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PIV MEASUREMENT OF FLOW OVER SQUARE CYLINDERS IN TANDEM ARRANGEMENT*

Sığ Suda Ardı Ardına Dizili Kare Kesitli Silindirler Arkasındaki AkışYapısının PIV Yöntemiyle İncelenmesi

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ÖZET

Bu çalışmanın amacı, farklı silindirler arası boşluğa sahip ardı ardına dizili iki kare kesitli silindir arasındaki akış özelliklerini parçacık görüntülemeli hız ölçüm tekniği (PIV) kullanılarak deneysel olarak araştırmaktır. Bütün deneyler de 28 mm çapında kare kesitli iki eşit silindir kullanılmıştır ve 14 mm su yüksekliğinde ve 160 mm/s serbest akış hızında gerçekleştirilmiş olup bu da 4470 Reynolds sayısına tekabül etmektedir. Yan görüntü, silindir tabanından su yüksekliği 2 mm de plan görüntü ve ve su orta yüzeyinde (7 mm) plan görüntü olmak üzere 3 değişik yükseklikte ölçümler alınmıştır. Silindirler arası boşluk 0 mm ve 140 mm arası mesafelerde değiştirilmiş olup bu da boyutsuz boşluk oranı G/D'nin 0 ile 5 arası değişmesine karşılık gelmektedir. Ortalama hız vektörleri, akım çizgisi, girdap değerleri ve Reynolds gerilim yoğunlaşması gibi akış özellikleri 350 anlık görüntü ile elde edilmiştir.

Aralık oranı G/D=3.5'dan sonar ikinci silindirin varlığı iki silindir arasındaki bölgede akış özelliklerini etkilememektedir.

Anahtar Kelimeler: PIV, Sığ su, Ardı ardına dizili kare kesitli iki silindir

ABSTRACT

The aim of this thesis is to investigate the flow structure past two tandem square cylinders under shallow water condition by using Particle Image Velocimetry (PIV) technique. In all experiments, two plexsiglas square cylinders having the diameter of D = 28 mm were used. All experiments were carried out in 14 mm deep water and free stream velocity was U = 160 mm/sn. Experiments were performed for three different types of view section; side view, plan view bottom plane (2mm), plan view top-plane (14mm). The distance between the cylinders was changed between G=0mm and 140mm, which corresponds to a dimensionless gap ratio of G/D = 0 to 5. In order to understand the effect of the spacing between square cylinders, three sets of experiments were performed and each set includes 350 instantaneous images. In this way, average velocity vectors, streamlines, vortex structures and Reynold stresses were obtained. *

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The results of the experiments reveal that the flow characteristics between the two cylinders are not affected from the presence of downstream cylinder when the gap ratio G/D exceeds 3.5.
Key words: PIV, Shallow water, tandem arrangement square cylinder

INTRODUCTION

External flows past objects have been studied extensively because of their many practical applications that include marine structures, offshore structures, process industries (turbine blades, heat exchanger tubes, cooling systems for nuclear power plants, power transmission lines), underwater acoustics, civil, wind and aerospace engineering. In this study, the flow past two square cylinders will be investigated and the turbulent wake flow field will be studied using the Particle Image Velocimetry (PIV) technique. Based on the PIV velocity field measurements and other reference information, a comprehensive discussion about many important flow concepts such as: boundary layer flow separation, wake flow, vortex shedding on an immerse body and shallow water will be given in the following sections.

A shallow flow is one in which the horizontal dimensions are much larger than the vertical extent and the vertical component of water particle acceleration is negligible compared with the horizontal acceleration components so that the pressure variation can be assumed hydrostatic. Typical examples include wide rivers, lakes, coastal lagoons, estuaries, and so on. The majority of the whole world's population reside near to these areas. Hence, better understanding of the shallow flow hydrodynamics and related processes, such as flooding, sediment transport, spreading and mixing of pollutant and its effects on water quality, is of great importance. Mathematically, shallow flow hydrodynamics may be approximated by the shallow water equations, which include the continuity equation and the x- and y-direction momentum equations, and can be derived by depth integrating the three-dimensional Navier-Stokes equations.

Particle Image Velocimetry (PIV) is a non-intrusive technique for studying the velocity of particles in some type of flow. This is most commonly either a gas flow in a wind tunnel, or a liquid flow of some viscous fluid. The medium is then seeded with some sort of tracer particles and then illuminated periodically by some high power light source, which is often a laser. The idea is to obtain successive digital images from charged coupled device (CCD) cameras. These images can then be analyzed by a computer, which determines the velocities of the tracer particles, which can be used to understand the velocity of the given medium. The advantage of this technique is that it does not require the placement of any type of probe in the medium, which could affect the overall flow.

