FLOW STRUCTURE AROUND IN-LINE HORIZONTAL CIRCULAR CYLINDERS AT DIFFERENT ELEVATIONS IN SHALLOW WATER

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Abstract

In this study, the flow characteristics around in-line horizontal circular cylinders were investigated using PIV technique in shallow water. The diameter of both circular cylinder, height of shallow water and free stream velocity were constant during the experimental study as D=30 mm, h_w=60 mm and U=167 mm/sn, respectively. Particle Image Velocimetry (PIV) was used to measure the instantaneous velocity vector field in the wake region at Reynolds number Re_D = 5000 based on the cylinder diameter. In order to investigate the effect of the gap between two horizontal cylinders, gap was increased from 0 to 90 mm with 15 mm increments and gap was increased from 90 to 150 mm with 30 mm increments. In addition to gap, the other parameter was the submergency level, elevations between bottom and free-surface. The eight different elevations were used from 7.5 to 60 mm with 7.5 mm increment (h_D/D= 0.25 – 2) during the experiments. The mean velocity vector field, corresponding streamline topology and Reynolds Stress correlation were obtained using 500 instantaneous images. The observation showed that the second cylinder attenuate the size of the wake region for L/D=0 case. The wake region clearly occurs between cylinders beginning of L/D=1 case. As the gap between cylinders rises, the size of the wake region increases.

Key words: horizontal cylinder, flow around the pipeline, particle image velocimetry

1. Introduction

Vortex shedding behind a circular cylinder not only is an important fundamental question in fluid dynamics because of the geometric simplicity, but also is in various areas of engineering and science because of the practical importance. These areas include mechanical and aerospace engineering, power and process industries (turbine blades, heat exchanger tubes, cooling systems for nucleer power plants, power transmission lines), civil engineering (chimney stacks, bridges, buildings, radio telescopes, ice dams, offshore structures, power lins), and undersea technology (offshore drilling rigs, underwater pipelines, marine cables).

Vortex formation from a horizontal cylinder coincident with a free surface of shallow water has been examined by Kahraman et al. [1] using PIV technique. They found that the variation of reattachment location of the separated flow to the free surface is a strong function of the cylinder

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diameter and the Froude number. On the other hand, the flow characteristic of the[1] horizontal cylinder placed on the plane boundary has been investigated by Akoz et al. [2] using particle image velocimetry technique. They found that intersection of the bed surface and cylinder enhanced the burial mechanisms hydrodynamically even in wake flow region. And the wake flow region was shortened in size in longitudinal direction as a function of Reynolds number. Lin et al. [3] has examined the instantaneous and averaged flow structure in past the two cylinders in tandem. They observed both symmetrical and asymmetrical patterns within the gap. When the gap was sufficiently large, Karman-like vortices formed between the cylinders. And both the wake width and the magnitude of the Reynolds stresses became larger, relative to those at smaller gap width in the near-wake of the downstream cylinder. The flow behaviour around two circular cylinders arranged in tandem has been investigated by Tsutsui [4]. He found that the separated shear layer from the upper and lower sides of the first cylinder alternately reattach to the upper and lower sides of the downstreem cylinder. He also noticed that the gap flow was pushed back by the flow where reattached to the lower side of the second cylinder. Singha and Sinhamahapatra [5] has examined the flows over two circular cylinders in tandem for a range of Reynolds numbers with varying gap size at low Reynolds number numerically. They found that flow field was significantly influenced by gap between cylinders and Reynolds number. Sumner et. al. [6] has studied the impulsively started flow field for circular cylinders arranged in tandem using flow visualization and particle image velocimetry (PIV). They determined three different types of fluid behaviour based on L/D: single bluff-body behaviour when the cylinders were in contact, constrained streamwise growth and lateral expansion of the gap recirculation zones at small and intermediate L/D, and independent formation of recirculation zones similar to a single impulsively started circular cylinder at larger L/D. Huarte and Gharib [7] has examined the dynamic response of two flexible cylinders in tandem arrangement partially immersed in a uniform flow. They determined that the centre-to-centre separations were chosen to fall in the regime in which two separate wakes exist behind each one of the models. They noticed that the main excitation mechanism was wake-induced vibration (WIV). They concluded that the rear cylinder showed large amplitudes of response, at reduced velocities over the expected ones at lock-in when a cylinder was undergoing VIV being isolated.

