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Research Article

Base Bleed Flow Control Tool for Circular Cylinders with three Side-By-Side Arrangements in Shallow Water

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ABSTRACT

In this study, Particulate Image Velocimetry (PIV) was utilized to determine the flow characteristics of three side-by-side circular cylinders with a base bleed. The height of the water was set as h_W=20 mm which has characteristics of shallow water and flow images were captured from an elevation of h_L/h_W= 0.5 (mid-plane of water height). The freestream velocity of water and circular cylinder diameters were chosen as U_∞=0.125 m/sec and D=40 mm, respectively which are the corresponding Reynolds number of Re_D=5000. Three different gap/diameter ratios between the cylinders were tested as G/D=1.0, 1.25, and 1.5 throughout the experiments. As a passive flow control technique, base bleed slots located through the cylinders were used with the dimensionless width ratio of B/D= 0.05 to 0.25 with 0.05 increment. As a result of the study, the base bleed was found out an effective way to control unsteady wake. Besides, whereas the increasing height of VSP results in further decrement turbulence statistics, Increasing the width of base bleed leads to a reduction of maximum Reynolds shear stress concentration. Nevertheless, jet deflection flow cannot be avoided for the G/D=1.25 while, flow deflection is avoided with all base bleed case the gap ratio increases to G/D=1.5. The wake size of each cylinder is almost the same for G/D=1.5.

1. Introduction

Turbulent flow around side-by-side bluff bodies can be seen in numerous engineering applications such as bridge piers, marine structures, tall buildings, towers, etc. For these types of applications, it is crucial to understand flow structures. Hence, many numerical, theoretical, and experimental studies were conducted in previous years. Zdravkovich [1] studied side-by-side circular cylinders that have different arrangements to comprehend the phenomena. Unsteady wakes formed behind the objects may cause a structural problem and must be controlled in some way [2]. On the other hand, when it comes to the water flow is shallow, unsteady wakes may have more detrimental effects on the objects [3]. For this reason, flow control becomes more critical for shallow water. Since material enhancement could be high-priced, flow control methods may be a solution in engineering applications to overcome these structural problems [4]. Because of the vital importance of vortex shedding suppression, the flow control methods have been investigated in a widespread manner. The main purpose of an effective flow control is to decrease the magnitude and the resistance of dynamic forces acting on the body, saving waste energy, increasing propulsion energy, and reducing oscillations [5].

Considering the literature, flow control could fall into three groups; passive, active open-loop, and active closed-loop flow control techniques [2]. For active flow control techniques, there is an energy requirement for the system to perform flow control. Moreover, open-loop flow controls do not have any feedback from sensors, whereas closed-loop flow control techniques do. Fransson et al. [6] implemented continuous suction and blowing through the cylinder walls for active, control and investigated the vortex shedding frequency surface pressure distribution, and, the unsteady flow downstream of a porous circular cylinder. They concluded that suction delays flow separation and contribute to narrower wake width, a corresponding drag reduction while blowing effects oppositely. Sudhakar and Vengadesan [6] applied harmonic oscillating splitter plates (L/D=1). They pointed out that their technique showed almost the same effect of flow control as the static splitter plate which has an (L/D=5) length/cylinder diameter ratio. Consequently, they advised the method suitable especially for applications that have space constraints.

As for passive control, there is no power input required; flow control is performed by structural modification on the body or adding some instruments to the flow area [8]. In literature, there are a lot of passive flow control techniques. Base bleed, wavy cylinder, surface protrusions, and cylinder perforation are some of these flow control techniques [9]–[14]. Splitter plates placed in a flow medium are also one of the most studied passive flow control techniques by researchers. Gerrard [15] researched the effect of splitter plate length on turbulent flow formed behind the cylinder. He observed that when the splitter plate length is less than the cylinder diameter Strouhal Number decreases, however when the splitter plate length is two times greater than the cylinder diameter Strouhal Number increases. They also indicated when the length of the splitter plate flow control element is five times greater than the cylinder diameter, vortex formations disappeared. Kwon and Choi [16] reported for laminar flow after a critical plate length which depends on Reynolds Number, vortex flow separations vanished completely. Hwang et al. [17] analyzed the effect of a splitter plate without

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any contact with the cylinder on flow statistics. As a result of their study, they determined an optimum point where the plate should be placed, and in case of any further placement of that point, the plate loses its effect on flow control. Akilli et al. [18] implemented a splitter plate behind a singular circular cylinder to control flow behavior in shallow water using the PIV technique. For another splitter plate investigation, Akilli et al. [19] observed the flow structure behind the cylinder contacting splitter plates has different lengths. For both studies, it was seen that plates have changed flow structure significantly. The formation of a large-scale Von Karman Streets vortex was prevented as well. Flow characteristics and control flow control methods for side-by-side arrangements also have been studied by many scientists [3], [20]–[22].

