Flow Structures Around a Finite Wall-Mounted Cylinder Having an Inclined Hole

Hiroka Rinoshika and Akira Rinoshika

Abstract To study the effect of a hole on the wake structures of a low aspect ratio circular cylinder, an inclined hole going from the front face to the top end face is drilled inside cylinder having height *H* and diameter *D* of 70 mm (an aspect ratio *H/D* = 1). In order to compare the flow structures between the hole and no-hole cylinders, the PIV measurement of Reynolds number of 8,570 is carried out in a water tunnel. Furthermore, to evaluate the position effect of the hole, three kinds of the hole cylinders having different height of hole from the flat plate are used. It was found that the separation region of the hole cylinder on the top face is evident smaller than that of the standard cylinder. An area of a high negative *u*-component velocity was observed in a rear recirculation region by using the hole, indicated a strong separation flow. The Reynolds shear stresses were evidently suppressed by the blowing flow from the hole, but their distribution spread out.

Keywords Passive flow control · PIV · Vortex · Wake flow

1 Introduction

The wake flow behind a cylinder of low aspect ratio exhibits a complex three-dimensional flow structures, such as tip-vortices, a horse shoe vortex and arch-type vortex [1, 4] that is different from two-dimensional wake flow structures [2]. The fundamental researches concerning controlling vortex-induced vibration of short and surface-mounted cylinders are few in the literature. It has practical interest in various engineering applications, such as suppressing noise and drag to design automobile, structural vibrations, and increasing drag in heat exchangers and offshore structures. Recently, Rinoshika et al. [3] studied a passive control method for a short cylinder that has an inclined hole drilled from the top face to the rear

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face. It is made to produce blowing and suction flows, and effectively leads to the reduction of the rear recirculation zone of cylinder.

To control the separation region of the top face and the rear vortices of cylinder, this study developed another passive flow control method, in which an inclined hole drilled from the front side face to the free-end face is applied to originate blowing flow on the free-end face for increasing drag in the offshore structures. Firstly, the controlling and non-controlling flows around a short circular cylinder placed on a flat plate are measured by PIV in a circulation water tunnel. Then the time-averaged streamlines and velocity components and Reynolds shear stresses are compared between the standard and hole cylinders.

2 Experimental Setup

Figure 1a shows a short standard circular cylinder model having diameter D and height H of 70 mm (with an aspect ratio $H/D = 1$), which is placed on a ground plane. A circular cylinder model with an inclined hole having a diameter of $d = 10$ mm, as shown in Fig. 1b, is proposed in order to control the wake flow of three-dimensional cylinder. The inclined hole, called the controlling hole (CH), is drilled from the front side face to the top face. To study the effect of the CH position, the central locations of the CH on the front side face are varied at $h = 20$, 35 and 50 mm and the central location of the CH on the top face is fixed at $L = 30$ mm. The experiment is carried out in a circulating water tunnel with a constant free stream velocity of $U = 0.16$ m/s, which corresponds to Reynolds

