

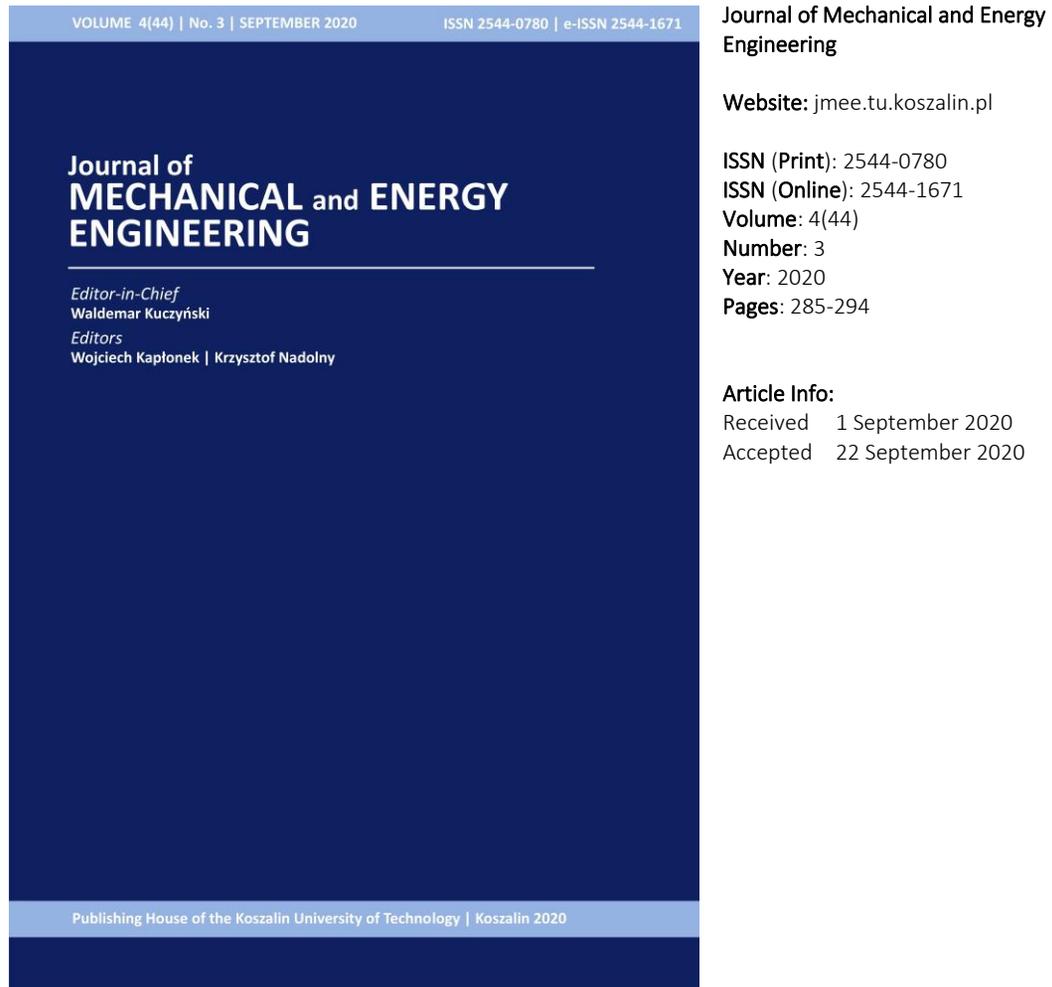
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DOI: 10.30464/jmee.2020.4.3.285

Cite this article as:

Virkam C. K., Ravindra H. V., Krishne Gowda Y. T. Visualization of flow past square cylinders with corner modification. Journal of Mechanical and Energy Engineering, Vol. 4(44), No. 3, 2020, pp. 285-294.



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VISUALIZATION OF FLOW PAST SQUARE CYLINDERS WITH CORNER MODIFICATION

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(Received 1 September 2020, Accepted 22 September 2020)

Abstract: This article presents the results for flow past a square cylinder and two square cylinders of same and different size with corner modifications by varying the spacing ratio. Here, experimental work is conducted in a recirculatory channel filled with water. A set of aluminum discs made to rotate to create the flow in the test section. Motor is used to vary the speed of water. Fine aluminum powder is used as a tracer medium. It is observed that vortex shedding frequency decreases by placing second cylinder in the downstream of the first cylinder. For a similar size cylinders, the width of the eddy in the middle of the cylinders increases with increase in spacing ratio. With the increase of spacing ratio to 6, the flow past each cylinder behaves like single square cylinder. If upstream square cylinder size is smaller than the downstream square cylinder, the eddy size is reduced in between the cylinder compared to the downstream of the second cylinder. If upstream square cylinder size is bigger than the downstream square cylinder, the eddy size is larger in between the cylinder compared to the downstream of the second cylinder.

