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Turbulence of oscillatory flow over three-dimensional ripples

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The objective of this study was the large-eddy simulation of the turbulent flow over three-dimensional (3D) vortex ripples, and the comparison of the turbulence statistics with respect to the corresponding ones over two-dimensional (2D) ripples. The discretization of the Navier-Stokes equations was done on a Cartesian grid where the bed surface was immersed in the numerical grid, following the 3D immersed boundary (IB) method. As a result, the implementation of the boundary conditions was achieved through additional terms in the Navier-Stokes equations at the nodes closest to the boundaries, which are called forcing points. The spatial discretization was based on the use of finite differences on a staggered grid for the dependent variables (u, v, w, p), and a two-stage time-splitting method was employed for the velocity-pressure coupling. To validate the accuracy of the computational model, simulations were conducted for turbulent uniform flow over 3D dunes and the numerical results were matched well to previous numerical simulations and existing experimental results. In addition, four cases of vortex ripples (one 2-D and three 3-D) were examined at Reynolds number Re = 20,000. Results are presented for the phase-averaged vorticity, the mean velocity field as well as turbulent statistics of the flow. It is concluded that even though the spanwise changes of the streamwise ripple steepness results into more energetic conditions locally, the spatially-averaged turbulent kinetic energy (TKE) has a smaller peak than for the corresponding 2D case but it experiences a stronger vertical diffusion which leads to higher values at vertical distances larger than one ripple height above the ripple crest.

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