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The aspect of the flow around a circular cylinder in a free surface water flow

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Abstract. The purpose of this study is in collection of the basic data for development of the simple flow velocity measurement equipment. A 10mm diameter circular cylinder was inserted into the free surface stream, and investigation of the water surface height and the relationship of the flow velocity which creep up the circular cylinder surface were performed. The experiment performed in the closed circuit water channel apparatus (the range of stream velocity is 0.07 - 0.98m/s) and carried out image-processing measurement using the video recording apparatus. In the insertion depth of various circular cylinders, observation of the height which creeps up the circular cylinder when varying the flow velocity was carried out. As a result, it became clear that the height of the water surface which creeps up by the increase in the flow velocity increases. And it also became clear for the phenomenon not to be based on the insertion depth. It was obtained that measured rising height and the flow velocity is required from Bernouilli's equation using the value. In the measurement, it became clear that 5 or more times of the cylinder diameter are required for the required insertion depth.

1 Introduction

In our research group, flow visualization observation of the around of a body has been carried out using water tank experimental apparatus (a closed circuit water channel and a towing water tank). And the aspect of various flows has been shown in comparatively low Reynolds number [1][2]. These reports of research were carried out at stream velocity and towing velocity at which the water surface of the around of a body is not choppy in a water tank with a free surface. Generally, if stream velocity exceeds 23cm/s, it is known that a surface wave will occur on the water surface. Moreover, if stream velocity and towing velocity become fast, a necklace vortex will be formed so that the bluff cylinder may be surrounded the front of the bluff cylinder inserted in the flow. The phenomenon in which the water surface which is formed by the bow of a ship by the bluff cylinder front part of the jumping phenomenon of the water accompanying formation of this necklace vortex rises is seen. About the phenomenon produced at such a flow field, it is treated in fields, such as civil engineering and marine engineering, for many years, and many knowledge is accumulated [3][4]. However, it seems that there is no example which applied the phenomenon in which this water surface rose to the flow velocity measurement in an author's knowledge. Although rising of the water surface can be seen in a bridge pier at the time of rise of water of a river, and a flood, the report which determined for the height of this rising and the relationship of stream velocity is not found. The flow velocity measurement method of a river differs in the method by the flow velocity. When the flow velocity is slow, on foot observation, observation by a ship, and observation from a bridge are carried out. On the other hand, when the flow velocity is fast, it is carried out by stretching a wire and locating sensors, such as an electromagnetism current meter and a price current meter, among both banks, at predetermined depth of water. Anyway, advance preparations and large-scale equipment are required. In the site at the time of rise of water of a river, and a flood, it seems that it is important to get to know stream velocity immediately also when planning subsequent measures. So, an idea which gets to know stream velocity simply with easy equipment is desired.

In this study, for development of the simple flow velocity measurement equipment, the circular cylinder was inserted in the stream which has a free surface, the water surface height and the relationship of the flow velocity which creep up the circular cylinder surface were investigated, and some obtained knowledge was shown.

2 Experimental apparatus and method

2.1 Outline of experimental apparatus

The experimental apparatus consists of a small closed circuit water channel, a test circular cylinder unit, and a video recording apparatus. The closed circuit water channel apparatus is a small water tank with a water capacity of 0.4m^3, and the size of test section of water

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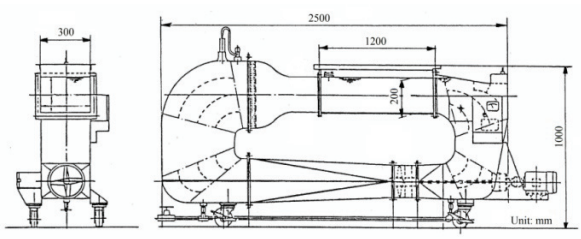


Fig. 1. Schematic diagram of closed circuit water channel.

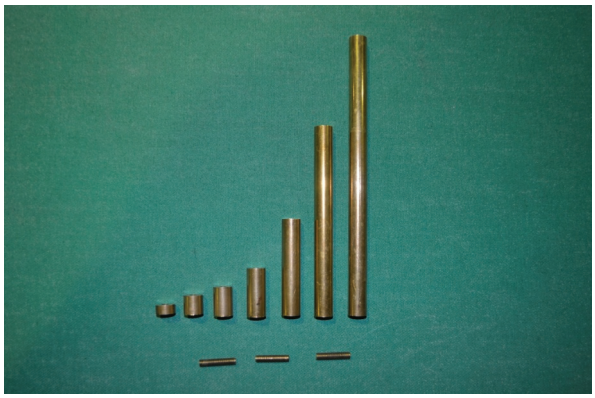


Fig. 2. The elements of underwater section, from left hand side; 5mm, 10mm, 15mm, 25mm, 50mm, 100mm and 150mm; They are attached with the screw shown below.

