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Numerical analysis of two square cylinders of different sizes with and without corner modification

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ABSTRACT

Flow past square cylinders has attracted a great deal of attention because of its practical significance in engineering e.g., High rise buildings, monuments and towers. Similarly, bridge pillars, and legs of offshore platforms are continuously subjected to the load produced by maritime or fluvial streams. The presence of separated flows, reattachment, formation the vortices, un steadiness of flow, mass and momentum transfer across shear layer makes the flow field quite complex. Many research work was carried out for a single square cylinder and flow past two square cylinders, but with corner medications in square cylinder of different size arranged in tandem was not taken up. This has motivated to take up the flow past two different sized square cylinders i.e.,smaller in upstream and larger in downstream which is numerically simulated by using Fluent software. Reynolds number of 100 and 200 is considered for the investigation. The flow is assumed to be two dimensional, unsteady and incompressible. The computational methodology is carried out once the problem is defined, the first step in solving the problem is to construct a geometry then proper assignment of boundaries are set. After setting the boundary types, the geometry is discretized into small control volumes. Once the surface mesh is completed by using Gambit software, the mesh along with boundary conditions are exported to fluent, which is CFD solver usually run in background mode. The run would continue until the required convergence criterion is reached or till the maximum number of iterations is completed. Results indicate, in case of chamfered and rounded corners in square cylinders of different size, there is decrease in the wake width and thereby the lift and drag coefficient values. The lift coefficients in Square cylinders of different size with corner modifications decreases but Strouhal number increases when compared with a single square cylinder without corner modifications. Frequency of vortex shedding decreases with the introduction of second cylinder either in the upstream or downstream of the first cylinder. As the centre distance between two square cylinders i.e., PPR(pitch to perimeter ratio) with and without corner modifications is increased to 6,the flow velocity almost approaches to flow past a single square cylinder with and without modifications for same condition. When the size of the upstream square cylinder with and without modifications is smaller than that of the downstream square cylinder, the size of the eddies is always smaller in between the cylinders compared to the downstream of the second cylinder. The flow velocity in between the cylinders with and without corner modifications are less compared to the downstream of the second cylinder. Pressure on the downstream side of the cylinder is smaller than that on the upstream side of the cylinder for with and without corner modifications. Also, the front portion of the cylinder is experiencing highest pressure compared to the second cylinder for all the three cases i.e., PPR=2,4 and 6. Pressure at the upper side, bottom side and back side of square cylinder with and without corner modifications is of negative pressure, it is because of vortices generated at that surfaces. The downstream cylinder is found to experience higher lift compared to the upstream cylinder. The results are presented in the form of while the downstream cylinder is found to experience higher drag compared to the streamlines, flow velocity, pressure distribution, drag coefficient, lift coefficient and strouhal number.

INTRODUCTION

Over the past several years, flow past around two square cylinders with and without corner modification of different size with different vertical spacing's relative to each other has received a remarkable attention due to its wide and practical applications in real world engineering concerns. These concerns can be seen in various fields such as tall buildings, monuments and towers. Similarly, piers, bridge pillars, and legs of offshore platforms are continuously subjected to the load produced by maritime or fluvial streams. The fluid flow around a single cylinder quite different due to the interaction of the flow fields caused by neighboring cylinders. This interaction is owing to the buoyant plume that is generated by each cylinder and which may impinge on other cylinders. In real world, the devices used in various appliances are often operating under dynamic condition caused by motion, oscillation, and so on. Therefore a comprehensive knowledge in the vicinity of fluid flow induced by vibrating mechanisms seems to be crucial due to high speed development of technologies such as microprocessors and micro fins. A lot of research has been carried out on flow past square cylinder and other geometric structures but in case of the presence of the another square cylinder with varying in size and distance with or without sharp corners, the flow over the square cylinder becomes more complex due to proximity interference, also the wake flow field is strongly influenced due to wake interference. These interference effects will depend on various factors like relative perimeter of the square cylinders, spacing, Reynolds number; the approach angle of flow etc. A typical flow field observed indicates the complexity and differences existing between single and multiple square cylinders. The interferences effects could be very predominant. In all such cases the resulting forces on the square cylinders may be amplified several times depending on the relative sizes and positions, the square cylinders could also be subjected to flow induced vibrations due to the resulting periodic forces. Square cylinders cause different separation points and downstream effects of the flow. The separation points for square cylinders are also dependent on the angle that the square is to the free stream flow.Hiroshi Hasebe et al. [2009] brought out the conclusions for flow field between two square cylinders in tandem arrangement that surface pressure distributions vary considerably between the spacing and vortex shedding from the upstream cylinder has a great influence on the property of the turbulent flow structure between two square cylinders. The effects of the Reynolds number, spacing ratio and rotation angle of the downstream cylinder on flow characteristic modes, drag coefficients and vortex shedding properties were studied by Yen et al.[2008] for the case of two identical square cylinders were installed in tandem in a vertical water tank. Results showed the Strouhal number decreases as the Reynolds number increases in the viscosity- dominant flow field. But in the inertia dominant flow field, the Strouhal number increases with the Reynolds numbers and approaches a constant for high Reynolds numbers. Lakshmana Gowda et al. [2009] studied the near wake flow field features of transversely oscillating square section cylinders with different corner radii. Results indicate that increasing the corner radius suppresses the possible instabilities of the cylinder. Bandyopadhyay [2004] has simulated flow past a square cylinder placed inside a channel with two different blockage ratios and for different Reynolds numbers. The average drag coefficient found to increase with an increase in blockage ratio for a given Reynolds number. Dalton and Zheng [2003] presented numerical results for a uniform approach flow past square and diamond cylinders, with and without corner modifications at Re=250 and 1,000. They noted that rounding corners of the bluff bodies produced a noticeable decrease in the calculated drag and lift coefficients. The vortex shedding frequency is also found to increase with increase in blockage ratio. Tamura and Miyagi [1999] also Tamura et al.[1998] investigated numerically and experimentally the aerodynamic forces on square cylinders and observed a decrease in the wake width as well as Cd with the corner chamfered or rounded. Similar studies emphasizing corner effects were also conducted by Delany and Sorensen [1953], Naudascher et.al. [1981], Kwok et.al.[1988] and Okamoto and Uemura [1991]. The numerical model used is based on a 2D Navier-Stokes incompressible flow momentum and energy equations solver on an unstructured grid. Discretization of the governing equations that include the continuity and momentum, equations is achieved through a finite volume scheme. The main objective of the present paper is to investigate on the effect of corner radii on the hydrodynamic characteristics, such as drag/lift forces and shedding frequency of bluff bodies, how the corner variation may alter the near wake, however, yet to be sufficiently documented, particularly in the base region. Therefore, in the present work is to characterize quantitatively the corner effects on the near-wake flow structure.

