THE APPLICATION OF SAMOS-AVALANCHE MODEL FOR WINTER ROAD PROTECTION

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Abstract

A coupled moredimensional catastrophic avalanche model has been developed in cooperation with the Austrian Torrent and Avalanche Control (BMLFUW, WLV, 1989), the AVL (Research Institute for Internal Combusting Engines) in Graz, the department of Fluid Dynamics TU (Technical University) in Vienna, and the Institute for Avalanche and Torrent Research at the Austrian Federal Forest Research Station (FBVA) in Innsbruck. The results of the model are in good agreement with mapped field studies of natural disasters (Hufnagl, 1988). This mathematical model is used to forecast the run-out distance of the avalanche, the flow height, the height of deposition, as well as the vertical distribution of densities, velocities and total pressures. For the last year this model has been used as a tool to solve engineering problems (high way-protection) in cableway constructions such as the influence of designs relating to the behavior of catastrophic avalanches.

On the hand of three case studies by means the results of the SAMOS model is reported (Galtür disaster 1999 , tunnel bridge Gruber valley and the affectivity of a catching dam for road protection).
Key words: Avalanche road protection, design criteria, avalanche dynamics.

The SAMOS Catastrophic Avalanche Model

Catastrophic avalanches are characterized by a dense flow part with a high powder component. Due to the SAMOS-model (Snow Avalanche Modeling and Simulation) dry avalanches are described as a mass of non cohesive particles with flow densities in the range from 70 to 350 kg/m^3. In the dense flow regime the momentum transfer is caused by particle contact-collision in the powder snow regime the momentum transfer by turbulence. For the numerical implementations (Sampl, Zwinger, 1999) a finite volume (>10^3 volume elements) scheme is used and the conservation laws of mass and momentum are integrated over a material control volume that moves with the dense part of the avalanche (Lagrangian-formulation). Further details of the modeling and the model equations are given in the papers by Sampl and Zwinger (1999).

The powder avalanche simulation model duplicates the turbulent flux of a gas phase of powder avalanches along a three dimensional site model. Basis of the computer simulation of flux processes are the conservation equations of mass, energy and momentum (Brandstätter, Wieser, Schaffhauser, 1992). These equations posses general validity and therefore they are not reduced to the contemplation of a special flux problem. Also the behaviour of a powder avalanche, which flows downwards along an avalanche path can be described with these govern equations as dense gas influenced by the gravity and interaction with the surrounding air. Both models are coupled by a mass-transfer modul between the dense flow part and the powder part.

By means of fixed 3D-Eulerian grid which is fitted by a coordinate transformation to the surface of the avalanche catchments and the SIMPLE algorithm (Patankar, 1980) the before mentioned equation are solved.

The modified routine SAMOS includes a preprocessing part, the main routine, and a post processing part. After having entered the preprocessing section, first the area of topographic influence of the avalanche, the potential avalanche starting zone, above the limiting coordinates, the depth of the snow-pack, the density and the snow mass are entered. With the help of a system utility the isohypses are modified. Landmarks, screen dots, the surface roughness and the permeability of buildings (e.g. deflecting-dams) and vegetation (forests) are settled and inscribed with different key numbers. Prior to the geometric delimitation of the calculation grid the centerline of the avalanche has to be determined. After the sizes of the grids and the allowed time (variable running time of the simulation, time intervals between 0.1 and 0.4 sec output interval) have been entered, the calculation grids are generated. Thereby by preprocessing phase has been terminated and after having safed the project the programme is ready to run. Immediately after the start the computing process and the input parameters (mass of snow, iteration steps, gas density) can be checked at any time.

In the post processing part one can call in the maximum and minimum total pressure, the velocity vectors and the densities within the three space axes in longitudinal and cross sections as well as in the horizontal projection for each and every selected time internal and for any element number.

