Using GIS to Manage and Analyse Spatial and Temporal Data in the Study of Massive Landslide Behaviour

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Abstract

Research is underway to develop a rigorous and geomechanically sound approach to analyzing risk potential associated with slow-moving, massive landslides. Multi-dimensional instability analyses of complex landslides integrate data from instrumented sensor networks with three-dimensional numerical modeling. Field monitoring data and numerical model output provide impressive volumes of information describing slope behaviour. Major challenges lie in managing the large quantities of data returned from simulated case histories, in visualizing both field and simulated data and in comparing simulated data with field data. The use of geographic information systems (GIS) tools is vital to overcoming this challenge.

Background and Relevance

History has demonstrated catastrophic impact of massive landslide failure, for example the Frank Slide of 1903 [McConnell and Brock, 2003] and the 1963 Vaiont failure [Müller, 1987]. Infrastructure and community development in landslide prone regions demands knowledge of complex landslide behaviour. Extensive monitoring systems are used to track landslide deformations, although monitoring data is often cumbersome and complicated, especially when complex deformations are occurring. Massive landslides are generally impossible to prevent, and very difficult to mitigate: experts must therefore be trained to deal with, and interpret, monitoring data in such a fashion that advance warning can be used to avoid catastrophe. Numerical modeling, a fundamental component of ongoing research, is being used to probe the sensitivity of landslide behaviour to key geomechanical factors [Kalenchuk, 2007] and also to create cause-effect models of large landslides which will be used to train decision systems [Hutchinson et al, 2006]. Integrating numerical model outputs with instrumentation data and spatial data management tools (GIS) will aid in the development of geotechnical rule sets for landslide hazard identification and risk management.

Methods and Data

Field data is collected through monitoring networks of borehole inclinometers, extensometers, survey monuments, and piezometers. The interpretation of cumbersome spatial and temporal data is difficult. GIS tools aid the visual representation and manipulation of the data significantly. Spatial regression techniques compare the sensitivity of displacement rates to local factors such as local shear zone thickness, slip surface orientation or groundwater response time. These functions contribute to four-dimensional data analysis, providing insight into the key parameters that may influence landslide behaviour.

Numerical modeling plays a major role in the study of complex landslide behaviour. Slope stability is generally assessed using plane strain models of slope cross-sections, or three-dimensional models with basic geometries [Agliardi et al, 2001, Eberhardt et al, 2004, Hutchinson et al, 2006], neither of which adequately simulate massive landslide behavior. With ongoing research, sophisticated three-dimensional models have been developed to replicate massive landslides based on geological information and instrumentation data. Field data provides information for specific discrete locations within a landslide system, and therefore many factors, such as shear surface geometry, strength parameters and piezometric conditions, must be inferred for most of the landslide extents. Careful calibration of the models is thus required to assure that simulated deformation processes accurately reflect recorded slope behaviour.

Results

A comparison of preliminary modeling results to field data using visual analysis and spatial regression will be presented. Areas of the landslide model that do not accurately reflect the true landslide behaviour are isolated. Sensitivity analysis is then applied to determine which input factors: first, the inferred shear surface geometry and later, the distribution of mechanical strength parameters, contribute to discrepancies between real and simulated landslide deformations. Once numerical models achieve adequate representation of observed behaviour from case studies, the simulation of potential trigger scenarios will be used to generate synthetic response data for individual and groups of sensors. Synthetic records will be fed into decision support systems, to model the various potential combinations of sensor output. This has valuable application in hazard management of massive landslides, enhancing the ability of technical experts to interpret large amounts of field data and respond to rapid changes in sensor output, allowing for advanced warning of possible failure scenarios.

Conclusions

Vast quantities of data returned from real time monitoring and numerical simulations can be overwhelming and difficult to interpret. This approach to managing and analysing spatial and temporal data using GIS tools is key to the effective analysis of landslide behaviour. GIS tools are being used to assess real and simulated data in order to better understand the mechanical process taking place in massive landslides. Comparing these two data sources improves calibration of numerical models which replicate ongoing deformation processes and test geometric and parametric assumptions. Calibrated simulations of landslide case histories allow for the simulation of possible trigger scenarios and the establishment of failure thresholds. GIS tools are used to amalgamate modeling output with real field data, improving the decision-making capabilities of technical experts and the management of landslide-associated hazards.

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