GEOMETRY AND BOUNDARY CONDITIONS.

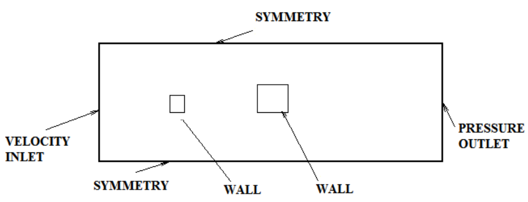
The problem considered is the flow past two square cylinders of different size i.e., smaller cylinder in upstream and bigger cylinder in downstream with and without corner modification of PPR 2, 4 and 6 for a Reynolds number 100 and 200 for laminar unsteady liquid. Fluent solver of SIMPLE algorithm is used to carry out simulation mathematically. It is important to locate the inflow a top and bottom boundaries at sufficient distance from the main square cylinder such that the boundary conditions applied to these boundaries should not have any undesirable effects into the main region of interest i.e., around the cylinder. After going through the literatures of experimental and numerical simulations of flow past cylinders in detail, it is concluded to locate the inflow, top and bottom boundaries 6.5square cylinders with respect to the center of the square cylinder. Similarly, in order to minimize the effects of the outflow boundary condition on the flow in the vicinity of the cylinder, the computational domain has been extended to 30 square cylinders in the downstream. The Fig.1 shows geometry and boundary condition in the present investigation for all the cases.

Inlet-Velocity (U=1.0 cm/s, V=0.0 cm/s)

Cylinder surface -Wall (U=0.0 cm/s, V=0.0 cm/s)

Top and Bottom boundaries-symmetry(U=1.0 cm/s,V=0.0 cm/s)

Outlet boundary-continuative boundary condition can be expressed as P=0N/cm^2.



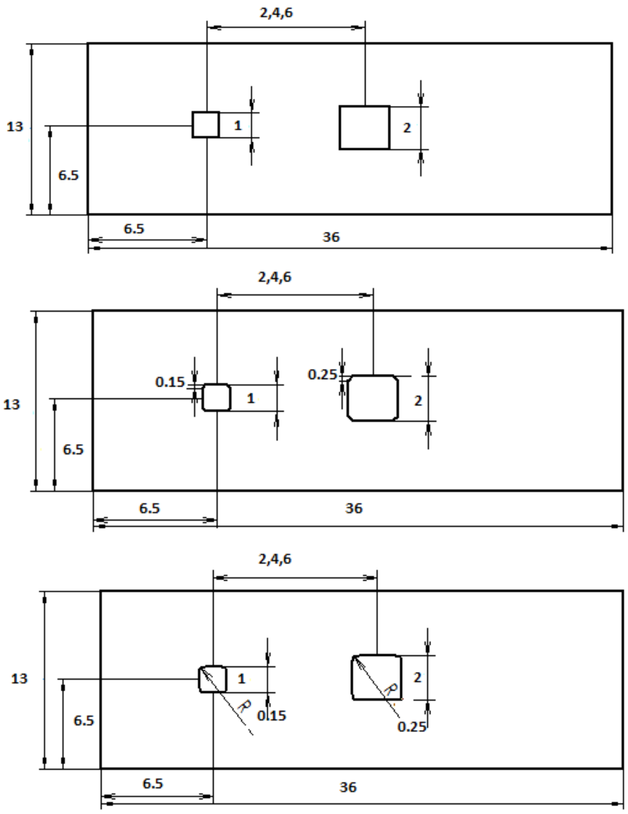


Fig.1 Geometry and boundary condition for all the cases

RESULTS AND DISCUSSIONS

Mesh Sensitivity Analysis

The commercial software Gambit is used to create and mesh the computational models. Model consists of structured quadrilateral mesh throughout, but the areas around the cylinders are densely meshed for capturing more detail flow information, and a use of coarser mesh in other regions for reducing computational effort. Meshing is an integral part of the computer-aided engineering simulation process. The mesh influences the accuracy, convergence and speed of the solution. In numerical computations, it becomes essential to perform a grid independence study. In the present work, the grid independence is carried out using three different grid sizes for same computational domain size. Grid sizes of 93830, 120350 and143480 are considered for the investigation. Grid independence test has been conducted for the velocity 1cm/s. The result in the form of Strouhal number is presented in Table1.respectively. It can be seen readily that the results are independent of Mesh size.

Table 1 Strouhal number obtained from time histories of lift coefficient

Grid size	Re=100	Re=200
93830	0.15	0.16
120350	0.15	0.16
143480	0.15	0.16

Table 2 Comparison of Strouhal number with Experimental and Numerical investigation of other investigators.

Reynolds number	Contributors	Experimental/ Numerical	Year	St
Re=200	Ahmad Sohankar, C. Norberg and L. Davidson	Numerical	1999	0.160
Re=200	Sohankar ,Norberg and Davidson	Numerical	1996	0.168
Re=200	Ahmad Sohankar, Davidson and Christoffer Norberg	Numerical	1995	0.165
Re=100 Re=200	Kavya H.P, Banjara Kotresha, Kishan Naik	Numerical	2014	0.147 0.119
Re=100	Okajima	Experimental	1982	0.154
Re=100	Kelkar and Patankar	Experimental / Numerical	1992	0.13
Re=100	Sohankar et al.	Numerical	1998	0.146
Re=100	Norberg	Experimental	1993	0.143
Re=100 Re=200	Davis and Moore	Experimental / Numerical	1982	0.154 0.123
Re=200	Davis et al.	Experimental	1984	0.184
Re=100	A. Lankadasu, S. Vengadesan	Numerical	2008	0.143
Re=200	A. K. Saha, K. Muralidhar, and G. Biswas	Numerical	2000	0.163
Re=200	Franke et al.	Experimental / Numerical	1990	0.157
Re=100 Re=200	Present			0.15 0.16

Strouhal number obtained from the present investigation has been compared with results of other investigators in Table 2.A good agreement has been seen with other investigators.

