SUDIP CHAKRABORTY
SAIKAT CHATERJEE
and
RANJAN KUMAR

Effect of gap ratio on flow influenced actions of two circular cylinders in side-by-side arrangement

In order to understand the flow characteristics over cylinders, the investigation is required on a particular structure where interaction of fluid and solid must be there. This phenomenon is quite common in many industrial applications like transmission cables, heat exchanger tubes, cooling towers etc. Flow influenced forces can cause unwanted vibration in the structure that may cause permanent damage to the structure. In this study, one particular set up has been chosen where circular cylinders have been placed in a flow field using side-by-side arrangement in a fluid domain and the effects of the flow influenced vibration have been observed by varying the gaps between two cylinders. The entire work has been done using a CFD software based on the finite element analysis.

Keywords : Flow induced vibration, CFD, gap ratio, FEM, fluid-structure interface.

1.0 Introduction

Flow over two or more than two cylinders is a common interaction of fluid and solid and it has major applications such as offshore platforms, cooling towers, heat exchanger tubes, transmission cables and marine risers. The constitutions are subjected to dynamic flows and encounter flow-induced forces, which cause failure in the structure. The various flow parameters, which influence the vortex-induced responses, are like Reynolds number (Re), viscosity of fluid (μ), density of flowing fluid (ñ) etc. The Reynolds number ranges from 10^3 to 10^9 in ocean. In this present work I take a high Reynolds number $Re=5\times10^5$. When a fluid is flowing over a cylinder, lift force causes vibrations of the cylinder due to the flow. These vibrations will make remarkable changes in the dynamic forces like lift and drag. The present work carries out numerical simulation studies to study the flow induced behaviour of two side-by-side cylindrical bodies. The main objectives of the work are to determine pressure and velocity distributions between and around the two cylinders. To evaluate the time history of the lift and drag forces acting on the cylinders. To predict the influence of the spacing distance between two cylinders on the flow induced behaviour. According to Hongjun Z. (2020) et al. [1] the flow-induced vibration (FIV) of two rigidly coupled cylinders arranged in tandem having unequal diameters at a Reynolds number of 150 at different typical center-to-center spacing ratios is observed. Goutam P. (2020) et al. [7] investigated the result of different spacing ratio in a specific array of four cylinders on wake generation. The computational methods have been done. For all spacing ratios, coefficient of drag of upstream cylinders is higher than the downstream cylinders. The sensitivity of coefficient of lift is higher than that of drag coefficient. Adnan M. (2019) et al. [2] Vortex-induced vibration of two rigidly coupled side-by-side circular cylinders in uniform flow is investigated using Direct Numerical Simulations. The two cylinders are allowed to vibrate in the cross-flow direction only. The aim of this study is to investigate the effect of gap ratio between the two cylinders on the vibration and wake flow. The Reynolds number for this study is 1000. Simulations are performed for gap ratios of 0.5 and 1, the range of reduced velocities from 1 to 20. Wang E. (2019) et al. [3] presented an experimental study on the FIVs of three and four flexible cylinders in tandem arrangement. The FIV response characteristics of the three and four-cylinder systems were investigated and their similarities to and differences from an isolated single cylinder and two flexible cylinders arranged in tandem at the same spacing ratio were identified. Mazir A. (2012) et al. [6] the flow around bluff bodies, arranged in tandem where one of the bodies is in the wake region of the second one, was studied using numerical simulation. This paper presents the result of a 2D numerical simulation of the wake interaction of two circular cylinders at low Reynolds number using ANSYS Fluent Workbench. The exerted lift force on the elastic downstream cylinder is almost three times bigger than the lift force exerted on the stationary cylinder due to effects of the produced vortices. Sangmo K. (2003) et al. [5] investigated two-dimensional flow over two circular

Messrs. Sudip Chakraborty, Adamas University, Barasat-Barrackpore Road, Kolkata, Saikat Chaterjee, Sanaka Educational Trust's Group of Institutions, Durgapur and Ranjan Kumar, Swami Vivekananda University, Kolkata, West Bengal, India. E-mail: csudip41@yahoo.com

2.0 Methods

Cylinders in a side-by-side arrangement at low Reynolds numbers and performed numerical simulations, using the immersed boundary method. Results show that six kinds of wake patterns are observed over the ranges: antiphase-synchronized, in-phase-synchronized, flip-flopping, deflected, single bluff-body, and steady wake patterns. It is found that the characteristics of the flow significantly depend both on the Reynolds number and gap spacing, with the latter much stronger than the former. Dixia F. (2020) et al. [9] gave some discussions on the FIV of offshore circular cylinders, including the research progress on the basic VIV mechanism of an isolated rigid or flexible cylinder, interference of multiple cylinders concerning WIV of multiple cylinders, practical VIV suppression and unwanted galloping for cylinder of attachment.