There are numerous studies on flow over cylindrical, square, rectangular shaped objects. For example, the suppression of fluid forces acting on two square prisms in a tandem arrangement in which a flow approaching the upstream prism was controlled by a thin flat plate was examined with variation in spacing between the plate and the upstream prism by Mahbub Alam et.al. The width of the plate was one ninth of the prism width. The position of the control plate was varied from the front surface of the upstream prism to 2-25 times the prism width in the upstream direction, and the position of the downstream prism was varied from the rear surface of the upstream prism to 10 times the prism width in the dwnstream direction. A dramatic decrease in fluid forces acting on both prism was observed for a certain range of control plate positions. For such optimum positions of the control plate, the shear layers that seperated from the control plate attached near the edges of the front surface of the upstream prism and each shear layer bifurcated into two layers, one part of the shear layers making a quasi-steady recirculating region between the control plate and the upstream prism, and the other part seperating from the leading edge and attachingagain to the side-surfaces of the upstream prism.

A technique of high-image-density particle image velocimetry is employed to characterize the instantaneous and averaged patterns of velocity, vorticity and Reynold stres due to flow past two cylinders in tandem by Lin et.al. These features of the flow patterns are characterized in the gap region as a function of the distance between the cylinders. In turn, they are related to the patterns in the near-wake of the two-cylinder system. Along gap between the cylinders, small-scale concentrations of vorticity are formed in the seperated shear layers. These concentrations buffet the surface boundary layer on the downstream cylinder, and there by influence the eventual shedding of the large-scale vortices. Within the gap, the instantaneous structure of the recirculation zones can exhibit both symmetrical and asymmetrical patterns. In the near-wake of the downstream cylinder, the form of the vortex shedding, as well as the averaged patterns of the flow structure, are substantially altered, relative to the case of a single cylinder.

On the other hand; by Yen et. al. two identical square cylinders were installed in tandem in a vertical water tank.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. The particle image velocimetry (PIV) scheme was applied to examine and classify the flow field into three characteristic modes: vortex sheet of the single mode, reattached mode and binary mode. Via topological analysis, the velocity vector field, streamline pattern, and the properties of these flow modes are presented and discussed. In the viscosity-dominant flow field, the Strouhal number decreases as the Reynolds number increases. However, in the intertia-dominant flow field, the Strouhal number increases with the Reynolds numbers and approaches a constant for high Reynolds number.The maximum drag coefficient in the vortex sheet of reattached mode is approixmetaly 76% lower than that in the single square cylinder case.

An experimental investigation of flow around a square cyliner placed at various angles with respect to the approach fluid velocity is reported by Dutta, et. al. The focus of the study was toward examining the sensitivity of the wake properties to the cylinder orientation and Reynolds number. Angles of incidence in the range of 0-60° and Reynolds numbers of 1340, 4990, and 9980 have been considered.

Velocity measurements have been carried out using an X-wire hotwire anemometer.

In this study, it is aimed to investigate the flow structure around and behind two tanem square cylinders located in a turbulent upstream flow in a shallow water channel. The cylinder used in the experiments has 28 mm length (D) and the water depth is 14 mm. The spacing (G) between the two square cylinders was changed and the effect of dimensionless spacing (G/D), which changes from 0 to 5 was investigated. The results are given in figures in terms of streamline, vorticity and Reynolds Stress plots.

MATERIAL AND METHOD

A state of the art experimental system, namely Particle Image Velocimetry (PIV) was used to perform the experiments in a large-scale water channel located in the Fluid Mechanics Laboratory of Cukurova University. The water channel test section - which has the following dimensions: a length of 8000 mm, width of 1000 mm, and a depth of 750 mm - was constructed of transparent Plexiglas with upstream and downstream fiberglass reservoirs. The water channel also has honeycomb screen arrangement, which is located at the entrance of contraction. These reservoirs and honeycomb screen arrangements are used to maintain the turbulence intensity in the section at a level of below 0.1 %.

In this study, the flow structure behind two tandem square cylinders was investigated on different intervals by using Particle Image Velocimetry (PIV) technique. The square cylinder models were constructed from Plexiglas (D = 28 mm) material. The free stream velocity was arranged to be U = 160 mm/sn, which represents a Reynolds number value, based on diameter of cylinder, of ReD = 4470 and during all experiments, the water level was (hw) maintained at the depth of 14 mm. In this experimental study, the effect of the distance between square cylinders (G) on the flow structure was investigated. For each experiment, the distance (G) between the square cylinders were changed in the interval of 0 mm and 140 mm. In order to investigate the effect of the distance between the two square cylinders, three sets of experiments were performed.

Firstly, the flow was investigated at side view and four types of experiments were performed at four different camera positions. In all camera positions, experiments were carried out at variable distances with three sets and each set includes 350 instantaneous images. . In this way, average velocity vectors $<V>$, streamlines $<S>$, vortex $<\omega>$ and Reynold stresses $< u'v'>$ were obtained.

