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Author(s):
Yokoi, Y.

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THE OBSERVATION OF THE FLOW ASPECT AROUND A CIRCULAR CYLINDER SET IN THE FREE SURFACE FLOW

Y. Yokoi[1,c]

[1]Mechanical Engineering, National Defense Academy of Japan, 1-10-20 Hashirimizu, Yokosuka, 239-8686 Japan
[c]Corresponding author: Tel.: +81468413810; Fax: +81468405900; Email: yokoi@nda.ac.jp

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Fluid: separation, water flow
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Other keywords: Vortex, Free Surface, Wave, Air Bubble

ABSTRACT: *This study reports the knowledge which could observe systematically the aspect of the flow around a circular cylinder using the water tank apparatus with an open channel in the flow velocities other than the flow velocity range usually used in a flow visualization experiment. The flow visualization of the vortex shedding made tracer ink (Rhodamine B and poster paint) ooze from the cylinder surface, and was performed. It determined for measurement of the vortex shedding frequency by synchronizing the luminescence period of a stroboscope scope with vortex shedding frequency. The main parameters of the experiment are the flow velocity (0.07 m/s ~ 0.98 m/s) and cylinder diameter (4 mm, 6 mm, 10 mm and 20 mm). The flow velocity was varied and the aspect of the flow around each cylinder was investigated. As a result, the variation of the water level around the cylinder and the aspect of involvement of air became clear. The relationship between the flow velocity and vortex shedding frequency was shown. It was found that a sudden discontinuous change appeared in the relationship. It became clear that the flow velocity became fast, so that, as for the jumping point of the value of Strouhal number, the cylinder diameter became large.*

1 Introduction

The "flow visualization" is one of most effective tool for good understanding about flow phenomenon. So, the newest visualization apparatus and visualization technique were developed and it has been used for many studies. Many of those research findings have produced important value in engineering. The technique which looks at "the flow which is not visible" is very important. However, even if it does not carry out a visible work, a flow may show an interesting phenomenon. It is the case where a "flow" modifies and metamorphoses. By an author's research group, in comparatively low Reynolds number, the flow visualization experiment around a body is performed using water tank experimental apparatus (a closed circuit water channel and a towing water tank), and the aspect of the flow in various cases has been shown [1][2]. These reports of research were performed in the water tank with an open channel at the flow velocity and towing velocity at which the water surface around a body is not choppy. If the flow velocity generally exceeds 23 cm/s, it is known for the open channel that a surface wave will occur. Moreover, if the flow velocity and towing velocity become fast, in the front of the bluff cylinder, the phenomenon in which the water surface which is produced in the bow of a ship rises will be seen. In spite of knowing such a phenomenon well, the example of a report related with the vortex shedding phenomenon from cylinder cannot be seen as far as an author gets to know. So, this study reports the knowledge which could observe systematically the aspect of the flow around the circular cylinder using the water tank apparatus with an open channel in the flow velocities other than the flow velocity range usually used in the flow visualization experiment.

2 Experimental Apparatus and Method

2.1 Outline of Experimental Apparatus

The experimental apparatus consists of a closed circuit water channel apparatus, a video recording apparatus, and a flow visualization apparatus. The closed circuit water channel apparatus is a small water tank with a water capacity of 0.4 m^3, and the sizes of test section of water tank are length of 1.2 m and cross-section of 0.3 m x 0.3 m square meters. The test section is an open channel. The aspect of experimental apparatus is shown in Fig. 1. At the time of the experiment, the water level was set as 0.2 m. Generating of the stream is performed by operating the digital operator for operation. The video recording apparatus is a digital camera and a personal computer. The aspects of the water surface in front and in rear of the circular cylinder and the aspects of the flow which overlooked the direction of a circular cylinder span were observed. The position of photography is being fixed so that it may not change for every photography time. Measurement processing was performed using the application software in the personal computer using the image data shot with the digital camera.

