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SNOW AVALANCHE RESEARCH IN CANADA

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INTRODUCTION

The effects of snow avalanches on life and property in Canada are documented by Ommanney (1978) and Stethem and Schaerer (1979). Western provinces and the Yukon suffer the heaviest losses, although there are occasional incidents of avalanche death and property damage in the East. According to current statistics, about 10 to 15 lives are lost in avalanches each year across Canada. The largest proportion of victims are engaged in winter recreation, principally helicopter skiing and winter mountaineering. Catastrophes sometimes reach serious magnitudes; for example: 60 fatalities on April 3, 1898 near Dyea Trail, B.C.; 58 fatalities on March 5, 1910 near RogersPass, B.C.; 57 fatalities due to rock and snow slides on March 22, 1915 at Brittania Mine, B.C.; and 26 fatalities on February 18, 1965 at Grand Duc Mine, B.C. Avalanche disasters would be considerably more frequent if it were not for the conscientious avalanche forecasting and control programes that protect ski areas, highways, railroads, national parks, and provincial parks. Especially noteworthy, the highway protection program co-ordinated by Parks Canada at

Rogers Pass, B.C. is a model of highest international standards (Perla and Martinelli, 1976).

In addition to causing death and property damage, avalanches delay winter transportation, put communication systems out of service, and cause shutdowns of electrical power transmission. Each year avalanche problems intensify in response to the population shift to the West. Motivated by these escalating problems, Canadian scientists have made substantial progress on a wide variety of avalanche research topics.

ARTIFICIAL RELEASE OF AVALANCHES

One of the most important methods for avalanche control in Canada is the artificial release of avalanches by explosive blasting during opportune times when the public is restricted from the hazardous areas. Perla (1978) summarizes the state-of-the-art for using explosives on slopes that are readily accessible via foot, ski, helicopter, tram, etc. If the slopes are inaccessible, it is sometimes necessary to use military artillery. Although military artillery is highly effective, shrapnel and noise are objectionable, and the cost of weapons and ammunition are restrictively high for civilian use. Also, the military sector is justifiably reluctant to release weapons and ammunition into the civilian sector. Moreover, it is not always feasible to locate gun positions which have line-of-sight to target, and at the same time are convenient and safe for personnel. Because of these difficulties, Canadian scientists

(Schaerer, unpub.; Everts and Laidlaw, 1978) have developed and tested an alternative that utilizes explosives *preplanted* in the starting zone and detonated by a special combination of signals on a VHF carrier. The preplanted system is presently used to release avalanches which threaten the road to the Sunshine ski area in Banff National Park.

AVALANCHE FORECASTING

Decisions to restrict the public from a hazardous area in order to initiate explosive blasting are usually based on highly subjective appraisals of weather and snow conditions. Canadian scientists have studied various systems for removing some of this subjectivity. Environment Canada (AES) meteorologists have improved mountain weather forecasts and are able to relay to field personnel at avalanche areas detailed forecasts of crucial variables such as new snow amounts, temperatures at select atmospheric levels, and upper air wind speed and direction (Daly, 1978; Gigliotti and Parent, 1978). Feedback of information from field personnel to AES meteorologists provides verification and continuing optimization of the forecast.

Attempts have also been made to correlate avalanche activity, as a dependent variable, with various combinations of independent variables (Salway, in prep.). Avalanche activity appears to correlate highest with the history of precipitation, wind, temperature, and past avalanche activity. Because of the complex interaction of the variables, the numerical models cannot replace human judgement (in statistical language, the variance is too high for confident decisions), although the Canadian efforts to quantitize avalanche forecasting are at least as successful as similar efforts made in several other countries (Switzerland, U.S.A., U.S.S.R.).

With regard to long term forecasting, Fitzharris and Schaerer (in prep.) have compiled a 70 year avalanche record for Rogers Pass, B.C. They found weak rhythms in avalanche activity that could be related to meteorological patterns reconstructed from historical weather records made available by AES.

MECHANISM OF AVALANCHE RELEASE

Progress in the forecasting and control of avalanches ultimately depends on learning more about the mechanisms of avalanche instability. Using theoretical, laboratory, and field methods, Canadian scientists have studied processes which could lend to the failure and release of the most dangerous type of avalanche, the so called *slab avalanche*.

