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Wave Pattern in Cloaking Phenomenon Around a Body Surrounded by Multiple Vertical Circular Cylinders

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For a special arrangement of multiple floating bodies, it is known that the wave drift force acting on a body surrounded by a finite number of bodies becomes zero at a certain frequency because of hydrodynamic interactions; this is related to the "cloaking" phenomenon. To study this phenomenon in more detail and its application to engineering problems, we have developed an accurate computer code and an optimization scheme using a genetic algorithm and presented some preliminary results. In this paper, a study is made of the wave pattern in the cloaking phenomenon and its relationship with the wave drift force. Specifically, we conducted the measurement of not only hydrodynamic forces but also the wave pattern around vertical circular cylinders of finite draft arranged in a cloaking configuration. Comparison is made between the numerical and measured results, and it is shown that when the geometric parameters of surrounding circular cylinders are optimized such that the total scattered-wave energy becomes minimal, the wave drift force reduces to nearly zero not only on the central cylinder but also on the outer surrounding cylinders individually.

INTRODUCTION

In recent years, the cloaking phenomenon has been enthusiastically studied in the electromagnetic wave field following a paper by Pendry et al. (2006). "Cloaking" refers to the phenomenon that there is no wave scattering in the form of radial outgoing waves. Now this cloaking phenomenon has been introduced in other wave fields, such as acoustic wave (Zigoneanu et al., 2014) and seismic wave (Brule et al., 2014) on experimental bases. Newman (2013) analyzed the cloaking phenomenon in the water–wave field, using a circular cylinder of finite draft that is surrounded by a finite number of smaller cylinders as shown in Fig. 1. Newman numerically demonstrated that the scattered-wave energy can be reduced to practically zero by optimizing the geometric parameters of outer surrounding cylinders at a specific wave number; then the mean wave drift force acting on whole cylinders becomes very small. It was also demonstrated that, even if the number of surrounding bodies is increased to more than eight, the computed results of the wave drift force are practically the same.

Our previous paper (Iida and Kashiwagi, 2014) studied the same problem with higher numerical accuracy by adopting the interaction theory of Kagemoto and Yue (1986) combined with a higher-order boundary element method (HOBEM). It has been shown that the frequency range in which the wave drift force becomes very small can be widened by controlling the draft of outer surrounding bodies and the distance of location from the central body. For optimization of the parameters of outer surrounding cylinders, the real-coded genetic algorithm (Ono et al., 1999) is adopted.

In this paper, a model experiment is conducted to confirm the cloaking phenomenon at nondimensional wave number $Kd_0 = 1.0$ (where d_0 is the draft of the central circular cylinder). The spatial wave elevation around the cylinders and the wave drift force acting on each cylinder are measured. It is shown that the cloaking phenomenon can be realized in the model experiment as well; additionally, at the frequency where the cloaking phenomenon is realized, the wave drift force becomes very small, not only on entire bodies but also on the inner cylinder and outer surrounding cylinders individually.

THEORY

Velocity Potential

A number of vertical circular cylinders of finite draft are considered (total number equal to M); specifically, a central inner cylinder with radius r_0 and draft d_0 is surrounded by N $(= M - 1)$ outer cylinders of the same size with radius r_N and draft d_N that are uniformly spaced on a circle of radius R_N, concentric with the inner cylinder (see Fig. 1 for these notations). In this paper, all of these cylinders are assumed to be fixed in space; that is, the so-called diffraction problem will be considered.

To analyze multiple wave interactions among these vertical circular cylinders, the linearized potential-flow problem is considered

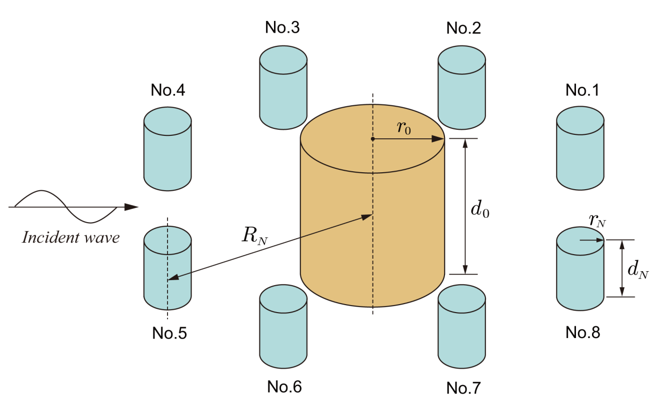

Fig. 1 Perspective view of the entire structure consisting of a central (inner) circular cylinder and $N = 8$ outer surrounding cylinders

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KEY WORDS: Cloaking, experiment, wave pattern, scattered-wave energy, wave drift force, higher-order boundary element method, real-coded genetic algorithm.