INFLUENCE OF VERTICAL PLATES ON FORCE COEFFICIENTS OF SQUARE CYLINDER BY NUMERICAL SIMULATION

Md. N Haque*[1]

[1] *Assistant Professor, Department of Civil Engineering, East West University, Bangladesh, e-mail: naimul@ewubd.edu*

***Corresponding Author**

ABSTRACT

The aim of this study is to investigate the influence of attaching vertical plates on force coefficients of square cylinder. Four vertical plates of equal height are attached at the middle position on four sides of square cylinder to control the flow and investigate its effect on force coefficients. The normalized height w.r.t. to the depth of the square cylinder is varied from 0.01 to 0.14. Direct Numerical Simulation (DNS) is adopted to calculate the responses of the cylinder. Second order accurate numerical schemes are utimized to dicretize the flow both in space and time. Reynolds number is kept constant at 100. Aerodynamic force coefficients such as drag, lift and moment are predicted and flow filed are analyzed. The calculated force coefficients are compared in between various cases. It is found that due to attachment of vertical plate the force coefficients of the square cylinder altered noticeably and showed specific trend in the result due to variation of plate height. For a specific value of a normalized plate height, the drag coefficient showed a minimum value which is also lower than the square cylinder without any attachment. Similar to the force coefficients, the strouhal number of the square cylinders also showed very high sensitivity to the height of vertical plate.

Keywords: *Drag coefficient, Square cylinder, Flow field, Vertical plate, Flow control.*

1. INTRODUCTION

Flow around bluff bodies has drawn the attention of engineers of various fields such as civil, mechanical, chemical, naval and aerospace engineering etc. due to its huge practical application. Reduction of force coefficients, especially the drag force coefficient by understanding the flow mechanism is one of the main interests to optimize the design. Past researchers explored various active and passive control systems to reduce the force coefficients and improve the flow field. Among the passive control systems, the effectiveness for wake control of circular cylinder by attaching a horizontal plate (splitter plate) at the downstream side of the circular cylinder was shown by Roshko (1954). The mechanism of splitter plate for square cylinder was different as the leading edge separated flow goes at the downstream with large side bubbles (Doolan 2009). Over the time, a number of other effective passive control systems have also been invented for square cylinder and their effectiveness have been investigated at various Reynolds number.

Shiraishi et al. (1986) experimentally investigated the influence of corner cut on square cylinder and found that corner modification significantly reduced the drag and fluctuating lift coefficient. The influence of corner cut, recession and roundness was experimentally investigated by Kawai (1998). Among the three methods, the corner roundness was the most effective to suppress the aeroelastic instability. Tamura and Miyagi (1999) found that the square cylinder with corner cut and roundness have lower drag both in smooth and turbulent flows. Suppression of fluid force on square cylinder by putting a small bluff body was achieved by number researchers. Lesage and Gartshore (1987) placed a small rod, Igarashi and Ito (1993) placed a square prism, Sakamoto et al. (1997) placed a flat plate the upstream of the square prism and successfully decreased the fluid forces on the square cylinder. A variant of this method, by placing a control cylinder at the shear layer for forced reattachment of

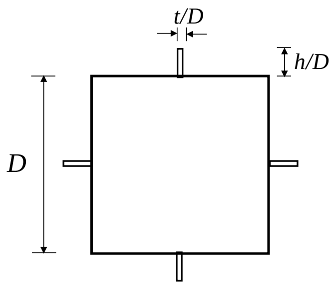


Figure 1: Side view of the square cylinder with vertical plate

flow to reduce the drag coefficient was achieved by Igarashi and Tsutsui (1989) and Shakamoto et al. (1991). A reduction of both in drag a lift force coefficient was obtained by Dey and Das (2015) by attaching a triangular thorn at the upstream face of the square prism. The reduction in drag was obtained mainly due to the weakening pressure and friction drag. By placing multiple small square prisms around the square cylinder, the reduction of drag force was obtained by Islam et al. (2017 and 2018).

In relation to this, in the present study vertical square plates are attached at the side faces of a square cylinder to improve the aerodynamic responses. Fig. 1 shows the side view of the square cylinder. As the plate is attached at the all four side faces of the cylinder, the dependency of performance on the direction of the flow has reduced. The normalized height (*h/D*) of the cylinder was varied from 0 to 0.14. The thickness of the plate is constant at 0.005 for all the cases. The aerodynamic responses are predicted numerically at Reynolds number 100. The mean and RMS values of the force coefficients are calculated to observe the influence of attaching the vertical plate at the side face of the square cylinder. Along with the force coefficients, the time dependent vorticity fields are also explored.

