Abstract

The local flow and turbulence characteristics of rigid submerged vegetated flow are studied using laboratory observations. A laboratory experiment was conducted with a model vegetation canopy on a gravel bed. Instantaneous three-dimensional velocity measurements were obtained using an Acoustic Doppler Velocimeter.

The double-averaging method is employed to study various turbulence quantities. The results suggest that the double-averaged streamwise velocity profile follows a logarithmic law, while within the canopy, the canopy drag significantly reduces the velocity. At the top of the canopy, an inflection occurs in the velocity profile, implying the existence of Kelvin-Helmholtz instability. The faster-moving fluid above the canopy interacts with the slower-moving fluid within the canopy, creating a strong shear layer at the canopy interface. This induces Reynolds shear stress, which peaks at the canopy top. The localized accelerated and decelerated flow regions occurring within the canopy layer produce dispersive shear stress that enhances fluid mixing and momentum transport. The higher-order correlations of velocity fluctuations demonstrate the presence of coherent structures due to this. The turbulent kinetic energy fluxes also confirm these findings. The negative dispersive kinetic energy flux within the canopy layer suggests that local interactions transport the turbulent energy upstream and upward. The analysis of the TKE budget terms reveals that the TKE production rate peaks at the canopy top, while tke dissipation rate continues to increase in the canopy layer. Moreover, higher spatial variations are observed directly behind the canopy elements.

The role of coherent flow structures, in terms of conditional statistics, induced by the shear layer in fluid mixing, remains poorly understood. Hence, the conditional turbulence and dispersive quantities derived from quadrant analysis in a rigid, submerged vegetated flow are examined. The conditional spatially averaged velocity profiles exhibit an inflection at the top of the canopy. Their contributions vary by over 30% from the total streamwise velocity. Conditional analysis of spatially averaged Reynolds shear and normal stresses show that ejections dominate momentum and energy fluxes in the outer layer, while sweeps are predominant within the canopy. At the canopy interface, ejections and sweeps produce more than twice the overall Reynolds shear stress. The conditional analysis of dispersive stresses showed that dispersive ejections were the major contributors to momentum and energy redistribution within the canopy layer. Additionally, the study reveals that ejections occur more frequently within the canopy layer while sweeps occur more frequently above the canopy.

Furthermore, spatial variations of Reynolds stress anisotropy are studied using anisotropic invariant maps. The wake interactions downstream of the canopy elements act locally, along with the shear at the canopy top increases the anisotropy in the flow.

Keywords: Submerged Vegetation, Turbulence, Conditional statistics, Reynolds stress anisotropy, Double-averaging method.