Keywords: flow visualization, spacing ratio, strouhal number

1. INTRODUCTION

Over the last 100 years, the flow around circular cylinder have been the subject of intense research, mainly due to the engineering significance of structural design and flow induced vibration. In recent years, such studies have received a great deal of attention as a result of increasing computer capabilities and improvements in experimental measurement techniques. Most of work has been done on the flow past a circular cylinder than a square cylinder. Flow past a square cylinder resembles flow past a circular cylinder as far as instabilities are concerned. In case of the flow past a circular cylinder, separation occurs due to adverse pressure gradient in the downstream direction, resulting in back and forth movement of the separation point on the cylinder surface. In case of the flow past a square cylinder, however, the location of flow separation is fixed at upstream corners of the cylinder due to the abrupt geometrical change. Nowadays, high rise buildings are not isolated but situated close to other building. These structures can get energy from surrounded flow and cause flow

induced oscillation under certain circumstances. When one of the bodies is subjected to oscillation, the interference becomes more complex and depends on oscillation frequency and amplitude. Oscillation of a cylinder significantly influences the wake of the downstream side of the bluff bodies. However, when the Reynolds number exceeds a critical value, vortex shedding occurs in the wake, resulting in a significant pressure drop on the rear surface of the body. Also, vortex shedding occurs over a wide range of Reynolds numbers, causing serious structural vibrations and resonance. A little attention has been directed towards the flow past multiple cylinders. The fluid flow interference between two cylinders placed one behind the other has been the subject of considerable research. Such a two-body arrangement has many engineering applications such as twin-conductor transmission lines, two parallel suspension bridges and ocean structures. Flow interference between the bodies depends on various factors such as body geometry, spacing ratio, reduced velocity, supports and end conditions of the arrangement. For a square cylinder, the separation points are fixed. But no systematic

study is available in the literature that deals with the effect of rounding or chamfering the corners of square cylinder or multiple cylinders on flow structures. Therefore, experimental and numerical study is done to study the influence of rounding and chamfering the corners of flow past square cylinder.

2. GEOMETRY AND BOUNDARY CONDITIONS

Fig.1 indicates geometry of flow past square cylinder. In the current work, the simulation of the vortex shedding behind a square cylinder is considered. It is essential to find the top, bottom and inflow boundaries at adequate separation from the square cylinder to such an extent that the boundary conditions connected should not have any adverse impacts across the square cylinder. The extent of the computational area is of extraordinary significance. Selection of a poor computational area leads to inaccurate results. A too little space is not ready to catch the whole flow field which is impacted by the cylinder accordingly, essential impacts will get ignored and furthermore the blockage ratio should be under 0.01. After going through the most of the literatures carried out experimental and numerical simulations on flow past a square cylinder, it is concluded to locate the top, bottom and inflow boundaries $6.5D$ square cylinders. Correspondingly, so as to limit the impacts of the outpouring condition on the flow in the region of the cylinder, the computational area has been stretched out to $30D$ square cylinders in the cylinder of the downstream.

Boundary condition for flow past a square cylinder is shown in Fig.2. The inlet boundary condition is considered as uniform velocity $U=1$, $V=0$ and outlet boundary condition is set zero for pressure. No-slip boundary conditions are applied on the walls of the cylinder and symmetry boundary condition is applied to the lateral upper and lower boundaries. This boundary condition is maintained for all the remaining cases.

Figs.3-13 show geometry of a square cylinder of same and different size with corners chamfered and rounded square cylinder.

In all the above cases, cylinder of the upstream is fixed and the spacing ratios of 2, 4 and 6 are used. In all the cases geometry condition is not as per the scale.

