PREDICTING RESPONSE OF MUNITIONS TO MASSIVE SECONDARY FRAGMENT IMPACT
A Proposed Analytical Method

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ABSTRACT

This paper presents an analytic method for studying the mechanisms that lead to the detonation of cased munitions filled with molten explosives when impacted by large concrete fragments, representing failed wall sections. This is a single degree of freedom dynamic structural analysis method which makes use of predetermined, nonlinear load-deflection characteristics of the shell casing. In the analysis described, the method was applied to predict the pressure-time history in the molten explosive when subjected to impact. A reasonable comparison between analytic and experimental results was obtained.

INTRODUCTION

At one state of the munition production process, molten explosives are poured into empty shell casings. At this, and most stages of the production process there is a finite probability that an accidental explosion may occur. To limit the propagation of an accidental explosion, the pouring area is subdivided into smaller areas separated by reinforced concrete walls. This does not completely eliminate the danger of propagation because an explosion in a cubicle can cause some breakup of dividing walls, producing energized fragments which may impact shell casings in neighboring cubicles thus possibly producing additional detonations. Whether or not an explosion is produced by such impact depends on the dynamic pressures produced within the molten explosive, which in turn depends on the mass of the impacting fragment, its impact velocity, point and angle of the impact, etc. The size of fragments produced by a separation wall depends on the physical characteristics of the wall, i.e. reinforcement details, concrete strength, aggregate size, thickness, span, support conditions, etc. It also depends on the intensity and distribution of the blast load produced by the donor charge on the dividing wall.

This paper describes a project (Ref. 1) whose objective was to study the mechanisms controlling the impact sensitivity of shell casings filled with molten explosives when impacted by secondary fragments. (It was determined in earlier experimental investigations that a shell in the molten or just-poured state was more sensitive to initiation than when the explosive was cool and hardened). The project was divided into two parts.

The first part was an analytic effort whose purpose was to predict the pressure buildup within the molten explosive when the casing and the contained explosive interact with a secondary fragment. It is hypothesized that pressure buildup (or the rate of pressure buildup) and the resulting rise in temperature is a good measure of explosive detonation sensitivity.

The second part was an experimental effort whose aim was to ascertain the credibility and accuracy of the analysis. Instrumented, full scale experiments were performed to obtain quantitative data for comparison with analytic results. The experiments also provided an insight into what was occurring during the impact process and thus helped guide the analysis.

ANALYSIS OF SHELL EXPLOSIONS DUE TO IMPACT BY LARGE CONCRETE FRAGMENTS

Figure 1 is a schematic showing the shell-fragment configuration analyzed. The shell casing, open at its apex and completely filled with molten explosive, is stationary on the ground plane. At the time of impact the explosive is at a sufficiently high temperature to be in a liquid state. The fragment, a concrete cylinder, is moving in a horizontal direction with velocity, V. The conditions are assumed to be such that during impact the shell casing will be plastically deformed and will experience an acceleration. The plastic deformation of the casing will cause the molten explosive to be pressurized and to be forced to flow up and through the filling orifice at the apex of the casing. This pressure buildup during the time of impact and the associated temperature rise, is hypothesized to be a measure for determining if the explosive will detonate. The analytic procedure used to obtain the pressure-time relationship in the explosive during impact is described next.

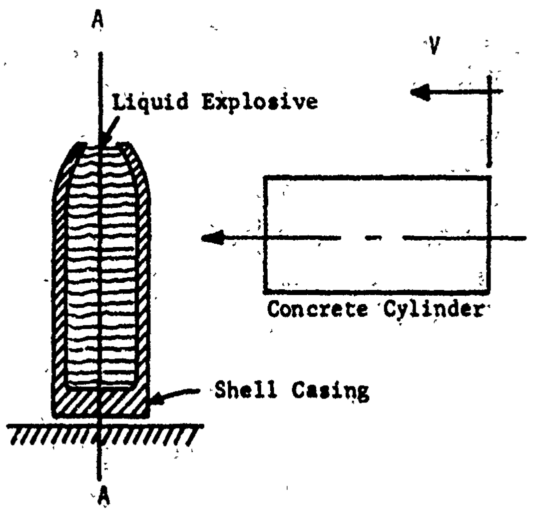

FIG. 1.- Shell-Fragment Configuration

Analytic Solution Requirements

The analytic solution is a single-degree of freedom dynamic analysis which requires certain postulated explosive, shell casing, and fragment interaction characteristics which are the following:

1. Force-deflection characteristics (resistance function) of the shell casing
2. Volume versus deflection characteristic of the shell casing
3. Orifice area versus deflection characteristics