Verification

In February 1999 a large dry avalanche killed 37 persons in the village of Galtür, Tyrol, and caused considerable damage. A stationary situation with an anticyclone over the Atlantic and a cyclone over northeast Europe characterized the meteorological conditions during February 1999. Alternately moist warm air masses from the Atlantic and moist polar air masses advanced with strong north to northwesterly winds towards the Alps. In this period the snow height in Galtür increased from 80 cm at the beginning of the month to more than 200 cm at the end of the month.

This increase of snow height corresponds to a precipitation amount of 245 mm during February 1999, 422 % of the monthly average in February. This was the highest positive deviation from the monthly mean value ever observed in this region. The release area was estimated by the Federal Service for Torrent and Avalanche Control, Tyrol, partly based on observations and on the meteorological data reported above. According to this a total snow mass of 136 kilotons (kt) was released at an altitude of 300 to 1300 m above the village. Figure 1 shows the terrain model and the outline of the release areas (light blue) used for the simulation together with the computed distribution of maximal pressures resulting from the dense flow part of the avalanche (scaling 0-250 kPa). The central part of the computed dense flow crosses a highway and hits the village, as was observed in reality. The computed pressure where buildings were destroyed is of the order of 100 kPa. The agreement can be regarded as very satisfying. Deviations in the vicinity of buildings are to some extent due to their very coarse representation in the terrain model. Figure 2 shows computed maximal pressures resulting from the powder snow part of the avalanche at a height of 2.4 m above ground (scaling 0-25 kPa) together with the observed zone of powder snow impact. Computed powder pressures are much lower than dense flow pressures both in simulation and reality. However, the effected area can be much larger. According to the simulation 36 of the totally released 136 kilotons of snow were transferred to the powder snow part of the avalanche.

Evaluation Of Avalanche Effects On A Tunnel-Bridge

A specific application of the SAMOS-model resulted from a simulation of the forces from the powder part of an avalanche exerted on a tunnel-bridge. The tunnel-bridge was constructed 40 m above the bottom of the Gröber avalanche path to improve the safety along the Bschlaber access road (Außerfern, Tyrol; Fig. 3).

A maximum permissible static load of 20 kPa was allowed in the design criteria. In the release area of this avalanche the slope angles are between 25° to 48° and the track is inclined at 40°. The avalanche track is directed from southeast to southwest, with a release area of 1.4 km². The three-dimensional grid for the powder-snow-calculation contained 60.000 elements. The released snow mass assumed for the simulation was 23 kt. The simulation was done as if the tunnel bridge was absent. For the evaluation of the upper limit of pressures acting on the bridge the dynamic avalanche pressures at the corresponding position were considered. During the computed impact phase, 40 seconds after release, the powder part attained a maximum speed of 70 m/s with a maximum dynamic pressure of 17.5 kPa at the position of the bridge (Fig. 4). The computed pressure hence was below the permissible limit. However, since no avalanche of the assumed size hit the tunnel-bridge yet, verification was not possible up to now.

Evaluation Of The Effectiveness Of An Avalanche Dam

To demonstrate the potential use of SAMOS for the evaluation and optimization of avalanche dams the flow of a hypothetical avalanche was computed for two different terrain models, with and without a dam. The length of the considered dam is roughly 400 m, the dam height 14 m, inclination of the dam is nearly 70°. The terrain models also differ slightly in front of the dam. The simulation was done only for the dense flow part of the avalanche, which is usually of main interest concerning avalanche protection dams. The loss of energy due to the impact of the avalanche on a wall perpendicular to its flow direction is caused, in part, by three-dimensional effects. Since the dense flow part of the model is two-dimensional this three-dimensional effects cannot be computed directly, their effect has to be modeled by using friction coefficients, which still have to be determined in future research work. An in-depth investigation, including laboratory and field experiments, on the additional friction effects caused by avalanche dams and other protective constructions will be carried out in next three years. This test simulation, however, was done without considering additional friction, so the effect of the dam is underestimated to some degree. Figure 5 shows the terrain model for the simulation, without dam, together with the assumed avalanche release area (light blue outline; released mass: 19 kt) and the computed pressure distribution from the dense flow part. Figure 6 shows the terrain including the dam and the computed dense flow pressure distribution for the same release area. The pressure is reduced from 220 to below 200 kPa behind the dam. The deposited avalanche mass in the catching area is also reduced drastically.