Secondly, the flow is investigated at plan view with two diffrent types. First type is performed plan view when the laser sheet is at water bottom surface (laser sheet is positioned 2 mm up from the water bottom). Second type is performed plan view when Laser Sheet is at Water Mid Surface (Ls = 7 mm) These experiments were also performed at four different camera positions, which are explained before. In all camera positions, experiments were carried out at variable distances with three sets and each set includes 350 instantaneous images. In this way, average velocity vectors <V>, streamlines <S>, vortex <ω> and Reynold stresses < u'v'> were obtained.

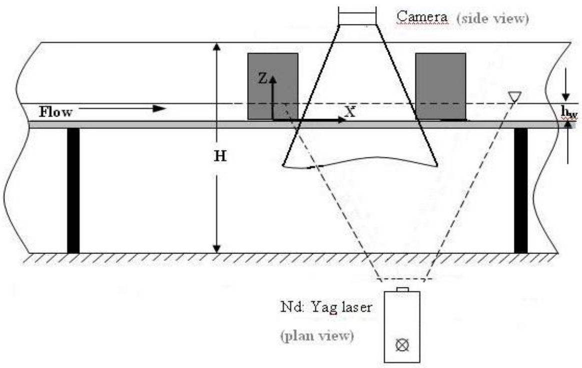

Figure 1. Overview of tandem arrangement square cylinders in shallow water for Side view experiments.

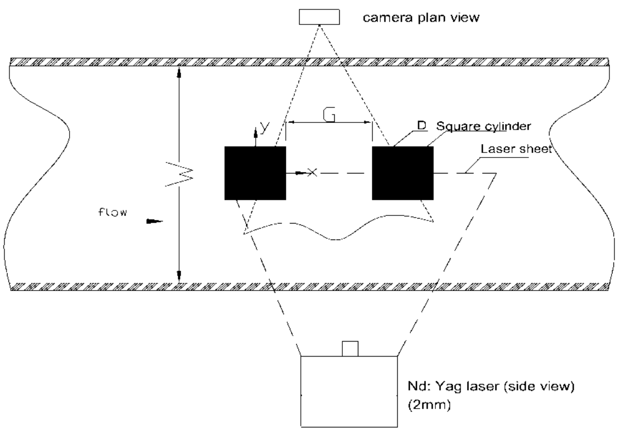

Figure 2. Overview of tandem arrangement square cylinders in shallow water for Plan view experiments.

RESULTS AND DISCUSSION

Side View Experiments

Firstly the flow was investigated at side view and four types of experiments were performed at four different camera positions.

First experiment was performed at camera position A where upstream cylinder is fixed while downstream cylinder is moving in the flow direction. In this case, the view section is in front of upstream cylinder with G/D ratio of 0 ÷ 5. In this case, the view section is in front of upstream cylinder with G/D ratio of 0 ÷ 5. It can be easily said that there is no critical gap ratio which affect the flow characteristic in front of the upstream cylinder in this experiments because all of the results are nearly the same at camera position A.

Second experiment was performed at camera position B where upstream cylinder is fixed while downstream cylinder is moving in the flow direction. In this case, the view section is behind upstream cylinder with G/D ratio of 0.5 ÷ 5. From gap ratio 0.5 to 2.5 nearly same characteristics are shown. All of these (0.5-2.5) gap ratios, it can be said that flow shows foci like the region of flow from single cylinder, there are no flow separation due to the limited distance and no saddle occurs. At gap ratios of 3-5, it can be seen that the effect of downstream cylinder disappeared. Flow shows the same characteristics as single cylinder that explained of the previous section. It is concluded that the gap ratio of 3 is the critical gap ratio. The flow characteristics behind upstream cylinder are affected from downstream cylinder up to G/D=3, after this gap ratio, the effect of downstream cylinder diminishes.

Third type of experiment was performed at camera position C where downstream cylinder is fixed while upstream cylinder is moving opposite to the flow direction. In this case, the view section is in front of downstream cylinder with G/D ratio of 2.5 ÷ 5. After the gap ratio of 3, saddle points and separation are observed up to the gap ratio of 5. The flow becomes nearly uniform at the gap ratio 5. For these experiments, it can be said as a conclusion that the gap ratio of 3 is the critical gap ratio because the flow separation is observed after this gap ratio.

