Investigation of Flow Past Circular Cylinder Near Planar Boundary

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The starting and steady flows past a circular cylinder placed near a planar boundary are investigated both experimentally and numerically. The flow is accelerated until it reaches an ultimate speed and then remains steady. The flow field is visualized using a hydrogen bubble technique. In numerical simulations, the Navier-Stokes equations for unsteady incompressible viscous flow combined with a $k - \omega$ turbulence model are solved via a finite volume method with SIMPLEC algorithm. The investigation reveals that vortex shedding takes place at the starting flow stage but is suppressed when the gap ratio $G/D$ becomes smaller than 0.3.

INTRODUCTION

Flow around a circular cylinder near a planar boundary may be an ideal simplification of many practical problems, such as the hydrodynamics of marine pipeline and cables. With regard to steady incoming flow, Bearman and Zdravkovich (1978), Grass et al. (1984), Taniguchi and Miyakoshi (1990), Buresti and Lanciotti (1992), Lei et al. (1999) and others have experimentally investigated the flow past a circular cylinder above a planar boundary. The features of flow field and the effects of the boundary to the hydrodynamic loads on the cylinder are the major concerns. Advanced flow visualization techniques, such as the particle image velocimetry (PIV) technique, have been used during research on this subject (Price et al., 2002; Wang and Tan, 2008; Lin et al., 2009). Plenty of related works also involve local scour and shear stress distribution around submarine pipeline, both experimental and numerical, such as Mao (1986), Fredsøe et al. (1992), Sumer et al. (2001), Chen and Cheng (2004), Zhao et al. (2006), Zhao and Cheng (2010), and Chen et al. (2010). These works investigated the flow around the pipeline from the view of local scour as the vortices' motion plays an important role on scour.

Similar to the case of steady incoming flow, a number of studies about unsteady incoming flow past near-bed pipelines has been conducted, experimentally by Sarıpaya (1976) with regard to sinusoidally oscillating flow, and by Jarno-Druaux et al. (1995) and Roopsekhar and Sundar (2004) with regard to wave flow. With numerical models, Liang and Cheng (2005) use sinusoidally oscillating flow to simulate the effect of wave flow to local scour under pipeline. Chen et al. (1999), Zhu et al. (2001), Zhao et al. (2004), and Zang et al. (2007) use numerical wave tanks to study the wave loads on, as well as local scouring below, submarine pipelines.

The influences of the gap ratio $G/D$ (where $G$ is the net gap between the cylinder and the plane boundary, and $D$ is the diameter of the cylinder), the features of the boundary layer, and the Reynolds number have all attracted lots of attention in previous investigations. Such experiments revealed that when the gap ratio $G/D > 2.0$, the effect of the planar boundary on the cylinder’s wake is negligible (Lei et al., 1999). As the gap ratio decreases, the vorticity generated in the shear layers at the bottom of the cylinder and above the planar boundary will partially cancel each other; this weakens the vortex rolling up from the bottom side of the circular cylinder and leads to an asymmetrical wake. When $G/D < 0.3$, the bottom side vortex behind the circular cylinder is so weak that it cannot fully grow up and shed; thus the regular vortex shedding is suppressed. Some researchers have reported that the critical gap ratio of vortex shedding suppression is affected by the thickness of the boundary layer and the Reynolds number. For example, Lei et al. (2000) have pointed out that the $(G/D)_{\omega}$ decreases as the Reynolds number increases. As a consequence, the shear layer on both sides of the gap becomes thinner at higher Reynolds numbers, and the layers encounter greater difficulty when trying to interact with each other. A comprehensive summary of this may be found in Lin et al. (2009). In addition to the experimental investigations, Lee et al. (1994) and Lei et al. (2000) study this subject numerically, and their results confirm the experimental results.

Although the flow field around a circular cylinder close to a planar boundary can be approximately obtained from previous studies, further details require additional investigation. In this paper, flow past a circular cylinder placed near a planar boundary is investigated both experimentally and numerically. We limit our investigation to unidirectional flow cases because in bidirectional flow or wave flow cases, the vortices in wake are carried by reverse flow and flock around the cylinder, which makes it hard to determine the effects of gap ratio on vortex shedding. Besides the steady state of the flow, we also pay attention to the acceleration stage when the flow is initiated. Despite the fact the starting vortex is usually stronger, this important stage of the flow has not been the subject of previous investigations. We vary the gap ratio $(G/D)$ from 0 to 0.53. In the investigations, the Reynolds numbers in the starting flow stage (defined as $Re_a = \sqrt{D^3/\nu}$, based on the dimensional analysis) range between 930 and 2570; the Reynolds numbers during steady flow (defined as $Re = UD/\nu$) range between 950 and 2850. However, turbulent models are mostly developed based on a high Reynolds number situation; like most of the widely used turbulent flow models, our model does not include any transition modeling capacity and is not designed.