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

Vol. 16, No. 1, March 2006, pp. 25–32

Nonlinear Time-domain Simulation of Pneumatic Floating Breakwater

Weoncheol Koo*
Art Anderson Associates, Bremerton, Washington, USA

M. H. Kim* and D. H. Lee
Department of Civil Engineering, Texas A&M University, College Station, Texas, USA

S. Y. Hong*
Maritime and Ocean Engineering Research Institute, Daejeon, Korea

The performance of pneumatic-type floating breakwaters is studied using a numerical wave tank (NWT) simulation in time domain. The 2-dimensional fully nonlinear NWT is developed based on the potential theory, Boundary Element Method (BEM)/Constant Panel Method (CPM), Mixed Eulerian-Lagrangian (MEL)-nonlinear free-surface treatment, and Runge-Kutta 4th-order (RK4) time-marching scheme. The inner chamber of the pneumatic breakwater is modeled such that the time-dependent air pressure is linearly or quadratically proportional to the change of air volume at each time step, that is, the volume change results in airflow through an opening causing pneumatic damping. The air-chamber effect on wave-blocking performance is then assessed for various wave conditions and damping coefficients. Both fixed and floating breakwaters are considered. It is found that a significant enhancement of performance can be achieved by the damping effect if breakwaters are stationary. When the breakwater is floating against incident waves, the pneumatic damping effect becomes less significant in most wave frequencies considered, since the floating body tends to follow the vertical motion of incident waves and the resulting volume-change effect is small. However, near the resonance frequency, the air damping can play an important role by suppressing large motions. The fully nonlinear simulations with different wave heights are compared with linear ones. The energy conservation formula for pneumatic breakwaters is derived and confirmed by numerical simulations.

INTRODUCTION

A proper understanding of hydrodynamic interactions between waves and structures is always important for the safe and optimal design of offshore platforms, ships and coastal structures. In this regard, many computational tools, mostly based on linear frequency-domain analysis, have been widely used for predicting wave loads and body motions until recently. The linear analysis, however, may not provide reliable solutions for high waves and large motions causing stronger nonlinear interactions. To better understand such nonlinear wave-body interaction phenomena, accurate and robust numerical simulation tools are required.

During the past 2 decades, many researchers have contributed to the development of various kinds of numerical wave tanks (NWT). The potential-theory-based NWT have used either the perturbation approach or fully nonlinear method, and the latter provided more accurate and realistic solutions for higher waves and larger motions. Selected examples of such NWT are the papers of Dommermuth and Yue (1987), Cointe et al. (1990), Sen (1993), Beck et al. (1994), Tanizawa (1995), Contento (1996), Boo and Kim (1997), Kashiwagi et al. (1998), Berkvens (1998), Grilli and Horrillo (1998), Ferrant (1998), Celebi et al. (1998), Hong and Kim (2000), Grilli et al. (2001), Koo et al. (2004), and Koo and Kim (2004). For a more detailed review, readers are directed, for example, to Kim et al. (1999) and Koo and Kim (2004).

*ISOPE Member.

Received July 25, 2005; revised manuscript received by the editors November 30, 2005. The original version (prior to the final revised manuscript) was presented at the 15th International Offshore and Polar Engineering Conference (ISOPE-2005), Seoul, June 19–24, 2005.

KEY WORDS: Pneumatic breakwater, air chamber, linear and parabolic damping, fully nonlinear, numerical wave tank (NWT), time domain, energy conservation.

For the present 2-dimensional fully nonlinear NWT, the potential theory, Boundary Element Method (BEM)/Constant Panel Method (CPM), Mixed Eulerian-Lagrangian (MEL)-nonlinear free surface treatment, and Runge-Kutta 4th order (RK4) time-marching scheme are used. The artificial numerical damping applied to both kinematic and dynamic free-surface conditions was placed far downstream and in front of the wave-maker to suppress transmitted and reflected waves. To prevent the possible development of the sawtooth numerical instability on the free surface, both regriding and smoothing techniques are applied. The developed NWT is proved to be efficient and reliable even for floating bodies with large motions, where results were also compared reasonably against physical experiment (Koo and Kim, 2004).

Fully nonlinear time-domain analyses can obtain the detailed time histories of wave and body behaviors including transient motions, thus proving more beneficial in gaining insights into novel nonlinear phenomena. In this study, the developed 2-D linear and nonlinear NWT are further extended to include the inner air chamber, and applied to the performance evaluation of pneumatic floating breakwaters (PBW). In particular, theoretical and numerical models for pneumatic chambers, including volume-dependent pressure and air velocity, are developed to assess the effects of airflow damping and breakwater performance.

To reliably assess an air chamber's damping and wave-trapping/generation effects, a robust and accurate numerical model for air pressure and airflow is essential. According to the papers by Falnes and McIver (1985), Kim and Iwata (1991), Suzuki and Arakawa (2003) and Hong et al. (2004), the mean vertical velocity of the water surface inside the chamber is the main factor for affecting air pressure and predicting airflow damping. Particularly for floating breakwaters, the relative vertical velocity between the breakwater and water surface inside the chamber has to be accu-