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Numerical study of mean drift force on stationary flexible barge

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ABSTRACT

In this study, a fully coupled fluid–structure interaction model was used to compute the mean drift force on a flexible barge under various wave conditions. The fluid domain was solved using a time domain B-spline 3-D Rankine panel method. The structural domain was modeled using a shell-element-based 3-D finite element model. The fluid model was coupled with the 3-D FE model via eigenvectors. Seakeeping analysis of the flexible body was performed by the fully coupled model. In the computation of drift force, two approaches were employed: a near-field method and a far-field method. The near-field method included an extension of the rigid body formula in the flexible body formula. The far-field method used the same formula for the rigid body and the flexible body. To the knowledge of the authors, it was not easy to find validation data for the mean drift force on a flexible barge. Therefore, an indirect validation was conducted by comparison of numerical results using a different approach. As a test model, a virtual barge model was used. The motion and mean drift force on the rigid barge were compared with the results of a commercial software, WADAM. The mean drift force on the flexible barge was compared to the results of the near-field and far-field methods.

1. Introduction

As ships and floating structures increase in size, their relative stiffness decreases. For larger structures, the flexible body deformation becomes more important; as a result, many studies have been conducted to investigate the effects of flexibility on structural problems, such as maximum stress and fatigue damage amongst others. However, there have been very few studies investigating the effects of flexibility on drift force, which is important to the mooring of structures in waves.

The hydroelasticity of a floating body is a complex problem involving the interaction between the fluid domain and the structural domain. The development of a hydroelastic field follows the development of the fluid and structural domains. In the early stages of development, the strip theory (Salvesen et al., 1970) was used as a basic tool to calculate the hydrodynamic force (Bishop and Price, 1979; Price and Temarel, 1982). In this approach, a linear strip is extended to a nonlinear strip to consider the non-linear wave exciting force and geometrical nonlinearity (Jensen and Pedersen, 1981; Jensen and Dogliani, 1996; Vidic-Perunovic, 2005). Based on the strip solution, an impulse response function (IRF, Cummins, 1962) method was used to account for the nonlinear effect in the time domain (Wu and Moan, 1996; Wu and Hermundstad, 2002). A frequency

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domain wave Green function method was applied to the hydroelasticity problem as a 3-D-based approach (Malenica et al., 2003). Additionally, a time domain Rankine panel method was applied by Kim et al. (2009a). A complete second-order force was solved and the second-order excitation forces were applied to the hydroelasticity problem (Shao and Faltinsen, 2011). Recently, a Reynolds Averaged Navier–Stokes (RANS) method was applied by Oberhagemann and Moctar (2011). In the fluid domain, the trend of numerical tools for determining hydrodynamic solutions has evolved from strip theory to 3-D schemes.

In the early stages of the structural domain, the body was considered to be a uniform beam; this concept was used in the symmetric response (Bishop and Price, 1974). The beam model was also extended to antisymmetric responses (Bishop and Price, 1976). The beam-based method was useful in the initial stages due to its simplicity. However, it has limitations in its ability to model complex flexible structures. To overcome these limitations, a 3-D finite element model was developed (Price and Wu, 1985; Bishop et al., 1986). In the structural domain, the trend of analysis has evolved from the beam-based method to a 3-D FE model approach.

The drift force of rigid bodies has been investigated in many research studies. In the computation of drift force, there are two main approaches: the far-field method and the near-field method. The far-field method was introduced by Maruo (1960) and was further elaborated by Newman (1967). This method uses the momentum conservation theory in the computation of drift force. The near-field method was developed by Pinkster and van Oortmerssen (1977). In this method, the pressures on the body surfaces are directly integrated to obtain the drift force. Each of the two methods has advantages and disadvantages. The near-field method provides three directional forces and moments for a single body or multiple bodies. It also provides the distribution of pressure on the body. However, the near-field method is very sensitive to the panels. On the other hand, the far-field method is restricted to global surges, sways, and yaw forces/moments. The far-field is numerically robust compared to the near-field method.

For the second-order force of a flexible body, Wu et al. (1997) extended the rigid body formula to the flexible body. Chen et al. (2003) applied Wu's method to floating structures. However, these studies focused on the motion response generated by second-order forces.

After the late 1990s, much research was conducted on very large floating structures (VLFSs) due to the construction of a floating airport in Japan. For the design of mooring systems of VLFSs, the drift force was studied and showed promising results (Kashiwagi, 1997; Namba et al., 2000; Maeda et al., 1997). Kida and Utsunomiya (2006) suggested a more accurate and practical method and compared several methods. The dimensions of VLFSs are typically 5 km in length, 1 km in width, and a few meters in depth. The flexible motion of VLFSs is larger than the rigid body motion. In the case of recent offshore floating structures such as floating liquefied natural gas (FLNG) platform and floating production, storage and offloading (FPSO) unit, since the body and wavelength are of similar order, and both the flexible body motion and rigid body motion should be considered to be important. When this is the case, the numerical method and results of VLFS cannot be directly applied.

This study concerns the numerical computation of the drift force on the flexible barge. To solve this problem, the domain is decomposed into fluid and structure domains and these domains are fully coupled. A time domain B-spline 3-D Rankine panel method is applied to the fluid domain and a shell-element-based 3-D FE model is applied to the structural domain; the two domains are coupled using an eigenvector. The drift force of the flexible body is obtained using two methods: the near-field method, which is the extended formulation of the rigid body drift force, and the far-field method. A virtual barge model is used as the test model. The motion and mean drift force of the rigid barge are compared with the results of the commercial software, WADAM. Lastly, the mean drift force of the flexible barge is compared to the results of the near-field and far-field methods.

2. Mathematical formulations

Fig. 1 shows the coordinate system of a fluid–structure interaction problem. The system is a right-handed system that is fixed with respect to the mean position of the body. The x-axis is positive in the forward direction, and the y-axis and z-axis are positive in the port side and upward directions, respectively. The incident wave amplitude and frequency are represented as A and ω, and the wave heading angle is represented by β ($\beta = 180°$ is head sea). In this study, the floating body is flexible; therefore, the domain is decomposed into two subdomains: the fluid domain (S_F) and the structural domain (S_S). The fluid domain is solved using the B-spline 3-D Rankine panel method and the structural domain is modeled using a shell-element-based 3-D FE model. A detailed explanation of these methods is described below.

2.1. Fluid domain

Under the assumptions that the fluid is incompressible and inviscid, and the flow is irrotational, the velocity potential (ϕ) can be introduced; it satisfies the Laplace equation.

$$\nabla^2\phi = 0 \quad \text{in } S_F. \tag{1}$$