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On the regimes of underwater explosion for a submerged slender structure by pulsating bubble

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Three regimes: near-, middle- and far-fields of underwater explosion are proposed in this study aiming at providing an overview on the responses of submerged slender structure by pulsating bubble. In the near-field, the material starts to yield, thus leading to structure breakdown immediately; remarkable structural global elastic deformation occurs in the middle-field as well as substantial movement; and a structure moves as a rigid body with negligible deformation for the far-field. Equivalent dimensionless parameters are obtained by two different dimensional analysis methods, among which a dominant similarity parameter is found out. Thus, a scaling law providing us with a relation between structural global response and the dominant similarity parameter is yielded, which can be used for demarcating the three regimes quantitatively. To demonstrate, three models corresponding to typical submarine parameters are performed in the case studies. Quantitative criterion of the three regimes is presented along with the regime diagrams. The structural global response features such as the deformation and maximal acceleration/speed of different regimes are provided as well.

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1. Introduction

Shock, pulsating bubble and subsequent jet are three well-known processes of damage in an underwater explosion. When the failures due to shock and jet are localized, a structure tends to globally respond to pulsating bubble. As we know, an explosive bubble at first expands owing to the high pressure of detonative gas inside and then contracts from an over-expanding state under high ambient hydraulic pressure to an over-contraction state. The expanding–contracting cycle repeats several times in this way. It is estimated that about two-thirds of the bubble energy are dissipated in the first period. The bubble duration is of the order of one second, much longer than that of shock or jet. Moreover, if the bubble frequency is in the neighborhood of the eigen-frequency of a slender structure or the explosion is violent (for example large TNT exploded nearby), strong or even destructive “whipping response” could be excited.

Earlier theoretical studies on bubble dynamics were concerned with the bubble's migration and oscillation by assuming that the water is incompressible and the bubble maintains spherical shape in its life [1]. Later, non-spherical effects [2] and also the roles of compressibility in both external water and internal gas were examined [3,4]. Numerical method of explosive bubble simulation is booming during the last three decades. Boundary Element Method (BEM) has been proved an effective tool to reproduce the bubble process [5–7]. Computational Fluid Dynamics (CFD) with interface-capture algorithms has been adopted in explosion bubble modeling [8]. Moreover, the meshless method seemingly promising for the simulation of a collapsing bubble has also been developed [9]. Foregoing new advancements enhance modeling capability and enrich the contents of bubble dynamics, thus further deepening the understanding of bubble's migration and deformation features especially for the bubble nearby boundaries or in the bubble's extreme collapse phase.

Bubble dynamics studies also push forward the exploration of global response of a submerged slender structure as shown in Fig. 1. The earliest one can be traced back to the work on whipping response by Hick [10]. Then, Vernon examined the fluid velocity field by a pulsating bubble under the incompressible assumption aiming at establishing the whipping response of a nearby surface ship [1]. Moreover, the velocity field for compressible fluid was obtained by the method of matched asymptotic expansions [11], but the results have not been used in global structure response researches so far. Global response of a surface ship was analyzed by estimating the bubble loading by Vernon's method and simplifying the structure as a Bernoulli–Euler beam as well as finite element method [12–14]. Also, BEM was used to estimate bubble loading in the structural global response studies [5,6]. All those works primarily focused on the deformation of a specific structure with less universality. They also scarcely discussed the distribution and amplitude of the acceleration and speed response, which are closely related to equipment failure and crew's injury onboard. Furthermore, structural reverse response denoting the structural displacement has an opposite direction to the flow velocity is observed experimentally, but not well discussed yet for both small fixed plates [5] and large surface warships [15].

In recent years, the applications of high strength material and blast-resistant structure remarkably enhanced the local strength of ships and submarines. So the resistant ability to global damage has become a noteworthy challenge. Instead of discussing the global response for a specific slender

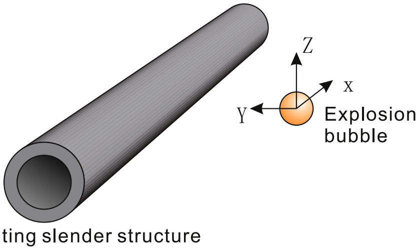

Fig. 1. A submerged floating slender structure subjected to underwater explosion bubble located at the symmetric plane. Z-axis is vertical to the free surface, and X-axis is parallel to neutral axis of the structure.