The Viscous Flow Induced by an Oscillating Circular Cylinder

Chih-Chun Chu and Bang-Fuh Chen
Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung, TAIWAN, China

ABSTRACT

Arbitrary oscillations of a circular cylinder in a steady uniform flow are investigated numerically using a technique of coordinates transformation and finite differences method. The numerical method is validated by rigorous bench mark studies. Three cases of numerical comparison were made and they are stream-wise oscillating cylinder in static fluid, uniform flow past transverse and rotational oscillating circular cylinder. The method is then extended to study the flow past a simultaneous stream-wise and transversal moving circular cylinder and the proposed novel numerical method can be used to study the flow past an arbitrary oscillating circular cylinder.

KEYWORDS: arbitrary oscillating cylinder; Strouhal number; vortex shedding; vortex induced vibration.

INTRODUCTION

In marine engineering, offshore structures often encounter waves, currents and earthquake excitations. The fluid-structure interaction is a topic of primary interest in research and design. One of the basic studies is flow across a moving cylinder. During earthquake excitations, the relative velocity between the cross flow (current) and a moving cylinder (induced by ground motion) could be very large and the flow might be turbulent.

Extensive numerical simulations have been reported in the literature. Dütsch et al (1998) presented a harmonic oscillation of a circular cylinder in a fluid at rest based on experimental and numerical methods, and three cases were reported: (Re = 100, KC = 5), (Re = 200, KC = 10) and (Re = 210, KC = 6). Blackburn and Henderson (1999) simulated two-dimensional flows past a circular cylinder that is either stationary or in simple harmonic cross-flow oscillation. Results were for Re = 500 and fixed motion amplitude of y max / D = 0.25, the study concentrated on a domain of oscillation frequencies near the natural shedding frequency of the fixed cylinder. For cross-flow oscillations of a cylinder in uniform flow, we also simulated the case with the Reynolds number is 500 and the forcing Strouhal number is \( \pi/6 \), the simulation results were made a comparison with results of Dennis.

NUMERICAL METHOD

The governing equations are stream function \( \phi \) and vorticity \( \omega \) transport equations, which can be written in the polar coordinate system \((r, \theta)\) as following Eq. 1 and 2, where \( \eta \) is the kinematic viscosity:

\[
\begin{align*}
\dot{\omega} &= -\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial \phi}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 \phi}{\partial \theta^2} \\
\frac{\partial \phi}{\partial t} + \frac{1}{r} \frac{\partial (r \phi)}{\partial r} + \frac{\partial \phi}{\partial \theta} &= \eta \nabla^2 \phi
\end{align*}
\]

The relationships of displacement of cylinder on polar coordinate system are given as Eq. 3 and 4, in which \( \chi \) and \( \delta \) is the corresponding horizontal and cross-flow displacement of the cylinder. The position of an oscillating cylinder is varying with time and Eq. 5 (Hung 1981) is used to transfer the calculating domain that from cylinder surface to