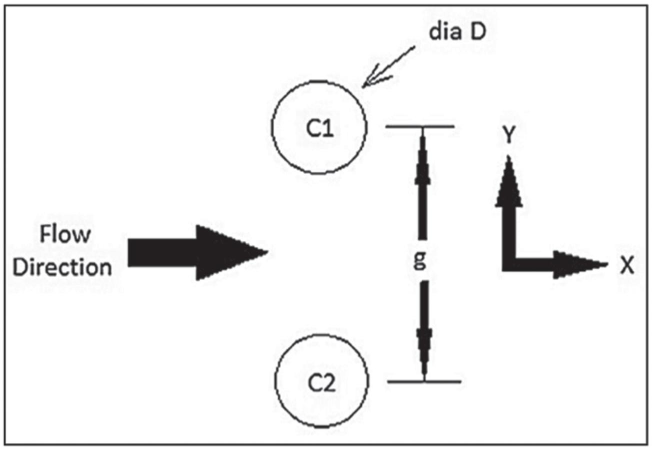


Fig.1: Schematic representation of different arrangements and two side-by-side cylinders

There are some important cylinder arrangement configurations like cylinders in tandem, cylinders in side-by-side, cylinders in staggered arrangement etc. In this work, analysis has been done on two cylinders in side-by-side arrangement.

2.1 Computational Domain and Boundary conditions

Two cylinders having diameter 0.5m are placed in a 30m×50 m rectangular domain, in which the center of both the cylinders are located at 10m from the inlet boundary. This simulation is done at a high Reynolds number Re=5×10^5. At inlet, free stream conditions are imposed. At outlet, zero-gauge pressure is applied. No-slip boundary condition is applied on cylinder walls. Fine mesh is used at the near of cylinder walls. Triangular elements are used in the fluid flow domain.

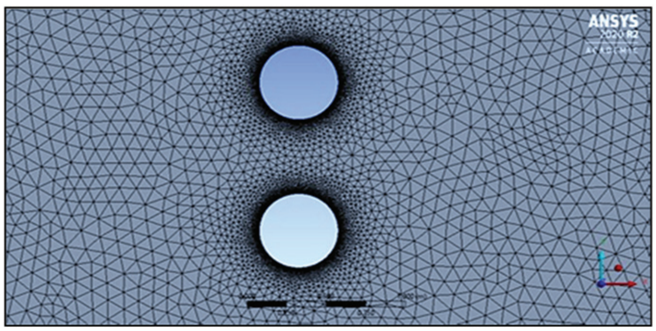


Fig.2: Schematic of the structured grid used in simulations (Computational domain)

2.2 Simulation Methodology

ANSYS-Fluent is used for simulating the flow field around two side-by-side cylinders. Pressure based and transient model are used for simulating purpose. SIMPLE algorithm is used to solve incompressible Navier-Stokes equations as this algorithm is an acronym for semi-implicit method for pressure-linked equations and second order accuracy is used for spatial discretization. SST k-M¦ turbulence model 3. Results is used for turbulence closure as SST k-M¦ model provides a better prediction of flow separation than most RANS models and accounts for its good behaviour in adverse pressure gradients.

2.3 Convergence Study

A mesh convergence study provides a justification for mesh independence and additional refinement is unnecessary. For that, we have taken three different no. of elements to calculate corresponding drag, and lift forces for different gap ratios (g/D).

