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FLOW FIELDS FOR UNDERWATER LAYING HYDRODYNAMIC STRUCTURE AND ITS ENVIRONMENTAL ASPECTS

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ABSTRACT

The study was carried out to examine, probe and approximate the flow fields around a submerged hydrodynamic structure, using an acoustic Doppler velocimeter. In the experimental setup a cylinder of 5 cm diameter was placed at a distance of about 5.5 cm away from another bluff body or a hydrodynamic structure, that is a vertical plate of 5 cm width, both acting as obstructions to the flow. To carry out the experiment in a recirculating flume, water flow of 52 lps and flow depth of 20 cm were maintained. The study was carried out in turbulent flow conditions and vortex formation was expected around the cylinder. The ADV helped to determine the velocity and its direction while vortices were being created around the cylinder and in its wake, and also to record the velocity and observe its characteristics in the boundary layer. With the determination of flow fields of the underwater composite hydrodynamic structures various other environmental issues come into play. This types of under-laying structures not only helps in dispersion of sediment decomposition in the river bed but also in this juncture help to get a free passage and movement area for aquatic fauna for a shallow type of water channel. Seeing so many advantages of this type of study could really boost to maintain aquatic ecological balance in addition to the territorial environment and socio-economic development.

Keywords: flow fields, acoustic doppler velocimeter, vortices, vortex induced vibration, submerged cylinder, aquatic fauna.

INTRODUCTION

Knowledge of hydrodynamic forces on pipelines is gaining interest in view of the rapidly increasing number of underwater pipelines. These pipelines are normally exposed to a complex wave-current climate. The water channel bed being erodible, scour takes place under the pipe. Furthermore, local scour below pipelines lay on and across the riverbeds to convey water, oil, gas, or any fluid, commonly occurs by the erosive action of flowing stream. Moreover these effects could also help in dredging process and statistically the locations could be accessed as depicted by [1] along with movements of sediments due equilibrium scour was clearly shown in the works of [2,3] against the detrimental effects as seen in reservoir and river flow paths as described in the works of [4,5]. The aspects also become much important when the question arouse while assessing hydrological feasibility of an environment friendly mini hydro power plant which is known in the work of [6]. Scour may leave a pipeline unsupported over a considerable distance resulting in fatigue failure due to flow-induced oscillation by wake-vortex shedding. Previously various types of works had been carried out in scouring by [7, 8] occurring at the base of the vertically mounted piers that are also related with the movements of sediments of the river beds from one locations to other locations in the revelation of the works of [9-12]. Additionally problem of vortex-induced vibration of structures is important in various fields of engineering, as it is also a cause for concern in the dynamics of riser tubes bringing oil from the seabed to the surface, in flow around heat exchanger tubes, in the dynamics of civil engineering structures such as bridges and chimneys, and also in many other situations of practical importance.

Therefore, one of the imperative aspects of pipeline design is the prediction of the extent of scour below pipelines. Thus the evaluation of forces on cylinders some distance away from the bottom becomes of interest. Recently, Acoustic Doppler Velocimeter (ADV) has become popular in the field of fluid dynamics. They are applied to study the three-dimensional flow field and turbulence in laboratory applications, as well as in rivers, lakes and the ocean. ADVs typically consist of one emitter surrounded by a number of receivers, each of them measuring one projection of the velocity vector as used in the studies of [13-16].

This study is majorly concerned with the main features of ADV as measurement process discussed in [17] that are beneficially applicable for the study of water fields and also determining and discussing velocity profiles occurring due to flow around a horizontally placed submerged cylinder, which is placed before another obstruction, i.e. a vertical plate. The study of the field is intensely studied as likes of [18, 19].

If a cylinder is set in an open channel, the flow upstream will undergo a separation of the turbulent boundary layer and rolls up to form the well-known horseshoe-vortex system also visualized by [20] is swept around the cylinder. This type of flow occurs in a variety of situations, such as flow around bridge piers, around buildings and structures (stacks, cooling towers, gas tanks), and at different types of junctions.

