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Beware! The noise in critical shear stresses hides a signal of grain resistance

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Critical Shields stresses are often used in estimating bedload transport rates, channel stability and long-term channel evolution. In lower gradient channels, critical Shields stresses can widely vary, which is often attributed to differences in measurement methodology or grain size distributions between studies. In steep, rough streams, critical Shields stresses may correlate with channel slope because of flow roughness effects on channel hydraulics. We demonstrate using field, numerical modeling, and laboratory data that critical Shields stress variations in both lower-gradient and steep channels may instead be partly driven by variations in grain resistance to motion. Grain resistance is in turn controlled by protrusion (inverse of burial) above the surrounding bed sediment. We incorporate these effects in a novel theory for grain resistance that significantly improves predictions over existing models that do not account for the effects of grain burial. Using our theory and field data, we further demonstrate that the observed critical Shields stress variation between various lower-gradient channels is partly controlled by protrusion. In steep streams, we use field data to show that protrusion can vary with channel slope, implying that some of the observed relation between critical Shields stresses and channel gradient may in fact be driven by protrusion. We conclude that each critical Shields stress value may be uniquely defined by the channel bed conditions and the use of a single value for this parameter is likely inappropriate.