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In the present study, the flow characteristics around in-line horizontal cylinders have been represented for different elevations. Aim of this experimental study first of all is to demonstrate the flow structure away from both the free and bottom surfaces in the near wake region. This study focuses the effect of the second cylinder on flow structure. The effect of the gap between two horizontal cylinders was investigated.

2. Experimental set-up

The experiments was carried out in a closed-loop water channel. The overall dimension of the water channel was 8000 mm in length, 1000 mm in width and 750 mm in depth. In this study, investigation of flow characteristics around in-line horizantal circular cylinders was observed changing gap between cylinder and immersion level (h_D/D) of the both cylinders ranged from 0.25 to 2 with 0,25 increments from the surface. All experiments was carried out in shallow water. The water level of shallow water (h_w) was 60 mm. For each cylinder, value of diameter was 30 mm. The test section was constructed of 15 mm thick clear Plexiglas sheet and top was a free surface. In figure 1 schematic of experimental set up was shown. The free stream velocity was U=167 mm/sec, which represented a value of Reynolds number based on cylinder diameter of between Re_D= 5000. The experiments were conducted in the water channel for two-cylinder configuration with L/D varied from 0 to 3 with 0.5 increments and varied from 3 to 5 with 1 increments.

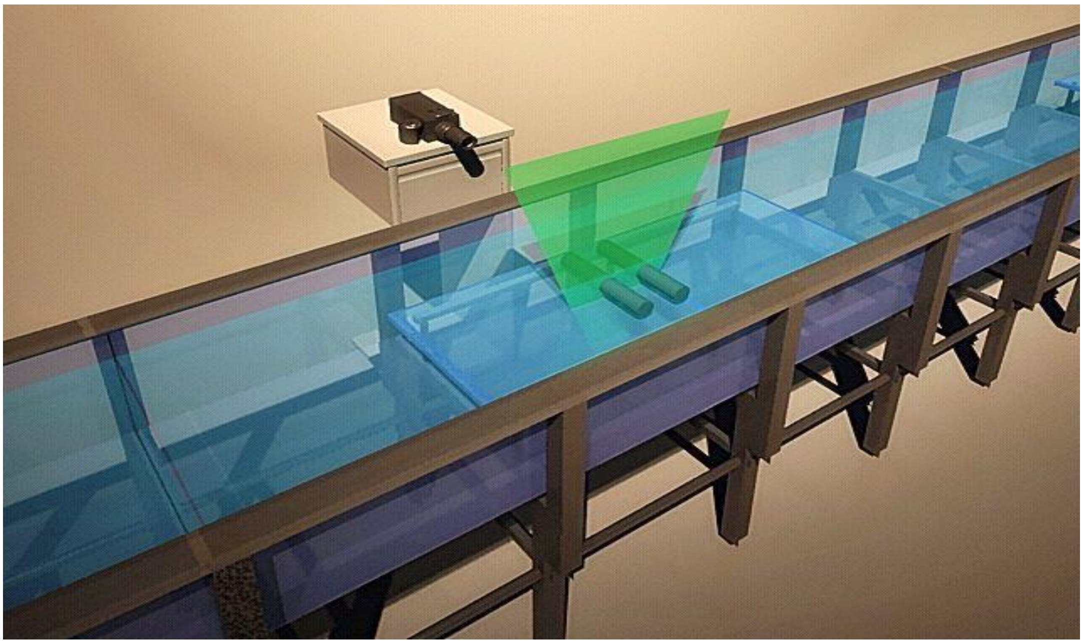

Figure 1. Experimental Set up

Using the PIV technique, instantaneous velocity vectors was measured in a region illuminated by a two-dimensional laser sheet. Velocity vector measurements was carried out using Dantec PIV system. The flow field illumination was provided by two Nd: Yag pulsed laser sources of a wavelength of 532 nm, each with a maximum energy output of 120 mJ. Dantec Dynamics Processor, that was controlled the timing of the data acquisition, was used to synchronize the image taking and laser unit. Particle image velocimetry measurements were taken in two different plan in order to observe both area between two cylinder and area behind second