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Flow structure around perforated cylinders in shallow water

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ABSTRACT

The experimental investigations were carried out in order to have detailed information on the flow structure around perforated cylinders using high-image density Particle Image Velocimetry technique in shallow water flow. The depth-averaged free-stream velocity was kept constant as $U_\infty = 100$ mm/s corresponding to the Reynolds number of Re = 10 000 based on the perforated cylinder diameter. In order to analyze the effect of porosity, β on the flow structure, the porosities in the range of $0.1 \le \beta \le 0.8$ with an increment of 0.1 were used and the results were compared with the bare cylinder case by means of velocity and vorticity contours, turbulent kinetic energy, Reynolds shear stress and streamline topologies. It was concluded that the porosity, β had a substantial effect on the control of large-scale vortical structures downstream of the cylinder in which the shear layers were elongated, fluctuations were significantly attenuated and formation of Karman Vortex Street was successfully prevented by the use of perforated cylinders.

1. Introduction

The vortex shedding and consequent Karman Vortex Street downstream of bluff bodies may result in serious structural and environmental problems in many engineering applications such as chimney stacks, long-span bridges, marine structures, tall buildings and towers, transport ships etc. and has been steadily investigated by the researchers (see e.g. Bearman, 1984, 2009, 2011; Matsumato, 1999; Williamson, 1996; Williamson and Govardhan, 2004, 2008). The source of this mechanism is the flow separation followed by shedding of the upper and lower vortices formed in the wake of the body after a critical value of Reynolds number. In order to reduce or eliminate the adverse effects of vortex shedding, it is inevitably important to control the flow structure around the bluff body and/or alter the mechanical properties of the material used in terms of damping and bare frequency. Since the material enhancement might be high-priced, various techniques about the flow control have been studied extensively in recent years. Every et al. (1982) stated in their review that the flow can be controlled by means of an alteration of the structural profile in order to affect the separation of the boundary layer to prevent the occurrence of vortex shedding along the length of the structure or alter the formation of the wake vortices and their interactions. These can be accomplished by active and passive control techniques in which energy is given to the fluid for the active methods while no power input is required for the passive ones. Injection of fluid, acoustic excitation, alteration of fluid viscosity and temperature, plasma, oscillation are some examples for active control methods. Since active methods need energy input and much difficult to

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implement, passive methods are widely used by means of splitter plate, base bleed, geometric modifications, surface roughness, control rod, shrouds and so on. Choi et al. (2008) conducted a comprehensive review on the flow control over bluff bodies and brought a new insight by classifying existing control methods in three different ways; passive, active open-loop and active closed-loop controls.

Within the context of geometric modifications, passive control of the flow by shrouded cylinders has been firstly studied by Price (1956). In his study, various porous shrouds were used to investigate their effects on suppression of the vortex-excited vibrations. He pointed out that the vibration suppression can be achieved by shrouded cylinders because of the delay in forming the normal Karman Street. After Price's study, the effect of shrouds on the flow control has been started to be investigated by other researchers. Every et al. (1982) reviewed the practical aspects of vortex excited structural vibrations in a marine environment with particular emphasis on methods of their suppression. In a part of their study, they focused on the effect of shrouds on the flow control, reported a comprehensive literature and stated that shrouds with the optimum dimension gave a 50% reduction in oscillations of a plain study on suppressing flow induced vibrations (Every and King, 1979). Molin (1993) performed a numerical study about perforated shrouds used to reduce vortex-induced vibrations of cylinders. They compared their numerical results with the available experimental data and demonstrated that the loading on the shroud is reasonably well predicted and the load on the inner cylinder is found to be negative. However, he concluded that their proposed theory cannot be said to predict reliable values of the drag of shrouded cylinders since it fails to reproduce correctly the flow in the downstream part of the annular region, in-between the shroud and cylinder. A similar logic is being used in recent years called porous media which includes the idea of generating a permeable medium around a bluff body. Zhao and Cheng (2010) established a numerical model for simulating the flow in and out of a porous media and concluded that lift reduction can be achieved by properly choosing the porous material. Another disadvantage of VIV is the noise generation which is also an important problem in many engineering applications. In this context, Boorsma (2008) studied the effect of perforated fairings in order to investigate and optimize their effect on the noise control of landing gears. He clarified the effects of porosity, β and location of perforation and found that perforated fairings applied to the simplified landing gear models reduce the low frequency noise introduced by the solid fairings.