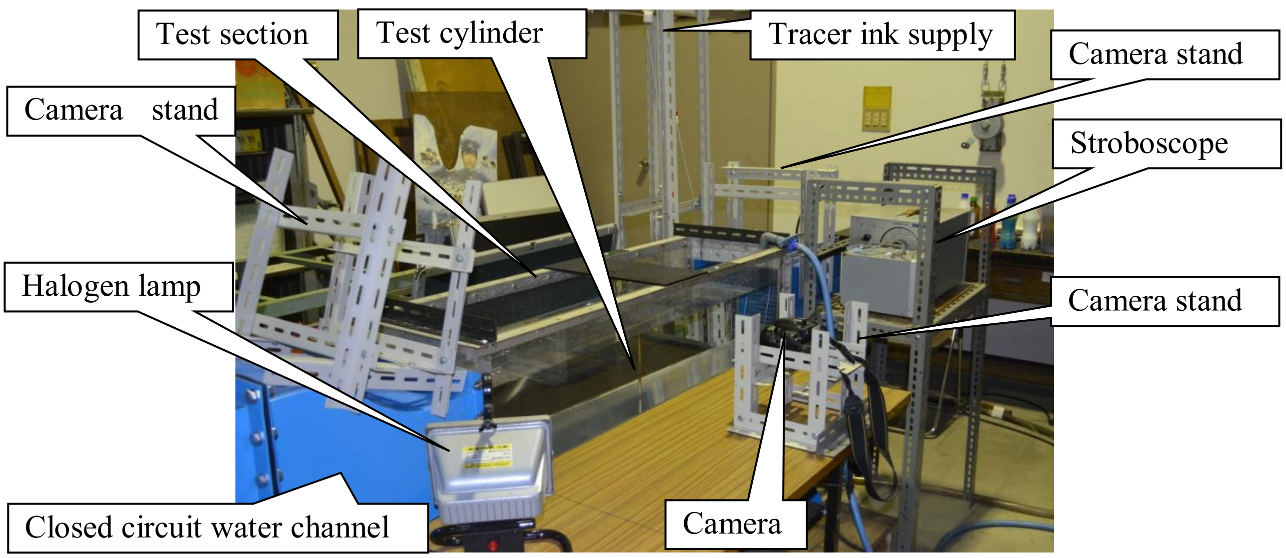


Fig. 1. Aspect of experimental apparatus

2.2 Experimental Method

The experiment procedure is the following. One circular cylinder is set in the test section. The flow velocity is adjusted to a target value. After placing time for a while after adjustment of the flow velocity, the aspects of flow around the circular cylinder are photographed. In order to visualize the aspect of the vortex shedding from the cylinder, the dye injection method was used. Tracer ink oozes from two oozing holes provided on the surface of the circular cylinder. As for tracer ink, Rhodamine B and poster paint were used. The tracer oozing was performed using the head difference between the oozing hole on the circular cylinder surface, and a tracer tank. It determined for measurement of the vortex shedding frequency by synchronizing the luminescence period of a stroboscope scope with vortex shedding frequency.

2.3 Experimental Parameters

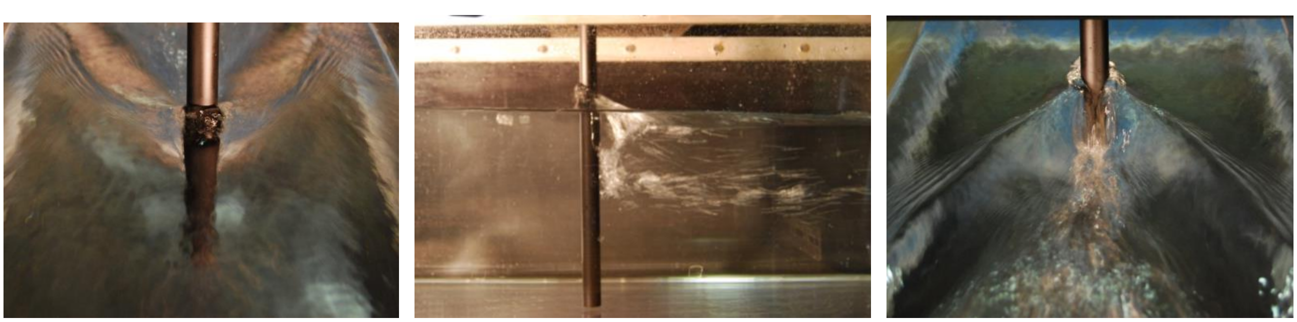
The main experimental parameters are the flow velocity and the diameter of circular cylinder. The flow velocity range is from 0.07 m/s to 0.98 m/s, and the diameter of circular cylinder is four kinds, 4 mm, 6 mm, 10 mm and 20 mm. Here, the cylinder length is 0.3 m and the circular cylinder is installed by the fixed board in the open section of the test section.

