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Flow Characteristics Study around Two Vertical Cylinders

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ABSTRACT: *In a multiple array of vertical cylinders, flow patterns are very complex and very interactive between cylinders. The patterns are turbulent and non-linear depending on vari·ous factors. The gap and flow incoming velocity of upstream can affect on the downstream cylinder. In this study, the flow characteristics around two vertical cylinders are investigated numerically and experimentally. As the gap between cylinders is changed at fixed coming velocity, the pressure distributions around cylinders are observed and compared by experimental and numerical approaches. The F.D.M and multi-block method are applied in the study. The pressures at 12 points around the cylinder are measured in the experiment. The results can be applied in the understanding and design of multiple pile array structures.*

1. INTRODUCTION

Generally the offshore structures are constructed with number of vertical cylinders. In a multiple array of vertical cylinders, flow patterns are very complex and interactive between them. The patterns are turbulent and non-linear affected by various factors. The space and flow velocity of upstream can affect on the downstream cylinder.

Multiple arrays of cylindrical bodies create a complex flow behavior in turbulent form. In past studies, several investigations on the linear interaction between arrays of identical cylinders have been undertaken. Sumer (1997) has issued a book covering widely about the flow patterns around cylindrical bodies. A study considering unequal diameters was presented by Spring and Monkmeyer (1974). Their results were obtained by a method of multiple scattering and restricted to the diffraction force on uniform vertical cylinders in intermediate or deep water. Kaemoto and Yue (1986) used an algebraicmethod to calculate added mass and damping for a two or four equal-sized circular cylinder array using diffraction solution of a single isolated cylinder, but for having different geometries their solution is likely to become very inefficient. For the large spacing between cylinders, McIver and Eans (1984) and Williams and Abul-Azm (1989) have published their studies. Song et al. (1997) presented a paper showing the flow patterns in images obtained by VCR at rate of 10 seconds. Zhifu and Tianfeng (2001) have studied flow patterns on three circular cylinders.

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In the present research, flow visualization and measurement of pressure around circular cylinders were established. The experiment was performed in a circulating water channel. The pressures around the cylinder were measured. The numerical approach was also conducted by multiblock grid system. The F.D.M. method was applied without free surface effect. To optimize the running time, the number of mesh has been minimized along the depth of cylinder.

2. THEORIES

The non-dimensional continuity and momentum equations for the incompressible viscous flow are expressed as below

$$D \equiv \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{R_n}\nabla^2 u$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{R_n}\nabla^2 v \tag{2}$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{R_n}\nabla^2 w$$

where u, v and w are non-dimensionalized by the characteristic velocity Uo, t by the L/U_o and also x, y and z by the L, p by the ρU_o^2. R_n stands for U_oL/ν.

The F, G and H can be defined as below:

$$F \equiv \frac{1}{R_n}\nabla^2 u - u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} \tag{3}$$

$$G \equiv \frac{1}{R_n}\nabla^2 v - u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} \tag{4}$$

$$H \equiv \frac{1}{R_n}\nabla^2 w - u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} \tag{5}$$

Substituting Eq. (2) to Eq. (1)

$$\frac{u^{n+1}}{\Delta t} = \frac{u^n}{\Delta t} + F^n - \frac{\partial p^n}{\partial x} \tag{6}$$

$$\frac{v^{n+1}}{\Delta t} = \frac{v^n}{\Delta t} + G^n - \frac{\partial p^n}{\partial y}$$

$$\frac{w^{n+1}}{\Delta t} = \frac{w^n}{\Delta t} + H^n - \frac{\partial p^n}{\partial z}$$

In Equation (3), n is time level. The pressure poisson equation having D^{n+1} of 0, the following relationship can be derived.

$$\nabla^2 p^n = R^n \tag{7}$$

The R^n is as shown below:

$$R^n = \frac{D^n}{\Delta t} + F_x^n + G_y^n + H_z^n \tag{8}$$

The meshes were created by multiblock and elliptic transformation method. The time is integrated explicitly and the S.O.R. method is used in pressure equation.

3. EXPERIMENTAL SETUP

The two cylinders are positioned one behind the other in tandem arrangement to approaching flow direction. The cylinders are made of acryl tube of 100mm outer diameter and 1,000mm long. Two cylinders are placed vertically from the bottom of the channel to the free surface.

The experiment was conducted in a circulating water channel at Inha Technical College. The dimensions of the circulating water channel are described in Table 1. The schematic diagram showing the water channel is depicted in Fig. 1.