Streamlines

Fig. 2, 3 and 4 shows streamlines of flow past two square cylinders with and without corner modification of different size when PPR is 2, and 6 for Reynolds number 100. The flow is uniform and symmetric in the upstream as it passes square cylinders of different size with and without corner modification, its flow pattern, Recirculation, Reattachment and flow separation differs and alternate eddies are formed in between the cylinders and in the downstream of the second cylinder for all the cases. When the perimeter of the upstream cylinder is smaller than the downstream cylinder, the size of the eddies is always smaller in between the cylinders compared to the downstream of the second cylinder with and without corner modification when PPR is 2.This is due to second cylinder is suppressing the eddy formation, also the formation of eddies in between the cylinders is less when compared to the downstream of the second cylinder because the distance between the two cylinders is very small. But in case of PPR 6 the size of the eddy in between square, chamfered and rounded cylinders it is elongated. As the flow past square cylinder side face which is larger in size when compared with corner modification, width of the wake behind the square cylinders becomes small. When Reynolds number increased from 100 to 200, a similar flow pattern has been observed except the length of its vortex formation with increasing Reynolds number.

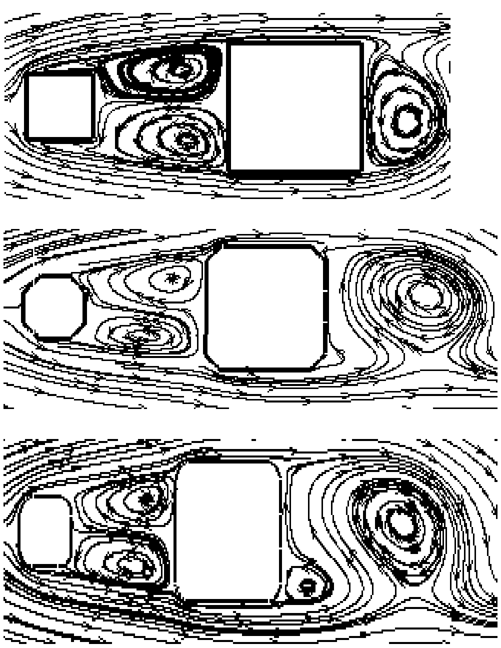


Fig. 2 Streamlines of two square cylinders with and without corner modification of different size when PPR is 2 for Re=100.

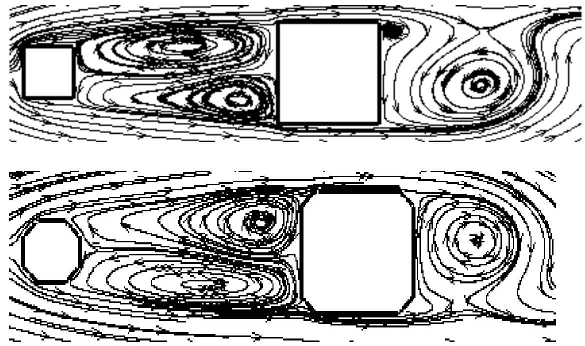


Fig. 3 Streamlines of two square cylinders and chamfered at the corners of different size when PPR is 4 for Re=100.

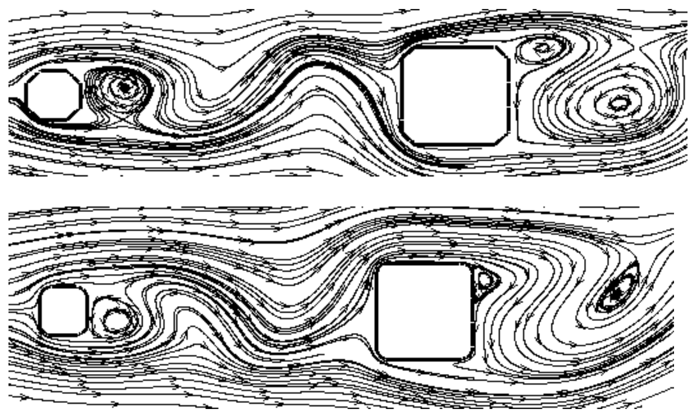


Fig.4 Streamlines of chamfered and rounded at the corner of two square cylinders with different size when PPR is 6 for Re=100.

Pressure distributions

Fig. 5,6and7 shows non dimensional pressure distribution plot for flow past two square cylinders with and without corner modification of different size for the Re=200. In case of two cylinders, upstream cylinder experience maximum pressure than downstream cylinder. Without corner modification in square cylinders experiences highest pressure when compared with modification. Pressure on the downstream side of the cylinder is lower i.e., negative than that on the upstream side of the cylinder i.e., positive for all the three cases under investigation. It is clear that the pressure on the downstream side of the square cylinder with corner modification becomes greater than on the downstream side of the square cylinder without corner modification. Also, front portion of the cylinder is experiencing maximum pressure compared to the second cylinder for all the three cases. It is due to fluid is brought to rest and hence the front cylinder experiences the absence of the kinetic energy and the domination of pressure energy.

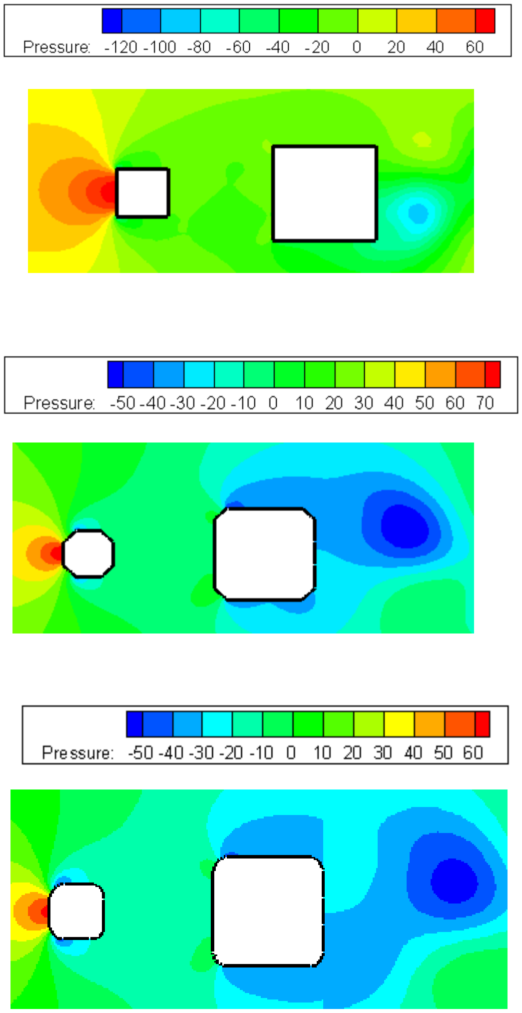
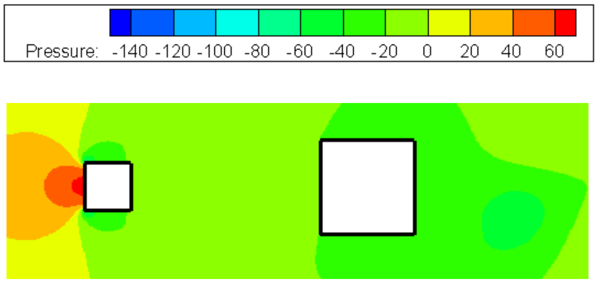


Fig.5 Pressure distribution plot for two square cylinders with and without corner modification of different size when PPR is 2 for Re=200.