Fourth type of experiment was performed at camera position D where downstream cylinder is fixed while upstream cylinder is moving opposite to the flow direction. In this case, the view section is in behind of downstream cylinder with G/D ratio of 0 ÷5. When the flow characteristics are inspected for higher gap ratios, meaning from G/D of 1 to 5, one can say that increasing the gap ratio has in fact does not show any significant differences on vorticity, streamline, Reynolds stresses and velocity contours. Almost the same results are observed: a saddle point and separation, resulting in the reverse flow. This scenario almost repeats similarly when the gap ratio is increased. Therefore, one can conclude that the presence of upstream cylinder as well as moving this upstream cylinder opposite to flow direction do not have any significant effect on the flow characteristics inspected behind downstream cylinder.

Secondly, the flow was investigated at plan view when the laser sheet was at water bottom surface (laser sheet was positioned 2 mm up from the water bottom). These experiments were also performed at four different camera positions.

First experiment was performed camera position A; where upstream cylinder is fixed within the view section while downstream cylinder is moving in the flow direction out of view section with G/D ratio 0 ÷ 5. When the camera position A,

in this flow, uniform flow characteristics are observed except for the near cylinder region. When flow approaches cylinder wall, reverse flow occurs in front of upstream cylinder. This reverse flow leads to horseshoe vortex system to occur in front of the cylinder. It can be easily said that the critical gap ratio is 0.5 in this experiment because after the gap ratio 0.5 all of the results are nearly the same and it can be seen that the effect of downstream cylinder disappears. Another important conclusion for this experiment is that, when two tandem cylinders are examined with a view section in front of upstream cylinder, downstream cylinder movements in the flow direction shows no effect at the inspection section

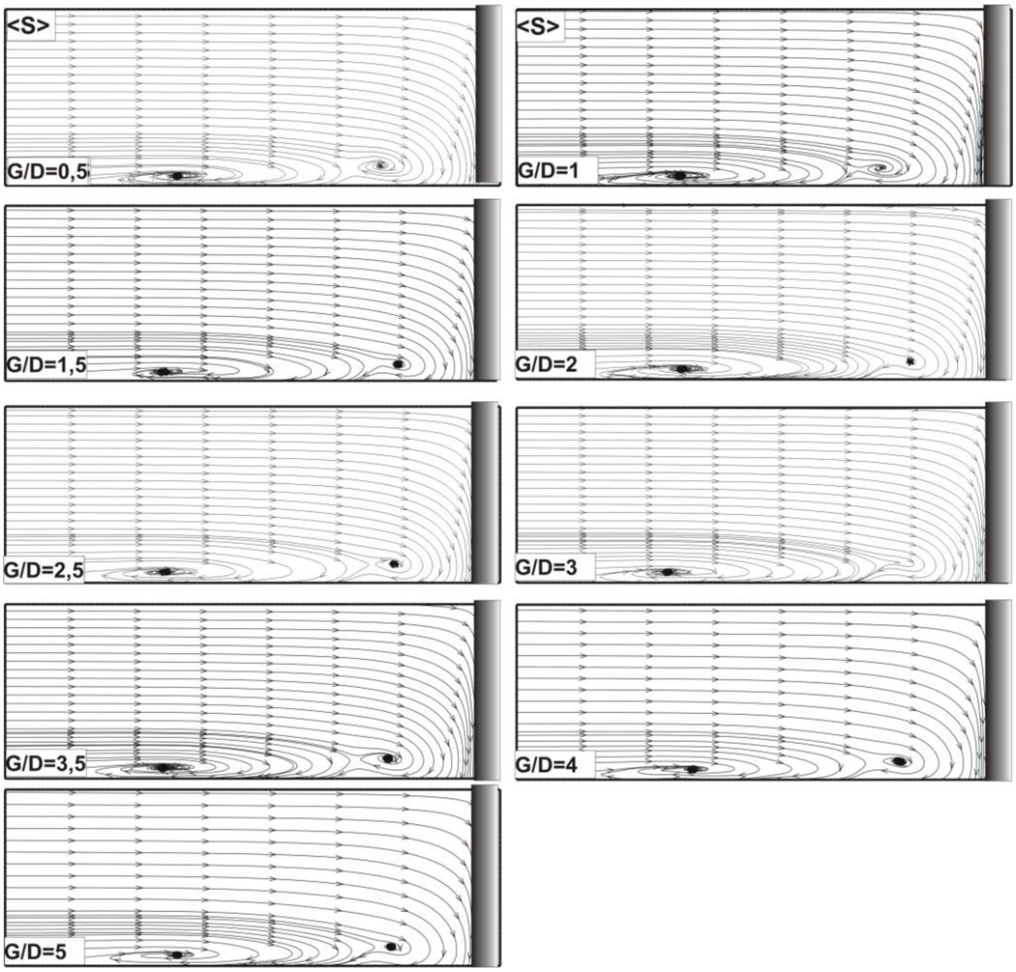

Figure 3. Time-averaged stream line <S> in the view section of the flow in front of the upstream cylinder in side –view plane at camera position –A.

