ABSTRACT

Particle Image Velocimetry (PIV) measurements in the fully developed turbulent flow over three-bed roughness transitions (i.e., abrupt, gradual, and abrupt step) were carried out to study the detailed flow physics and turbulence mechanisms. The Reynolds stress results reveal that for a given vertical distance, both the Reynolds shear and normal stresses in the downstream bed increase with the streamwise length compared to their upstream values. Their peak magnitudes appear at the edge of the wall-shear layer. In addition, the bed shear stress enhances with the streamwise distance. The stress colour maps corroborate that the formation of roughness-induced layer over the downstream bed thickens with streamwise distance.

The analysis of the instantaneous velocity vectors and colour maps at different times infers that the motions of the fluid streaks are repetitive in nature with time. The instantaneous vorticity fields at different times show that the clockwise motions of vortices near the bed are persistent, while counterclockwise motions above the bed arise in dispersed form. The clockwise and counterclockwise motions cause the flow to decelerate and accelerate, respectively. The time-averaged distributions demonstrate that an abrupt and gradual change in bed roughness converting the flow from hydraulically smooth to rough elevates the zero-velocity level as the streamwise distance increases. At the same time, the Nikuradse zero-plane displacement remains almost unaffected.

The high order correlations reveal that an inrush of rapidly moving fluid streaks associated with a downward-upstream Reynolds stress diffusion is the primary mechanism in the near-bed flow zone of the downstream bed. In contrast, an arrival of slowly moving fluid streaks associated with an upward-streamwise Reynolds stress diffusion prevails in the flow on the upstream bed. These results are in conformity with those obtained from the turbulent kinetic energy (TKE) fluxes. With regard to the TKE budget, the peaks of TKE production and dissipation rates form near the downstream bed and are greater than those in the upstream bed. However, in the near-bed flow zone of the downstream bed, a lowpressure prevails. Bursting analysis also endorses that the sweeps govern the near-bed flow on the downstream bed and the ejections prevail far from the bed.

Keywords: *Bed roughness; Flow characteristics; Fluid flow; Hydraulics; Open-channel flow; Turbulent flow*.