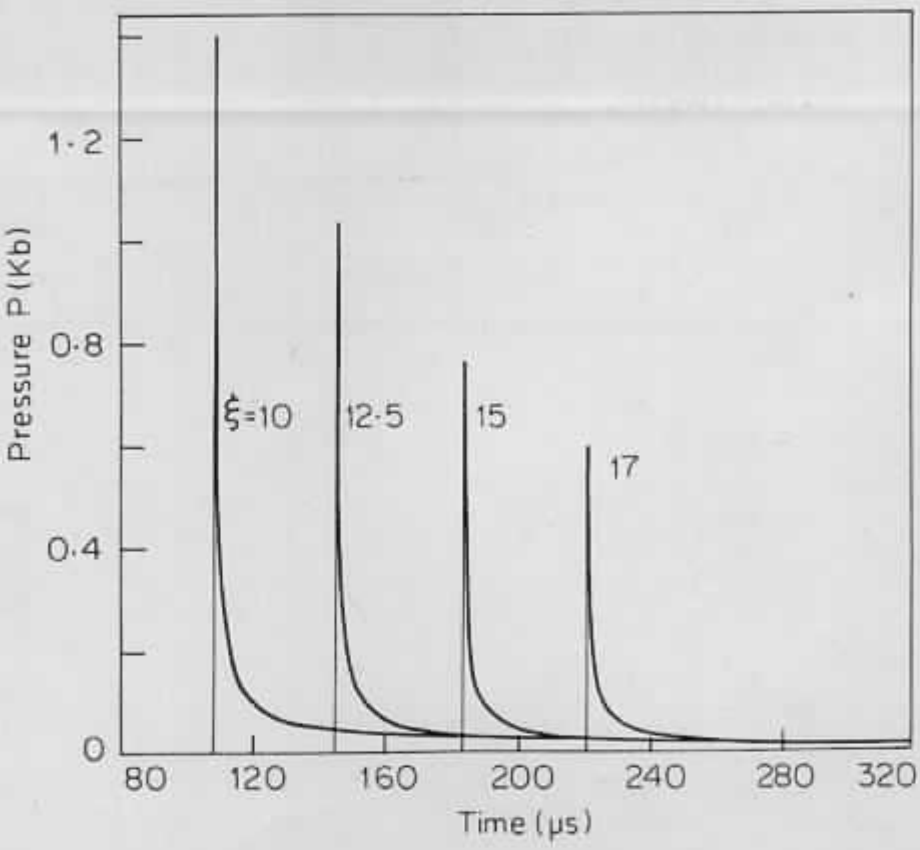

Figure 1. Pressure-space-time curve for various distance (ξ = 10 to 17·5) for TNT spherical charge.