cylinder. In first plan, flow characteristic which was mainly observed, was the area between two horizantal cylinders. In second plan, flow characteristics which was greatly observed, was the area behind the second cylinder. The image capturing was performed by an 8-bit cross-correlation charge-coupled device (CCD) camera having a resolution of 1,600 pixels x 1,200 pixels, equipped with a Nikon AF Micro 60 f/2.8D lens. In the image processing, 32 x32 pixels rectangular effective interrogation windows was used. The total 3,168 (99 x 32) velocity vectors were obtained for an instantaneous velocity field at a rate of 15 frames/s. The time interval between pulses was 1.750, and the thickness of the laser sheet illuminating the measuring plane was nearly 2 mm throughout the experiments. Erroneous vectors will be removed (less than 2%) and replaced by using interpolation between surrounding vectors in the post-processing step. The vorticity patterns of the wake flow will be calculated from the velocity field using a finite difference scheme. Streamlines and circulation will be obtained by post processing of the velocity data. The overall field of view was 180 x 180 mm^2. Patterns of instantaneous particle images (total of 500 images for a continuous series) was taken at a rate of 15 Hz. In each experiment, 500 instantaneous images were captured and recorded.

3. Results and Discussion

3.1. Flow Behaviour Around In-Line Horizontal Cylinders

As can be seen in Fig. 2, a general trend is that a strong upflow is observed but a weaker deflection occurs in comparison with the bare cylinder case. The intensity and length of the wake region decreases compared to bare cylinder cases because of the presence of the downstream cylinder. Both time-averaged velocity and streamline topology ($<\psi>$) show two foci, F, and a saddle point, S, between cylinders for hD/D=1.5, 1.25 and 1 cases as seen in Fig. 3. These foci, F, between the cylinders are not shedding vortices for hD/D=1 case. They are shear vortices. Moreover, the length of the wake region is the smallest downstream of the second cylinder for hD/D=1.5 case due to the lack of the viscous and free-surface effects because of the increase in momentum transfer.

