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The Amount of Snow Deposited at Avalanche Sites

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Abstract

It is often important, when designing defence structures in the avalanche path and in the terminus, as well as for hydrological studies, to know the amount of snow that slides at known avalanche sites. The total amount of avalanche snow deposited during several winters was investigated at selected sites in Glacier National Park, in British Columbia, Canada. The number, type, and size of avalanches depend on the weather and vary considerably from year to year. A simple relationship was found, however, between the greatest amount of snow that could be brought to the valley bottom in any one year and the characteristics of terrain, exposure, and snowfall in the starting zone of the avalanches.

I. Introduction

One of the actions of avalanches is to transport snow from the mountain side to the valley. For engineering purposes, such as the design of diversion dams, barriers, snowsheds, or for hydrologic investigations, it is often necessary to have information on:

a) the maximum amount of snow that could be brought to the valley by a single avalanche,

b) the total amount of snow that is brought down by avalanches during any given winter,

c) the maximum amount of snow that could be brought down by avalanches in one year.

It is often necessary, in addition, to estimate from this information and knowledge of the characteristics of the path, the width, depth, and speed of avalanches and the location where the snow would be deposited.

The problem of predicting the amount of snow brought to the valley by avalanches is similar to that of forecasting runoff associated with rain and the melting of snow. Both problems are influenced by climatic factors which include intensity, frequency, and total amount of precipitation, wind, temperature, and terrain factors such as size of the accumulation zone, exposure, slope, and ground cover. There is a close relationship between these various factors and it is often difficult to isolate the influence of any particular factor. As the snowfall and the size of the accumulation zone determine the amount of snow available for avalanches, it would be expected that the amount of snow brought down to the valley would depend primarily on these two factors; the remaining factors would have only a secondary influence. A study was undertaken at selected avalanche sites at Rogers Pass, British Columbia, Canada to determine if this was so. This paper reports the results of this study.

Rogers Pass is the summit of the Trans-Canada Highway in the Selkirk Mountains famous for numerous avalanches. The highway was built between 1957 and 1962. An extensive study of the avalanches along the route was initiated in 1954 to obtain the information necessary for the design of the most suitable avalanche defence. This study and the avalanche defence measures chosen have been described by Schaerer (1962).

In general it was observed at the selected sites that avalanches that occur as a direct result of snowstorms are usually small. Large avalanches occur when snowfalls are followed by warm weather; the largest ones were observed during the snowmelt period. Unfortunately, the number of available observations was not sufficient to study the factors that determine the characteristics of individual avalanches. Only the total amount of snow brought down in one year is dealt with in this study.

Fig. 1. Tupper cliffs site, a typical site that was used for the study

II. Climate and Terrain

The annual average snowfall measured on the west side of Rogers Pass is 810 cm; on the east side it would be about 650 cm. Most of the snow is deposited in frequent minor snowfalls which yield less than 20 cm/day. Temperatures during the winter range between 0 and −15°C and drop below −20°C only occasionally. The general terrain characteristics of the avalanche sites investigated, of which Fig. 1 is an example, were as follows:

a) well-defined accumulation zone between 1 400 and 2 000 m above sea level,
b) the direction of the main valley is east-west and the avalanche slopes are exposed from southeast to southwest,
c) the starting zones consist of areas of bedrock with average slope angles between 50 and 60 degrees, cliffs 2 to 8 m high, and scree slopes with inclines between 35 and 42 degrees (Fig. 2),
d) occasional shallow gullies in the lower part of the accumulation zone,
e) sparse short brush, grass, and only a few trees on the scree slopes,
f) short and steep paths where no avalanche snow could be deposited,
g) avalanches terminate on talus slopes with inclines ranging between 30 and 35 degrees and at the valley bottom, between 900 and 1 100 m above sea level.