Most of the previous experiments were conducted in test sections of large depths compared to the width of the wake. However, many turbulent shear flows exist in shallow environments where the horizontal length scale is significantly large compared to the depth of the flow field [23]. Many wake flows can be characterized as shallow turbulent flow in nature e.g. most notably at the merging of two rivers or in wide rivers, at entrances to lakes, in shallow lakes or in the upper mixed layer of deep stratified lakes, in estuaries, in shallow coastal waters and the stratified atmosphere. The wake regions in shallow water also occur in a variety of engineering applications, e.g. behind a bridge pier, other types of hydraulic structures, in various types of channels and reservoirs. Most of the wakes of island is said to be shallow because, the horizontal length scale of the flow is approximately two the orders of magnitude larger than their depths.

In this paper, a base bleed as a passive flow control element was attached side-by-side by three circular cylinders and this cylinder system was investigated in shallow water to diminish turbulence statistics and vibrations. Flow characteristics captured at the elevation of $h_L/h_W = 0.5$ were observed for each base bleed configuration which has the width ratio of B/D=0, 0.05, 0.1, 0.15, 0.2, and 0.25 for the gap/diameter ratios (G/D) of 1.0, 1.25 and 1.5 during all experiments.

2. Material and Methods

2.1. Materials

PIV is an experimental technique to investigate the instantaneous velocity vector field of the studied area where the velocity is measured from the displacement of particles freely moving in the flow field is lightened by a laser sheet. The turbulence intensity in the water channel in the section is below 0.1 % owing to a honeycomb screen arrangement of the water channel. The speed of the water was controlled by an axial flow pump whose rotation speed was under control by an ABB controller unit. The experiments were conducted at Cukurova University, Mechanical Engineering Fluid Mechanics Laboratory. The circulating open water channel of PIV has $8000 \times 1000 \times 750$ (in mm) length, width, and height, respectively. The temperature was 22° C and kept constant in the PIV laboratory throughout experiments. A demonstration of the water channel used in this study is shown in Figure 1.

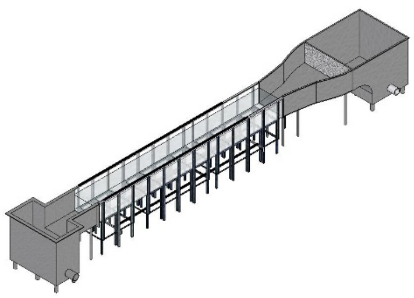

Fig. 1. The water channel

The measured area was lightened by an intense and thin laser sheet source by utilizing a pair of Nd:YAG (yttrium aluminum garnet) double-pulsed laser units whose output of maximum energy is 120 mJ at 532 nm wavelengths. The laser sheet thickness was almost 2 mm. The time interval between pulses was kept at 1.75 ms for all measurements. The time interval and the thickness of the laser sheet were determined so that the maximum number of particles was attained in the flow field. The particle numbers in an investigated flow field vary between 20-25. The velocity uncertainty which is related to depth-averaged velocity was approximately 2%. The flow was seeded with 10 μm diameter silver particles. Instantaneous photos were taken to get time-averaged velocity vectors and the other turbulence statistics of the wake flow. Spurious and parasitic velocity vectors (less than 3%) were clarified by the way of the local median-filter technique.

To prevent extraordinary variations in the velocity field, the velocity vector field was also smoothed by the Gaussian smoothing method. Time-averaged velocity (<v>), vorticity (<ω>), and Reynolds stress (<u'v'>) contours can also be acquired from a velocity vector map. Images at a rate of 15 frames/sec. were taken by a 1024×1024 resolution CCD camera. Images are captured from a field with an area of 140 mm x 190 mm which is downstream of the cylinders. The post-processes were conducted by FLOW MANAGER Software and the Dantec Dynamics Particle Image Velocimetry system. A schematic representation of experiments can be seen in Figure 2.

