Overland flow hydrodynamic characteristics at low Reynolds number with roughness bed

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April 28, 2020

Abstract

Overland flow is the major contributor to soil erosion. To clarify the hydrodynamic characteristics of overland flow at small Reynolds number, indoor experiments with fifteen unit-width flow discharges from 0.069 × 10-3 m2·s-1 to 2.5 × 10-3 m2·s-1, five slope gradients from 5.23% to 25.88%, three surface roughnesses and two kinds of flow (80% glycerol and water mixed flow and water flow) were systematically investigated. Results showed that mean depth and mean flow velocity can be good predicted by unit-width flow discharge, slope gradient and surface roughness. Based on flow regime criterion of parameter m, for 80% glycerol and water mixed flow, the flow regime was laminar flow. For water flow, it was between laminar flow and turbulent flow. According to the transitional Fr of 1, the experimental flow state tended to subcritical laminar flow with the increase of surface roughness. For 80% glycerol and water mixed flow, parameter K was 57. For water flow, parameter K was increased with the increase of surface roughness and fluctuated as slope gradient increased. The resistance law of open channel hydraulic for laminar flow (f = 96/Re) is not suitable for overland flow. In general, resistance coefficient had a good power function with Re. Meanwhile, there was a high significant correlation between resistance coefficient and inundation ratio and slope gradient. Resistance coefficient decreased as inundation ratio and slope gradient increased. For all flow regime in this study, a more accurate resistance coefficient prediction model was established by multiple regression analysis. As for hydrodynamic parameters, shear stress had a positive correlation with surface roughness. Meanwhile, stream power is not affected by increasing surface roughness, while unit stream power was negative with surface roughness. The slope gradient played a more important role in increasing the flow energy.

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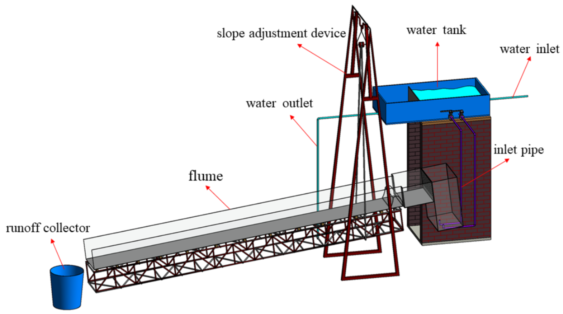


