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Variations in grain-scale sediment structure and entrainment force in a gravel-bed channel as a function of fine sediment content and morphological location

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One of the major causes of uncertainty in estimates of bedload transport rates in gravel-bed rivers is a lack of understanding of grain-scale sediment structure, and the impact that this structure has on the force required to entrain sediment. There are at least two factors that standard entrainment models do not consider. The first is the way in which the spatial arrangement and orientation of grains and the resultant forces varies throughout a channel and over time, ways that have yet to be fully quantified. The second is that sediment entrainment is a 3D process, yet calculations of entrainment thresholds for sediment grains are typically based on 2D diagrams where we calculate static moments of force vectors about a pivot angle, represented as a single point rather than as a more realistic axis of rotation. Our research addresses these limitations by quantifying variations in 3D sediment structure and entrainment force requirements across two key parameters: morphological location within a riffle-pool sequence (reflecting variation in hydraulic conditions), and the fine sediment content of the gravel-bed (sand and clay). We report results from a series of flume experiments in which we water-worked a gravel-bed with a riffle-pool morphology containing varying amounts of fine sediment. After each experimental run intact samples of the bed at different locations were extracted and the internal structure of the bed was measured using non-destructive, micro-focus X-ray computed tomography (CT) imaging. The CT images were processed to measure the properties of individual grains, including volume, center of mass, dimension, and contact points. From these data we were able to quantify the sediment structure and entrainment force requirements through measurement of 3D metrics including grain pivot angles, grain exposure and protrusion. Comparison of the metrics across different morphological locations and fine sediment content demonstrates how these factors affect the bed structure and entrainment force requirement. These results have implications for the development of sediment entrainment models for gravel-bed rivers.

Keywords: fluvial sediment, geomorphology, entrainment models, X-ray computed tomography, 3D imaging, vector mechanics