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# Investigation of flow structure around a horizontal cylinder at different elevations in shallow water

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ABSTRACT

Flow characteristics around a horizontal circular cylinder were investigated in shallow water. The diameter of circular cylinder, the height of shallow water and free stream velocity were kept constant during the experiments as $D=30$ mm, $h_w=60$ mm and $U=167$ mm/s, respectively. Particle Image Velocimetry (PIV) was used to measure instantaneous and time-averaged velocity vector fields in the near wake region. In order to investigate the effect of immersion, the cylinder was placed at eight different elevations ($h_D$) between bottom and free surface (from 7.5 to 60 mm with 7.5 mm increments). Instantaneous and time-averaged velocity vector field, corresponding streamline patterns and Reynolds stress correlation were used to analyze the behavior of the flow downstream of horizontal cylinder. The mean velocity vector field, corresponding streamline topology and Reynolds stress correlation were obtained using 500 instantaneous images. As the immersion level ratio ($h_D/D$) increases, the magnitude of jet-like flow velocity goes up ranged from $h_D/D=0.25$–1. Time averaged flow characteristics show that there is a difference between primary and developing circulation bubble depending on direction of rotation. This occurrence causes the entrainment and this stimulates the momentum transfer between the core and wake flow region for $h_D/D=1$ and 2 cases.



## 1. Introduction

Vortex shedding behind bluff body is a fundamental question in fluid dynamics because of the geometric simplicity. Moreover, this is a key tool in various areas of engineering and science due to its practical importance such as pipelines, bridges, marine and offshore structures. Besides, these areas include many industries, which are mechanical, and aerospace engineering, power and process industries, civil engineering and undersea technologies. Understanding of the vortex flow structure may provide the different solutions for these areas. Because, periodic shedding of Karman vortices from bluff body leads to problems with flow-induced vibration and noise in above mentioned applications as mentioned by Sumner et al. (2004). The structural evaluation of offshore structures is very important tool for the design of them. Namely, the interaction of waves with bluff body is a basis of unsteady loading and vibration in the offshore and ocean applications such as long cables, component of offshore platforms and other geometrical structures. The analysis of offshore structures can be largely divided in two main categories namely structural analysis and hydrodynamic analysis. As mentioned by Hirdaris et al. (2014), the prediction of motions and wave-induced loads has been employed both ship motion prediction programs and the software engineering/computer technology. For those predictions, prediction of environmental and operational loads from waves, wind, current, ice, slamming is great important. The prediction of wave loading of body wave interactions has been attributed on potential flow solutions. Solution of the specific problems such as the calculation of slow drift motion of offshore structures, has been limited due to the viscous effects. Therefore, a great number of experimental and theoretical studies have been investigated. Vortex formation of the flow around cylindrical structure, vortex shedding, velocity and pressure fields and hydrodynamic forces on bodies have been examined in these studies. Many researchers studied on the flow structure around circular cylinders which are located to vertical cylinders in shallow and deep water (Wolanski et al., 1984; Ingram and Chu, 1987; Akilli et al., 2004, 2005, 2008; Chen and Jirka, 1995). Moreover, some of them studied on the flow structure around circular cylinders, which are located to horizontal cylinders (Cokgor and Avci, 2001; Teh et al., 2003; Akoz et al., 2010; Kahraman et al., 2012).

Yan and Liu (2010) examined analysis of a vessel in shallow water using the Lagrangian–Eulerian finite element method. They carried out effect of water depth on forces. They concluded that as the water depth decreases, nonlinear components can be greater.

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Lee et al. (2010a, 2010b) investigated act of two floating bodies in shallow water. They found out that nonlinear wave or wave interactions magnified fluctuate motion in low frequency waves. Tognarelli et al. (2008) declared on the hydrodynamic performance of various offshore units and production platforms. Their data revealed the physical details of full scale riser response omitted from predictive riser design tools. Namely, it is evident that there is far more desirable to eliminate or reduce VIVs than it is to amplify their effects in this study.

