2D Time-Domain Discrete-Module-Beam Method for Hydro-Elastic Behavior Analysis of Moored Box Barge

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ABSTRACT

This study investigates the 2D hydro-elastic behaviors of moored box barge. Multi-body-based discrete-module-beam (DMB) method was extended to take into account longitudinal and traverse hydro-elastic behaviors in both frequency and time domains. The time-domain governing equation of motion for rigid bodies was based on the Cummins equation. Timoshenko beam elements were employed to connect rigid bodies. Then, we modeled mooring lines based on Rod theory with finite element formulations. The proposed frequency- and time-domain DMB methods were validated by comparing the numerical results with experimental ones under different wavelengths and wave headings. Then, mooring effects on the dynamic motions and vice versa were further checked through time-domain numerical simulations. Vertical displacements and mooring tensions were presented and systematically analyzed.

KEY WORDS: Discrete module beam method; 2D hydro-elasticity; time domain; box barge; very large floating structure; mooring lines.

INTRODUCTION

There are three representative hydro-elasticity analysis methods—modal superposition, direct coupling, and discrete-module-beam (DMB) methods. The former two methods have been widely utilized while the last method was recently proposed. The most accurate method is the 3D direct coupling method (Kim, Bang, Kim, Kim, and Kim, 2013; Lee, Kim, and Kwon, 2020), where the finite element method (FEM) for structural dynamics is fully coupled with the boundary element method for hydrodynamics. The biggest problem with this method is simulation time. A DMB method (Lu, Fu, Zhang, Guo, and Gao, 2016) is a compromising method to both give precise results and reduce simulation time. In this method, a very large floating structure (VLFS) is divided into independently moving rigid bodies that are connected by beam elements. This method can be applied to both frequency (Wei, Fu, Moan, Lu, and Deng, 2017) and time (Zhang, Lu, Gao, and Chen, 2018) domains. Several extensions of this method were made—such as VLFS coupled with mooring lines in time domain (Jin, Bakti, and Kim, 2020), VLFS with forward speed effects (Bakti, Jin, and Kim, 2021), and VLFS under second-order sum and difference frequency excitations (Jin, Kim, Kim, Kim, and Kwak, 2023; Li, Fu, Zhang, and Xu, 2023). Most of the above problems were based on longitudinal hydroelasticity, i.e., 1D hydro-elasticity. Recently, the 2D DMB method was proposed; Bakti, Jin, and Kim (2022) considered beam elements laying in both longitudinal and traverse directions to consider 2D hydro-elasticity in frequency domain, which can be completed by further placing rigid bodies in the lateral direction.

Hydro-elastic analysis for a box barge is a classical problem. A representative example is experiments done by Yago and Endo (1996). They measured the hydro-elastic behaviors of a scaled box barge under different regular wavelengths and wave headings in the wave tank. In addition, many numerical studies (Fu, Moan, Chen, and Cui, 2007) were conducted to validate their numerical model by comparing their numerical results with experimental ones by Yago and Endo (1996).

In this study, the 2D DMB method in frequency and time domain is proposed to simulate 2D hydro-elastic behaviors. Experimental results by Yago and Endo (1996) were first compared to validate our numerical model in different wavelengths and headings. In addition, mooring lines were additionally considered to compare the mooring