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Hydroelastic Behavior of Floating Artificial Islands in Waves

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ABSTRACT

A new method is presented to analyze the elastic response in waves of a large floating platform of thin plate configuration which is typical of a recent design for a floating airport. An advantage of this new method is that the modal analysis of the body deflection is not needed; the solution of a hydrodynamic boundary value problem and the solution for the body vibration are simultaneously obtained. Results of numerical implementation of the method are presented.

INTRODUCTION

The feasibility of a floating artificial island is vigorously studied in Japan where appropriate land for the site of very large public facilities such as airports is scarce near the urban areas. Another reason the floating artificial islands are attractive is that their influence on the environment is less than the reclaimed ones'. No doubt there are many problems, technical or social, to be solved before we conclude the feasibility and the safety of such huge floating structures. Most technical problems arise from the fact that they are extremely large beyond our experience in ship and ocean engineering.

A proposed design for floating airports is of a thin mat-like configuration of very large horizontal size: several kilometers long and several meters thick. Naturally the bending rigidity is relatively small with this configuration. Moreover a very wide area of the structure's surface is directly in contact with the water surface and wave action must be extremely large. Elastic deflection due to wave action will be crucial; a large deflection might happen and disrupt the function of the airport, which must be horizontally flat. Hydroelastic analysis of the vibration of such a huge but thin structure in waves will be itself a challenging subject for applied mechanics.

In this report we propose a mathematical approach to analyze the bending vibration of a very thin elastic plate floating on waves, whose horizontal size is very large and whose thickness is very small compared with the wave length. The basic idea for formulating the boundary value problem to determine both plate deflection and fluid flow is that the draft of the plate is so small that the kinematic condition underneath the plate may be imposed on the level of calm water surface. This assumption is quite reasonable in that it accounts correctly for given geometric and physical conditions. It makes it easier to solve the problem and to understand the characteristics of the hydroelastic interaction of the wave and the structure. We need not employ the traditional two-step way of decomposing the deflection into many modes to determine the hydrodynamic force at each mode and superposing the responses through all the modes. The plate is treated in our approach as if it were a part of the water surface. The fluid flow and the deflection are determined simultaneously. This mathematical modeling was originally proposed for simpler problems by Stoker (1957) and Meylan and Squire (1994): the former is for the vibration of a beam in shallow water waves and the latter for the two-dimensional analysis of stress induced in ice floe by waves of deep water.

We present in this paper examples of the analysis for a geometrically simple case: a very long rectangular plate in oblique incident waves. We assume the plate is infinitely long. Even with this simplification we will not fail to evaluate correctly the dynamic deflection of a long plate of finite length in oblique waves if it is away from the edges. If the waves are head-on the plate, we need a more mathematically complicated analysis with some consideration of the edge effect (Ohkusu and Nanba, 1996, 1997).

The real floating airport to be designed in the future will not be so simple in its configuration as our example: nonrectangular shape and nonuniform draft, etc. It is obvious that a much more computationally involved approach will be needed for predicting the dynamic responses of the real floating airport of complicated shape (for example, Kashiwagi, 1998). Nevertheless simple but reasonable modeling and its results will be useful for understanding the unknown hydroelastic mechanics of the floating airport in waves and for providing the means of validation of the computationally involved approach required for practical purposes.

FORMULATION — SHALLOW WATER

A thin plate representing a floating airport covers a part of the undisturbed water surface, which is designated as the x, y-plane ($-b \le y \le b$, $0 \le x \le L$) shown in Fig. 1, where $2b$ is the breadth and L the length of the plate. We consider the positive z axis to be vertically upward. The airport size is supposed to be so huge that we may assume the length of sea waves of our concern is very small compared with L and b. We assume the thickness d of the plate is small compared with other-length scales, the horizontal size of the plate and wave length.

First we consider the case that the water is shallow and of the uniform depth h; the water depth is very small compared with b,L and the wave length. We may use linear shallow-water theory for the analysis of the interaction of the plate and sea waves.

Let us suppose the regular waves:

$$\zeta_0(x,y)\, e^{i\omega t} = e^{-i(Kx\cos\theta + Ky\sin\theta - \omega t)} \tag{1}$$

being incident on the plate at angle θ with the x axis as shown in Fig. 1. Linear shallow-water theory gives the relation between the wave frequency ω and the wave number K:

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