McClung (in prep.) has developed a theory of snow slab release based on current models used successfully to explain the failure of soil, clay, and rock slopes. The theory describes shear fracture propagation along a weakened snow layer under the slab. The weak layer often exhibits special behavior, known as *strain-softening*, which McClung (1977) has observed in the laboratory during slow shear tests of alpine snow samples.

Weak layers have also been examined in the field at the release zone of slab avalanches. In a recent study conducted at the Whistler ski area, B.C., Stethem and Perla (in prep.) extracted snow samples from the weak layers of 30 slabs and transported the samples to a refrigerated laboratory for detailed inspection using a polarizing microscope. It was possible in several cases to identity the detailed fabric of the critical weakness. In related field studies at the Whistler Ski area and at Sunshine, Alberta, the shear strength of the weak layer and the statistical distribution of this shear strength have been measured *in situ* around the release zones of several large slab avalanches (Perla, 1977).

AVALANCHE PATHS

An avalanche path can be divided into three zones: *starting zone, track, and runout zone.* Avalanches initiate in the starting zone, accelerate to a maximum speed in the track, and decelerate to rest in the runout zone. The characteristics of the starting zone have been studied at Sunshine, Alberta (Perla, 1977), at Whistler, B.C. (Stethem and Perla, 1979), and at Rogers Pass, B.C. (Schaerer, 1977). These studies provide practical guidelines that enable skiers to avoid hazardous slopes while away from developed areas on ski tours and helicopter trips. They also provide the basic data which prove or disprove proposed models of avalanche release, as discussed in the previous section; and furthermore, provide data on the amount of snow that feeds into the track, data that relate to the size, velocity, and runout distance of extreme events.

Surveys and maps of complete paths (starting zone, track, and runout zone) are needed in order to prepare plans for avalanche defense structures and zoning ordinances. In Canada, the most active investigations are Schaerer (1977) who has compiled avalanche path statistics for the area at Rogers Pass, B.C., and Freer (1978, in prep.) who has surveyed and mapped a high proportion of avalanche paths that affect British Columbia highways.

Each year, avalanches significantly alter forests and watersheds. On a geological time scale, avalanches transport large amounts of debris, and thus gradually alter rock and soil features. Luckman (1977) has studied these effects in the Canadian Rockies, and has compiled a comprehensive review of avalanche geomorphology.

AVALANCHE MOTION

There is a worldwide effort to develop an adequate model which will describe the motion of an avalanche over its complete path. The majority of investigators have used hydraulic analogies from the theory of open channel flow, but with only partial success due to the nonsteady behavior of the flow and the terrain complexities. Taking into account the effects of nonsteady flow, Perla, Cheng, and McClung (in prep.) have developed a concise method for numerical computation of avalanche motion from initiation in the starting zone, over terrain of unlimited complexity, to the stopping position in the runout zone. The method should assist the preparation of avalanche zoning plans.

Experimental studies of avalanche motion have been in progress at Rogers Pass since the mid-1960's, shortly after the Trans Canada Highway was opened across the Pass. The work is sponsored by the National Research Council of Canada (NRC), and co-ordinated by Peter Schaerer who has authored numerous papers with his colleagues and assistants. In a recent, innovative study, Salway (1978) and Schaerer and Salway (in prep.) have used seismic geophones to monitor the motions of large avalanches. The geophone signals were processed to trigger relays, which in practical application could be used to issue warnings to oncoming trains or traffic.

AVALANCHE FORCES

The NRC group at Rogers Pass has also worked on the difficult problem of measuring the impact forces of high speed avalanches (Schaerer and Salway, in prep.). Force transducers have been installed on a large avalanche path that is active about six or more times each season. The transducer signals are fed to magnetic tape recorders and oscillographs which are located under concrete highway sheds. As the avalanche strikes the transducers it produces a characteristic signal made up of sharp peaks superimposed on a steadier base signal. The peak signal presumably represents the impact of sizeable snow blocks, while the steadier signal, which is roughly one third of the peak signal, is thought to represent a mixture of snow and air. Analysis indicated that impact pressure is

ρv^2 where ρ and v are the respective density and speed of the avalanche. Impact pressures are believed to exceed 10 tons per square meter (10 T/m^2).

A knowledge of impact phenomena is of practical importance as prerequisite to design of structures located near avalanche paths. The NRC work at Rogers Pass is world recognized.

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