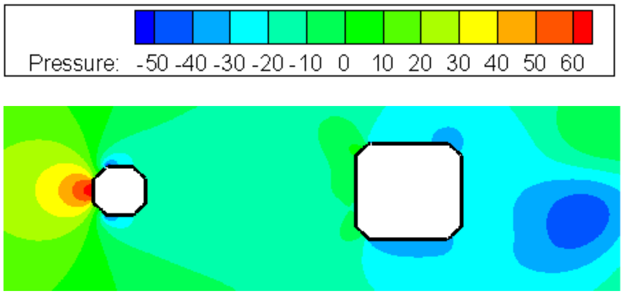


Fig.6 Pressure distribution plot for two square cylinders and with chamfered at the corners of different size when PPR is 4 for Re=200.

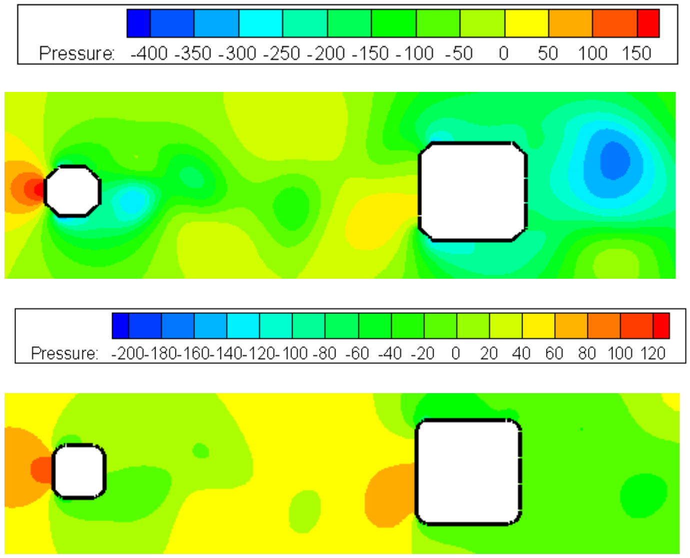


Fig.7 Pressure distribution plot for two square cylinders with chamfered and rounded at the corner of different size when PPR is 6 for Re=200.

Flow Velocity

Frequency of vortex shedding can also be predicted in the direction perpendicular to the flow of liquid, flow velocity in between the two cylinders at any point and in the downstream of the second cylinder which is measured from the inlet section and centre line of the geometry under investigation for PPR 2, 4 and 6. Flow velocity in between the square, chamfered and rounded cylinders are less compared to the downstream of the second cylinder for PPR 2 and 4.But in case of PPR 6 for all the cases flow velocity in between cylinders and in the downstream is almost same which can be observed in plots. Fig. 8-17 Shows Geometry of flow velocity and flow velocity in between and downstream of square cylinders with and without corner modification for Re=100 when PPR=2, 4 and 6.If Reynolds number is increased to 200, only the magnitude of oscillations is increased.

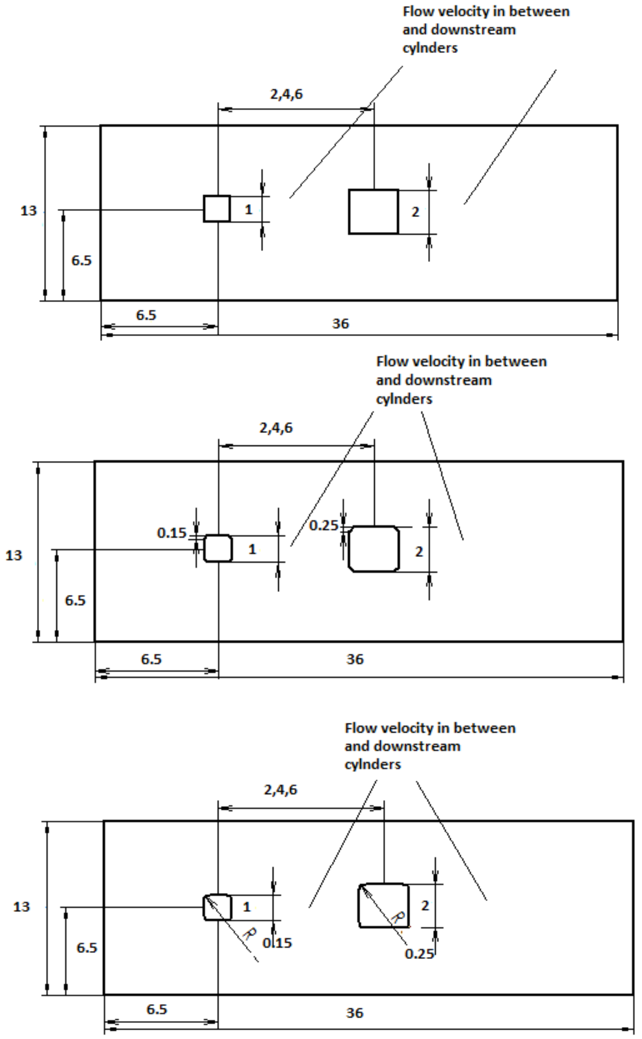
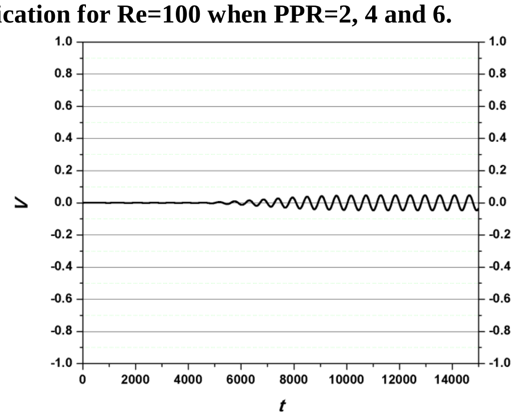


Fig.8 Shows Geometry of flow velocity in between and downstream of square cylinders with and without corner modification for Re=100 when PPR=2, 4 and 6.