The maximum pressure on the dam itself in the order of 250 kPa. Figure 7 shows in detail the computed dense flow deposition.

Conclusions

One month before the disaster in Galtür the SAMONS model project brought to a close. In the case of Galtür there was one of the rare and important possibilities for the verification of the results and the usefulness of the avalanche dynamics model.

The results obtained with the coupled dense flow – powder snow model described above show fairly good agreements with observations if one takes into account the uncertainties in the input data and the simplicity of the used transition model. The model is clearly superior to statistical or one-dimensional center of mass models since it predicts avalanche paths and impact pressures in two and three dimensions, respectively, and treats the dense flow and powder snow layers as separate parts explicitly. It also allows to assess protective constructions such as avalanche dams or retaining walls as these enter the calculation by modifying boundary (terrain model) or initial (release areas) conditions. Upper limits of pressures on constructions can be obtained by considering dynamic avalanche pressures predicted by the model.

Further improvements of the model can be achieved by a more detailed analysis of the transition zone between the dense flow and the powder snow part of the avalanche. The current model is not sufficient to account for all physical effects (e.g. saltation or hindered settling). It will also be necessary to include a model for erosion of material directly from the resting snow cover, a module which is meanwhile in the model implemented. A further task will be the investigation of the interaction of the dense flow part of the avalanche with dams and other protective constructions. Since a model can only be as good as the experimental or field data it is verified with, reliable and accurate data coming from laboratory experiments and real scale field measurements are of utmost importance (Sampl, Zwinger, Schaffhauser, 2000).

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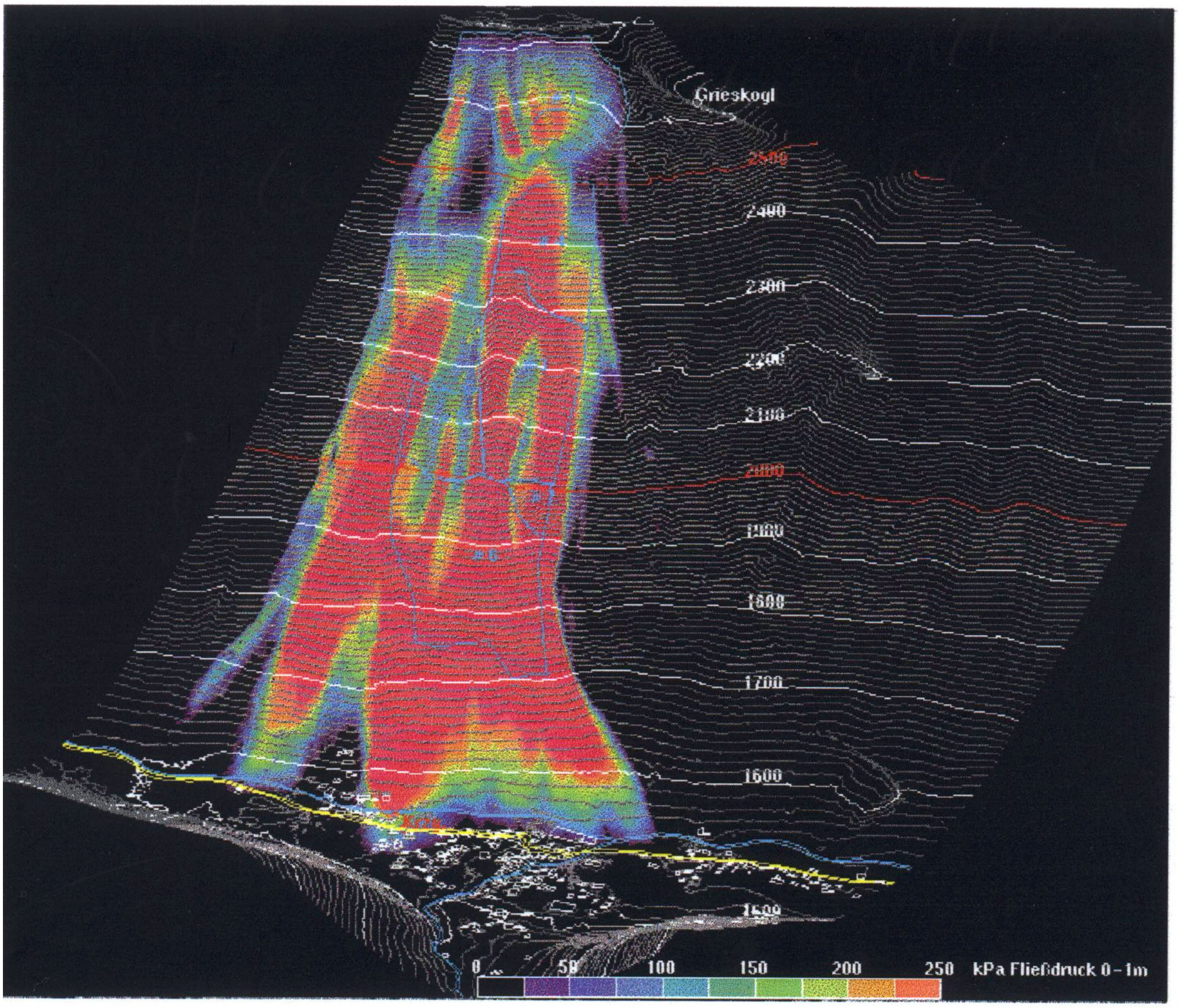

