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Vortex-excited Vibration of a Circular Cylinder in Planar Oscillating Flow

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ABSTRACT

Laboratory investigation has been made for a comprehensive study of the dynamic transverse response of a circular cylinder in planar oscillating flow. The test cylinder, 0.03 m in diameter and 0.48 m in length, is mounted horizontally at the mid-point of the water depth and is supported flexibly by a spring in the transverse direction. The variations of the transverse response of the test cylinder with frequency ratio f_d/f_{nw} (f_d: frequency of oscillatory incident flow; f_{nw}: natural frequency of the test cylinder in still water) and Keulegan-Carpenter number, KC, as the function of typical combined mass ratio-damping parameter, Scruton number K_{sp}, are obtained in the range of $4 < KC < 20$ and $0.75 < K_{sp} < 14.5$. The appearance of 2 types of peak in the amplitude of vortex-excited vibration, which occurs similarly in the vortex-excited vibration of a vertical circular cylinder in waves, is also recognized for the right value of typical Scruton number K_{sp}.

INTRODUCTION

The wave forces acting on a small-diameter offshore structure are usually resolved into 2 components. One, the in-line force, acts in the direction of wave propagation; the other, the lift force or transverse force, acts at right angles to the wave propagation direction. The in-line force is usually expressed by using the Morison equation and acts predominantly at a frequency equal to the incident wave frequency f_w. On the other hand, the predominant frequency of the lift force is a multiple of that of in-line force. The structure's dynamic response to the lift forces must then be considered more significantly.

A great many experiments have been carried out in order to study the phenomenon of the vortex-excited vibration of a cylinder in steady flow. Summaries have been made by Blevins (1977), Sarpkaya (1979), Bearman (1984), and Sumer and Fredsoe (1997). In this case, if the vortex shedding frequency approaches the natural frequency of a lightly damped cylinder, the vibration of a cylinder becomes larger, and this large vibration can drive the eddies to be shed with a frequency ranging between the natural frequency of the cylinder and the Strouhal frequency. This phenomenon is usually called lock-in between the frequency of vortex shedding and the frequency of the vibrating cylinder. Under lock-in conditions, large resonant vibration occurs, and the lift forces are amplified both by the increase of vortex strength and by the improved correlation in the phase of vortex shedding along the cylinder axis.

A similar phenomenon may occur under certain conditions, if an elastically mounted vertical cylinder is placed in waves. However, this has not been sufficiently understood, and relatively little work has been carried out in this interesting problem in waves and in planar oscillating flow. This is mainly due to the complexity of the phenomenon, because the incident flow acting on a vertical cylinder in waves is oscillatory, varies with water depth and possesses a vertical component. Sumer and Fredsoe (1997) have prepared a comprehensive summary.

In this paper, an experimental investigation has been undertaken into the nonlinear vortex-excited vibration of a circular cylinder in planar oscillatory flow, with emphasis placed on the appearance of 2 types of peak in the amplitude of the vortex-excited vibration. A similar phenomenon, which is produced by perfect resonance coupled with waves-wave coupling—and by vortex-vortex coupling—occurs in the vortex-excited vibration of a vertical circular cylinder in waves for right damping and small Scruton number K_s (Hayashi, 1984; Hayashi and Chaplin, 1998). In the case of steady flow, perfect resonance appears in the locked-in range, but in waves, it appears only near the ratios of wave frequency f_w to the natural frequency f_{nw} of the cylinder in still water in the sequence of f_w/f_{nw} = about 1/2, 1/3, 1/4, ...; elsewhere, vortex coupling may occur for light damping in which the oscillation frequency is not a simple multiple of wave frequency (Hayashi and Chaplin, 1998).

The work presented here is an experimental investigation into the nonlinear vortex-excited vibration of a circular cylinder in planar oscillatory flow. Emphasis is placed on the influence of the damping factor ζ, Scruton number K_s and Keulegan Carpenter number KC on the relationship between the transverse response and the ratio of oscillatory incident flow frequency f_d to the cylinder's natural frequency f_{nw}.

EXPERIMENTS

The experiments were carried out using a water tank with the internal dimension of 1 m in length, 0.5 m in depth and 0.5 m in width, which is oscillating in true harmonic horizontal motion. Fig. 1 shows the experimental setup. In order to prevent the shaking of the water surface, a cover plate is put on the upper part of the tank. The test cylinder is mounted horizontally at the mid-point of the water depth. Both ends of the test cylinder are

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KEY WORDS: Vortex-excited vibration, planar oscillatory flow, lift force, fluid structure interaction, Scruton number.