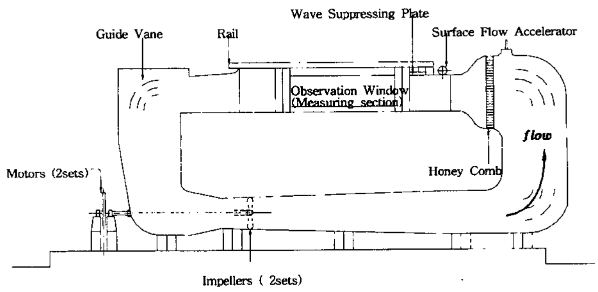

Fig. 1 Schematic diagram of CWC

The gap between cylinders is changed from 1D to 5D where D is the diameter. The speed of uniform flow were set at 0.5m/s and 0.7m/s and the corresponding Reynolds numbers of 3.13×10^4 ~ 7.30×10^4 respectively. The pressure gradient around cylinders was measured by manometer. For the pressure measurement a circular cylinder with 12 holes of 1.5mm diameter was vertically located at 350mm from the bottom. The pressure tap configuration is shown in Fig. 2 where the No.1 hole is facing to in-coming flow.

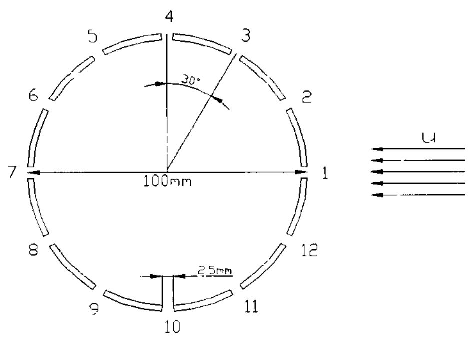

Fig. 2 Circular cylinder with 12 holes

4. DISCUSSION

The numerical mesh consists of six blocks as shown in Figs. 3 and 4 with two vertical cylinders in the center. The interfaceerror was minimized considering pressure and velocity distribution around blocks and resolving the F, G, H and Rn in Eqs. 2 and 5.

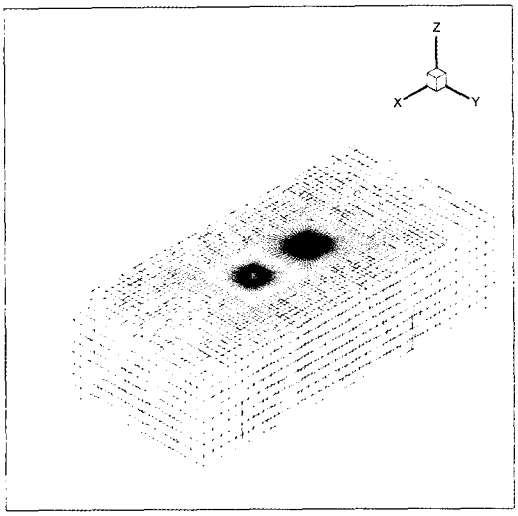

Fig. 3 Perspective view of the generated blocks

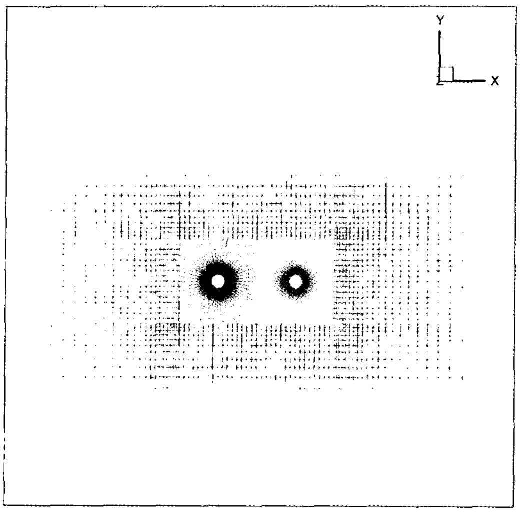

Fig. 4 Dimensional view of the generated block

It is noted that the blocks connected each other have different coordinate system. The derivatives of the physical quantities at block interface are calculated in the local node and cell oriented axis to prevent numerical discrepancies due to different coordinate systems.

Fig. 5 illustrates the drag and lift coefficients with respect to time for the gap of 1D between cylinders. It presents that the coefficients converge as time goes by and the lift coefficient fluctuates periodically. It is noted that negative drag contrary to flow direction occurs on downstream cylinder due to the interaction effect.