For the purpose of determining the force-deflection characteristics, the shell casing was assumed to be restrained in the horizontal direction only, all along the line formed by the intersection of the midplane of the shell surface and the vertical plane whose edge view is indicated by line A-A in Fig. 1. Making use of the shell symmetry, one quarter of the shell surface is modeled for finite element analysis as shown in Fig. 2. Thickness is varied along the height in discrete intervals. ANSYS (Ref. 2) finite element computer program which meets the requirements of large deflection and plastic deformation of the casing material, was used in the analysis. Force-deflection characteristics were obtained by imposing deflections and then computing the corresponding forces required to produce them. Deflections were imposed on the shell casing at nodes representing an area approximately equal to the contact area between the casing and the impacting concrete cylinder. Load deflection characteristics were determined for three pressures applied to the interior of the shell. Results are shown in Fig. 3. Along with force-deflection characteristics of the shell casing, volume-deflection and orifice area-deflection characteristics were obtained from this analysis. These results are shown in Fig. 4 and Fig. 5 respectively. It will be noted that both of these characteristics are independent of internal pressure. Also, at least for this shell casing, there was essentially no change in the orifice area with change in deflection, see Fig. 5.

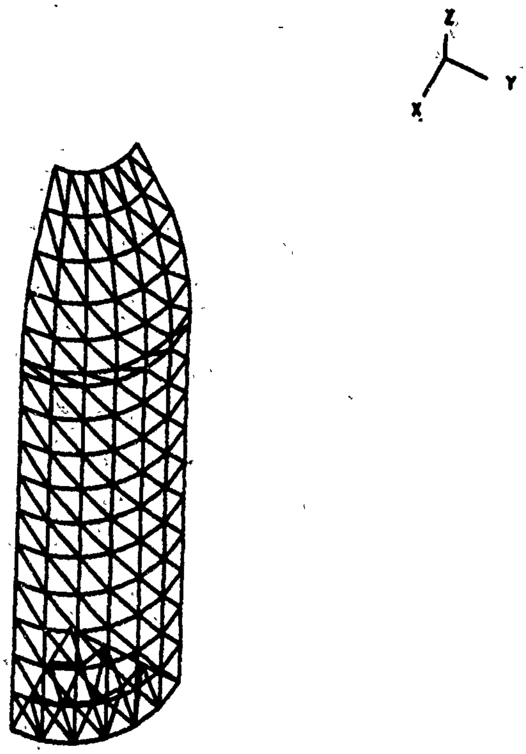

FIG. 2.-Finite Element Mesh of One Quarter of the Shell

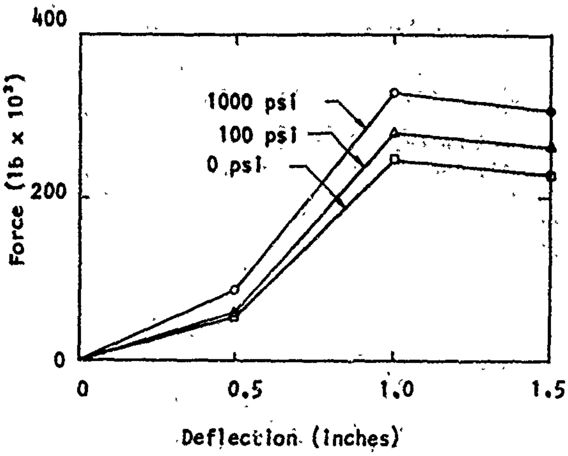

FIG. 3.-Force Versus Deflection Characteristics of the Shell Casing for Indicated Internal Pressures