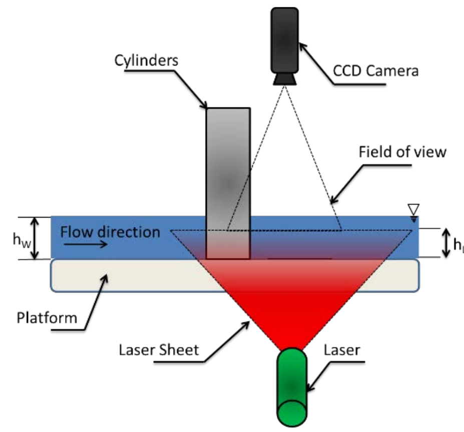

Fig. 2. Schematic representation of the PIV experiments

2.2. Methods

All measurements were conducted above a fixed platform with a length of 2300 mm to attain fully developed shallow water flow conditions. The freestream velocity was U_∞=0.125 m/sec and correspondingly, Reynolds Number is Re_D= 5000 based on the diameters of the circular cylinders which were D=40 mm. During all measurements, the height of the water was (h_W) kept at the depth of 20 mm. The measurements were fulfilled at the mid-plane of shallow water (h_L/h_W=0.5). The schematic orientation of the imaging view of the experimental setup can be seen in Figure 3.

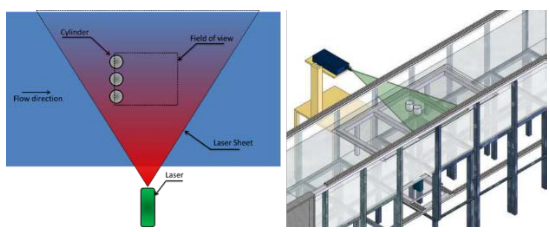

Fig. 3 Schematic orientation of plan view (right) and isometric view (left) of the experimental setup

A view of the experimental setup of the three side-by-side cylinder configurations with base bleed flow control element is shown in Figure 3. The slot width of the cylinders is between 2 mm - 10mm, with an increment of 2 mm, corresponding to the width of slots to cylinder diameters ratios of B/D = 0.05, 0.1, 0.15, 0.2, and 0.25. The base bleed height was kept same as water height during the experiments. The identification of G, D, and B is presented in Figure 4. The effect of changing the gap ratios G/D= 1.00, 1.25, and 1.50 as a function of slot width on flow structure was determined by qualitative analysis of the near wake. Water tunnel PIV measurements were performed for three side-by-side cylinder configurations.

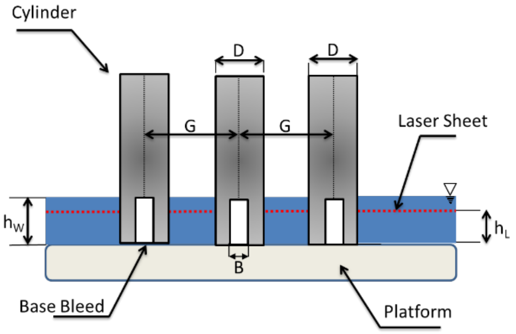

Fig. 4. The view and dimensions of the cylinder arrangements in the PIV measurements

3. Results and Discussion

The validation of these experiments is performed by singular circular cylinder tested with same Reynolds number. According to the previous studies [24], a circular cylinder in the water has Strouhal number of 0.225 at Re_D=5000 which is good agreement with this study (St=0.225).

There are numerous investigations on shallow water flow passing circular cylindric blunt bodies have been conducted to elucidate characteristics of large-scale wake instability downstream of cylinders. Relatively a few studies have been carried out controlling large-scale vortical flowa in shallow water. The focal point of this part is to evaluate the near wake vortex formation and prevent biased flow downstream of the cylinders arranged side-by-side by the way of a base bleed flow control located central portion of the cylinders. The jet flow injected into the near-wake regions through slots of the cylinders does not require an external energy source therefore, the base bleed methodology can be considered as a passive flow control technique.