tank are length of 1.2m and cross-section of 0.3m × 0.3m square meters. The test section is an open channel. The board for circular cylinder attachment is prepared in the open section of the test section. At the time of an experiment, the water level was set as 0.2m. The sketch of the closed circuit water channel is shown in **Fig. 1**. At the time of the experiment, the water level was set as 0.2m. The stream is generated by carrying out input operation of the operation frequency f Hz in a digital inverter. The stream velocity v is obtained by v=0.0327× f (Hz).

A test circular cylinder is 10mm in diameter, and it is blocked by the water upper part (100mm) and the underwater section (5-200mm) so that the length under the water surface can be adjusted. The block of an underwater section was prepared seven kinds and length was 5mm, 10mm, 15mm, 25mm, 50mm, 100mm, and 150mm, respectively. They are shown in **Fig. 2**. Adjustment of the length of the underwater section was carried out by combining these seven blocks.

The video recording apparatus consists of a camera for photography, and a personal computer for image processing. The camera for photography used the digital camera (Nikon D40) and the digital camcorder (WAT-250D2) properly by the use. Those cameras fixed to the tripod mount were set in the manometer front. The personal computer (NEC LaVie) commercial note type was used for image-processing measurement. Measurement of the length of picture was performed using "Microsoft Paint" [5] installed as application software. The video signal converter (Alterplus AX-200) was used for dealing with the image signal from the digital camcorder with the personal computer.

2.2 Experimental procedure

The experimental procedure is the following. Water is filled in a closed circuit water channel, and the water level of the test section is adjusted to 200mm. Warming up is performed. A test circular cylinder is set in the test section. Since the record camera is set beside the test section, the aspect of the flow around a circular cylinder seen from the side is photographed. The focus and zoom of the record camera are adjusted. Those conditions are held after completing this adjustment until a series of recording is completed.

The flow velocity for which it wishes operates the inverter for the flow velocity setup, and is set up. Here, the digital input of the frequency for operation f (Hz) is carried out to an inverter, and the flow velocity v (m/s) is obtained from the authorization formula. If the flow velocity for which it wishes is obtained, the aspect of a flow will be recorded with a digital camera, and the aspect of a flow is observed about another flow velocity.

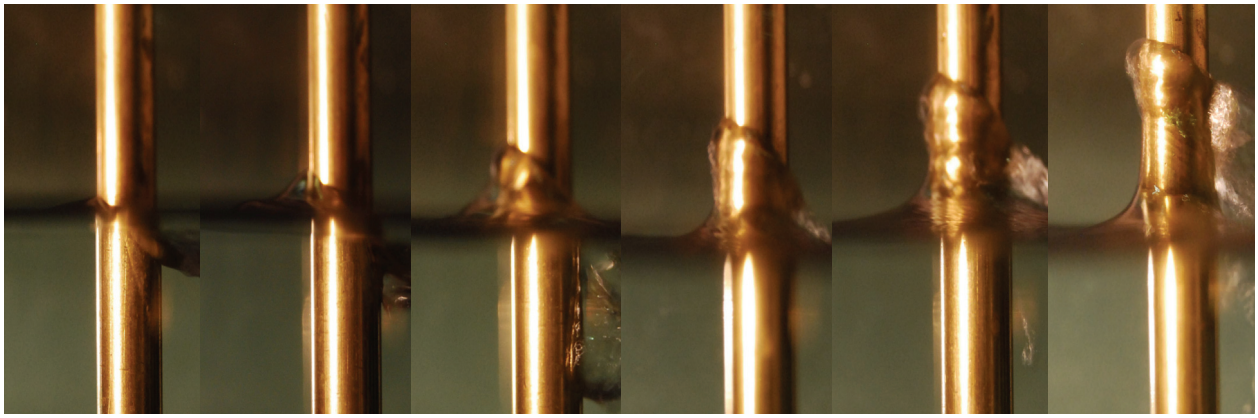
The obtained picture is downloaded to the computer; the image-processing measurement is performed.