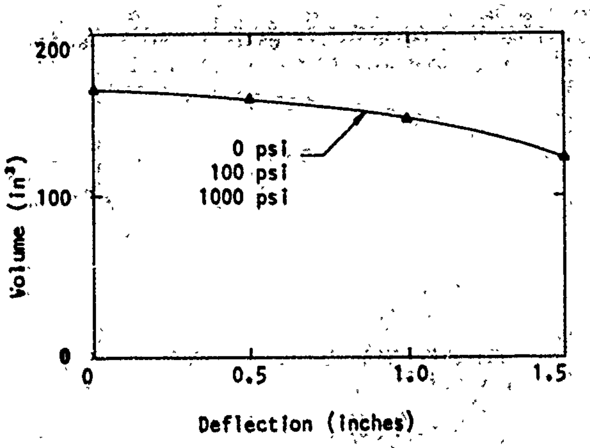

FIG. 4.-Volume Versus Deflection Characteristic of the Shell Casing

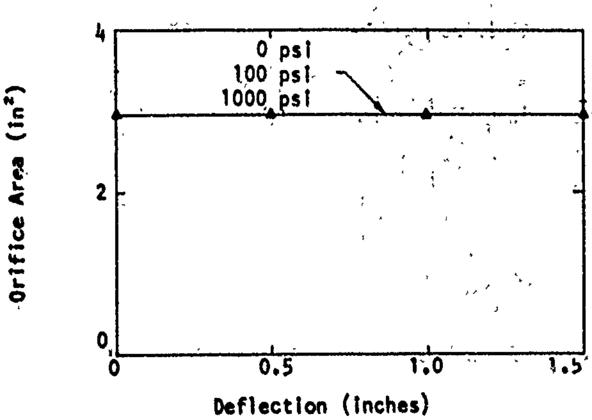

FIG. 5.-Orifice Area Versus Deflection Characteristic of the Shell Casing

Next, we were concerned with the flow characteristics of the molten explosive through the filling orifice of the casing. The flow is dependent on the orifice area, the fluid pressure, viscosity and the orifice coefficient. The following formula (Ref. 3) was used to relate the flow rate, Q to the internal pressure, p of the liquid explosive and other parameters.

$$Q = C_c A \sqrt{2gp/\gamma} \qquad (1)$$

where C_c = the orifice coefficient, taken as 0.64
- A = the orifice area
- g = acceleration due to gravity
- γ = weight density of the molten explosive, taken as approximately 85 lb/cu ft

Flow characteristics are shown in Fig. 6 for three orifice areas.

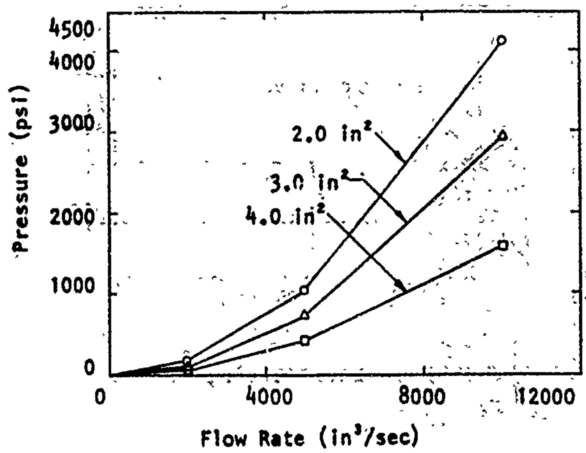

FIG. 6.-Pressure Versus Flow Rate for Three Orifice Areas

In the initial analysis it was assumed that the molten explosive was incompressible. Analytic results using this assumption showed large rapid changes in the liquid explosive pressure, suggesting compressibility. The analysis was modified to take into account fluid compressibility. In the modified analysis the characteristics shown in Fig. 6 are still used, however the corresponding internal pressure is modified on the basis of the bulk modulus of the explosive, i.e.

$$B = \rho \frac{\Delta p}{\Delta \rho} \qquad (2)$$

where B = the bulk modulus taken as 580,000 psi
- ρ = the weight density of the molten explosive
- Δp = change in internal pressure

Analytic Solution Procedure

As indicated earlier, the analytic solution is a single-degree of freedom analysis. Referring to Fig. 1, assuming that the concrete cylinder and the shell move in a straight line, the equations of motion and initial conditions are given as follows:

$$M_c \ddot{x}_c = -F \qquad (3)$$

$$M_s \ddot{x}_s = F \qquad (4)$$

where M_c and M_s represent the mass of the cylinder and the shell casing respectively. F is the interaction force between the shell and the concrete cylinder, and $\ddot{x}_c$ and $\ddot{x}_s$ are the center of gravity accelerations of the concrete cylinder and the shell respectively.

The initial conditions for the concrete cylinder and the shell are (at t=0, impact is initiated) $\dot{x}_c$; the initial velocity of the cylinder is equal to V; $\dot{x}_s$, the initial velocity of the shell is equal to zero. The initial displacements x_c and x_s, of the cylinder and the shell are equal to zero. Euler equations were used in the integration process, i.e.

$$\dot{x}(t+\Delta t) = \dot{x}(t) + \ddot{x}(t)\Delta t \quad (5)$$

$$x(t+\Delta t) = x(t) + \dot{x}(t)\Delta t \quad (6)$$

The solution procedure is detailed below.

Solution Procedure

1. Read data describing the system
2. Set time to zero (t=0) and displacements and velocities to their initial values. Set initial internal pressure to zero, and the orifice area and the casing volume to the initial values.
3. Print out time and pressure
4. If time exceeds maximum value, stop.
5. From force-deflection-pressure curves (Fig. 3) determine the interaction force, F. Note that the casing deflection δ, is the difference in the cylinder and shell motions (displacements), i.e. $\delta = x_c - x_s$.
6. Compute cylinder and shell accelerations, see equations (3) and (4).
7. Use the Euler integration formulas, expressions (5) and (6), to determine velocities and displacements of the cylinder and the casing at time $t + \Delta t$. Update time to $t + \Delta t$.
8. Determine shell casing volume using volume-deflection-pressure curve (Fig. 4). Compute volume rate of flow from difference in volume from previous time step divided by time step, Δt.
9. Determine orifice area from orifice area-deflection-pressure curves (Fig. 5).
10. Determine new internal pressure from pressure-volume flow rate-area curves (Fig. 6).