Ever since Leonardo da Vinci first observed Vortex Induced Vibration (VIV), circa 1500 AD in the form of "Aeolian Tones," engineers have been trying to spoil vortex shedding and suppress VIV to prevent damage to equipment and structures. Furthermore, Von Karman at Cal Tech proved that the Tacoma Narrows bridge collapse in 1940 was due to VIV. This fluid-structure interaction phenomenon occurs due to the nonlinear resonance of cylinders or spheres through vortex shedding lock-in. VIV is also called synchronization

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between vortex shedding and cylinder or sphere oscillations. In this paper, the terms VIV, synchronization, vortex shedding lock-in, and nonlinear resonance are used alternating to refer to the same phenomenon. Many a times this phenomenon can be used to generate green energy as discussed in the works of [21-23] which aids to development of the rural India by the power of its electricity.

In the condition of the constant Strouhal number, when the vortex shedding frequency for a stationary cylinder approaches the natural frequency of oscillation of the cylinder from below, the cylinder will start oscillating and vortex shedding will start to correlate along the cylinder axis. This leads to a large increase in the forces acting on the cylinder. By increasing the current velocity further, the vortex shedding frequency will finally jump back to the linear curve defined by the Strouhal number. The changes taking place in the vortex shedding frequency in the synchronization ranges. In this range, vortex shedding frequency and the oscillation frequency, collapse into the natural frequency of the system in flow. It is interesting to note here that sustained oscillations extend over a range of velocity values and the vortex shedding is controlled by the vibrating cylinder like types of research carried out by [24-26]. While discussing about the environmental aspects in the natural water channels then the knowledge of the sediment loading and scouring also comes into play where due to various types of obstructing piers the movement of river bed sediments are visualized in the series of works done by [27-30]. Today the scenario of the natural channels in the world specially in India is very critical since the water depths of such channels are decreasing day by day due to immense sediment loading. Works by [31-33] shows how to develop special types of fundamental open channel discharge measuring devices. Utilizing these types of devices shows that the discharges natural streams and channels have decreased with the water depth. So, the assessment of sediment loading becomes much important while viewing the environmental aspects in the natural water channels.

EXPERIMENTAL SETUP AND PROCEDURE

The experimental arrangement, data acquisition system and variables measured in the model study are described in this research. Typical investigation of water fields for a composite hydrodynamic structure which consists of a submerged cylinder placed transverse to the flow of water and a vertical plate in line to flow of water along with velocity measurement by ADV around the cylinder has been carried out through various experiments; also the main features of ADV have been studied. All the experiments were conducted in the Fluvial Hydraulics laboratory of the School Water Resources Engineering in Jadavpur University, Kolkata. The experiments are carried out in a recirculating flume 3.96 m long, 0.355 m wide, and 0.45 m deep including free board. Water flows in flume with a depth of 20 cm, and the depth falls to 17 cm after flowing past both the structures. The working section of the flume is made up of a steel bottom and Plexiglas side walls along two sides for most of its length to facilitate visual observations as seen from Figure-1. The recirculating flow system is served by a centrifugal pump located at the upstream end of the flume whose technical details power capacity 10 HP are having variable speed. Water flows through a 20 cm diameter pipe line which runs directly into the flume. The rpm of the pump is 1430; power 7.5 kW, maximum discharge is 25.5 lps. There are two pumps for additive discharge and hence the total discharge maintained to be around 52 lps.

A cylinder of 5 cm diameter was used for the purpose of experiment. This cylinder was hung from top to the bed of the flume with the help of special metallic supports in order to get it in horizontal submerged position. A 5 cm iron plate is placed after the cylinder, at a distance of about 5.5 cm, towards the direction of flow. Taking the help from the previous researches the 5 cm plate have been considered since in that dimension parameter of the flume the wall effect could be neglected.

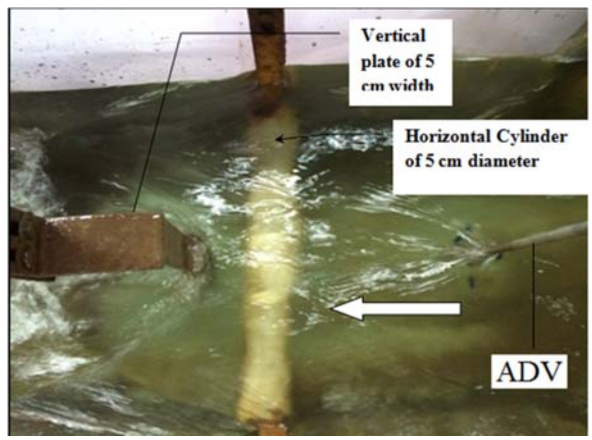

Figure-1. Hydrodynamic structures submerged in water channel.

