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Effect of Gap and Diameter Ratio on Vortex-induced Forces for Cylinders in Tandem at Re=100

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Abstract. The article investigates fluctuations of the vortex-induced loads related to the effects of gap and diameter ratio on the mean drag and lift coefficients of the downstream cylinder, when two circular stationary cylinders of different diameters are arranged in a tandem configuration. The study is performed with the method of computational fluid dynamics for the low Reynolds number of 100. The benchmarking of the numerical model is followed by the parametric investigation with the variation of: a) the ratio of diameters of the upstream to downstream cylinder (d/D), in order to observe the effects associated with relative sizes of structures; b) the gap-to-diameter ratio (G/D), in order to observe the combined effects of varying these geometrical quantities. The results demonstrate a rapid change in the mean drag and lift coefficient values at the gap-to-diameter ratio between 2.0 and 3.0 at the diameter ratios of 0.7 and 1.0.
Keyword: Lift coefficient; Drag coefficient; Tandem cylinder; Gap-to-diameter ratio and diameter ratio.

1. Introduction

The vortex shedding phenomenon and associated fluid loads generally lead to a risk of an accelerated fatigue failure for submerged structures, such as offshore pipelines and risers, when the structure is exposed to the waves and currents for an extended period of time. Other structures, experiencing this phenomenon, include suspension bridges, chimney towers, tubes bundles in heat exchangers, etc.

Majority of these structures are arranged in groups, in a close proximity to other elements of offshore systems. Arrangement in a group can alter the vortex formation in the fluid flow over a structure, compared to standalone, single structures, with a pronounced effect of cross-sectional sizes, shapes and their combination. In many engineering and mechanical applications related to external fluid flows, vortex-induced vibrations (VIV) become inevitably a major safety concern due to a high sensitivity of the phenomenon to the specific conditions.

A fluid flow over two circular cylinders of equal diameters in a tandem placed in the same flow field have been studied well in both experimental and numerical aspects during the past fifty years. Igarashi (1981) carried out an experiment of a flow around two cylinders at a Reynolds number $8.7 \times 10^3 \leq Re \leq 5.2 \times 10^4$ with cylinders spacing at $1.0 \leq L/D \leq 5.0$ from each other, with L standing as the distance between the cylinder centers and D being the cylinder diameter. This study reports results on the pressure distribution, drag coefficient, location of reattachment points at a different spacing. Alam (2016) numerically studied the flow-induced forces on two circular tandem cylinders of identical diameters at a Reynolds number of 200 where the center-to-center spacing ratio of the cylinder varied from 2 to 9 with their main focus on the fluctuating (rms) lift coefficient on the upstream cylinder. Systems of two circular cylinders of identical diameters were also investigated by Zdravkovich (1977, 1987), Sharman et al. (2005), Lin et al. (2002), Alam et al. (2003).

Concerning flow over two circular cylinders of different diameters, Yong-tao et al. (2013) numerically investigated the flow past two circular cylinders of different diameters with the aim to investigate the effects of vortex shedding behind the two-cylinder system in tandem arrangement. Alam and Zhou (2008) indicated that decreasing d/D causes the width of the wake between the cylinders to be narrowed which increases the time-averaged drag force on the downstream cylinder. A numerical simulation was performed by Zhao et al. (2005, 2007) for flow over two cylinders of different diameters at Reynolds number of 500 and 5 x 10^4 which was based on the larger cylinder diameter. The results of the simulation showed that the small cylinder had an effect on the hydrodynamic forces and vortex-shedding characteristics of the large cylinder. Dalton et al. (2021) also conducted a research to find out how a small cylinder suppresses the vortex shedding or the lift force on a large circular cylinder when place next to it. Zhao et al (2005) conducted a numerical simulation on flow past two circular cylinders with the diameter ratio of 0.25. Reynolds numbers of 500 and 125 were used respectively for the large and small cylinders. The gap considered between the cylinders was varied from 0.05 to 1.

