FLOW STRUCTURE AROUND A HORIZONTAL CYLINDER AT DIFFERENT ELEVATIONS IN SHALLOW WATER

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Abstract

In this study, the flow characteristics around a horizontal circular cylinder were investigated using PIV technique in shallow water. The diameter of circular cylinder, height of shallow water and free stream velocity were kept 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 submergency, the cylinder was positioned at different elevations between bottom and free-surface (from 7.5 to 60 mm). The mean velocity vector field, corresponding streamline topology and Reynolds Stress correlation were obtained using 500 instantaneous images. As the blockage rate increases, the magnitude of jet-like flow velocity increases for h_D/D=0.25, 0.5, 0.75 and 1 cases.

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

1. Introduction

Vortex shedding behind a circular cylinder is an important fundamental question 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).

The wake flow behavior behind bluff bodies in shallow water flow helps us to understand the transport characteristics of the flow. Akıllı and Rockwell [1] investigated the near wake of a vertical, circular cylinder in shallow water using a combination of visulation marker and particle image velocimetry tecnique (PIV). At the bed, the time- averaged streamline topology downstream of the base of the cylinder takes on a form known as an owl face of the first kind, which was originally defined for a completely different exterior flow. Immediately adjacent to

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[1]the base of the cylinder, an additional system of saddle points is located at either end of a nodal line. At locations above bed, one of the two principle saddle points of the owl face of the first kind disappears and the principle foci are transformed from a stable to an unstable state. Vortex formation from a horizontal cylinder coincident with a free surface of shallow water has been examined by Kahraman et al. [2] 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 diameter and the Froude number. On the other hand, the flow characteristic of the horizontal cylinder placed on the plane boundary has been investigated by Akoz et al. [3] 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.

In the present study, the flow characteristics around a horizontal cylinder 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.

2. Experimental set-up

The experiments was carried out in a closed-loop water channel. The overall dimensions of the water channel were 8000 mm in length, 1000 mm in width and 750 mm in depth.

In this study, the investigation of flow characteristics around a horizontal circular cylinder was carried out changing immersion level (h_D/D) of the cylinder from the surface ranged from 0.25 to 2 with 0,25 increments. All experiments were carried out in shallow water. The water level of shallow water (h_w) was 60 mm. The diameter of horizontal cylinder was 30 mm. The schematic of experimental set up was shown in figure 1. 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. 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. 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.

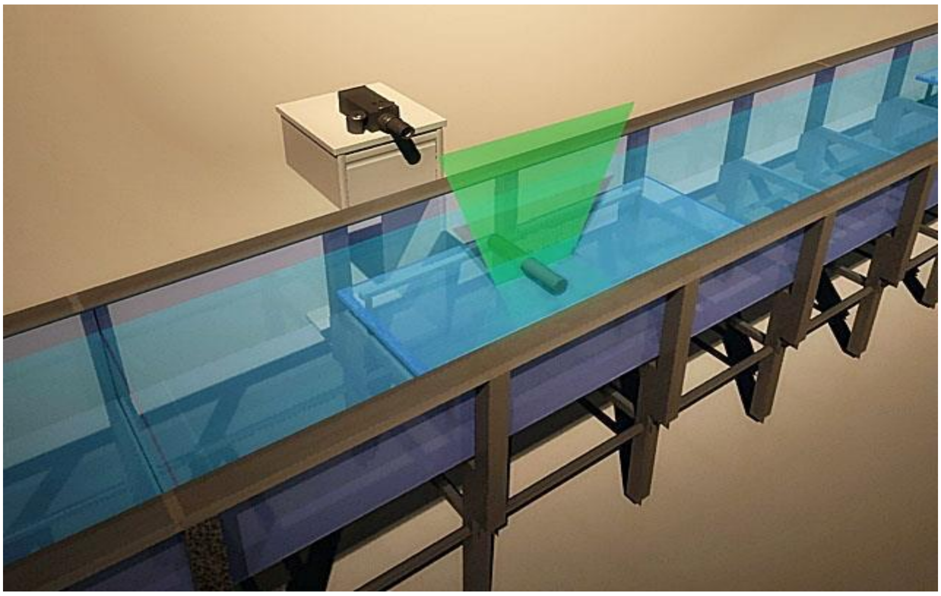

Figure 1. Experimental Set up

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. Streamlines and circulation will be obtained by post processing of the velocity data. The overall field of view was 180 x 180 mm^2. In each experiment, 500 instantaneous images were captured and recorded.

