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# Longitudinal variations of hydraulic characteristics of overland flow with different roughness*

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**Abstract:** The evolution of the overland flow velocity along the distance downslope on smooth and granular beds in different cases is investigated by means of the electrolyte tracer via flume experiments. The results demonstrate that a non-uniform flow regime and a uniform flow regime exist in the development process of the overland flow. Owing to the different attributes of beds' roughness, the position of those zones with different flow regimes varies correspondingly: (1) the overland flow on granular beds enters into the uniform regime much sooner, additionally, the roll waves tend to appear because of the presence of the proper flow resistance imparted by the roughness (coarse sands), and large slopes ($20^{\circ}$ and $25^{\circ}$) which makes the flow velocities and depths to undulate spatially. Furthermore, the flow resistance of the overland flows with different roughness elements, that is the non-sands, the fine sands and the coarse sands, is calculated. A quadratic interpolation method of the third order accuracy is employed in the calculation of the longitudinal flow resistance. The results show that it is rational to use the bed slope to approximate the hydraulic energy slope over a relative small roughness (the present roughness), however on the other hand, if the mean flow velocities and depths rather than the local parameters are used to calculate the flow resistance, a considerable error will be induced within the non-uniform regime of the overland flows, including the acceleration zone and the roll-wave zone.

**Key words:** overland flow, longitudinal hydraulic characteristics, flow resistance, quadratic interpolation

## Introduction

The overland flow dominating the soil erosion, the scouring and the transport capacity[1-4] is one type of important natural flow patterns. Similar to the open-channel flow, the overland flow can be depicted by some hydraulic parameters. However, the overland flow is comparatively more complex than the open-channel flow due to the shallow sheet flow, the large slope and the changing roughness element. In many aspects, the overland flow can be characterized in terms of the flow patterns, the flow regimes and the flow resistance. On one hand, under the condition of a very low flow depth, the flow regime is more readily maintained as quasi-laminar, on the other hand, for relatively large and steep slopes, the high flow speed makes the overland flow absolutely turbulent. For the observation of the overland flow, the methods of observing traditional hydraulics and sediment transport mechanics are usually employed. For instance, the mean velocity, the mean flow depth, the discharge, the

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slopes and so on are measured to analyze the overland-flow characteristics. Nevertheless, due to the limitation of the flow depth, the investigation of the flow field and structure is relatively difficult, which hinders the overland flow studies.

For a realistic overland flow, due to the complexity of the boundary configuration, the characteristics of the overland flow can be very complicated. The roughness of the slope surface such as the vegetation on hillslopes and the large-scale stones on semiarid spots increases the total resistances, to reduce the mean flow velocity, the mechanical energy, and to increase the erosion. Those resistances in turn raise the flow depth. Thus the above aspects make it quite difficult to predict the overland-flow characteristics.

The mean velocity of the overland flow is initially associated with discharges and slopes in the form of a power function[5]. With a further study, the mean flow velocity is found to be less dependent on the varying slopes than the discharges in absence of large-scale roughness elements; thereby the discharge is understood to be the main influencing factor of the mean flow velocity without large-scale roughness.

Similarly, the flow depth as one of most basic variables determines the overland-flow characteristics. In comparison with the mean flow velocity, the feature of the overland flow depth itself, however, makes it more difficult to carry out practical measurements. One factor responsible is that the flow is so shallow that either the fluctuation or the turbulence can produce a significant deviation in the flow depth, in particular, in cases of complicated boundaries like the uneven bottoms with vegetation and large-scale stones, and the characteristics of the fluctuation and the turbulence tend to be more intensive. Furthermore, the hydraulic phenomenon with roll waves in streams with relatively large-slope beds will make the flow velocities and the flow depths vary periodically in space, and the situations are also suitable for the overland flow[6,7]. To overcome above shortcomings, some particular measurements like the statistical approaches characterized by possibility functions[8,9] are applied to evaluate the mean flow depth. But, these approaches are usually rather complicated. A more conservative but effective method to dealing with the overland flow depth, however, is employed to calculate the flow depth $h$ described by the following equation[9,10]

$$h = \frac{q}{v} \tag{1}$$

where $q$ denotes the unit discharge, and $v$ denotes the mean flow velocity. The results of the calculated flow depth are subsequently used to estimate other parameters such as the Froude number, the Reynolds number and the resistance coefficient.

The resistance as the essential parameter of the overland flow was widely in studied[4,9,12]. According to the available measured parameters, the resistance of the overland flow is well characterized by the Darcy-Weisbach coefficient $f$

$$f = \frac{8gJ}{v^2} \tag{2}$$

where $g$ is the gravitational acceleration, and $J$ signifies the energy slope.

In accordance with literature[4,12], the Darcy-Weisbach resistance is empirically understood as the total resistance, which generally contains the surface (grain) resistance, the wave resistance, and the form resistance. Additionally, as with the rainfall and the mobility of the bed being taken into account, the rain resistance and the bed-mobility resistance should be included. Gary's work[7] experimentally verified that the total resistance is not a simple linear superposition of those individual resistance components but in a more complicated non-linear relation. In the present paper, only the surface (grain) resistance is investigated since the fixed beds are designed to be smooth and granular fixed beds.

Instead of the mean hydraulic characteristics, the local ones along the distance downslope in the streamwise direction were rarely reported in literature[11]. In the conventional way, the overland flow for simplicity is technically treated as a uniform flow, which indicates that the developed overland flow does not vary spatially. And the mean flow velocities and depths are frequently evaluated to calculate the Darcy-Weisbach coefficient[12,13], with the assumption of replacing approximately the hydraulic energy slope with the bed slope. Nevertheless in actuality, the evolution of the overland flow with the roll waves generated due to the flow resistance is likely to make the longitudinal hydraulic features significantly fluctuate in space. More specifically, the treatment with the space-mean parameters in place of the local parameters seems inaccurate and may induce unavoidable error. In addition to roll waves, another factor affecting the result is the limitation of the length of the flume beds, the overland flow evidently includes the acceleration zone and the constant velocity zone on beds in laboratory experiments[5]. Furthermore, with significant achievements of the numerical simulations of open channel flows, the numerical models were more often used to analyze the overland flow[11,14]. Therefore, a new experimental approach is presented in this paper with the longitudinal hydraulic parameters being measured based on the above arguments, to investigate the spatially distributed variations of the hydraulic characteristics and the calculation of the flow resistance over different-roughness-element flumes.