WHAT CAUSES FRICTIONAL BEHAVIOR IN FLUID-MEDIATED SEDIMENT TRANSPORT?

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Bagnoldian analytical models of sediment transport in Newtonian fluid (e.g., air or water) are based on Bagnold's assumption of a constant friction coefficient (particle-shear-pressure ratio, μ) at the interface ($z = z_b$) between sediment bed and transport layer. In fact, this assumption is the main reason why these models predict the sediment load (which is the ratio between sediment transport rate and average particle velocity) to be proportional to the excess shear stress ($\tau - \tau_t$), a scaling that has been confirmed in many wind-tunnel and flume experiments. Here, using numerical simulations with the coupled DEM/RANS model of sediment transport in Newtonian fluid by Duran et al. [1], we investigate the physical reasons for this frictional behavior. In the case of subaqueous transport, we find that a local rheology $\mu(I)$, where I is the viscous number, can explain most of the simulation data. However, this rheology breaks down for aeolian transport. In an attempt to unify these transport regimes, we propose a novel characterization of frictional behavior through the dimensionless parameter $\zeta = \langle F^c_x v_x - F^c_z v_z\rangle / \langle F^c_z v_x - F^c_x v_z\rangle$, where $\mathbf{F}^c$ is the contact force, $\mathbf{v}$ the particle velocity, and $\langle\cdot\rangle$ a local ensemble average. We analytically derive $\zeta \approx \sqrt{3} - 1$ for locations within the transport layer and slightly within the particle bed, where each derivation step and the final result are consistent with our numerical simulations throughout all simulated conditions. Our derivation is mainly based on the assumption that the conversion of horizontal kinetic particle energy into vertical kinetic particle energy in low-angle particle-bed impacts is the predominant collisional energy transformation process occurring in sediment transport. We then show that $\zeta(z_s) \approx \mu(z_s)$, where z_s is the location at which the local production rate of particle fluctuation energy is maximal, and thus $\mu(z_s) \approx \sqrt{3} - 1$. This final result, which explains the success of Bagnold's assumption in analytical models of subaqueous and aeolian sediment transport, is consistent with our numerical simulations throughout all simulated conditions. Interestingly, the location z_s can deviate from the bed top (z_b) by up to two particle diameters depending on the simulated conditions.

References

[1] O. Durán, P. Claudin, B. Andreotti *Numerical simulation of turbulent sediment transport, from bed load to saltation*, Physics of Fluids **24**, 103306 (2012).