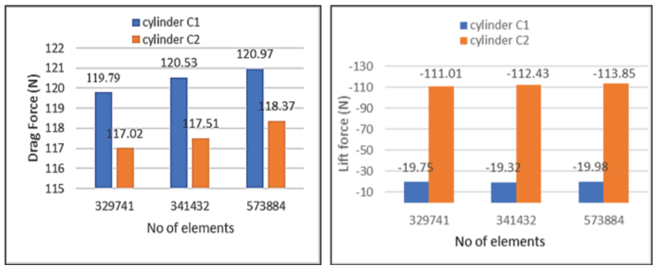


Fig.3: Simulated lift and drag force using different number of elements when g/D=2

- for g/D = 2
- for g/D = 6
- for g/D = 14

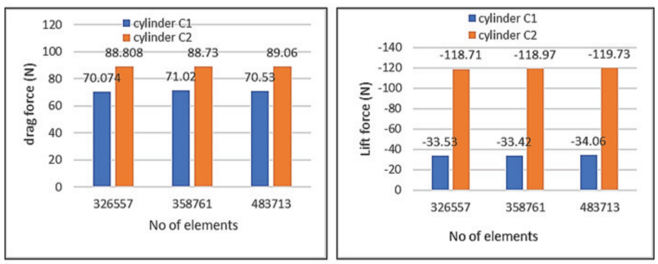


Fig.4: Simulated lift and drag force using different number of elements when g/D=6

3.0 Results

3.1 Validation of Numerical Results

To validate the CFD results we compare the time-averaged drag coefficient and the maximum amplitude of the lift coefficient fluctuations for flow over two side-by-side circular cylinders at Re=100 and g/D=2.5 with numerical results of Sangmo Kang [5].

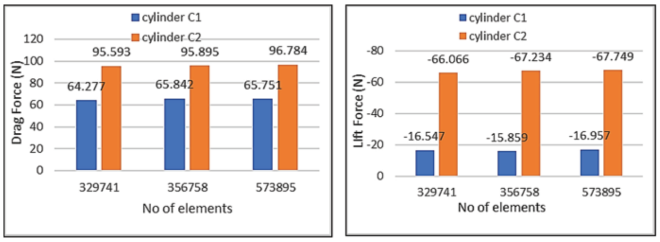


Fig.5: Simulated lift and drag force using different number of elements when g/D=14

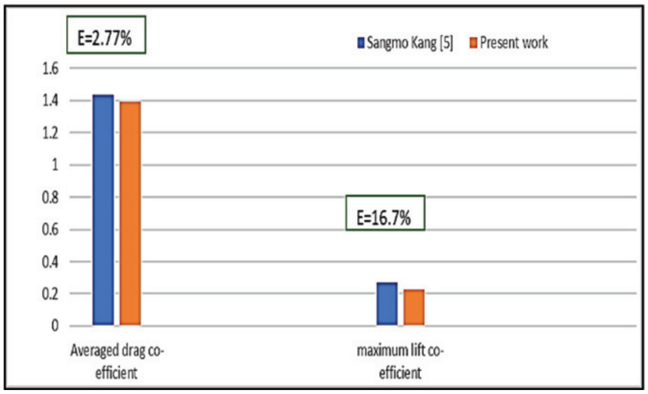


Fig.6: Validation with the previous literatures

3.2 Velocity field

From the velocity field we saw that maximum velocity occurs near the top and bottom side of both the cylinders. The velocity over the cylinder walls is zero due to no-slip boundary condition. The velocity is zero at front for all the cylinders and gradually increases to maximum value at top and bottom of cylinders. The intermediate velocity gradually decreases as gap ratio increases. At g/D=14, the intermediate velocity between two cylinders is almost free stream velocity.

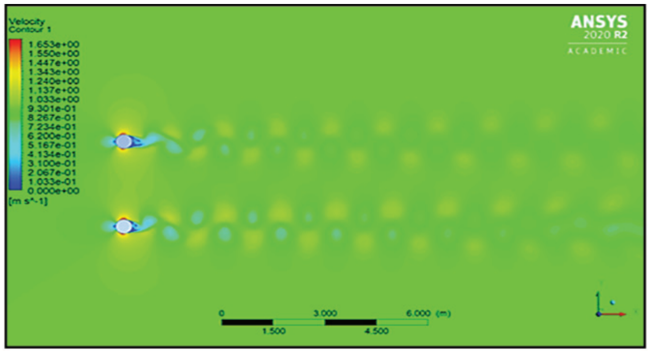
3.3 Pressure field

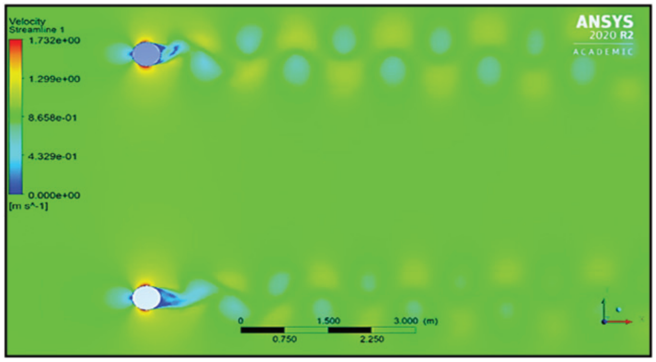
From the pressure field, we can see that pressure at the front of both the cylinders is higher than the pressure behind of them, which indicates positive drag forces for all the gap ratios. Except the frontal area for both the cylinders, we get a negative pressure zone over the cylinders for all gap ratios. The total pressure at the intermediate zone increases as gap ratio increases.

