Characteristics of Residual Currents due to Asymmetrical Pipes

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1. Introduction

Recently, water deterioration by pollution in a stagnant sea area in the semi enclosed bay occurs mainly due to the lack of water exchange with the open sea. Komatsu et al. (2001), based on a laboratory experiment, suggested to use unidirectional residual currents in order to increase water flow to the open sea. These residual currents can be generated by asymmetrical structures placed under a wave field. Kawano et al. (2006) proposed a specific pipe called One-Way Pipe, which has asymmetrical structures inside. It can produce unidirectional residual currents. However, it is not easy to make such kind of pipe with small asymmetrical structures inside the pipe. Therefore, a simple shape that is easy to construct is needed for a practical implementation of the One-Way Pipe. The asymmetrical characteristic can be created by just modifying the inlet or outlet of the pipe or making a diffuser type. These types of pipes can also be expected to produce the residual currents.

2. Numerical Solver and Computational Conditions

The oscillatory flow around a structure is resolved based on the horizontal two-dimensional Reynolds-averaged Navier-Stokes (:RANS) equations with the k-ε turbulent model. The computational domain is about $14.1L \times 6.6L$, where L is x-directional length of the pipe. The numerical grid used is a stretched rectangular grid. The grid size of the first grid near the wall boundaries is 2.5mm. On the two side boundaries, the free slip ones are used for the velocities, and the normal gradient equals zero for the pressure, k and ε. For the fixed boundaries, the wall function method is applied for the velocities, k and ε , and a zero normal gradient is used to determine the pressure. On the velocity components and pressures at the right side and the left side open boundaries, a sinusoidal function is used as an oscillatory flow. The amplitude of velocity, U_o and the period of the oscillatory flow, T are 0.27m/s and 1.86s, respectively.

3. Test Cases

The magnitude and the pattern of the residual currents are compared among six types of the pipe. The first type is a pipe with a vertical flange, namely Type-1. A pipe with a flange that has a 45 degree outward angle measured from one end of the straight pipe is taken as Type-2. A pipe equipped with a flange like a nozzle which has about a 32.7 degree inward angle measured from one end of the straight pipe is Type-3. The fourth type, namely Type-4, is a straight diffuser pipe which has a 10.0cm diameter at one side and a 17.0cm diameter at another. Type-5 is the combination between Type-2 and Typ-4. Type-6 is the combination between Type-3 and Type-5. The first three types of the pipes have 10.0cm constant diameter. Type-3 and Type-6 have small inlets whose diameter is about 6.0cm. All the types of the pipes have 53.5cm long in x-direction. The x-directional length of the oblique flanges is 3.5cm for Type-2 and Type-3 and 1.75cm for Type-5 and Type-6.

4. Stream Lines

The residual currents were calculated averaging over last one period of the oscillatory flow. In this study, the directions of residual currents are examined by using the pattern of stream lines. The stream lines for all cases are presented in Fig.1. Fig.1a and Fig. 1b show that the stream line patterns of Type-1 and Type-2 are quite similar. The residual currents inside the pipe are positive direction indicating that water flows from the plain shape to the edge with flanges. The Type-3, illustrated in Fig. 1c, produces negative residual currents inside the pipe. Fig.1d illustrates that the diffuser type of Type-4 creates positive directional residual currents inside the pipe. Basically the streamlines of Type-5 and Type-6 are almost similar with those of Type-4, see Fig. 1e and Fig. 1f.

