MEASUREMENTS OF THE AMOUNT OF SNOW BROUGHT DOWN BY AVALANCHES[1]

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Abstract.--Annual mass of avalanche snow has been observed for 18 years on 45 paths at Rogers Pass. The proportion of avalanche snow making up the total snowfall varied strongly with year and path, but was 11% on average.

INTRODUCTION

Knowledge of the amount of avalanche snow expected to accumulate in run-out zones is of significance in planning avalanche control structures and roads, predicting snow melt and run-off, and estimating the mass balance of glaciers. With the object of developing this information the Avalanche Centre of the National Research Council of Canada has made observations at Rogers Pass, B.C., since 1966. Results of a study of the mass of individual avalanches have been reported (Schaerer and Fitzharris, 1984); the present paper summarizes a preliminary analysis of the total amount of avalanche snow brought down in the course of a winter.

Observations were carried out at 45 avalanche paths having vertical heights between 500 and 1300 m from starting to run-out zones, catchment areas between 27 000 and 560 000 m^2, and track inclines of 34 to 46 deg. The average annual snowfall of 700 to 1200 mm water equivalent varied strongly with the elevation of the catchment. The steep terrain together with heavy snowfall produced between one and thirty avalanches per path every winter.

OBSERVATION TECHNIQUE

The mass of avalanche snow per winter may be obtained by either measuring each individual avalanche and totalling the results or measuring the volume and average density of the mass at the end of the winter. After investigating both approaches, each with a variety of measuring methods, observation of individual avalanches was adopted as the most efficient. The volume of large avalanches was determined by measuring length and width with tape and probing the depth. Visual estimates of width, depth, and length proved to be adequate for small avalanches having depths less than 0.8 m. Density samples could be obtained from pits when the observations were made soon after the avalanches had occurred, but a core auger had to be used for deep deposits.

Trial observations of avalanche deposits at the end of the winter included tape measurement of the surface area, probing with long steel probes, survey of cross-sections with level and tape, photogrammetry, mapping by stadia and plane table. The principal difficulties with observations at the end of the winter involved time restrictions and dependence on weather to make it possible to survey all the avalanche paths before the snow melted.

YIELD OF AVALANCHE SNOW

The amount of avalanche snow an individual avalanche path yields is a function of terrain factors such as area of catchment, inclines of starting zone and track, aspect, roughness of the ground, and weather (snowfall, windspeed and direction, and temperature). In addition, it may be influenced by avalanche control measures. These influences were investigated in a correlation analysis.

The area of the catchment, defined as the land surface of the starting zone and track, and the total snowfall of the winter proved to be most significant. The best correlation was achieved when the area of catchment was expressed as $A^{0.8}$, although expressed as A it was very little worse.

Exposure with respect to wind and average incline of track had a weak correlation with the annual mass of avalanche snow. Effect of variations in ground roughness and the incline of the starting zone proved to be negligible. Although the starting zone angle usually determines how frequently avalanches start, the

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average incline of track seems to have an influence on whether or not avalanches reach the run-out zone.

Based on these results the annual mass of avalanche snow, M_a, may be expressed by the simple equation

$$M_a = f \cdot A \cdot S_a \cdot \rho \qquad (1)$$

where

A = Area of catchment,
S_a = Amount of precipitation (snow plus rain into snow) during the winter in the centre of the catchment,
ρ = Density of water = 1000 kg/m^3,
f = Yield ratio.

Yield ratio, f, is the ratio between the mass of avalanche snow in the run-out zone and the annual amount of snowfall in the catchment. In other words, it represents the percentage of snow that slides down in the form of avalanches.

Yield ratios were determined from 18 years of observation of avalanche mass, between 1966 and 1984, for 45 paths grouped according to exposure to prevailing winds, incline of track, and whether or not control by artillery was applied.

There was a strong variation among years and avalanche paths, even when wind exposure, terrain inclines, and avalanche control were taken into account, suggesting that other factors or combinations of factors are involved. A few avalanche paths had consistently high yields and others consistently low ones for no obvious reasons. Small variations in the interaction between weather and terrain would appear to determine the yield of avalanche snow.

The average yield ratio ranged between 4 and 23% for individual avalanche paths, with a mean of 10.7% for all. Paths with a track incline greater than 40 deg had an average yield ratio 2.1% greater than those having tracks with a low incline. Paths with starting zones receiving large amounts of drifting snow had average yields of 12% compared with 9.5% for paths sheltered from wind.

Artillery had no significant influence on the yield of avalanche snow. The 18 paths controlled in this way had a mean yield ratio of 11.2% and the 27 uncontrolled paths one of 10.4%.

Conclusions about maximum amounts of avalanche snow were made by fitting frequency distributions to the series of 18-year observations. The estimated 30-year maximum yield ratios ranged between 11 and 46%, with an average of 28%. Terrain factors and artillery control were found to be even less significant than for mean yield ratios.

CONCLUSION

The amount of avalanche snow brought down per winter varies strongly with year and avalanche path, probably as a result of complex interaction between terrain and weather. The mean and maximum yield ratios listed in this paper may serve as a guideline for Rogers Pass and, with caution, for similar areas. An analysis of terrain and weather in detail greater than was possible for this study would have to be made to develop more accurate information.

REFERENCE

Schaerer P.A. and B.B. Fitzharris. 1984. Estimation of the mass of large snow avalanches. Canadian Journal of Civil Engineering 11(1):74-81.

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