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Flow-induced Vibrations of a Cylinder with Two Degrees of Freedom near Rigid Plane Boundary

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Based on similarity analyses, the flow-induced vibrations of a near-wall cylinder with 2 degrees of freedom are investigated experimentally by employing a hydroelastic apparatus in conjunction with a flume. The cylinder's vibration amplitude, vibration frequency and vortex shedding frequency were measured and analyzed. The effects of gap-to-diameter ratio (e_0/D) upon the vibration responses are further investigated. The experimental results indicate that, when the reduced velocity (Vr) is small (e.g. $Vr = 1.2 \sim 2.6$), only streamwise vibration occurs, and its frequency is quite close to its natural frequency in still water. When increasing Vr (e.g. $Vr > 3.4$), both streamwise and transverse vibrations of the near-wall cylinder may occur. In the examined range of gap-to-diameter ratio ($0.42 < e_0/D < 2.68$), 2 vibration stages (in terms of Vr) of streamwise vibrations usually exist: First Streamwise Vibration (FSV) and Second Streamwise Vibration (SSV). In the SSV stage, the vortex shedding frequency may either undergo a jump to that of the streamwise vibration, or stay consistent with that of the transverse vibration. The amplitudes of transverse vibration are usually much larger than those of streamwise vibration for the same value of e_0/D. The maximum amplitudes of both streamwise and transverse vibration get larger with the increase of e_0/D ($0.42 < e_0/D < 2.68$).

INTRODUCTION

The flow-induced vibrations (FIV) of a cylinder are a typical fluid-structure interaction problem with a wide practical background. For example, the bridges and chimneys under wind actions in civil engineering, the risers and pipelines in offshore engineering, the heat exchanger tubes in chemical engineering, they are all prone to FIV. In the past few decades, FIV have attracted wide interest from numerous researchers, e.g., Blevins (1977), Sarpkaya (1979), Griffin and Ramberg (1982), Bearman (1984), Parkinson (1989), Sumer and Fredsoe (1997), Williamson and Govardhan (2004).

Most previous research has focused mainly on the transverse dynamic responses of the cylinder undergoing FIV. Feng (1968) studied the FIV of a cylinder with a single degree of freedom in the transverse direction, and demonstrated that the resonance of the cylinder will occur when the vortex shedding frequency at the wake region of the cylinder is close to the latter's natural frequency. Brika and Laneville (1993), Khalak and Williamson (1996) and Govardhan and Williamson (2000) intensely investigated the vibration amplitude branches. Yet, studies on the FIV of the cylinder with 2 degrees of freedom have been scarce until now (Williamson and Govardhan, 2004). Moe and Wu (1990) found that the position of maximum amplitude of the cylinder with 2 degrees of freedom shifts to a higher value of reduced velocity (Vr), and the maximum amplitude gets larger as well as those for only the transverse-motion case. Sarpkaya (1995) drew conclusions similar to those by Moe and Wu (1990). Jauvtis and Williamson (2003) studied the responses of an elastically mounted cylinder with 2 degrees of freedom at low mass-damping parameters. Their results showed that the streamwise oscillation has slight effects on the transverse vibration for the mass ratios larger than 5.0. The experimental results by Williamson and Jauvtis (2004) showed there exists much difference between the response of the cylinder with one degree of freedom (transverse) and that with 2 degrees of freedom (both transverse and streamwise) for the case of mass ratios less than 6.0; also, the FIV are mainly under the wall-free conditions.

Under some practical circumstances, the cylinders are close to a wall, e.g., the submarine pipelines laid upon the seafloor. Wilson and Caldwell (1971) and King and Jones (1980) preliminarily investigated experimentally the influence of proximity to a plane boundary upon the FIV of flexible cylinders exposed to a steady flow. Tsahalis and Jones (1981) investigated the FIV of a flexible cylinder with $e_0/D \geq 1.0$ in steady currents. (e_0 is the gap between cylinder and boundary; D, the cylinder's diameter.) It was found in their experiments that the maximum vibration amplitude appeared at a higher value of reduced velocity and the maximum amplitude was reduced due to proximity of the boundary when $e_0/D \geq 1.0$. Further, the vibrations of the submarine pipeline may have interaction with the local scour of the surrounding erodible seabed (Gao et al., 2006). In the aforementioned FIV experiments for flexible cylinders, the vibration characteristics of the cylinder in the streamwise direction and in the transverse direction have not been investigated separately. Tsahalis (1984) further studied the streamwise and transverse vibration responses of a flexible cylinder in steady currents, and found that proximity to a plane boundary has a pronounced effect on both the transverse and the streamwise amplitude responses. Until now, the FIV of a near-wall cylinder with 2 degrees of freedom have not been well understood.

In this study, on the basis of similarity analyses, a series of FIV experiments was conducted with a hydroelastic apparatus in a flume, to further investigate the typical characteristics of the transverse and streamwise vibration amplitude and frequency of a cylinder near a rigid plane boundary.

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