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OBSERVATION OF THE FLOW AROUND A CIRCULAR CYLINDER AND A TRAPEZOIDAL CYLINDER IN A CIRCULAR PIPE BY A DYE-INJECTION METHOD

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ABSTRACT

In order to understand the complex flow in a vortex flowmeter, water flows around a circular cylinder and a trapezoidal cylinder in a circular pipe were observed with the aid of a putting-dye method, in the Reynolds number range from 780 to 19,000 of the pipe flow. From the visualization experiments, three dimensional characteristics of the flow such as formation and shedding of three-dimensional vortices and appearace of three-dimensional separation regions on the pipe wall were known.

INTRODUCTION

Recently, the vortex shedding phenomenon in the flow past a two-dimensional bluff body has been applied to flow measurement in a pipe or a duct as known as a so-called Karman vortex flowmeter. It is known from a number of past studies that there exists the proportional relation between the vortex shedding frequency and the flow velocity, which is considered to be independent from both density and viscosity of fluid. Since the feature of the vortex shedding is quit convenient for the construction of a simple flow meter which has no movable components, various types of vortex flowmeters have been widely used for flow mesurement of not only ordinary fluids like air, water, steam and oil, but also special fluids like liquid hydrogen, liquid nitrogen, liquid natural gas and so on. And their measurement accuracy is usually regarded to be so high as the maximum error is less than +1% of reading. Although these excellent features of the vortex flowmeter are expected to bring further extension and improvement of its applicability, the accumulation of knowledges with respect to the vortex shedding flow in a pipe is still not enough. So, it is interesting at this point to study the essential structure of the vortex shedding flow in detail.

In the present study, in order to understand the complex flow in a vortex flowmeter, water flows around a circular cylinder and a trapezoidal cylinder in a circular pipe were investigated by flow visualization of a putting-dye method, in a rather low Reynolds number range. From the visualization study, interactive formation of Karman vortices and horce-shoe vortices were understood, and the appearance of three-dimensional separation babbles over the pipe wall just downstream of the cylinder body was observed.

EXPERIMENTAL APPARATUS AND PROCEDURES

Figure 1 shows a schemstic diagram of the experimental apparatus consisting of a water tank, a centrifugal pump, flow reguration valves, flow rectifying devices and a transparent acrylic circular pipe with the inner diameter of 50mm, around which a water jacket is attached in order to diminish the lens effect. Figure 2 shows the configurations of two cylinders to be mounted in the circular pipe as a vortex

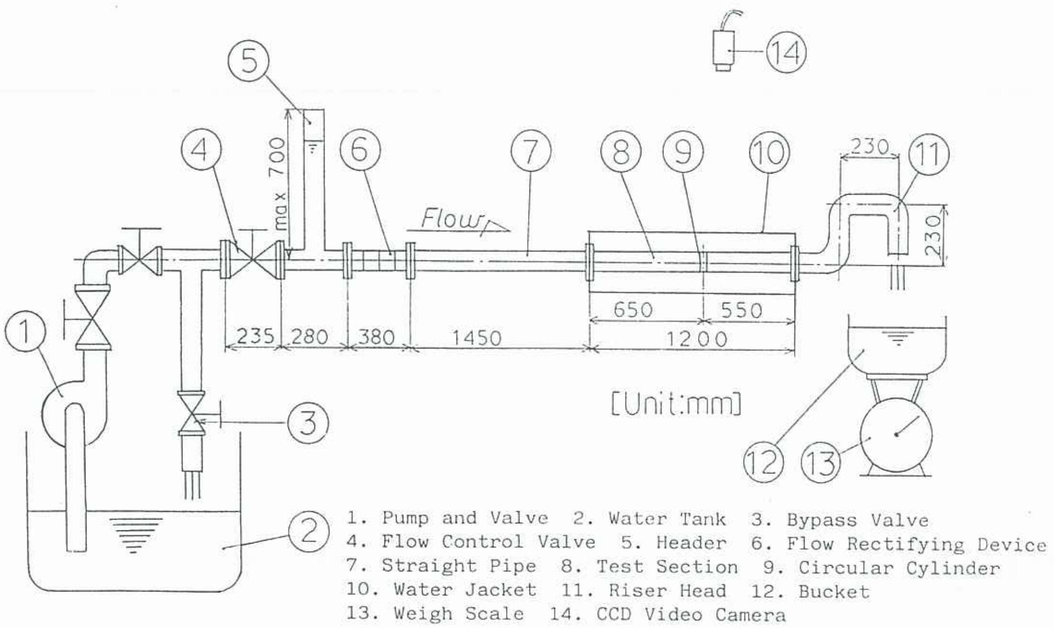
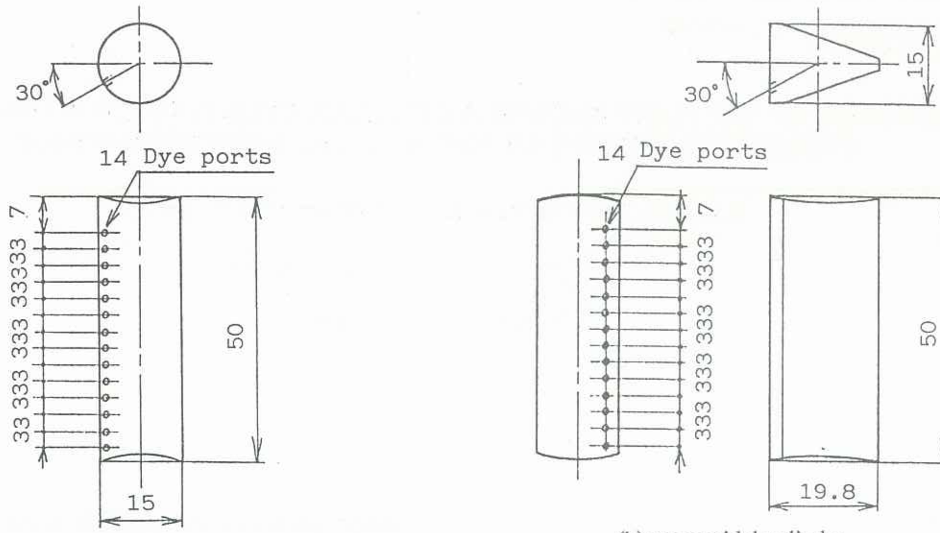


