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Numerical Investigation of Flow Past a Circular Cylinder Beneath a Free Surface with Volume of Fluid Method

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ABSTRACT: In this paper, flow through a fixed two-dimensional circular cylinder beneath a free surface at various gap ratios at Reynolds number of 180 and Froude number of 0.2 is numerically investigated. Continuity and momentum equations are resolved with Control Volume method by commercial software Ansys Fluent 14.00. For the low Froude number case (i.e. gravity-dominated), the obtained results are similar to those for flow past a cylinder close to a no-slip boundary, so that similar vortex shedding mechanism can be observed. As the distance between the surface and the cylinder is reduced, the Strouhal number, as measured from the time varying lift, increases to a maximum at a Gap-Ratio of 0.70. Further Gap-Ratio reduction leads to a rapid decrease in the Strouhal number, with shedding finally ceasing altogether at Gap-Ratios below 0.16. The agreement between the results for a free surface and a no-slip boundary suggests that the mechanism behind the suppression of vortex shedding is common to an adjacent no-slip boundary. In this research, lift coefficients and velocity contours for various gap ratios have been investigated, also the effect of free surface on flow hydrodynamic for low Froude numbers is considered.

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Strouhal number

1- Introduction

Fluid flow through a circular cylinder near a free surface is important in design of offshore structures, pipelines and power generation systems based on hydropower. This research is a kind of the flow simulator for flow around the pipelines close to the sea free surface and it gives an efficient numerical model to the analysis of free surface flows and laminar flow regimes. In particular, this model argues the effect of free surface on the velocity profile, pressure, aerodynamic coefficients and vortex shedding. Sheridan et al. [1,2] in an experimental evaluation of flow around a cylinder near the free surface, with constant depth of the cylinder and the free-flow speed, investigated effect of the Froude number on free surface shape. Reichl et al. [3,4] discussed flow around a cylinder near a free surface with a numerical approach. They examined effect of distance on physical parameters and noted the similarity of results in low Froude number flows and flow close to a no-slip boundary.

Continuing the studies, in this paper by examining the speed contours, streamlines, lift and drag coefficient diagrams, comprehensive reviews on flow around a cylinder near a free surface at low Froude numbers and its similarities with the case of slip-free wall instead of free surface, both quantitatively and qualitatively are provided.

2- Methodology

For the simulation, a two-dimensional flow through a cylinder near the free surface of fluid in the Reynolds number 180 and Froude number 0.2 is selected. Fig. 1 shows a schematic view for the simulation, and in this study we have:

$$Fr = U/\sqrt{gd} \qquad Gap-Ratio = h/d$$

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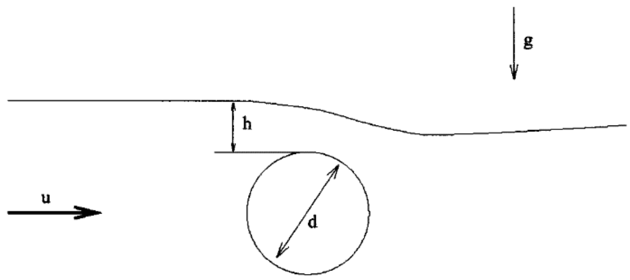

Figure 1. Flow around a circular cylinder near the free surface of fluid

2-1- Meshing

In this issue, two areas have finer mesh zones: wake zone and free surface of fluid. Fig. 2 shows the grid. Mesh number of about 53,000, due to a slight change parameters compared to 89,000 the number of mesh, is considered as the efficient meshing.

2-2- Governing equations

Continuity equation:

$$\frac{\partial \alpha_q}{\partial t} + u_i \frac{\partial \alpha_q}{\partial x_i} = 0 \tag{1}$$

Momentum equations:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_j u_i) = -\frac{\partial P}{\partial x_i} + \mu\left(\frac{\partial^2 u_i}{\partial x_j \partial x_j}\right) + \rho g_i \tag{2}$$

The equations of continuity, momentum to determine the speed, pressure and volume fraction fields would be solved simultaneously.

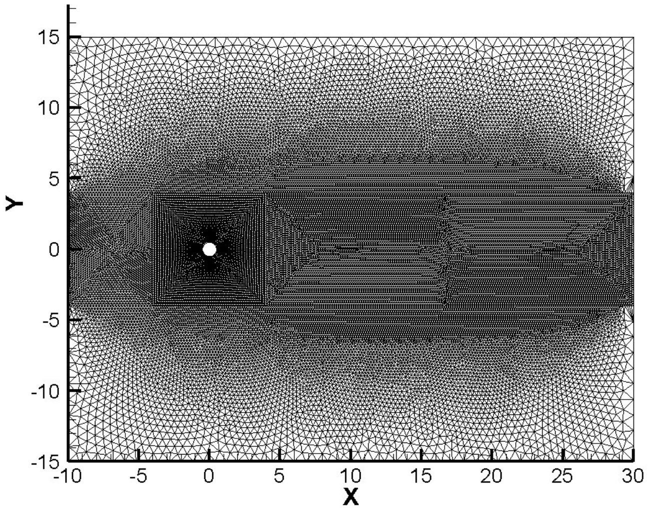

Figure 2. Numerical grid (dimensions in meter)

3- Validation and Analysis of Results

Change in vortex shedding behavior as a function of the distance from the free surface is presented in Fig. 3 (Strouhal in dimensionless distances).