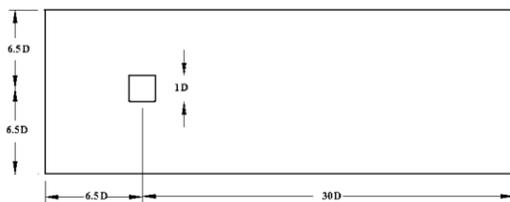


Fig. 1. Geometry of the square cylinder



Fig. 2. Boundary condition for square cylinder

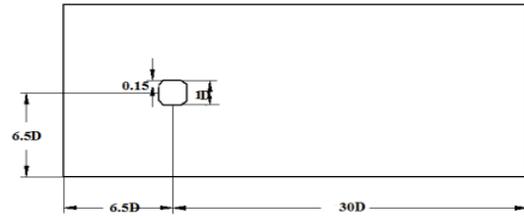


Fig. 3. Square cylinder with corners chamfered

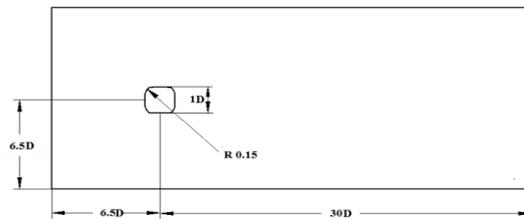


Fig. 4. Square cylinder with corners rounded

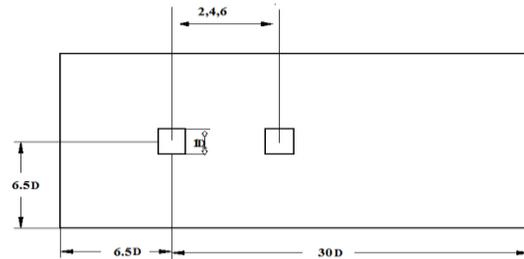


Fig. 5. Two square cylinders of same size, SR= 2, 4 and 6

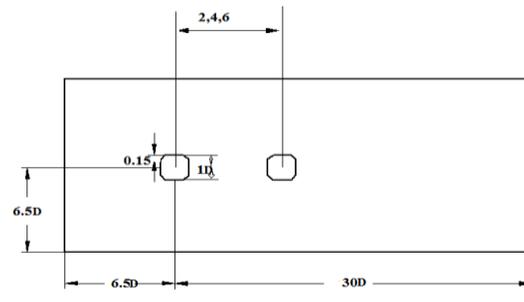


Fig. 6. Two corners chamfered cylinders, SR = 2, 4 & 6

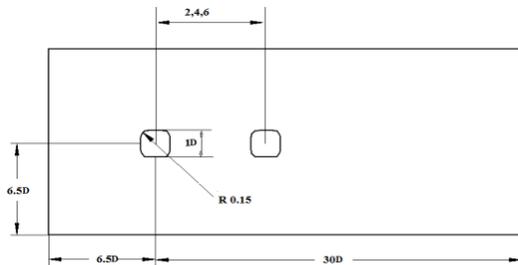


Fig. 7. Two corners rounded cylinders, SR= of 2, 4 & 6

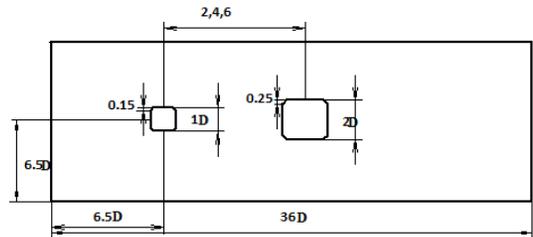


Fig. 12. Corners chamfered, SR= of 2, 4 & 6

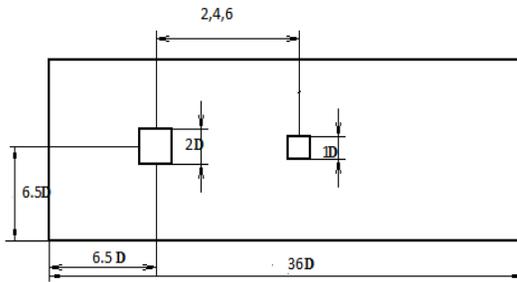


Fig. 8. Two square cylinders, SR= 2, 4 & 6

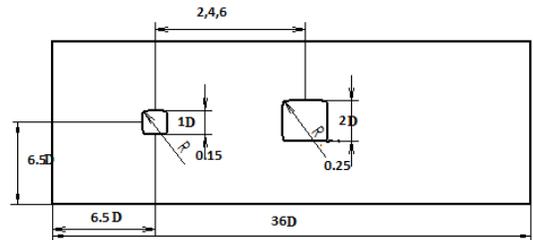


Fig. 13. Corners rounded cylinders, SR= 2, 4 & 6

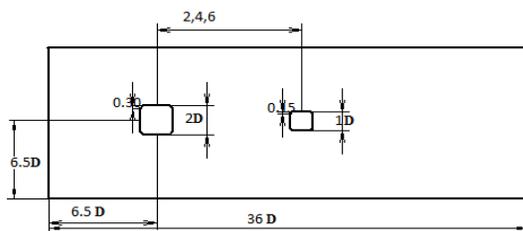


Fig. 9. Corners chamfered cylinders, SR= 2, 4 & 6

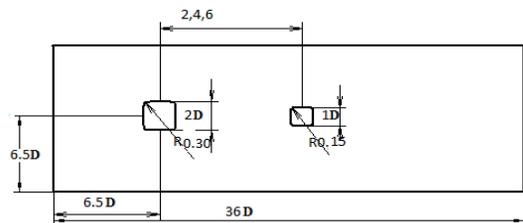


Fig. 10. Corners rounded cylinders, SR= 2, 4 & 6

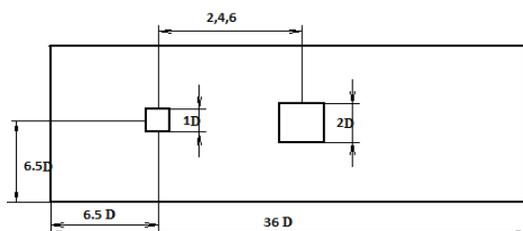


Fig. 11. Two square cylinders, SR=2, 4 & 6

3. EXPERIMENTAL ARRANGEMENT

Here it is discussed about the flow visualization equipment. The experiment is performed for flow past single square cylinder with corner modification. Further, experiments are repeated for two square cylinders with corner modification of same and different size arranged in tandem with different spacing ratio of 2,4 and 6. Fig. 14 and Fig. 15 shows the line diagram and experimental setup of flow visualization equipment. Experimental setup consists of three phase induction motor with speed control arrangement, fabrication of recirculatory water tank and aluminum discs. Further, DSLR camera, aluminum powder, flash lights and experimental models are used. Initially, recirculatory tank is filled with water which measures 2.6 m in length and breadth of 1.5 m and depth of 0.13 m. The test section width is 380 mm. Pair of aluminum disc with appropriate spacing between them is made to rotate, acting as paddles and thereby creating the flow in the recirculatory tank. The discs are connected to a variable speed motor so; extensive variety of speed flow in the test section can be achieved. At higher velocities the water surface ends up plainly wavy. For the investigations, a reasonable speed is picked where such waves does not take place. Fine aluminum powder is utilized as a tracer medium in the recirculatory water tank to know the flow pattern as it passes the experimental models. The perimeter of square cylinder, density, and viscosity are known. In order to find the velocity of water which is collected in a tank, the tuft is made to travel a specified distance in water and the time is noted using a stopwatch. The procedure is repeated for 5 times and the average velocity is calculated.

The flow visualization experiment has been conducted by keeping a stationary model in a flowing

fluid in a recirculatory water tank in such a way that, the side face of the square cylinder with corner alteration is facing to the oncoming flow. The experiment is conducted for square cylinder with corner modification. Further, experiments are repeated for two square cylinders of same and diverse size with corner modification arranged in tandem. The upstream cylinder is kept stationary while downstream cylinder is varied in a recirculatory channel to the spacing ratio (S/D) 2, 4 and 6 and Reynolds number used is 3483 and 3732 in the range of 3000 to 4000 for all the cases. The center distance between two cylinders is designated by S and characteristic length of square cylinder is designated by D . Two lamps are used to obtain proper lighting. Fluid flow behind the experimental models is projected by two lamps. Digital single lens reflex (DSLR) camera is placed at a suitable height above the cylinders to video graph the fluid flow pattern in between the cylinders and in the downstream of the cylinder.

