Resistance to Flow for Liquid-Granular Flows in Steep Channels

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Abstract. One of the problems of debris flow modeling is represented by the necessity to have resistance formulae suited to describe the behaviour of the flow, ranging from the steep reaches of the channel up to the mild flow in the deposition basins, that is to obtain a formula able to describe the flow from mature debris flows to hyperconcentrated bed load transport. For this purpose a set of experiments on uniform of flow mixtures of non cohesive particles and water has been carried out in a laboratory flume in uniform flow in equilibrium. Tests have been done with different solid and liquid discharges. The measurements regard geometrical variables and depth-integrated quantities that have been combined to obtain the following dimensionless groups: the slope of the mobile-bed, the Froude number, the solid concentration and the ratio, *h/d*, between flow depth and sediment diameter. It has been observed that at small solid concentrations and small slopes the Froude number increases both with the concentration and with the slope, while for higher value of concentration or slope it tends to decrease. The experimental data have been employed to establish relationships between these parameters in order to develop a global resistance relation. The experiments show that in high-concentration flows the global flow resistance is due to the presence of both the water and the solid-particles. Therefore a *sum of effects* approach related to depth integrated quantities has been proposed. The Froude number has been defined according to the Darcy-Weisbach resistance law where the Darcy-Weisbach resistance coefficient has been written as the sum of two terms: the grain friction factor and a debris-flow resistance coefficient. The last term has been derived from the depth-integrated quantities related to the Bagnold's grain-inertia theory. It has been found also that the most appropriate relationship to close the problem is the Bagnold-Takahashi transportcapacity formula (1991). Some further considerations have been developed about the maximum concentration value that is inside the Bagnold's linear concentration. Experimental observations have shown that the maximum concentration to be accounted for (solid concentration in static conditions after the deposit) is lower than the maximum possible concentration (maximum packing concentration), we have identified this parameter as the *frozen concentration.* The theoretical prediction reproduced correctly the general trend of the Froude number with the bed slope and the concentration according to the global flow resistance formula, while the experimental data seems to be less sensitive to the relative roughness, *h/d*.