Fig. 6 depicts the pressure coefficients around cylinder. The negative pressure also occurs at 0 degree of downstream cylinder. The same was observed in the experiment as shown in Fig 7. The maximum pressures from the numerical analysis and experiment have the similar values but the minimum pressure from experiment indicates lower negativevalue than the numerical result.

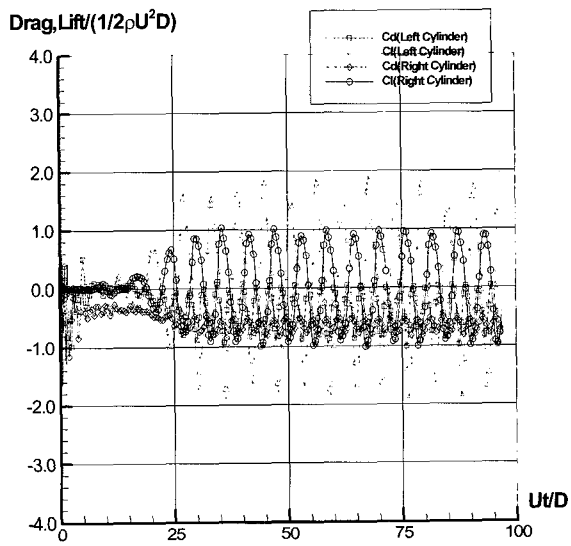

Fig. 5 Drag and lift coefficients at 1D

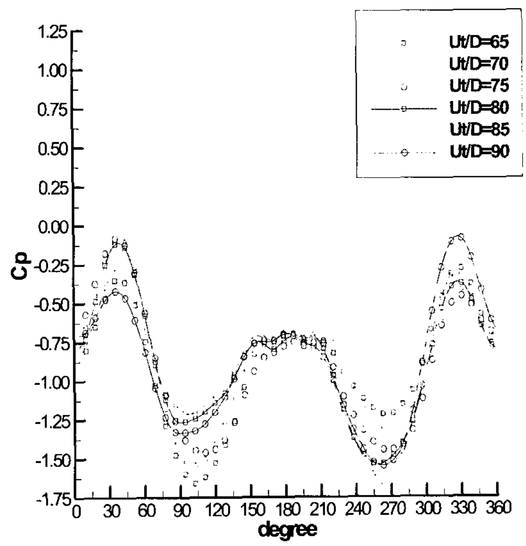

Fig. 6 Pressure distributions along the cylinder surface at 1D

The pressure distribution around cylinders is shown in Fig. 8. It is shown that the downstream cylinder is located in the turbulent region of downstream flow that is in the strong negative pressure region. The pressure distribution fluctuates with time. Figs. 9 to 12 are the pressure distributions and coefficients for various gaps between cylinders.

