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MODELING PROGRESSIVE FAILURE AND LANDSLIDE PRECURSOR EVENTS - IMPLICATIONS FOR EARLY WARNING SYSTEMS

PETER LEHMANN[1]

[1] *Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, 8092 Zurich, Switzerland.*
E-mail: peter.lehmann@env.ethz.ch

Shallow landslides are often released abruptly without clear precursory signs. The short time span between measurable precursors and mass release is a tremendous challenge for the development of early warning systems (EWS). Modeling can help to specify situations with a higher risk of mass release based on site specific rainfall thresholds. However, due to the inherent heterogeneity (of soil mantle and rainfall) and the complexity of the triggering process (involving interactions at various scales), exact prediction of time and location may remain impossible. More specifically, the process of landslide triggering has similarities with systems approaching a critical state, where similar perturbations (rainfall amounts) can lead to very different results (no landslide or huge landslides). Such 'criticality' can be understood as result of the interactions of many interconnected elements. Due to these interactions, local damage can be intercepted by load redistribution to stronger elements, or can progress and cumulate into a hazardous mass release.

In slopes such local failures correspond to (i) breaking of roots and cementing agents, (ii) rearrangement of force chains and capillary water and (iii) friction and growing fissures between particles (Michlmayr et al., 2012; see Figure 1b). These damages occur at a much smaller scale compared to large-scale precursors like opening cracks and soil deformation. The local damages generate mechanical waves that can be measured as acoustic emission (AE). Experimental evidence from lab and field experiments with AE sensors suggest that they start long before a slope becomes unstable. In this study we present a modeling framework (Lehmann and Or, 2012; see Figure 1a) that simulates load distribution and progressive failure by representing the interactions between adjacent soil columns and bedrock with a fiber bundle model (FBM). An FBM consists of many mechanical elements (called fibers) with a certain strength distribution matching macroscopic soil strength properties.

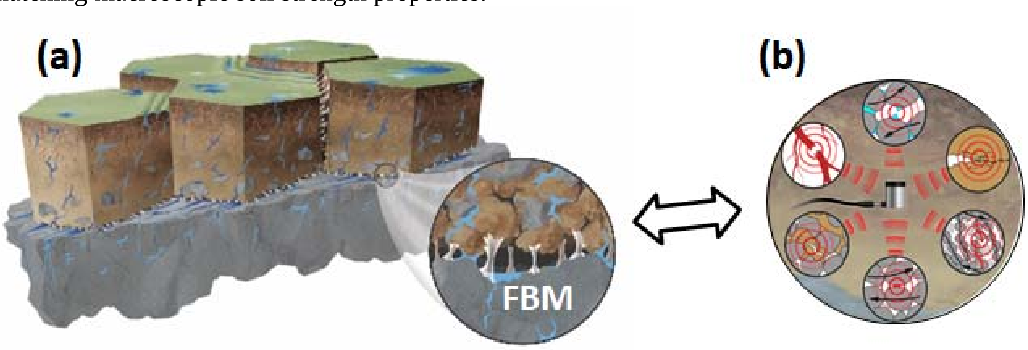

Figure 1. Linking the modeling and measurement of landslide precursors. (a) The columns representing the soil mantle are interconnected to adjacent elements and underlying bedrock by fiber bundle models (FBM). These fibers may break long before the mass release. (b) Breaking fibers represent various physical processes (see text) that can be measured by acoustic emission sensors.

When load is applied to an FBM the weakest fibers break and redistribute their load, initiating breakage of other fibers until eventually the entire bundle breaks. In Figure 2 the statistics of breaking fibers is presented for a numerical hillslope study. After 14 hours the first bundles break (Fig. 2a), four hours before landslide triggering. During this period the frequency-magnitude statistics of breaking fibers (following a power law) change significantly with a decreasing (absolute) value of exponent ζ (Fig. 2b).

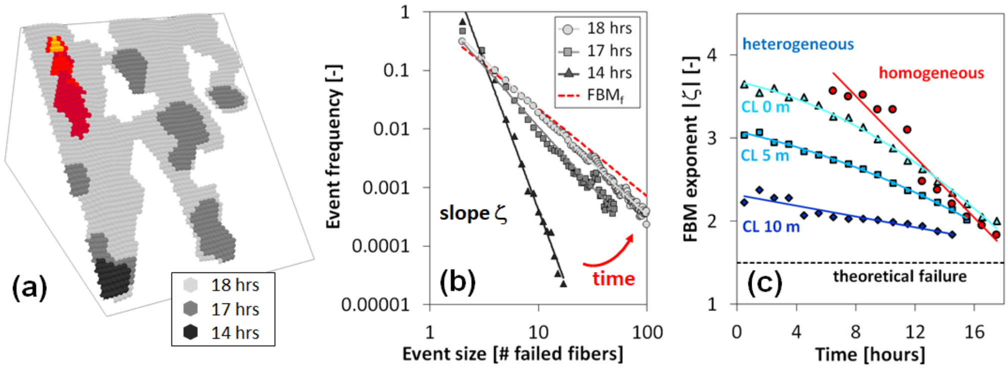

Figure 2. Modeling precursors and progressive failure in hillslope (50 x 50 m, slope angle 38°) during rainfall of 5 mm per hour. (a) After 14 hours the first fiber bundles break at the base of soil columns (dark gray). Additional spots with broken basal bundles appear after 17 hours (intermediate gray) and connect at 18 hours (bright gray), initiating a landslide (orange to red colors). (b) Hourly statistics of breaking fibers for the same time steps compared to the theoretically deduced statistics of a Fiber Bundle Model (dashed red line, FBM_f). (c) Evolution of fiber failure statistics (quantified by power-law exponent ζ) for hillslopes with homogenous and heterogeneous water distributions (differing in correlation length CL).

As shown in Figure 2c the failure process in the FBM starts long before mass release and offers a precursory signature before soil deformation or crack formation occur. Conceptually, by monitoring the statistics of local failures (simulated by breaking fibers and measurable as acoustic emission) the imminence of a landslide could be anticipated when statistics start to change. To test the predictive power of local failure statistics at the relevant catchment scale of early warning systems we will use the modeling framework STEP TRAMM (http://www.step.ethz.ch/step-tramm.html) that is based on the original model concept shown in Figure 1a but is adapted to run at catchment scale. In numerical experiments, we will determine the fiber failure statistics in different regions and check if we can anticipate where and when landslides occur. In the (near) future it should become possible to measure precursor statistics with distributed acoustic emission sensors at appropriate temporal and spatial scale. Measured and simulated failure statistics may then be combined to make more reliable estimates of risk of hazardous mass release.

Keywords: Shallow landslides, precursors, acoustic emission, fiber bundle.

References

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