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Shallow landslide size distributions controlled by the form, amplitude, and spatial correlation of strength variability across landscapes

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Shallow landslide size is important because of its impacts on hazards and landscape evolution, but a mechanistic explanation for size remains elusive. While shallow landslide size varies over orders of magnitude, observed size distributions can be strikingly similar even for very different landscapes. Recent work has suggested that the lower and upper limits of shallow landslide size are controlled by edge effects and strength patchiness, respectively. This produces the hypothesis that size distributions should be a function of the correlation length (CL) and amplitude of strength variability. We test this hypothesis using a multi-dimensional limit-equilibrium stability model and an efficient graph-theoretic search algorithm. We perform numerical experiments on a set of synthetic planar slopes with conditions typical of those on which landslides are observed. We test a wide range of planar slopes by spatially varying pore pressures with an imposed CL and amplitude. We explore three different types of variability: smoothly varying and symmetric, abrupt and symmetric; and abrupt and non-symmetric. We find two unexpected results: first, landslide size is insensitive to bulk average strength parameters; and second asymmetric spatial strength variability is required to localize landslides (preventing very large landslides). First, increasing slope or pore pressure in isolation increases the number of predicted landslides and reduces their minimum and median size, while decreasing slope or pore pressure has the opposite effect. This is consistent with existing theory and is true for all CLs independent of type of variability. However, when the pore pressure is set so that each inclined plane is at the point of failure (critical), then both landslide number and size becomes insensitive to slope angle at all CLs. This suggests that for slopes under critical conditions landslides size distributions are insensitive to bulk average strength parameters. Second, when using a smooth and symmetric (Gaussian) pore-pressure field, median landslide size declines slightly with increasing CL but maximum size remains invariant. Large landslides can occur within individual large low-strength patches (at long CLs), or when many small patches coalesce (at short CLs). This behavior persists with larger amplitude of variation and/or assuming an abrupt but symmetric pore pressure field. However, when assuming an abrupt and non-symmetric pore pressure field, as the CL is increased, high pore-pressure patches become more widely spaced and thus less likely to connect, resulting in a much smaller median size. This suggests that a non-linear pattern of variability is required to separate low-strength patches, prevent landslides from exploiting the entire domain, and produce realistic size distributions. In fact, using realistic form and amplitude of variability for two very different study sites (Cumbria, UK and Coos Bay, Oregon) we reproduce the observed landslide size distributions at a correlation length that corresponds to observed variability in each landscape. Taken together, these results suggest that landslide size distributions on critical landscapes are controlled solely by the form, amplitude, and spatial correlation of parameters relevant to slope-stability; and that they do so by defining the strength connectivity of the landscape - the cost associated with combining low-strength patches.