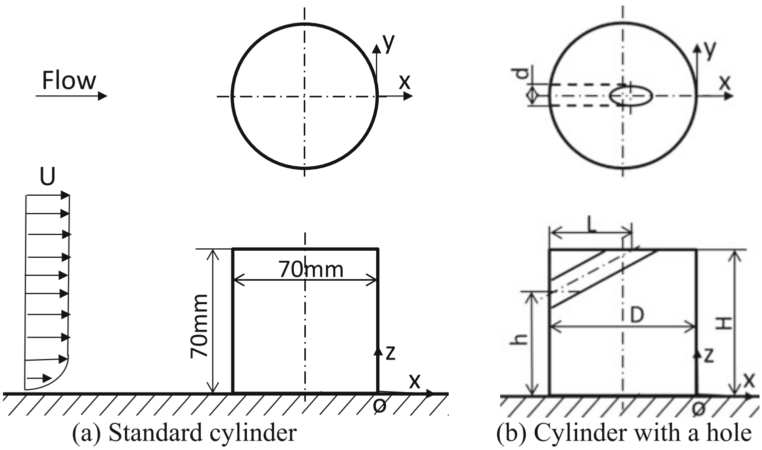


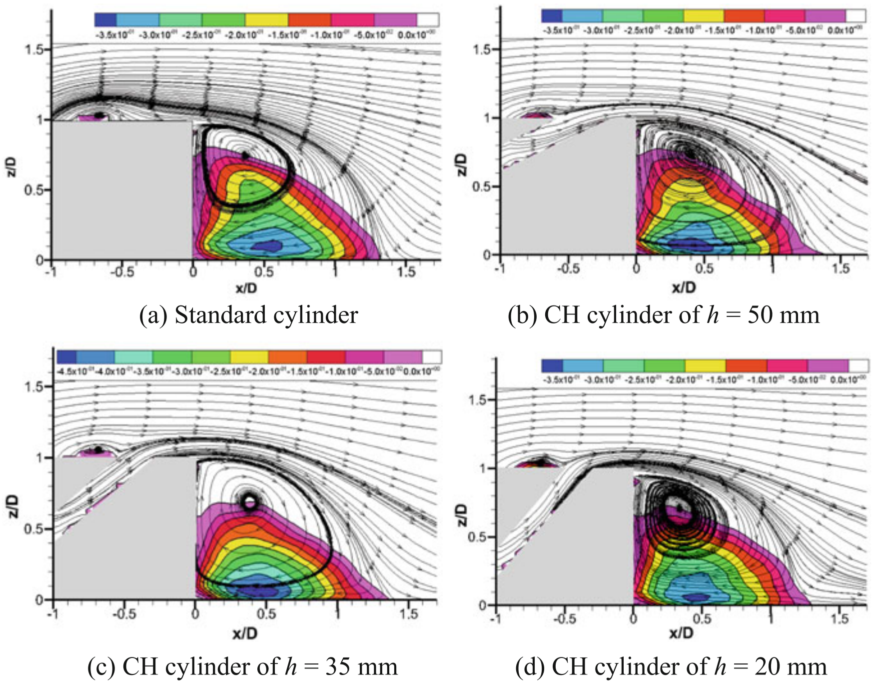
Fig. 1 Experimental models and setup

number Re ($\equiv UD/\nu$) = 8,570. The high-speed PIV measurements are adopted, and 6,000 digital images are analyzed by PIV software. PIV interrogation window size of 24 × 24 pixels with 50% overlap is used.

3 Results and Discussion

The contours of the normalized time-averaged streamwise (*u*-component) velocity and the mean streamlines around the standard cylinder (no-hole) and three kinds of CH cylinders in the (*x, z*)-plane, obtained from the measured instantaneous velocity, are shown in Fig. 2. In order to visualize the rear recirculation region, the negative contours of *u*-component velocity are only plotted, and white region represents positive *u*-component velocity.

Comparing the streamlines of the standard cylinder with CH cylinders, the small separation zone on the free-end face is reduced because of the flow blowing from the CH. With increasing height of the CH or decreasing the angle of the CH with the streamwise direction, the recirculation region on the free end surface becomes smaller. It is because the flow velocity blowing from the CH increases. However,



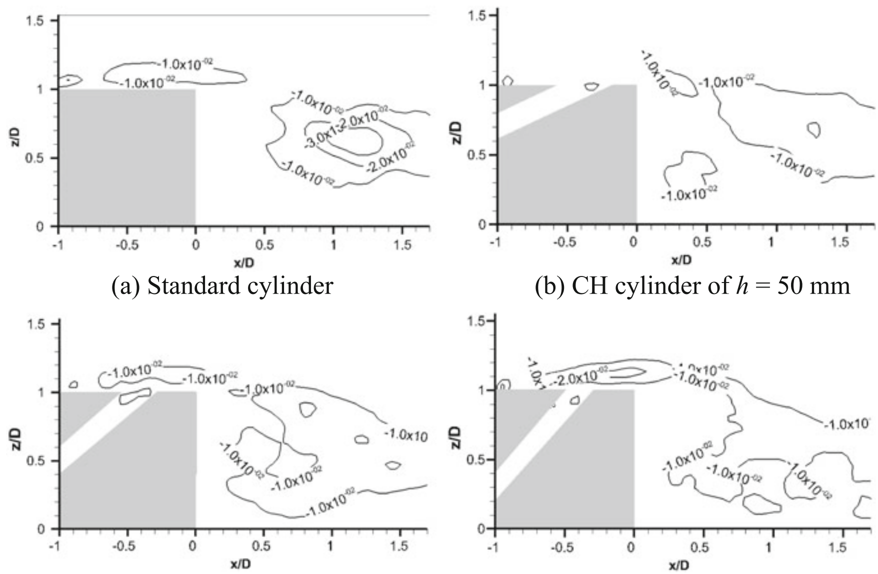
(a) Standard cylinder (b) CH cylinder of h = 50 mm

(c) CH cylinder of h = 35 mm (d) CH cylinder of h = 20 mm

Fig. 2 The time-averaged streamlines and contours of mean streamwise velocity $\bar{u}/U$ in the (*x, z*)-plane a large vortex (separation zone) originated from side of the rear face and leading edge of the top face, is slightly increased in the case of the CH. As indicated in the negative contours of *u*-component velocity, no evident variation of the region of negative *u*-component velocity can be found, but stronger negative *u*-component velocity is observed in the case of CH cylinder of $h = 35$ mm. It implies that the blowing flow of the CH increases the strength of recirculation behind the cylinder and may lead to increase of drag, which have important applications in heat exchangers, offshore structures and reducing Tsunami energy.

Figure 3 shows the normalized Reynolds shear stress contours $\overline{u'w'}/U^2$ around the standard cylinder and CH cylinder with different height holes in the (x, z)-plane, obtained from the measured instantaneous velocity fields. Making comparison with the standard cylinder, although the Reynolds shear stress is decreased by using CH, the region of the Reynolds shear stress in the rear recirculation zone increases and distributes to the cylinder and flat plate.

From above results, it is clearly that the angle or position of the CH effects or changes the structures of wake flow, and controls the separation region and Reynolds stresses.



(a) Standard cylinder (b) CH cylinder of $h = 50$ mm

(c) CH cylinder of $h = 35$ mm (d) CH cylinder of $h = 20$ mm

Fig. 3 The contours of Reynolds shear stress in the (x, z)-plane

4 Conclusions

For studying the effect of an inclined hole on the wake flow structures of a circular cylinder having one aspect-ratio, the PIV measurements are performed. By making a comparision with the wake flow of the standard cylinder, the following conclusions can be obtained.

(1) The separation region of the top face is evident smaller than that of the standard cylinder by using the CH.
(2) An area of a high negative u-component velocity appears in a rear recirculation region in the case of CH cylinder of $h = 35$ mm, which indicates a strong separation flow.
(3) The Reynolds shear stresses are evidently reduced by the flow blowing from the CH, but the region of the high Reynolds shear stress in the rear recirculation zone increases.

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