Nine experimental models are used which is made with wood at a height of 130 mm. It is rigidly fixed to the base plate of mild steel of 50 mm in diameter with a thickness of 10 mm using nut and bolts. The dimensions of the experimental models are shown below:

- larger square cylinder = 40×40 mm,
- smaller square cylinders = 25×25 mm,
- square cylinder with corners chamfered by 5 mm = 40×40 mm,
- square cylinder with corners rounded by 5 mm = 40×40 mm.

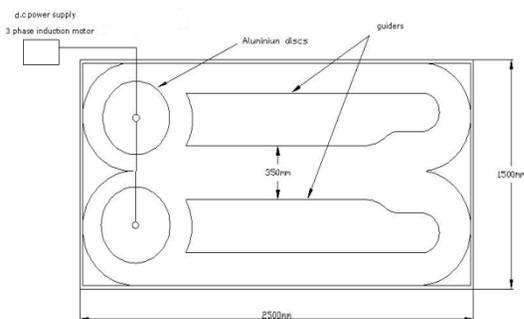


Fig. 14. Line diagram of experimental setup



Fig. 15. Fabrication of recirculatory water tank

4. RESULTS AND DISCUSSION

Figs.16-36 show the streamlines of single square cylinder and two square cylinders of same size and different sizes with corner modifications along with flow visualization photograph with $SR=2$ and 6. For a square cylinder, the flow is separated from two sharp corners of the front face. The eddies are alternatively formed on either side of the square cylinder in the downstream. As the flow forms a clockwise eddy, it rushes past the top of the square cylinder faster than the flow across the bottom. The square cylinder is more bluffer body compared to the square cylinder with corners chamfered and corners rounded. Therefore, the vortex formation region is significantly broader and longer, the separation points are fixed, either at the leading edge or the trailing edge. This makes the flow diverge further and creates a wide wake. When Re is increased, the clockwise eddy rushes past the top of the square cylinder much faster than the flow across the bottom. The flow is uniform and symmetrical in the upstream of the square cylinder with corner modification. Further, the eddies grow in size as they move away from the cylinder upto a certain length from the cylinder and then gradually die out and the flow becomes uniform as in the upstream in all the cases under investigation. The flow visualization images representing the flow pattern around the square cylinder with corners modification obtained from the experiment is of different size compared to numerical work, the vortex formed is much far when compared to the images obtained from numerical simulations. By experimental and numerical work, it might be said the vortex shedding frequency behind the square cylinder takes more time compared to the square cylinder with corners rounded whereas, square cylinder with corners chamfered lies in between them. For two square cylinders of same size for spacing ratio 2 and 6. The flow is uniform and symmetrical in the upstream of the square cylinder in all the cases under investigation. The flow is separated from two sharp corners of the front face of the upstream cylinder. Since the separation points in square cylinder is fixed at the front edge and the back edge which make the flow diverge further and creates a wider wake in the downstream. When spacing ratio is 2, the size of alternate eddies which are formed in between the cylinders are smaller than the eddies formed behind the downstream of the second cylinder. This is because second cylinder is suppressing the eddy formation in between the square cylinders. Also, the frequency of formation of eddies in between the cylinders is less when compared to the downstream of the second cylinder. This is due to the distance between the two cylinders is very small. But in case of spacing ratio 6, the size of the eddy in between the square cylinders is elongated where eddies are alternatively formed on either side of the upstream