Fig.1 Schematic diagram of the experimental apparatus.



(a) circular cylinder (b) trapezoidal cylinder

Fig.2 Vortex shedding cylinders.

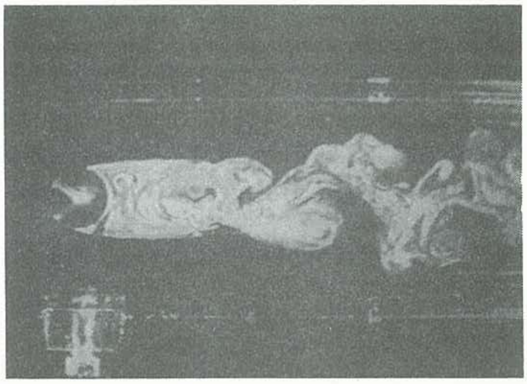
shedding body, one of which is of circular section with the outer diameter of 15mm, and another is of trapezoidal section with the width of 15mm in the wider side facing upstream. On the surface of each cylinder, a row of 14 dye ports of 1mm diameter were aligned parallel to the cylinder axis at 30 degrees downstream of the front stagnation point concerning its geometrical center. Once either the circular cylinder or the trapezoidel cylinder is mounted on the test section of the 50-mm circular pipe, the blockage rate of its projected width to the pipe diameter becomes 0.3 in the same manner as that adopted in an ordinary vortex flowmeter on the maket. Furthermore, on the surface of the circular pipe, an isolated dye port of 0.6 mm diameter was arranged at 70mm upstream of a foot of the tested cylinder, and also three dye ports of 0.6mm diameter for were aligned on the circular pipe wall in a central section perpendicular to the axis of the tested cylinder at 40, 70 and 100mm downstream of the cylinder.

Using the experimental apparatus for flow visualization, the three-dimensionality of the Karman vortex shedding around the cylinders, the three-dimensional flow structure near a foot of each cylinder, and the three-dimensional vortex flow in the near wake were investigated stressingly. The flow was visualized by means of fluorescent water color paints, and as lightning equipments, a 2w-Ar-gas laser light sheet and an ordinary 200w white light were used for two-dimensionally sectional observaiton of Karman vortex shedding and three dimensional investigations, respectively. The visualized flow fields were monitured and recorded on video tapes by an ordinary ccd video camera, and also pictured by a normal camera. The time mean flow rates in the circular pipe were measured by so-called weighing method with the aid of a baket of 5 liters, a weigh scale (full scale 98N (10Kgf)) and a stop watch, within the maximum error of 5%. In the present experiments, the tested mean velocities in the pipe were in the range of 15mm/s to 380mm/s, which corresponds to the Reynolds number range of $Re = UmD/\nu = 780$ to 19,000, here Um, D and ν denote the mean velocity, the inner diameter of the pipe and the kinetic viscosity of the water, respectively.

