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Numerical prediction of slamming on bow-flared section considering geometrical and kinematic asymmetry

Hang Xie, Huilong Ren *, Hui Li, Kaidong Tao

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

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ABSTRACT

Asymmetric impacting phenomenon is quite common for the sailing ship when it encounters oblique waves. The asymmetrical water entry problem of a full scale bow-flared section from Ultra Large Container Ship (ULCS) was investigated using CFD method in commercial code FLUENT. A two-phase flow model was established based on N-S equations, which were discretized through the finite volume method and the free surface was captured by VOF model. The body motion was achieved in the dynamic mesh model with prescribed dynamic boundary condition. The impacting forces were obtained through direct numerical integration on the body surface. The validation and convergence were carried out through comparing experimental data and other numerical methods in already published literature. Two kinds of asymmetry, heel angle as geometrical asymmetry and horizontal velocity as the kinematic asymmetry, were comprehensively considered in numerical simulation and significant attention is given into the discussion of their effects on impacting hydrodynamics including pile-up water, pressure and slamming forces. The results show the geometrical asymmetry is important on these hydrodynamics if the flow separation does not happen. Otherwise, the kinematic asymmetry can significantly influence pile-up water form and further determines the pressure and slamming forces.

1. Introduction

Slamming phenomenon occurs frequently when the ship sails in rough seas with a high speed. Enormous slamming loads can cause structural damage and even threaten the mariners' personal safety. In some oblique wave cases, asymmetric impacting phenomenon will occur due to the free motion of ship when the ship bow exits water and then re-enters into water. This impacting phenomenon may result in greater slamming loads than the case in the head sea due to the decrease of the effective impacting angle. In fact, such an asymmetric case is more common for the ship which sails in actual marine environment.

Massive studies on the water entry problem of symmetric cases have been done. An analytical solution was firstly put forward by Von Karman (1929) based on the momentum theory. In his study, the concept of added mass was introduced and the pile-up water was ignored. Later, Wagner (1932) improved this solution by considering the effect of pile-up water. In his theory, the rather panel assumption was used and the results are closer to the corresponding experimental data. However, there exists a singularity at the edge of the panel. To avoid this dilemma, Watanabe (1986) adopted a matched asymptotic approach by introducing the inner domain. Most early theoretical researches focused on the pressure peaks and paid less attention on the characteristics of time. Such a situation causes some inconveniences for the analysis of structural dynamic response. Dobrovol'Skaya (1969) developed a similarity solution for the water entry problem of wedges through supposing the flow is self-similarity in the water entry process, where the time information can be considered. Wu et al. (2004) extended it to the free drop case. An auxiliary function was introduced to uncouple the acceleration and flow field. The excellent agreement of acceleration is achieved between the numerical and experimental results. Although the self-similar theory is further extended to an expanding paraboloid in Wu and Sun (2014), the similarity solution is hard to obtain for complex flow form such as flow separation and ventilation. On the other hand, some researchers begin to concern on the cases of ship-like section to satisfy the requirements of marine engineering. Zhao and Faltinsen (1993) solved the water entry problems of arbitrarily section using a fully nonlinear boundary element method. The thin jet flow was dealt by using the numerical truncation to avoid the divergence in time stepping. Later, the fully nonlinear numerical method is applied to the case with flow separation in Zhao et al. (1996). A joint point of body and free surface was introduced to approximate the jet flow and the effect of flow separation from knuckles or fixed separation points was incorporated by the Kutta condition. For

* Corresponding author.
E-mail addresses: xiehang199228@hrbeu.edu.cn (H. Xie), renhuilong@hrbeu.edu.cn (H. Ren).

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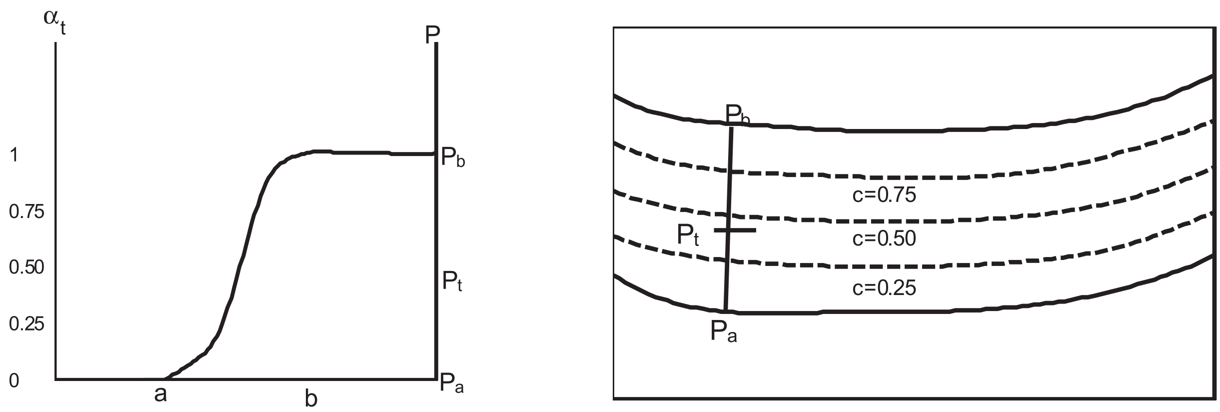

Fig. 1. The definition of continuous pressure function and *c*: (a) the pressure function (b) the definition of *c*.