2.3 Measurement procedure of the rising water-head length with the aid of image processing

The "Paint" is started and the target picture file is opened. A reference position is decided in the displayed picture. Here, a reference position uses the same position over a series of measurement. A square is chosen from the "figure" in the section of a menu display of the software screen upper part. The displayed square is drawn on the target point. It meets with the reference position which determined one of the sides of the square. Another side is met with the rising water-head position. For example, the upper side will be met with the rising water-head position if the base of the square is met with the reference position. Here, the reference point is the water surface at the time of flow rest. Since the information on the length of two sides of the square (the number of horizontal pixels, x, the number of vertical pixels) is displayed on the software screen bottom, the information on the number of vertical pixels is read. The actual dimension per pixel is obtained by authorization. For example, it is investigated by the box function whether an actual length of 10mm shown on the screen is displayed with how much number of pixels. The thickness of the drawing line sets up so that it may be easy to operate it.

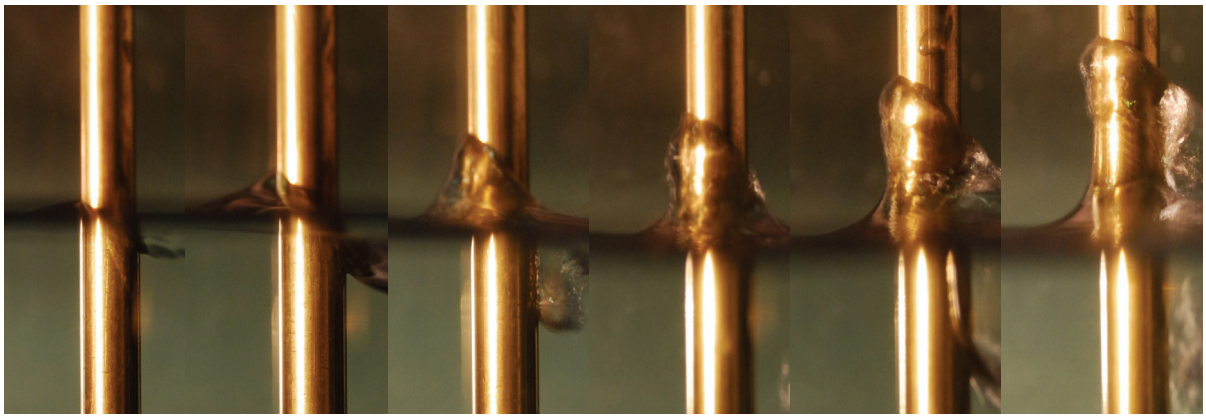
2.4 Experimental parameters

The experimental parameters are the flow velocity and underwater circular cylinder length. The flow velocity is the range of 0.07 - 0.98m/s (the inverter input frequency f is 2Hz unit to 2-30Hz) in 15 kinds. The underwater circular cylinder length is 5mm, 10mm, 15mm, 20mm, 25mm, 30mm, 40mm, 50mm, 100mm, 150mm, and



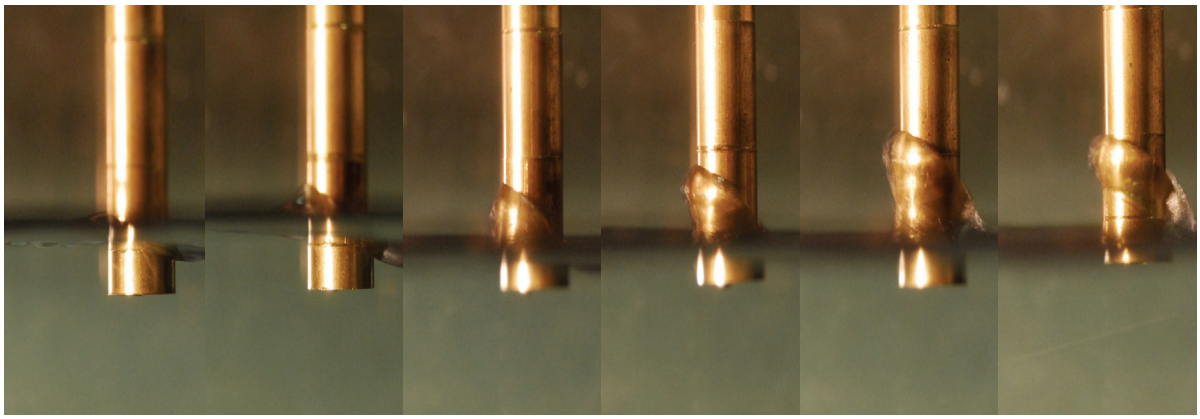
(a) (b) (c) (d) (e) (f)

Fig. 3. The aspect of rising of the water surface, submerge depth is 200mm; (a) 0.33m/s, (b) 0.46m/s, (c) 0.59m/s, (d) 0.72m/s, (e) 0.85m/s, (f) 0.98m/s.



