DOUBLE-AVERAGED VELOCITY PROFILE OVER LARGE-SCALE ROUGHNESS

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Abstract

The present paper investigates double (time and space) averaged velocity profiles in open-channel flow over large-scale roughness elements for providing a simplified description of the flow structure and its velocity profiles. Mean velocity profiles and turbulence characteristics are obtained numerically and experimentally for surfaces roughened by two-dimensional dunes and transverse square ribs. The roughness geometry and height (k) are of the k-type. The Reynolds number, based on the flow depth (h) and the bulk velocity (U_b), is between 23,200 and 32,600. Large Eddy Simulation (LES) and Laser Doppler Velocimetry (LDV) experiments are jointly employed to study double averaged velocity and turbulence characteristics with sufficient spatial resolution and accuracy to reveal important structural properties of the flow, including the two-layer structure of the averaged flow, the virtual origin of the rough surface, and the extent of the inner region.

Two-dimensional dunes and square ribs were used in the tests (Fig. 1). A train of two-dimensional fixed dunes was attached to the bottom along the length of the channel (Figure 1). The dune height (k) was 20 mm, and the dune wavelength (λ) was 400 mm, so that $\lambda/k = 20$, which is typical of many previous studies. For flow over rib roughness, 1cm × 1cm square ribs were placed at the channel bottom. LDV measurements were obtained at six and two measurement locations over the wavelength of dunes and ribs, respectively, while LES results were analyzed over the entire roughness wavelength. The tested analyzed flows are listed in Table 1.

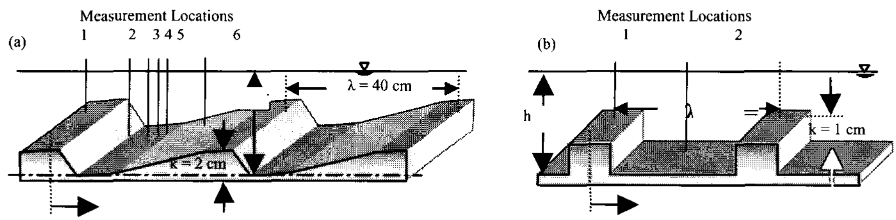

Fig. 1 Roughness geometries: (a) 2D dunes; (b) Ribs

The double-averaged velocity profiles for the investigated flow cases are plotted in Figure 2. The virtual origin, z_0, was defined for each flow case as the layer where streamwise component of double-averaged velocity diminishes. The location of the maximum streamwise turbulence intensity was chosen as the extent of the inner region, z_i. The values for z_i's are plotted in Fig. 2.

Table 1. Flow conditions

	Roughness	h	h/k
D1	Dunes	0.080	4.0
D2	Dunes	0.100	5.0
R1	Ribs	0.065	6.5
R2	Ribs	0.085	8.5

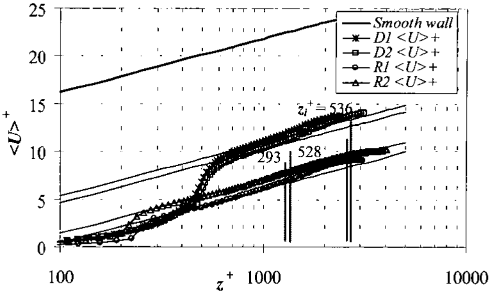

Fig. 2 Double-averaged profiles for all four cases

From a hydraulic engineering perspective, it would be useful to adopt a two-layer characterization of the flows over large-scale roughness, whereby velocity profiles can be uniquely described as a function of bed roughness characteristics. This simplified flow description is based on the log law for flows over smooth wall and the virtual origin and inner region extent concepts, as illustrated in Fig. 3. The velocity profile in the outer layer is described by the log law for the smooth wall adjusted with the roughness function, ΔU^+. The velocity profile in the inner region (between the virtual origin, z_0 and z_i) is approximated by a linear velocity distribution.

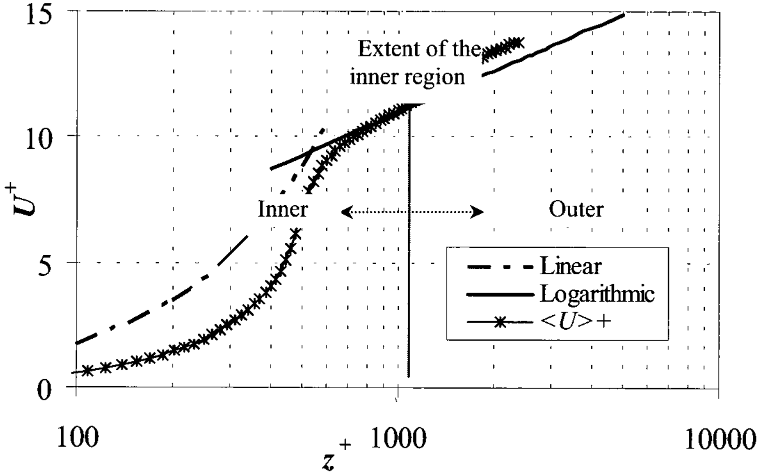

Fig. 3 Two layered profile for case D1

Formulations are sought for expressing unique relationships for ΔU^+, z_0 and z_i using only roughness characteristics (geometry, absolute roughness height, submergence) and to test the accuracy of this velocity model. The present paper demonstrates that these relationships can be reliably and conveniently obtained from LES simulations for a wide variety of large bed roughness. Currently, the authors are deriving such relationships for dunes and ribs of various geometry, submergence and flow regimes.