Marine Structures 52 (2017) 82–93

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

The whipping response of a fluid filled cylindrical shell subjected to an underwater explosion

W. Xiao [a], A.M. Zhang [b, *], S.P. Wang [b]

[a] College of Engineering, Ocean University of China, Qingdao 266100, China
[b] College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China

ARTICLE INFO

Article history:
Received 23 June 2016
Received in revised form 19 October 2016
Accepted 10 December 2016

Keywords:
Underwater explosion
Internal fluid
Whipping
Doubly asymptotic approximation

ABSTRACT

Fluid filled structure widely exists in the field of ship and ocean engineering, but the investigation concerned with the whipping response of a fluid filled structure subjected to an underwater explosion is very less. A numerical model considering the effect of an internal fluid is established in this paper. In the implementation of the numerical model, the doubly asymptotic approximation for the external fluid is used to model the external fluid domain, the doubly asymptotic approximation for the internal fluid is used to model the internal fluid domain, and the dynamic response of the structure is simulated by the finite element method. After that, the numerical model is validated against the analytical solution. The numerical result agrees well with the analytical result. Finally, the whipping response of a fluid filled cylindrical shell subjected to an underwater explosion is investigated and the influence of the internal fluid on the whipping response is analyzed. The main results are as follows. The existence of the internal fluid makes the maximum relative displacement decrease, as the density of the internal fluid and the sound speed within the internal fluid increase, the maximum of the maximum relative displacement decreases.

1. Introduction

Fluid filled structures widely exists in the field of ship and ocean engineering, such as underwater pipelines, double bottom structure of surface ships and double shell structure of submarines. In recent years, some scholars investigated dynamic response of fluid filled structure subjected to underwater explosion. For example, Hickling (1962) [1] studied pressure pulse emanating from a point source impinging on a fluid filled spherical shell. Neubauer et al. (1970) [2] investigated the interaction between a shock wave and a fluid filled cylindrical shell experimentally, and analyzed the propagation and reflection of shock wave in external and internal fluid. Huang (1979) [3] used modal expansion and Laplace transformations to study dynamic response of concentric spherical shells filled with fluid between the shells due to a plane step wave, Neilson et al. (1981) [4] studies the same problem by the finite element method associated with the doubly asymptotic approximation method. Zhang & Geers (1993) [5] obtained a series solution of dynamic response of a submerged elastic spherical shell filled with internal fluid due to a plane step wave through convergence enhancement technique. Based on the work of Zhang &

* Corresponding author.
E-mail address: zhangaman@hrbeu.edu.cn (A.M. Zhang).

http://dx.doi.org/10.1016/j.marstruc.2016.12.002
0951-8339/

Geers (1993) [5], Sprague & Geers (1999) [6] obtained an analytical solution for the dynamic response of a submerged elastic spherical shell filled with an internal fluid due to a spherical exponential shock wave. Iakovlev (2006 [7], 2009 [8]) established an analytical approach based on the separation of variables and Laplace transformations to investigate the dynamic response of a submerged cylindrical shell filled with an internal fluid subjected to a shock wave and analyzed the interaction between the shock wave and the cylindrical shell. Hasheminejad et al. (2011) [9] studied the interaction between a submerged elastic spherical shell filled with internal fluid and a plane exponential shock wave through numerical Laplace inversion, and analyzed the influences of shell thickness and internal fluid impedance on it. However, these studies are mainly concerned with the local response of structure. The study was concerned with the total response of the structure, also known as the whipping response, is much less known. Furthermore the whipping response of structure is very important to the total strength design of the structure.

In addition, in recent years, some scholars have investigated the whipping response of a structure subjected to underwater explosions. For example, Vernon (1986) [10] proposed an underwater explosion bubble pulsation model based on the incompressible potential flow, and applied it to calculate the whipping response of a hull girder. Considering the effect of plastic deformation, Zong (2003 [11], 2005 [12]) investigated the whipping response of a submerged free-free beam and a free-free beam floating on water subjected to an underwater bubble. Zhang & Zong (2011) [13] investigated the effect of rigid body motions on the whipping response of a ship hull subjected to an underwater bubble. Zhang et al. (2011) [14] proposed an evaluation method of total damage to a ship experiencing underwater explosions. However all of these studies have not considered the influence of an internal fluid. Therefore the present paper will investigate the whipping response of a fluid filled structure subjected to underwater explosions.