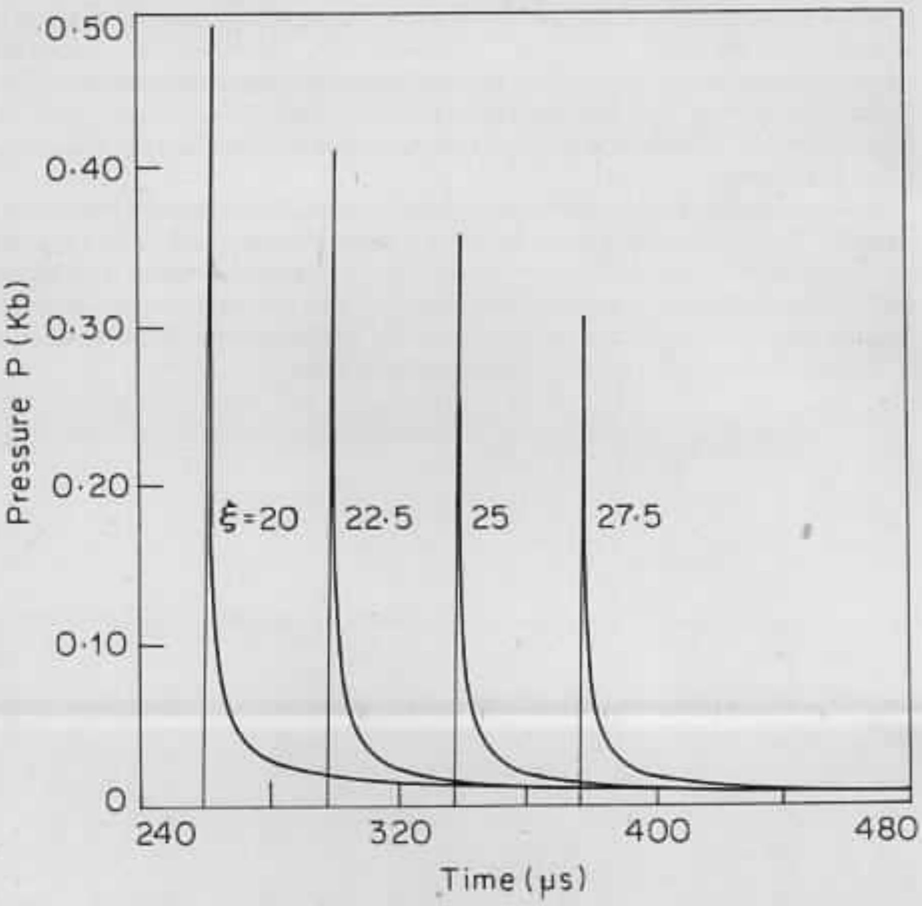

Figure 2. Pressure-space-time curve for various distance ($\xi = 20$ to 27·5) for TNT spherical charge.

$$dg_0/d\lambda = \frac{-2f_0(f_0-\lambda)g_0}{[\lambda\{(f_0-\lambda)^2-1\}]}, \tag{4b}$$

$$df_1/d\lambda = \frac{-[h_1(f_0-\lambda)+h_2]}{[g_0\{(f_0-\lambda)^2-1\}]}, \tag{4c}$$

$$dg_1/d\lambda = \frac{[h_1+(f_0-\lambda)h_2]}{[(f_0-\lambda)^2-1]}, \tag{4d}$$

$$df_2/d\lambda = \frac{-[h_3(f_0-\lambda)+h_4]}{[g_0\{(f_0-\lambda)^2-1\}]}, \tag{4e}$$

