International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 19, No. 3, September 2009, pp. 189–197

Nonlinear Solution for Vibration of Vertical Plate and Transient Waves Generated by Wave Impact

Guanghua He
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka, Japan

Masashi Kashiwagi*
Department of Naval Architecture and Ocean Engineering, Osaka University, Osaka, Japan

The vibration of a vertical plate induced by the impact of a pulse-type wave and resultant generation of nonlinear transient waves are simulated using the full-nonlinear boundary-element method. A hybrid scheme coupling the numerical damping beach with the piston-like wave absorber is incorporated to absorb transient waves, and the implicit boundary-condition method for computing the temporal derivative of the velocity potential is also incorporated after checking the performance of several alternatives. An analytical solution for the corresponding linearized problem is presented; this is compared with nonlinear numerical solutions, and then nonlinear effects are investigated. Nonlinear behavior at the early stage of response of a plate is observed particularly when the spring constant in the restoring force is larger. The transient wave generated by the plate's vibration also shows a nonlinear feature when the amplitude of the initial pulse-type wave is large.

INTRODUCTION

In recent seakeeping and ocean engineering research, attention has been focused on the green-water impact, that is, the response of a ship or structure such as whipping and springing, large-scale fluid-structure interactions, local damage of a structure, and so on. Conventional analysis methods for these fluid-structure interactions are mostly based on the so-called one-way analysis. That is, the distribution of wave forces is computed first by a hydrodynamic method, and then used as the input for the computation of structure responses. However, the development of an advanced method which can treat genuine (2-way) fluid-structure interactions, and if possible fully nonlinear ones, has been expected. At present, a promising method for realizing that objective is the full-nonlinear boundary-element method (the mixed Eulerian Lagrangian method) initiated by Longuet-Higgins and Cokelet (1976) and extended by other researchers (Cao et al., 1993; Tanizawa, 1996; Wu and Eatock Taylor, 1996; Kashiwagi, 1998; and others).

In order to treat transient structure responses due to wave impact and the resulting generation of nonlinear waves on the free surface, there are a couple of issues in the numerical schemes to be adopted in the so-called numerical wave tank (NWT). The first is the establishment of an efficient scheme for absorbing transient waves with a wide spectrum of frequencies. The second is the precise evaluation of the temporal derivative of the velocity potential $\partial\phi/\partial t \equiv \phi_t$ appearing in Bernoulli's pressure equation. In the time-domain wave-body interaction problem, the acceleration of the body must be computed from the motion equation, which includes the hydrodynamic force to be computed by integrating ϕ_t. On the other hand, the boundary condition for ϕ_t on the body surface includes the acceleration of the body, which implies a nested situation.

Regarding the first issue, various types of the numerical damping beach have been proposed by Cointe et al. (1990), Romate (1992) and Cao et al. (1993), to name a few. However, it is well recognized that the damping beaches are effective only for the waves of relatively high frequency. As Clement (1996) studied, if the waves involve wide-spectrum frequencies like transient waves, we should use a hybrid absorption scheme coupling with the piston-like wave absorber to be installed at the far downstream end of an NWT. Therefore, in this paper we check the performance of some damping beaches and hybrid schemes to find an appropriate wave-absorbing scheme for this study. Regarding the second issue, 3 different methods for computing ϕ_t are tested: the substitution method, mode-decomposition method (Cointe et al., 1990), and implicit boundary-condition method (Tanizawa, 1995). With the developed NWT and the full-nonlinear boundary-element method, we study the vibration of a vertical rigid plate induced by the impact of an initial pulse-type elevation of the free surface and resulting generation of transient waves on the free surface. For the corresponding linearized boundary-value problem, Sturova (2006) presented an analytical solution, which is not published as a paper and thus summarized in the Appendix, and a comparison is made with nonlinear numerical results.

Our final objective in this study is to treat an elastic body and nonlinear fluid-structure interactions. As a step toward that objective, a linear spring is considered as an element exerting the restoring force in the vibration of a plate. Although this is just a primitive model, the knowledge obtained and the numerical schemes established in this paper will be useful in the future study of the genuine nonlinear interactions of an elastic structure with the impact of transient waves.

SOLUTION METHOD FOR VELOCITY FIELD

We consider the motion of a vertical rigid plate induced by the impact of a pulse-type wave which has a prescribed profile at initial time. The back of the plate is connected to linear springs exerting a restoring force, which induces the plate's vibration and then generates transient waves on the free surface. Understanding the characteristics of a plate's transient vibration and the genera-

*ISOPE Member.

Received May 2, 2009; revised manuscript received by the editors June 11, 2009. The original version was submitted directly to the Journal.
KEY WORDS: Numerical wave tank, nonlinear transient wave, wave absorption, fluid-structure interaction, wave impact.