Fig. 1: Simulation of Galtür-avalanche 1999: Terrain model, release areas (outline in light blue) and pressure distribution (scaling 0-250 kPa) resulting from dense-flow part of avalanche.

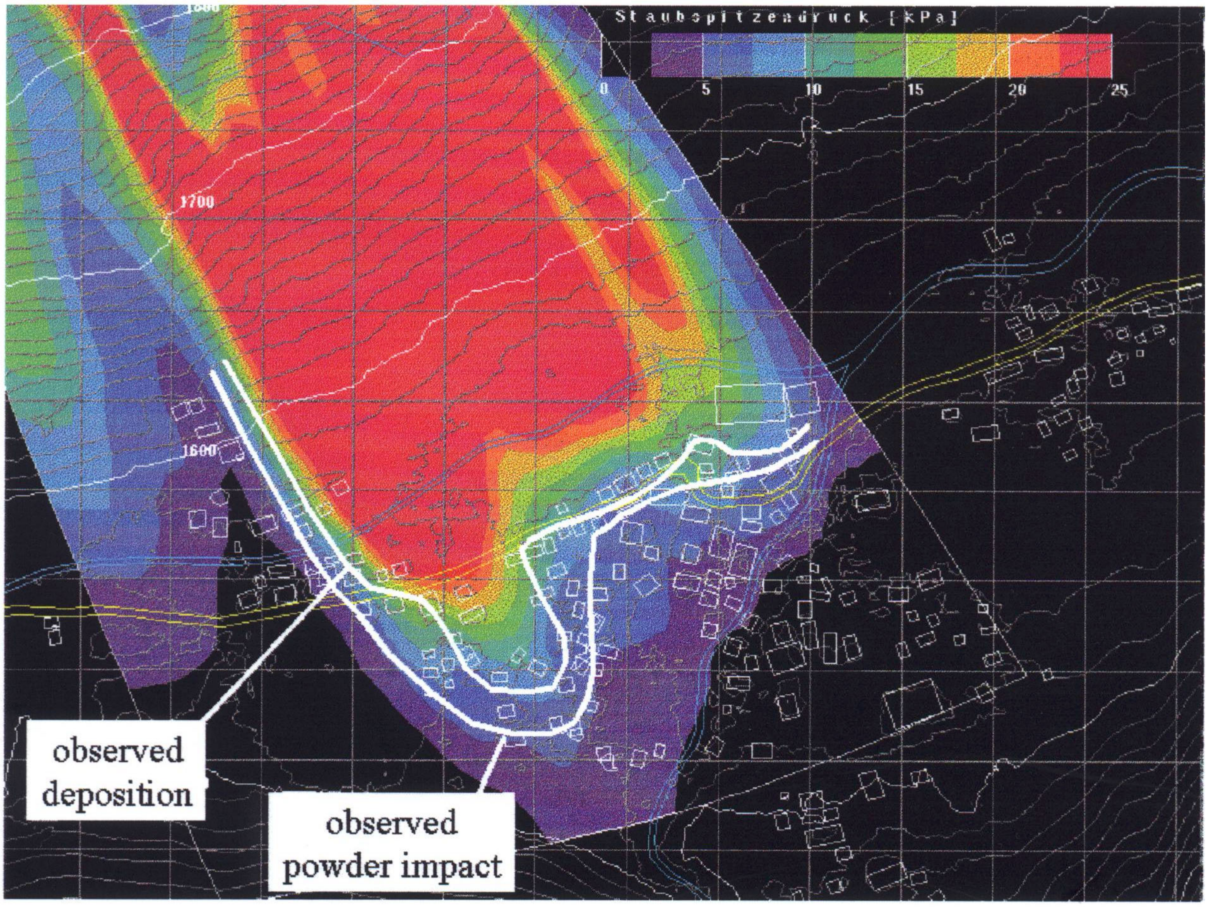

Fig. 2: Simulation of Galtür-avalanche 1999: computed pressure distribution from powder snow part of avalanche, 2.4m above ground/dense-flow (scaling 0-25 kPa).

Fig. 3: Gröber avalanche path with tunnel-bridge.

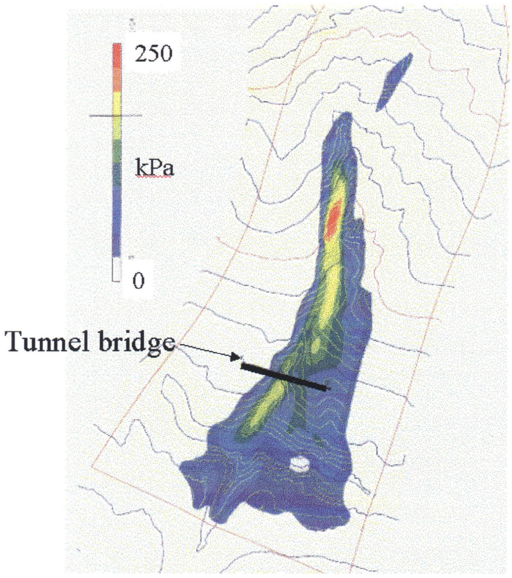

Fig. 4: Gröber Avalanche: Computed powder snow pressures (scaling 0-25 kPa) 40 m above ground; tunnel-bridge indicated by black bar.