The current work follows up on the study by Yong-tao et al. (2013) and considers the effect of a gap and diameter ratio on the mean drag and lift coefficients for two circular cylinders of different diameters in a tandem. The study intends to report the time histories and lift coefficients frequencies and also to consider additional diameter ratios of 1.5 and 2.0 (higher diameter ratios). Simulations are performed using the computational fluid dynamics method in 2D at Re = 100. The downstream cylinder of a tandem pair has a constant diameter D and is placed in the wake generated from an upstream cylinder of a varying diameter d. The gap ratio G/D between the two cylinders is varied from 0.1 to 4.0, where G is the shortest distance from the surface of the upstream cylinder to the surface of the downstream cylinder. The diameter ratio d/D of the upstream cylinder is also varied from 0.3 to 2.0.

The first section of this paper provides a short theoretical background on the studied problem. The second section represents the system and the numerical method in details. Results of this modelling are reported and discussed in the third section. Concluding remarks are presented in the fourth section of this paper.

2. Numerical Model

2.1. System Model

The study considers two stationary tandem cylinders, as presented in Fig. 1, with the uniform flow of velocity U coming in the domain from the left boundary. The diameter D = 1 m is modelled in this research. The investigation uses a rectangular 2D computational domain for the fluid with a length of 30D and a width of 15D. The structures are placed at a distance of 7.5D from the boundary walls. The center of the downstream cylinder is placed at a distance of 10D from the inlet. The model is verified using a range of Reynolds numbers from 100 to 300 for the incoming flow, as presented in the next subsection.

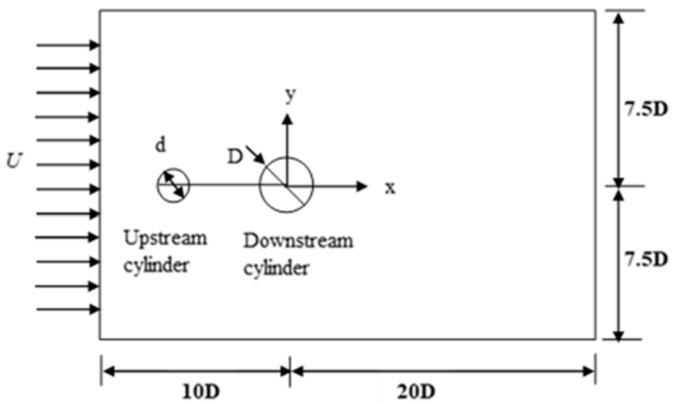


Figure 1. The system of tandem cylinders immersed in the uniform flow.

The two-dimensional Navier-Stokes system of equations is solved using the finite volume method in the ANSYS Fluent software in this work:

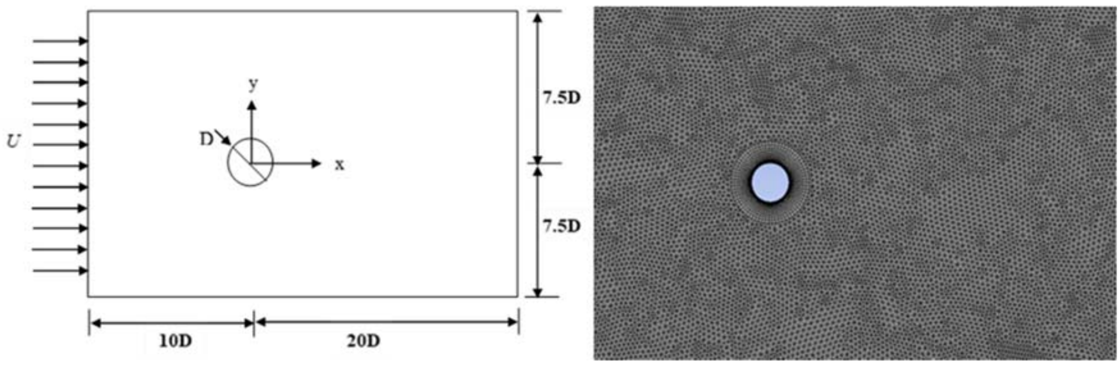
$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \quad (1)$$

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\rho g_x, \quad (2)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g_y, \quad (3)$$

where P is the pressure, u is the flow velocity in the x direction, v is the flow velocity in the y direction, g is the body acceleration, ρ is the density of the fluid, μ is the dynamic viscosity of the fluid, t is the time.

2.2. Benchmarking the Numerical Method
To verify the numerical model, a uniform flow past a single circular cylinder with a diameter of 1 m for Reynolds numbers ranging from 100 to 300 is simulated using four meshes of a different resolution, for the domain layout shown in Fig. 2(a). The study generally employs an unstructured triangular grid, as in Fig. 2(b), and the accuracy for the four types of meshes is presented in Fig. 3, with 64176, 65532, 69988 and 104578 cells. The time step of 0.01 s is used for all simulations.