The finite element method and the boundary element method that are widely used to investigate underwater explosion loads and the corresponding dynamic response on a structure [15–20]. Compared with the finite element method, the boundary element method transforms volume integration of the fluid domain to a surface integration of the wetted surface, which can greatly reduce calculation costs. The doubly asymptotic approximation (DAA) for the external fluid is currently the most widely used boundary element method, which was established by Geers (1978) [21] through the asymptotic expansion matching method based on the early time approximation and the late time approximation. For example, Liang & Tai (2006) [22] investigated the dynamic response of surface ship subjected to underwater non-contact explosion through the doubly asymptotic approximation for the external fluid. Hung et al. (2009) [23] used the doubly asymptotic approximation for the external fluid to study the dynamic response of cylindrical shells subjected to underwater explosions. In addition, the doubly asymptotic approximation for the internal fluid was obtained by Geers & Zhang (1994) [24] through the asymptotic expansion matching method. The occurrence of low frequency dilatational motion in internal fluid subjected to underwater explosion, which does not occur in the external fluid, leads to the difference between the doubly asymptotic approximation for the internal fluid and that for the external fluid.

Based on the work of Geers [21,24], in this paper a numerical model considering the effect of an internal fluid is established. In the implementation of the numerical model, the doubly asymptotic approximation for the external fluid is used to model the external fluid domain, the doubly asymptotic approximation for the internal fluid is used to model the internal fluid domain, the dynamic response of the structure is simulated by the non-linear finite element software ABAQUS [25], and a user subroutine is developed to exchange the pressures of the external and internal fluids and the normal velocities of wetted surface of structure. Then, the whipping response of fluid filled cylindrical shell subjected to an underwater explosion is investigated and the influence of the internal fluid on the whipping response is analyzed. The main contents of this paper is as follows: (1) the numerical model considered the effect of the internal fluid; (2) the validity of the numerical model; (3) and the influence of the internal fluid on the whipping response.

2. Numerical model

2.1. The boundary integral equations

A fluid subjected to an underwater explosion can be regarded as a small perturbation, inviscid, irrotational and weakly compressible fluid, therefore it can be governed by the linear wave equation [26]:

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}. \tag{1}$$

where p is the pressure of fluid, c is the sound speed in the fluid.

Kirchhoff's retarded potential formula gives the integral equation solution to (1), and can be given as [27]:

$$\lambda p(\boldsymbol{r}_{q_1}, t) = \iint_S \rho \frac{1}{r_{q_1q_2}} \dot{u}(\boldsymbol{r}_{q_2}, t-\tau) dS_{q_2} - \iint_S \frac{\boldsymbol{r}_{q_1q_2}\cdot \boldsymbol{n}_{q_2}}{r^3_{q_1q_2}} \left[p(\boldsymbol{r}_{q_2}, t\text{-}\tau) + \frac{r_{q_1q_2}}{c}\dot{p}(\boldsymbol{r}_{q_2}, t\text{-}\tau)\right] dS_{q_2} \tag{2}$$

where ρ is the density of fluid, $\tau = r_{q_1q_2}/c$ is the retarded time, $r_{q_1q_2} = |\boldsymbol{r}_{q_2} - \boldsymbol{r}_{q_1}|$ is the distance between point q_1 and point q_2, $\boldsymbol{r}_{q_1q_2} = \boldsymbol{r}_{q_2} - \boldsymbol{r}_{q_1}$ is the position vector between point q_1 and point q_2, $u(\boldsymbol{r}_{q_2}, t-\tau)$ is the normal velocity of point q_2, $\boldsymbol{n}_{q_2}$ is the normal vector of point q_2 as the direction going into fluid. λ is the solid angle of point q_1, when point q_1 lies in the fluid, $\lambda = 4\pi$; when point q_1 lies on the smooth boundary, $\lambda = 2\pi$.