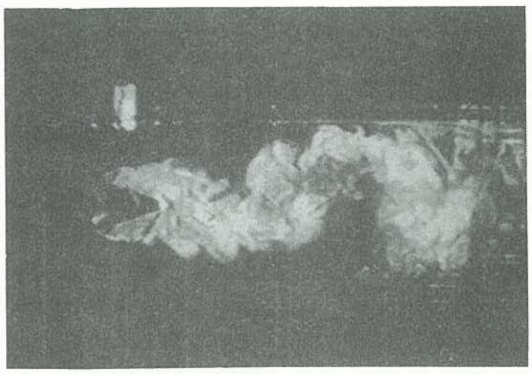
RESULTS AND DISCUSSIONS

Sectional Observation of Vortex Shedding

Photograph 1 shows sectional patterns of vortex shedding from the circular cylinder and the trapezoidal cylinder which were visualized by oozing fluorescent paint from dye ports of the cylinder and illiminating the mid-span section of the flow field with the laser light sheet. It is clear that in the wake behind either the circular cylinder or the trapezoidal cylinder, vortex structure like a Karman vortex street comes into existence in the pipe flow. It should be noted here that in the same manner as reported by Yokoi et al.(1990), not only the Karman vortex shedding as shown in Photo.1 (a), but also twin vortex shedding were detected intermitently and alternatively behind the circular cylinder, at a Reynolds number smaller than 2,300.



(a) circular cylinder (Re = 2,200)



(b) trapezoidal cylinder (Re = 3,200)

Photo.1 Vortex shedding patterns in the mid-span section of the pipe.

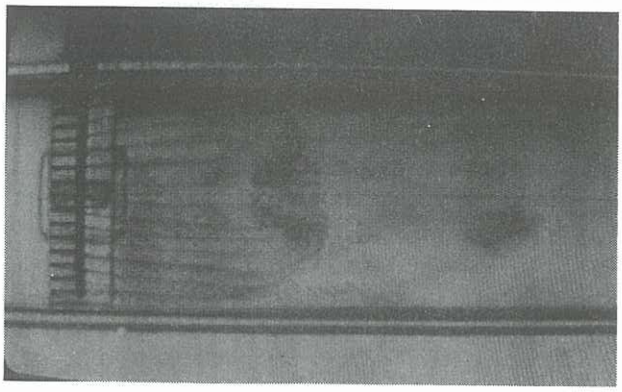


Photo.2 Three dimensional rolling of velocity shear layer separated from the circular cylinder (Re = 2,000).

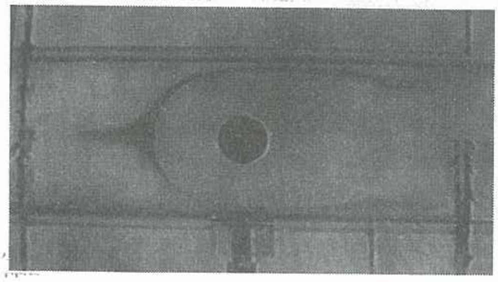


Photo.3 Horse-shoe vortex formed around a foot of the circular cylinder (Re = 2,400).

Three-dimensional Structure of Flow around a Circular Cylinder

Photograph 2 shows the side view of three-dimensional rolling up of a velocity shear layer separated from the circular cylinder at Re = 2,000 which was visualized by oozing water color paint from 14 dye ports aligned spanwise on the cylinder surface. It is recognized that the separated shear layer slightly spreads and rolls up like it wraps up the fluid just behind the cylinder.

Photograph 3 shows a horse-shoe vortex formed around a foot of the circular cylinder at Re = 2,400 which was visualized by oozing water color paint from a dye port prepared at 70mm upstream from the center of the cylinder.

Photograph 4 shows the existence of a three-dimensional separation babble over one side of the pipe wall surface just downstream of the cylinder, which was visualized by water color paint at Re = 4,000. In this photograph, water color paint oozing from a dye port spreads upstream, and visualizes the configuration of the very thin and three-dimensional separation babble.

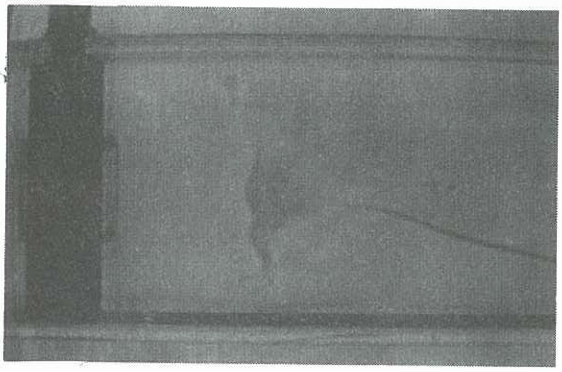


Photo.4 Visualized 3-D separation babble on the pipe wall downstream of the circular cylinder (Re = 4,000).