3 Experimental Results and Discussions

3.1 Flow Features

The change of the aspect of the water surface and the involvement of air bubbles were observed by change of the flow velocity. Upheaval of the water surface was observed near the upstream-side stagnation point of cylinder. The upheaval height became large by the increase in the flow velocity, and a wave which is made from a bow was formed. When the flow velocity increased more, it was observed that the wave forms a wall which wraps the circular cylinder. In the case of the slow flow velocity, the dimples of the water surface by rotation of the Karman vortex were observed at the down-stream side of cylinder. The dimples by rotation of the Karman vortex are no longer observed by the influence wave from a circular cylinder as the flow velocity becomes fast. It was observed that a water-level-gap occurs in front and in rear of the circular cylinder by the increase in the flow velocity. When the water-level-gap became large, it was observed that a cavity is formed behind of the circular cylinder. The mixing phenomenon of air bubbles was also observed. There are two kinds of taking-in mechanisms of air bubbles. The case where air is torn to pieces from a cavity and it becomes air bubbles, and others are the cases where it takes in from the water surface.

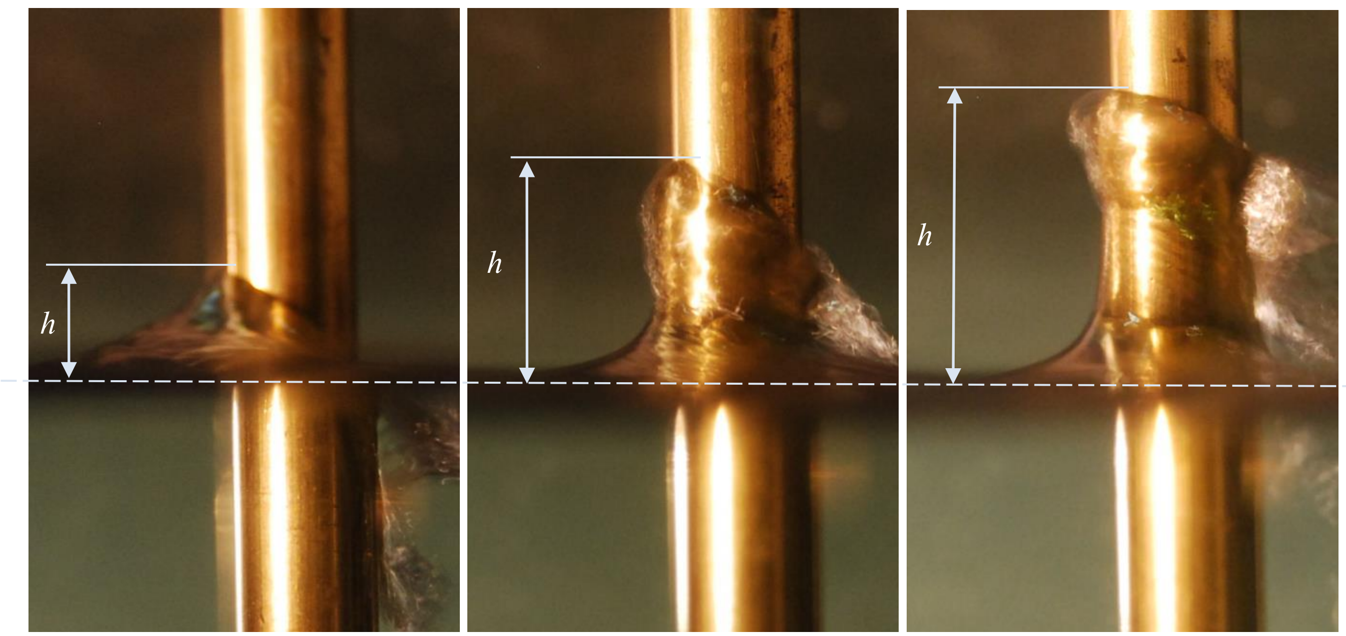
An example of the aspect of the flow around the circular cylinder which entangled in air is shown in Fig. 2. Figure 2 (a) shows the aspect of the flow around the circular cylinder seen from the front. In response to the influence to which the flow is dammed up and the water surface rises with the circular cylinder, it can confirm that the water surface by the side of the circular cylinder upstream is choppy. Figure 2 (b) shows the aspect of the flow around the circular cylinder seen from the side direction. In the section of the circular cylinder which came out from the water surface, it turns out that water rises and is covered as the muffler was related. Under the water surface, existence of a cavity and the air bubbles taken into the flow can be seen clearly. And Fig. 2 (c) shows the aspect of the flow around the circular cylinder seen from rear. The shape of the wave which the cylinder generates can understand clearly. Since the flow is dammed up by the circular cylinder, the cavity is formed behind cylinder.



