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Direct simulation of open-channel flow in the fully rough regime: focus on fluid-roughness interaction

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The interaction between an incompressible open-channel flow at $Re_b = 6900$ and rigid spheres of size $k^+ = 120$ mounted in square arrangement on the bottom, has been investigated by means of Direct Numerical Simulation (DNS) for the purpose of contributing to the knowledge of the basic mechanism of sediment transport. The shift generated by the roughness on mean velocity profile in the log-region is in the range of values characterizing the Fully-Rough Regime (FRR). First, average quantities (i.e. flow velocity, shear-stress distribution on the sphere surface, force and torque acting on the spheres) are analyzed exploiting the spatial periodicity of the arrangement of roughness elements. Then, spatial and temporal fluctuations of the quantities are studied. Results are compared with those obtained for a similar DNS at $Re_b = 2900$, which is in the Transitionally-Rough Regime (TRR). Although the largest fluctuations of the velocity components are observed ~ 8 wall units below the crest of the spheres in the FRR, their effect on the drag and lift fluctuations acting on individual spheres is weaker than in the TRR. Nonetheless, the lift coefficient in the FRR case was found the 24% larger than in the TRR case. The characteristics of vortex structures in the vicinity of roughness elements are also investigated. Differences in the flow structure between the two simulations in the TRR and in the FRR reflect on the stress distribution on the surface of the spheres. Finally, the arrangement of the roughness elements might play a key role in the modulation of turbulence.