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Comparability research on impulsive response of double stiffened cylindrical shells subjected to underwater explosion

Xiong-liang Yao, Jun Guo*, Lin-han Feng, A-man Zhang

College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China

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ABSTRACT

In order to evaluate the strength and comparability of impulsive environment of model and practical structure in the water when subjected to underwater explosion, a new shock factor based on energy acting on the structure is presented to describe the loading of underwater explosion. To test the validity of this new factor, numerical experiments of double stiffened cylindrical shells are carried out a series of cases designed by the new factor and two other standard shock factors respectively. The results of the cases designed by the new factor indicate that the kinetic energy, potential energy and shock response spectrums of the structures agree well with each other in different cases designed by the equal new shock factor. However, the results of the cases designed by the two other standard shock factors are rather diverse. The analysis considers that the old shock factors do not take the spherical characteristics of shock wave front and relative position between detonation and structure into account, which can hardly reflect the similarity of underwater explosion loadings. The new shock factor can make up for such limitations.

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1. Introduction

The dynamic response of submerged structures subjected to underwater explosions is increasingly valued. The accurate theoretical research is difficult to execute due to its complexity, so model testing and numerical experiments become the main research methods. However, how to convert the results of model testing to real ship has not been completely solved, which makes model testing less significant, and only qualitative results could be obtained. Therefore, in the developed countries, e.g. America, each first-made ship must pass the qualification testing by the full scale underwater experiment. For lack of simple and effective parameters to describe underwater explosions, usually the standard shock factors are employed to describe work cases in military standards [1,2]. However, these types of shock factors are lack of general meanings, the experimental results of one case cannot be popularized to other cases. Innumerable cases will crop out when a ship is attacked. There are only two methods to get a general cognition about the shock resistance of a ship through numerical experiments: one is to do a large number of numerical experiments considering (including) any possible cases; the other is to do a few of numerical tests and extend the results with certain method. Obviously, the first one is unrealistic so the second one is the unique way to solve the problem. This paper attempts to investigate the similarity of underwater explosion loadings from the viewpoint of energy, so as to get a whole cognition about the ability of a ship subjected to shock with the results of a few cases.

2. Calculating model and analytical method

To verify the validity of all kinds of shock factors and perform formula derivation, a double stiffened cylindrical shell is designed. The basic structure of the model is shown in Fig. 1.

Except for the marked dimensions, the concrete dimensions of model are shown in Table 1. The ribs are fixed at each frame on the inner structures, inner shells and outer shells. The brackets shown in the figure are fixed at each frame between the inner shell and the outer shell. There is full of water between the inner shells and the outer shells.

The finite element code ABAQUS is used for dynamic response analysis of the double cylinder shells. The pre-processor of ABAQUS is used for three-dimensional mesh generation with the shell element for meshing the structure and the solid element for meshing surrounding water. The loading of underwater explosion is applied to the structure throughout the water around. The coupling between structure and water is simulated by the acoustic-structure interaction method in ABAQUS.

* Corresponding author. Fax: +86 451 82518296.
E-mail address: guojun9911228@gmail.com (J. Guo).

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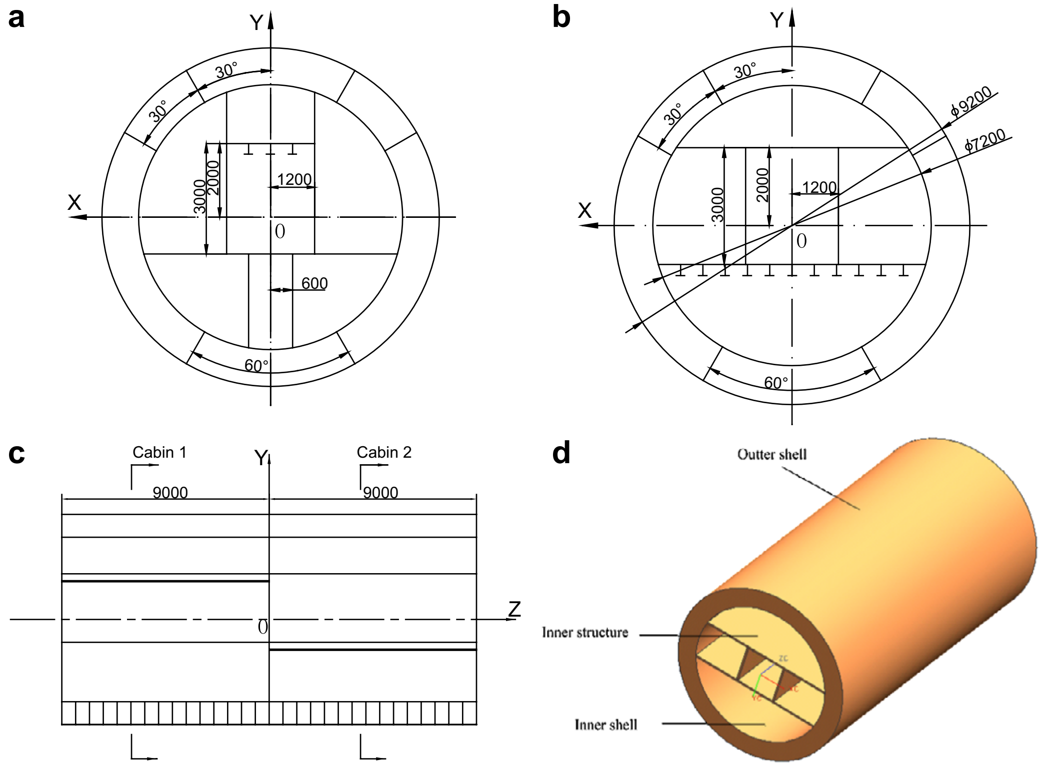