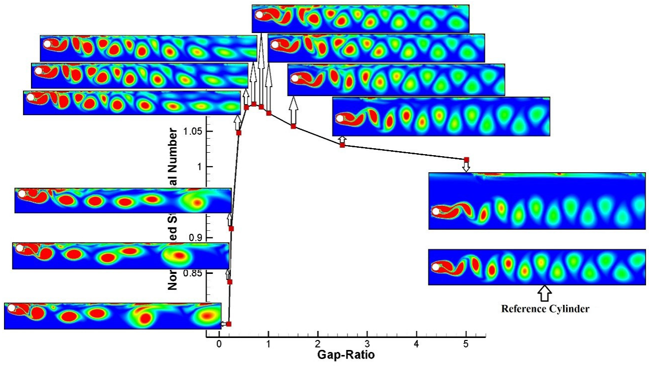

Figure 3. Vortex shedding contours

Be considerate when the cylinder is closer to the surface, Strouhal number reaches its maximum in Gap-Ratio 0.7, then further reduce the distance decreases Strouhal number due to the change in vortex formation length by changing the Gap-Ratio. Validation with Root Mean Square (RMS) of normalized lift coefficient in various Gap-Ratios are presented in Fig. 4 with acceptable accuracy compared to Reichl et al. study [4].

To better understand the behavior of streamlines around the cylinder at various Gap-Ratios, Fig. 5 presents contours of streamlines. To investigate the distribution of local pressure, we present static and dynamic pressure contours for Gap-Ratio of 1.00 in Fig. 6. Contour of static pressure shows the hydrostatic distribution of pressure, on the other hand, because dynamic pressure is a function of velocity, it is similar to streamline and velocity contours.

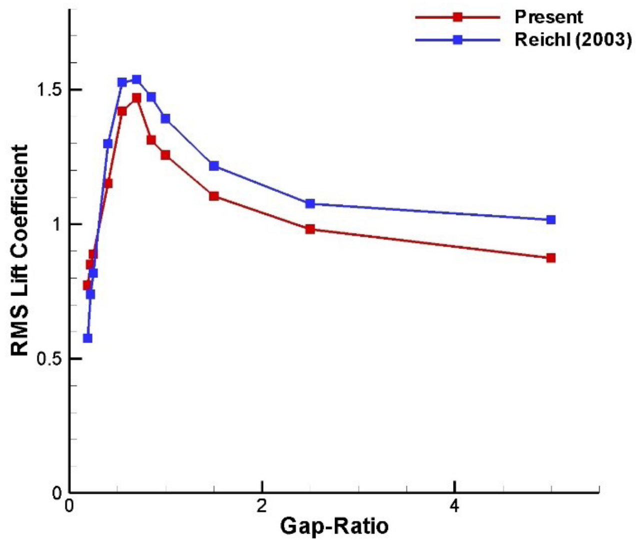

Figure 4. Validation for flow at *Re*=180, *Fr*=0.2 by comparing to Reichl et al. study [4]

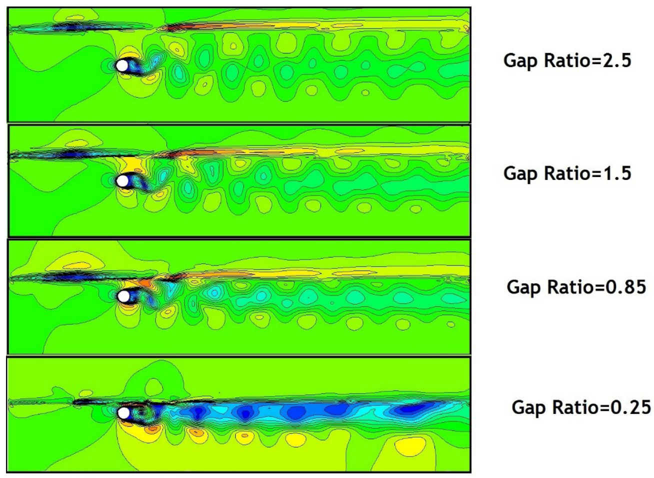

Figure 5. Contours of Streamlines

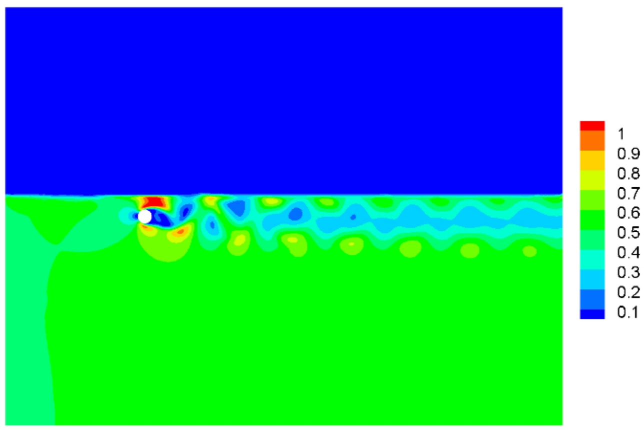

Figure 6. Contours of Static (top) and Dynamic (down) pressure

4- Conclusion

Here, flow through a fixed two-dimensional circular cylinder beneath of a free surface at various gap ratios at Reynolds number of 180 and Froude number of 0.2 was numerically investigated. The results reveal that existence of free surface, compacts streamlines at the top of the cylinder and elongates vortices behind the cylinder; therefore, free surface at low Froude numbers acts like a no-slip boundary. Moreover, the existence of free surface near the cylinder compared to state of cylinder at unlimited fluid, increases vortices length also causes somewhat small waves on the surface. On the other hand, it also reduces oscillations amplitude of lift coefficient and decreases the amount of lift.

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