In Figure 6, cylinders without the flow control are shown for G/D ratios of 1.0, 1.25, and 1.5. In Figure 6, time-averaged flow features behind three cylinders with side-by-side arrangements as a function of G/D for dimensionless base bleed width of B/D=0.05 are shown. The first row of the figure illustrates the flow characteristics for G/D=1.0. Flow structures for this gap ratio have many similarities compared to base configuration (without base bleed). Flow characteristics for the G/D=1.25 arrangement can be seen in the 2nd row. A wider wake region seems downstream of the central cylinder. Base bleed with the width ratio of B/D=0.05 does not affect the flow downstream of the cylinder much. No effective flow control for G/D=1.5 configuration is observed in the 3rd column. As result, the dimensionless slot width ratio of B/D=0.05 does not affect flow characteristic downstream of 3 side-by-side cylinders.

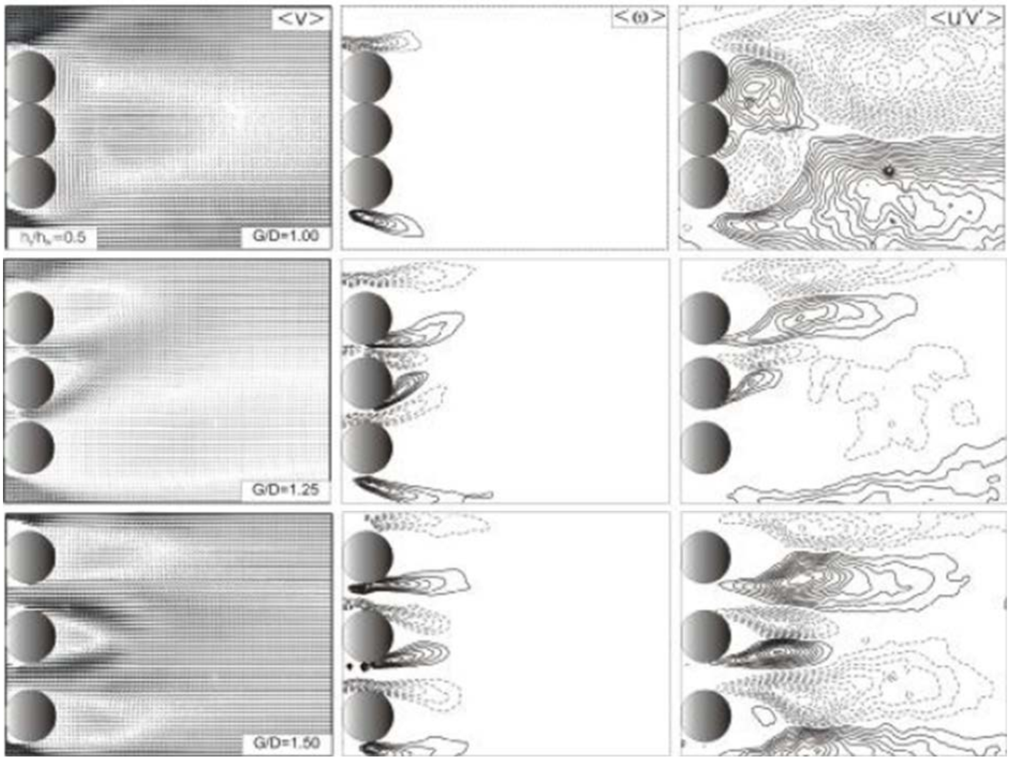

Fig. 5. 3 Side-by-side cylinders configurations without flow control and G/D ratios of 1.0, 1.25 and 1.5