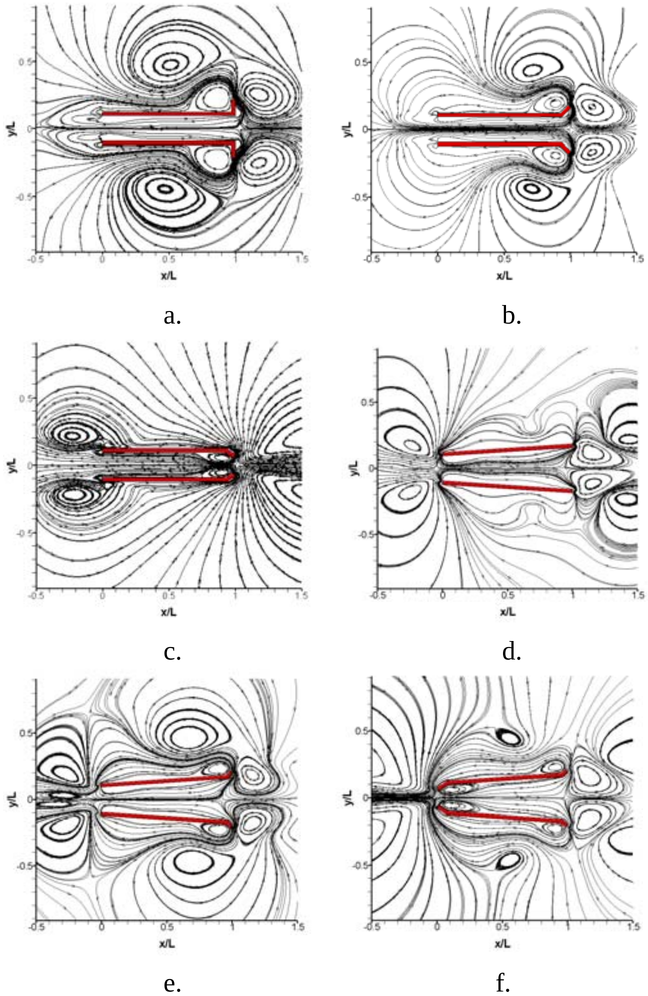

Fig. 1 The Streamlines in the different pipe shapes; a: Type-1, b: Type-2, c: Type-3, d: Type-4, e: Type-5, f: Type-6.

5. Residual Currents and Flow Discharges

Inside the pipes, the *y*-directional distribution of normalized *x*-directional residual currents at x/L=0.5 for all six cases are available in Fig. 2. The influence of the differences of the pipe diameters is modified by a normalization using D_c. D_c is the diameter at x/L=0.5, it is 10.0cm for Type-1, Type-2, and Type-3, and 13.5cm for the other diffuser types. According to Fig. 2, it is understood that the outward oblique flange in Type-2 and the inward oblique flange in Type-3 produce relatively large residual currents. It is quite interesting when the both flange types are attached to the diffuser pipe of Type-4. This Type-6 gives the largest residual currents.

Another parameter used to examine the effects of the shapes of the asymmetrical pipes is the residual flow discharge, *q*. From Table 1, it can be clearly seen that Type-2 and Type-3 give quite large discharge compared with Type-1 and Type-4 do. In addition, Type-6, which is the combination of Type-2, Type-3, and Type-4, yields a maximum flow discharge that is almost three times larger than that produced by Type-4.

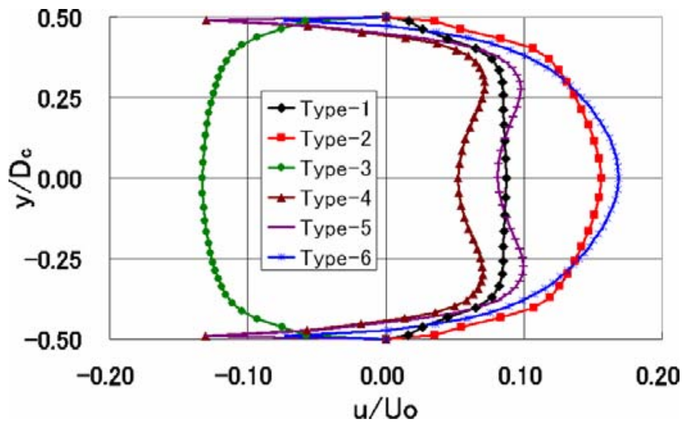

Fig. 2 Dimensionless *x*-directional residual currents at the center of the pipes

Table 1 The flow discharges for various pipe types

Type	1	2	3	4	5	6
q $\times10^{-4}$ ($m^3/s/m$)	20.10	34.01	-31.73	16.16	24.85	43.90

6. Conclusions

This study reveals that the asymmetrical shape of a pipe can produce residual currents. The residual currents and the residual discharges of all the type of the One-Way Pipe are enough large and provide promising evidence to encourage substance transport in a semi-enclosed sea area.

References

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