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Numerical study on the dynamic response of the large containership's bow structure under slamming pressures

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ABSTRACT

The dynamic behaviors of the large containership's bow structures subjected to slamming pressures with different influence parameters are studied based on 3D finite element method. The slamming pressure is characterized as symmetrical and non-symmetrical half sine impact load, traveling over the side shell of the bow at a constant speed. The yield failure criterion is used to determine the critical slamming pressures of the bow structure under slamming pressures in the present paper. Various influence parameters which are relevant to the dynamic response of the bow structure are discussed, including the amplitude of slamming pressures, impact duration, rise time of slamming pressures, load attenuation coefficient, the position of maximum slamming pressures and traveling speed of the slamming pressures over side shell of the bow flare. The results show that the maximum stress responses of the bow structure increase with the increase of slamming pressures amplitude and with the decrease of the load attenuation coefficient, the other parameters also have a great influence on the dynamic response of bow structure. The safety margin coefficient is presented to evaluate the safety performance of large container ships under slamming pressures. The obtained results contribute to help the naval architect to design a ship which has a stronger capacity of resisting slamming.

1. Introduction

In recent decades, with the development of global trade and the increase of shipping volume, the size of a container ship is getting larger. As a result, the large container ship usually has larger bow flare and stern areas to carry more cargos without decreasing the sailing speed. However, the larger bow flare and stern increase the probability and extent of slamming phenomenon, which results in higher risk of slamming failure. It was reported that slamming induced whipping can lead to local structural damage of ship [1]. Therefore, it is necessary to take into account dynamic response of large container ships subject to slamming loads.

Typically, ship slamming can be categorized into three types of slamming loads on commercial vessels: bottom slamming, bow flare slamming, and stern slamming depending on the ship geometrical shape at the bow and stern. The dynamic characteristic of each category are different with each other, but these slamming loads are all mainly dependent upon vertical velocity and dead rise angle relative to the free surface [2].

For the analysis of the water impact of a wedge, an enormous number of tests and numerical calculations have been conducted by previous scholars. De Backer et al. [3] conducted a new experimental study of the water impact on hemisphere and cone shapes with larger deadrise angles, in order to assess the slamming loads. These experimental results are used as references to validate 3-D

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numerical studies, which follow earlier work in two-dimensions. Yang and Qiu [4] studied slamming problems on two-dimensional and three-dimensional bodies with constant water entry velocities and free-fall motions based on the CIP method. Wang and Guedes Soares [5] investigated the hydrodynamic problem of 3-D bodies, including hemisphere and cones with different deadrise angles by applying the explicit finite element method, and the numerical results are compared with the experimental results of De Backer et al. [3]. Maki et al. [6] investigated the impact of a wedge-shaped body on to a calm free-surface based on a hydroelastic method which combines computational fluid dynamics and dynamic finite-element techniques to predict the hydroelastic response of a structure in the time domain. Yettou, Desrochers, and Champoux [7] presented an analytical solution to symmetrical water impact problems of a two-dimensional wedge, and the effect of velocity reduction of the wedge during water entry are taken into account. The main aim of these papers is to study the dynamic response and slamming loads of two-dimensional and three-dimensional bodies with different water entry.

In terms of the experimental study of the dynamic response of similar model under slamming loads, some important papers can be found. Hermundstad and Moan [8] presented a method for the prediction of slamming loads on ship hulls and model test results for a 120-m Ro–Ro vessel is used for validation. In the method, the relative vertical and roll velocities are obtained from nonlinear strip theory, they are used as input parameters of a generalized two-dimensional Wagner formulation which can compute the slamming loads. Iijima, Yao, and Moan [9] proposed a consistent procedure for the dynamic response of a ship in severe seas considering global hydroelastic vibrations. Drummen, Wu, and Moan [10] conducted an experimental and numerical study of containership responses in severe head seas by using a flexible model of a containership of newer design. Wang and Guedes Soares [11,12] carried out an experimental and numerical study of the bow flare and bottom slamming of a chemical tanker in irregular waves, slamming occurrence probability and slamming loads were calculated. Iijima, Suzaki and Fujikubo [13] presented a series of scaled model tests investigations on the collapse behavior of a ship's hull girder under whipping loads. Hong [14] investigated the characteristics of bow flare slamming, and the spatial and temporal distributions of slamming force are discussed detailed in regular and irregular waves. The main aim of these papers is to explain the dynamic behavior of slamming loads appeared on bow flare when the ship is encountering an extreme wave. Very few papers study the dynamic response of large containership's bow structures subjected to slamming loads, which is the basis of evaluation of failure characteristics. Therefore, enough attention should be paid to dynamic response analysis of bow structures under slamming loads.