(a) (b) (c)

Fig. 2. A typical flow pattern when entangling in air; cylinder diameter *d*=20mm, flow velocity *v*=0.98 m/s (*Re*=19600) , (a) front view, (b) side view, (c) rear view

It was investigated about the height *h* in which the flow is dammed up and the water surface rises with cylinder. Figure 3 shows change of the height in which the water surface rises. It is found that the aspect of the rising changes with increases of the flow velocity. Here, the difference of the water level at the time of stream stationary and the top of the water surface which rises is defined as the height in which the water surface rises. The height in which this water surface rises was measured by the picture measurement which used the computer. Since this picture measurement method is a trial stage, it has applied expectation to development of the further research from now on now. So, it is planning to summarize by another report. Figure 4 shows the relationship between the water surface rise height *h* and the flow velocity *v*. The abscissa is the flow velocity and the ordinate is the height of the water surface rise. The measurement values in the circular cylinder of 10 mm diameter are shown by the circle symbol. And the value of the height calculated from Bernouilli's equation is shown by the dashed line for comparison. It is found that the height of water surface rise quantity also increases in parabola by the increase in the flow velocity. It is expected that this thing can be contributed to the development as a simple current meter in a river or a waterway.



(a) (b) (c)

Fig. 3. The aspect of rising of the water surface, 10 mm cylinder diameter, The character *h* in the figure is rising height, and it is obtained by the picture measurement which used the computer, The dashed line shows the position of the water surface at the time of stream stationary, (a) *v*=0.5232 m/s, (b) *v*= 0.7848 m/s, (c) *v*= 0.9810 m/s

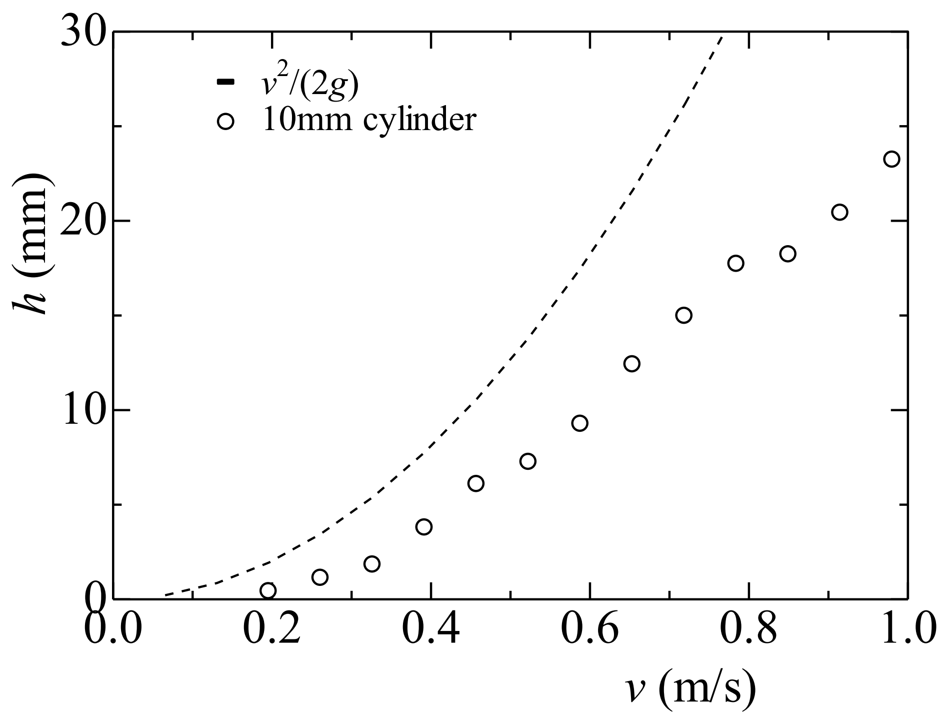


Fig. 4. The relationship between the flow velocity and the height of water surface

3.2 Characteristics of Vortex Shedding

The phenomenon in which the circular cylinder made a wave and entangled in air bubbles was observed. It is one of the most interesting things of this study to investigate the vortex shedding characteristic at the time of being accompanied by such a phenomenon. If the flow velocity generally exceeds 23 cm/s, it is known for the open channel that a surface wave will occur. Moreover, if the flow velocity and towing velocity become quick, in the front of the bluff cylinder, the phenomenon in which the water surface which is produced in the bow of a ship rises will be seen. In spite of knowing such a phenomenon well, the example of a report related with the vortex shedding phenomenon from a circular cylinder cannot be seen. Figure 5 shows the relationship of the flow velocity and Strouhal number in the circular cylinders of each diameter. The abscissa is the flow velocity and the ordinate is Strouhal number St. The Strouhal number is defined by $St=fd/v$. Here, f is measured by the synchronization of stroboscope scope luminescence on vortex shedding frequency, d is a circular cylinder diameter and v is the flow velocity. The dashed line in the figure shows the critical flow velocity in which a surface wave appears. If the flow velocity increases in all cases, it will be found that the value of Strouhal number St increased rapidly. It seemed that it jumped on another stage. The rate of increase was about 25%. This jumping point has appeared in the high speed side, so that the cylinder diameter becomes large. The circular cylinder diameter d and the relationship with the flow velocity v which the jump produces were d=0.0345v. It turns out that the value of the Strouhal number after a jump is fluctuated. In the case of 4 mm circular cylinder and 6 mm circular cylinder, it is shown that the value of Strouhal number is decreasing with the increase in the flow velocity. The cylinder self oscillation phenomenon was observed at this time.