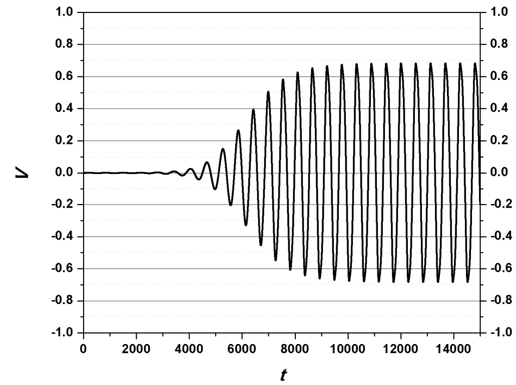


Fig. 9 Flow velocity in between and downstream of square cylinders when PPR=2 for Re=100.

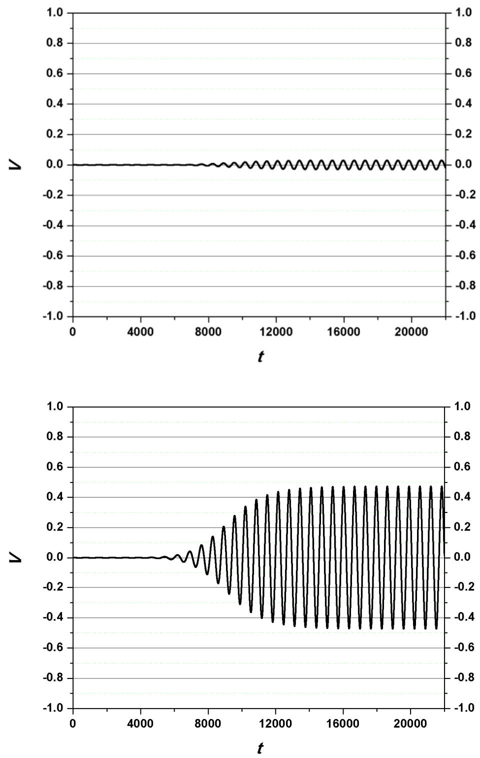


Fig.10 Flow velocity in between and downstream chamfered at the corner of square cylinders when PPR=2 of Re=100.

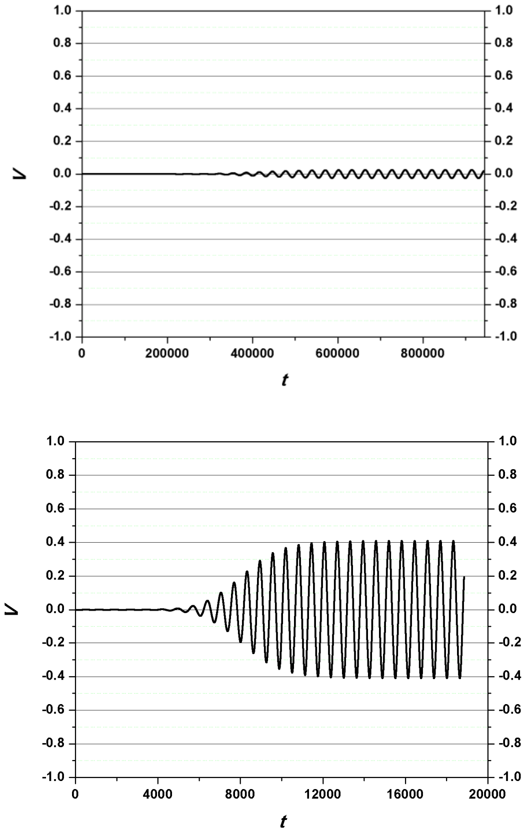
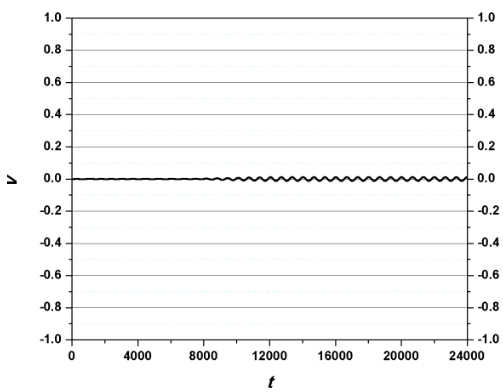


Fig. 11 Flow velocity in between and downstream rounded at the corner of square cylinders when PPR=2 for Re=100.



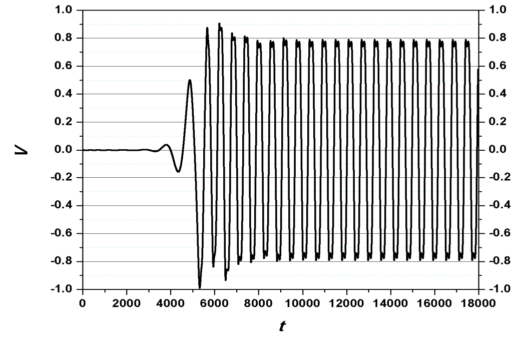


Fig. 12 Flow velocity in between and downstream of square cylinders when PPR=4 for Re=100.

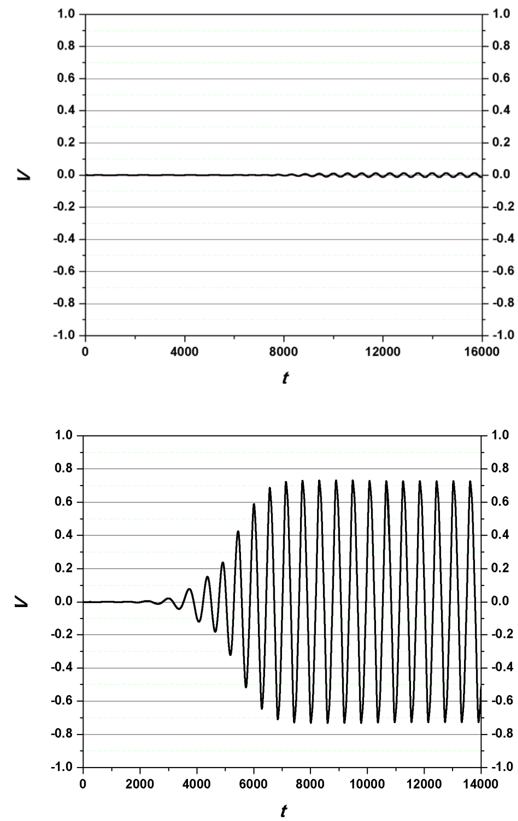


Fig.13 Flow velocity in between and downstream chamfered at the corner of square cylinders when PPR=4 for Re=100