RESULTS

The experiment was carried out using the plate of width and thickness as 5 cm and 5 mm, respectively and cylinder of diameter 5 cm placed at a spacing of 5.5 cm to each other. And also the cylinder about 3.0 m away from the intake side of the flume in order to receive lower turbulent water at its end. The gap between the cylinder and the bed of the flume for the experiment was maintained to be 2 cm. For this experiment, the instrument ADV and Origin Lab Software were used to measure and plot contours, respectively for time-averaged velocity vectors, time-averaged longitudinal flow velocity (u), time-averaged transverse velocity (v), time-averaged vertical velocity (w), and time-averaged absolute velocity (V).

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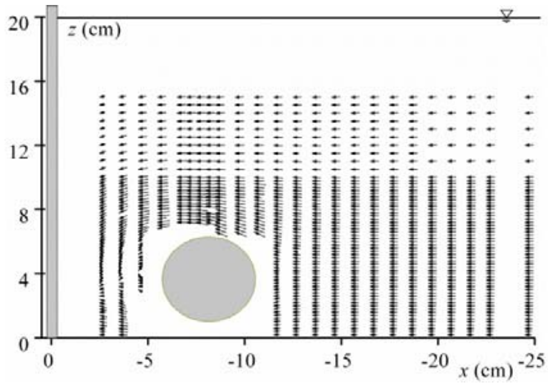

Figure-2. Full view of the velocity vectors in and around the plate and cylinder.

As per the planned study the velocity vectors were observed at various depth of the water as shown in the Figure-3 and accordingly a flow separation is seen when the flow approaches the cylinder where the direction of arrow shows the direction of the flow of water. Here the negative value of the x says that they are in the upstream position. The water depth ranging from 15-9 cm above flume bed remains undisturbed as it not hindered at all by the cylinder. When the ADV is far from the cylinder velocity is recorded at farther intervals as no disturbance is expected but as the ADV draws closer to the cylinder; velocity is recorded at shorter intervals to assure keen observation of the flow around the cylinder. As the flow approaches the cylinder a separation of flow was observe as expected, which can be clearly seen as a closer view is depicted in Figure-3.

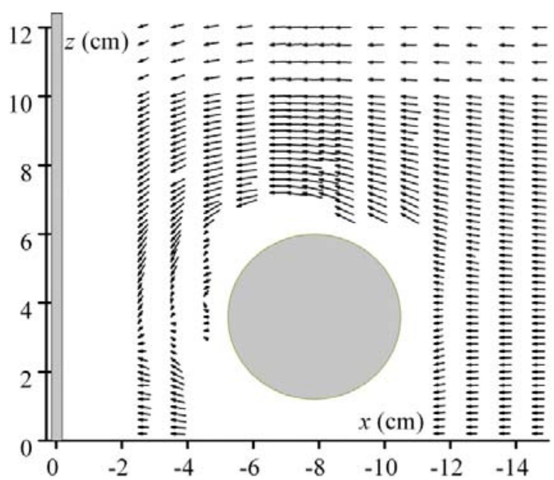

Figure-3. Closed view of the velocity vectors in and around the plate and cylinder.

As closer view of the flow phenomenon was observed it was found that the flow above the cylinder and nearer to the plate is tending downwards and the downward flow coming out from under the cylinder is trending upward. Two vortices are predominant in this case in between the cylinder and plates are wake and horseshoe vortices respectively. Interestingly as a result an adverse pressure gradient is formed at the cylinder which would tend to lift the cylinder. Moreover to access more about the characteristics of the vortices the depth-velocity profile for the various region between the plate and the cylinders (as shown in Figures 4-7) were carried out. The profiles in the region between the plate and the cylinder show that the flow there is of huge turbulence due to combined effects of horseshoe and the wake vortices. The contours of time-averaged longitudinal flow velocity for horizontal cylinder at bed level 2 cm with fixed 5 cm plate is shown in Figure-4 which represents the flow phenomenon occurring due to the combined effect of flow around the cylinder and obstruction. Importantly, it drives the combined effect of wake vortex due to cylinder and the horseshoe vortex due to plate.