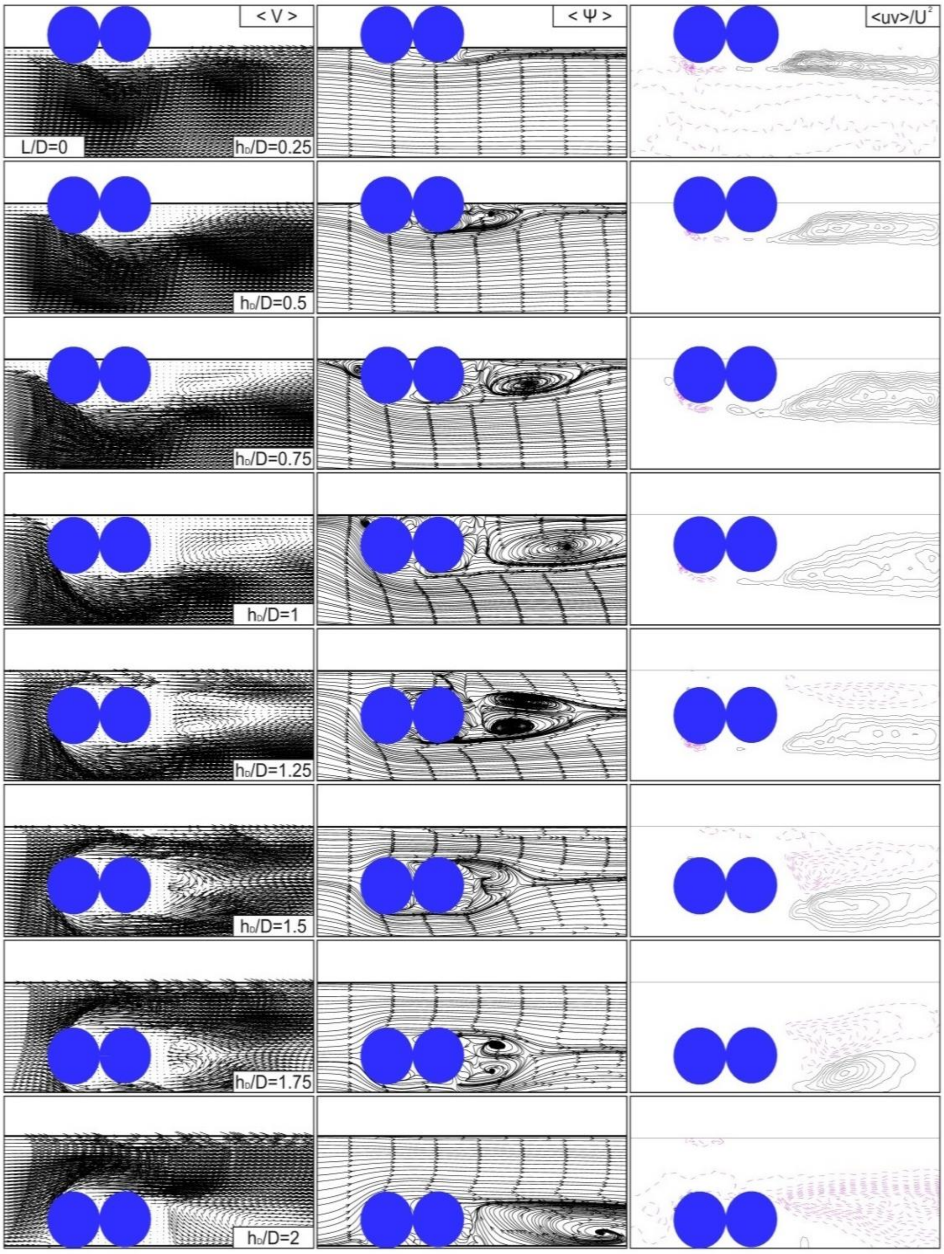

Figure 2. Time-averaged velocity vector fields for various cases of immersion ratio

In Fig. 4, time-averaged velocity vector fields (<V>) shows that, a reverse flow forms a great extent downstream of the second cylinder for $h_D/D=0.75$, 1 and 2 cases compared to $h_D/D=0.5$ case. However, flow structure alters and centers of the foci, F, are closer to second cylinder. Besides, centers of the foci, F, are symmetric but sizes of the foci, F, are different because of the interaction with the second cylinder. For $h_D/D=1.5$ case, size of the bottom side focus, F, is smaller than the size of the upper side focus, F, because bottom surface is more resistant against the flow and amortizes the size of the focus, F.

