Abstract

In this study, the turbulence characteristics in water-worked gravel-bed (WGB) and screeded gravel-bed (SGB) streams are quantified experimentally by measuring the instantaneous velocity field using a two-dimensional Particle Image Velocimetry (PIV) system. To study the response of water work roughness to the double-averaged velocity and various spatially-averaged turbulence characteristics, the flow Froude numbers in both the WGB and SGB were maintained identical in the experiments. Owing to the action of water work, the surface gravels in the WGB are more spatially organized than those of the SGB, where they are randomly oriented, resulting in a higher roughness in the WGB than in the SGB. The streamwise length scale of the WGB roughness structure is higher than that of the SGB roughness structure. Analysis of bed roughness fluctuations of both the beds reveals that the distribution of bed roughness fluctuations is negatively skewed in the WGB, whereas it is positively skewed in the SGB. To analyse the flow parameters, double averaging methodology is implemented.

First, the vertical profiles of the double-averaged streamwise velocity and the turbulence parameters, specifically the spatially averaged Reynolds shear stress, streamwise and vertical Reynolds normal stresses, dispersive shear stress, streamwise and vertical dispersive normal stresses, turbulent kinetic energy and dispersive fluxes, quadrant analysis of Reynolds shear stress, and quadrant plots of spatial velocity fluctuations are presented and analysed critically by focusing on comparisons between a WGB and an SGB.

Next, to examine the effects of the temporal and advective bursting events on the flows through WGB and SGB, conditional double-averaged streamwise velocity and spatially-averaged turbulence and dispersive quantities in both the beds are investigated. The comparison of the results in the WGB and SGB flows elucidates that owing to the higher WGB bed roughness than the SGB, the conditional spatially-averaged turbulence and dispersive quantities in the WGB are greater than those in the SGB. Within the roughness layer, the bursting events in the WGB are more persistent and frequent than those in the SGB.

To understand the effects of water work roughness on the turbulent kinetic energy related parameters, the characteristics of the spatially averaged turbulent kinetic energy dissipation rate are studied in WGBs and an SGB. The presence of an inertial subrange is ascertained by examining the second- and the third-order velocity structure functions in both the WGB and SGB. Kolmogorov's two-thirds and four-fifths laws are preserved within the inertial subrange. Furthermore, to study the effects of the shear Reynolds number on the turbulent kinetic energy dissipation rate and the scaling law parameters, two additional experiments with different shear Reynolds numbers are conducted in the WGBs and the results are compared.

Finally, the coherent structures and their impact on the near-bed time-averaged flow structure in a WGB and SGB are investigated. Time series analysis for the instantaneous velocity and vorticity on a central vertical plane along the streamwise direction proves that the coherent structures in the near-bed flow zone are constituted by rapidly and slowly moving fluid streaks. Vorticity contours confirms that the clockwise and countercloskwise fluid motions are responsible for flow acceleration and decelaration.

Besides, to study the spatial distribution, contours of time-averaged streamwise velocity, vorticity, turbulence level, third-order correlations, and turbulent kinetic energy budget in the WGB and SGB are plotted and analysed. In addition, the spatially-averaged higher-order correlations and turbulent kinetic energy budget in the WGB and SGB are examined.

Keywords: Bed roughness; flow characteristics; bursting events; scaling laws; stream beds; turbulent flow