(a) (b)

Figure 2. Computational domain for a single cylinder for the model verification: (a) general view; (b) triangular grid with an enhanced accuracy around a single cylinder.

Figure 3 provides results for the computed mean drag coefficients for Reynolds numbers ranging from 100 to 300. The results obtained for four meshes indicate a suitable agreement of the second, third and fourth meshes with the published experimental data from Sucker and Brauer (1975) and numerical results obtained by Sarkar and Sarkar (2010) and Yong-tao et al. (2013). A better agreement among the data is generally achieved in the range of Re from 100 to 200. Based on this grid independence study, the fourth mesh is used for all further simulations.

2.3. Simulation Outline
The numerical grid in Fig. 4 is constructed based on the benchmarked single-cylinder simulation in the previous subsection. Effects of the gap-to-diameter ratio G/D and diameter ratio d/D on the drag and lift coefficients for the tandem cylinders are studied for the range of d/D = 0.3, 0.7, 1.0, 1.5 and 2.0 with the constant downstream cylinder diameter D = 1 m. The gap-to-diameter ratio in these simulations is set to G/D = 0.1, 0.4, 1.0, 2.5, 3.0 and 4.0.

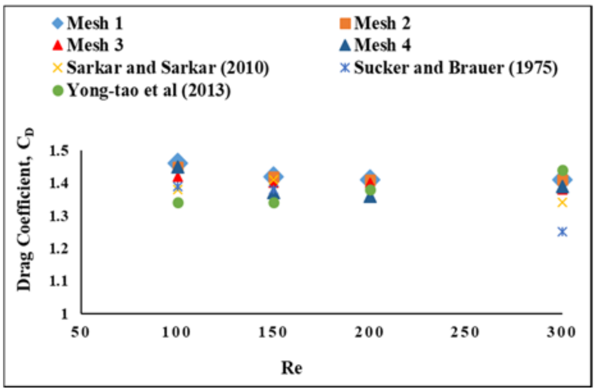


Figure 3. Comparison of time-averaged drag coefficients between different meshes and previous studies.

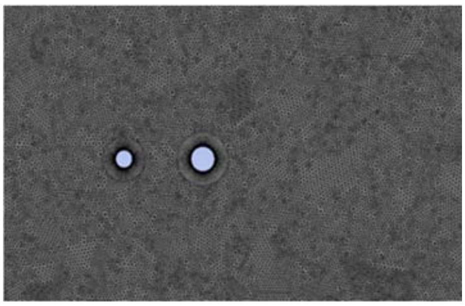


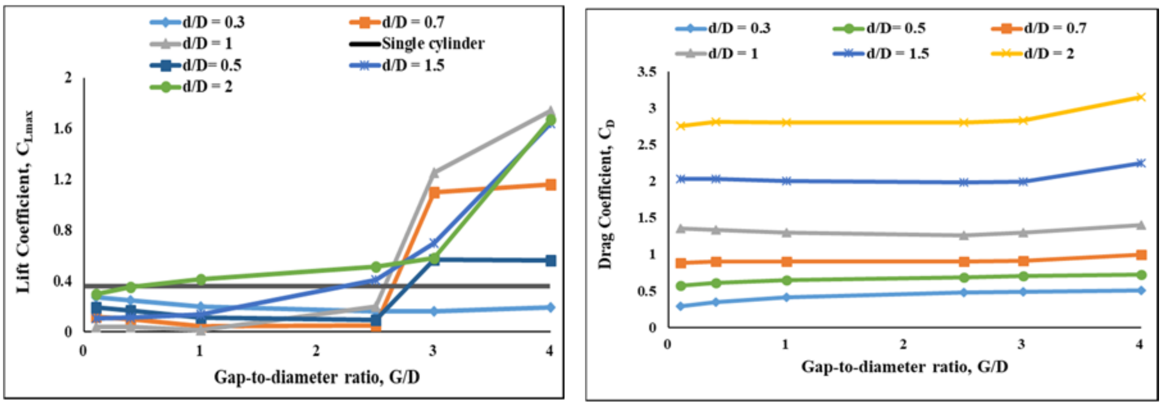
Figure 4. Computational mesh in proximity of two cylinders for G/D = 2.5 and d/D = 0.7.