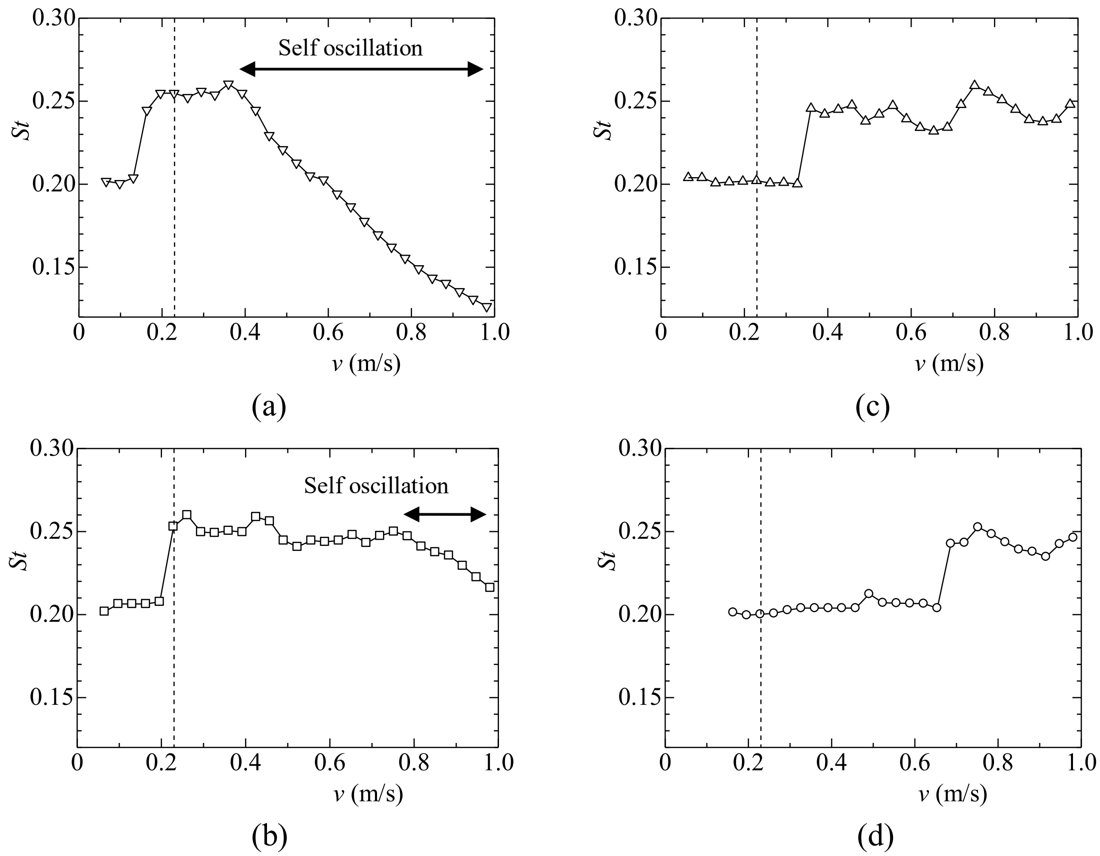


Fig. 5. The relationship between the flow velocity and Strouhal number,
(a) *d*=4 mm, (b) *d*=6 mm, (c) *d*=10 mm, (d) *d*=20 mm

4 Conclusions

Visualized flow observation around the circular cylinder set in the flow with the free surface was performed. The following conclusions were obtained.

(1) Upheaval of the water surface was observed in the cylinder upstream side, and the relationship between the upheaval height of the water surface and the flow velocity was shown.

(2) When the water level gap in front and in rear of circular cylinder became large, it was shown that the cavity is formed behind cylinder.

(3) It was observed that air bubbles are taken into the flow and the mechanism was found. It was found that air bubbles are taken in from the cavity and water surface.

(4) The relationship between the flow velocity and vortex shedding frequency was investigated, and the relationship was shown. A sudden discontinuous change appeared in the relationship.

(5) It became clear that the flow velocity became fast, so that, as for the jumping point of the value of Strouhal number, the cylinder diameter became large.

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