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Modeling waves and short-lived peak velocities and impact loads associated with snow avalanches

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Abstract

The one-dimensional, unsteady, gradually varying free surface, open channel equations are solved numerically using the lax diffusive scheme. The numerical model is applied to simulate avalanche flow and to capture the existence of waveforms leading to the estimation of short-lived peak velocities and impact pressures for any point along a given avalanche track.

The simulation of both laboratory and field experiments are presented to demonstrate the viability of the discretization scheme. To verify numerical results of this new numerical model, results from the Swiss hydraulic continuum model for avalanche motion are presented and compared. The lax diffusive scheme provides acceptable results when compared to these laboratory and full-scale avalanche results and when compared to the Swiss numerical results.

Simulations are presented to demonstrate the ability for the numerical model to capture and track waveforms within the avalanche flow, to estimate short-lived peak velocities and impact pressures for any position along the avalanche track—especially when perturbations (i.e., terrain changes) are introduced into the flow. These perturbations are particularly evident when releasing a wave-like form from rest down an incline. Difficulties are encountered when trying to simulate in situ results and recreating the richness of the data.

Keywords: Snow avalanches; Granular flows; Debris flows; Hydraulics; Numerical modeling

1. Introduction

To date, scientists and engineers have successfully developed numerical models to estimate the mean, spatially varying velocity of an avalanche along a given avalanche's track, its runout, and its potential impact pressure, which is a spatially varying para-

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meter that is typically modeled as being proportional to the square of the mean velocity. These calculations are specific for an avalanche track with its specific and unique terrain geometry. Estimates of impact forces are utilized by engineers to establish the design load environment for constructed facilities within a given avalanche's path. In addition, information regarding the avalanche's runout and debris zone is used extensively to establish land-use zoning restrictions within and adjacent to a given avalanche's path.

By virtue of the relative simplicity of their formulations, these numerical avalanche models are not capable of estimating peak velocities and impact pressures associated with short-lived, high-speed waves and surges superimposed upon the mean flow. Full-scale field measurements of avalanches have recorded waves, surges, or both within the flow and the associated peak impact pressure (Salway, 1978; Schaerer and Salway, 1980; Shimizu et al., 1980; Kawada et al., 1985; McClung and Schaerer, 1985; Norem et al., 1985, Nishimura and Ito, 1997). In certain cases, these peak impact pressures, associated with these wave velocities, can be twice as large as the sustained impact pressure. Sustained and peak impact loads from 50 to 200 and from 470 to 2000 kPa, respectively, have been measured (Shimizu et al., 1980; Hopfinger, 1983).

In addition, recent forensic investigations of modern code-designed structures in Europe indicate that significant damage and subsequent fatalities have occurred due to poor understanding of the avalanche's short-lived peak impact loads.

Hence, both the peak and sustained avalanche velocities and impact pressures, along with maximum runout distances of avalanches, are critical to the successful design of buildings and passive avalanche defense structures (i.e., deflectors, arrestors, splitters, snow sheds, and retarders), as well as land-use planning for these hazardous areas.

2. Problem formulation

Numerical modelers of avalanches have struggled with obtaining realistic flow values. Clearly, the application of sophisticated numerical models does not present a problem in terms of computational effort. On the other hand, a lack of experimental data does not allow for the complete evaluation of the terms within a given model (i.e., resistance terms). McClung et al. (1994) pointed out that more experimental data are needed to allow for reliable applications of numerical models. The problem of experimental data is being resolved with the continued efforts of the Ryggfohn project in Norway in which 20 years of data have been collected, as well as the Vallee de la Sionne/Valais project in Switzerland (Ammann, 1999; Lied, 1998; Norem et al., 1985; Norem and Kristensen, 1986).

In situ experimental results (Salway, 1978; Schaerer and Salway, 1980; Shimizu et al., 1980; Kawada et al., 1985; McClung and Schaerer, 1985; Nishimura and Ito, 1997) suggest the existence of waveforms within the avalanche flow. Salway (1978) found that the avalanche consists of a series of waves and surges, whereas the pressure record consists of a series of high-pressure peaks superimposed on a uniform base pressure. Schaerer and Salway (1980) supported Salway's initial work and measured impact pressures with an initial peak, dropping to a constant value that was sustained as long as the dense snow moved against a load cell (see Fig. 1). Furthermore, the data indicated that initial peak pressures appear with every wave in the dense-flowing component of an avalanche. These data led to speculation that an improperly designed structure that has not considered these loads will be pounded by a series of waves that could result in structural failure.

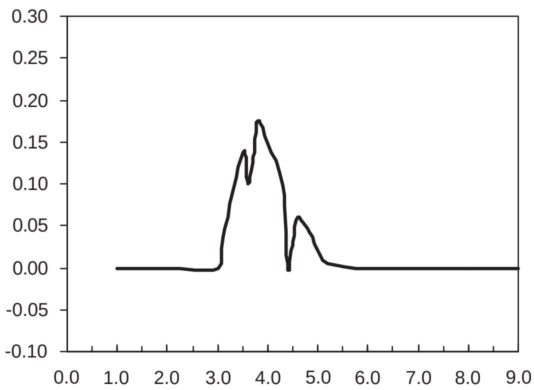

Fig. 1. Impact measurement from a load cell of an avalanche on Mount Baldy at Alta, UT. The data are recorded at the Alta Impact Pylon. The horizontal axis (x) is in seconds, while the vertical axis (y) is in voltages.