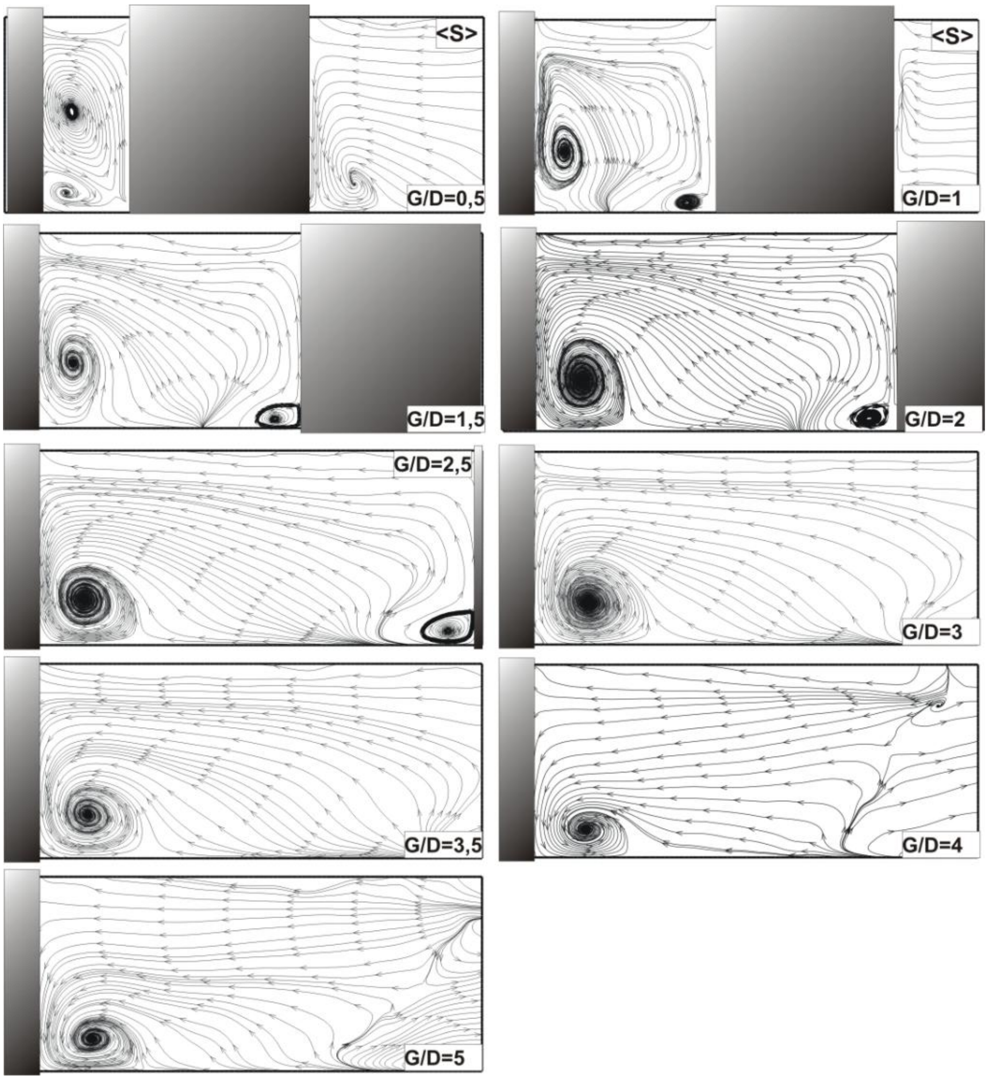

Figure 4. Time-averaged stream line <S> in the view section of the flow between two square cylinders in tandem arrangement with G/D 0.5-5 in side-view plane at camera position-B.

Second experiment was performed camera position B-C; where upstream cylinder is fixed while downstream cylinder is moving in the flow direction within view section with G/D ratio 0,5÷ 5. At camera position B-C, note that the above results are given for the flow region between the two cylinders. When the flow structure behind downstream cylinder is inspected, one can easily say that it is the same for all gap ratios and therefore the movement of downstream cylinder in flow direction has no effect of the flow structure behind downstream cylinder.

Fourth type of experiment was performed, camera position D where downstream cylinder is fixed within the beginning of the view section while upstream cylinder is moving opposite to the flow direction with G/D ratio 0,5÷ 5. At camera position D, when the gap ratio of 2, two foci become more clear and when the gap ratio is increased, these two foci points remain behind downstream cylinder. As a result, one can say that after the gap ratio of 2.5, increasing the gap ratio has no effect on the flow structure in the view section. After these two foci regions, the flow is uniform. Two counter-rotating vortices, one positive and one negative, are present for all gap ratios inspected.