cylinder and downstream cylinder. As the flow forms a clockwise eddy, it rushes past the top of the square cylinder faster than the flow across the bottom because it is more bluffer. Therefore, the vortex formation region is significantly broader and longer. When Re is increased, the clockwise eddy rushes past the top of the square cylinder faster than the flow across the bottom in all the cases under investigation. For two square cylinders with corners chamfered of same size for $SR=2$ and 6 . When $SR=2$, the alternate eddies shed quite faster which are formed in between the cylinders and single large eddy is formed in the downstream of second cylinder since square cylinders is chamfered at the corners. In $SR=6$, eddy is fully formed at the bottom and vortex gets folded up at the top of the upstream cylinder occurring in between the cylinders and large eddy is formed behind the downstream cylinder because both the front and rear edges is chamfered at the corners. So the vortex formation region is significantly less broader and shorter. When Re is increased, the eddy is moved across square cylinders with corners chamfered faster than the flow across the bottom compared. For two square cylinders with corners rounded of same size for spacing ratio 2 and 6 . When spacing ratio is 2 , the alternate eddies shed at a very fast rate across the cylinders in the middle of the cylinders and second cylinder of the downstream. since the cylinder corners are rounded. But in case of spacing ratio 6 , the vortex formation region is significantly narrow and shorter. When Re is increased, since there is no fixed separation points at the front and rear edges. The vortex shedding behind the cylinders is much faster. For two square cylinders with corner modification different size with larger upstream and smaller downstream for $SR=2$ and 6 . In these cases, the size of the eddies is bigger in between the cylinders compared to the downstream of the second cylinder when $SR=2$. For two square cylinders with corners modification of different size with smaller upstream and larger downstream for $SR=2$ and 6 , the size of the eddies is smaller in between the cylinders compared to the downstream of the second cylinder when $SR=2$. It has been found that in all the cases under investigation, when spacing ratio is increased to 4 , the size of the eddies which are formed in between the cylinders and behind the second cylinder of the downstream lies in between spacing ratio 2 and 6 . The frequency of eddies formation in between the cylinders and downstream of the second cylinder lies in between them. But in case of $SR=6$, the flow over upstream cylinder and downstream cylinder almost behave as a single cylinder because distance between the cylinders is more. But change can be seen in the formation of vortex region around the cylinders when $SR=2, 4$ & 6 . The flow visualization images are shown along with the streamlines obtained

by numerical simulation thereby, representing flow pattern which are conducted during the experiment.