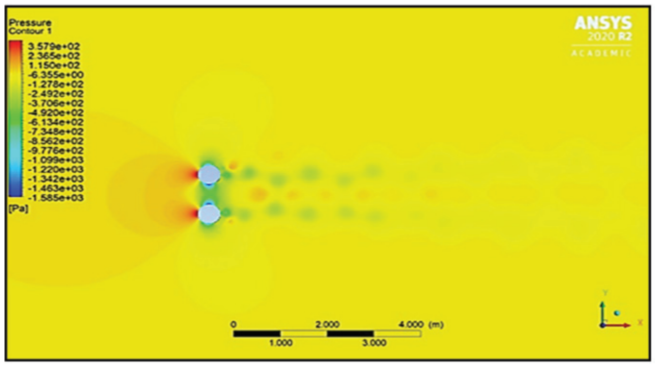
- for g/D = 2
- for g/D = 6
- for g/D = 14
- for g/D = 14

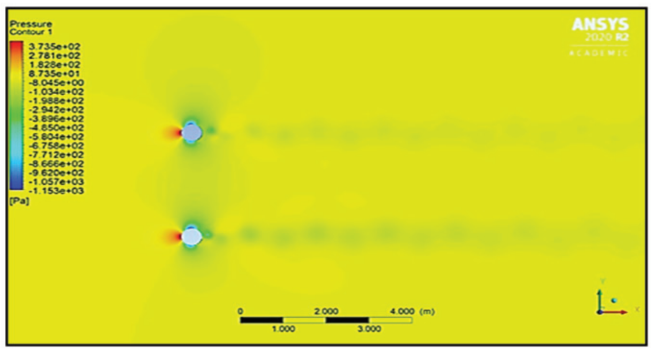
3.4 Drag Force Analysis

Drag forces are positive for both the cylinders at all gap ratios. At g/D=2, the drag forces for both the cylinders show almost same responses. At g/D=14, the fluctuation of drag force for both the cylinders are higher than other gap ratios. At g/D=2, the drag forces for both the cylinders are almost



