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Measurements and theory for transport layer structure in intense bed-load

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We focus on sediment laden flows driven by turbulent open-channel flows where the bed surface is fully mobilized and nonetheless the thickness of the bedload layer is conveniently smaller than the flow depth. This regime presents dynamic and kinematic features which persist in the range of applied Shields stress between about 0.3 and 3. Below the lower limit the moving grains do not develop significant stresses compared to the applied ones; above the upper limit, debris-flow type frictional contacts develop in a non negligible portion of the bedload layer. We report laboratory experiments in which, using high-speed cameras and a laser light sheet, detailed profiles of granular velocity and concentration have been measured. We checked that the transversal bed profile is flat and that the sidewall measurements are representative of the interior domain. The profiles provide new information on transport layer structure and its relation to the applied Shields stress. Contrary to expectations, we find that intense bed-load layers respond to changes in flow conditions by adjusting their granular concentration at the base. Two mechanisms account for the resulting behavior: stresses generated by immersed granular collisions, and equilibration by density stratification. Without parameter adjustment, the deduced constitutive relations capture the responses of velocity, concentration, and layer thickness in the above reported ten-fold increase Shields-stress range. Away from this intermediate range, in both directions, we show how the flow features rapidly change and the theoretical inferences decay.