Preface

Landslides and slope stability are one of the leading professional and research fields for engineering geologists. They have been addressed in the IAEG conferences and meetings since the very beginning of the Association. More than 400 contributions related to landslide processes have been submitted to this 12th IAEG congress. They constitute a representative sample of the developments achieved during the last few years and of the challenges our geoscientific community is faced with.

Landslide Mechanisms

Landslides and catastrophic rock and soil failures are due to a variety of mechanisms, some of which are still insufficiently known. This may explain why after more than 35 years, the well-known classification of landslide processes proposed by Varnes in 1978 is still being revisited and updated.

Several sessions in the Congress are devoted to the mechanisms affecting complex geological formations and large slope failures. One of them is focused on the so-called hard soils and soft rocks. Overconsolidated clays and argillaceous soft rocks cause frequent problems in civil works regarding the stability and degradation on exposed surfaces. These materials exhibit a quasi-brittle behavior. Fragility is often associated with loss of cementation of the material and consequently a drop of the shear strength which favors strain localization phenomena and development of progressive failure. The evolution of the movements may include catastrophic acceleration.

Significant research efforts have also been devoted to gain better understanding of the evolution of large slope deformations and to the prediction of their potential to catastrophic failures. Some slope deformations are slow and ductile, moving in a continuous or intermittent manner, others are brittle and after a certain deformation, or as a result of sudden loading (e.g., during an earthquake), they may accelerate, fail, and attain extremely rapid velocities. The failure of large rock masses may involve in-situ rock blocks bounded by a combination of nonsystematic joints and intact rock bridges. The instability process may lead to loss of cohesion, fragmentation of the rock mass, and very rapid flow such as rock avalanching (sturzstroms).

Techniques for Landslide Characterization and Monitoring

Different instrumentation systems have been developed to monitor landslide behavior, and they are used in many locations around the world. They are often employed in conjunction with surface mapping and subsurface investigations for a detailed characterization of slopes and landslides. Landslide monitoring has several purposes: it provides information about the geometry of the failure, the movement pattern as well as data for the calibration of analytical and numerical models. The interpretation of the temporal evolution of the different variables is the basis of early warning systems.

The automation of piezometers, inclinometers, extensometers, and distance meters has made possible the monitoring of virtually continuous motion and pore pressure changes. The interpretation of the data recorded has allowed the establishment of consistent relationships between instability triggers and slope deformations. Furthermore, it has highlighted the importance of elements such as cracks and macropores in the hydrological response of landslides.

Many landslides show spatially complex movements. Ground-based equipment such as extensometers or inclinometers are situated at specific locations on a landslide. Such monitoring devices are often costly to install, require access to the site while they yield spatially discontinuous data. The interpretation of the monitoring results requires a proper understanding of the landslide's geomorphological context, and of its different units. Remote sensing techniques are being now increasingly used in landslide investigations, because of their ability to survey large areas and acquire data with high accuracy and high spatial resolution without the accessibility constraints of other equipment and their performance in adverse weather conditions. Two main remote sensing techniques have been intensively tested in the recent years: the terrestrial and aerial laser scanner (LiDAR) and radar interferometry (InSAR), both satellite or ground-based. The laser scanner has multiple applications in slope stability, particularly in rock slopes. It generates high-resolution point clouds of the topographic surface from which one can derive detailed DEMs with highlighted geomorphological features; this can improve the quality of landslide inventories. Detailed DEMs can be used to define discontinuity surfaces and their attributes (i.e., orientation, persistence, spacing) and the deformation pattern of the monitored surfaces allowing the characterization of the instability process. Multitemporal DEMs analysis can also be used to detect morphological and volumetric changes over time.

Advanced InSAR techniques have become a powerful tool for spatio-temporal monitoring ground movements such as subsidence, surface displacements due to landslides or tectonic activity. An additional advantage of InSAR is the existence of a historical database of satellite SAR images (since 1992), enabling retrospective studies.

Other satellite-based sensors are currently available providing information with different spatial, temporal, and spectral resolution. A large number of crucial input data are obtained regarding soil type, vegetation, or land cover; these can be converted into maps through spatial interpolation using environmental correlation with landscape attributes (e.g., geostatistical interpolation methods such as cokriging) that can be easily integrated into GIS for landslide susceptibility and hazard analyses.