Finally, the flow was investigated at plan view when the laser sheet was at water mid surface (laser sheet is 7 mm up from the water bottom level). In this situation, the experiments were performed at three different camera positions.

First experiment was performed camera position B-C; where upstream cylinder is fixed while downstream cylinder is moving in the flow direction within the experiment area with G/D ratio 0,5÷ 5. At camera position B-C, when gap ratios from 1.5 to3, the flow structure is pretty much the same: two foci points growing in size and one focus point behind downstream cylinder. After gap ratio 3.5, the two foci points get closer to upstream cylinder and as the gap ratio increases, the flow after these two foci points start to become uniform. Again, one focus point is observed behind downstream cylinder.

Third types of experiment was performed, camera position D; where downstream cylinder is stationary at the beginning of view section while upstream cylinder is moving opposite to the flow direction with G/D ratio of 0 ÷ 5. The results obtained for different gap ratios are almost the same, it is more appropriate to interpret all the results together here. Two foci points are observed close to downstream cylinder and as a result, two counter-rotating positive and negative vorticities are observed at vortex contour diagrams. As the gap ratio increases, there is no difference on this general result. Therefore, one can conclude that the gap ratio has no effect on the view section considered here.

CONCLUSION

This study represents a detailed investigation of the wake flows behind, between and in front of two square cylinders placed in tandem arrangement with the view section of 155 x 115 mm. The two square cylinders are identical with diameter of D = 28 mm, immersed in steady cross-flow in the shallow water having a depth of 14 mm. Upstream velocity U in the water channel was kept constant during all experiments with a value of 160 mm/s, which corresponds to a Reynolds number value of 4470.

