ABSTRACT

Accurate prediction of flow rate in open-channel hydraulic environment is still limited. Adequate mathematical models to describe the coherent structures in turbulence over fluvial scour are even not available. The sustainable development of rivers requires knowledge on the three-dimensional mean flow field and the turbulence. The physical knowledge in the complex river flow is, however, at present insufficient; the majority of experimental research concerns straight-uniform flow and even complex numerical models are based on geometry of straight-uniform flow conditions. A sound understanding of the relevant physical process is always essential in complex problems such as the river management including scouring, which concerns a variety of different fields, and this is irrespective of the available computational capacity. Turbulent flows are common in nature and have an important role in several geophysical processes related to a variety of phenomena, such as river morphology, landscape modelling, atmospheric dynamics and ocean currents. At present, new measurement and observation techniques suitable for fieldwork can be combined with laboratory and theoretical work in order to understand scouring processes in fluvial environment.

The main goal of the thesis is to focus the experimental and theoretical investigations of turbulent flows over fluvial scour structures generated upstream of short horizontal static cylinders and to compare turbulence among three different types of equilibrium scour holes induced by different cylinder diameters. In this work, 3D micro-acoustic Doppler velocimeter (ADV) was used to measure velocity components with fluctuations for investigation of turbulent characteristics over the entire water depth as well as along the flow over and within the scour structures. The velocity data were analyzed to determine the relative importance of mean flows, Reynolds
stresses, the turbulent kinetic energy (TKE) fluxes and the contributions of burst-sweep cycles to Reynolds shear stress. The motivation of this study was to identify the spatial changes of mean flow, turbulence intensities, and turbulent events over these structures, and to gain better insight in the flow physics. The knowledge of flow structures over the fluvial scour was essential for the prediction of morphogenesis and stability of the scour in a given flow conditions. Therefore, velocity, turbulence and prediction of coherent structures over fluvial scour were studied in a re-circulating flume at the Fluvial Mechanics Laboratory (FML), Indian Statistical Institute, Kolkata.

In the dissertation, overall thirty-eight experiments were performed in different flow conditions and obstacles of different geometries. The physics of flow and the role played by the coherent structures in the scouring processes around obstacles were mainly focused. In the dissertation, the coherent structures over fluvial scour induced by three different cylinders of diameters $D_c = 3.2$ cm, 4.2 cm and 6.0 cm were discussed.

Experiments performed in the present study are classified into two cases:

1. **Case-I:** flow over plane bed surface, and

2. **Case-II:** flow over fluvial scour marks induced by obstacles of different sizes.

In the dissertation, several innovative empirical relationships were established in scouring problems in fluvial environments using applied mathematical tools and predicted the natural phenomena, like trends of coherent structure over equilibrium scour holes induced by obstacles of different sizes on the river bottom. The statistical modelling of various turbulent parameters like velocity components ($u$, $v$ and $w$), Reynolds stresses were developed. Using quadrant threshold technique for coherent motion during scouring process around obstacles, it was shown that over
the smooth surface the ejections and sweeps were the largest contribution near bed region; and
the outward and inward interactions were the largest contribution near the water surface, but
within the scouring region that was not true.

The quadrant threshold technique in \((x, y), (x, z)\) and \((y, z)\) planes over scour holes was used
to identify the leading shear stress plane, which was responsible to form the scour geometry. It
is discovered that the \(yz\) and \(xy\)-planes were much more important in the scouring regions, but
reverse were true for the smooth surface. Using cumulant-discard method (taking into account
the cumulants of less than forth order), it was shown that the qualitative and quantitative be-
haviours of bursting events fitted well with experimental data on the smooth surface. However,
within the equilibrium scour hole the qualitative behavior of bursting events fitted well with
experimental data, but quantitative behavior did not match well. Finally, it was concluded that
for understanding the turbulent phenomenon up to cumulants of order three was enough. The
distribution of the joint probability density function in the near-bed region changes cyclically
along the scour hole depending on the bottom fluid velocity, which implies a change from up-
ward to downward flux of momentum and vice versa. Both the ejection and sweep events at
near-bed points on the level surface are more important than within the scour region; and in con-
trast, both events are stronger for the scour marks than the level bed surface at the outer layer.
Sweeps dominate over ejections for the scour hole induced by smaller diameter and ejections
dominate for larger diameter.

The study of scour marks around the objects on the sandy bed under the action of turbu-
lent flows in natural environments has the potential to be useful to researchers who consider
the dynamics of pipelines and short cylinders placed on river-beds, sea-beds and shallow wa-
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ter regions of coastal areas; and who examine the formations of crescentic scour marks in a recent stream to establish palaeocurrent directions. Therefore, in the present study, the use of submerged horizontal short cylinders justifies the design of experiments for understanding the physics of fluids around the objects. Moreover, this is important to determine the turbulence and flow parameters across the crescentic scour marks available at the ancient sedimentary deposits in the light of modern analog as present is the key to the past.