2. METHODOLOGY

The flow around the cylinders was assumed as two dimensional and simulated by solving the unsteady incompressible Navier-Stokes Equations as presented below.

$$\nabla \cdot u = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + (u \cdot \nabla)u = -\nabla p + \frac{1}{R_e}\nabla^2 u \tag{2}$$

where u is the velocity vectors and p denote the pressure. These dimensionless governing equations are integrated in time using second order accurate backward differentiation method. The convective and diffusive terms are discretized with a second-order accurate central differencing scheme. In space, the governing equations are discretized by the finite volume approach in an unstructured grid system. The pressure-velocity coupled discretized equations are solved by pimpleFoam algorithm which combines the conventional PISO (Pressure Implicit with Splitting of Operator) and SIMPLE (Semi-Implicit Method for Pressure Linked Equations) methods. The domain was sufficiently large. In the horizontal direction, the domain was stretched up to 61*D* (where, *D* is the height of the cylinder) and 25D was stretched in the vertical direction. Non-slip boundary condition was applied on the cylinders surface. The domain was divided into two parts. In the inner domain, finer mesh and in the outer domain, coarser mesh was utilized. A grid size of 0.05D and 0.02D were utilized around the square cylinder and vertical plate, respectively. The grid system, boundary condition and domain dimensions are shown in Fig. 2. A validation study was carried out to examine the reliability of the numerical setup for a square cylinder at Re 100. Force coefficients are compared with past numerical results and very good agreement was found which is not presented here.

3. RESULTS AND DISCUSSION

In two-dimensional analysis, the mean value of drag and rms value of lift force coefficients are two important parameters. All the force coefficients are calculated based on a characteristic length of (*d+2h*). The influence of vertical plate on mean drag coefficient is summarized in fig. 3. As can be seen the addition of vertical plate has great influence on the mean drag force coefficient. With the variation of plate height (*h*), the mean drag coefficient varies a lot. First the drag force decreases gradually with the increase in plate height (*h*), then increases again with the increase in plate height (*h*). For a normalized plate height of 0.09, the magnitude of drag force coefficient is significantly lower than bare square cylinder. The rms value of the lift force coefficient is summarized in fig. 4. Similar to the mean drag force coefficient, the rms of lift force coefficient also shows very high sensitivity to the addition of plate to square cylinder. Unlike mean drag force coefficient, the minimum rms value of lift force coefficient was found for a normalized plate height (*h*) of 0.05. The behaviour of shedding frequency is summarized in fig. 5. As can be seen there are two distinct zone in the shedding frequency. For normalized plate height (*h/d*) from 0.02 to 0.07, the shedding frequency decreases gradually and then increases again with decreasing trend. The instantaneous vorticity plot for normalized plate height (*h/d*) of 0.0, 0.04, 0.09 and 0.14 are summarized in fig. 6. Clear after-body vortex shedding can be seen for all four cases without any distinct variation. To reveal the flow mechanism, especially the reduction of drag force coefficient, further detail flow analysis is required.

