Numerical Study of Fluid Force Reduction on a Square Cylinder using a Control Plate

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ABSTRACT A numerical investigation on the effects of a flat plate on the fluid force over a square cylinder in a cross flow is carried out using finite volume method. The control plate is placed upstream of the cylinder. The effects of the control plate on the force coefficients, flow pattern and vortex shedding frequency of the cylinder are studied in detail. A further study on the effect of the control plate on the fluid force of an elastically mounted square cylinder is also carried out. Reynolds number is set at 200 for all cases studied.

KEY WORDS: Square cylinder; fluid force reduction; vortex-induced vibration.

INTRODUCTION

Flow over a square cylinder is practically related to many engineering applications, such as vertical columns of a platform in the sea, tall buildings and bridges. The flow separation and the periodic vortex shedding of the fluid flow from the structures produce drag and fluctuating lift forces on the structures and may cause structural damage under certain unfavorable conditions. Flow control aims to reduce the drag and the magnitude of the fluctuating force acting on the structures. An effective flow control may save energy, increase propulsion efficiency and also reduce the vibration of the body.

Many attempts have been made to achieve better flow controls. Bearman (1965, 1967) attempted to reduce fluid forces as well as vortex shedding by fitting a splitter plate to the rear of a rectangular prism. Morel and Bohn (1980), Igarashi (1982) and Koenig and Roshko (1985) found that the fluid forces can be effectively suppressed by putting a small bluff body in front of a big body. Their experiments showed that placing two bluff bodies in series in a uniform stream may sometimes lead to a total drag reduction compared to that of either body alone. Using this idea, a number of methods to reduce the drag and lift forces were developed. Lesage and Garthshore (1987) successfully suppressed both the time-averaged drag and fluctuating forces on a bluff body by putting a small rod upstream. In their experiments, they used a flat plate, a square or a circular cylinder as the bluff body. Igarashi and Tsutsui (1989) proposed an idea of flow control by using the control rod in the shear layer. They found that by inserting a small cylinder in the shear layer near the main cylinder, a forced reattachment of the separated shear layer from the cylinder was realized, and the drag of the main cylinder was decreased. This method was used by Strykowski & Sreenivasan (1990) and Sakamoto et al. (1991) soon after. They successfully suppressed vortex shedding by setting a control cylinder in a separated shear layer on one side of a circular cylinder and also a square prism. Igarashi and Ito (1993) reported their experimental work on flow control where a control rod was placed in the upstream of a square prism and drag reduction on the square prism was investigated. In a further study of drag reduction on a square prism by using the rod, Igarashi (1997) indicates the existence of the critical gap distance between the prism and the control rod, at which the vortex shedding from the prism is totally suppressed. Sakamoto et al. (1997) performed further investigations on the flow past a square prism with control. They put a flat control plate upstream and examined the effects of the control plate on the flow forces acting on the square prism by changing the width of a flat plate and its position on the center-line.

All these studies have confirmed the effectiveness of this type of flow control. A literature search shows that there are few numerical studies on the flow around a controlled square cylinder. Compared with experimental studies, numerical simulations are both cost-effective and more informative. The objective of this paper is to numerically study the reduction of fluid forces acting on a square cylinder by the use of a control plate. A flat plate is placed upstream of the square cylinder in order to control the approach flow to it. The effects of the control plate height and its placed position on the flow characteristics of the cylinder including the force coefficients, flow pattern and vortex shedding frequency are studied. The control plate height varies from 0.1 to 0.9 times of the square width and the distance between the control plate and the cylinder ranges from 0.5 to 2.5 times of the square width. The Reynolds number is fixed at 200, based on the square width and the incoming flow velocity. In addition, the control effect of the plate on an elastic square cylinder with single degree of freedom in transverse direction is also examined. The calculated results are compared with that for an isolated cylinder in a cross flow.

NUMERICAL METHOD

Problem Description

Figure 1 shows a schematic view of a square cylinder with control plate placed on the center line near its front surface and the system is