Hydro-elasticity of Two Side-by-side Flexible Cylinders

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ABSTRACT

In this paper, we present the effects of proximity interference on the hydro-elastic responses of two pre-tensioned flexible cylinders in side-by- side arrangement subjected to uniform cross-flow (CF). The experimental results of the side- by-side cylinders are presented and compared with an isolated flexible cylinder. Two flexible cylinders of the same size, properties, and pretensions were tested with two different vertical separation distances, namely, 2.75 and 5.5 diameters. Reynolds numbers ranged from 1400 to 20000 (subcritical regime). The aspect ratio of the cylinders was 162 (length over diameter). The mass ratio (cylinder's mass over mass of displaced water) was 1.17. It was found that at the small separation distance of 2.75 diameters, the upper cylinder showed no upper branch in the first CF lock-in region, in contrast to the lower and the single cylinder. With the increase in the initial vertical separation to 5.5 diameters, both cylinders exhibit amplitude responses similar to the isolated cylinder. At the small separation distance, the upper cylinder showed quite a distinct CF frequency response (higher values) than both the lower cylinder and the single cylinder within the reduced velocity range of $4 < U_r < 6.74$.

KEYWORDS: Side-by-side; Flexible cylinders; Amplitude response; Frequency response.

INTRODUCTION

The interference among groups of cylinders is an important factor in the design of marine and civil structures (such as production and drilling risers, Tensioned Leg Platforms (TLP) tendons and moorings, subsea group pipelines, transmission lines, heat exchangers and chimneys, etc.), and has been the subject of some studies in the past. The behavior of a group of cylinders can be very complex because it involves the mutual effects of adjacent cylinders and depends on their different relative positions.

Although the sea risers are generally found in group arrangements, studies on a special arrangement of group cylinders cannot well explain the interference phenomenon. Hence, it is believed that investigation of the flow around pairs of cylinders can lead to a better understanding of the interference effects for any case involving large numbers of cylinders.

Numerous experimental and computational studies for flow past a single cylinder and stationary pairs of cylinders have been reported in the literature, but information about flow around multiple flexible cylinders is scarce because of the complexities in the responses. The complexities involved in the behavior of multiple pre-tensioned flexible cylinders (compared with the stationary cylinders and flexibly-mounted oscillating rigid cylinders that only respond in the first mode of vibration) may arise from this fact: The initial separation distance between flexible cylinders during oscillation cannot remain constant. Most of the studies of the cylinder pairs were conducted for the case where the oscillation of the cylinders was restrained. Hence this cannot be truly representative of those in the real sea applications, e.g., risers and so on. A recent publication by Sumner (2010) demonstrated a complete review and detailed assessment of flow around a pair of stationary cylinders. For the side-by-side arrangement, where both cylinders were arranged transverse to the incoming flow, it was found that if the cylinders are in close proximity, they may behave as a single cylinder. If the separation is significant, they may behave as two independent bodies, although synchronization between the adjacent vortex streets may occur. Complex wake and vortex-street interaction occurred when the cylinders were spaced between these two extremes, in particular an asymmetric, or biased flow pattern that may be bi-stable in nature (Sumner, 2010).

There are some recent studies by Huera-Huarte and Bearman (2011) and Huera-Huarte and Gharib (2011a, 2011b) for the cases in which the pair of flexible cylinders was free to oscillate. Based on their experiments on two flexible circular cylinders with various separations, they re-defined the regions in which the proximity interference (in the side-by-side arrangement) and the wake interference (in the tandem arrangement) occur. Zdravkovich (1988) presented a graph for the interference regions for two stationary circular cylinders of equal diameters. He defined two interference regimes, namely proximity and wake interference. These cited studies on pairs of flexible cylinders focused mainly on analyzing the amplitude response, frequency response, and synchronization between the cylinders.

For the side-by-side arrangement, Huera-Huarte and Gharib (2011a) reported that in the large hydro-elastic response region, with a reduced velocity between 4 and 8, and the center-to-center separations smaller than 3.5D, strong proximity interference exists. They found that in this region, the cross-flow motion of the cylinders was either out-of-phase for reduced velocities smaller than 6, or in-phase for reduced velocities between 6 and 8. This behavior has been previously reported by Zdravkovich (1988) as a