Response of a Cylindrical Steel Container to Internal Explosive Loading with Variation in the Degree of Water Filling


Results of an experimental study of the response of cylindrical steel containers to internal explosive loading as a function of the degree of water filling are presented. The experiment was supported by numerical calculations of the system “explosive-filling medium-container.” A significant effect of the filling medium on the shape and deformation of the container was found. The main contribution is made by the compressibility of the filling medium and the ratio of its mass to the mass of the deformable walls of the container.

Explosion-protective containers with a cylindrical carrier containment are widely used in the explosion-localization technology. In particular, in studying the explosion resistance of containments, tubes, and tanks filled with air or water (see, e.g., [1–6]), a strong effect of the filling medium on the container response was established [1, 4]. Nevertheless, the reasons for this effect remained unclear without a comprehensive investigation of explosive processes. The present paper is devoted to this particular aspect of the problem of explosion localization.

This work was conducted in 1976–1987 within the framework of an extensive program on studying the explosion resistance of the body of a fast reactor of the BN-600 type [6]. This body is partly filled with liquid sodium, which is similar to water in a number of physico-mechanical properties. In the case of emergency explosive-like energy release in the core region, not only the equipment inside the reactor but also the body would experience pulse loading. Since the body is a barrier for evolution of an accident, explosion resistance is an important characteristic of its strength [7].

Layout of the Experiment. The layout of the experiments is shown in Fig. 1. The objects of the study are cylindrical containments of two types and sizes: large (Nos. 1 and 2) and small (Nos. 3 and 4), which were made of steel 12Kh18N10T; the butt-end elements of the containments (the bottom and the lid) were flat. The containments had, respectively, the following dimensions: outside radii R₀ = 1.22 and 0.1525 m, thicknesses h₀ = 0.03 and 0.004 m, and...
TABLE 1
Initial Experimental Data and Kinematic Parameters of the Containments in the Middle Cross Section

<table>
<thead>
<tr>
<th>Container No.</th>
<th>( R_0, ) m</th>
<th>( h_0/R_0, ) %</th>
<th>( \sigma_{0.2}, ) MPa</th>
<th>( m_\perp ), kg</th>
<th>( \xi_\perp ), %</th>
<th>Strain</th>
<th>( v_0, ) m/sec</th>
<th>( t_{\text{max}}, ) ( \mu\text{sec} )</th>
<th>( t_{\text{max}}, ) ( \mu\text{sec} )</th>
<th>( \Delta_{\text{pl}}, ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.22</td>
<td>2.5</td>
<td>314</td>
<td>112.51</td>
<td>1.29</td>
<td>Circumferential</td>
<td>( \approx 91^* )</td>
<td>( \approx 85^* )</td>
<td>( \approx 1900^* )</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Meridional</td>
<td>-</td>
<td>-0.3</td>
<td>800</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1.22</td>
<td>2.5</td>
<td>314</td>
<td>77.80</td>
<td>0.89</td>
<td>Circumferential</td>
<td>182</td>
<td>39.1</td>
<td>7300</td>
<td>37.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Meridional</td>
<td>-</td>
<td>-</td>
<td>-3.0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.1525</td>
<td>2.6</td>
<td>315</td>
<td>0.071</td>
<td>0.39</td>
<td>Circumferential</td>
<td>106</td>
<td>17.1</td>
<td>650</td>
<td>16.3</td>
</tr>
<tr>
<td>4</td>
<td>0.1525</td>
<td>2.6</td>
<td>315</td>
<td>0.071</td>
<td>0.39</td>
<td>-</td>
<td>107</td>
<td>18.5</td>
<td>675</td>
<td>16.9</td>
</tr>
</tbody>
</table>

Note. *Calculated estimate in the plane of the explosion center, which is shifted from the gauge by \( \approx 130 \) mm (see footnote 6).

lengths \( L \approx 5.5 \) and \( \approx 0.62 \) m. Taking into account the close values of \( h_0/R_0 \) \( \approx 2.5 \) and \( 2.6\% \) and \( L/R_0 \) \( \approx 4.5 \) and \( 4.1 \), the containments of containers of different size may be considered to be geometrically similar. Therefore, the difference in containment dimensions seems to be insignificant for a comparative analysis of experimental results.

The following cases of container filling were studied:

- with air (container No. 1);
- with water (container Nos. 2 and 3);
- with water up to \( 3/4 \) of volume (container No. 4).\(^4\)

A spherical charge of a condensed high explosive (HE) was blasted in the center of a container mounted vertically on a wooden board on a concrete platform (Nos. 1 and 2) or on a wooden table (Nos. 3 and 4). Detonation was initiated in the center of the charge. All containers experienced one-time loading by an explosion of a charge, which was \( 40/60 \) TNT/RDX for container Nos. 1 and 2 (HE density \( \rho_{\text{HE}} = 1720 \) kg/m\(^3\), and heat of explosion \( Q = 4.93 \) MJ/kg), and \( 50/50 \) TNT/RDX for container Nos. 3 and 4 (\( \rho_{\text{HE}} = 1650 \) kg/m\(^3\) and \( Q = 4.78 \) MJ/kg). Since HE of different power were used for large and small containers, for convenience of comparison of results, Table 1 contains TNT equivalents of charge masses determined from formulas based on [8, pp. 493, 575, 576] under conditions of energy similarity of the compared HE and identical shock pulses of pressure:

\[
m = m_\perp \sqrt{Q_\perp/Q}
\]

for an explosion in air (the mass of air is ignored) or

\[
m = m_\perp Q_\perp/Q
\]

\(^4\)Results of experiments with container Nos. 1 and 4 are published for the first time, and those for Nos. 2 and 3 are given in [6].

for an explosion in water (in the acoustic approximation). Here \( m \) and \( Q \) \((4.232 \) MJ/kg) are the mass and heat of explosion of an equivalent TNT charge \((\rho_{\text{HE}} = 1620 \) kg/m\(^3\)) and \( m_\perp \) and \( Q_\perp \) are the same parameters for another HE. For a comparative analysis of explosion efficiency, it is convenient to use a parameter such as the relative HE mass:

\[
\xi = m/M.
\]

For an explosion in water (in the acoustic approximation), \( M \approx 8\pi \rho R_0^2 h_0 \) is the mass of the containment of length \( 4R_0 \) and \( \rho = 7800 \) kg/m\(^3\) is the steel density.

Identical HE charges were used for loading container Nos. 3 and 4 with different degrees of water filling, and container No. 3 was assumed to be a reference one.

The experiments were conducted under normal conditions. Methods of high-velocity photochronography [9] and strain measurement technique were used to register the containment expansion \( r(t) = R(t) - R_0 \) in various cross sections \( t \) is the time from the beginning of the process and \( R \) is the current value of the outer radius) or the relative strain \( \varepsilon(t) = r(t)/R_0 \); the relative error of the data was less than 5 and 10%, respectively. Wire bifilar strain gauges and circular (see [10]) and zigzag grids (with a base of 50–100 mm) were used in the strain measurement technique.\(^5\) In addition, high-velocity filming of the containments was performed. After the experiments, the plastic (residual) strain of the containments (with a relative error of less than 0.2%) was determined from the marking made prior to the tests without damaging the containment surface.

**Test Results.** The initial data and some measurement results are listed in Tables 1–3, where \( \sigma_{0.2} \)

\(^5\)The circumferential and meridional strains were registered using the strain gauge and the zigzag grid, respectively. The bifilar construction was used to compensate for electromagnetic induction.