(a) (b) (c) (d) (e) (f)

Fig. 4. The aspect of rising of the water surface, submerge depth is 50mm; (a) 0.33m/s, (b) 0.46m/s, (c) 0.59m/s, (d) 0.72m/s, (e) 0.85m/s, (f) 0.98m/s.



(a) (b) (c) (d) (e) (f)

Fig. 5. The aspect of rising of the water surface, submerge depth is 5mm; (a) 0.33m/s, (b) 0.46m/s, (c) 0.59m/s, (d) 0.72m/s, (e) 0.85m/s, (f) 0.98m/s.

200mm in 11 kinds, respectively. Here, in the case of 200mm length, the circular cylinder has arrived at the bottom of test section.

3 Experimental results and discussion

The height of the water which creeps up the circular cylinder corresponding to the flow velocity was

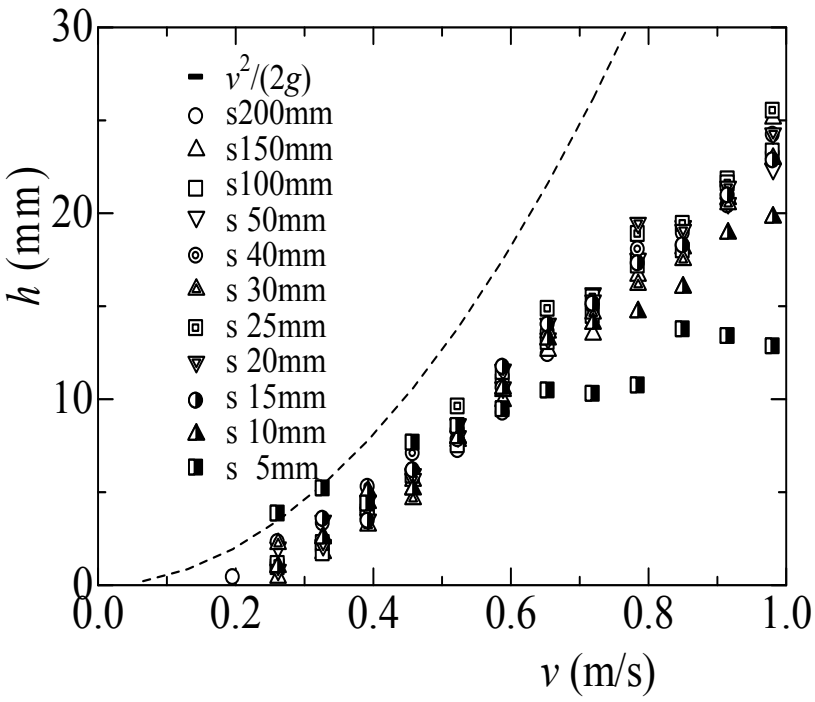


Fig. 6. The relationship between the flow velocity and the height of water surface.

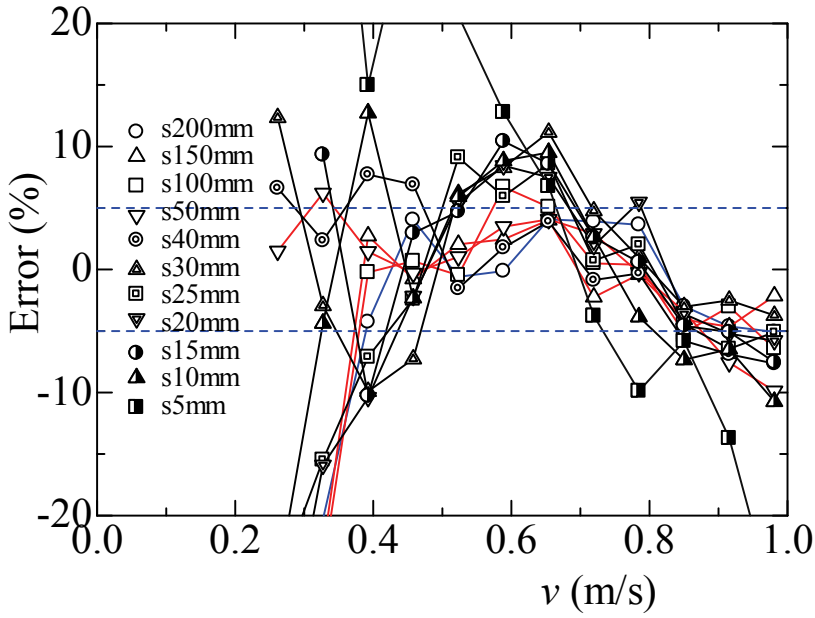


Fig. 7. The error of the guess flow velocity for every submerge depth.

