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Added Mass and Damping on an Oscillating Surface-Piercing Circular Column with a Circular Footing

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ABSTRACT

Added mass and damping on a vertical, surface-piercing, circular cylinder or column with a submerged sharp-cornered circular footing, oscillating in water of finite and infinite depths, are measured using a planar motion mechanism. The model is made of aluminum, and the outer diameters of the column and footing are 26.67 cm and 60.96 cm, and their lengths are 90.17 cm and 22.86 cm, respectively. The bodies were forced to oscillate sinusoidally with small amplitudes, for several submergences below a free surface. The added-mass and wave-damping coefficients are shown to be influenced strongly by the free-surface effect and are presented as a function of water depth, frequency and direction of oscillation and of depth of submergence from the free surface. For the vertical oscillation close to the free surface, negative added mass values are measured, and the predictions of the added mass by a 3-D diffraction theory are 10-20% lower than the experimental values at the model submergences tested. The experimental added mass coefficient values for the horizontal oscillation and the wave damping coefficients for the vertical oscillation in finite depth differ more than 100% from the corresponding 3-D theory prediction at a certain at-sea operational frequency range. This set of data provides further experimental information for the improvement of theoretical predictions.

INTRODUCTION

Recently, 3-D (three-dimensional) potential theories and computational methods have made much progress in contributing to the theoretical prediction of hydrodynamic forces and motions of floating structures. However, the accuracy of theoretical predictions needs to be confirmed by experimental results. Previously, Miao, Liu and Chung (1985) showed for a vertical circular cylinder or column with a circular footing that the prediction by a 3-D diffraction theory was more than 100% different at a certain frequency range of horizontal oscillation from the corresponding experimental values. Also for the vertical oscillation, the predictions of the added mass by potential theory are 10-20% lower than the experimental values at the model submergences tested. Kudo and Kinoshita (1981) conducted an experiment for the vertical oscillation of similar models of smaller size in infinite depth and also reported the underestimates of the coefficients by their source distribution method.

Most floating semisubmersible structures for offshore petroleum drilling and production operations consist of members of circular, rectangular and other cross sections. Their submerged members oscillate near the free surface. For submerged bodies oscillating in an infinite fluid, the added-mass coefficients are constants, and the wave damping is zero. But as the submerged body oscillates close to the free surface, the free-surface effect can influence the added-mass and wave-damping coefficient values greatly, as a function of the body geometry, frequency and direction of oscillations, and water depth. These frequency-dependent coefficient values provide better accuracy for computing the motion of a floating structure and forces on its submerged structural members.

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As a contribution to this matter, with emphasis on practical applications, a series of experiments were carried out with the harmonic oscillations of a vertical surface-piercing circular cylinder with a sharp-cornered circular footing (e.g. similar to a Sedco-135 series, 3-leg semisubmersible structure) in still water having a free surface. The experiments are conducted at several submerged distances over the frequency range from the free surface for both finite and infinite depths. The model geometry, submergence and frequency range represent closely the actual ocean operation of the 3-leg Sedco-135 series semisubmersible structures. The corresponding added-mass and wave-damping coefficients for both vertical and horizontal oscillations were determined, including the effects of the free surface and finite depth. In-phase and out-of-phase forces, which are linear with the oscillation amplitude, were measured by a planar-motion mechanism. The motion amplitudes are kept small with respect to the dimensions of the cross sections, and the generated waves have amplitudes that are small with respect to the wavelength. The measured added-mass coefficients are presented in a form suitable with the hydrodynamic force equation (Chung, 1976) within the range of the experimental variables. As the present experiment was conducted for the purpose of specific engineering applications, data points at a few theoretically interesting submergences and frequencies were not taken.

MODEL AND EXPERIMENTS

General Setup

Experiments were conducted in a towing tank, whose dimensions are 122 m in length and 7.62 m in width. Water depth was h = 4.57 m. About halfway along its length was a planar motion mechanism (PMM) (Goodman, 1968) installed on a stiff towing carriage. Braces were installed between the PMM assembly and the towing carriage for stiffness, and the entire carriage was lifted off its wheels and supported on blocks to provide a rigid base during testing. A sonic probe measured the outgoing waves at a distance of about 2 m from the axis of the model.

The forced harmonic oscillation experiments were conducted