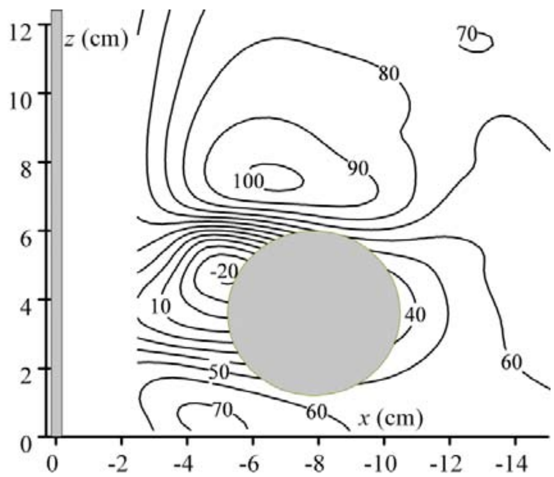

Figure-4. Contour plot for time averaged longitudinal flow velocity (u).

From experimental Figure-4 the longitudinalvelocity u, is maximum at around 7.5 cm from bed level and around the range of 5.5 cm - 8 cm distance from plate and minimum at 4 cm from bed level and around the range 2.5 cm - 5.5 cm distance from plates was detected by the ADV.

From the contour profiles of longitudinal flow velocity u, as displayed in Figure-1 shows that changes of u below the cylinder increases due to increase of height of the cylinder from bed level. Moreover, the horseshoe vortex develops at the upstream of the plate, aids to the increase in longitudinal velocity and at the same time the region where the longitudinal velocity is found to be minimum due to collision between the horseshoe vortex of plate and wake vortex of the cylinder. This also justifies the reason that the aid in longitudinalvelocity depends upon the strength of the horseshoe vortex also, which is indirectly depending upon the shape of the plate structure. From Figure-1 it is observed that the turbulence effect is produced at the upside of the cylinder whereas negligible turbulence effect is produced at downstream of the cylinder.

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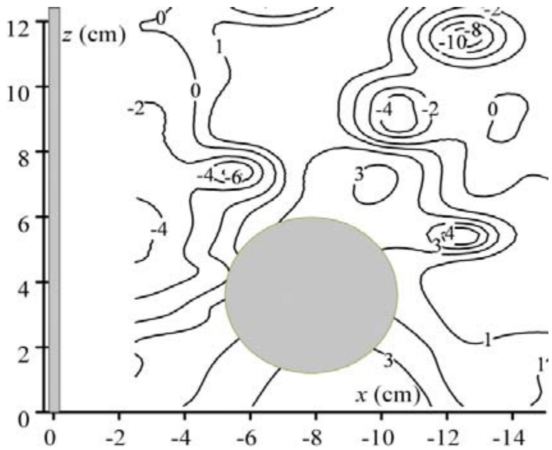

Figure-5. Contour plot for time averaged transverse flow velocity (v).

From the contour profiles in Figure-5 the combined effect of wake vortex due to cylinder and the horseshoe vortex due to plate are shown for time-averaged transverse velocity.

From Figure-5 (for 2 cm gap of the cylinder from bed level) the transverse velocity(v), is maximum in the range of 7.5 cm - 13.5 cm distance from plate and changes rapidly at the range of 6 cm - 7.5 cm distance from plate which was detected by the ADV.

The contours of time-averaged vertical velocity for horizontal cylinder at 2 cm gap from bed level is shown in Figures-6 which represent the flow phenomenon occurring due to the combined effect of flow around the cylinder and obstruction.

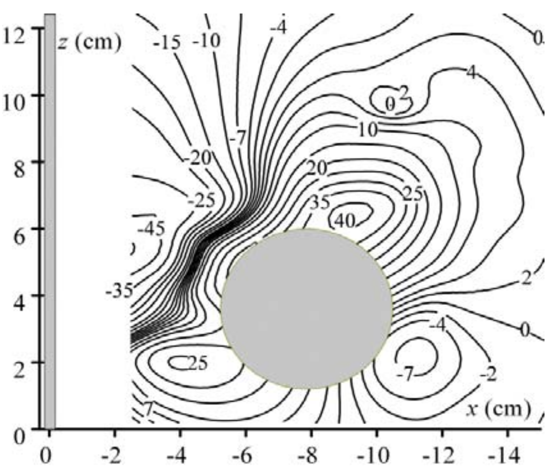

Figure-6. Contour plot for time averaged vertical flow velocity (w).

