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Effect of Orientation Angle on Flow Field around Submerged Vertical Square Cylinder Subjected to Steady Current Over Plane Bed

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Abstract

The experimental and numerical simulation of the three dimensional flow around fully submerged vertical aligned square and circular cylinder due to steady current over plane bed is reported. The focus of the present investigation is toward assessing the flow characteristics and reattachment length around these cylinders. Streamlines around these cylinders are obtained from normalized longitudinal velocity. In addition, power spectra are determined to explain the variation of dominant vortex shedding frequency around cylinders, which is employed to determine the entrainment of the bed sediment particles around these cylinders. The dominant shedding frequency is evident for circular than square cylinder. Results show that the magnitude of the normalized streamwise velocity is 20–40% less for square than circular cylinder. Further, scour prone zone is determined from the bed shear distribution around various cylinders. Bed shear stress is higher for circular than aligned square cylinder. Reattachment length is higher for higher size of the cylinders.

Keywords: alignment angle, fully submerged cylinders, bed shear stress, submergence ratio, reattachment length.

1. INTRODUCTION AND OBJECTIVES

A vertical cylinder turns into fully submerged when the depth of flow is above the cylinder's height. Various investigations were reported, which focus on the flow around the cylinders.

In addition, the majority of the investigations were carried out to measure the flow characteristics around the different shapes of fully submerged structures, but there is deficiency of data on the effect of alignment angle on the flow around square cylinder over plane bed. Moreover, the present study focuses on the variation of maximum bed shear stress around aligned square cylinder over plane bed.

2. MATERIAL AND METHODS

The study provides the measurements of the flow characteristics around submerged vertical cylinders in a rectangular open channel over the plane bed. Further, numerical simulations were carried out to validate the experimental results. Velocity measurement at different sections around the submerged cylinders were carried out using Acoustic Doppler Velocimeter (ADV). Numerical simulations were performed using COMSOL Multiphysics 5.0 with k-ω turbulence closure model. The simulations are also used to investigate the variations of flow characteristics and reattachment length around the submerged cylinders. The simulations show the variation of reattachment length with the variation of submergence ratio, velocity and orientation of the square cylinder. In this study, the steady-state Reynolds Averaged Navier-Stokes equation (RANS) with constant turbulence viscosity for the conservation of mass and momentum equations were used for the simulation of the recirculating flow around the submerged cylinders. The geometry boundary elements were distincted into triangular or quadrilateral. The grid spacing was considered adequate for the convergence of solution and resembled good agreement with the experimental results.

3. RESULTS

Results show that re-attachment length is higher for larger diameter of the cylinder as well as the square side of the square cylinder. Reattachment length is 10–35% more in the case of square cylinder compared to the circular cylinder. The higher recirculation zone is noticed in the mid-depth compared to near the bed and free surface for all the submerged cylinders, whereas the center of the eddy reduces due to increasing of submergence depth for all the submerged cylinders. The flow separation is evident at the top of the fully submerged cylinders below the free surface. Bed shear stress is found to be higher near to the submerged cylinders and it decreases away from the cylinder, which is shown in Fig. 1. Besides, the bed shear increases with alignment angle in the downstream, whereas it decreases in upstream and transverse directions of the square cylinders.

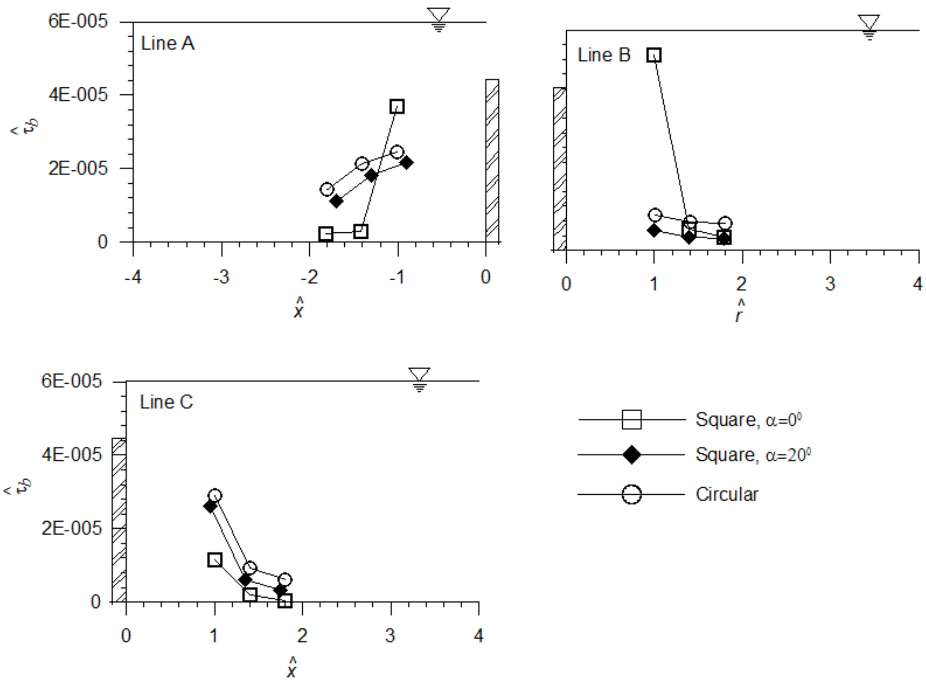

Fig. 1. Variations of normalized bed shear stress ($\hat{\tau}_b$) with $\hat{x}$ and $\hat{r}$: A ($\theta = 0°$), B ($\theta = 90°$), and C ($\theta = 180°$). The peak of power spectra is significant for circular cylinder than square and aligned square cylinder. The peak shows the strength of vortices to transport the bed sediments around the cylinders.

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