3. Results and Discussion

Fig. 2 and 3 show the flow characteristics which includes the time-averaged velocity vectors distribution ($\langle V \rangle$) and Reynolds Stress correlation ($\langle uv/U^2 \rangle$). In order to investigate the effect of the different value of dimensionless height, the cylinder was immersed in shallow water ranging from $h_D/D=0.25$ to $h_D/D=2$ with 0.25 increments in each case. As seen in Fig. 2 and 3, developing focus, F, and a primary circulating bubble are observed for $h_D/D=2$ case, as mentioned by Kahraman et al. [2]. The primary circulating bubble spreads in a very large area in the wake region. In Fig. 3, positive values are characterized by solid lines, while negative values are described by dash lines. For $h_D/D=1.75$ and 1.25 configurations, the Reynolds Stress ($<uv/U^2>$) contours, are almost symmetrical and get closer to each other. A saddle point, S, and two foci, F, occur in close region of the cylinder. On the other hand, due to the effects of free-surface and bottom surface at $h_D/D=1.5$ case, the minumum wake width is observed at $h_D/D=1.5$ case because of the increase in momentum transfer. Velocity vector map ($<V>$), presented in the first column, shows that low velocity region which represents the wake region just downstream of the cylinder for this case. The velocity vectors ($<V>$) exterior to the bubble type wake region are much greater than those of in the wake region. The near wake is relatively narrow and symmetrical. Reynolds Stress concentrations ($<uv/U^2>$), pronounced concentrations of Reynolds Stress ($<uv/U^2>$) occur adjacent to the base of the cylinder. As the flow goes downstream, the Reynolds stress ($<uv/U^2>$) concentration of the wake downstream of the cylinder increases initially, reaches a peak value of 0.09 and then decreases. Besides the well-defined Reynolds stress ($<uv/U^2>$) pattern due to fluctuations in the shear layers, a weaker Reynolds stress ($<uv/U^2>$) region very close to the base of the cylinder occurs as a result of the entrainment of free-stream flow into this wake region.

However, for $h_D/D=1$, 0.75, 0.5 cases, a well-defined swirl takes place downstream of the cylinder. And also, because of the extent of this primary circulating bubble, second plan measurements are taken. As seen in Fig. 2, the primary circulating bubble elongates in the second plan for $h_D/D=1$, 0.75 cases. The other important observation is that there is a separation in the forward face of the horizantal cylinder for $h_D/D=1$ and 0.75 cases as reported by Akoz et al. [3] Because the stagnation point is moved to upper side of the cylinder and this causes a perturbation at free-surface of the flow. Therefore, a small-scale focus, F, arises; lives only two immersion level, disappears immediately after $h_D/D=1$, 0.75 cases. Besides, the time-averaged velocity vector ($<V>$), presented in Fig. 2, shows also that there is an upstream wake region on the shoulder of the cylinder and a high magnitude of velocity vectors ($<V>$) occurs along the shear layers. The Reynolds Stress ($<uv/U^2>$), clearly indicates that positive contours dominate and negative contours disappear due to the movement of flow in the upward direction for $h_D/D=1$, 0.75 cases. Namely, the shear layer can not form at the upper left quarter of the cylinder because the cylinder is positioned coincident with free-surface. This means that the momentum of flow decreases and Karman Street vanishes. For $h_D/D=0.5$ and 0.25 configurations, well defined clusters of contour structures are observed in Reynolds Stress ($<uv/U^2>$) correlations. However, the most important point is that the wake region expands in the streamwise direction as the dimensionless value of immersion level ratio (h_D/D) increases. An effected area of flow region decrements because of the falling of the dimensionless immersion level ratio (h_D/D). Positive contours are observed due to the presence of free-surface effect, whereas negative contours are not observed because of the lack of the viscous effect. At the $h_D/D=0.25$ case, there is a smaller reverse flow than at the upper h_D/D level. As the h_D/D level rises, the center of the focus, F, in the wake region is moved further downward. The attached boundary layer on the bottom side of the cylinder elongates further downstream. This gives rise to a smaller wake at $h_D/D=0.25$ case compared with upper h_D/D level. Besides, there is an increase in flow velocity due to the reduction of the blockage rate for $h_D/D=0.25$ case. Small wake doesn't subscribe to the clear transport of fluid in the upstream direction for this case.

