SIMULATING AVALANCHE, DEBRIS FLOW AND ROCK-FALL

Hazard Mapping and GIS

The extreme avalanche winters of 1951 and 1999 in Switzerland clearly demonstrated the need for hazard mapping in mountainous areas. Hazard mapping helps in devising mitigation measures such as the construction of natural and artificial protection against avalanches, debris flow and rock-fall. The authors developed a new system called RAMMS (Rapid Mass Movements) comprising avalanche, debris-flow and rock-fall, protect and visualisation modules linked to a GIS.<P>

Nets provide one example of an artificial protection against rock-fall. Natural protection is afforded by stands of forest on mountain slopes. Knowing how trees dissipate energy, by for example either the trunk or root system, makes it possible to judge the protective capacity of a forest stand. Recent research has shown that a tree can dissipate energy during rock impact in several ways: by rotation and translation of the root system, by deformation and oscillation of the trunk, and by local penetration of the rock at the point of impact. This information has been used to determine the protective capacity of forest.

Avalanche

The system enables prediction of avalanche run-out distance, impact pressure and flow velocity using a digital terrain model (DTM), and is coupled with a GIS to simplify specification of terrain and initial conditions. Automatic GIS schemes may determine the location and magnitude of the conditions under which the avalanche was released, as well as friction parameters. The GIS-based user interface allows specification of a multi-layered pack of snow that may be entrained according to an updated Grigorian–Ostroumov procedure. Three entrainment mechanisms are used: frontal ploughing, step-entrainment and basal erosion. Entrainment rates are based on such parameters as avalanche speed and strength of snow cover. The model was calibrated using extreme avalanche events from the catastrophic winter of 1999, events in the SLF database, and an artificially released powder-snow avalanche at the Vallée de la Sionne test-site.

Debris Flow

Debris flow exhibits many modes of behaviour and may resemble either landslide or flood, depending on material, such as water and clay, and on the nature of the path of flow. Modelling is usually approached from the angle of both soil mechanics and hydraulics. A 2D-model is being developed to simulate run-out distance, velocity and flow-depth. The two-phase approach, based on shallow-water equations modified for granular flows, potentially allows for modelling the many modes of behaviour. However, details of frictional relationships and phase coupling for these flow types are not yet well understood. In most two-phase models developed so far, the Mohr–Coulomb description of stress–strain behaviour during the solid phase has been shown to be useful. Our model is based on a momentum-exchange concept, although the details of phase interactions remain a topic of intensive research. The friction parameters are therefore the internal and basal Coulomb friction angles, the pseudo-Chézy friction coefficient, a momentum exchange coefficient, bulk densities of the solid (equivalent dry bulk density) and fluid phases and initial volumetric concentrations. The resulting system of partial differential equations is strictly hyperbolic and is resolved using a finite-volume technique. Calibration is necessary to constrain model parameters. Our model will be calibrated using data from real debris-flow events recorded at our observation stations. This data includes front velocity and flow-height measurements and video observations, and coupled measurement of flow depth, fluid-pore pressure and normal and sheer forces. Before initialising a calculation, appropriate parameters can be selected specifying the nature of the debris flow, such as granular or muddy, and input volume via a hydrograph. Graphical output will allow overlaying simulated velocity, run-out and deposition profiles directly on topographic maps.

Rock-fall

To predict rock-fall hazard, computation of rock-fall trajectories in general terrain is needed. This is difficult, since rock-fall starting zones must be identified, rock size and shape defined, and impact/friction parameters assigned to terrain features. Robust computational procedures are then required in order to predict kinetic energy, bounce height and stopping points of rocks. Although statistical methods can be applied, engineers devising mitigation methods prefer deterministic calculations. These are based on predicting rock motion, including slide, roll and bounce. A rock-fall trajectory module is being implemented to predict avalanche and debris-flow run-out. Rock-fall starting zones and terrain friction, including presence of forests, can be automatically (or manually) identified. Numerical simulations at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) are currently limited to spherical rock geometry and soft-body ground/rock interaction.

User Interface

A graphical user interface wasdeveloped using IDL's new, pre-built Intelligent Tools. These tools, user-interface controls and custom algorithms reduce programming time and are easily integrated. Visualisation objects are defined as polygons, where georeferenced maps, aerial images and input parameters are mapped as texture maps on top. IDL is also used to handle all input and output specifications, including large DTM datasets. The DTM data, together with other input specifications, is then used to run one of the process modules (avalanche, debris flow or rock-fall). The numeric is solved using a 'C' program coupled to RAMMS. The binary output is then read, displayed and analysed using IDL. Results can be exported as ESRI Shapefiles and compared in ArcGis with real data from our large-scale test-sites. ESRI Shapefiles can also be imported, while GIF files, GIF animations and ASCII files can be exported and used in reports and on websites.

Concluding Remarks
The Swiss Federal Institute (SLF) is developing RAMMS in co-operation with Creative Software Systems (CREASO). Since many mitigation measures protect against other hazards for which they were not originally intended, the common interface allows for a comprehensive evaluation of such measures. As the system is linked to a GIS environment, RAMMS provides a powerful, user-friendly tool for hazard mitigation studies in mountainous regions affected by gravity-driven, rapid mass movement.