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Research on Hydroelastic Responses of VLFS: Recent Progress and Future Work

Masashi Kashiwagi*
Research Institute for Applied Mechanics, Kyushu University, Kasuga, Fukuoka, Japan

ABSTRACT

This paper presents a review of recent studies on the prediction of hydroelastic responses of a very large floating structure (VLFS). It is divided into the pontoon type and column-supported type structures. Studies on the pontoon type are divided further into the frequency-domain and time-domain analyses. A new calculation method for general time-dependent problems is also described, which is one of the future works required. The hierarchical interaction theory, developed recently by the author for analyzing hydrodynamic interactions among a large number of columns, is explained with some equations and numerical results. However, experimental work is not reviewed in detail, because this paper focuses on analytical calculation methods.

INTRODUCTION

Because of the lack of adequate land space and/or environmental concerns such as pollution or noise near residential areas, very large floating structures (VLFS) will become increasingly necessary in the future. Several years ago, the Mega-Float project started in Japan, aiming at establishing technologies for constructing a floating airport. Since then, a large number of studies have dealt with hydroelastic problems related to VLFS.

The preferred configuration of VLFS in Japan is of the pontoon type, and its size is 5 km long, 1 km wide, and a few m deep. This kind of structure features 2 points: (1) the wavelengths of practical interest are very small compared to the horizontal dimensions of the structure; (2) hydroelastic responses are more important than the rigid-body motions due to the relatively small flexural rigidity of the structure.

Considering realistic waves with wavelengths of 50 to 100 m, the length ratio to a VLFS under consideration is 1/50 — 1/100. Conventional calculation methods developed for ordinary offshore structures or ships could not be used for this order of short waves. Therefore the primary purpose in the project was the development of a computer code which gives accurate results in less computation time even for very short wavelengths. By virtue of many studies recently undertaken, we are now confident in predicting the wave-induced hydroelastic responses with good accuracy at least in the linear regime. Advanced research is still in progress, such as the time-domain analysis for various types of transient phenomena and the second-order analysis for slowly varying wave loads in irregular waves.

In the present paper, a review is given of recent progress in the prediction method for hydroelastic responses of VLFS. Since many works are concerned with a pontoon-type VLFS, the review starts from the frequency-domain and then the time-domain analyses for the pontoon type. Described is also a new calculation method for time-domain transient problems.

Recently there has been also a remarkable progress in the calculation method for a column-supported VLFS, concerning hydrodynamic interactions among a great number of buoyancy bodies. The essence of this new calculation method (hierarchical interaction theory) is explained at some length, using mathematical equations and numerical examples. At the end, studies on various nonlinear problems are briefly reviewed.

FREQUENCY-DOMAIN ANALYSIS METHODS FOR PONTOON-TYPE VLFS

Boundary Conditions

At the outset, let me introduce notations and describe basic equations necessary for the analysis to follow. Cartesian coordinates are defined, with $z = 0$ as the plane of the undisturbed free surface and $z = h$ as the horizontal sea bottom. The regular plane waves propagate with incidence angle β relative to the positive x-axis.

In the frequency-domain analysis, time-harmonic motions are considered, with the complex time dependence $e^{i\omega t}$ applied to all first-order oscillatory quantities. The boundary conditions on the body and free surface are linearized and the potential flow is assumed.

On the free surface, the dynamic and kinematic boundary conditions are expressed as:

$$p = -\rho i\omega\phi + \rho g\zeta, \quad \frac{\partial\phi}{\partial z} = i\omega\zeta \text{ on } z = 0 \tag{1}$$

where ρ is the fluid density, g is the gravitational acceleration, ω is the circular frequency, p is the pressure, ϕ is the disturbance velocity potential, and ζ is the resultant wave elevation.

Eliminating ζ from Eq. 1, it follows that:

$$\frac{\partial\phi}{\partial z} + K\phi = \frac{i\omega}{\rho g}p \text{ on } z = 0 \tag{2}$$

where $K = \omega^2/g$. Note that $p = 0$ on the water surface, whereas $p \neq 0$ beneath a structure because of the disturbance due to the structure. The draft of VLFS under consideration is very small relative to the dimensions in plan, and thus it can be regarded as zero as the first approximation in a series expansion. (This treatment has been validated as a flat-ship approximation in ship

*ISOPE Member.

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