Fig. 1 Schematic of the experimental setup

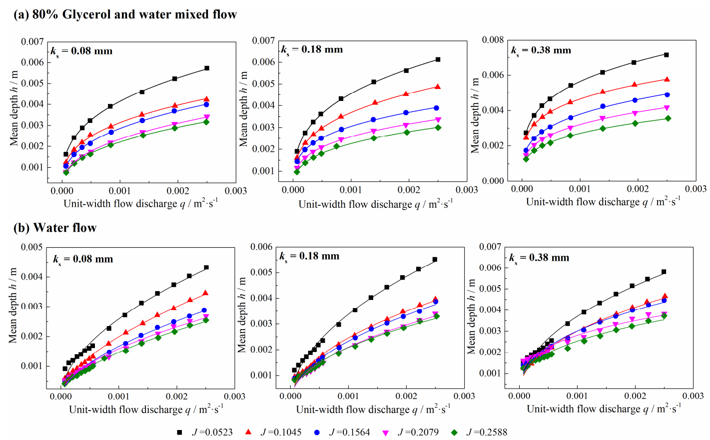


Fig. 2 The mean depth

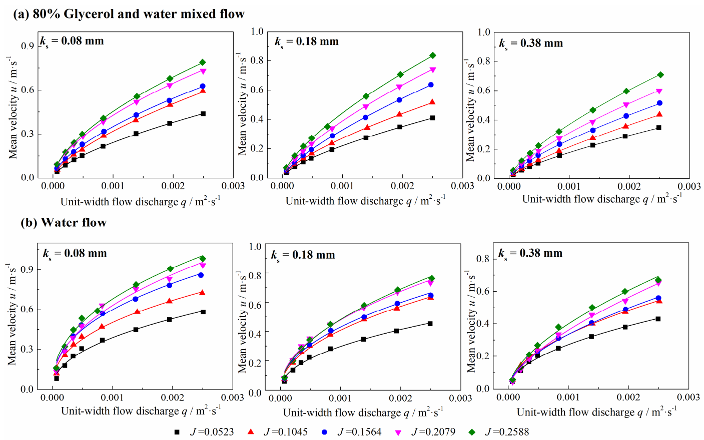


Fig. 3 The mean velocity

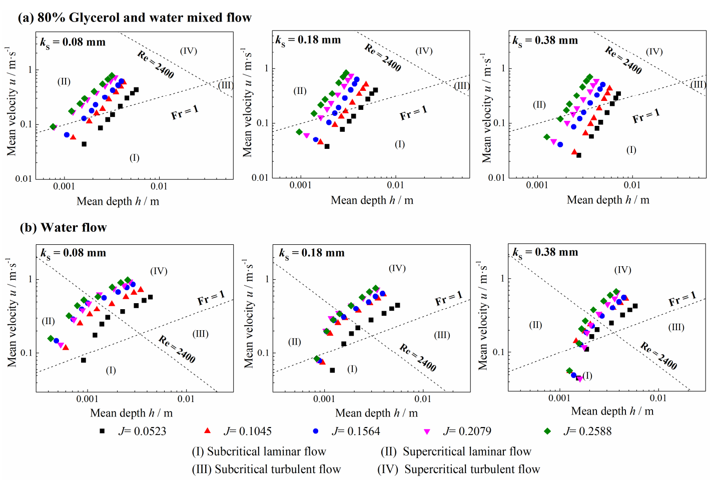
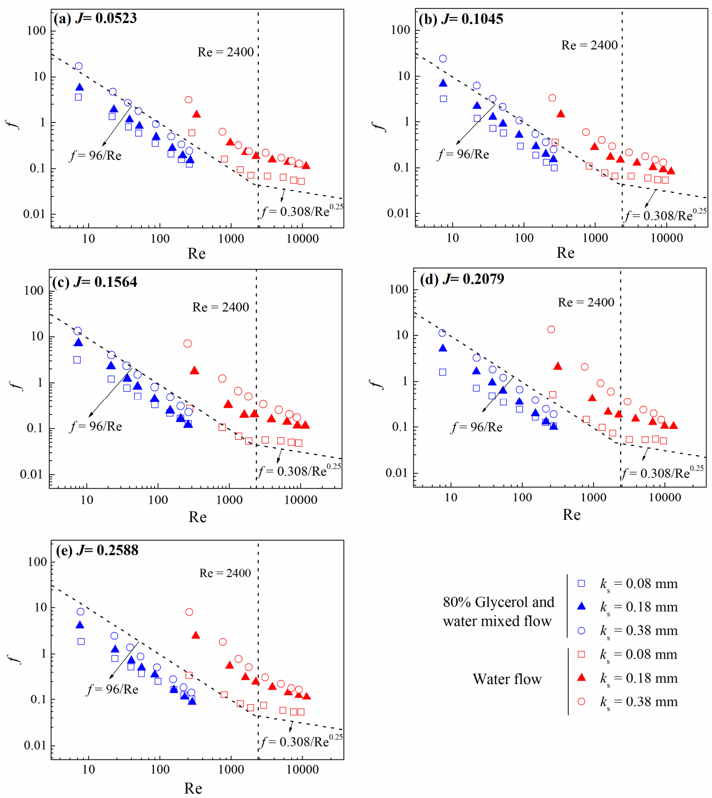


Fig. 4 The mean velocity versus mean depth



Note: The dash line ($f = 96/\mathrm{Re}$) represents the relationship between f and Re in open channel flow at laminar condition. The dash line ($f = 0.308/\mathrm{Re}^{0.25}$) represents the relationship between f and Re within 2,400 < Re < 20,000 (Savat, 1980).