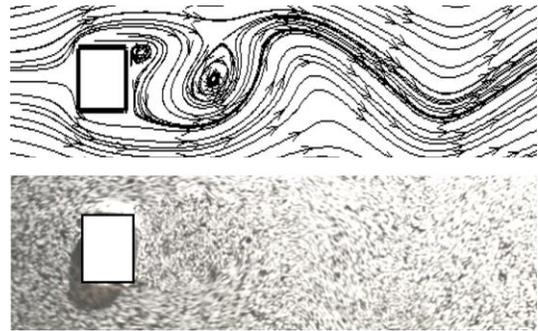


Fig. 16. Flow visualization photograph

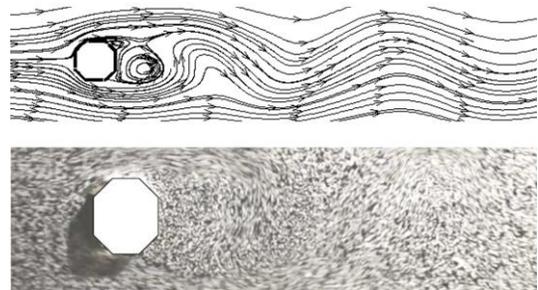


Fig. 17. Chamfered Square cylinder

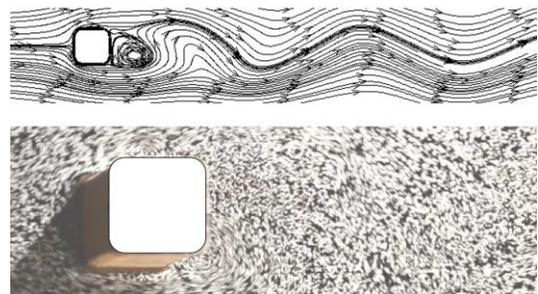


Fig. 18. Square cylinder with corners rounded

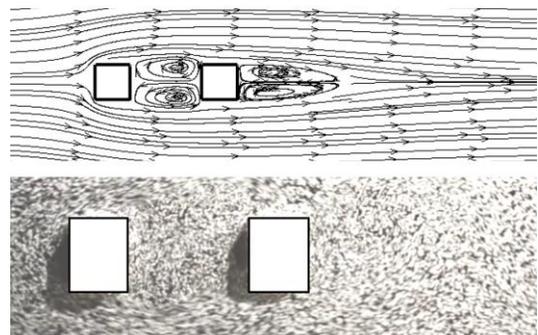


Fig. 19. Square cylinders, $SR=2$

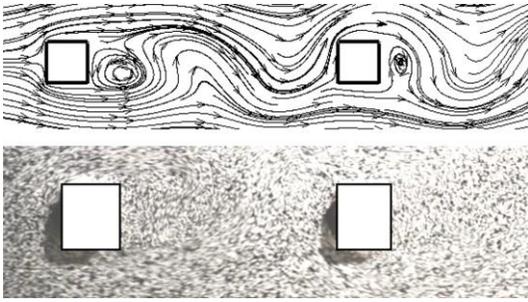


Fig. 20. Square cylinders with SR=6

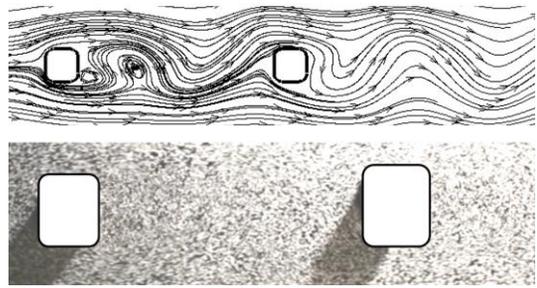


Fig. 24. Corners rounded cylinder, SR=6

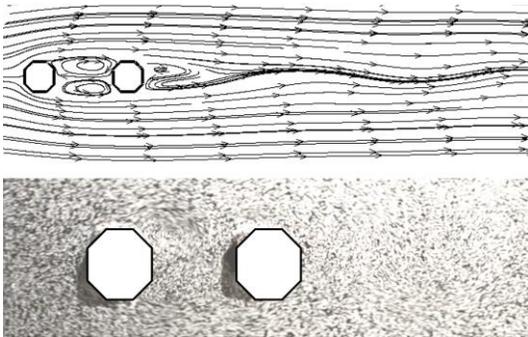


Fig. 21. Chamfered Square cylinders, SR=2

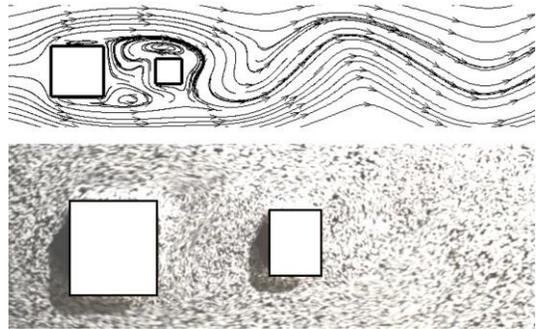


Fig. 25. Cylinders of different size, SR=2

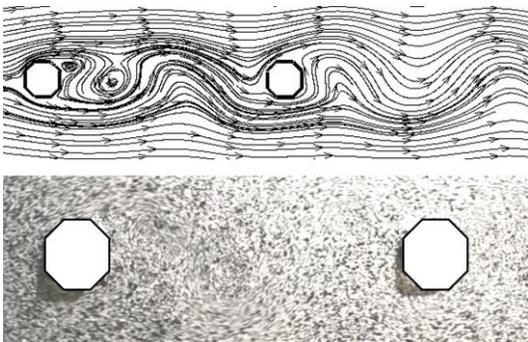


Fig. 22. Chamfered Square cylinders, SR=6

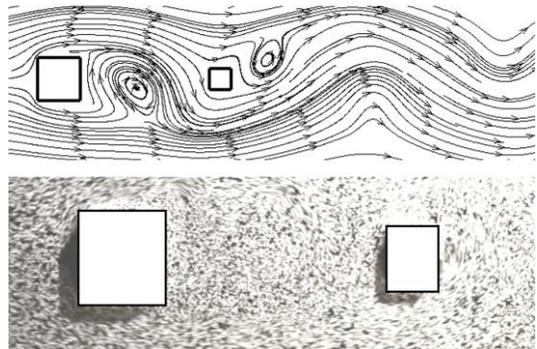


Fig. 26. Cylinders of different size, SR=6

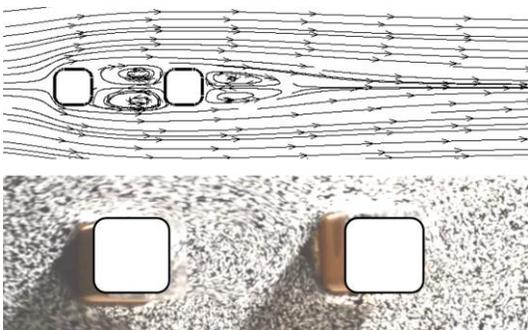


Fig. 23. Corners rounded cylinders, SR=2

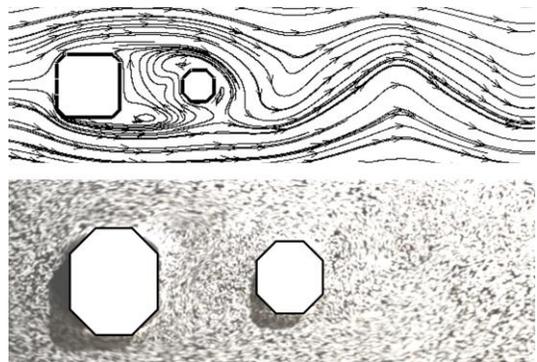


Fig. 27. Chamfered cylinders, SR=2

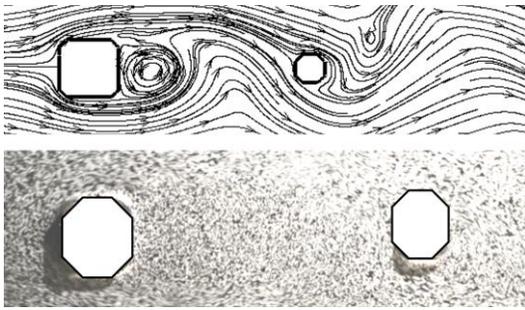


Fig. 28. Different size Chamfered cylinders, SR=6

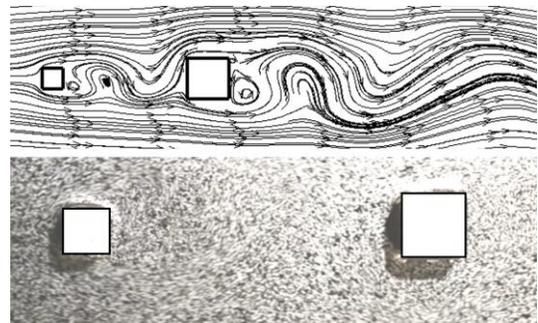


Fig. 32. Cylinders of different size, SR=6

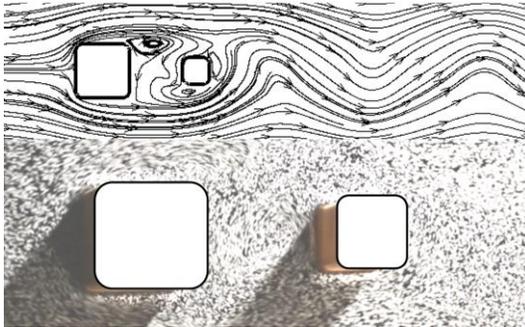


Fig. 29. Corners rounded cylinders, SR=2

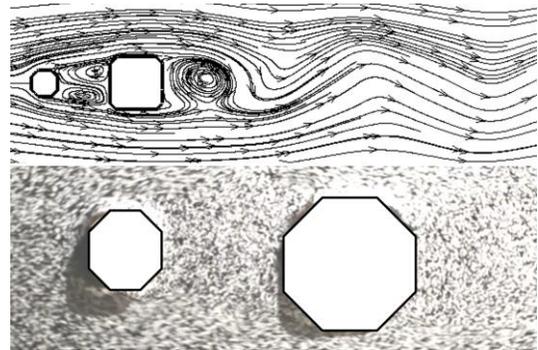


Fig. 33. Chamfered cylinders, SR=2

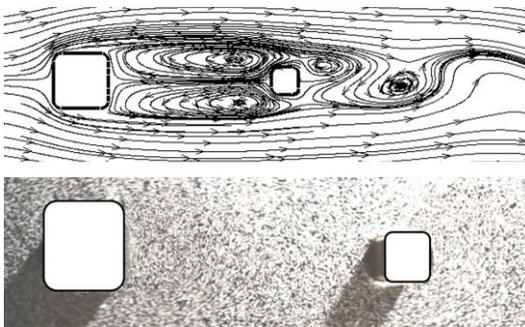


Fig. 30. Corners rounded cylinders, SR=6

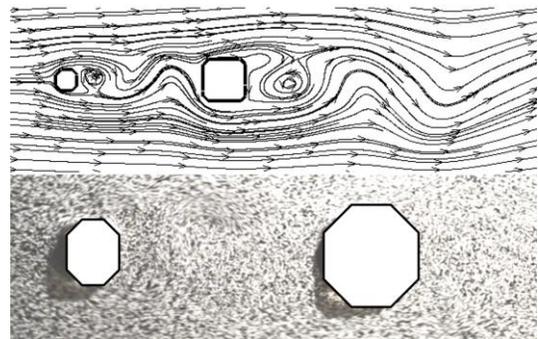


Fig. 34. Chamfered cylinders, SR=6

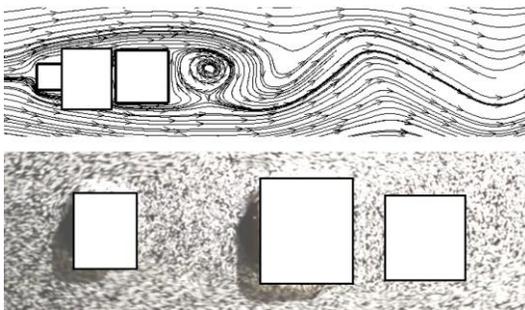


Fig. 31. Cylinders of different size, SR=2

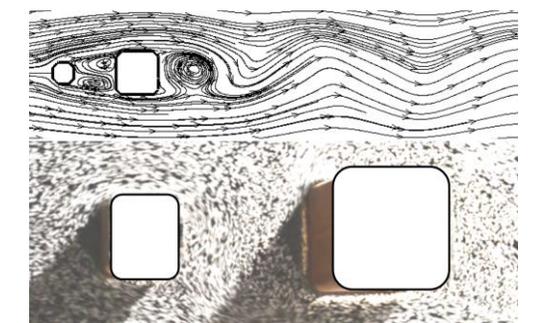


Fig. 35. Corner rounded cylinders, SR=2

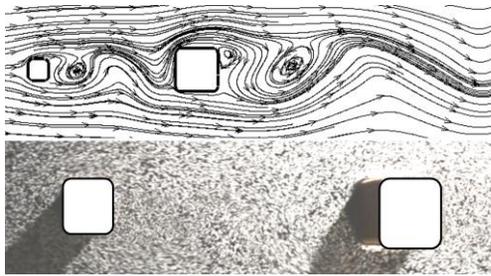


Fig. 36. Corner rounded cylinders, SR=6

5. CONCLUSIONS