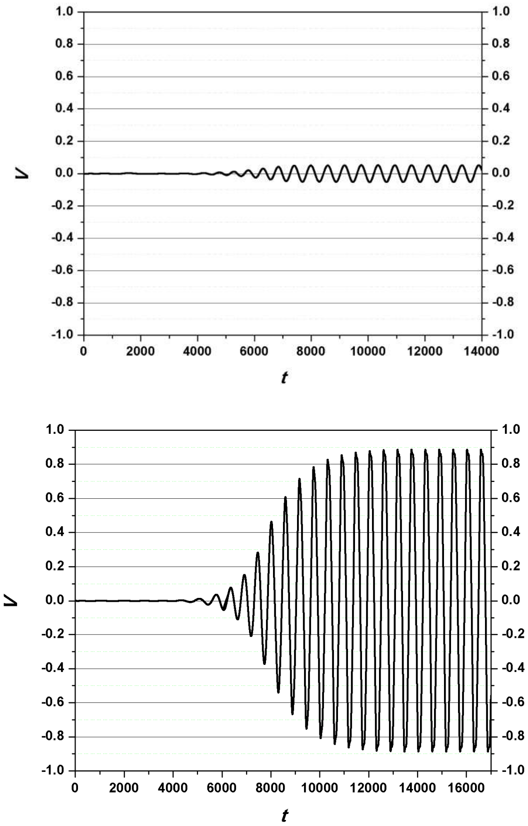
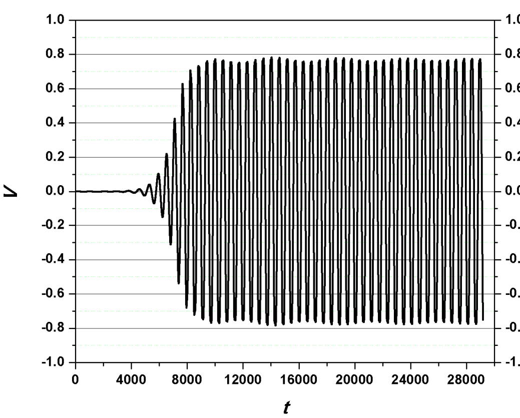


Fig. 14 Flow velocity in between and downstream rounded at the corner of square cylinders when PPR=4 for Re=100.



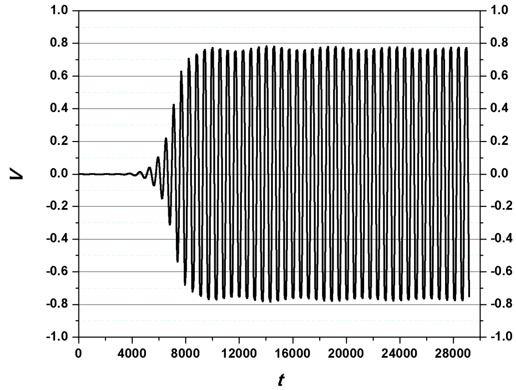


Fig. 15 Flow velocity in between and downstream square cylinders when PPR=6 for Re=100.

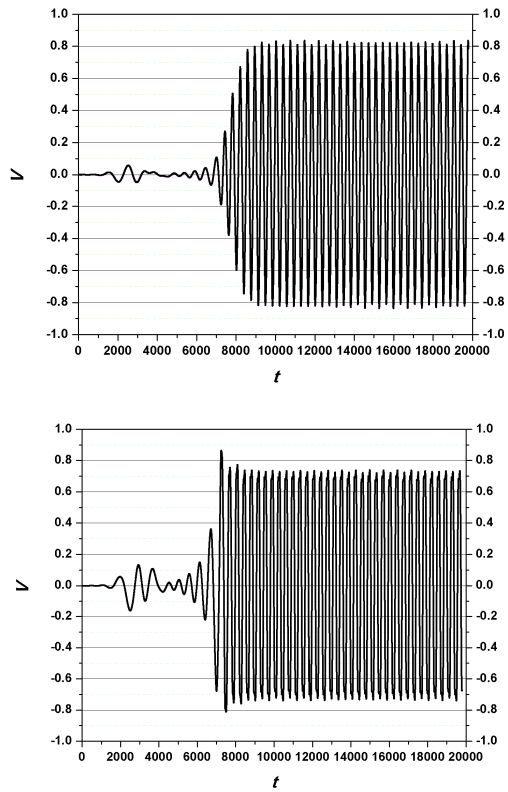


Fig.16 Flow velocity in between and downstream chamfered at the corner of square cylinders when PPR=6 for Re=100.

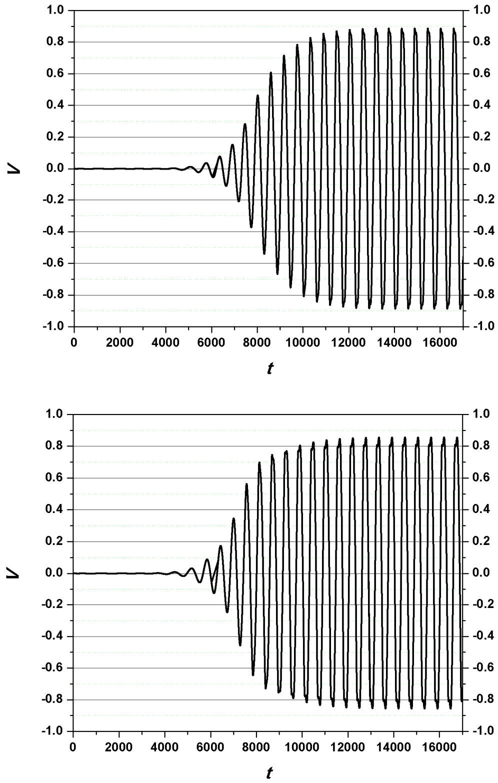


Fig. 17 Flow velocity in between and downstream rounded at the corner of square cylinders when PPR=6 for Re=100.

Lift and Drag coefficient

Fig. 18-26 shows time history of lift and drag coefficients of upstream and downstream plots for flow past square cylinders with chamfered and rounded at the corner of different size for Re=100 when PPR=2,4 and 6. Lift and drag coefficient are non dimensional which gradually increases up to certain time and becomes steady periodic. The lift coefficient is more for square cylinder than chamfered and rounded at the corner of square cylinder and drag coefficient decreases as the corners become more rounded and separation is delayed which can be observed from the plots shown below. The Strouhal number for square cylinder is less (0.15) compared to chamfered (0.17) and rounded corner cylinder (0.185).

