ABSTRACT

The turbulent characteristics in flow over the two-dimensional rigid subaqueous dunes are investigated experimentally. The flow was measured over three wavelengths of dunes in an open channel flume along the vertical centreline by using acoustic Doppler velocimeter (ADV). The spatial flow and the near-bed turbulence parameters are explored considering the double averaging approach. Besides, spatial averaged (SA) turbulence characteristics in flow are described taking into account the concept of conditional statistics. Further, in order to enhance the knowledge on the degree of departure from the ideal isotropic turbulence, Reynolds stress anisotropy in flow over the dunal bedforms is analysed critically.

The dunes act as macro-roughness elements, providing a quasi-regular variation of near-bed flow heterogeneity. This spatial recursive near-bed flow structure can be deemed as wake-interfernce flow. A close inspection on the time-averaged velocity field with respect to the double averaged velocity field reveals that at the downstream of the crest, the decelerated flow zone moves over the succeeding stoss-side of the dune and then extends towards the free surface, giving rise to the energetic kolk-boil effect in the flow over the dunal bedforms. On the leeside of the dune, a recirculation zone prevails and the flow reattaches at a distance five times the dune height. This flow reattachment can be ascribed from the viewpoint of Coandă effect. All the turbulent kinetic energy (TKE) budget terms achieve their respective peaks at or above the crest level. The TKE production rate is greater than the dissipation rate for the entire flow depth. The bursting analysis endorses that the sweep events prevails within the interfacial sublayer while ejection events dominate above the crest level.

The conditional SA streamwise velocity profiles reveal the dominance of temporal sweep events causes the flow to be spatially accelerated. Analysis of conditional SA Reynolds shear stresses and TKE fluxes show that within the interfacial layer, temporal sweep events and above the interfacial sublayer, temporal ejection events are the key mechanism to govern the turbulent flow. An inspection of the conditional dispersive stresses and dispersive kinetic energy (DKE) fluxes reveals that ejection events dominate in the form-induced sublayer, while dispersive outward interaction events prevail within the interfacial sublayer. The frequency of both the events are more within interfacial sublayer than the main flow layer indicating the flow to be more turbulent within the interfacial sublayer.

The Reynolds stress anisotropy is envisaged from the viewpoint of stress ellipsoid shape. The anisotropic invariant map (AIM), anisotropic invariant function, eigenvalues of the scaled Reynolds stress tensor, and eccentricities of the stress ellipsoid are examined at various streamwise distances along the vertical. Analysis of AIM reveals that the oblate spheroid axisymmetric turbulence dominates near the top of the crest while the prolate axisymmetric turbulence prevails near the free surface. As the streamwise distance increases, the turbulence anisotropy at the edge of the boundary layer approaches the plane-strain limit up to the two-thirds of the stoss-side, intersecting the plane-strain limit at the top of the crest and thereafter, moving towards the oblate spheroid axisymmetric turbulence.

Keywords: Dunes, turbulence, conditional statistics, Reynolds stress anisotropy.