Flow around single square cylinder with corners modification is performed experimentally and simulated numerically. The following conclusions have been drawn. Experimental work and numerical simulations is carried out for two square cylinders of same and different size with corners variation by varying the spacing ratio 2.4 and 6 are considered for the investigation. Vortex shedding frequency behind the square cylinder takes more time compared to the square cylinder with corners rounded whereas, square cylinder with corners chamfered lies in between them. Frequency of vortex shedding decreases by placing second cylinder in the downstream of the first cylinder. For a same size cylinders, the width of the eddy in the middle of the cylinders increases with increase in spacing ratio. With the increase of spacing ratio to 6, the flow past each cylinder behaves like single square cylinder. If upstream square cylinder size is smaller than the downstream square cylinder, the eddy size is reduced in between the cylinder compared to the downstream of the second cylinder. If upstream square cylinder size is bigger than the downstream square cylinder, the eddy size is larger in between the cylinder compared to the downstream of the second cylinder.

Acknowledgements

I would like to sincerely thank IIT Madras, Applied science department for providing the lab to conduct experiment. Also I, thank PES College of engineering Mandya for giving the CAD lab in Mechanical Department to carry out the simulation work.

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Biographical notes



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Ph.D scholars are pursuing research under his guidance Around 200 International and 32 National Publications (Journals and conferences) published. Several projects (around 135) have been guided for UG & PG Students Sponsored Projects Six projects sponsored by AICTE, Five projects sponsored by UGC, Three projects sponsored by DST, One each project sponsored by VTU, DRDO-Pune and NRB.



Y. T. Krishne Gowda after graduating in Mechanical Engineering from P.E.S.College of Engineering Mandya, University of Mysore, received his Masters in Engineering from Indian Institute of Science, Bangalore. Then completed his Ph.D from prestigious Indian Institute of Technology,

