Abstract

It is essential to understand the flow characteristics in open channel flows to assess fluid-sediment interaction and sediment erosion, which are directly linked to the hydrodynamic characteristics. A significant number of studies have focussed on the flow in wide open channels. However, no comprehensive experimental investigation has been carried out so far to study the turbulence characteristics in narrow hydraulically rough and transitional open channel flows. Hence, in this thesis, the effects of aspect ratio (ratio of width of the channel to depth of the flow) on the turbulence characteristics in narrow open channel flows have been investigated experimentally over a rough bed.

Generally, the flow becomes disturbed whenever there is a change in boundary condition because of imbalance of viscous, gravitational and inertial forces. Subsequently, the flow tries to attain a fully developed flow condition in the downstream direction. The developing turbulent flow in the open channel is a complex three-dimensional flow, which is influenced by aspect ratio, bed roughness, and other parameters. Therefore, the first objective of the present study is to unravel the effect of aspect ratio on the turbulence characteristics in developing and fully developed narrow open channel flows over a fixed continuous rough bed. Instantaneous 3-D velocities were acquired using a Nortek VectrinoPlus down looking acoustic Doppler velocimeter at streamwise intervals of 50 cm along the centerline of the flume. In this study, six sets of flow conditions have been investigated by varying aspect ratio 2.5 to 4.

The effects of Reynolds number and aspect ratio on vertical distributions of normalized flow velocities, turbulence intensities, Reynolds shear stresses, turbulent kinetic energy and anisotropy along the flow development were analyzed. Aspect ratio was found to influence the velocity characteristics throughout the depth in the developing flow region, while the effects are confined to the outer layer for fully developed flows. In the range of aspect ratio studied herein, for a given Reynolds number, the shear velocity was found to increase with increasing aspect ratio For a given Reynolds number, the aspect ratio is found to influence the classification of flow regime to be either fully rough or transitionally rough. New equations to describe the variation of turbulence intensities and turbulent kinetic energy are proposed for narrow open channel flows. Reynolds stress anisotropy analysis reveals that level of anisotropy in narrow open channel flow is less than the wide open channel flows. The decreasing turbulence intensities at mid-depth along the flow developing region demonstrates the attainment of isotropic turbulence as the flow development occurs in the narrow open channel. By comparing the profiles of turbulence characteristics at different streamwise locations, the flow development lengths have been obtained for different flow conditions. Finally, a non-linear regression model is proposed to predict flow development length as a function of Reynolds number, Froude number, sediment size and aspect ratio. A new correlation between the equivalent roughness and velocity shift from the smooth wall logarithmic equation as a function of aspect ratio is proposed. A new analytical power law for velocity distribution has been developed and validated with the experimental results in fully developed flow. The new analytical power law equation developed accurately describes the fully developed velocity profile in narrow open channel flow with the dip phenomenon.

The second objective of the thesis is to investigate the influence of aspect ratio on the higher- order statistics of velocity fluctuations, conditional statistics, turbulent kinetic energy (TKE) fluxes, TKE budget and Reynolds stress anisotropy in the fully developed flow region. The higher-order moments, quadrant analysis and TKE budget from the present experiments were compared with available literature data in wide and narrow open channel flows to elucidate the effect of the aspect ratio. In this analysis, the third-order moments of velocity fluctuations were found to be sensitive to the aspect ratio in the outer region. The quadrant analysis revealed that the sweep events are equally dominant as compared to the ejection events in narrow OCF. The fractional contributions of all quadrant events are approximately equal in magnitude in lower aspect ratio flows, whereas ejections and sweeps are the dominant events as the aspect ratio increases. The upward transfer of TKE flux increases in the outer layer with increase in aspect ratio. However, retardation of streamwise transport of TKE flux takes place in the outer layer with increasing aspect ratio. In the inner layer, the TKE production and rate of dissipation are found to be increasing with decreasing aspect ratio. Therefore, the production and dissipation of TKE are dependent on the aspect ratio of the flow. The analysis of anisotropy invariant map (AIM) for low aspect ratio flows reveal that only in the intermediate layer turbulence tends to attain rod like axisymmetric turbulence whereas for higher aspect ratio, turbulence tries to attain rod like axisymmetric turbulence throughout the depth.

The third objective of the thesis is to propose a new analytical model to predict the streamwise time-averaged velocity profile affected by the dip phenomenon in open channel flows. The novel approach of the present study is that the Finley wake law has been used instead of Coles wake law for the outer layer. To validate the new analytical model, the present experimental data, fourteen sets of available experimental data, including five field experiments conducted across the globe were also used. The comparison of the FDMLWL model with the experimental data belonging to hydraulically smooth, transition and rough regimes has consistently indicated better representation of the velocity dip phenomenon. The FDMLWL model has also been compared with other analytical models available in the literature and the superior performance of the proposed model is further observed. Finally, based on the satisfactory validation between experimental data and FDMLWL, it is concluded that the proposed model is superior for modelling zero velocity gradient at the boundary layer edge, as in open channel flows with dip phenomenon. In addition, the present study can be used for the secondary currents modelling in narrow open channel flows.

Finally, this study presents useful information regarding the effect of aspect ratio increase on the turbulence characteristics of narrow open channel flow with the rough bed.

Keywords: Aspect Ratio; Narrow Open Channel Flow; Turbulence; Flow Development; Higher-order Moments; Quadrant Analysis; Turbulent Kinetic Energy Budget; Anisotropy Invariant Map.