3. Results and Discussion

The current section presents the results obtained for the case matrix outlined in the subsection 2.3, and they include the averaged values for the drag and lift coefficients and also lift coefficient frequencies and time histories, extending the findings of Yong-tao et al. (2013) for laminar flow of Re = 100.

Figure 5(a) illustrates the mean drag coefficients of the downstream cylinder (main structure) in the presence of an upstream cylinder (control structure) of different diameter ratios. The results are compared with the drag coefficient of a single isolated cylinder of diameter D which appears to exceed all the drag coefficients of the downstream cylinder (main structure). In presence of an upstream cylinder (control structure) with diameter ratio of 1.5 and 2 which this paper seeks to investigate showed that the downstream cylinder experiences a negative drag coefficient when the G/D ≤ 3 but begins to move into the positive region when G/D >3 unlike other diameter ratios where the drag coefficient of the downstream cylinder becomes almost stable in the positive region for G/D ≥ 3. For diameter ratios of 0.3 to 1, the obtained results are in agreement with the findings of Yong-tao et al. (2013) as presented in Fig 5(a).

In Fig. 5b, it is shown that increasing the diameter ratio of the upstream cylinder increases the effect of the drag coefficient on it. The individual diameter ratios almost showed a constant drag coefficient for G/D ≤ 3.

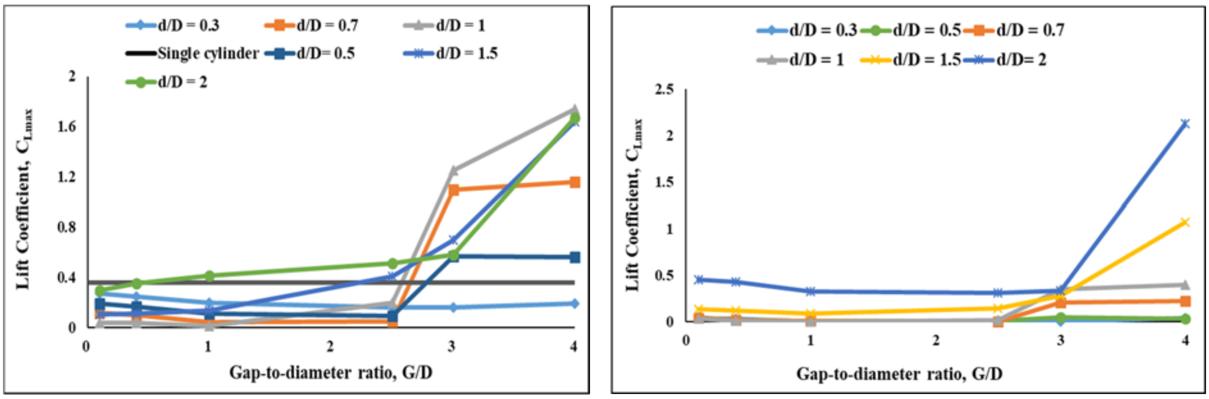


(a) (b)

Figure 5. Mean drag coefficient for: (a) downstream cylinder, (b) upstream cylinder.

In Fig. 6(a), the presence of the upstream cylinder (control structure) makes the lift coefficient of the downstream cylinder smaller than the lift coefficient of a single cylinder in the range of G/D ≤ 2.5. For diameter ratio of 2, the lift coefficient of the downstream cylinder is less than that of the single cylinder when G/D < 0.4. The downstream cylinder experiences a sharp increase in lift coefficient at G/D = 3 when d/D = 2.

For a small diameter ratio of 0.3 of the two cylinders, the lift coefficient is almost constant. An increase in gap-to-diameter ratio above 2.5 for other considered diameter ratios leads to a notable elevation in the lift coefficient, with the highest values observed for d/D = 1.0. Figure 6b demonstrates generally similar trends for lift coefficients of the upstream cylinder (control structure) with the highest value recorded for the lift coefficient at d/D = 2.0.

