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Vortex Regimes Around a Freely Vibrating Cylinder in Oscillatory Flow

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ABSTRACT

The study concerns the vortex-flow regimes around a cylinder exposed to an oscillatory flow and undergoing vibrations in the cross-flow direction. The flow of vortices was visualized, using the aluminum-powder technique. The study focuses on the lock-in regions. The tests have been carried out for the values of the Keulegan-Carpenter number KC = 10 and 20, and for a range of reduced velocities. The identified vortex-flow regimes were compared with the fixed cylinder case. The changes to the vortex-flow patterns were discussed with regard to their influence on the lift force. To complement the results of the experimental study, an attempt has been made to simulate the flow numerically, using the discrete vortex model. The numerical results agree with the experiments.

INTRODUCTION

The vortex-induced vibrations of slender structures can occur in both steady currents and wave flows. In steady currents, in the lock-in region, the vibrating structure takes control of vortex shedding, which leads to the amplification of the lift force; this, in turn, generates higher amplitude vibrations (see e.g. Blevins, 1976). The amplitude of vibrations increase as the reduced velocity is increased. When the amplitude of cross-flow vibrations reaches a certain value, the mode of vortex shedding changes. This apparently leads to a decrease of vibration amplitudes and a jump in the phase between the vibrations and the lift force (Williamson and Roshko, 1988).

In a wave flow, the cross-flow amplitude response of a freely vibrating cylinder reveals the multipeak behaviour; the lock-in occurs not only once but rather several times. Each of these peaks occurs at a certain value of the reduced velocity, V_R, which corresponds to the ratio f_r/f_w being an integer value. Here, fr is the response frequency of the system, f_w is the flow frequency. The number of these peaks depends on the value of the Keulegan-Carpenter parameter, KC, and increases with KC (Sumer and Fredsøe, 1988).

The interaction between the cross-flow vibrations and the wave flow has not yet been fully explored. There are indications that the three frequencies, namely the vibration frequency, f_r, the fundamental lift frequency, f_L, and the natural frequency of the system, f_n, coincide at all the lock-in points as in the case of steady current (Sarpkaya, 1976; McConnel and Park, 1982). However, there is still a lack of knowledge of how the cross-flow vibrations influence the vortex-flow patterns around the cylinder, and how the frequency structure of the lift force changes when amplitudes of cross-flow vibrations grow.

The flow visualization studies published so far did not reveal substantial changes in the flow regime around an oscillating cylinder in a wave flow when compared to the fixed-cylinder case (see e.g. Hayashi et al., 1993). The results of the numerical simulation studies of oscillatory flow around vibrating cylinders, based on the vortex-in-cell method, which were carried out for a relatively small KC number (namely, KC = 10) and for a two-degree-of-freedom system, did not show any significant changes in the flow either (Graham and Djahausouzi, 1991; Slaouti and Stansby, 1991).

The purpose of the present study is to investigate the motion of vortices around a cylinder exposed to an oscillatory flow and undergoing transverse vibrations. This is basically to increase our general understanding of vortex-flow processes under the described conditions. Clearly, this would assist the development of predictive capabilities, essential for the design of slender flexible bodies subject to waves.

It turns out that the vortex-flow regimes, known from the fixed-cylinder case, can be subject to substantial changes when the cylinder is undergoing lock-in vibrations with large amplitudes.

EXPERIMENTAL SETUP AND PROCEDURE

The tests were carried out in a water tank 2.00 m long, 0.60 m wide, and 0.75 m deep.

A smooth-surface rigid plastic pipe, D = 2 cm in diameter and 55 cm in length, was used as the test cylinder. It was filled with metal balls to increase its mass. The cylinder was mounted on a carriage (Fig. 1). The carriage and therefore the cylinder were driven back and forth by a hydraulic system in otherwise still water. This simulated the two-dimensional oscillatory flow around the cylinder. The cylinder was mounted on the carriage by means of a pin-point joint at its base, and its motion was restrained in the in-line direction (x-axis) by nylon strings attached to the top of the cylinder. Such an arrangement allowed the cylinder to vibrate in the transverse direction (y-axis) only as a one-degree-of-freedom, lightly damped system. The spring constant of the system could be controlled by adjusting the tension and/or the length of the nylon strings. In the fixed-cylinder case additional strings at right angle to the in-line direction prevented

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KEY WORDS: Vibrating cylinder, oscillating flow, vortex regimes.