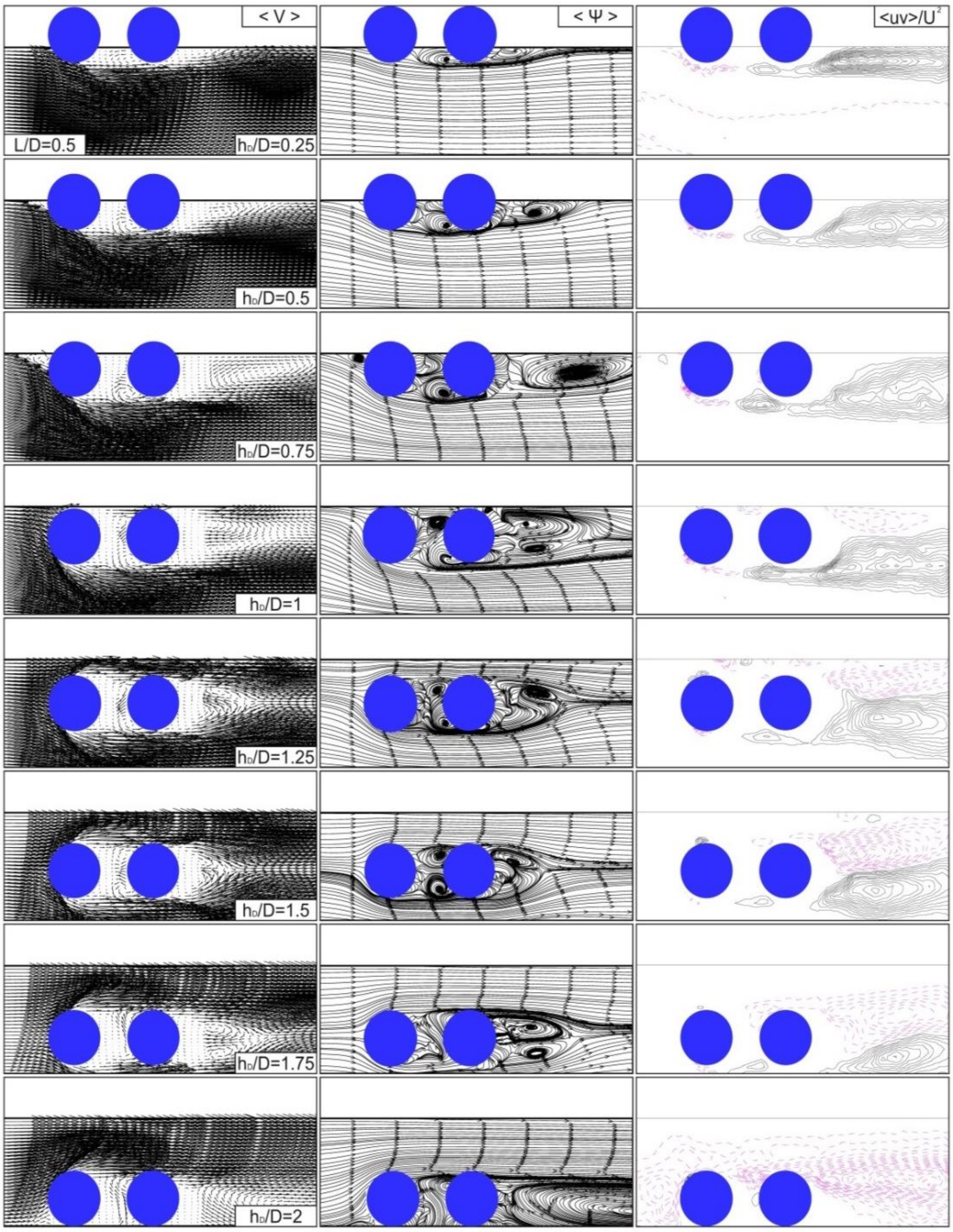

Figure 3. Time-avaraged velocity vector field(<V>), corresponding streamline topology(<ψ>) and Reynolds Stress(<uv/U^2>) (Dashed and solid lines correspond to negative and positive contours, respectively)