In order to understand the effect of shrouds on the suppression of vortex induced vibrations, the flow around the shrouds having different geometries should be investigated thoroughly. Alridge et al. (1978) studied the drag coefficients on a perforated cylinder having an open area ratio (porosity) of β=0.6. They also conducted flow visualization experiments to demonstrate how the fluid moves through the perforated cylinder. Comparing their drag measurements with the study of Castro (1971) they stated that more detailed calculations and measurements at different open area ratio, β are certainly necessary. To our knowledge, there is no recent study about the flow structure around perforated cylinders.

If the horizontal dimension of a flow is much higher than its vertical extent, the condition is called as shallow and effect of bottom friction plays an important role on the flow characteristics. Wide rivers, lakes, estuaries, mountains are some of the examples for shallow flows. Another definition of shallow water is given by Fu and Rockwell (2004) according to the body size as: the condition as the characteristic diameter or width of the body is larger than the depth of the flow. Chu et al. (1991), Chen and Jirka (1995), and Akilli and Rockwell (2002) are the researchers who investigated the detailed physics of the shallow flow and more studies are being performed in order to understand its complex three dimensional flow structure. Moreover, flow control in shallow applications is also being investigated due to its complexity. Akilli et al. (2005) studied the flow behavior around a vertical cylinder placed in shallow water and control the flow structure by a splitter plate inserted at various locations. They concluded that the splitter plate has a substantial effect on suppression of the vortex shedding for the gap ratio between 0 and 0.75D. Recently, the study of Ozkan et al. (2012) presents an example of flow control by shrouded cylinder in shallow water. They investigated the flow around a cylinder (inner cylinder) by a permeable outer cylinder having different porosities, β and diameter ratios, D/d. They stated that the permeable outer cylinder suppresses the organized vortex street by reducing the velocity fluctuations in the near wake of the cylinder.

In this study, we have investigated the flow structure around perforated circular cylinders of 100 mm diameter having different porosities, β in shallow water to understand the effect of porosity on suppression of vortex-induced vibrations and Karman Vortex Street.

2. Experimental method

Both PIV and dye visualization experiments were performed in a large-scale closed-loop recirculating water channel, located in the Mechanical Engineering Department of Cukurova University, Turkey having a test section of 1000 mm wide × 750 mm deep and 8000 mm length made of a 15 mm thick transparent Plexiglas sheet. Free stream velocity was controlled by a 15 kW centrifugal pump with speed control unit which was used to adjust pump frequency. Honeycomb arrangements were located inside the channel at the entrance of contraction section in order to minimize the free-stream turbulence, which is expected to be less than 1%. The free stream velocity was taken as 100 mm/s. All experiments were performed above a platform, having a length of 2300 mm to obtain shallow flow conditions. Perforated cylinder is placed at the distance of 1800 mm from the leading edge of the platform to provide fully-developed boundary layer flow. The water level was taken as 50 mm (h_w) which corresponded to the Froude number of $\mathrm{Fr} = U_\infty/\sqrt{gh} = 0.1$ (U_∞ is the depth-averaged free-stream velocity and h is the water depth) and the Reynolds number is calculated to be (ν is the kinematic viscosity) based on the cylinder diameter, D=100 mm. During all experiments, the total depth of the water in the channel was kept constant as 600 mm. A schematic view of the test section mounted in the water channel is shown in Fig. 1.