$$dg_2/d\lambda = \frac{[h_3+h_4(f_0-\lambda)]}{[(f_0-\lambda)^2-1]}, \tag{4f}$$

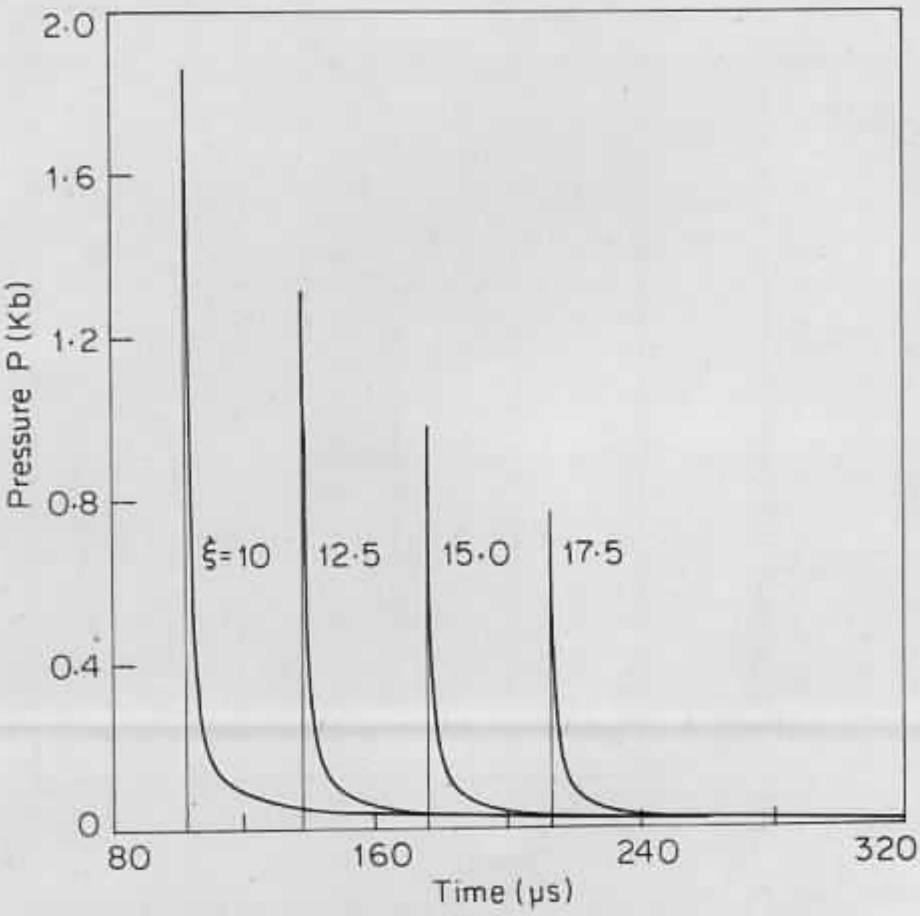

Figure 3. Pressure-space-time curve for various distance ($\xi = 10$ to $17{\cdot}5$) for Comp-B spherical charge.

where f_0, g_0, f_1, g_1, f_2, and g_2 are the zeroth, first and second order perturbations of f and g which are defined as

$$f = u/U \quad \text{and} \quad g = \rho/\rho_2$$

and h_1, h_2, h_3, h_4 are functions of f_0, f_1, g_0, g_1 etc and their derivatives are as follows

$$h_1 = f_1 g_0 f'_0 + (2b - 2 - g_1/g_0)g'_0 - \beta_0 g_0 (f_1 + b f_0),$$

$$h_2 = -g_1 f'_0 - f_1 g'_0 + \beta_0 (g_0 + g_1) - 2(f_1 g_0 + f_0 g_1)/\lambda,$$

$$h_3 = f_2 g_0 f'_0 + f_1 g_0 f'_1 + g'_0 [g_1^2/g_0^2 - g_2/g_0 - g_1(2b-2)/g_0 + 2b^2 - 6b + 3]$$
$$- g'_1 (g_1/g_0 - 2b + 2) - \beta_0 g_0 [f_0 (b^2 - 2b) + f_1 b + 2 f_2]$$
$$- \beta_1 g_0 (b f_0 + f_1),$$

$$h_4 = -g_2 f'_0 - g_1 f'_1 - f_2 g'_0 - f_1 g'_1 - \beta_0 (g_0 - g_1 - 2g_2) + \beta_1 (g_0 + g_1)$$
$$- 2(f_0 g_2 + f_1 g_1 + f_2 g_0)/\lambda. \qquad (5)$$