Three-dimensional Structure of Flow around a Trapezoidal Cylinder

In the same manner as observed in the flow around the circular cylinder, there exists three-dimensional structure of the flow around the trapezoidal cylinder which is a typical configuration of vortex shedding bodies mounted on vortex flowmeters widely used in various engineering fields.

Photograph 5 shows the three-dimensional rolling up of a velocity shear layer separated from the trapezoidal cylinder at Re = 940.

Photographs 6 and 7 respectively show the horse-shoe vortex formed around a foot of the cylinder at Re = 3,100 and the very thin separation babble developed on the surface of the pipe wall downstream of the trapezoidal cylinder at Re = 2,400.

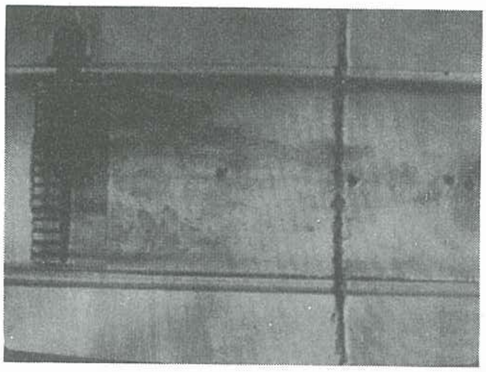


Photo.5 Three-dimensional rolling of velocity shear layer separated from the trapezoidal cylinder (Re = 940).

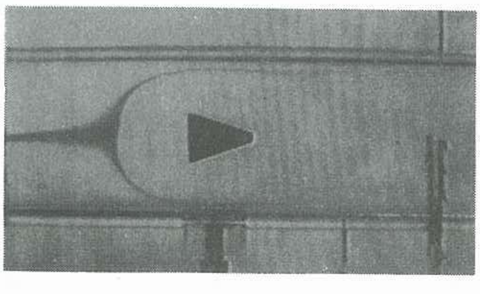


Photo.6 Horse-shoe vortex formed around a foot of the trapezoidal cylinder (Re = 3,100).

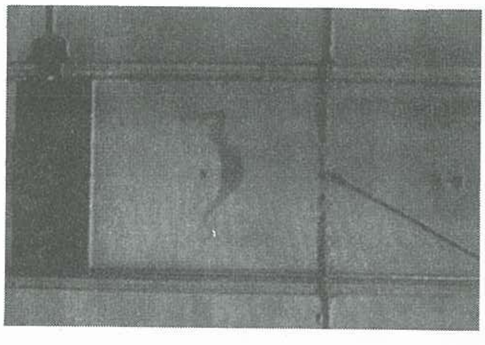


Photo.7 Three-dimensional separation babble on the pipe wall downstream of the trapezoidal cylinder (Re = 2,400).

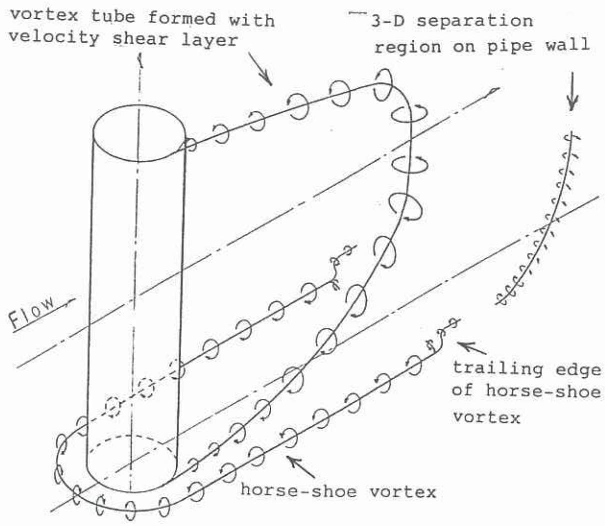


Fig.3 Schematic view of 3–D structure of the flow around the circular cylinder.

