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Hydrodynamic Forces on Multiple Free-hanging Circular Cantilevers in Uniform Flows

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An experimental study has been carried out to investigate time-dependent hydrodynamic forces on 2 different triangular configurations of 3 flexible free-hanging circular cantilevers with a free-end condition and subjected to uniform cross-flows. Each cantilever has a 34.4 aspect ratio and a low mass ratio of 1.24. The Reynolds number varied from 10,800 to 37,800. Four variations on the gap between upstream and downstream cylinders (L_{UD}) were considered. The results demonstrated that at high reduced velocities (Ur), the drag-lift frequency ratios were independent of the parameters Ur and L_{UD}. At moderate Ur, the configuration with 2 cylinders at the downstream position produced significantly higher total forces on the downstream cylinders.

INTRODUCTION

The dynamic response of an array of flexible circular cylinders subjected to cross-flow is very complex. Many factors dictated the response, such as the Reynolds number, cylinder arrangement, and incoming flow condition. The general characteristics of cylinder response in the cross-flow are not well understood in the various parameter ranges. For example, when several flexible cylinders are free to oscillate due to current flows, the wake interference among them becomes much more complex. The wake of the upstream cylinder(s) impinging on the downstream cylinder(s) differs from the case of stationary cylinders. In turn, the response of the downstream cylinder(s) differs from that of both single and cylinder(s) in the wake of fixed cylinder(s). Due to this complexity, some phenomena which are still not clearly understood, e.g. the induced time-dependent fluid forces, need to be clarified.

In the past, some experimental works have been initiated on the subject of fluid forces acting on a vibrating cylinder, e.g. by Sarpkaya (1978), Moe and Wu (1989), and Khalak and Williamson (1996, 1997). They found that the lift force was irregular, particularly in the self-excited case. It was concluded that the effect of the cylinder-end boundaries held great importance for the characteristics of the measured drag and lift forces. Khalak and Williamson, in direct measurement of the lift force acting on a freely vibrating cylinder, noted that a large discrepancy over the stationary cylinder case occurred in which the rms lift force was increased 6-fold.

During the early investigations, a short-rigid cylinder was commonly used, and typically the cylinder motion allowed in only one direction, while restricted in another. However, some researchers have introduced works in which the cylinder is allowed to oscillate in-line and transverse to the fluid flow simultaneously. Moe et al. (1994) showed that subcritical average drag coefficients increased and shifted to larger reduced velocity as the ratio of the transverse-inline motion frequencies increased, compared to the case without in-line motion. Sarpkaya (1995) observed that the mean drag for a cylinder undergoing biharmonic free vibration can become 3.5 times that for the static cylinder. Similar subjects can also be found in excellent compilations and reviews (e.g. Sumer and Fredsøe, 1997; Blevins, 2001; Gabbai and Benaroya, 2005; and Williamson and Govardhan, 2008).

On the other side, some efforts have been devoted to works on the dynamic response and fluid-force measurement of circular cylinder arrays due to cross-flow. Brika and Laneville (1997) performed a wake interference study on various configurations of 2 horizontally positioned cylinders, including tandem and staggered arrangements. They found that when the upstream cylinder is free to oscillate, the downstream cylinder response becomes hysteretic, which is contrary to the case of the stationary upstream cylinder. More recent studies conducted by Assi et al. (2006, 2007) have examined 2 vertically tandem cylinders with the upstream cylinder maintained fixed and the downstream cylinder allowed to oscillate only in the transverse direction. The earlier work (Assi et al., 2006) showed that the downstream cylinder's peak amplitude was about 50% higher than that experienced by a single cylinder, and the galloping-like phenomenon occurred in the gap range of $3D < L_{UD} < 5.6D$. Meanwhile, Assi et al. (2007) predicted that the high amplitude oscillation experienced by the downstream cylinder was due to excitation by the vortex component of the lift force at higher reduced velocity. Subjects relevant to the dynamic response and wake interference effect due to cross-flow for more than 2 circular cylinders in arrays can be found, for example, in Chen (1987) and Chen et al. (1996).

Despite the large number of studies on an array of 2 or more cylinders with various configurations, there have been no studies in which all of the test cylinders are free to oscillate in 2 directions, in-line and transverse to the flow direction, with the free-end condition taken into account. Thus, this study presents new results on the characteristics of the time-dependent hydrodynamic forces, which are measured simultaneously, acting on a group of self-excited cylinders with free-end condition. It is expected that the results can be utilized as basic considerations in the preliminary design process of floating platforms with a free-hanging type of risers, such as future ocean thermal energy conversion (OTEC) or CO_2 sequestration platforms with multiple cold water pipes (CWP) or CO_2 injection pipes.

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