Spectra of streamwise velocity fluctuations evaluated at various locations in the flow field for $h_D/D=1.25$ and 1.5, 1.75 case and bare cylinder case demonstrate different behavior of the flow. The locations taken for spectra are designated by numbers as indicated in Fig. 4. The spectra taken from the downstream locations of the cylinder (points 1-2-3) does not show a clear and distinct peak for $h_D/D=1.25$ due to the effect of free surface. However, the spectra taken from the downstream locations of the cylinder (points 1-2-3) show a clear and distinct peak at the frequencies of f=0.909 Hz, 0.909 Hz and 0.909 Hz respectively, corresponding to a Strouhal number (St) of 0.163 for $h_D/D=1.5$. Moreover, the spectra taken from the downstream locations of the cylinder (points 1-2-3) show a clear and distinct peak at the frequencies of f=0.928 Hz, 0.928 Hz and 0.341 Hz respectively, corresponding to a Strouhal number (St) of 0.166.

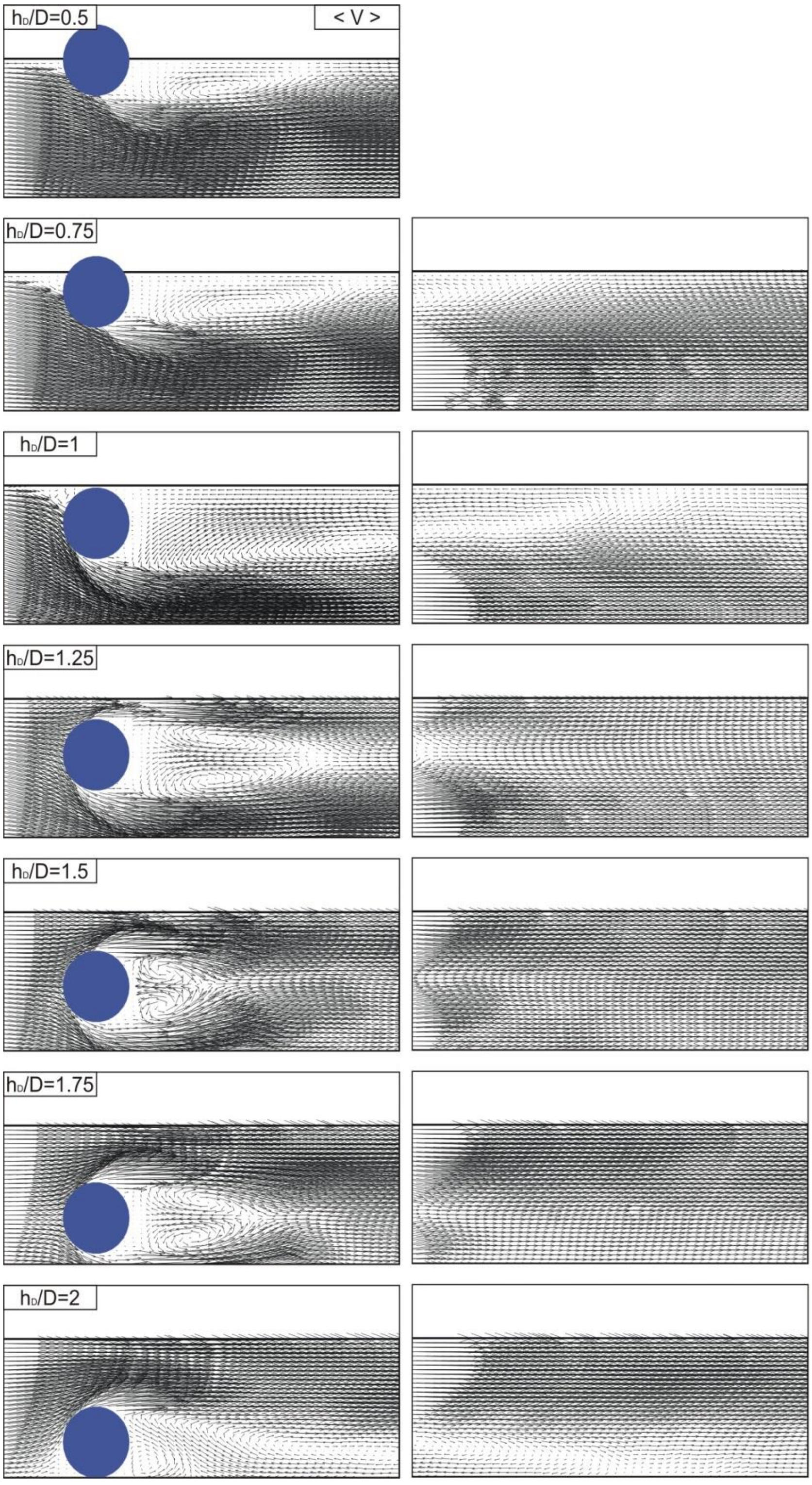

Figure 2. Velocity vector field for horizontal circular cylinder

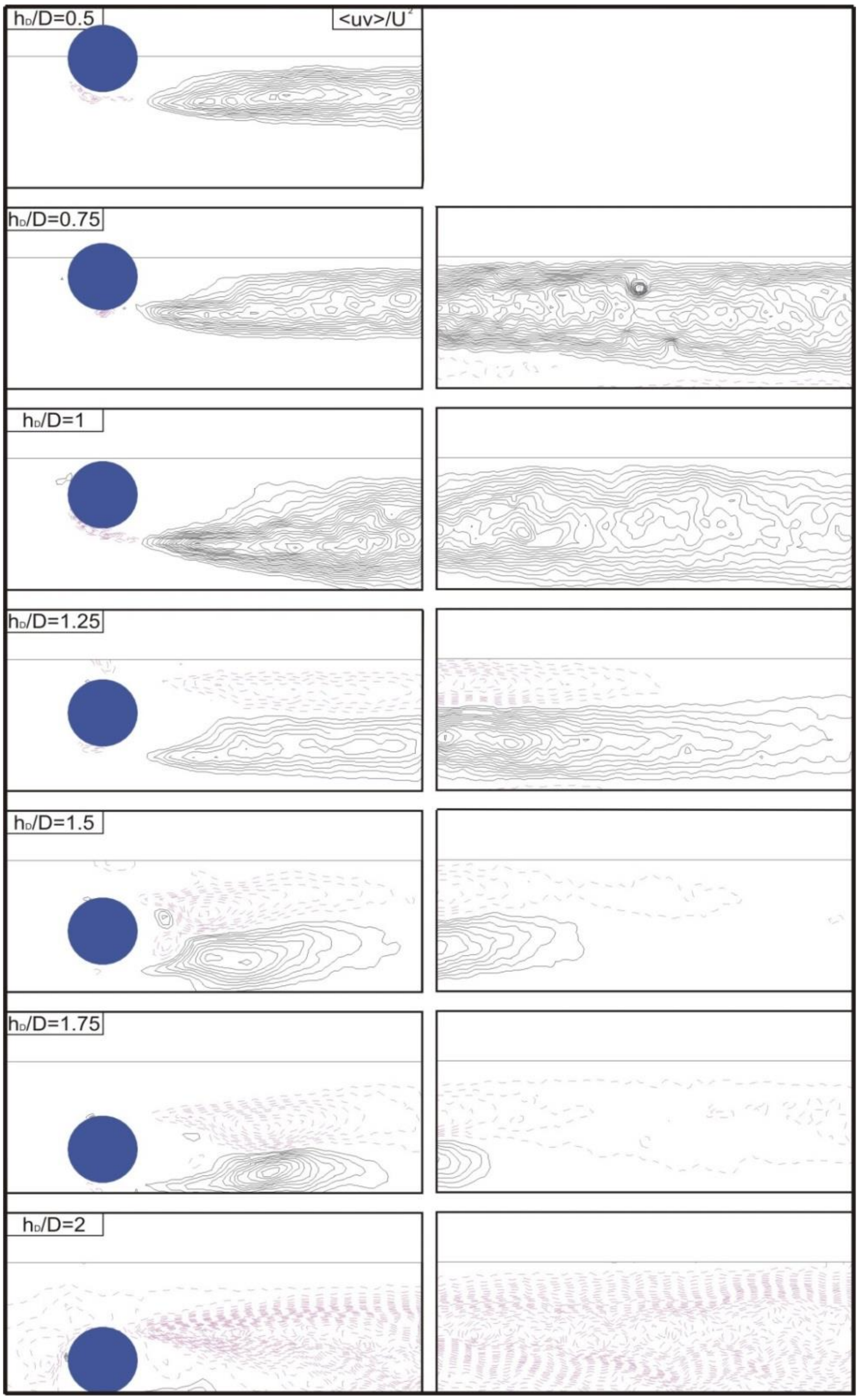

Figure 3. Reynolds stress correlation

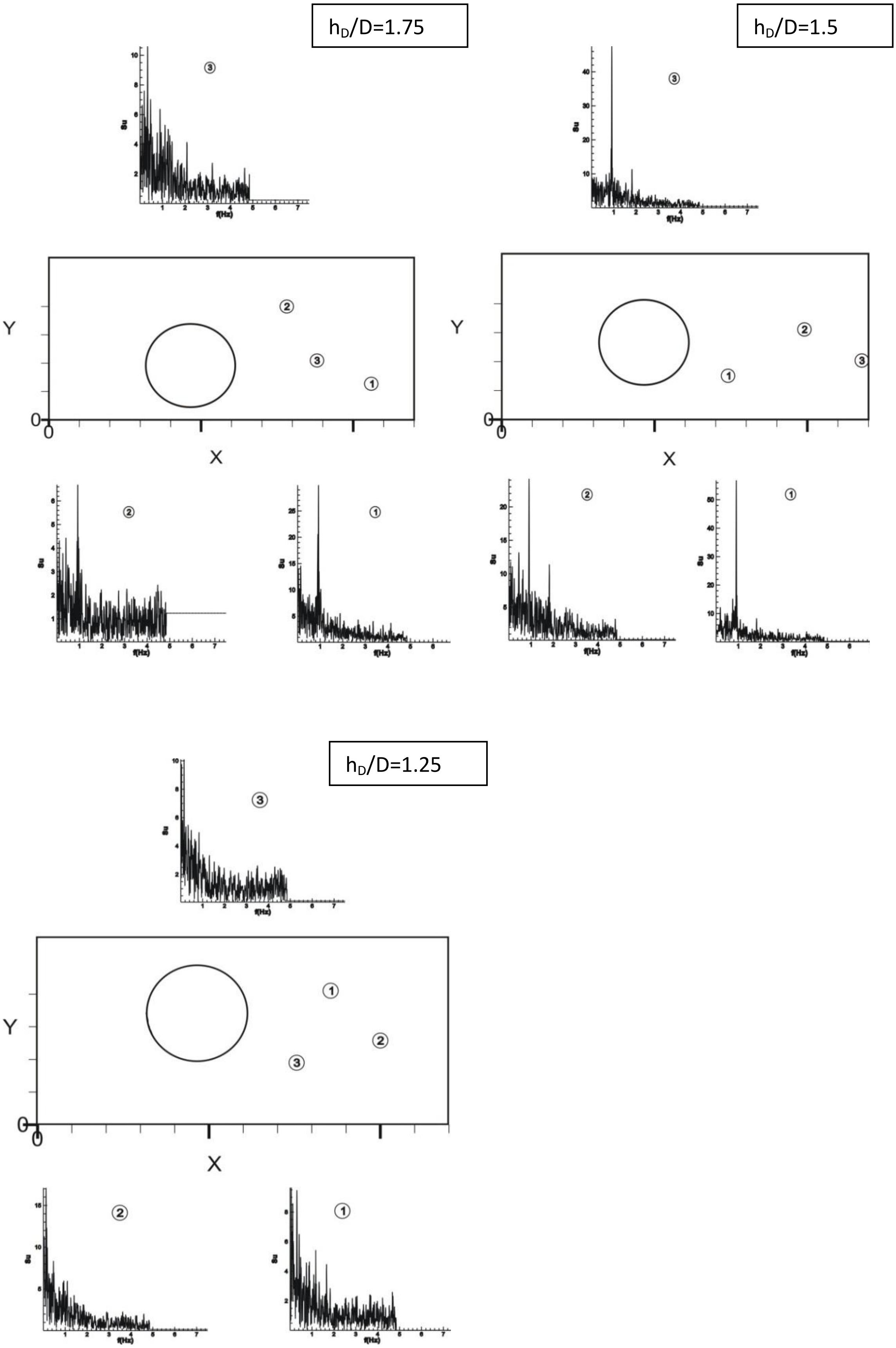

Figure 4. Spectra of streamwise velocity fluctuations evaluated at various locations in the flow field for h_D/D=1.25 and 1.5, 1.75

4. Conclusion

The flow structure around the horizontal circular cylinder has been represented for different elevations. This study has helped understanding the flow structure away from the free-surface and wall and near free-surface and wall at the same time.

Remarkable jet-like flow was observed for $h_D/D=0.25$, 0.5, 0.75 and 1 cases. Only one swirl was remarkably observed for $h_D/D=$ 0.5, 0.75, 1 and 2 immersion level ratios. However, two foci and a saddle point was obtained for $h_D/D=$ 1.25, 1.5 and 1.75 cases. The overall form of the time-averaged velocity vector field are almost similar for these cases. Regarding the patterns of Reynolds shear stress, positive or negative contours remain horizontal and extend in the streamwise direction for $h_D/D=$ 0.5, 0.75 and 1 while positive and negative contours are symmetrical for $h_D/D=$ 1.25, 1.5 and 1.75 cases. Reynolds stress contours elongate along the bed due to the bed friction for $h_D/D=2$. On the other hand, Reynolds shear stress contours for $h_D/D=$ 1 elongate along the free-stream direction due to the effect of the free surface.

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