From the contour profiles the combined effect of wake vortex due to cylinder and the horseshoe vortex due to plate are shown for Time-averaged vertical velocity.

From Figure-6 (for 2 cm gap of the cylinder from bed level) the vertical velocity (w), is maximum in the range of 6.5 cm - 8 cm from bed level and around 10.5 cm distance from plate and changes rapidly in the range of 3.5 cm - 6.5 cm distance from plate as was detected by the ADV.

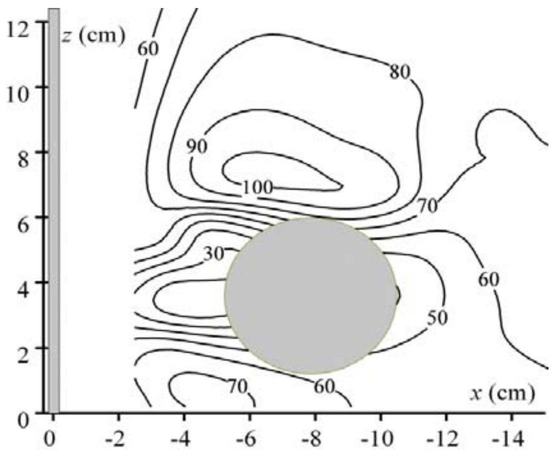

Figure-7. Contour plot for time averaged absolute flow velocity (V).

Figure-7 indicate the time-averaged absolute velocity $V = \sqrt{u^2 + v^2 + w^2}$ contours for horizontal cylinder at 2 cm above the bed level which represent the flow phenomenon occurring due to the combined effect of flow around the cylinder and obstruction.

From the contour profiles the combined effect of wake vortex due to cylinder and the horseshoe vortex due to plate are shown for time-averaged absolute velocity.

From Figure-7 (for 2 cm gap of the cylinder from bed level) the absolute velocity (V), is maximum at around 8 cm from bed level and around 6.5 cm distance from plate and changes rapidly at the range of 2.5 cm - 6.5 cm from bed level as was detected by the ADV.

CONCLUSIONS

It is demonstrated that the presence of the lift force on cylinder placed near the flume bed can be evaluated by a simple change in the description of the potential flow in the upstream part of the pipe. The flow description is the sum of the well-known potential flow description and a vortex body, which ensures that the top and bottom flow velocities become identical, due to the presence of the downstream wake. The theoretical findings are compared with experiments, and good agreement is found between predicted and measured lift forces in shear-free flow. In flows with shear in the incoming fluid, the small lift coefficients close to the flume bed are explained.

The ADV used in this research to determine the velocity and its direction while vortices were being developed around the cylinder and in its wake along with the horseshoe vortex, and also to record the velocity and observe its characteristics in the boundary layer. The velocity data recorded by the ADV were further converted and processed to determine the velocity profiles as results. Through this study a better understanding of the vortices and vortex induced vibrations is seen. This study also includes a detailed study of the various features of ADV and its working, and how it is usefully applicable for the determination of flow field. It was found that due to combined effect of the horseshoe vortex of the vertically mounted plate and the wake vortices coming out from the horizontally placed cylinder create an uplift force at the cylinder which happens due to adverse pressure gradient. Laser techniques of the measurements of the velocity would have also helped the research by getting the flow phenomena that is occurring below the cylinder. Hence this research is the beginning of a flow field study of the combined vortices due presence of combined hydraulic structures. With the determination of flow fields of the underwater composite hydrodynamic structures various other environmental issues come into play. This types of under-laying structures not only helps in dispersion of sediment decomposition in the river bed but also in this juncture help to get a free passage and movement area for aquatic fauna for a shallow type of water channel. As already discussed in the studies of [4,5] about the problems that is faced in the water channels due to sedimentations this study can help in increasing the scouring rate and aid to disperse the sediment from one location to other and this in turn helps to increase the water depth in order to accommodate more number of aquatic habitats. Using this phenomenon it has already proved that green or eco-friendly electrical energy generators could be developed. Seeing so many advantages of this type of study could really boost to maintain aquatic ecological balance in addition to the territorial environment and socio-economic development.

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