Steps 11 through 13 represent an iterative procedure used to take into account the compressibility of the liquid explosive.

11. Determine the change in pressure over the time step Δt and compute the change in the weight density of the liquid explosive, see Eq. (2).
12. Determine the new weight density.
13. Determine the change in volume due to the change in the weight density. Compute the volume rate of flow.

Continue the iteration until the change in volume is smaller than a preassigned value.

14. Return to step 3 and continue.

EXPERIMENTAL EFFORT

The purpose of the experimental effort was to measure the pressure-time history within the molten explosive when the shell containing it is impacted by a concrete fragment. The experimental setup is depicted in Fig. 7. A shell casing, containing a liquid, Glycerol, of the same density as molten composition B explosive is mounted (propped) on a pedestal, see "target" in Fig. 7. An air gun is then used to launch the concrete fragment at the shell casing to impact at a specified aiming point. The concrete fragment is in the shape of a cylinder. Two sizes and weights were used in this study (Ref. 1), 2-ft and 4-ft long and weighing 200-lbs and 400-lbs respectively. The instrumentation consisted of a pressure sensor located within the liquid for measuring the pressure-time history during impact. Photographic coverage was provided to measure the impact velocity of the concrete cylinder.

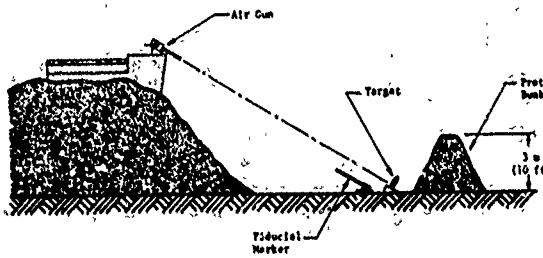

FIG. 7.-Secondary Fragments Impact Test Site

Selected Results

Figure 8 shows an experimentally determined and the corresponding analytic pressure-time history. This particular experiment dealt with a 4.2-in. mortar shell filled with Glycerol and water at ambient temperature. A concrete cylinder, simulating a wall fragment and weighing 200 lbs., impacted the shell at 272 ft/sec at a point 4.25 in below the filling orifice. In terms of the shape of the pressure-time history, duration and peak pressure, the comparison between experimental and analytic results appears to be favorable. Similar comparisons were obtained for other experiments conducted in the course of the study.

CONCLUSIONS AND RECOMMENDATIONS

A simple analytic method was formulated for predicting pressure-time histories in shell casings filled with molten explosives when impacted by secondary fragments. Analytic results compared favorably with experiments.

Additional analyses are required to study the sensitivity of results for a larger set of experiments with the objective of improving the accuracy of the predictive method. To date four other experimental programs have been conducted on the sensitivity to impact, by large concrete fragments, of a variety of molten and ambient temperature explosive-filled shells. For these previous experimental programs analytical predictions of time curves should be performed. With a larger number of curves, and hence larger number of test conditions, one would be able to distinguish between pressure-time conditions for explosion and no reaction. The scope of this method needs to be further expanded to study whether the peak pressure in the liquid explosive, rate of pressure rise, etc. are parameters which individually or in combination will predict the onset of detonation.

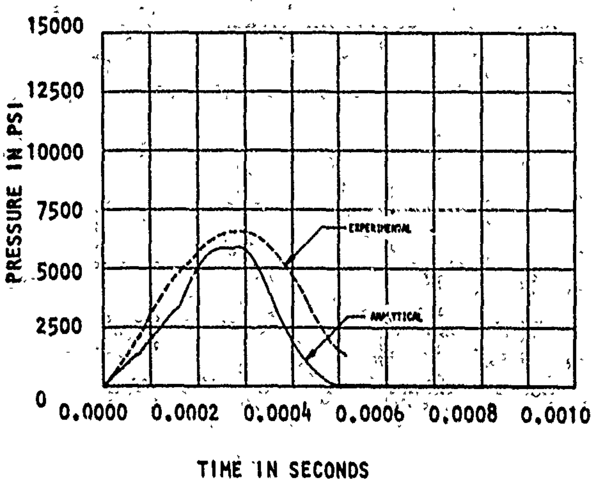

FIG. 8.-Pressure Versus Time Graph for Experiment 4 (Concrete Projectile 200 lb. at 272 ft/sec Velocity)

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