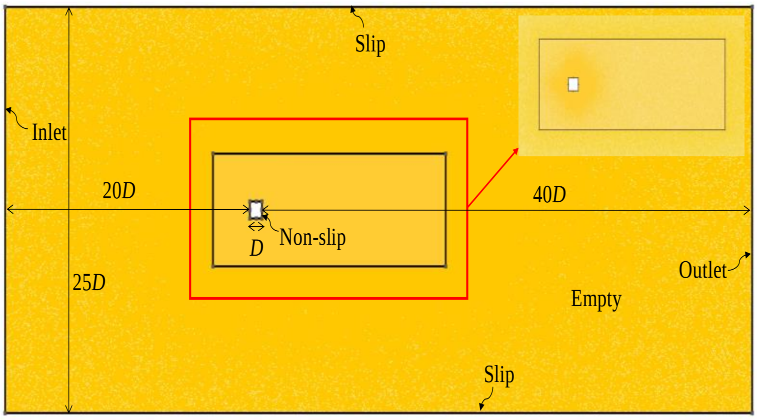


Figure 2: Flow domain and grid system utilized in the simulation

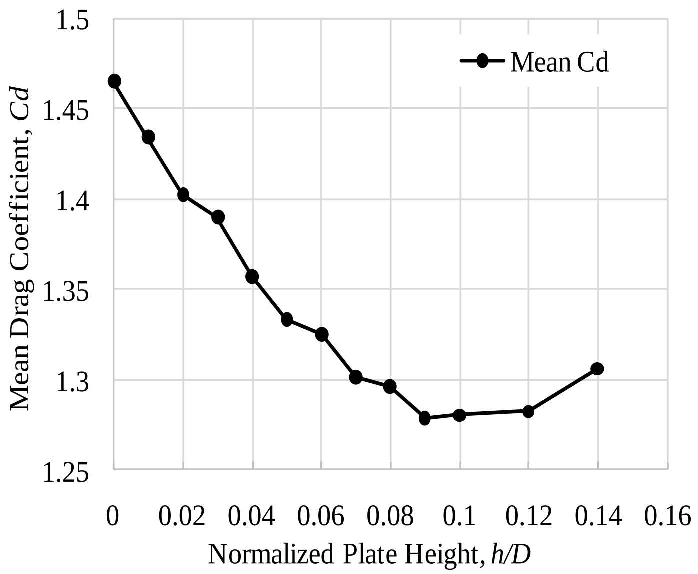


Figure 3: Influence of vertical plate on Mean Drag Force Coefficient

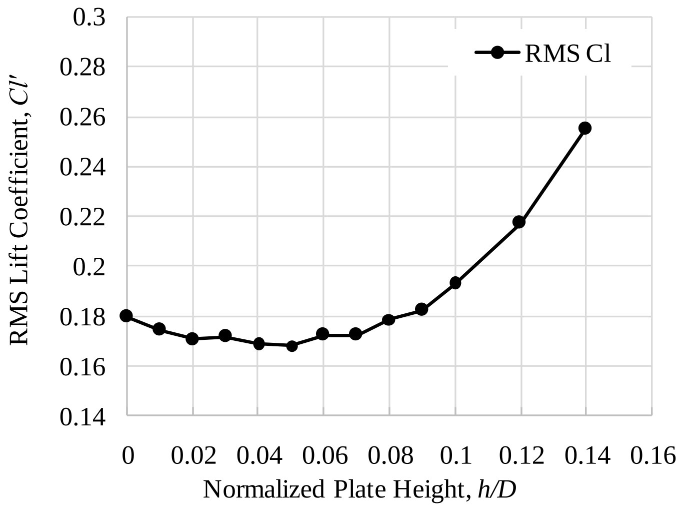