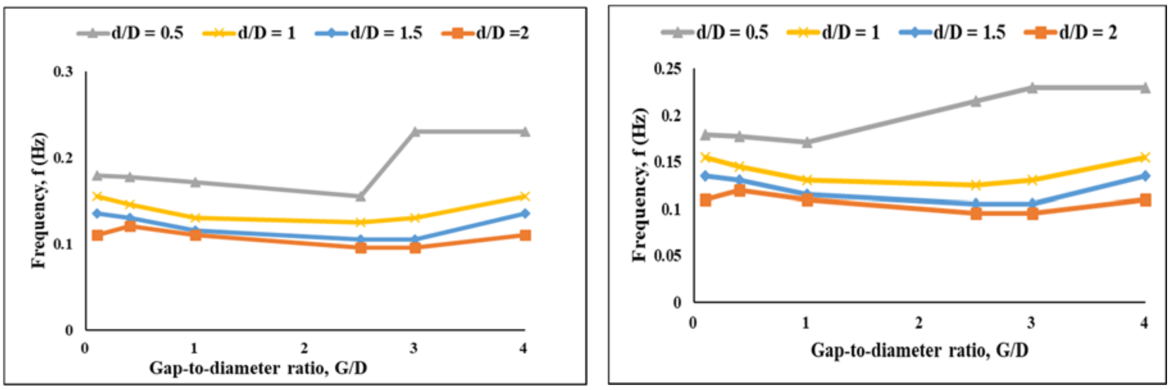


(a) (b)

Figure 6. Maximum amplitude of lift coefficients for: (a) downstream cylinder, (b) upstream cylinder.

Figures 7(a) and 7(b) report the oscillation frequencies of lift coefficients, for both structures which is also the focus of this paper. It is observed that the frequencies of the lift coefficients are almost the same for both cylinders. The downstream cylinder experiences an increase in frequency when the G/D >2.5 for diameter ratio of 0.5.

For the upstream cylinder, the diameter ratio of 0.5 experiences an increase in frequency of the lift coefficient when G/D > 1.

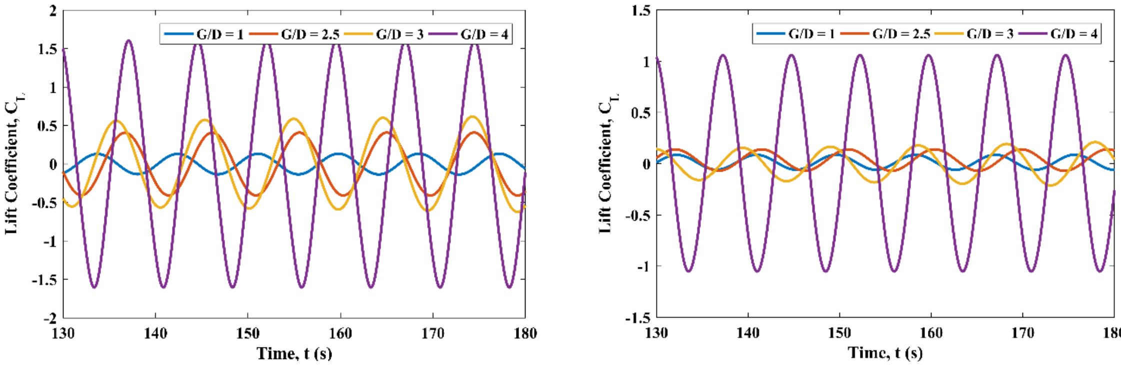


(a) (b)

Figure 7. Lift coefficient frequencies for a number of d/D ratios for: (a) downstream cylinder, (b) upstream cylinder.

Time histories of the lift coefficient amplitude in Figs 8(a) and 8(b) demonstrate a relative consistency in the frequency across the range of gap-to-diameter ratios for d/D = 1.5. The maximum amplitude of the lift coefficient is achieved at G/D = 4.0 for both upstream and downstream structures. Amplitudes observed in Fig. 9(a) for the downstream cylinder are approximately equal to the ones indicated in Fig. 8(a), so that the change from d/D = 1.5 to d/D = 2.0 has a minimal effect on the lift force fluctuations.

Fig. 9(b) illustrates a similar trend of the elevated value of the lift coefficient at G/D = 4.0 and d/D = 2.0, while the amplitude is twice higher for the upstream body.