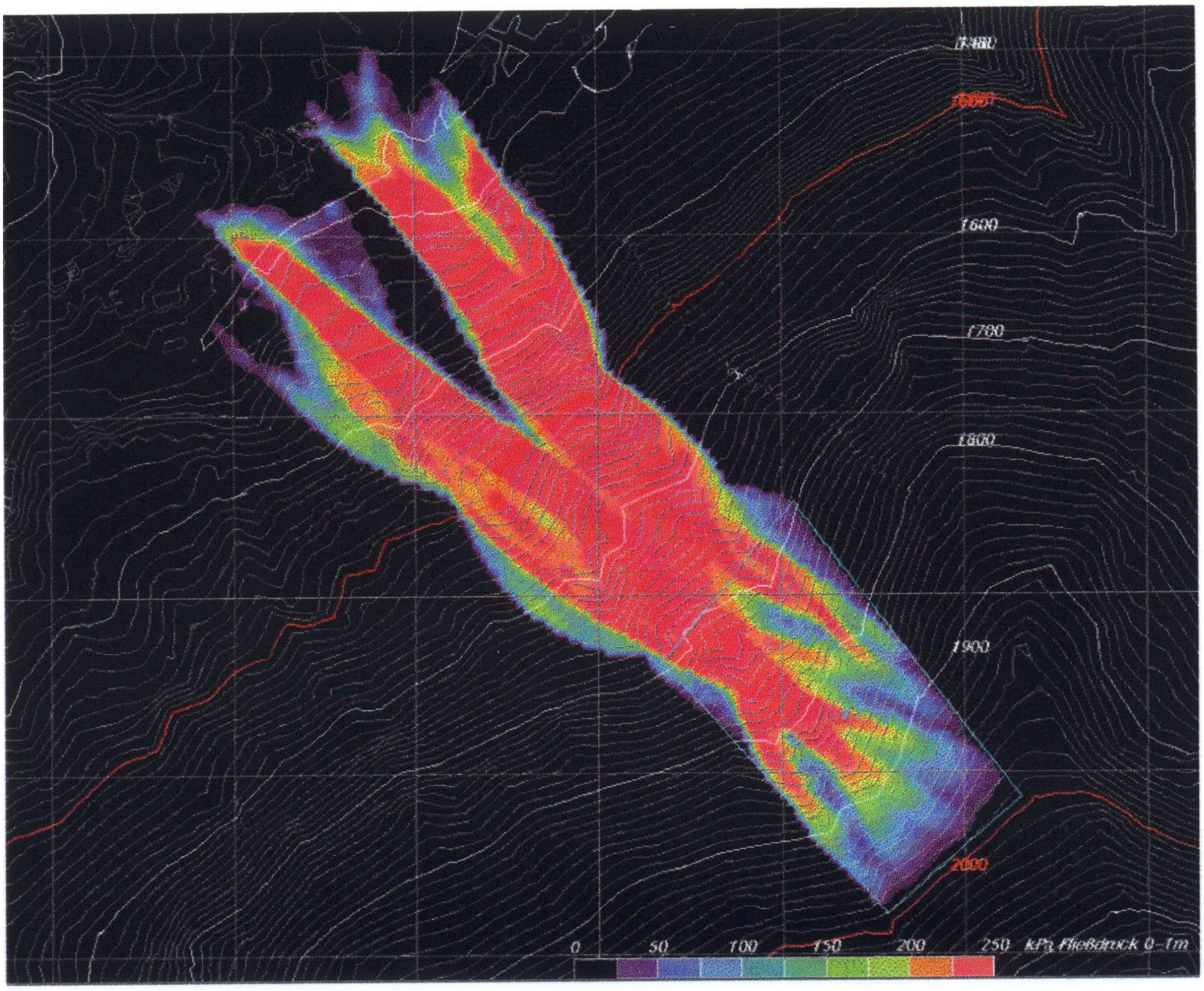

Fig. 5: Evaluation of an avalanche dam: Terrain model, release area (outline in light blue) and computed dense flow pressures (scaling 0-250 kPa) for the evaluation of an avalanche dam, scenario without dam.