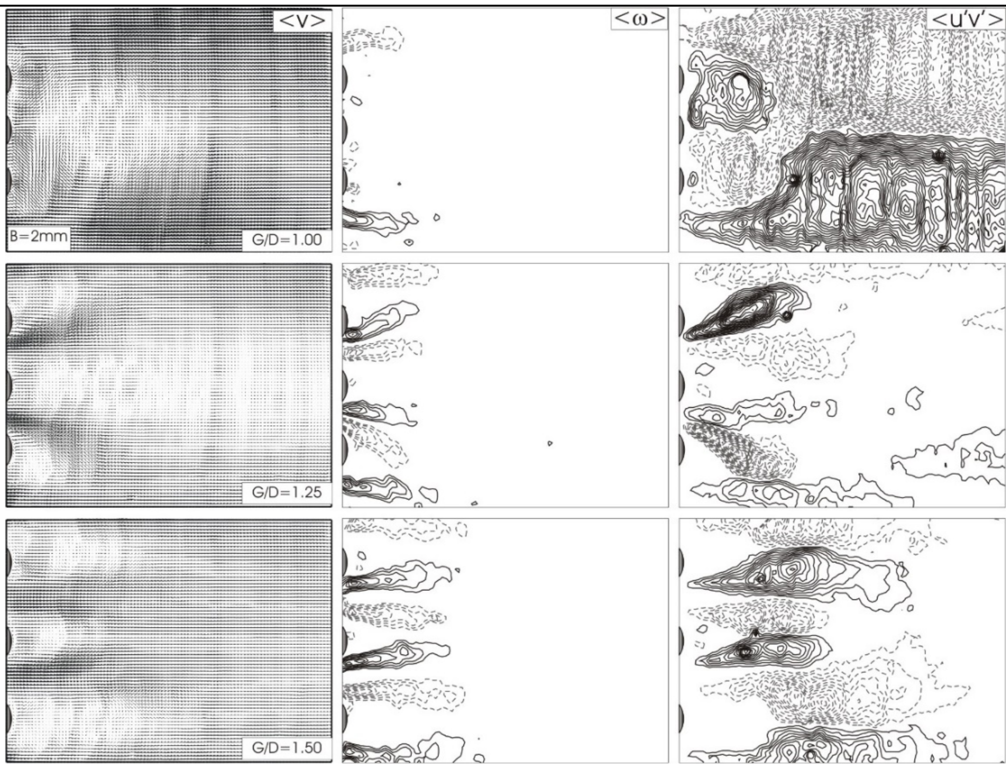

Fig. 6. Flow characteristics at the near wake of 3 side-by-side cylinders arrangement with base bleed having a slot width of B/D = 0.05 as a function of G/D.

When the base bleed is applied with the B/D=0.1 case, remarkable changes can be seen obviously in the flow structure (Figure 7). For the gap ratio of G/D=1.0, (shown in the first row of the figure), the wake region is extended further downstream, and the saddle point also moves further downstream, and the peak value of Reynolds shear stress reduces. Small-scale vortical structures are observed at the exit of the slots. The 2nd row of the figure presents the time-averaged flow structure for the G/D=1.25 case. It can be seen that flow is deflected downstream of the cylinders. Moreover, the maximum value of Reynolds shear stress concentration reduces slightly.

The third row for the G/D=1.5 case reveals that the slot width ratio of B/D=0.1 changes the flow characteristics, too. Flow deflection is controlled moreover, Wake size of each cylinder is almost same. The peak concentrations are lower than B/D=0.05 arrangements.

