Flow-Induced Vibration of an Elastically Supported Circular Cylinder above a Plane Boundary

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ABSTRACT

Experiments and numerical simulations are carried out to investigate the flow-induced vibration of an elastically-supported, circular cylinder placed near a plane boundary. The flow field is visualized using the hydrogen bubble technique. Two modes of flow-induced oscillations are recognized, namely fore-backward oscillation at lower flow speeds, and transverse oscillation at higher flow speeds. In numerical simulations, the Navier-Stokes equations for unsteady incompressible viscous flow combined with a k-ω turbulence model are solved via finite element method. Arbitrary Lagrangian-Eulerian (ALE) method using an overlapping grid system is used to capture the motion of the cylinder.

KEY WORDS: Flow-induced vibration; Circular cylinder; Flow visualization; Finite element method; Overlapping grids; ALE.

INTRODUCTION

The vortex induced vibration (VIV) of pipelines is a major topic in coastal and offshore engineering since it may lead to fatigue destruction of pipelines, causing tremendous economic losses and environmental disaster. So far, many experimental and numerical investigations on VIV problems have been conducted, most of them concerning isolated pipelines, usually represented by circular cylinders in research, such as Mendes and Branco (1999), Zhou and So et al. (1999), etc.

On the other hand, for the VIV problem of pipelines near the seabed, there is far less literature available than there is for the isolated pipeline case. The boundary layers from both the lower edge of circular cylinder and the seabed interact with each other. Thus the gap-to-diameter ratio G/D (where G is the net gap between the surface of pipeline and the bottom boundary and D is the diameter of the pipeline) becomes the key parameter featuring the flow behaviors.

Previous surveys of flow around a fixed cylinder reveals that when the gap-to-diameter ratio decreases to less than 0.3, the regular vortex shedding is suppressed. Chen and Su (2011) investigate the whole procedure from ignition to the steady stage of the flow around a circular cylinder above planar boundary; found that vortex shedding does happen at the starting flow stage even though the gap ratio is less than 0.3. A few cycles of vortex shedding may happen before the final steady flow state is reached for small gap ratios. The wider the gap, the greater the amount of cycles will be needed to reach the vortex suppression state. Therefore the question is: when the cylinder is flexibly supported, will the vortex induced oscillations occur although the cylinder is located very close to the plane boundary. In fact, Su and Lian (1991) had reported flow-excited vibrations of an elastically supported circular cylinder above a plane boundary when the gap ratio is 0.25; two modes of oscillations, namely fore-backward and transverse oscillations, respectively, are observed depend on flow speed.

In this paper, we reproduce the flow induced oscillations of the circular cylinder in the conditions the same as Su and Lian (1991)’s experiments by numerical model, to look deeper into the mechanism that leads to the oscillations.

FACILITIES & EXPERIMENT SET-UP

The experiment is performed in a water channel with re-circulating water (Figure 1A). Its test section is 0.3 m wide and 0.5 m long, with a water depth of 0.3 m. The flow speed is adjustable from near zero to 15 cm/s. The size of the test model and test arrangement is shown in Figure 1B. The cylinder of 38 mm diameter is made of Plexiglas. It is hollow, with two small holes in both ends. When it is placed in the water channel, its interior becomes filled with water. Each end of the cylinder is mounted on a steel spring as shown in Figure 1B. The other end of each steel spring is mounted on side plates. The springs are simple, linear and non-coupled, allowing cylinder to freely vibrate in any direction normal to the axis of the cylinder. Also mounted on these side plates is a false floor to suspend the model above the boundary layer of the channel. The false floor is a Plexiglas plate of 250 mm × 290 mm and is 5 mm thick, with its leading edge sharpened to initiate boundary layer flow. The foremost point of the cylinder is placed one diameter downstream of the leading edge of the false floor. This arrangement ensures that the local plane boundary layer is thin in the absence of the circular cylinder, thus minimizing the influence of the boundary layer. The gap between the cylinder and the false floor is 9.5mm, which means the gap ratio is 0.25. A hydrogen bubble technique is used to visualize the flow pattern and the vortex shedding around the model. The arrangement of the platinum wires for generating hydrogen bubbles is shown in Figure 1B. One wire is placed...