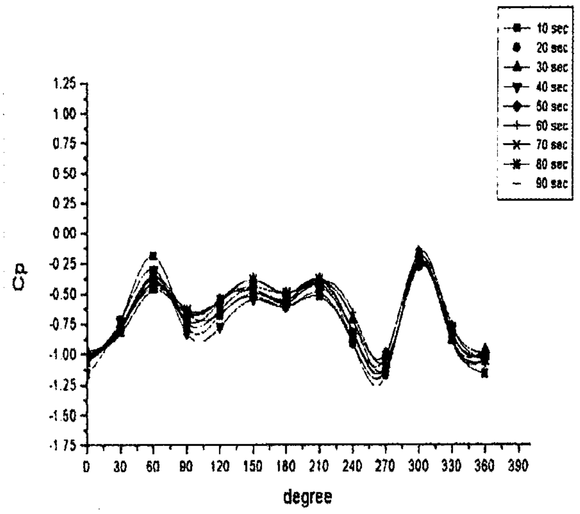

Fig. 7 Experimental pressure distributions at 1D

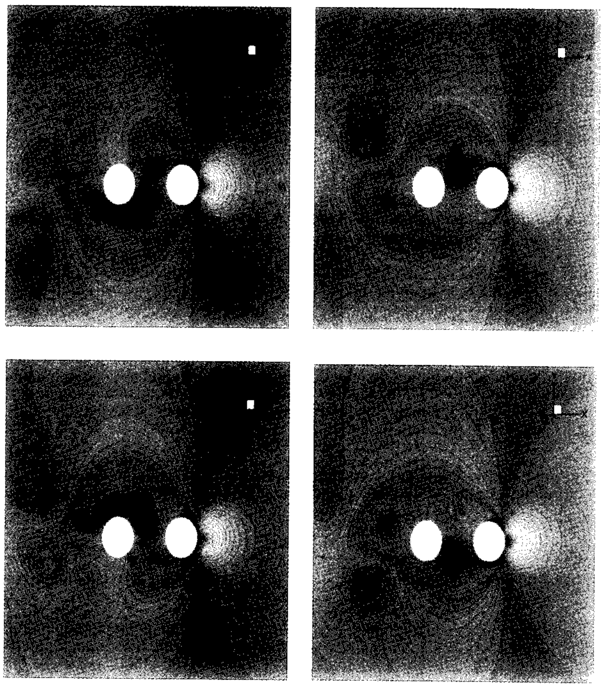

Fig. 8 Pressure distributions at 1D (Ut/D=170,180,190,200

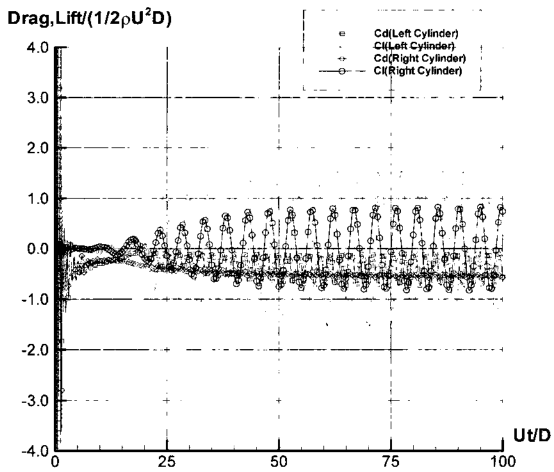

Fig. 9 Drag and lift coefficients at 3D

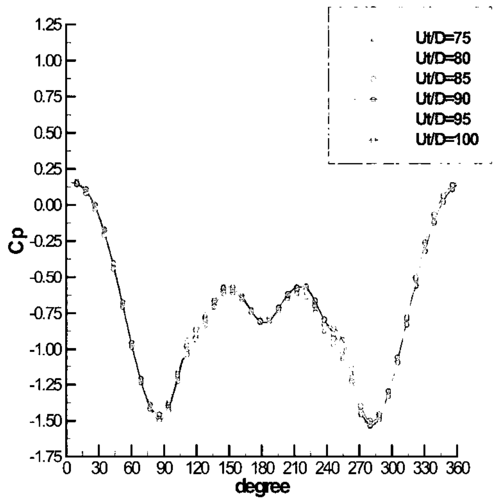

Fig. 10 Pressure distributions along the cylinder surface at 3D

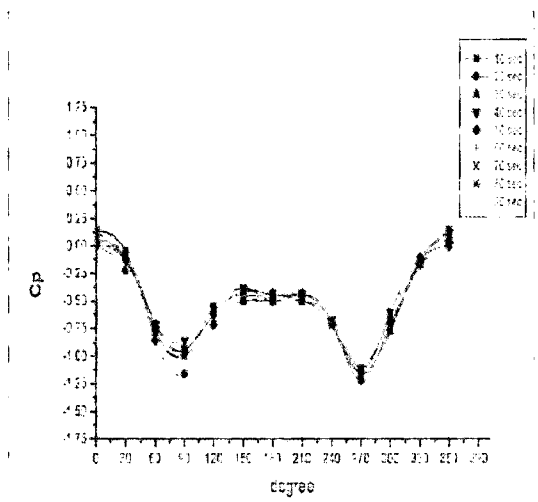

Fig. 11 Experimental pressure distributions at 3D

Fig. 12 depicts the drag and lift coefficients with respect to time for the gap of 5D. As the gap increases, the positive drag is observed on the downstream cylinder.

It is proved that as the gap increases the pressure increases and the influence of upstream cylinderdecreases as also shown in Figs. 13 and 14 of the pressure distribution around cylinder. Fig. 15 shows pressure distribution around cylinders.

