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Multi-mode flow-induced vibrations of two side-by-side slender flexible cylinders in a uniform flow

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ABSTRACT

Flow-induced vibration (FIV) of multiple marine risers frequently occurs in deepwater applications and might result in serious structural failure due to fatigue damage accumulation. It is known that long marine risers may experience high modes of vibration and behave multi-mode vibration features. Moreover, the interactions of multiple risers subject to FIV are very complex and still unclear. In this paper, a series of experimental tests were carried out to investigate FIV of two side-by-side flexible cylinders with high aspect ratio (length to diameter, L/D = 350) in a towing tank. Four cases of different spacing ratios (center-to-center separation distances to cylinder diameter, S/D = 3.0, 4.0, 6.0 and 8.0) were adopted to examine the effect of spacing on the multi-mode FIV of the two flexible cylinders. The maximum dominant modes are 4th and 6th in cross-flow (CF) and in-line (IL) directions for both side-by-side cylinders, as well as the single one. In the switching region of the adjacent modes of vibration, higher-order mode vibrations are less difficult to excite for side-by-side cylinders. The IL displacement amplitudes of the two cylinders could be enhanced by the remarkably strong interaction between cylinders, even with a center-to-center distance of up to 8.0 cylinder diameter. In addition, the IL FIV behaviors are much more complicated than those in CF direction, for instance the response spectra in IL direction exhibit several large peaks and lots of small spikes around. The IL and CF interactions of the two side-by-side flexible cylinders were also investigated by using the response trajectories collected from seven measurement points at different reduced velocities.

1. Introduction

As a key equipment for extracting oil and gas from oilfields located at deep sea, marine riser system is widely used to transport oil and gas drilled from underneath ocean floor to the production platforms in the oil industry. This system generally consists of a group of slender, flexible cylinder structures connecting floaters on the surface and wellheads at the seabed. It is well recognized that flow-induced vibration (FIV) is an important source of fatigue damage for marine risers. Compared with the case of a single cylinder, the oscillation characteristic and wake flow of multiple cylinders are much more complicated and haven't been fully understood due to the interactions of a bundle of cylinders [1–5]. In order to further comprehend the FIV of multiple risers, some research work has been reported over the past decade [6–9].

Two cylinders in a side-by-side arrangement can be viewed as one of the simplest cases of multiple cylinders. For a better

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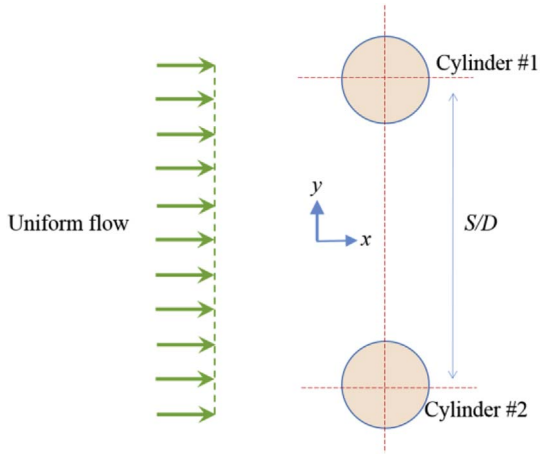

Fig. 1. Two side-by-side cylinders in steady uniform flow (cross-sectional view).

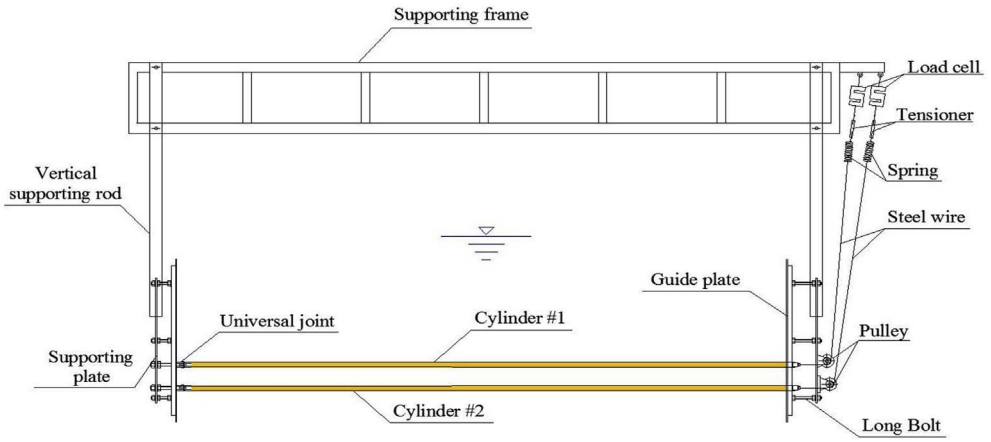

Fig. 2. Schematic diagram of the experimental set-up.

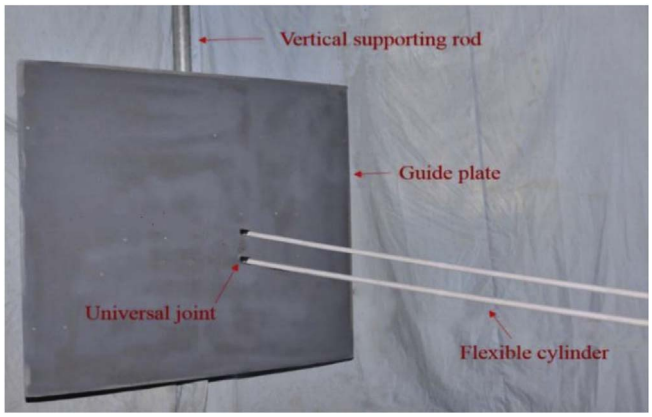

Fig. 3. Guide plate and flexible cylinder models.

understanding of the interference effects, experimental investigations of the flow around two side-by-side fixed cylinders have been performed by a large number of researchers. It was reported that there are three flow regimes for such an arrangement based on the spacing ratio, S/D (S is the center-to-center separation distance and D is the cylinder diameter). At very small spacing ratios ($S/D < 1.1$–1.2), one single vortex street is formed and no vortex is generated in the gap between cylinders [10]; at intermediate cylinder spacing ratios (1.1–$1.2 \leq S/D < 2.2$–2.7), a narrow wake behind one cylinder as well as a wide wake behind the other is observed and a bistable biased gap flow emerges [11]; at large spacing ratios ($S/D \geq 2.2$–2.7), a coupled wake street appears [12,13].