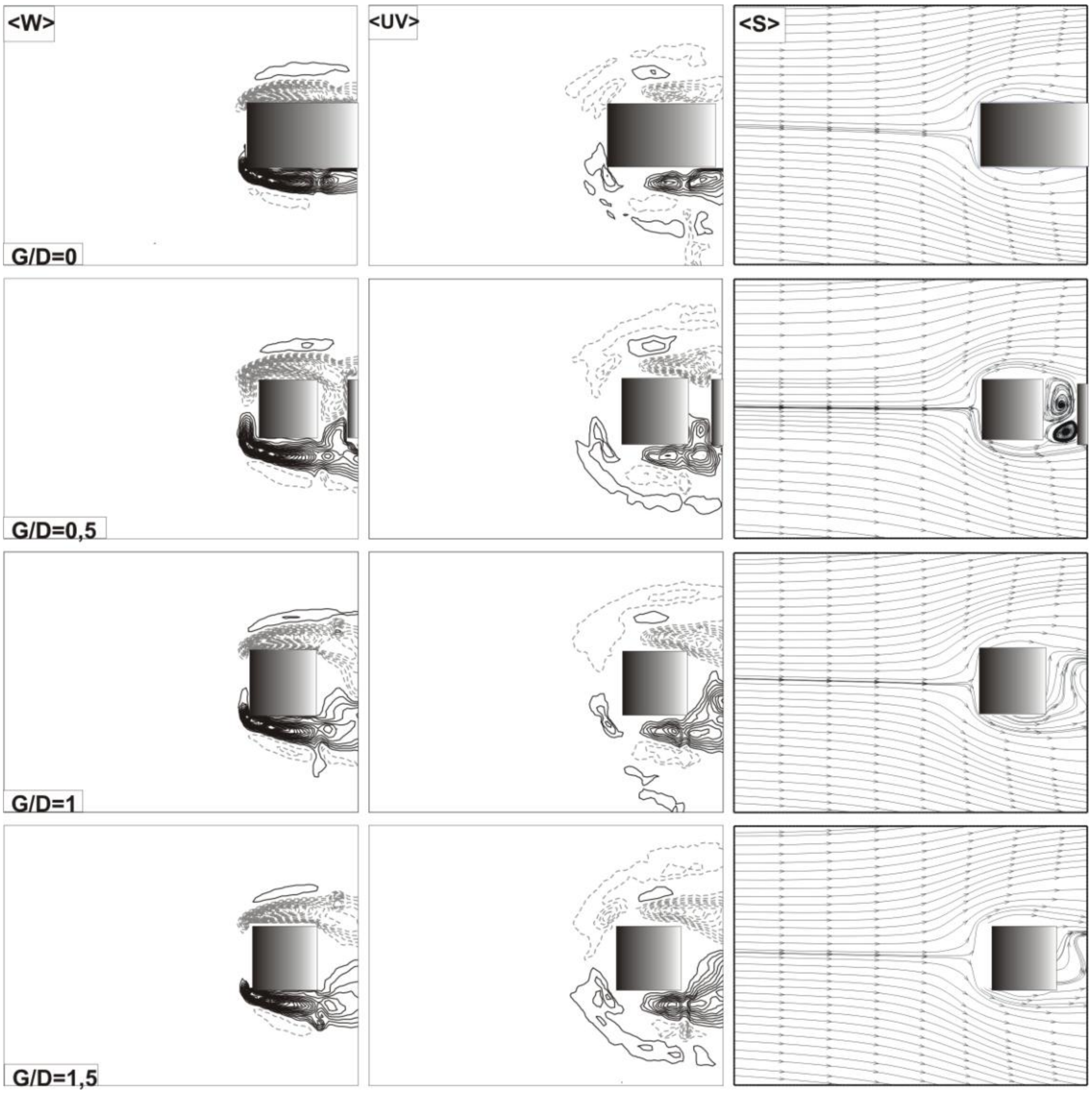

Figure 5. Time-averaged Reynold stress, <u'v'> and vorticity contours, <ω> in the view section of the flow behind upstream cylinder of two cylinders in tandem arrangement with G/D 0 ÷ 1.5 in plan-view plane. Minimumand incremental values of vorticity are ω_{min} =±2s^{-1} and $\Delta\omega$ =2s^{-1} at camera position-A.

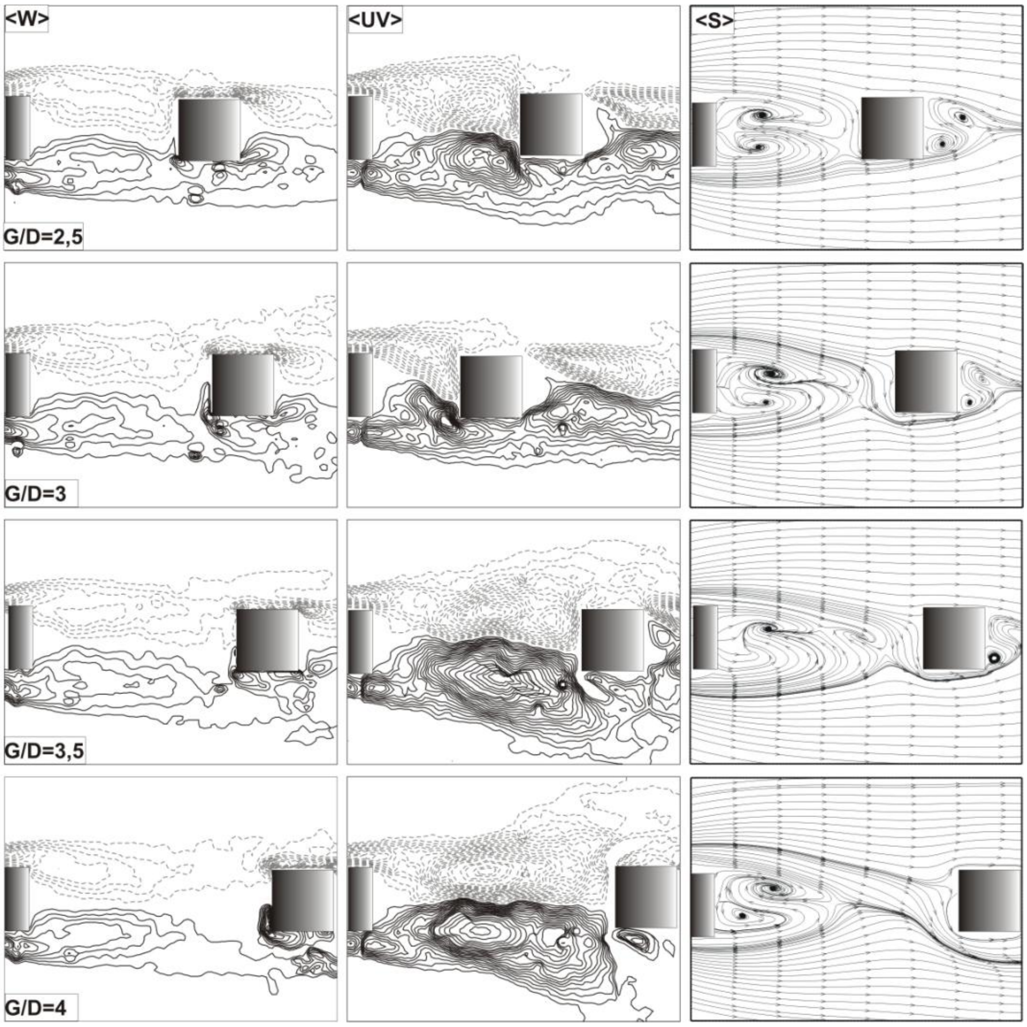

Figure 6. Time-averaged Reynold stress, <u'v'> and vorticity contours, <ω> in the view section of the flow behind upstream cylinder of two cylinders in tandem arrangement with G/D 2.5 ÷ 4 in plan-view plane. Minimum and incremental values of vorticity are ω_{min} =±2s^{-1} and $\Delta\omega$ =2s^{-1} at camera position B-C.