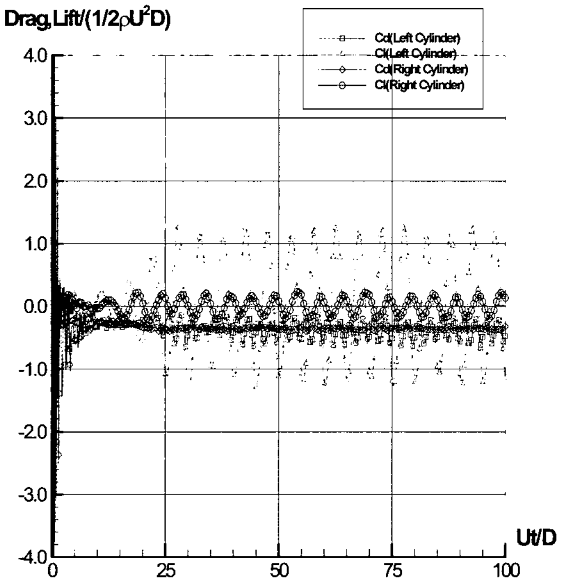

Fig. 12 Drag and lift coefficients at 5D

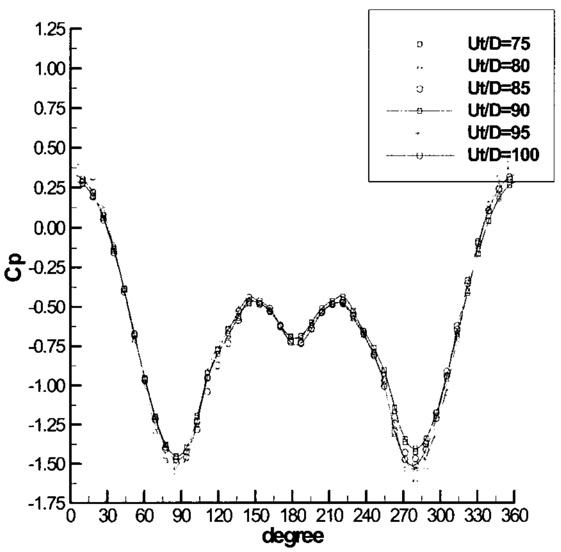

Fig. 13 Pressure distributions along the cylinder surface at 5D

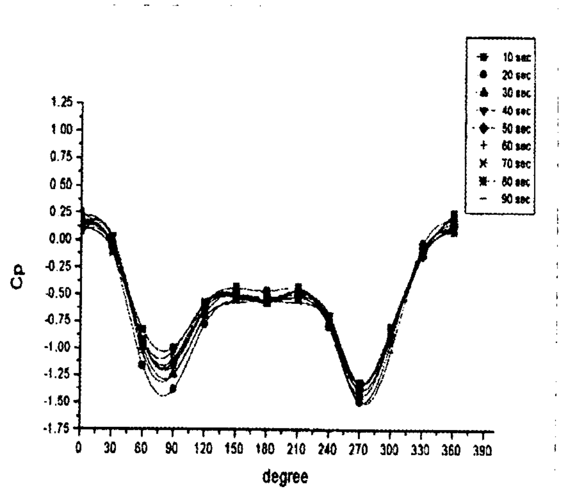

Fig. 14 Experimental pressure distributions at 5D

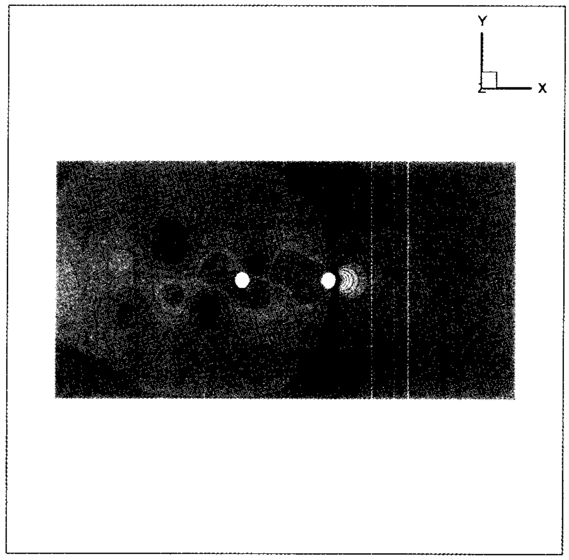

Fig. 15 Pressure distributions at 5D (Ut/D=200)

5. CONCLUSIONS

The study demonstrates the pressure distribution between two vertical cylinders considering the gap and pressure interaction effects. The numerical and experimental results were compared and verified. For the relative small gap between cylinders, the downstream cylinder is located in the turbulence region of downstream flow generating negative drag to the downstream cylinder. It is proved that as the gap increases, the drag increases on the downstream cylinder as well having less interaction influence of upstream cylinder.

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