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Is the critical Shields stress for incipient-sediment motion dependent on channel-bed slope?

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A compilation of data from laboratory flumes and natural streams shows that the critical Shields stress, the parameter most often used to assess sediment mobility, increases with bed slope in open-channel flows. This indicates that particles of the same size are more stable in steeper sloping streams, which is contrary to standard models that predict reduced stability with increasing slope due to the added downstream gravitational force. Several effects might explain this discrepancy including increased contributions to form and wall drag, variable friction angles, grain emergence, flow aeration, and variations in the structure of local flow velocity and turbulent fluctuations. A simple 1-D force-balance model is formulated to test these effects. Surprisingly, increased form drag does not appear to be the cause of the slope dependency because both the magnitude and trend of the critical Shields stress are similar for flume experiments and natural streams, and significant variations in form drag in flumes is unlikely. Instead, grain emergence, and changes in the local velocity and turbulent fluctuations due to heightened bed roughness seem to be responsible for the slope dependency. To quantify these effects, a model for the local velocity within the grain roughness layer is proposed based on a 1-D eddy viscosity with wake mixing. In addition, the magnitude of near-bed turbulent fluctuations are shown to scale with the depth-averaged flow velocity, the ratio of flow depth to the characteristic bed-roughness scale, and therefore channel slope (for the same boundary shear stress). Extension of the model to mixed grain sizes indicates that the coarser fraction become increasingly difficult to transport in steep rivers and streams.