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Hydrodynamic Forces on Multiple Hanging-off Circular Cylinders in Uniform Flows

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ABSTRACT

This study is addressed to evaluate the hydrodynamic forces experienced by multiple flexible cylinders arrays which are free to oscillate due to water crossflows. This paper presents a part of experimental results of two different configurations of three flexible circular cylinders which were towed in still water. The cylinders were submerged partially into the still water from a towing carriage as hanging-off vertical cantilevers. Each cylinder has length-to-diameter ratio of 34.4 with low mass ratio (= 1.24). The Reynolds number varied from 1.08×10^4 up to 3.78×10^4. A longitudinal gap between upstream and downstream cylinder (L_{UD}) was varied by 5*D*, 7*D*, 9*D*, and 10*D*, respectively. The measurement of the hydrodynamics forces in two, in-line (drag force) and transverse (lift force) directions were performed simultaneously. Frequency of the drag force was found approximately twice the corresponding lift force frequency at the related reduced velocity (*Ur*) for all cases, except at low *Ur*, and linearly increased as a function of the *Ur*. The variables *Ur* and L_{UD} revealed have significant influence on the characteristics of C_D and C_L for each test configuration. For upstream cylinders in both two configurations, there are basically three distinct regions dealing with the C_D and C_L characteristics as function of *Ur*, while for downstream cylinders the C_D and C_L decreased as *Ur* and L_{UD} increased. At the medium *Ur*, the configuration with two cylinders at the downstream position (Case B) produced higher total drag and lift coefficients on the downstream cylinders than another one.

KEY WORDS: multiple hanging-off flexible cylinders; drag and lift coefficients; upstream and downstream cylinders; wake interference.

INTRODUCTION

The dynamics response of an array of circular flexible cylinders subjected to cross-flow is very complex. Some factors dictated the response, such as Reynolds number, cylinders arrangement, and incoming flow condition. General characteristics of cylinders response in the cross-flow are not well understood in the various parameter ranges. When several cylinders are free to oscillate due to current flows, the wake interference among them gains much more complex and the downstream cylinder(s) response becomes hysteretic. 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 both that of a single and that of cylinders in the wake of fixed cylinders. Due to this complexity, some phenomena which were still not clearly understood need to be clarified, including their time-dependent fluid forces.

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

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

On the other hand, some efforts have been given in works on the dynamic response and fluid forces measurement of circular cylinder arrays due to cross-flow. Brika and Laneville (1997) performed wake interference study on various configurations of two horizontally positioned cylinders including tandem and staggered arrangements. They found when the upstream cylinder is free to oscillate, the downstream cylinder response become hysteretic which is contras with that stationer upstream cylinder case. More recent studies by Assi et al. (2006, 2007) examined two vertically tandem cylinders with the