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Double-averaged velocity and stress distributions for hydraulically-smooth and transitionally-rough turbulent flows

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A b s t r a c t

We analyse experimental measurements of turbulent open-channel flow over hydraulically-smooth and transitionally-rough beds using the double-averaging methodology. Oil with a viscosity of 15×10^{-6} m^2/s is used instead of water so that transitional-range roughness Reynolds numbers can be achieved with large (11.1 mm) roughness elements, allowing spatial variations in the mean velocity field to more easily be measured. Distributions of double-averaged velocities, turbulence intensities, form-induced intensities, and viscous, Reynolds, form-induced and total shear stresses are studied with comparisons made between distributions for hydraulically-smooth, transitionally-rough, and fully-rough boundaries. Measured streamwise turbulence intensities for all experiments peaked at a constant distance from the bed ($z^+ + d^+ = 15$) when elevation scale is adjusted using the zero-plane displacement d for the logarithmic velocity distribution. This collapse suggests that turbulence intensity distributions may be useful in assessing appropriate values of d for transitionally-rough and fully-rough boundaries. Form-induced normal and shear stresses above the roughness tops were found to collapse towards a common curve independent of roughness Reynolds number.

Key words: double-averaging methodology, open-channel flow, particle image velocimetry.