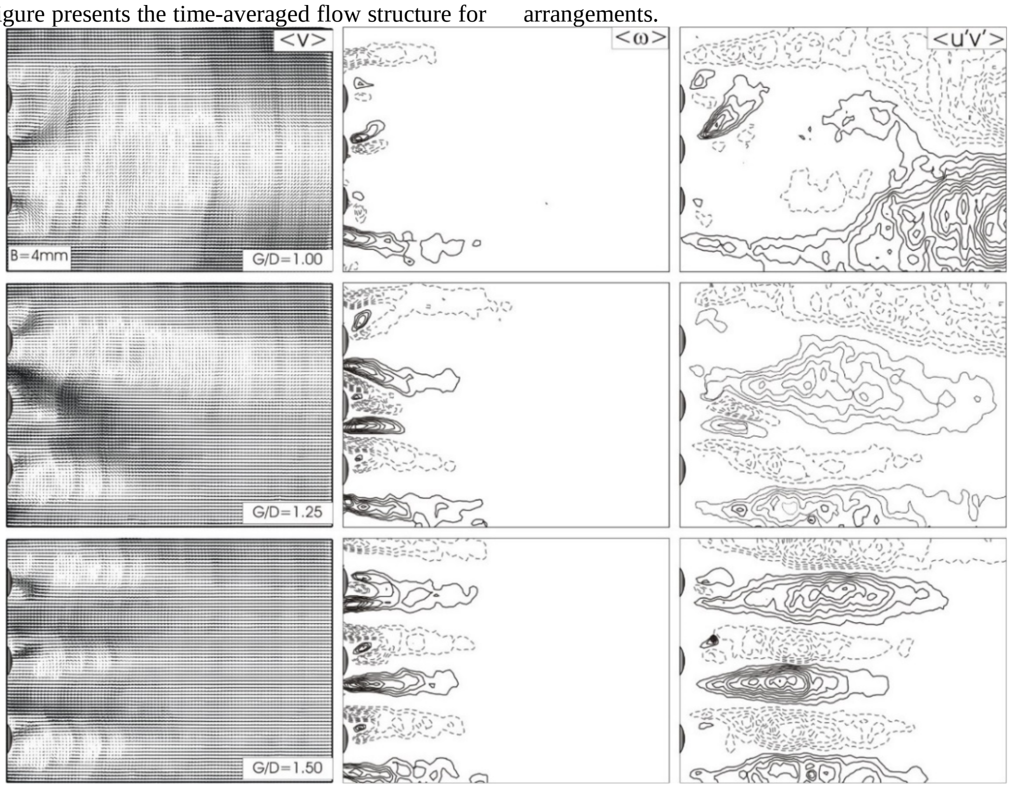

Fig. 7. Flow characteristics at the near wake of 3 side-by-side cylinders arrangement with base bleed having a slot width of B/D = 0.1 as a function of G/D.

Figures 8, 9, and 10 depict the time-averaged velocity vector field, vorticity contours, and concentrations of Reynolds shear stress as a function of G/D ratio for B/D= 0.15, 0.2, and 0.25, respectively. The wake region is extended further downstream of the cylinders and maximum Reynolds stress concentration reduces with the increment of B/D, as a general trend for the G/D=1.0 case. Small-scale vorticity and Reynolds stress concentrations can be seen at the exit of the base bleeds. The wake region shrinks in the transverse direction with an increment of slot width ratio. The jet flows from the slots deflect towards the shear layers. For G/D=1.25, jet flows between the cylinders are deflected towards the outer sides of the wake. Reynolds shear stress concentrations are reduced compared with the B/D=0.1 case. The wake region of the central cylinder is wider for B/D=0.15 and 0.2 cases.

As to the G/D=1.5 case, remarkable flow control is sustained for all base bleed configurations. The maximum Reynolds shear stress concentrations are approximately constant for all three slot widths.