Landslide Hazard and Risk Assessment

Risk analysis involves the location, characterization of the landslide (classification, size, velocity, mechanism), and assessment of its travel distance and frequency, which is the hazard analysis; and the consequence analysis that takes into account the presence of the elements at risk, their temporal spatial probability and vulnerability. Risk analysis includes both hazard and consequences analyses. In risk assessment, the results of both analyses are evaluated against value judgments and risk acceptance criteria.

There have been significant advances in regional and local mapping of landslide hazard. The contributions presented to this congress nicely show the recent achievements as well as the shifting of the researchers' interest from landslide susceptibility to landslide hazard assessment and mapping. Furthermore, a parallel evolution has taken place from qualitative to quantitative approaches. The latter have several advantages as they offer more objectivity in the assessment; eliminate misinterpretations and the use of ambiguous terms; yield reproducible and consistent results; provide a direct input to the cost/benefit analyses. Nowadays, there exist well-founded procedures for the quantitative analysis.

The methods for preparing hazard maps have evolved from the heuristic approaches, to the statistical analyses and data driven methods, and to the deterministic analyses. The capability of the latter has expanded from the stability of individual landslides to spatially distributed models that calculate likelihood of rupture in combination with the return period of the triggers (rain and/or seismicity). The main drawback of these models is that they often oversimplify the geological and geomechanical variables and that should be based on high quality collected data.

The reliability of the hazard maps has improved thanks to high-resolution DEM obtained with remote sensing techniques and the development of data capture techniques. Several researchers have shown that higher resolution DEM on one hand improves significantly the results of slope stability and susceptibility models and on the other hand reduces the errors associated to trajectographic analysis or landslide runout simulations.

The spatial distribution of the hazard may be challenging for long runout landslides for which the probability of failure at the source area may differ significantly from the probability of the landslide reaching a specific area. In this case, calculation of hazard must take into account that: (a) different landslide types may occur with different time frames; (b) a target area may be potentially affected by landslides originating from different source areas; (c) the frequency observed at any target location or section may change with the distance to the landslide source. The practical application of the landslide hazard assessment therefore requires a multiple approach which should take into account the different failure mechanisms, each with different characteristics and causal factors, size, and spatio-temporal probability.

Landslide Prevention and Management

Risk management identifies the measures that may be taken to avoid damages to the society, if required. Different strategies can be considered and they may be synthesized as: risk acceptance, hazard avoidance, hazard reduction, and risk mitigation. Each strategy implements specific measures aiming at either modifying the slope conditions to reduce instability or restrict its development and damaging capability (active measures), or at avoiding the harmful effects of the landslide without interfering with its occurrence (passive measures).

Landslide mitigation measures may include structural measures when they involve any kind of engineering construction or intensive earth work. Stabilization and protection methods are often expensive and may cause irreversible impacts on the mountain ecosystem. However, structural measures cannot always guarantee full protection; and they require careful engineering design, and appropriate maintenance. Among all the options, the avoidance of landslide-threatened areas is the best alternative, and land use planning is a fundamental tool in promoting less expensive and sustainable development. However, the landslide prevention measures, and specifically the implementation of alert systems, have to be considered when the population or infrastructures are directly threatened.

The risk from landslide activity ought to be reducible by implementing early warning systems (EWS). An EWS does not modify the hazard, but does contribute to a reduction in the landslides consequences, in particular the loss of lives and thus the risk. It requires appropriate monitoring, definition of threshold values, short-term prediction of behavior, and then taking action to minimize risk when hazardous events are expected. The scientific and engineering community is knowledgeable about what causes landslides and what reactivates them, however predicting short-term evolution of a slope or a change in landslide activity is still subjected to uncertainties and errors. Without accurate predictions of short-term behavior (based on appropriate monitoring), made without false alarms and with sufficient advance warning to enable the community at risk to take appropriate action, warning systems cannot be relied upon.

EWS are installed with the aim of making accurate predictions of the behavior of landslides. While some systems operate with triggering thresholds such as the recorded rainfall, others are based on the analysis of the deformation trend and for their interpretation adequate knowledge of material rheology is required. The capturing and interpretation of small-scale prefailure displacements is a fundamental task for landslide prevention. Researchers have shown that different types of landslide may display different patterns of acceleration before failure, and thus that monitoring very small-scale precursory movements offers the prospect of forecasting a slope failure.

Finally, monitored data may be integrated within predictive tools which can involve an empirical and semi-empirical interpretation of deformation field phenomena. This is done using quantitative geological and geomorphological criteria or through the development and implementation of more general and powerful computational models.

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