Coupling effects of sloshing and barge motion in variable bathymetry

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ABSTRACT

The motions of barge with partially filled tanks in variable bathymetry are investigated based on linearized potential theory in the frequency domain. The internal sloshing motion is simulated by linearized superposition of natural sloshing modes. The motion of barge is solved by matching eigen-functions expansion in the external fluid domain. Coupling sway and roll motions of floating body with different filling levels are compared. The effects of both inclined bottom with different slopes and hump-shaped bottom with different heights are analyzed. Viewing from the results, coupling sway and roll motions of floating body are significantly affected by the shapes of bottoms.

KEY WORDS: Coupling effects, variable bathymetry, eigen-functions expansion.

INTRODUCTION

The need for distribution and consumption of liquefied natural gas (LNG) results in significant research on floating structures used to store, convert and transfer LNG. A specific case is the sea-keeping of LNG floating storage unit in restricted water depth. Wave-induced loads and motions of floating body in variable bathymetry is important for the design of mooring system and insuring that under-keel clearance is sufficient.

The research on wave propagating in variable bathymetry regions is very important for coastal engineering. A nonlinear coupled-mode system is presented in Belibassakis and Athanassoulias (2011) for modelling the evolution of nonlinear water waves in finite depth over a general bottom topography. Fully nonlinear waves interacting with a rapidly varying bathymetry is modeled in Madsen et al (2006) by a Boussinesq-type model. The surface waves interacting with a vertical sheared current is simulated by extended mild-slope equation in Touboul et al (2016). The wave loads on fixed or floating body in coastal engineering is based on these shallow water computational model.

The motions of moored ship is predicted in Bingham (2000) by the hybrid Boussinesq-panel method. The Boussinesq model of Madsen and Sorensen (1992) is used for propagating an irregular wave system from the wave-maker to a moored ship. The local incident wave field is decomposed to be input into a linear sea-keeping software (WAMIT). However there is no feedback from the diffracted and radiated wave systems by the ship into the Boussinesq model. Nonlinear potential flow equations in an inner domain is coupled with Boussinesq equations of Zou (1997) in an outer domain in Wang et al (2008). The coupling conditions are rendered complicated by the fact that different variables are used in the two domains. A coupling method is proposed in Hamidou et al (2009) between extended Boussinesq equations (Jamois 2006) and integral equation method, under the assumption of potential flow. The fully nonlinear free surface equations are used in both numerical models. Linear Rankine panel method and nonlinear Boussinesq equation are applied for hydrodynamic features of floating body in arbitrary bathymetry in Kim and Kim (2013). In moderate depths, the nonlinear effect can be ignored and linear approach is expected to be reasonable and favorable choice for coastal areas. The hydrodynamic coefficients, exciting forces and motion responses present similar tendencies with results from the problem of constant depth.

A hybrid technique is presented in Belibassakis (2011) for the hydrodynamic analysis of floating bodies in variable bathymetry regions. A coupled-mode model is used for the propagation of wave waves in general bottom topography, in conjunction with a boundary integral representation of the near field in the vicinity of floating body. The results show that bottom variations could significantly influence the responses of floating body with respect to all degrees of freedom. Experimental studies of the effect of variable bathymetry on slow-drift wave response of floating body is presented in Liu et al (2011). A second-order model is proposed to predict the shoaling of a bichromatic sea-state propagating in varying water depth. Accounting for the amplitude and phase modifications of the long wave contribution to the second-order loads, better agreement has been obtained between measured and calculated slow-drift motions of barge.

Viewing from the literatures, coupling effects of sloshing and barge motion in variable bathymetry is rarely considered in the frequency domain. In this paper, linearized potential flow theory in the frequency domain is adopted for both internal sloshing motions and external fluid domain. The superposition of natural sloshing modes gives the internal sloshing motions. Coupling motions of floating body with internal tanks in constant water depth has been presented in Su and Liu (2017). Here the eigen-functions expansion is applied for the sea-keeping of