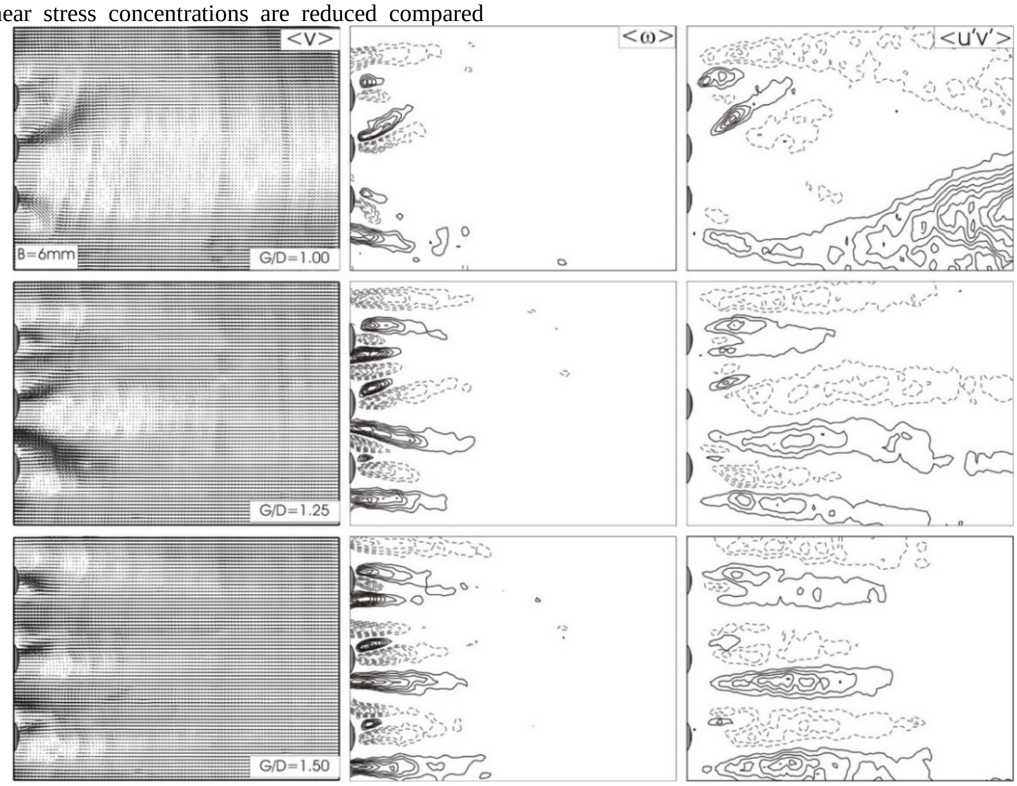

Fig. 8. Flow characteristics at the near wake of 3 side-by-side cylinders arrangement with base bleed having a slot width of B/D = 0.15 as a function of G/D.

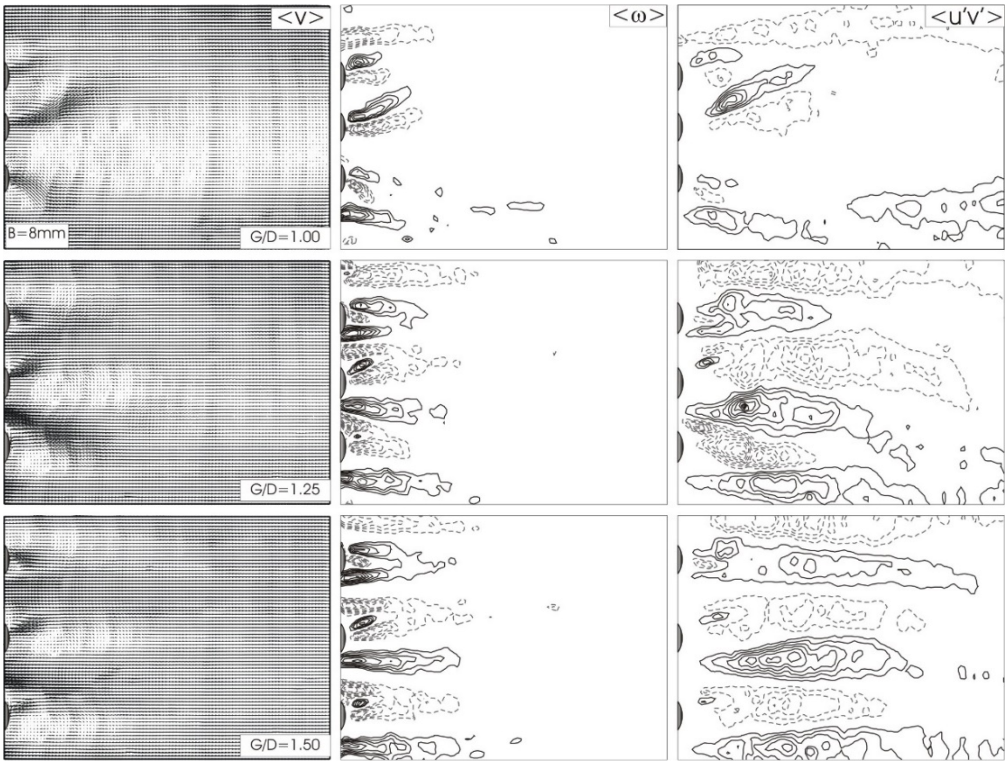

Fig. 9. Flow characteristics at the near wake of 3 side-by-side cylinders arrangement with base bleed having a slot width of B/D = 0.20 as a function of G/D