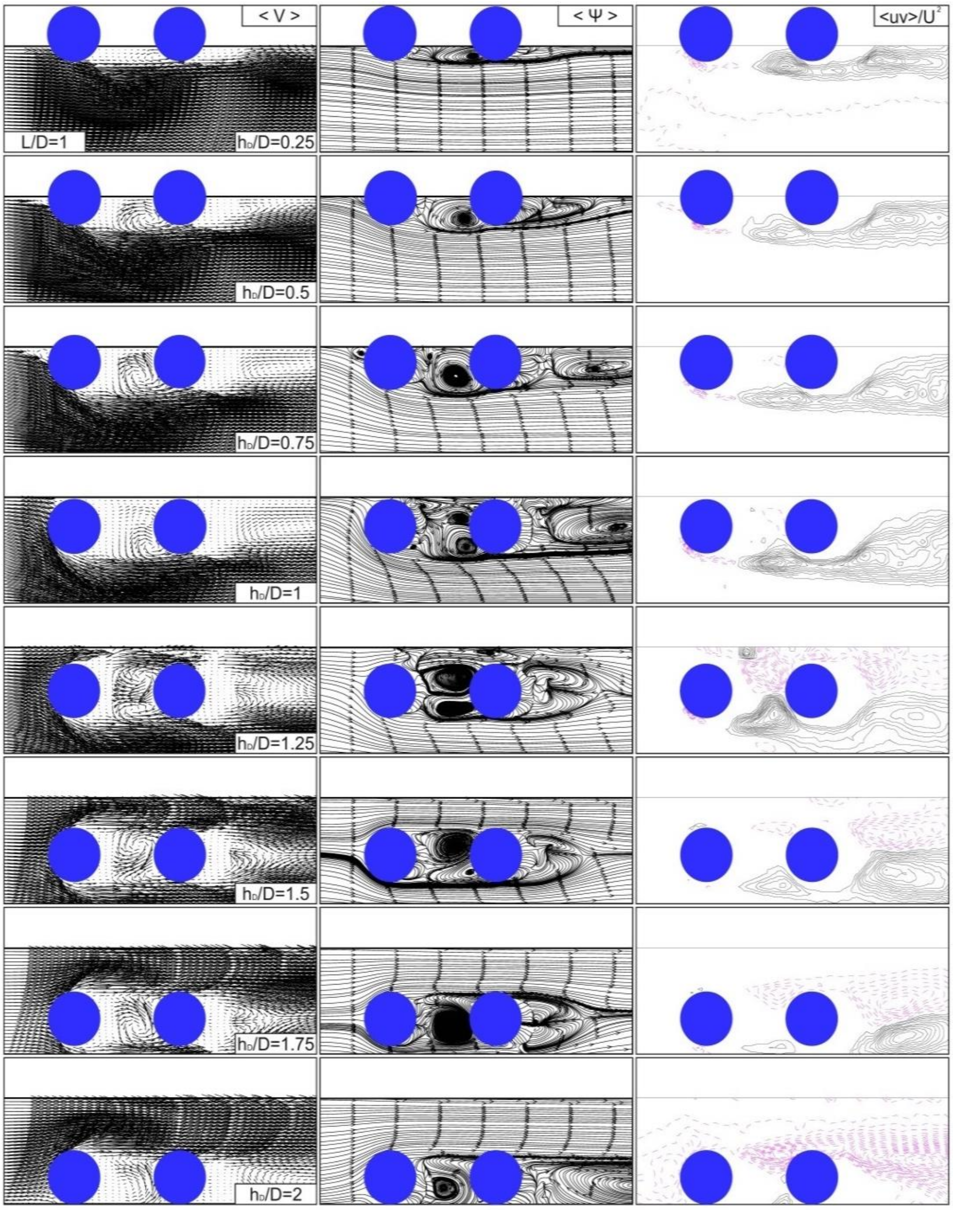

Figure 4. Time-avaraged velocity vector field, corresponding streamline topology and Reynolds Stress for L/D=1

