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Friction versus dilation revisited: insights from theoretical and numerical models

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The intimate relation between apparent friction of shearing granular layers and their dilation was already discussed by Mead in 1925. Motivated by the importance of this connection to the frictional strength of geological faults and to earthquake generation, many laboratory and numerical experiments on sheared granular layers investigated the relation between the apparent friction and dilation. Although the nature of the connection is not very well established, apparent friction is often cited to be a linear combination of two contributions: 1. The surface friction coefficient of the grains and 2. the dilation rate (which is equivalent to the ratio of the work done in dilating the system to the work required for shearing). The contribution of the dilation to apparent friction arises since dilation is required to allow grain rearrangement during shear, yet dilation requires input of work against the normal force. We revisit this connection using theoretical treatment of two-dimensional sheared uniform granular layers and complementary Discrete Element simulations, both for gouge layers and rough surfaces without gouge. The theoretical calculation shows that fluctuations in both apparent friction and dilation rate, that occur during a particular type of grain-scale shear motion, follow a relationship that is nonlinear, although in practice appears close to linear. Results show that dilation, and hence apparent friction, are connected to shear localization. In numerical simulations of granular layers (without grain breaking or chemical processes) shear localization occurs but does not persist; instead the systems fluctuate between a state of distributed shear and dilation and localized motion on short-lived shear planes, with overall compaction. The transitions between these two types of shear involve changes in the dilation rate-friction relationship. Large systems of uniform and nonuniform grains show significant scatter about the linear relationship, which are connected to variations in the extent of shear localization.