A simple method used for dynamic response analysis of bow structure is widely used by researchers. The ideal half-sine impact loads and triangular loads which are similar to the slamming loads are applied on the stiffened plates and flat plates to study their dynamic response. Srivastava, Datta, and Sheikh [15] investigated the dynamic characteristics of stiffened plates subjected to non-uniform harmonic in-plane edge loading by using finite element method. Paik [16] conducted a series of dynamic collapse tests on flat plates under in-plane compressive loads and the effect of strain rate on the ultimate strength of ship plates is discussed. Ji and Wang [17] studied the influence of impact loads shape on dynamic displacement response of across-stiffened plate subjected to in-plane impact loads based on Abaqus/explicit FEM code. Azarboni [18] investigated the nonlinear dynamic response and dynamic buckling of the imperfect rectangular plate under exponential, sinusoidal, damping and rectangular impulse functions with six different boundary constraints. Yang and Wang [19] studied the dynamic ultimate strength of the stiffened plates under in-plane dynamic compression based on Abaqus/explicit FEM code.

For these three different research techniques, very apparent limitations can also be found. The first method aims to obtain time and space characteristic of slamming loads and the second method aims to dynamic response and collapse behavior of local ship structures. Unfortunately, these two methods can not reflect the dynamic response and collapse behavior of the bow flare structure under slamming loads due to too much simplified of the calculation model. For the last method, although a 3-D model of bow structure was established, some important influence parameters of slamming loads were not taken into account. As a result, it is necessary to establish a 3-D FE model of the bow structure to obtain the accurate dynamic response of the bow subjected to slamming loads. Some researchers have done some researches on the dynamic behavior of the containership's bow flare under slamming loads by using 3-D nonlinear finite element analysis. Yang [20,21] established an explicit 3-D FE model of 1700TEU containership's bow structure model in MD Nastran, then the dynamic response and buckling of the bow structure subjected to slamming loads were investigated, one-time thickness deformation method and yielding failure method were used to accurately determine the critical buckling load of the bow structure subjected to slamming loads. Ren [22] investigated the dynamic response of bow flare structures under slamming loads of the design condition. Firstly, a design wave is determined through a long-term analysis of the relative vertical motion between the hull and the wave; secondly, the bow flare slamming pressure of the prescribed section motion is predicted by LS-DYNA software; finally, taking into account the geometric and material nonlinearity, dynamic response of the bow flare structure under slamming loads is calculated. Although the dynamic response of bow structures under slamming loads was evaluated by these papers, some influence parameters which have a great influence on the dynamic response of bow structures are not discussed, such as amplitude of slamming loads, pulse duration, rise time of slamming loads, loads shape, loads attenuation coefficient, the occurrence position of maximum slamming loads and traveling speed of the loads over side shell of the bow.

The present work mainly focuses on the analysis of the dynamic response of bow structures subjected to slamming induced loads which are given by simplified half-sine loads with millisecond order duration by using Abaqus/explicit FEM code. Only material nonlinearity is considered in the dynamic analysis. Firstly, the slamming pressure which has a half sine wave shape and the millisecond order duration is presented, then the slamming pressure considering various influence parameters are applied on the 3-D FE model of the bow structure, finally, the dynamic response of the bow structure is studied based on 3-D finite element method. The residual deformation of the bow structure would generate when the maximum stress reached the yield stress during slamming. The residual deformation reduces the structural strength and rigidity seriously and may lead to the ship collapse under the subsequent slamming loads. Therefore, the yield failure criterion is used to determine the critical slamming pressures of the bow structure in the