C1
C2

C1-Upstream cylinder [Smaller cylinder]
C2-Downstream cylinder [Larger cylinder]

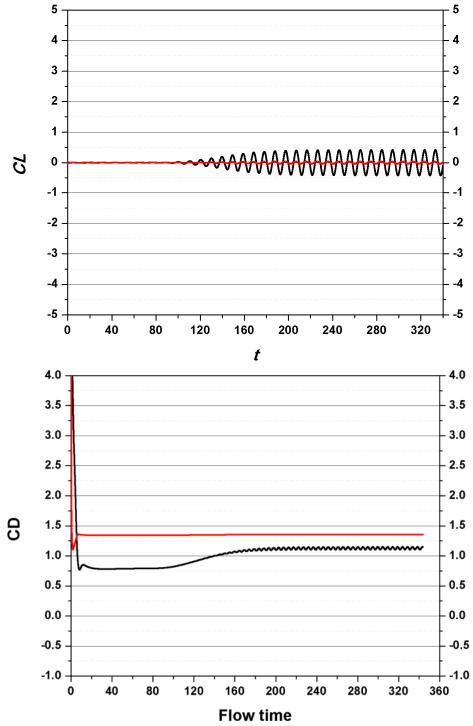


Fig.18 Time history of lift and drag coefficient of upstream and downstream square cylinder for Re=100 when PPR=2.

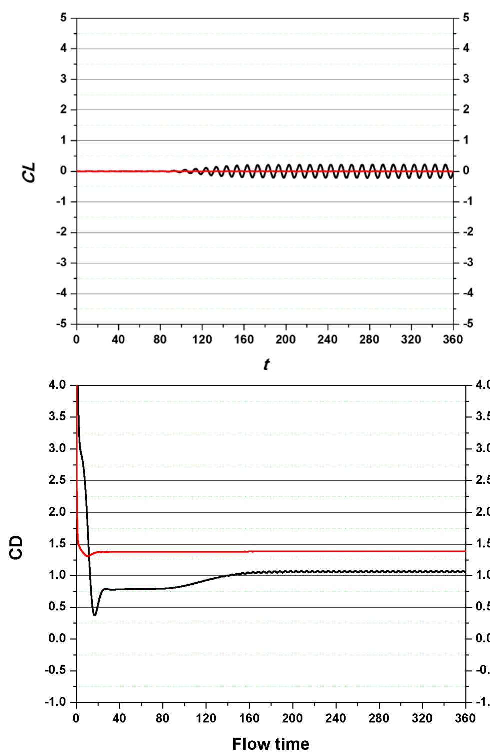


Fig.19 Time history of lift and drag coefficient of upstream and downstream square cylinder for Re=100 when PPR=4.

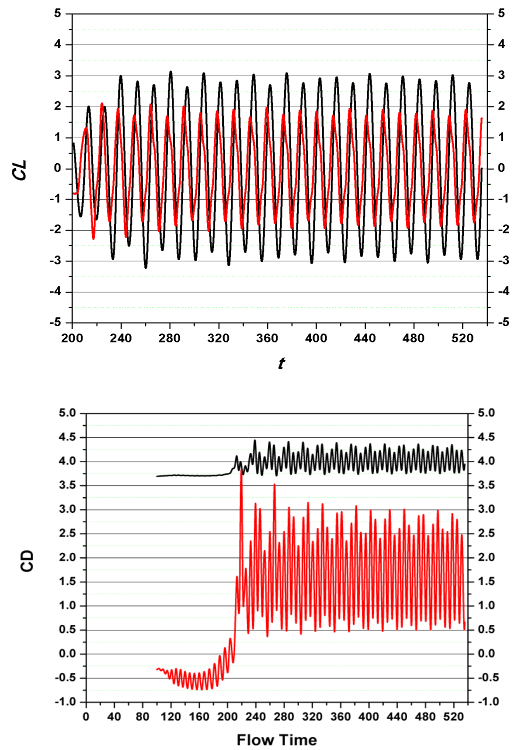


Fig.20 Time history of lift and drag coefficient of upstream and downstream square cylinder for Re=100 when PPR=6.

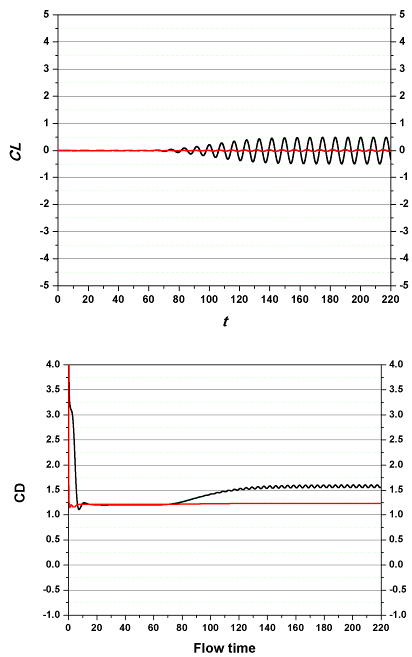


Fig.21 Lift and drag coefficient of upstream and downstream of chamfered square cylinder for Re=100 when PPR=2.

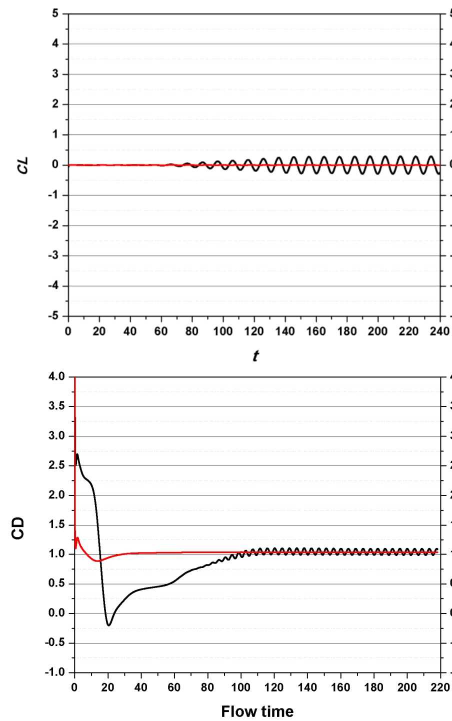


Fig.22Liftand drag coefficient of upstream and downstream of chamfered square cylinder for Re=100 when PPR=4.