Bearman and Zdravkovich (1978) performed a study on the flow structure around a cylinder, which is positioned horizontally. They demonstrate that vortex shedding was suppressed for the gap having less than 0.3. Zdravkovich (1980) investigated the flow separation from a flat plate induced by horizontal cylinder. $G$ is defined as the gap between the bottom surface and underside of the cylinder, and d is defined as the cylinder diameter. The vortex shedding did not occur for $G/d=0$ configuration. Nevertheless, vortex shedding observed in the turbulent boundary layer for $G/d=0.2$ case. Moreover, vortex shedding improved in the laminar boundary layer for $G/d=0.3$ configuration. Triantafyllou and Dimas (1989a, 1989b) analyzed characteristics of the flow past a half-immersed cylinder analytically. Their results demonstrated that the near wake exposed a convective. Tryggvason et al. (1991) demonstrated that generation of secondary vorticity at the surface diminished because of acting of surface tension to limit strong surface curvature. The diminished generation of secondary vorticity might alter the interaction of vortices with a free surface. Sheridan et al. (1995) examined the flow structure of a cylinder around free-surface. They observed two acceptable wake situations. Both of them were observed to have limited stability. Therefore, the flow construction was classified as metastable. Sheridan et al. (1997) investigated flow characteristics for a cylinder, which was located close to the free surface. They inferred the presence of three different states; the first one was the attachment to the free surface, the second one was the attachment to the cylinder and the last one was an intermediate state in between. Bearman and Zdravkovich (1978) indicated that the Karman formation can be disruption if cylinder is positioned near the wall. Lei et al. (1999) performed a study on flow past a horizontal cylinder, which was located in different place in the boundary layer. Their aim was to investigate the thickness of the boundary layer, the velocity gradient, the pressure distribution, the hydrodynamic forces and vortex shedding behavior changing the bed proximity. They demonstrated that gap ratio and boundary layer affected the drag and lift coefficients. Cokgor and Avci (2001) examined the forces on the horizontal cylinder. Their results showed that as the burial ratio increased, drag and lift coefficients decreased. Hatipoglu and Avci (2003) investigated the flow around a horizontal cylinder, which was positioned coincident with free surface and partial buried. They found that the length of separation region decreased with increasing burial ratio. The flow characteristic of the horizontal cylinder placed on the plane boundary was investigated by Akoz et al. (2010) using PIV technique. They revealed that intersection of the bed surface and cylinder enhanced the burial mechanisms hydrodynamically even in wake flow region, where the wake flow region was shortened in size in longitudinal direction as a function of Reynolds number. Kahraman et al. (2012) examined flow characteristics around a horizontal cylinder, which was located coincident with a free surface of shallow water using PIV technique. They researched the effect of the Reynolds and Froud numbers on flow structure. They found that the variation of reattachment location of the separated flow to the free surface strongly depended on the cylinder diameter and was affected by the Froude number.

Increase in instability of the vortical flow formation is appeared in the upstream and downstream regions of the pipeline. When a pipeline is placed on erodible bed, the pipeline is hanged on and erosion takes place around the pipeline. Vortex shedding gives rise to additional forces on the pipeline because of the scour process. The pipe is buried due to the spreading of the scour processes. This process depends on the hydrodynamic behavior of the flow around the pipeline. Therefore, investigation of flow characteristics around pipeline comes into prominence.

There is a limited data regarding the flow characteristics around a horizontal cylinder, which is positioned specifically away from the free, and bottom surfaces in shallow water. In the present study, the flow structure around a horizontal circular cylinder has been represented for different elevation ranges from $h_D/D=0.25$ to 2. The aim of this experimental study first is to demonstrate the flow structure around a horizontal cylinder for different elevations in the near wake region. Moreover, the present study focuses on the wake region of the horizontal cylinder in order to investigate complex vortical flow structure. Because, understanding of vortical flow formation is significant for stability of the structure.

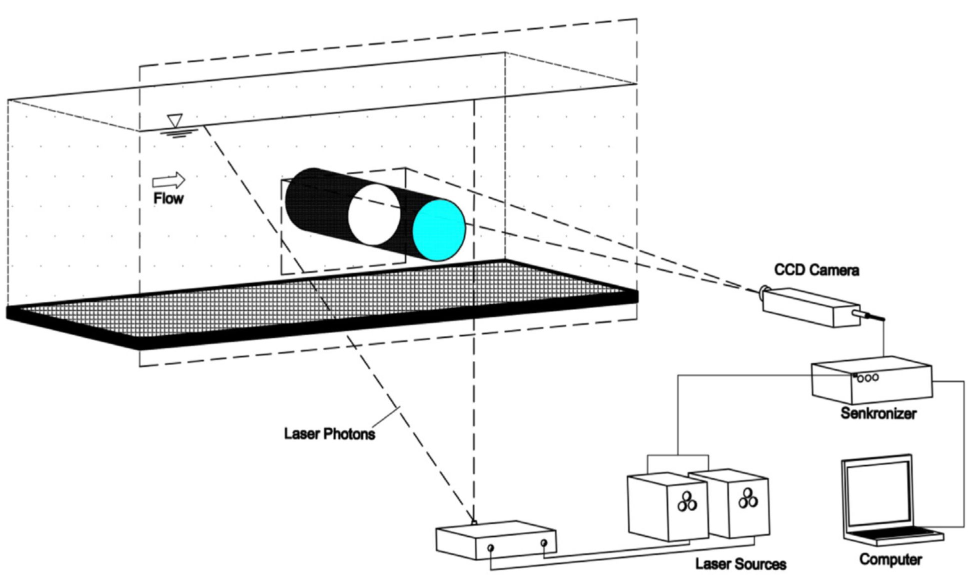


**Fig. 1.** Experimental set up.