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BY

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Relation between the mass of avalanches and characteristics of terrain at Rogers Pass, B.C., Canada

P. A. Schaerer

Abstract The mass of snow deposited by individual avalanches at 46 sites at Rogers Pass, Canada, was measured during five years. A limit avalanche was determined for each site from the 30-year maximum snowfall, type of ground surface, and the area of the catchment. The mass of an avalanche with a 10-year return period was determined by fitting an extreme value frequency distribution. It was found that the mass of a 10-year maximum avalanche is a function of the limit avalanche and the size of the catchment in a broad sense only, but not of other terrain parameters such as slope angles and exposure.

Résumé On a mesuré pendant cinq ans la masse de neige apportée par des avalanches en 46 endroits à Rogers Pass au Canada. On a établi une avalanche limite pour chaque site d'après la chute maximum de neige sur une période de 30 ans, la nature du sol et l'aire du bassin de départ. La masse de l'avalanche décennale a été déterminée en ajustant une distribution de valeurs extrêmes. On a trouvé que la masse de l'avalanche maximum décennale est fonction de l'avalanche limite et de l'étendue du bassin d'une façon qualitative seulement et n'est pas fonction des autres paramètres du terrain tels que l'angle des talus ou leur exposition.

OBSERVATIONS

The Division of Building Research of the National Research Council of Canada began a study in 1966 to establish a basis for predicting the average and maximum size of snow avalanches. Observations were carried out at Rogers Pass in Western Canada where a large number of avalanche sites are accessible from a major highway. The 46 avalanche sites selected for the study had well-defined catchment areas and outrun zones where the amount of snow contained in the avalanches could be observed.

The volume of snow deposited, its specific gravity, the location of the starting zone and the furthest point reached by the sliding snow were recorded for each avalanche that occurred at the selected sites between 1966 and 1971. A number of variables during the period 1966-71 e.g., depth of snowfall, number of storms per winter. number of avalanches per year were compared with the same observations recorded over periods of 14 to 30 years. The mean values of the short period were not significantly different from the means of the long period and this leads to the conclusion that the observed avalanches are representative of the avalanche activity of many years.

CLASSIFICATION OF AVALANCHE MASS

The mass, M_L , of a limit avalanche was determined for each individual site:

$$M_L = (S - R)A$$

where:

S = the 30-year maximum water equivalent of the snow in the catchment area. (The values of S varied with the location of the avalanche site and the elevation and were determined for Rogers Pass from observations that were available from the past 30 years.)

R = a measure of the retention of snow due to terrain features, such as the roughness of the ground. It represents the water equivalent of the snow that is retained behind boulders, in depressions, and between trees and is not removed by avalanches. The values that were assumed for R are listed in Table 1.

A = the total area of the land surface from which snow could slide into the avalanche track. The area A must also include zones outside the watershed of the catchment from which wind usually removes snow and deposits it on the avalanche slopes; such zones can be found on wide, exposed mountain ridges.

TABLE 1. Snow retained on ground, R

Character of terrain	Depth, R
Open slopes with smooth bare rock, scree or grass	0.15 m
Gullies with small boulders	0.20 m
Gullies with large boulders, rough sides	0.25 m
Open slopes with boulders	0.25 m
Open slopes covered with scrub and small trees	0.30 m

TABLE 2. Avalanche classification

Type	Mass
Slough	$M < M_L \times 10^{-4}$
Small avalanches	$M_L \times 10^{-4} \leq M < M_L \times 10^{-3}$
Medium avalanches	$M_L \times 10^{-3} \leq M < M_L \times 10^{-2}$
Large avalanches	$M_L \times 10^{-2} \leq M < M_L \times 10^{-1}$
Major, unusual avalanches	$M_L \times 10^{-1} \leq M$

The observed avalanches were classified with respect to their mass M as listed in Table 2. It was found that the mass of the observed avalanches and that of the limit avalanches could best be expressed in cubic metres water equivalent of the snow.

The classification uses class boundaries on a logarithmic scale, similar to the mass magnitude proposed by Shimizu (1967). This study confirms that the logarithm of the mass is a useful characteristic of avalanches. It has also been found that an experienced observer, using visual observations only, would usually assign avalanches to the same class as determined by measuring density and volume.

MASS OF MAXIMUM AVALANCHES

The mass of an avalanche having a return period of 10 years and longer was determined by fitting an extreme value frequency distribution (Gumbel distribution), to the set of logarithms corresponding with the masses of the observed large and major avalanches.

From the frequency distribution for each site and a regression analysis the relations shown in Table 3 were found. The values of the 30-year maximum avalanches must be treated with reservation because of the short observation period.

Avalanches that have covered the railroad tracks at Rogers Pass have been recorded during the past 50 years and those covering the highway for the past 17 years. Using recorded information on the length, width and depth of the avalanche deposit, the mass of the 10-year and 30-year maximum avalanches were calculated for certain sites. The values obtained agreed with those computed using the equations in Table 3.

TABLE 3. Expected mass of avalanches

Return period	Catchment area Medium 50,000 m² to 250,000 m²	Large greater than 250,000 m²
10 years	$M_{10} = 0.060\, M_L$	$M_{10} = 0.035\, M_L$
30 years	$M_{30} = 0.092\, M_L$	$M_{30} = 0.055\, M_L$

CORRELATION BETWEEN MAXIMUM AVALANCHES AND TERRAIN

The study indicated that the mass of a 10-year and a 30-year maximum avalanche depends only on the size of the limit avalanche M_L and whether the catchment area is small, medium or large. The reason for a difference between medium and large areas seems to be the ruggedness of the topography rather than the surface area of a single site. Large sites are broken into several gullies and the occurrence of an avalanche from one may be independent of and have no influence on the others. Each gully could really be treated as a separate small or medium site, but it is possible for avalanches to occur simultaneously in two or more gullies and combined to form a large avalanche. No analysis could be made of catchments with areas smaller than 50,000 m^2 because their number was insufficient.

One reason for the insignificant influence of terrain parameters other than size and roughness of surface is that the variation of terrain at the observed sites was limited. The slope angles of the catchment areas were analysed with the aid of topographical maps of scale 1:5000. The mean slope angles ranged between 37° and 48° and the standard deviation between 5.7° and 10.5°. Statistical tests revealed that the slopes of individual sites were not significantly different because of this high variance.

It is known that steep slopes produce frequent avalanches, but it was not possible to find a correlation between the mass of a 10-year maximum avalanche and the maximum slope angle, or between the 10-year maximum avalanche and the area that has an incline greater than 42°. Surfaces steeper than 42° consisted of bedrock, and avalanches slide on them more readily than on slopes with less incline.

The investigated sites had different exposures to wind and sun, but these parameters had no influence on the size of the maximum avalanches, providing the area that contributes drifting snow was included in the area of the catchment.

CONCLUSION

The study has shown that the 10-year and 30-year maximum avalanche occurring at a site depends primarily on the theoretical maximum amount of snow that can accumulate in the catchment area. The slope of the terrain and the size of individual starting zones appeared to have little influence.

The results are considered to be typical for the mountains of the interior of southern British Columbia, but should be applied with caution to other sites even in this general area. Observations are now required on similar characteristics for avalanches occurring under different terrain and climate conditions.

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