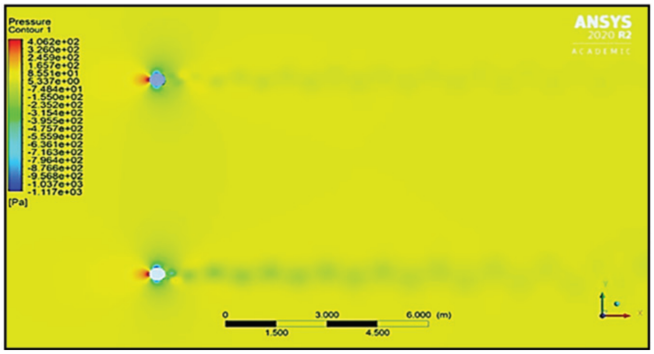


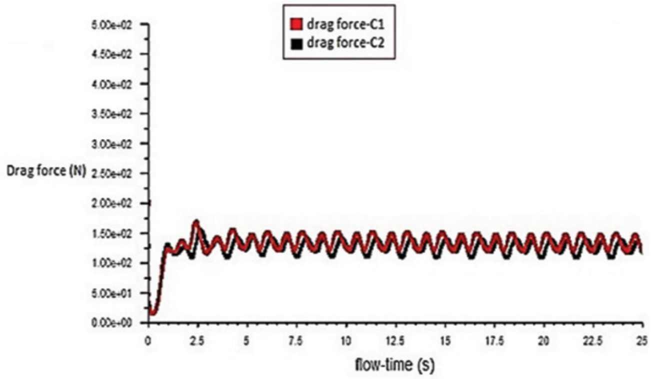


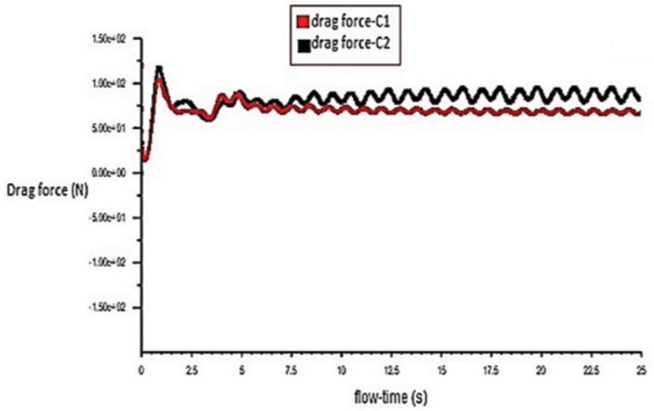


same, where for all other gap ratios the drag forces for both the cylinders are quite different. At g/D=14, the magnitude of drag force for both the cylinders are maximum.