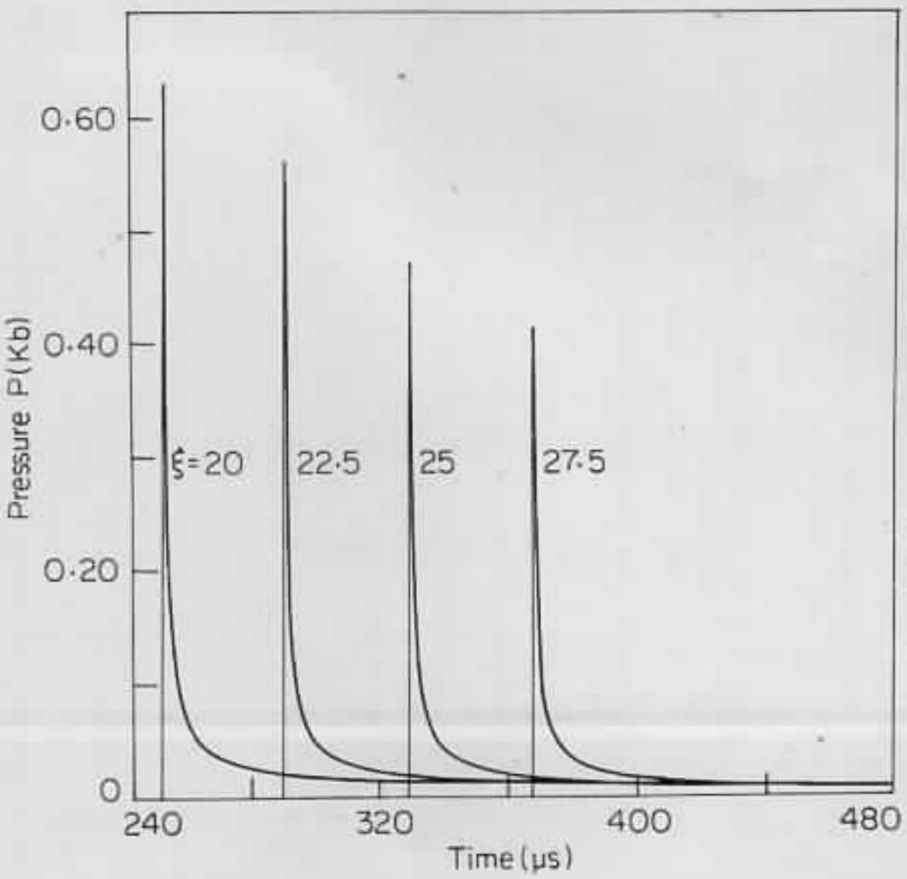

Figure 4. Pressure-space-time curve for various distance ($\xi = 20$ to $27{\cdot}5$) for Comp-B spherical charge.

This process is repeated until $R = R_{max}$, where R_{max} is the preassigned maximum value of R. Knowing ρ at t, the pressure can be evaluated from equation of state. Thus pressure time curves are obtained at eight fixed points in space, i.e. for $\xi = 10$ to $\xi = 27{\cdot}5$. In figures 1 and 2, we have plotted the pressure-space-time history of shock at different points varying from $\xi = 10$ to $\xi = 27{\cdot}50$ created by the detonation of a spherical charge of TNT and in figures 3 and 4, similar results are plotted for spherical charge of composition B.

3. Comparison with experiments

Singh *et al* (1986) have obtained pressure-space history of shock in water due to the detonation of spherical charge of composition-B, using quartz pressure gauge. The results obtained in §2 by computer simulation have been compared with that obtained experimentally by the above authors for a typical case of $\xi = 44{\cdot}7$. Good agreement of experimental results is seen between the two (figure 5). From the shape of pressure-time curves, it is observed that the curves are exponential.

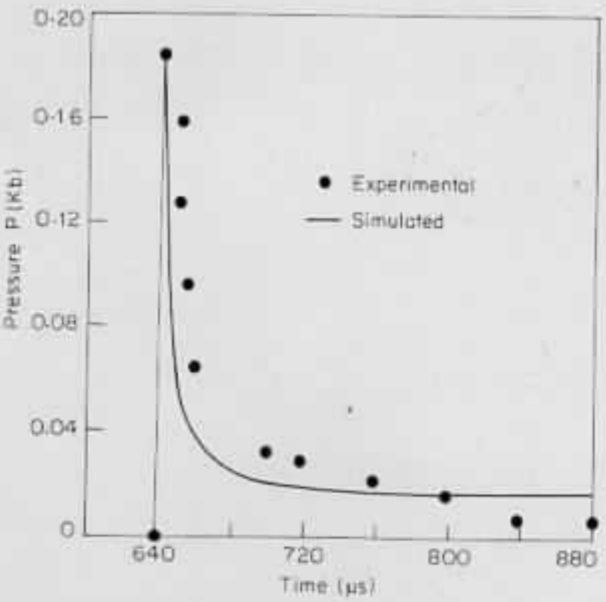

Figure 5. Comparison of simulated results with experimental results for a typical Comp-B charge.

Acknowledgement

The authors are thankful to Dr R Natarajan for encouragement.

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