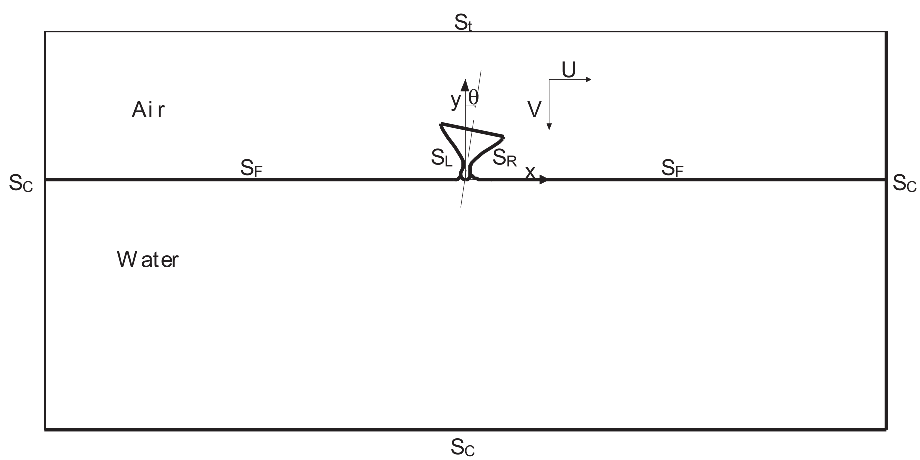

Fig. 2. The sketch of asymmetrical water entry problem of a bow-flared section.

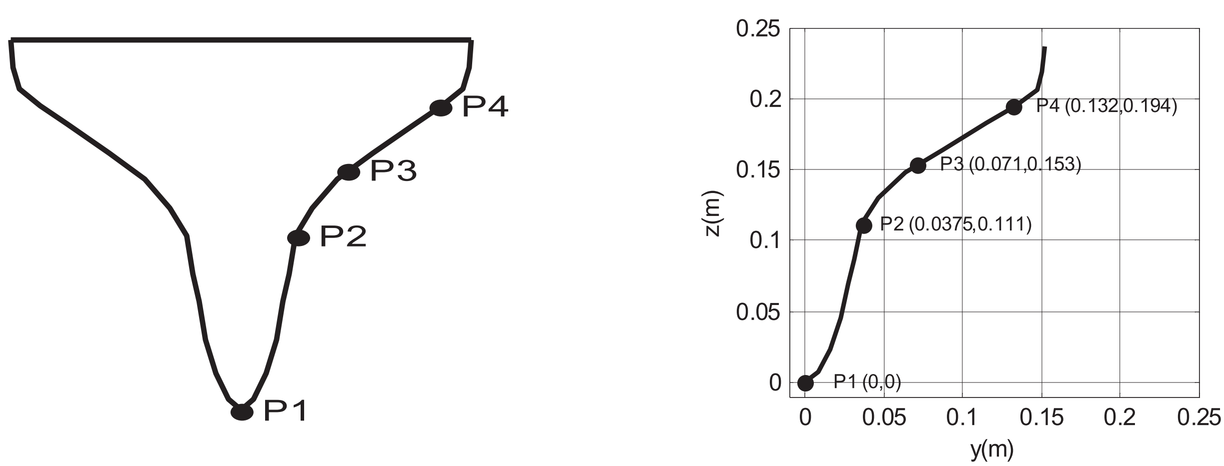

Fig. 3. The ship bow section in the drop tests: (a) the sketch of ship bow section, (b) the pressure measurement locations.

the pressure distribution, good agreement between theory and experiments is documented at an early stage of the water entry. The differences are larger at a later stage, but this is mainly due to three-dimensional effects in the experiments. The analysis shows that the three-dimensional effect causes 8% reduction of the force relative to the two-dimensional force when the spray roots of the jets reached the knuckles.

Only some researchers focus on the asymmetric cases even if it is more common in the ocean engineering field according to the survey of Howison et al. (2004). Garabedian (1953) firstly put forward the model of asymmetric wedge based on the potential flow theory. Later, some scholars did some improved work, such as Korobkin (1988) and Toyama