- for g/D = 2
- for g/D = 2
- for g/D = 6



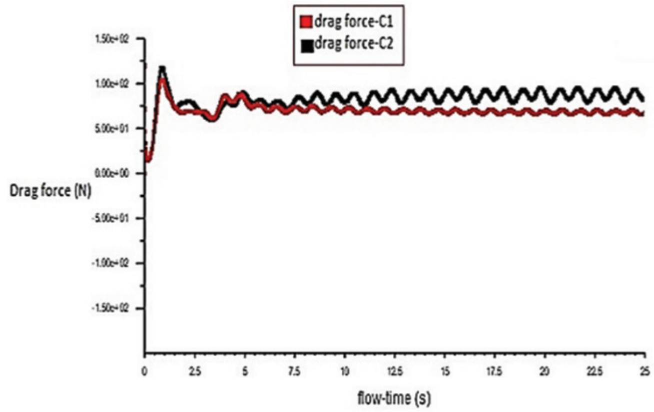


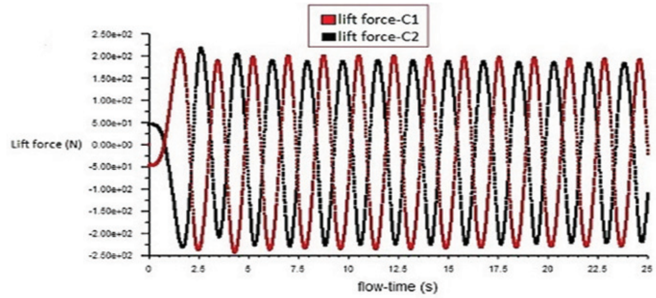


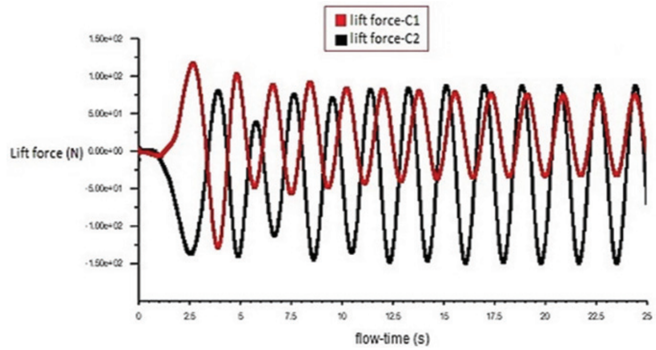
• for g/D = 6

• for g/D = 14

• for g/D = 14





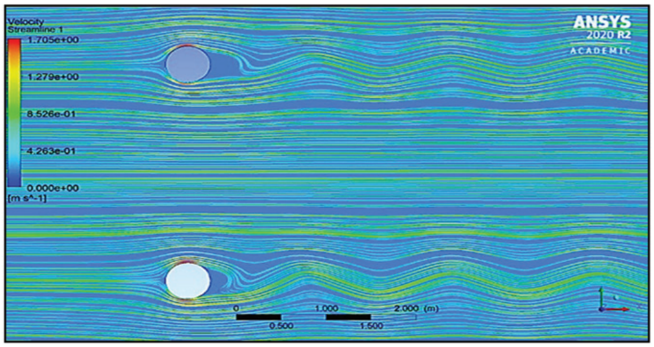


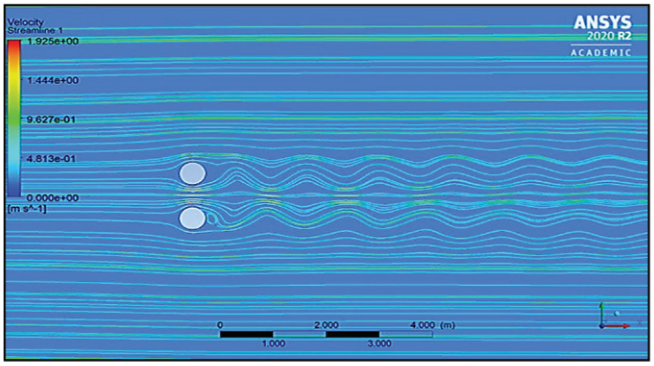
3.5 Lift Force Analysis

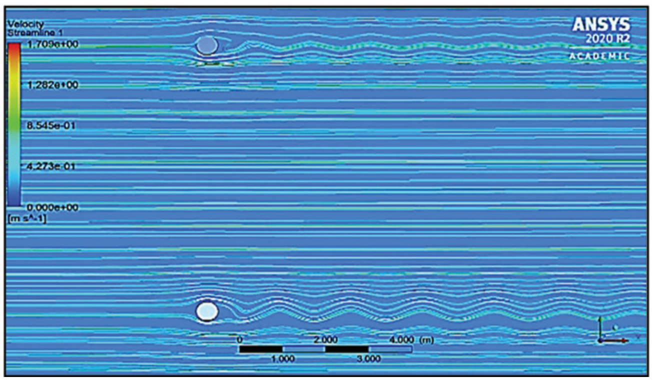
Lift force oscillates due to the asymmetric pressure distribution caused by periodic vortex shedding. The transient initial solution reaches to a steady state solution after some time. At g/D=10, the decaying lift force curve for cylinder-C2 highlights the role of viscosity of the fluid medium which diminishes the unsteady behaviour and turning it into a steady one. For g/D=2, the lift forces for both the

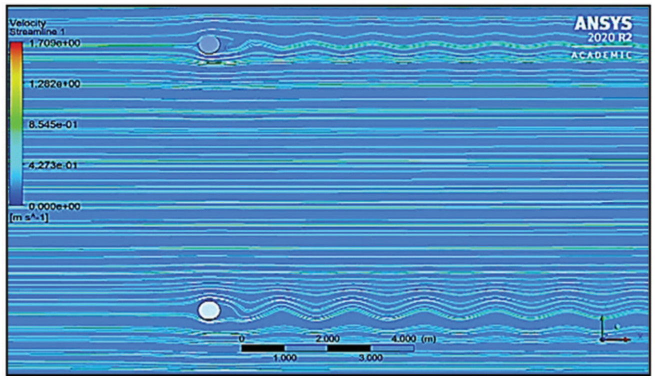
Table 1: Strouhal number analysis

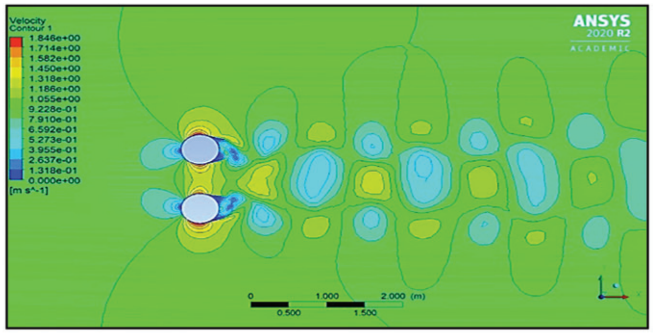
Gap ratio (g/D)	Vortex shedding frequency (Hz)		Strouhal number		Time lag between two cylinders responses (sec)
	Cylinder-C1	Cylinder-C2	Cylinder-C1	Cylinder-C2	
2	0.588	0.588	0.322	0.322	0.1
4	0.476	0.500	0.261	0.274	0.6
6	0.555	0.555	0.304	0.304	0.3
10	0.425	0.571	0.233	0.313	0.3
14	0.476	0.526	0.261	0.288	0.2