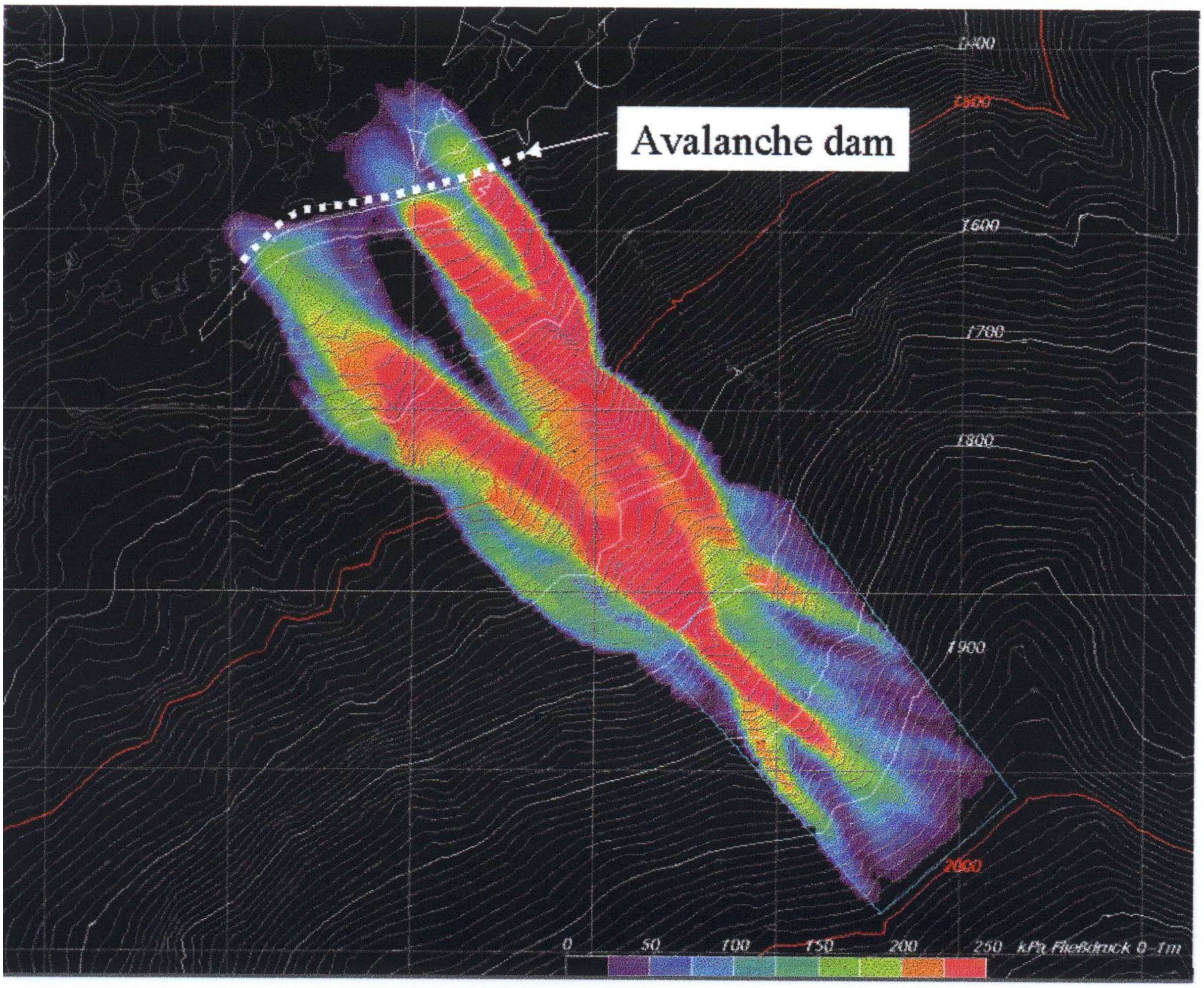

Fig. 6: Evaluation of an avalanche dam: Terrain model, release area (outline in light blue) and computed dense flow pressures (scaling 0-250 kPa) for the evaluation of an avalanche dam, scenario with dam.