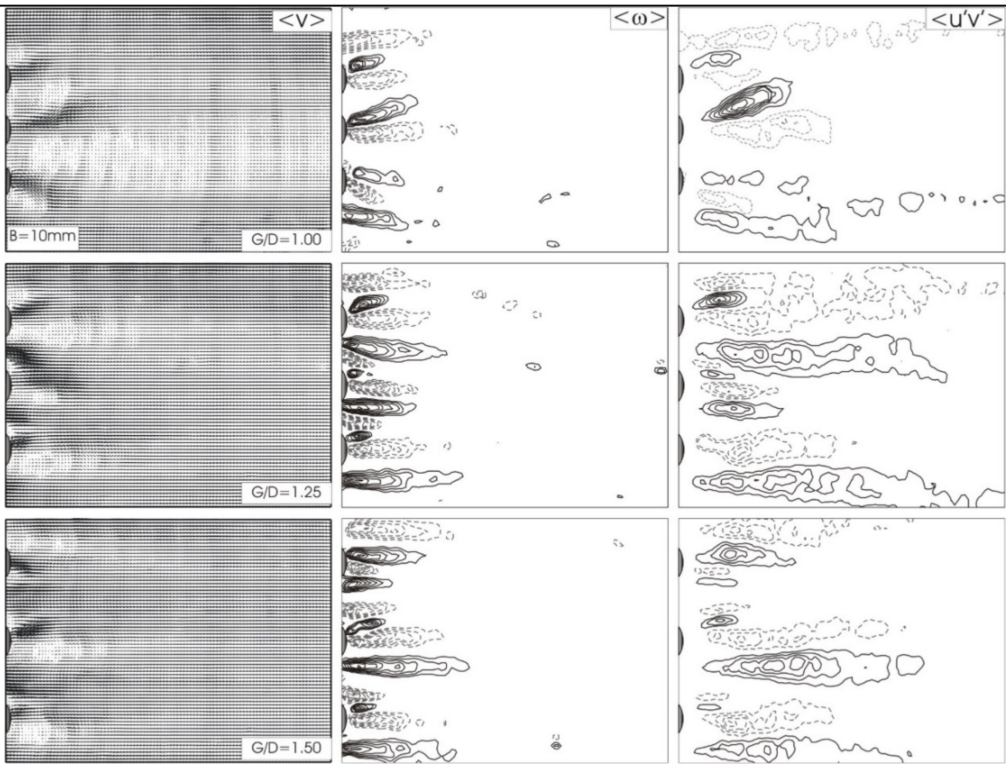

Fig. 10. Flow characteristics at the near wake of 3 side-by-side cylinders arrangement with base bleed having a slot width of B/D = 0.25 as a function of G/D.

4. Conclusions

In this study, base bleed with different width ratios was investigated to control unsteady flow downstream of side-by-side circular cylinders by the usage of the PIV technique in shallow water (h_W=20 mm). The base bleed width ratio (B/D) was varied from 0 to 0.25 with a 0.05 increment. Circular cylinders had a diameter of D=40 mm and the free stream velocity of water was U_∞=0.125 m/sec which was corresponding to a Reynolds number of Re_D=5000. The image capturing was carried out from the elevations of h_L/h_W= 0.5. Three different gap sizes between the cylinders were used with G/D=1.0, 1.25, and 1.5 during the experiments. Contours of the velocity vector field, vorticity, and Reynolds stress correlations were utilized to investigate turbulence statistics of the flow.

All base bleed configurations have a great effect on the flow characteristics, albeit at different levels. The maximum value of Reynolds shear stress concentrations is reduced by the increment of slot widths. Nevertheless, no-effective jet flow deflection can be ed for the gap ratio of G/D=1.25 for the three-cylinder case. When the gap ratio is increased to G/D=1.5, the deflected flow is prevented with all slot widths. The size of the wake of each cylinder is approximately the same for the G/D=1.5 case.

In this paper, the effects of the base bleed flow control method for 3 side-by-side circular cylinders were investigated in shallow water flow. As a future work, 3D experimental investigations with a 3-D PIV system should be considered to identify the 3rd velocity component and evaluate the three-dimensional effect of the flow field of side-by-side cylinders. Moreover, the base bleed flow control elements for three side-by-side cylinder experiments performed in shallow water may be conducted in deep water to test the effect of slots on the two-dimensional flow structure. Besides, different control techniques such as base bleed with diverging or converging diffuser shapes can be used to control unstable and vortical flow structures around the side-by-side cylinder. Besides, investigations on drag and lift measurements and spectral analysis could be conducted to have more information about the effect of base bleed on flow control for side-by-side circular cylinders in shallow water.

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Declaration of conflicting interests

The authors declare no competing interests.

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