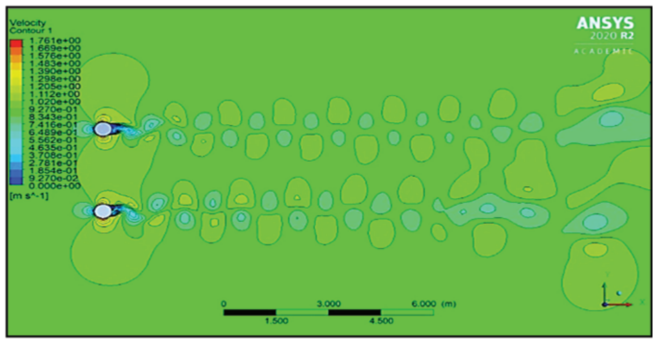












cylinders have same frequency. For g/D=6, the fluctuation of lift force for cylinder-C1 is lower than the fluctuation of cylinder-C2 that implies small size vortices are formed behind the cylinder-C1. For g/D=10, the fluctuation of lift force for cylinder-C1 is higher than the fluctuation of cylinder-C2. At g/D=6, the magnitude of lift force for both the cylinders are maximum. At g/D=14, the fluctuation of lift force for cylinder-C1 is much smaller than for cylinder-C2.

- for g/D = 2

3.6 Steam line Contour

The streamlines are in wavy nature due to vortex shedding behind the two cylinders. The streamline velocity between two cylinders at g/D=2 is maximum. The nature of streamlines between two cylinders becomes steady as gap ratio increases. The streamline velocity between two cylinders at g/D=14 is almost free stream velocity.

- for g/D = 2
- for g/D = 6
- for g/D = 6
- for g/D = 14

3.7 Vorticity Contour

3.8 Strouhal number for both cylinders at different gap (g/D)

Strouhal number is a dimensionless flow parameter which is given by St= f_v D/U. Where, f_v is the vortex shedding frequency, which is calculated from the oscillation frequency of lift force. D is the cylinder diameter and U is the free stream velocity. Vortex shedding frequency (f_v) = 1/T, where T is the time-period for lift oscillation.

- for g/D = 14
- for g/D = 6
- for g/D = 2

4.0 Conclusions

In the present study, we have numerically investigated the effect of gap ratio on flow-induced behaviour of two circular cylinders in side-by-side arrangement at high Reynolds numbers, to predict the influence of the spacing distance between two cylinders on the flow induced behaviour. From this CFD analysis the following conclusions can be made that the gap ratio has a dominant effect on the flow pattern as well as drag and lift forces. For all gap ratios the drag forces are positive i.e., acting on positive x-direction. The drag force oscillations for both the cylinders are much lower than the lift force oscillations. As gap ratio increases the streamlines between two cylinders becomes steady, that indicates flow interaction reduces as gap ratio increases. The lift forces for both the cylinders gradually increase up to g/D=6, then the lift forces gradually decrease.

5.0 References

[1] Hongjun Zhu, Xiaonian Tan, Yun Gao, Tongming Zhou, Wenli Liu, (2020): Two-degree-of-freedom flow-induced vibration of two rigidly coupled tandem cylinders of unequal diameters.

[2] Adnan Munir, Ming Zhao, Helen Wu, Lin Lu, (2019): Effects of gap ratio on flow-induced vibration of two rigidly coupled side-by-side cylinders.

[3] Enhao Wang, Wanhai Xu, Yang Yu, Lidan Zhou, Atilla Incecik, (2019): Flow-induced vibrations of three and four long flexible cylinders in tandem arrangement: An experimental study.

[4] Hamid Matin Nikoo, Kaiming Bi, Hong Hao, (2020): Textured pipe-in-pipe system: A compound passive technique for vortex induced vibration control.

[5] Sangmo Kang, (2003): Characteristics of flow over two circuler cylinders in a side-by-side arrangement at low Reynolds numbers.

[6] Javad Farrokhi Derakhshandeh, Miziar Arjomandi, (2012): Numerical simulation of vortex-induced vibration of elastic cylinder.

[7] P. Goutam and D Siva Krishna Reddy, (2020): Numerical investigation of flow over four cylinders in square arrangement for different spacing ratios.

[8] Dehkordi Behzad Ghadiri, Moghaddam Hesam Sarvghad, JAFARI Hamed Houri, (2010): Numerical simulation of flow over two circuler cylinders in tandem arrangement.

[9] Jai-song Wang, Dixia Fan, Ke Lin, (2020): A review on flow induced vibration of offshore circular cylinder.

[10] Keum-Shik Hong, Umer Hameed Shah, (2018): Vortex-induced vibrations and control of marine risers: A review.