Numerical Modeling of Bedform Development in Turbulent Flows

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Sedimentary bedform development is one of the fundamental problems in hydraulic engineering and has been the study subject of numerous researchers. However, although statistical quantities of bedforms in various flow and sediment conditions have been reported extensively, physical mechanisms of their initiation and development remain poorly understood. Aiming to achieve detailed understanding of such mechanisms, development of bedforms in turbulent flows is studied numerically in this study. The interested flows are in hydrodynamically smooth regions where effects of individual sediment particles on the flow fields are negligible. Initiation and evolution of bedforms from flat beds are reproduced by a model consisting of three modules which are coupled to each other: a module for hydrodynamic equations based on the Large-Eddy-Simulation (LES) and Immersed-Boundary-Method (IBM) which are implemented on fixed Cartesian grids, a module for sediment transport based on van Rijn's (1984) bedload formula, and a module for 2D bed surface evolution based on the Exner-Polya equation. The model is first validated with test cases of bed shear stress distributions and mean flow fields over fixed sinusoidal bed surface in open channel flows, by comparing with reported results computed by the traditional body-fitted Direct-Numerical-Simulation (DNS) method. The model is also shown to be able to produce realistic flow fields where the bed surface is evolving.

Test cases of sand wave evolution from flat beds in various flow and sediment conditions are then conducted. Computed results are analyzed in four categories: threshold for bedform initiation, the first sand waves appearing on a flat bed, initiation and evolution of successive waves which fill up the bed surface, and fully developed dimensions of the sand waves. Qualitative and quantitative comparisons with the experimental observations are made and agreements on major characteristics of the above categories are observed. To the author's knowledge, this is the first numerical work on this problem which can reproduce real-time interaction between evolving bedforms and a three-dimensional, fully solved flow field.