Fig. 1. Structure chart of double stiffened cylindrical shells (unit: mm). a. Cross section of cabin 1. b. Cross section of cabin 2. c. Median longitudinal section of structured. d. Geometry model.

The experiments of the double stiffened cylindrical shells subjected to underwater explosions are simulated by the software ABAQUS. In this paper, the results are analyzed from the following two viewpoints:

(1) The time-histories of kinetic energy and elastic strain energy of the whole structure, which reflect the whole structural response. In ABAQUS, kinetic energy E_k and elastic strain energy E_E are defined as follows:

$$E_K = \int_V \frac{1}{2}\rho \vec{v}\cdot\vec{v}dV \quad E_E = \int_0^t \left(\int_V \frac{(1-d_t)\sigma^u}{\dot{\varepsilon}^{el}} dV \right) d_\tau$$

where ρ is material density; $\vec{v}$ is velocity vector; d_t is material damage parameter, which is 0 in this paper when it is not involved in; σ^u is stress tensor of undamaged material; $\dot{\varepsilon}^{el}$ is elastic strain rate.

(2) The shock spectrum analysis (Fig. 2). Shock spectrum is a plot of an analysis of a motion (transient motions due to explosions, earthquakes, package drops, railroad car bumping, vehicle collisions, etc.) that calculates the maximum response of many different frequencies damped single degree of free single degree of freedom (SDOFs). Based on the varieties of the horizontal coordinate, shock spectrum can be divided into several species: absolute acceleration spectrum, equivalent acceleration spectrum, equivalent velocity spectrum, etc. Equivalent velocity spectrum is applied in this paper. As is shown in Fig. 3, horizontal coordinate is the frequency F(Hz) of the oscillator, and vertical coordinate is equivalent velocity, the product of relative displacement δ and circle frequency ω of the oscillator [3], where the relative displacement means the amplitude of vibration with frequency ω. The equivalent velocity V exactly means peak relative displacement δ, multiplied by the natural frequency ω in radians ($\sqrt{k/m}$), as shown in the following equation,

Table 1
Concrete dimensions of double stiffened cylindrical shells.

Thickness of outer shell	15 mm	Thickness of brackets	15 mm
Thickness of inner shell	30 mm	Ribs on outer shell and inner structure	9# bulb steel
Thickness of inner structure (deck and wall)	15 mm	Rib on inner shell	10# bulb steel
Dimension of inner ribs	$\perp\frac{250\times15}{150\times20}$	Distance between frames	600 mm

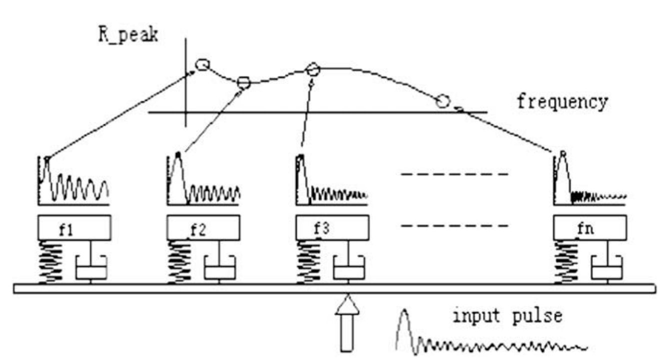

Fig. 2. Sketch map of shock spectrum calculation.