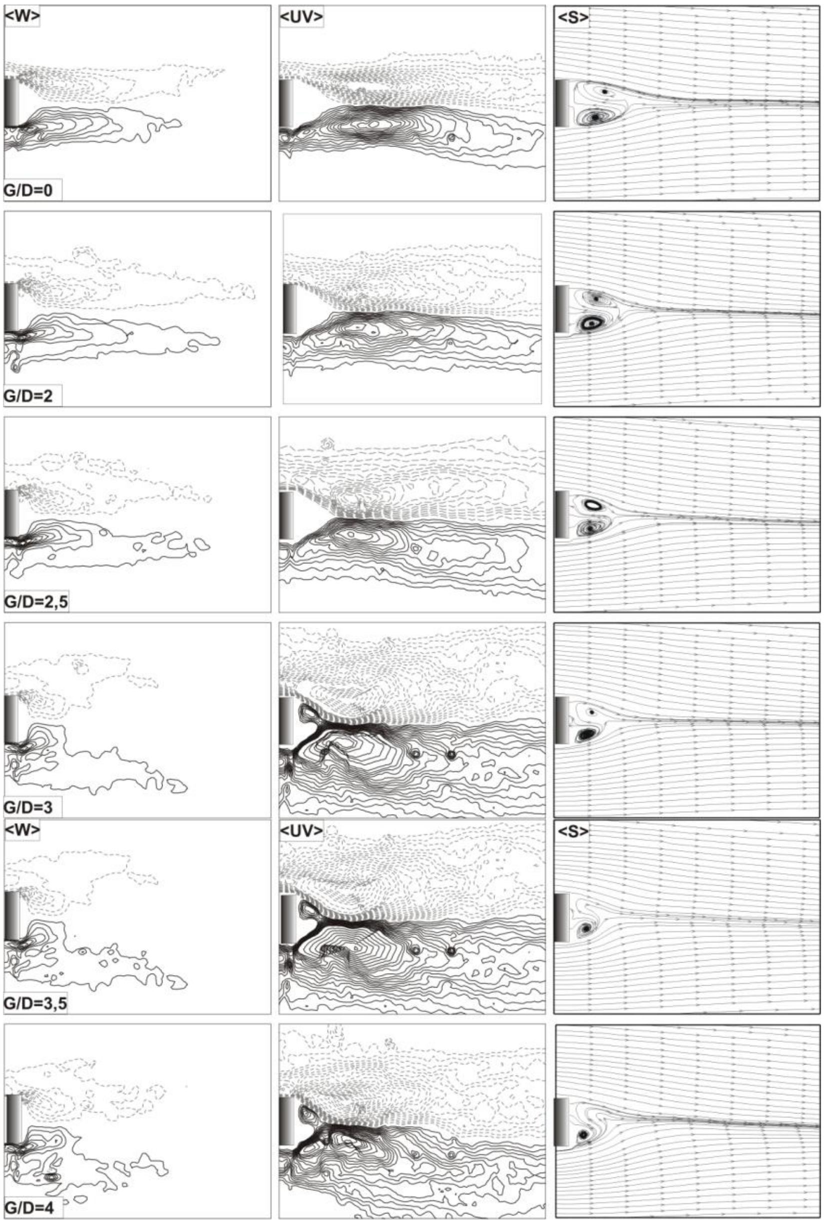

Figure 7. Time-averaged Reynolds stress, <u'v'> and vorticity contours, <ω> in the view section of the flow behind downstream second square of two cylinders in tandem arrangement with G/D 0 ÷ 4 in plan-view plane. Minimum and incremental values of vorticity are ω_{min} =±2s^{-1} and Δω =2s^{-1} at camera position-D.

Velocity vector field was obtained from Particle Image Velocimetry (PIV) Technique and using this velocity vector field, corresponding vorticity contours, Reynold Stresses and streamline topology were calculated using 350 instantaneous images.

During this experimental study, the effect of the distance (G) between the two square cylinders was investigated. In order to understand the effect of the distance between cylinders, three different set of experiments were performed: side view, plane view at the bottom section (L = 2 mm) and plan view at mid-plane (L = 7 mm). For each experiments, the distance (G) between the cylinders were changed in the interval of 0 mm and 140 mm, corresponding to a dimensionless gap ratio of G/D = 0 to 5.

As results; each experiment has a critical G/D ratio, flow develops its character after this critical ratio and other cylinder effects as appearing or disappearing directly related with the distance between cylinders. Another important point is that the peak concentrations of Reynolds stress occurred very close to the saddle points.

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