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Sympathetic underwater implosion in a confining environment

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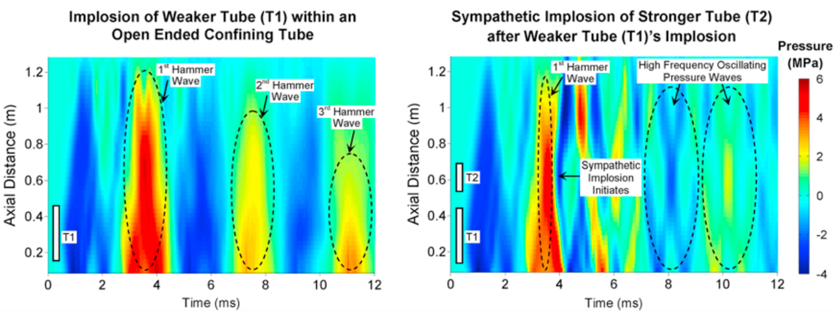
GRAPHICAL ABSTRACT



HIGHLIGHTS

- We report sympathetic underwater implosion phenomenon in confining environments.
- Implosion inside an open ended confining tube generates strong water hammer waves.
- Water hammer implosion waves can initiate damage in adjacently placed structures.
- Sympathetic implosion can possibly be used for water hammer wave mitigation purposes.

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ABSTRACT

An experimental study is conducted to investigate the phenomenon of sympathetic underwater implosion of cylindrical metallic shells in a confining environment. Two aluminum 6061-T6 implodable volumes with different collapse pressures are placed inside a confining tube with one end open to the environment and are hydrostatically loaded up to the weaker implodable volumes' critical collapse pressure. Experiments show that implosion of the weaker implodable volume (critical pressure $= P_c$) inside the confining tube leads to the subsequent sympathetic implosion of the stronger implodable volume (critical pressure $= 1.2P_c$). Implosion of the weaker implodable volume produces strong

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oscillating water hammer waves with $1.6P_c$ peak over-pressure, which initiates the implosion of the stronger implodable volume. Pressure histories recorded within the confining tube indicate that the sympathetic implosion of the stronger implodable volume generates low pressure high frequency implosion waves. The superposition of the low pressure waves with the high pressure water hammer waves mitigates to a great extent the later cyclic water hammer loading within the confining tube.

1. Introduction

Thin walled structures are extensively used in underwater applications such as submarines, underwater remote operated vehicles, and underwater pipelines [1–3]. The presence of lower pressure, uncompensated gas inside the structure and the large external hydrostatic pressures lead to a net pressure differential across the walls of the structures. If the hydrostatic pressure exceeds a certain critical limit for a given structure [4,5], it becomes unstable and collapses/implodes onto itself. This implosion process is shown to be highly violent in nature with resulting high velocity water motion and strong shock waves [6]. There have been several investigations reported by researchers in naval and marine communities on the mechanics and fluid–structure interaction during an implosion process [2,7–19]. Although the evolution of implosion pressure waves and its relation to structure geometry has been widely studied, there is a little information on the interaction of these pressure waves with the adjacent structures and on the potential of damage/sympathetic implosion. Orr and Schoenberg conducted experiments with a pre-weakened glass sphere and a non-weakened glass sphere submerged together for the possibility of sympathetic implosion [12], although none was observed. Later, Harben and Boro bundled five glass spheres together and mechanically initiated one of them at a prescribed depth [20]. It was reported that sympathetic implosion did occur in these experiments. The accidental failure of 7000 photomultipliers tubes at the Super Kamiokande laboratory in a chain reaction is a classic example of sympathetic implosion of near-field structures [21].

The damage potential of an implosion pressure pulse is generally estimated by the pressure–impulse and the energy flux released during the implosion event. Since both the pressure–impulse and the energy flux released in an underwater free-field implosion decays in a spherical manner [2] (pressure–impulse as 1/r and energy flux as $1/r^2$), a structure located at a sufficient distance from an imploding structure can be considered safe from the design point of view. But in certain situations, there may exist a confining structure around the implodable volume. In the event of an implosion occurring in such situations, the confining environment significantly alters the implosion process due to strong fluid–structure interaction with the confining environment [14,19,22]. Hence, all the energy released during the implosion process focuses inside the confining structure. This phenomenon leads to generation of extremely strong water hammer waves with significant time period [22]. Therefore, implosion of the weakest implodable volume inside the confining tube may damage the adjacent stronger structures. In the present study, an experimental investigation is conducted to understand the damage to the adjacent structures placed inside the confining tube with a weaker implodable volume. Study reveals that the implosion of an implodable volume inside the confining tube can generate a large enough pressure pulse to initiate implosion of comparatively stronger structures.

2. Experimental setup

The implosion experiments are conducted inside an underwater pressure vessel facility at the University of Rhode Island. The implodable volumes chosen in this study are made out of commercially available aluminum 6061-T6 seamless extruded tubing with an outer diameter ($2a$) of 38.1 mm (1.50 in.) and 0.870 mm (0.0343 in.) nominal wall thickness (h). All the primary and secondary implodable volumes are cut out from single 1.8 m long (72 in.) extruded tubing, thus there exists "no change in average wall thickness" between the implodable volumes[1] and implodable volumes with nearly identical and repeatable buckling pressures are manufactured as primary implodable volumes. Table 1 provides a summary of the experiments conducted and the details of the specimens used in this study. Ovality parameter ($\Delta_0 = (a_{\max} - a_{\min})/(a_{\max} + a_{\min})$) and wall eccentricity parameter ($\Xi_0 = (h_{\max} - h_{\min})/(h_{\max} + h_{\min})$) are measured for each specimen to quantify the initial imperfections present in the specimen prior to experiments [23] and are also shown in Table 1. Aluminum end-caps equipped with o-ring seals are press fitted at both the ends to avoid leakage of water into the implodable volume [14,15,19]. The theoretical buckling pressure (P_c) of the implodable volumes can be calculated from the following equation (derived by Von-Mises [4]):

$$P_c = \frac{Eh}{a}\frac{1}{n^2 + \frac{1}{2}\left(\frac{\pi a}{l}\right)^2 - 1}\left\{\frac{1}{\left[n^2(l/\pi a)^2 + 1\right]^2} + \frac{h^2}{12a^2(1-\nu^2)}\left[\left(n^2 + (\pi a/l)^2\right)^2 - 2n^2 + 1\right]\right\} \quad (1)$$

where the parameters are listed in Table 2.

[1] Due to the extruded nature of the tube, the geometry along with imperfections is consistent in direction of extrusion (i.e. length direction). Thus the average wall thickness is identical for single extruded tubing at any longitudinal location. This fact can be observed in the author's previous article [19], which shows three experiments of specimens cut from single extruded tubing. These experiments showed collapse pressure to be within 0.02 MPa (2 psi) for three different experiments.