Fig. 5 The relationship between *f* and Re

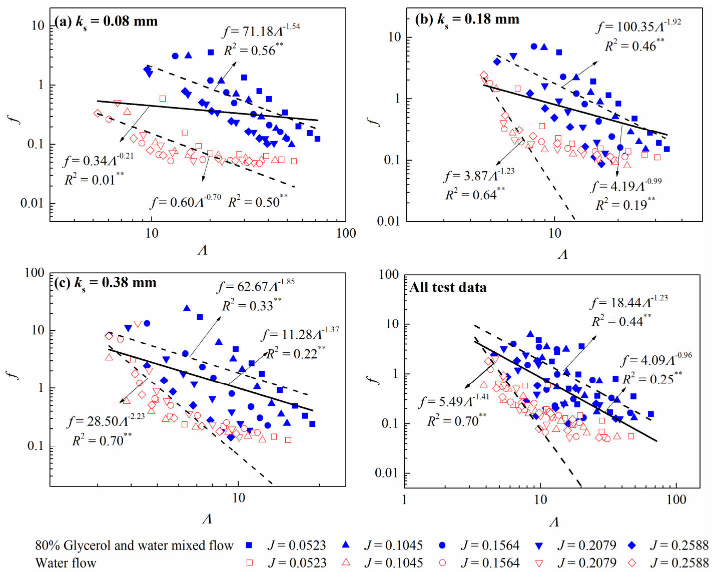


Fig. 6 The relationship between *f* and *Λ* (** represent the significance at p = 0.01)

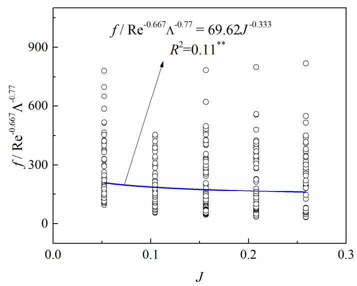


Fig. 7 The relationship between f / Re$^{-0.638}\Lambda^{-0.898}$ and J (** represent the significance at p = 0.01)

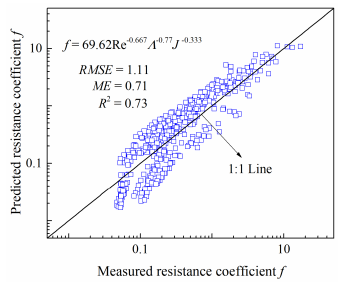
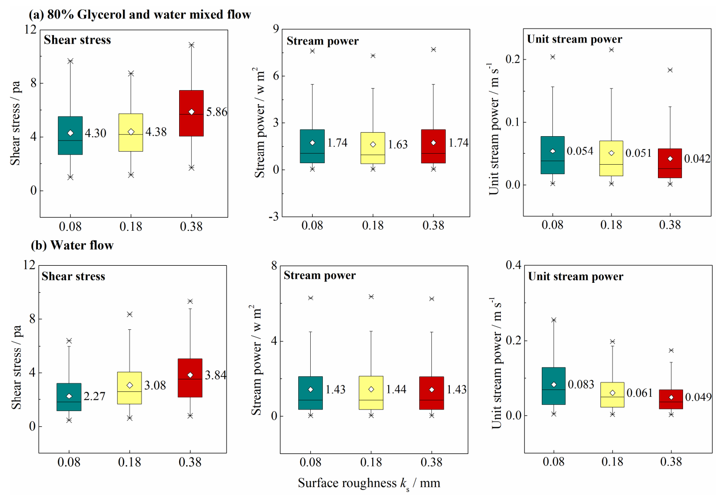


Fig. 8 Predicted resistance coefficient versus the measured value using Eq. (22)



Note: The upper and lower edges of boxes indicate 80th and 25th percentiles, the horizontal lines within boxes indicate median value, the upper/lower short lines extended from the box edges indicate 1.5 fold the interquartile range, and the rhombic markers indicate mean value.

Fig. 9 Summary estimation of the shear stress, stream power and unit stream power associated with three surface roughnesses

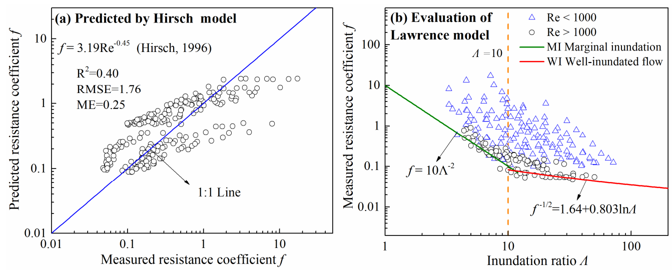


Fig. 10 Evaluation of two widely used models based on experimental data of this study

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