Topography-induced hydrodynamic roughness

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Turbulent flows above a solid surface are characterised by a hydrodynamic roughness that represents, for the far velocity field, the typical length scale at which momentum mixing occurs close to the surface. Here, we are theoretically interested in the hydrodynamic roughness induced by a sinusoidal bed of given wavelength and amplitude. We describe the flow with RANS equations closed by means of a mixing-length approach that takes into account a possible bed geometrical roughness as well as the presence of a viscous sublayer. It also incorporates transient effects at the laminar-turbulent transition. Performing of a weekly non-linear expansion in the bedform aspect ratio, we predict the effective hydrodynamic roughness when the bed wavelength is varied and show that it presents a non-monotonic behaviour at the laminar-turbulent transition when the surface is geometrically smooth. With a further self-consistent looped calculation, we are able to recover the smooth-rough transition of a flat bed, for which the hydrodynamic roughness changes from a regime where it is dominated by the viscous length to another one where it scales with the bed corrugation (Fig. 1). We finally apply the results to natural patterns resulting from hydrodynamic instabilities such as those associated with dissolution or sediment transport. We discuss in particular the aspect ratio selection of dissolution bedforms and roughness hierarchy in superimposed ripples and dunes.

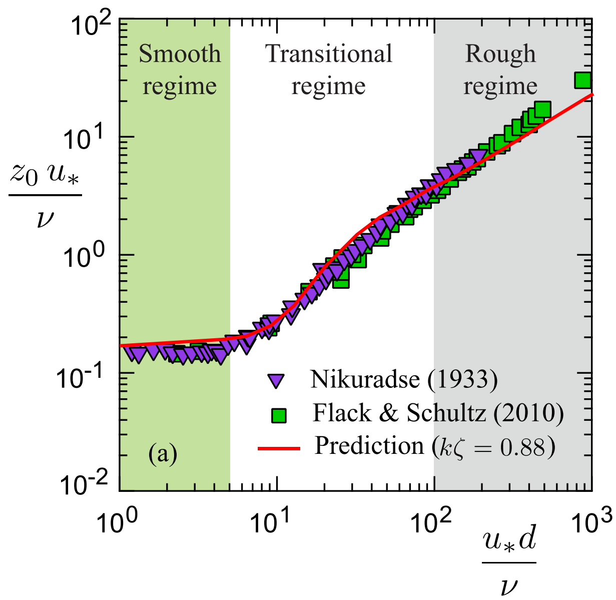

Figure 1. Hydrodynamic roughness z_0 as a function of the bed equivalent sand grain d. These quantities are made dimensionless by the viscous length ν/u_*, where ν is the kinematic viscosity of the fluid and u_* the shear velocity of the flow. Symbols: measurement data (see legend). Solid line: self-consistent prediction of the model.