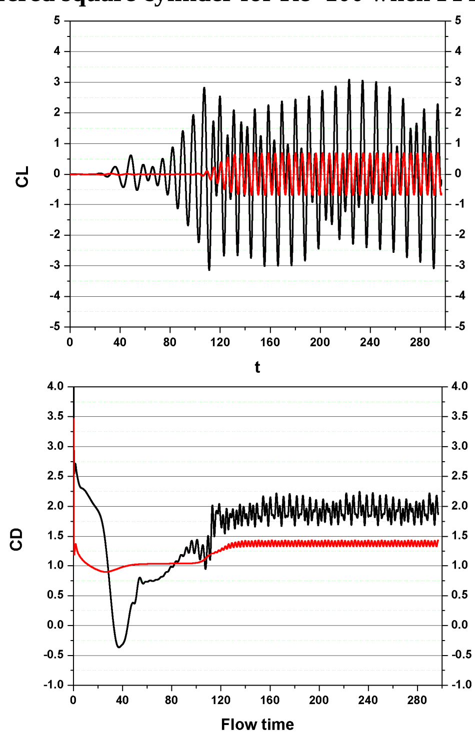


Fig.23 Lift and drag coefficient of upstream and downstream of chamfered square cylinder for Re=100 when PPR=6.

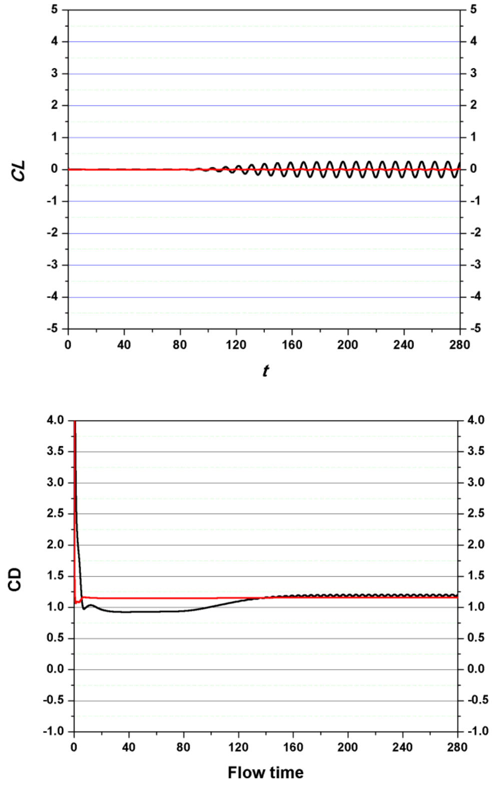


Fig.24 Lift and drag coefficient of upstream and downstream cylinder for rounded square cylinder for Re=100 when PPR=2.

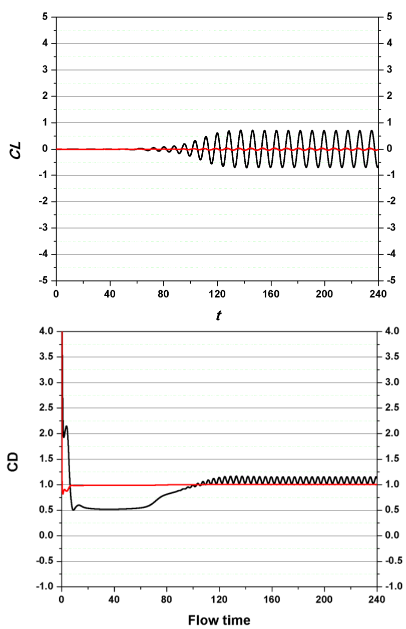


Fig.25 Lift and drag coefficient of upstream and downstream cylinder for rounded square cylinder for Re=100 when PPR=4.

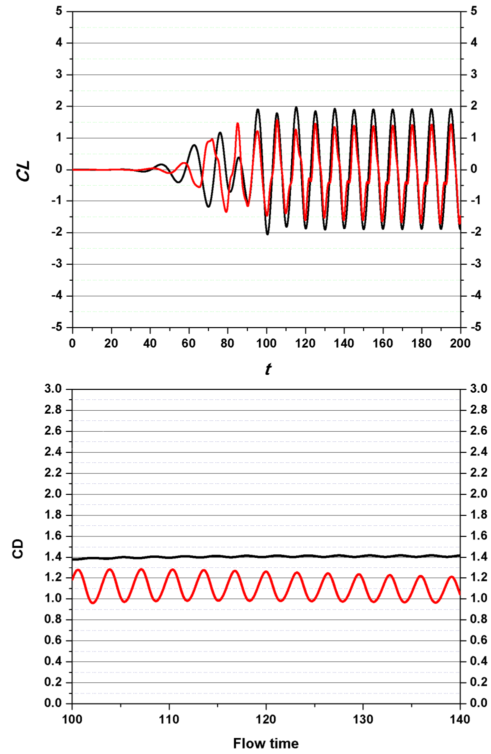


Fig. 26 Lift and drag coefficient of upstream and downstream cylinder for rounded square cylinder for Re=100 when PPR=6.

CONCLUSION

The results of the numerical analysis for flow past two square cylinders of different size with and without corner modification lead to the following conclusions:

- When the size of the upstream square cylinder with and without corner modification is smaller than that of the downstream square cylinder, the size of the eddies is always smaller in between square cylinder compared to the downstream of the second cylinder.
- Pressure on the downstream side of the cylinder is less than that of the upstream side of the cylinder with and without corner modification for all the three cases and also the pressure on the downstream side of the chamfered square cylinder becomes slightly greater than that of corner rounded on the downstream side of the square cylinder. Meanwhile, front portion of the cylinder side face experiences highest pressure compared to the second cylinder for all the three cases. A similar pressure distribution has been seen even with the increase in Reynolds number.
- Pressure at the upper side, bottom side and back side of cylinder is of negative pressure for with and without corner modification for all the three cases under investigations, because of vortices generated at the side of the surfaces.

- The flow velocity in between the square cylinder is less compared to the downstream of the second cylinder for with and without corner modification i.e., smaller upstream cylinder and larger downstream cylinder for PPR=2 and 4.Magnitude of oscillation is found to increase when Reynolds number is increased for all three cases.
- The flow velocity in between the chamfered cylinders is slightly less compared to the downstream of the second cylinder than that of corner rounded cylinder of same size and different size i.e., smaller upstream cylinder and larger downstream cylinder for PPR=2 and 4.
- The flow velocity in between the square cylinder is almost same compared to the downstream of the second cylinder for with and without corner modification i.e., smaller upstream cylinder and larger downstream cylinder for PPR=6.
- The lift coefficient is more for square cylinder than chamfered and rounded at the corner of square cylinder and drag coefficient decreases as the corners become more rounded and separation is delayed.
- The downstream cylinder is found to experience higher lift compared to the upstream cylinder.
- The upstream cylinder is found to experience higher drag compared to the downstream cylinder.
- In square cylinder Strouhal number is less compared to Chamfered and rounded at the corner of square cylinders.
- Frequency of vortex shedding is decreased with the introduction of a cylinder in the downstream of the second cylinder.

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