observed for every underwater circular cylinder length. An example of the aspect of the water surface which creeps up the circular cylinder is shown in **Figs. 3 - 5**. It became clear that the height which creeps up by the increase in the flow velocity is increasing, and that it is not dependent on underwater circular cylinder length. **Figure 3** is the case where underwater circular cylinder length is 200mm, and the lower end of the circular cylinder is in contact with the test section bottom. In this case, the flow which passes over the circular cylinder will go to the direction of cylinder side and the direction of water surface. **Figure 4** is the case where underwater circular cylinder length is 50mm, and the lower end of the circular cylinder exists underwater. In this case, the flow which passes over a circular cylinder will go to the circular cylinder side, the water surface, and the circular cylinder end. Although underwater flow around a circular cylinders differ in both, it is shown that the height of the water which creeps up the circular cylinder is almost same. **Figure 5** is the case where underwater

circular cylinder length is 5mm, and although there is a lower end of the circular cylinder underwater, it is located in a very shallow position. Therefore, it seems that the height of the water which creeps up the circular cylinder as compared with the case where underwater circular cylinder length is 50mm differs. The tendency for change of the aspect of the water surface which creeps up the circular cylinder which is not based on underwater circular cylinder length, but is observed to be the same was obtained. While the height of the water surface which creeps up is comparatively low, there is also no turbulence in the surface, and rising is smoothly shown as it, but if the height which the flow velocity becomes fast and creeps up becomes high, a knot will occur in the top part. **Figure 6** shows change of the height by the flow velocity which creeps up for every underwater circular cylinder length. An abscissa is the flow velocity and an ordinate is the height. The dashed line in the figure is the height ($h=v^2/(2g)$) corresponding to the flow velocity required from Bernouilli's equation. If the case where underwater circular cylinder length is 5mm and 10mm is removed, it is shown that the height which is not based on underwater circular cylinder length, but creeps up becomes the almost same quantity. This supports a possibility that the flow velocity can be known, in a flow with the free surface of a river etc. by inserting a bar thing like a circular cylinder from the surface of river. Accordingly, the flow velocity can be guessed using Bernouilli's equation, applying a coefficient to the actually measured rising height. Here, it becomes important to get to know how much length of an underwater circular cylinder is required. It is classified when it is in the case where the situation of the end is in contact with the bottom when inserting a bluff cylinder, and underwater. Furthermore, it is divided into whether the position of the underwater circular cylinder end is close to the water surface, or it is separated. Actually, the case where the end is underwater is assumed in on-site situation. The error of the flow velocity and the real flow velocity which were guessed is defined like an equation (1). Generally, the flow velocity measurement requires few errors and little scatter. It is necessary to estimate an acceptable value. In this study, the range of permissible error was made into ±5% in view of being rough measurement.

$$(\text{Guess flow velocity} - \text{Real flow velocity}) / (\text{Real flow velocity}) \times 100(\%) \quad (1)$$

The result of having calculated the error over the real flow velocity obtained from the equation (1) for every length of an underwater circular cylinder is shown in **Fig. 7**. An abscissa is the flow velocity and an ordinate is an error. The dashed line in the figure shows the range (±5%) of with error. If the underwater circular cylinder length is the case of 50mm or more, fitting in the scatter error (±5%) can be seen. Accordingly, it will be said that the circular cylinder diameter *d* (10mm) is required for underwater circular cylinder length 5 or more times. And also the flow velocity ranges from which an error becomes ±5% were 0.39 - 0.85m/s (an underwater circular cylinder length of 50mm), and 0.39 - 0.98m/s (an underwater circular cylinder length of 100mm, 150mm). Here, in an underwater circular cylinder length of 100mm, and 150mm, the flow velocity range which satisfies ±5% of scatter errors was the same as the state where the circular cylinder edge was attached to the test section bottom. This showed that enough measurement accuracy was obtained, when setting underwater circular cylinder length to 5*d* or more.

4 Conclusions

The circular cylinder was inserted into the stream with the free surface generated with a closed circuit water channel, and image-processing observation of the height of the water surface which creeps up the circular cylinder surface was carried out. The following conclusions were obtained.

(1) The height in which the water surface creeps up the circular cylinder by the increase in the flow velocity increases.

(2) It is not dependent on underwater circular cylinder length, and the phenomenon occurs.

(3) The flow velocity can be guessed if the height of the water surface which creeps up the circular cylinder is got to know.

(4) Required underwater circular cylinder length is 5 or more times of the circular cylinder diameter.

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