Figure 4: Influence of vertical plate on RMS of lift force coefficients

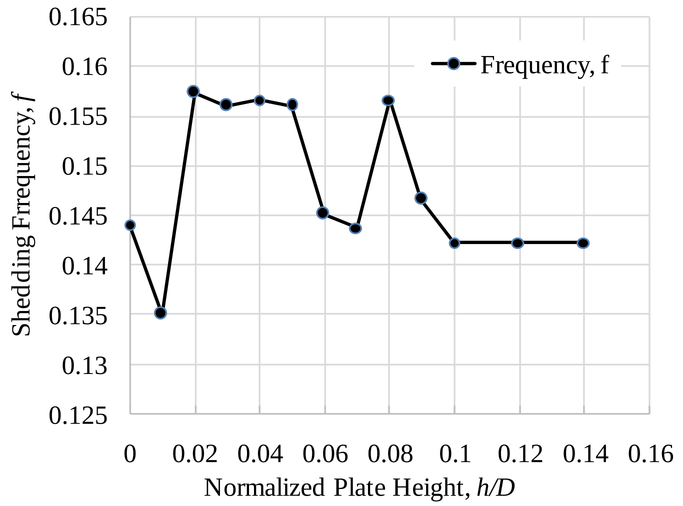
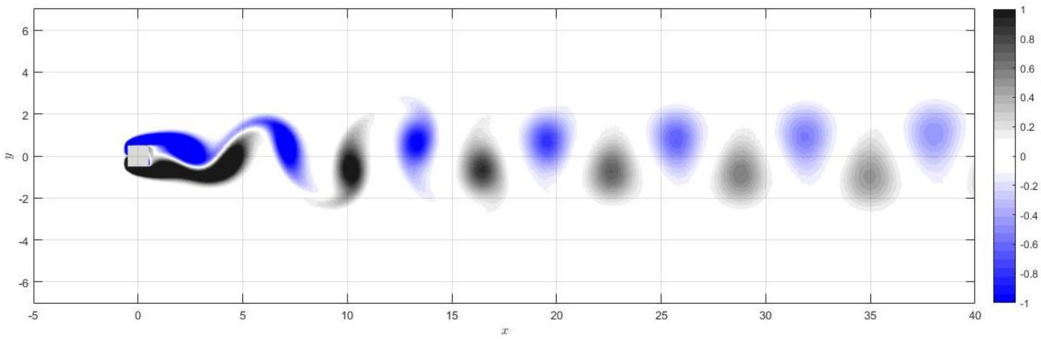
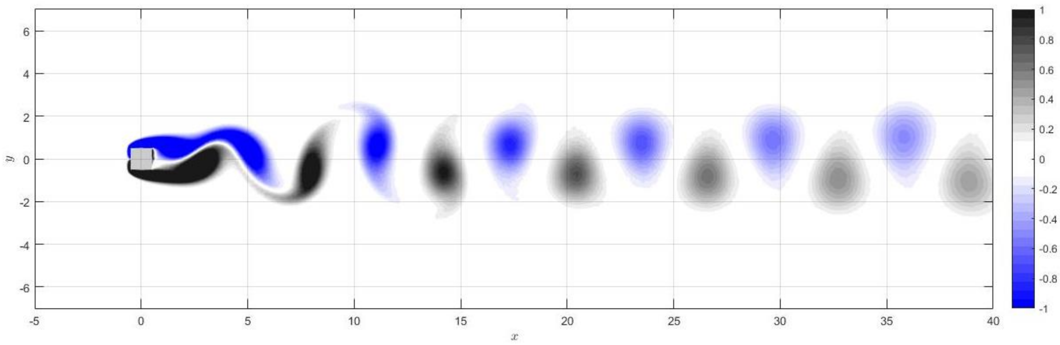


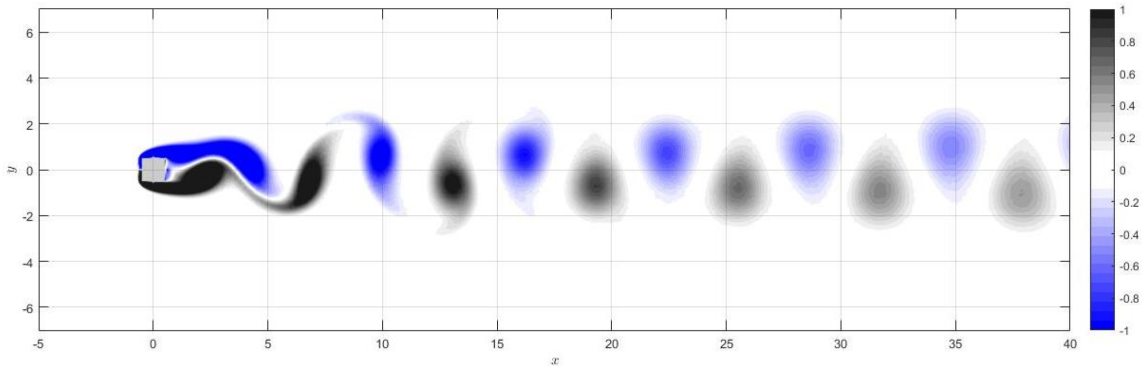
Figure 5: Influence of vertical plate on shedding frequency of square cylinder



