International Journal of Offshore and Polar Engineering
Vol. 2, No. 4, December 1992 (ISSN 1053-5381)

High Frequency Hydrodynamic Coefficients of a Vertical Cylinder

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ABSTRACT

Alternative methods of calculating high frequency added masses and damping coefficients of vertical cylinders of arbitrary section are described. Damping coefficients are calculated by a short-wave approximation relating to the local form of waves generated by the oscillating structure. As an alternative, they are also obtained from the exciting forces of the related scattering problem, with these forces obtained by a geometrical optics approximation. Added masses are obtained by discarding the propagating mode potential and using the evanescent mode potentials alone, which are free of irregular frequencies. They are also obtained by an application of the Kramers-Kronig relations, which requires the infinite frequency added mass and the damping coefficients at all frequencies. When the oscillation frequency is sufficiently high, extensions to the appropriate methods to account for compressibility may readily be made and are indicated. Numerical results obtained by the various methods are compared with corresponding analytical results for a vertical circular cylinder. As an example of the methods' application, results are obtained for square cylinders. The ranges of validity of the proposed approaches are summarized, and the practical application of the approaches is illustrated.

INTRODUCTION

In the design of offshore structures, an estimation of the interaction between the structure and the surrounding ocean is generally required, and may involve structural motions due to excitation from waves, earthquakes, ice impact and so on. For a large offshore structure oscillating in otherwise still water, the hydrodynamic forces on the structure are usually expressed in terms of added masses and damping coefficients, corresponding to force components in phase with the acceleration and velocity of the structure respectively. For small amplitude motions, flow separation effects may usually be neglected, and these hydrodynamic coefficients may then be obtained as a solution to the corresponding linearized potential flow problem.

For the general case relating to structures of arbitrary shape, the problem is usually solved by an integral equation method involving an appropriate three-dimensional Green's function (e.g., Sarpkaya and Isaacson, 1981). For the more restricted case of a vertical cylinder of arbitrary section extending to the seabed, the three-dimensional problem may be reduced to a series of two-dimensional problems in the horizontal plane. Each may be solved by an integral equation method, now corresponding to a line integral equation rather than a surface integral equation, and now involving appropriate two-dimensional Green's functions (e.g., Isaacson and Mathai, 1991).

In certain applications, such as those involving ice impact or earthquake excitation, or for very large structural concepts (e.g., Chow et al., 1991), these hydrodynamic coefficients are required at relatively high frequencies. However, difficulties with the integral equation methods may then arise on account of the presence of irregular frequencies. There have been various attempts to remove these by modifications to the integral equation (e.g., Lee and Sclavounos, 1989).

As an alternative approach to eliminating these frequencies, the present paper considers the use of suitable high frequency approximations to estimating the hydrodynamic coefficients. In fact, the damping coefficient may be obtained by a short-wave asymptotic solution relating to the local form of waves generated by the oscillating structure (Ursell, 1957). The damping coefficient may also be obtained on the basis of the Haskind relations from the exciting forces of the related scattering problem, with these forces at high frequencies obtained by a geometrical optics approximation. The added masses at high frequencies cannot be obtained in the same way. Instead, they may be obtained by discarding the propagating mode potential, and adding contributions from the evanescent mode potentials alone, which are free from irregular frequencies and hence can be accurately calculated. The added masses may also be obtained by a somewhat more elaborate procedure based on an application of the Kramers-Kronig relations (Kotik and Mangulis, 1962), which requires the infinite frequency added mass and the damping coefficients at all frequencies. The former may be obtained by the integral equation method, suitably modified so as to treat the infinite frequency limit. The present paper describes the above alternatives for obtaining high frequency hydrodynamic coefficients, assesses their suitability, and indicates their application.

It should be pointed out that when the oscillation frequency is sufficiently high, a further modification to the hydrodynamic loading arises from the effects of compressibility of the water. The significance of fluid compressibility at high excitation frequencies has been demonstrated in several studies of vertical circular cylinders and vertical axisymmetric structures undergoing forced harmonic motions, not to mention numerous studies of dam-reservoir systems. Goto and Toki (1963) formulated the problem considering surface waves and fluid compressibility, and indicated the form of the analytical solution for a vertical circular cylinder. Kotsubo (1965) provided the corresponding analytical solution for an elliptic cylinder. Subsequently, extensive results for a circular cylinder were obtained by Liaw and Chopra (1974), and Tanaka and Hudspeth (1988). These studies are useful in pro-

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Received January 8, 1992: revised manuscript received by the editors August 3, 1992. The original version (prior to the final revised manuscript) was presented at the Second International Offshore and Polar Engineering Conference (ISOPE-92), San Francisco, USA, June 14-19, 1992.
KEY WORDS: Added mass, cylinders, damping, hydrodynamics, ocean engineering, offshore structures, waves.