Geophysical Research Abstracts
Vol. 18, EGU2016-10528, 2016
EGU General Assembly 2016

Enhanced stability of hillslopes and channel beds to mass failure

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The stability of inclined, unconsolidated sediments subjected to groundwater flow on hillslopes and steep channel beds is important for both landscape evolution and natural hazards. Force-balance models have been used for seven decades to predict the stability of slopes, but they generally underpredict the degree of saturation required to destabilize the sediment. Researchers often appeal to heightened stabilizing forces from root and mineral cohesion, and friction acting on the margins of the failure to explain this underprediction. Surprisingly, infinite-slope stability models in their simplest form have never been tested under controlled laboratory conditions. To address this gap in data, we perform a set of controlled laboratory experiments with slope-parallel seepage in the simplest possible configuration. We performed 47 experiments in a 5 m laboratory flume with 4 grain sizes (D_{50} = 0.7, 2, 5, and 15 mm) and a wide range in bed angles (20° to 43°), spanning both Darcian and turbulent subsurface flow regimes. Our experiments show that granular slopes were more stable than predicted by simple force balance models in experiments that lack root or mineral cohesion. Despite the smooth plastic walls and the long aspect ratio of our flume, we calculate wall and toe friction to be important. Including these additional resistance terms in the model reduces the model misfit with our experimental results. However, there is considerable remaining misfit (up to 50% underestimation of the saturation level required for failure). We investigate two explanations of this heightened stability: 1) standard frictional resistance terms are underestimated, and 2) seepage stresses are overestimated. Both explanations require that we modify the models used to predict slope stability.