Forecasting the Failure of Large Landslides for Early Warning: Issues and Directions

F. AGLIARDI, G.B. CROSTA & P. FRATTINI

Dipartimento di Scienze Geologiche e Geotecnologie, Università degli Studi di Milano-Bicocca, Piazza della Scienza 4, I-20126 Milano, Italy.

Complex, deep-seated landslides (e.g. rockslides, debris slides) pose a significant threat to human lives and infrastructures in alpine valleys. These landslides usually show peculiar structural and kinematic features, generally related to their scale. They reach up to several tens of million cubic metres and affect steep slopes up to 1000 m high. This results in a significant interplay of rock slope instabilities with large-scale geological features, acting as constraints on the rockslide geometry and kinematics (AGLIARDI et al., 2009). The long-term evolution, scale and geometrical/geomechanical complexity of large rockslides result in complex onset, deformation and failure mechanisms. These take place over a timescale of 10^2–10^3 yrs in changing geomorphological systems under the action of multiple triggers, including: post-glacial debuttressing and rock mass strength degradation, toe erosion, rainfall/snowmelt and related groundwater changes, reservoir level fluctuation, and progressive failure processes. Forecasting the failure of these landslides is difficult, due to non-linear displacement trends and the superposition of seasonal effects. Large rockslides can show creep-type deformation patterns (CROSTA & AGLIARDI, 2003), possibly characterized by continuous acceleration until catastrophic failure. The temporal pattern of displacements (slow vs. catastrophic, continuous vs. episodic) will depend on the evolutionary stage, reference time interval, seasonal effects, and whether the landslides actually reach a critical acceleration stage (BROADBENT & ZAVODNI, 1982). In any case, a sound prediction of the landslide evolution to failure require a time-dependent description of landslide behaviour in terms of some kinematic of dynamic quantity, to be calibrated using time series of measurements. Several models based on the "slope creep" theory (i.e. micro-mechanical, rheological, empirical) have been proposed in the last fifty years to provide such description. Among them, empirical/phenomenological approaches (SAITO & UEZAWA, 1961; FUKUZONO, 1985; VOIGHT, 1988) proved to be suitable to describe time series of monitoring. Different approaches have been proposed to estimate the time of failure of landslides showing accelerating creep, mainly based on the use of "inverse velocity" (FUKUZONO) and "log a – log v" plots. These methods proved to perform well in simple cases, showing continuous acceleration. Nevertheless, they fail to provide reliable failure time estimates for landslides showing complex response to external actions (e.g. seasonal pattern of displacements controlled by rainfall/snowmelt) or complex deformation-failure mechanisms (e.g. progressive failure, landslide sub-units with different scale and kinematics). These factors can result in very different temporal patterns of displacements (Figure 1), which need to be carefully evaluated when attempting to model landslide evolution. Other modelling issues include the preliminary evaluation of the type of data (i.e. surface vs. deep instrumentation, local vs. distributed measures, accuracy) and the definition of required measurement frequency and time windows. The latter affects the ability to catch progressive trends and understand landslide response.

Taking into account the issues and difficulties mentioned above, innovative approaches were proposed to establish alert displacement / velocity thresholds to be used as Early Warning tools for complex landslides showing significant seasonality. CROSTA & AGLIARDI (2003) obtained alert velocity thresholds through non-linear estimation techniques. Although physically-meaningful, the Early Warning tools provided by this approach are affected by significant uncertainty and need continuous update to be representative of the landslide evolution to failure. Thus, the approach will be implemented in the SafeLand project framework by integration of surface and deep-monitoring data (e.g. inclinometer, DMS), spatially distributed displacement measurements (e.g. GB-InSAR), and deterministic modelling of triggering processes (e.g. rainfall, groundwater changes) for selected large rockslides and debris slides.

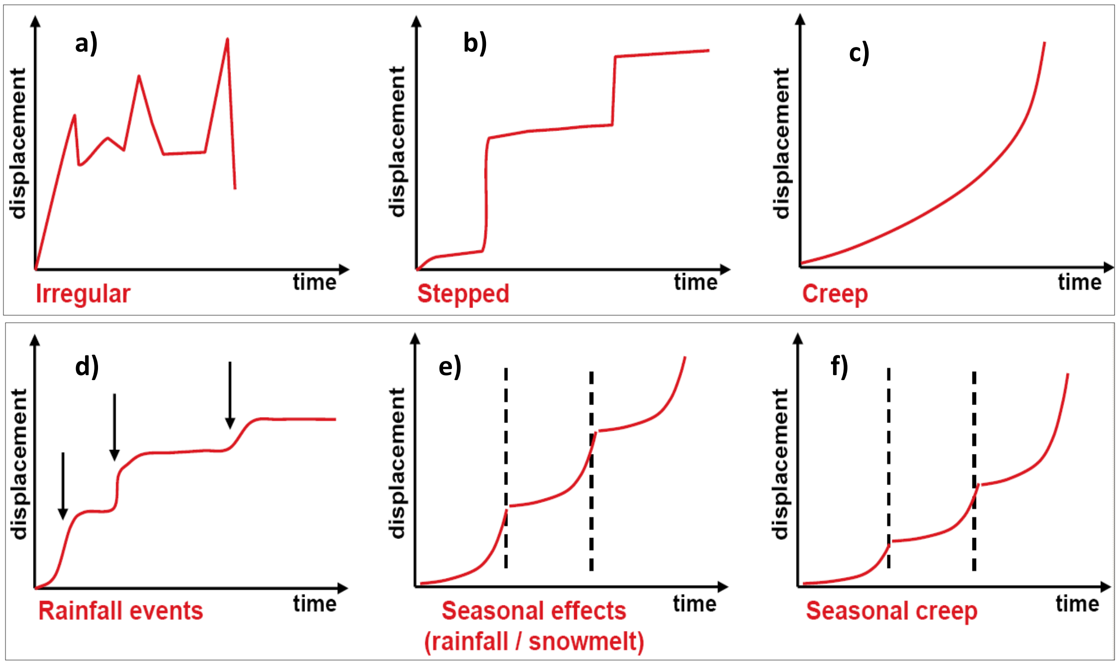

Fig. 1: Temporal pattern of displacements for large landslides, commonly derived by time series of monitoring data. Different patterns can be observed depending on the landslide failure mechanism and kinematics at different scale (a, b, c), and on the response to external actions (d, e, f).

References

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