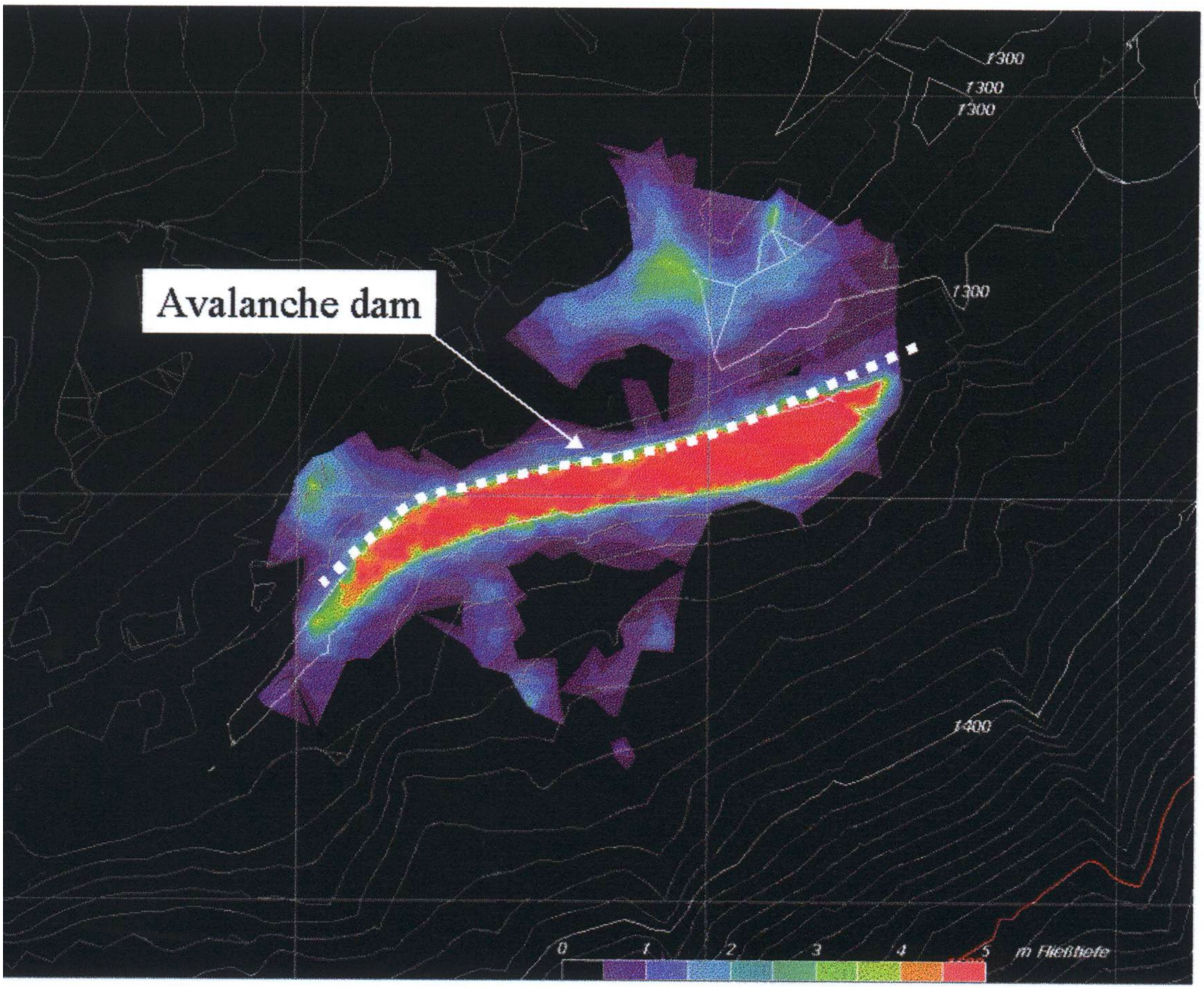

Fig. 7: Evaluation of an avalanche dam: Computed avalanche deposition heights (scaling 0-5 m) in the runout zone, scenario with dam.