3.2. Variation of Saddle Points Downstream of the Second Cylinder with the Gap Ratio

The variation of non-dimensional saddle points, S, downstream of the second cylinder for three different immersion level ratio are shown in Fig. 5 as a function of the gap ratio. The saddle point, S, and the gap are non-dimensionalized with cylinder diameter. The effect of the second cylinder can be seen clearly for h_D/D=1,25 and 1,75 while the second cylinder has not effective on flow structure for h_D/D=1,5 at L/D=0. Besides, the value of the S/D ratio is smaller for h_D/D=1,75 due to the effect of the bottom surface (viscous effect) compared to h_D/D=1,25. The second important point is that value of the S/D ratio is the same for single cylinder case and h_D/D=1,5 case at L/D=0 configuration. The dimensionless saddle ratio decreases severely for

h_D/D=1,25 case, while it increases for h_D/D=1,75 case at L/D=0,5 configuration. The vice-versa occurance is observed at L/D=1 configuration. At L/D=1,5 and 2,5 configurations, the same S/D value is observed for h_D/D=1,25 and 1,75 cases. After L/D=2,5 configuration, the S/D value is almost same for h_D/D=1,25 and 1,75 cases. On the other hand, theres is no drastically changes in S/D value for h_D/D=1,5 cases.

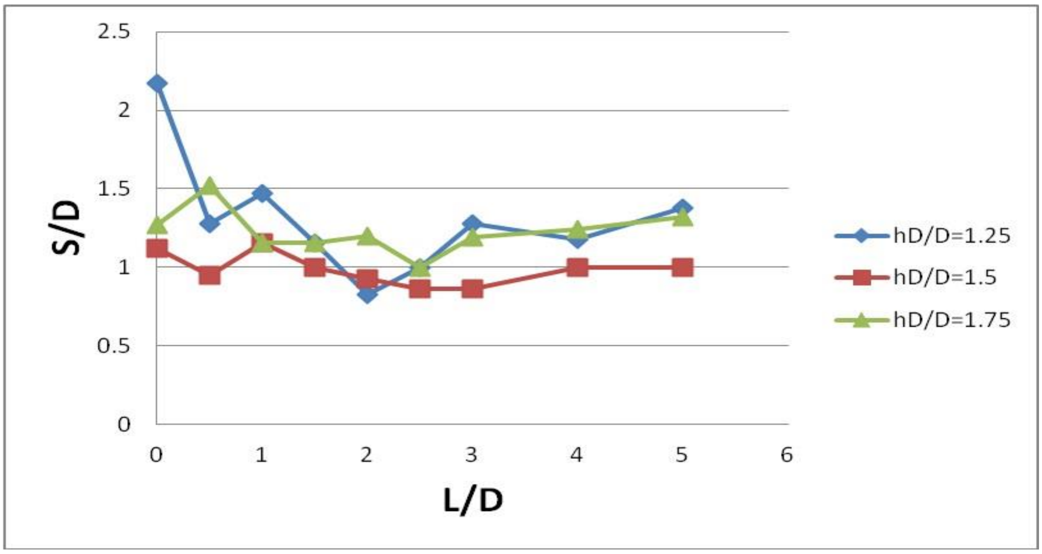

Figure 5. Variation of Saddle points downstream of the second cylinder with the gap ratio

4. Conclusion

PIV experiments were carried out for two circular cylinders in tandem arrangement for the values of L/D=0, 0.5, 1, 1.5, 2, 2.5, 3, 4 and 5. Second cylinder significantly changes the flow characteristics. The second cylinder attenuate size of the wake region for L/D=0 case. The wake region clearly occurs between cylinders beginning of L/D=1 case. As the gap between cylinders rises, size of the wake region increases.

In terms of the Reynolds Stress correlation, wake region elongates in streamwise direction due to the lack of momentum transfer from the free surface and bottom surface for h_D/D= 0.5, 0.75, 1 and 2. However, different results were obtained at these elevations compared to the h_D/D= 1.25, 1.5 and 1.75. Because of increase in momentum transfer, attenuation of wake region is observed. The effect of the second cylinder decreases beginning of L/D=2.

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