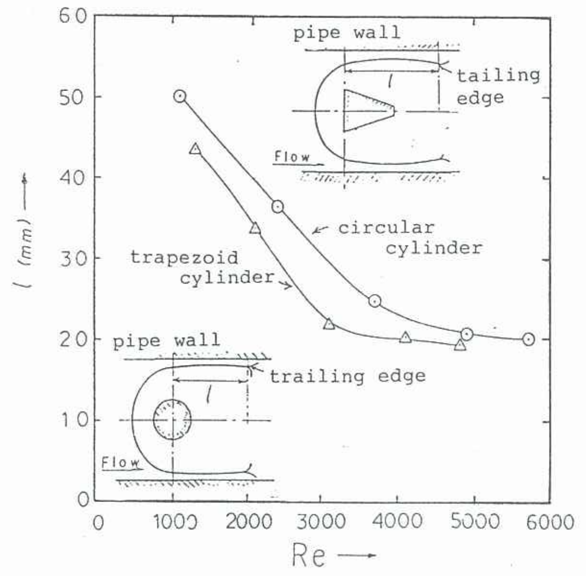


Fig.4 Variation of location of trailing edge of the horse–shoe vortex.

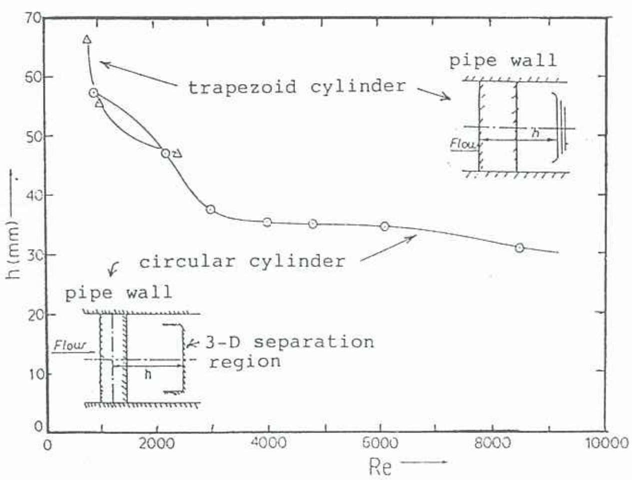


Fig.5 Variation of location of leading edge of the 3–D separation babble on the pipe wall.

Characteristics of Three–dimensional Flow Structure

In Figure 3, the essential elements of the three–dimensional flow structure observed around the circular cylinder are summerized schematically. It is one of the interesting points that both tips of the three–dimensional separation region locate in the close proximity of the trailing edges of horse–shoe vortices, and around here the three dimensional vortex is formed from the separated shear layer and leaves the cylinder base periodically.

In Figure 4, variation of the location of a trailing edge of the horse–shoe vortex is shown versus Reynolds number for either the circular cylinder case or the trapezoidal cylinder case, which was measured in pictures of visualized flows. It is clear that the distance from the cylinder to the trailing edge of the horse–shoe vortex decreases with the increase of Reynolds number as far as Re is less than about 3.500 in either case, and for a higher Reynolds number, the location tends to be fixed at a certain distance behind the cylinder.

In Figure 5, variation of the location of leading edge of the three–dimensional separation babble on the pipe wall is demonstrated for the flows of both cylinder, which was also obtained from pictures of visualized flows. It is also clear that the distance of the location from the center of the circular cylinder decreases with the increase of Reynolds number as far as a Reynolds number is less than about 3,500 and also the location tends to be settled at a certain distance from the circular cylinder for a higher Reynolds number than 3,500. It should be noted here that the existence of the three–dimensional separation babble for the trapezoidal cylinder could not be confirmed for a Reynolds number larger than 2,400 in the present experiments.

CONCLUSIONS

In order to understand the complex flow in a vortex flowmeter, water flows around a circular cylinder and a trapezoidal cylinder in a circular pipe were observed with the aid of a putting–dye method in a rather low Reynolds number range. The following conclusions were obtained.

(1) The formation of Karman–vortex–like vortices is completely so three–dimensional behind either a circular cylinder or a trapezoidal cylinder as the separated shear layer wraps up the fluid just behind the cylinder.

(2) There exist horse–shoe vortices around the feet of either cylinder, and the trailing edges of the vortices come up to a certain distance behind the cylinder as the Reynolds number increases.

(3) The existence of three–dimensional separation babbles was confirmed on the surface of the circular pipe in the near–wake region of either the circular cylinder or the trapezoidal cylinder, and the leading edge of the separation region moves up to a certain distance behind the circular cylinder with the increase of Reynolds number.

It was known from the present experiments that the characteristics of Karman vortex shedding from a cylinder in a circular pipe depends on both the formation of horse–shoe vortices around the cylinder feet and the appearance of the three–dimensional separation babbles on the pipe wall surface in the near–wake region. It can be concluded that the further improvement of the vortex flowmeter will be obtained by tuning the interaction of the essential elements of the three–dimensional flow structures.

ACKNOWLEDGMENT

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REFERENCES

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