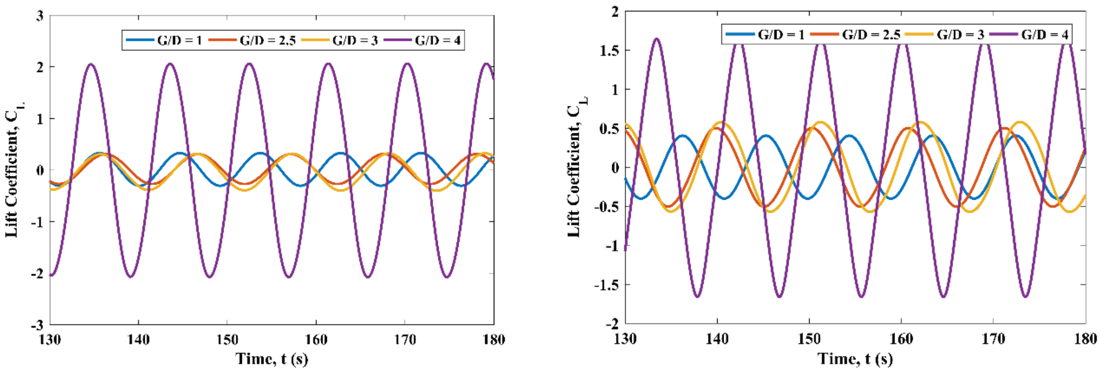


(a) (b)

Figure 8. Lift coefficient amplitudes for d/D = 1.5: (a) for the downstream cylinder; (b) for upstream cylinder.

4. Conclusions

Effects of the G/D and d/D ratio on the mean drag and lift coefficients of two stationary circular cylinders of different diameters in tandem at Reynolds number of 100 were considered in this research. This work is performed using a numerical model benchmarked with the experimental data by Sucker and Brauer (1975) and numerical results obtained by Sarkar and Sarkar (2010) and Yong-tao et al. (2013). The study generally extends the analysis by Yong-tao et al. (2013) towards the effect of the diameter ratios of 1.5 and 2.0.



(a) (b)

Figure 9. Lift coefficient amplitudes for d/D = 2: (a) for the upstream cylinder; (b) for downstream cylinder.

It can be concluded that the presence of the upstream control cylinder reduces the drag coefficient of the downstream cylinder, up to the values smaller than that of a single isolated cylinder. The downstream cylinder experienced a negative drag coefficient for G/D ≤ 3 when d/D = 1.5 and 2. Increasing the gap-to-diameter ratio increases the mean drag coefficient. The amplitude of the lift coefficient of the downstream cylinder is at maximum at d/D = 1.0 and 3.0 < G/D < 4.0 and at d/D = 2.0 and 3.0 < G/D < 4.0. The lift coefficient frequencies show some increase at G/D > 2.5 and highest values at d/D = 0.5 for both structures. The study could be continued by investigating 3D effects associated with variations in the cross-sectional geometry.

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References
[1] Sarkar S and Sarkar S 2010 Simulation of vortex dynamics in a cylinder wake by the Immersed Boundary technique. *Progress in Computational Fluid Dynamics*, 10(3), pp.129-145.
[2] Sucker D and Brauer H 1975 Fluiddynamik bei der angestromten Zilindern. *Wärme Stoffubertragung*, 8, pp. 149-158. (in German).
[3] Yong-tao, Zhong-min W Y, Hui-min W 2013 Numerical simulation of low-Reynolds number flows past two tandem cylinders of different diameters. *Water Science and Engineering*, 6(4): pp 433-445.
[4] Igarashi T 1981 Characteristics of the flow around two circular cylinders arranged in tandem (1st report). *Bull. JSME* 24, pp 323–331.
[5] Sharman B, Lien F S, Davidson L and Norberg C 2005 Numerical predictions of low Reynolds number flows over two tandem circular cylinders. *International Journal for Numerical Methods in Fluids*, 47(5), 423-447. [doi:10.1002/fld.812]
[6] Alam M M and Zhou Y 2008 Strouhal numbers, forces and flow structures around two tandem cylinders of different diameters. *Journal of Fluids and Structure*, 24(4), 505-526. [doi:10.1016/j. jfluidstructs.2007.10. 001]
[7] Alam M M 2016 Lift forces induced by phase lag between the vortex sheddings from two tandem bluff bodies. *Journal of Fluids and Structures* 65(2016) 217–237