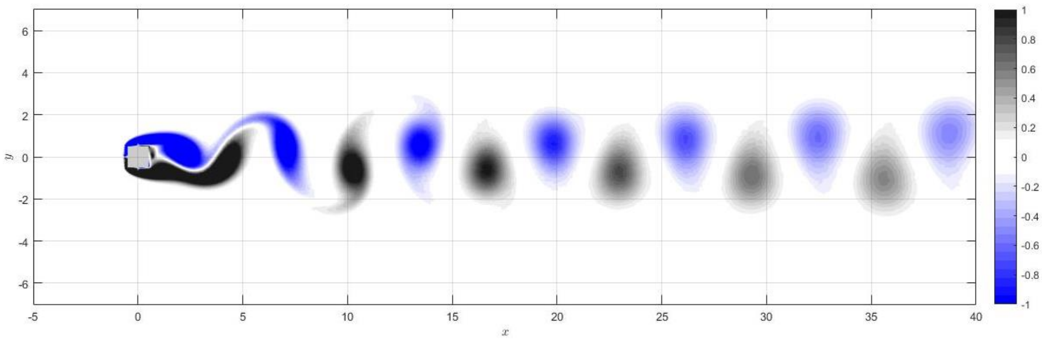
(a) Square cylinder with *h/D*=0.0



(b) Square cylinder with *h/D*=0.04



(c) Square cylinder with *h/D*=0.08



(d) Square cylinder with *h/D*=0.14

Figure 6: Instantaneous Z-vorticity for square cylinder with vertical plate of various height

4. CONCLUSIONS

The paper presented important force statistics of square cylinder with vertical plates. Vertical plates of various heights were attached at the four sides of the square cylinder. It was found that the addition of vertical plate significantly affected the mean drag and RMS of lift force coefficients. For a normalized plate height (*h/D*) of 0.09, the drag coefficient reduced and reached to a minimum value. On the other hand, the RMS of lift force coefficient became smallest for a normalized plate height (*h/D*) of 0.05. The shedding frequency also showed two distinct zones for various plate height. Important force statics and shedding frequency showed some interesting trends in results due to addition and variation of vertical plate in the square cylinder. The flow mechanism should be properly understood to grasp the reason behind the trends in the results. In future, the pressure filed, after body wake, the boundary layer flow and the velocity field will be explored in detail for understanding the flow mechanism.

REFERENCES

Roshko, A. (1954) On the drag and shedding frequency of two-dimensional bluff bodies. NACA Technical Note, No. 3169.

Doolan, C.J. (2009) Flat-plate interaction with the near wake of a square cylinder. AIAA J., 47, 475.

Shiraishi, M., Matsumoto, M., Shirato, H., Ishizaki, H. Nagata, H., Matsui, T. (1986) "On aerodynamic stability effects for bluff rectangular cylinders by their corners cut." Proc. 9th National Symp. on Wind Engineering, 193-198 (in Japanese).

Kawai, H. (1998) Effect of corner medications on aeroelastic instabilities of tall buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, 74-76, 719-729.

Tamura, T. and Miyagi, T. (1999) The effect of turbulence on aerodynamic forces on a square cylinder with various corner shapes. *Journal of Wind Engineering and Industrial Aerodynamics,* 83, 135.

Lesage, F., Gartshore, I.S. (1987) A method of reducing drag and fluctuating side force on bluff bodies. *Journal of Wind Engineering and Industrial Aerodynamics*, 25, 229–245.

Igarashi, T. & Ito, S., (1993) Drag reduction of a square prism, 1st Report, Flow control around a square prism using a small vortex shedder. *Transactions of JSME*, 59 (568), 3701-3707.

Sakamoto, H., Tan, K., Takeuchi, N., Haniu, H. (1997) Suppression of fluid forces acting on a square prism by passive control. *ASME Journal of Fluids Engineering*, 119, 506–511.

Sakamoto, H., Tan, K., Haniu, H. (1991) An optimum suppression of fluid forces by controlling a shear layer separated from a square prism. *ASME Journal of Fluids Engineering*, 113 (2), 183-189.

Igarashi, T., Tsutsui, T. (1989) Flow control around a circular cylinder by a new method, 1st Report, Forced reattachment of the separated shear layer. *Transactions of JSME*, 55 (511), 701–706.

Dey, P. and Das, A.K. (2015) Numerical analysis of drag and lift reduction of square cylinder, *Engineering Science and Technology, an International Journal*, 18(4), 758-768.

Islam, S., Manzoor, R., Islam, Z., Kalsoom, S. & Ying, Z.C. (2017) A computational study of drag reduction and vortex shedding suppression of flow past a square cylinder in presence of small control cylinders. *AIP ADVANCES*, 7, 045119.

Islam, S. Manzoor, R. Khan, U., Nazeer, G. & Hassan, S. (2018) Drag Reduction on a Square Cylinder using Multiple Detached Control Cylinders. *KSCE Journal of Civil Engineering*, 22(5):2023-2034.