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Dynamic response of a surface ship structure subjected to an underwater explosion bubble

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A B S T R A C T

Bubble load in a noncontact underwater explosion can cause the ship hull global response and local response. In current literature, the ship hull is usually simplified as a hull girder to analyze its global response. However, literature dealt with the local response of a 3-D surface ship hull subjected to an underwater bubble were limited. This investigation develops a procedure which couples the finite element method with doubly asymptotic approximation (DAA) method to study the problem of transient responses of a ship hull structure subjected to an underwater explosion bubble. Using a 3-D ship model as examples, the global and local responses of the ship model in vertical, transverse and longitudinal directions are performed in detail. The acceleration, velocity and displacement time histories are presented. The characteristics of both the global and local responses of the ship model are discussed. The numerical results show that besides global whipping response, the ship hull also sustains severe local responses in different directions subjected to underwater explosion bubble jetting, which should be taken into consideration.

1. Introduction

The dynamic responses of submerged structures subjected to noncontact underwater explosion have received attention as a concerned topic for a national defense since the 1950s. A number of

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approximation methods have been developed to predict the responses of submerged structures. Such as the plane wave approximation (PWA) [1], the cylindrical wave approximation (CWA) [2] and the virtual mass approximation (VMA) [3]. In 1970s, Geers systematically developed many theories in the technical area of transient interaction between a submerged spherical shell and an acoustic wave, and simultaneously examined the free vibration and forced response characteristics of doubly asymptotic approximation (DAA) [4–6]. The DAA methods have received widespread use for the study of fluid–structure interaction problems. This is an amalgam of the PWA and VMA methods. The PWA provides the early time response of the interaction and the VMA describes the late time response.

In an underwater explosion event, the ship structure is exposed to the effect of two types of time-dependent loads: shock wave and bubble pulsation. Both types of loads can have great damages on the ship hull structures. The shock wave has very high peak pressure and extremely short duration. It usually induces local structure damage. The energy in the bubble pulsation is nearly 47% of the total explosion energy [7]. And it can cause global damage and local damage on the ship structures [7,8].

Explosion bubble dynamics have been studied by many authors [9–17]. And previous studies about the dynamic responses of the ship hull structures subjected to underwater explosion bubble loads usually simplify the ship hull as a hull girder, so as to study the global responses of the hull girder [18–22]. Concerning 3-D surface ship, numerical applications have been studied by many authors based on the boundary element method or acoustic finite element method [23–31], which are mainly about the shock response or global response of bubble jetting. Literature dealt with the local response of a 3-D surface ship hull subjected to an underwater bubble, however, were limited.

This study aims to develop a procedure to investigate the global and local responses of ship hull structures subjected to the underwater explosion bubble load. The first bubble pulsation when the bubble radius decreases to its maximum value, is the most concerned in the calculation. So only the first bubble pulsation is taken into consideration in this paper. The finite element method is employed to model the three-dimensional structure, and the boundary element method based on DAA method is used to model the fluid domain. Meanwhile, the bubble load combined with the bubble migration, free surface effect and drag force considerations are solved numerically. Then the transient responses of a 4.5 m long ship model subjected to the bubble jetting are calculated using the procedure. The global and local responses of the ship model in vertical, transverse and longitudinal directions are performed in detail. Additionally, the acceleration, velocity and displacement time histories at different locations are also presented. At last, the characteristics of the global and local responses of the ship model are analyzed and discussed.

2. Theory

2.1. Governing equations

The ship structure immersed in the vicinity of a mid-field or far-field underwater explosion, the simulation domain is an infinite water domain. A general three-dimensional continuous structure possessing infinite number of degrees of freedom may be idealized as one having finite number of degrees of freedom. The equation of motion describing the response of the flexible structure to external excitation is therefore written as:

$$\mathbf{M_s}\ddot{\mathbf{x}} + \mathbf{C_s}\dot{\mathbf{x}} + \mathbf{K_s}\mathbf{x} = \mathbf{F}, \tag{1}$$

where $\mathbf{M_s}$, $\mathbf{C_s}$, $\mathbf{K_S}$ denote the (N × N) mass, damping and stiffness matrices, respectively. The (N × 1) vectors $\mathbf{x}$, $\dot{\mathbf{x}}$, $\ddot{\mathbf{x}}$ represent the structural displacements, velocities and accelerations, respectively. The column vector $\mathbf{F}$ denotes the external forces. N is the number of degrees of freedom assigned to the structure.

For excitation of a submerged structure by an acoustic flow, $\mathbf{F}$ can be expressed as

$$\mathbf{F} = -\mathbf{G}\mathbf{A_f}(\mathbf{p_i} + \mathbf{p_s}), \tag{2}$$

where $\mathbf{p_i}$ and $\mathbf{p_s}$ are the nodal pressure vector for wet-surface fluid mesh pertaining to the incident flow and scattered flow, respectively. $\mathbf{A_f}$ represents the diagonal area matrix associated with an element in