Chennai. During his Ph.D study, he was the winner of Dr. Despande Award for best research paper in the international conference at IIT, Chennai. Dr. Krishne Gowda has more than 35 years of teaching experience. He started his career as Lecturer in PES college of Engineering, Mandya and became professor. He was appointed as Deputy Director to AICTE and later became its Director. He worked in AICTE Delhi Bhopal, and Mumbai. While in Bhopal, he was Executive Committee member of Rajiv Gandhi Proudyogiki Vishwavidyalaya, involved in awarding doctorate to Late Dr. A P J Abdul Kalam when he was heading DRDO. Dr. Krishne Gowda is well-known for his advisory acumen. He worked as advisor to the following Institutions: Yegachi Institute of technology, Hassan, Karnataka Patel Institute of Technology, Mehsana, Gujarat Venkateshwara College of Engineering, Indore, Madhya Pradesh .He has published more than 30 papers in several major international and national journals in mechanical engineering, management science and information systems. In July 2016 Venus International Foundation, Chennai, conferred on him the Venus International Faculty Award for Life Time Achievement in recognition of his outstanding contribution in the area of Computational Fluid Dynamics and teaching excellence. He is actively involved in research and has successfully guided 5 Ph.D candidates and 5 in progress Dr. Krishne Gowda is a founder Secretary of Maharaja Education Trust He played a key role in establishing the following Educational Institutions: Maharaja Institute of Technology, Mysore Maharaja Institute of Technology, Thandavapura Center of Excellence in Corporate Social Responsibility Maharaja Research Foundation (MRF) is giving scholarship to its Research Scholars to Doctoral Research. Agricultural Food & Management Institute Gopaldaswamy PU and Degree College Recently on 15th September 2016 he has been awarded as Best Mechanical Engineer by Institutions of Engineers Mysore Chapter for his contribution in Engineering, Management and Education. Today, Dr. Krishne Gowda is best-known academician and educationist in Mysore region.