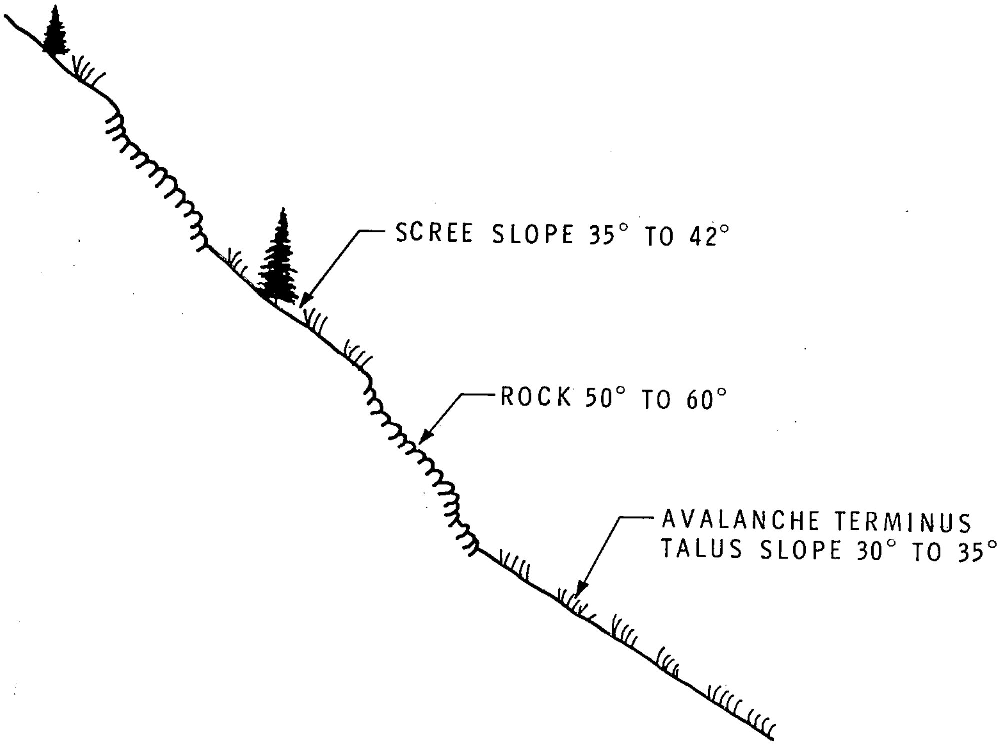

Fig. 2. Profile of avalanche site

III. Observations

The characteristics of the ground cover, size of the accumulation zone, and slope angles were determined directly in the field as well as from aerial and terrestrial photographs and maps (scale 1 : 12 000) made of the lower part of the accumulation zone. The most difficult part of the study was to measure the area of the accumulation zone. It appears that this can best be determined from maps prepared from air photographs.

The quantity of avalanche snow was calculated from observations of depth, width, and length of each avalanche that had occurred. Reliable records were available, however, only for the winters of 1955–1956, 1957–1958, 1958–1959, 1959–1960. Observations made since 1960 and damage to vegetation suggest that the number and size of avalanches that occurred between 1955 and 1960 were greater than average.

The density of avalanche snow was observed for several types of avalanches. Based on these measurements the following average densities were assumed:

minor, dry-snow avalanches in winter (November-February)	350 kg/m^3
medium-size, dry-snow avalanches in winter	400 kg/m^3
major, dry-snow avalanches in winter	450 kg/m^3
wet-snow avalanches in winter	500 kg/m^3
wet-snow avalanches in spring (March, April) surface layers sliding	550 kg/m^3
wet-snow avalanches in spring, sliding on ground	650 kg/m^3

Observations of the amount of snowfall were available for four locations in the valley and for two observatories located 2 100 m above sea level. It was possible to estimate by interpolation the amount of snow that fell in the starting zone of the avalanches. As is well known, wind has a major influence on the formation of avalanches. It was observed in the valley and on the slopes that wind removes on the average about 50% of the snow that falls on exposed terrain. The analysis of the observations indicated that this fact had to be taken into consideration when correlating the amount of avalanche snow with snowfall and area of accumulation zone. The areas of exposed regions that would contribute snow by drifting, both within and outside the accumulation zone, were estimated. Of this estimated area, 0.5 was added to the calculated area yielding avalanche snow. It can be seen in Table 1 that these areas, A_E, are relatively small.

IV. Results

The calculated areas of the accumulation zones and the amount of avalanche snow which was observed are listed in Table 1. There appears to be no correlation between the size of the total area and the amount of avalanche snow that was brought down to the valley, even for sites which have similar topography, and equal exposure and snowfall conditions. A better correlation was found when the steep areas only of the accumulation zones were assumed to yield the avalanche snow. In Fig. 3 is plotted

$$\frac{M}{S} \quad \text{vs.} \quad A_R + 0.5A_E ,$$

where

Table 1. Avalanche sites and observations of amount of avalanche snow

Site	Areas			Winter 1955/1956			Winter 1957/1958			Winter 1958/1959			Winter 1959/1960		
	A	*A*R	*A*E	*N*	*M*	*S*	*N*	*M*	*S*	*N*	*M*	*S*	*N*	*M*	*S*
	m²	m²	m²		m³	cm		m³	cm		m³	cm		m³	cm
Tupper Cliffs	55 000	19 000	4 000	*	*	67	5	8 900	73	9	14 100	91	5	8 400	64
Cougar Corner	114 000	24 000	6 000	*	*	103	2	2 200	98	9	17 800	116	4	11 100	88
Tupper 12	90 000	29 000	13 000	1	10 700	67	*	*	73	7	25 100	91	2	*	64
Tupper Minor	101 000	36 000	1 000	*	*	79	6	24 700	82	11	29 800	104	6	11 800	76
Bench	170 000	30 000	27 000	*	*	79	6	19 300	82	8	30 500	104	4	19 500	76
Atlas	145 000	52 000	22 000	*	*	76	5	6 300	82	10	35 900	98	9	11 300	73
Pioneer	89 000	55 000	20 000	4	30 300	76	6	13 700	82	14	48 200	100	7	6 600	76
Tupper Timber	195 000	68 000	13 000	3	13 300	76	7	1 100	82	13	44 100	100	5	39 700	76
Tupper 1	150 000	67 000	25 000	6	68 700	110	6	40 800	100	18	79 000	134	13	*	117
Tupper 3	166 000	90 000	38 000	6	82 000	100	10	37 500	92	19	105 000	120	9	79 000	106

A: Total area of accumulation zone.
*A*R : Area of accumulation zone steeper than 42 deg.
*A*E : Area exposed to wind.
*: Observations are not complete or unreliable.
N: Number of observed avalanches per winter.
M: Total amount of avalanche snow, water equivalent.
S: Water equivalent of accumulated snowfall.

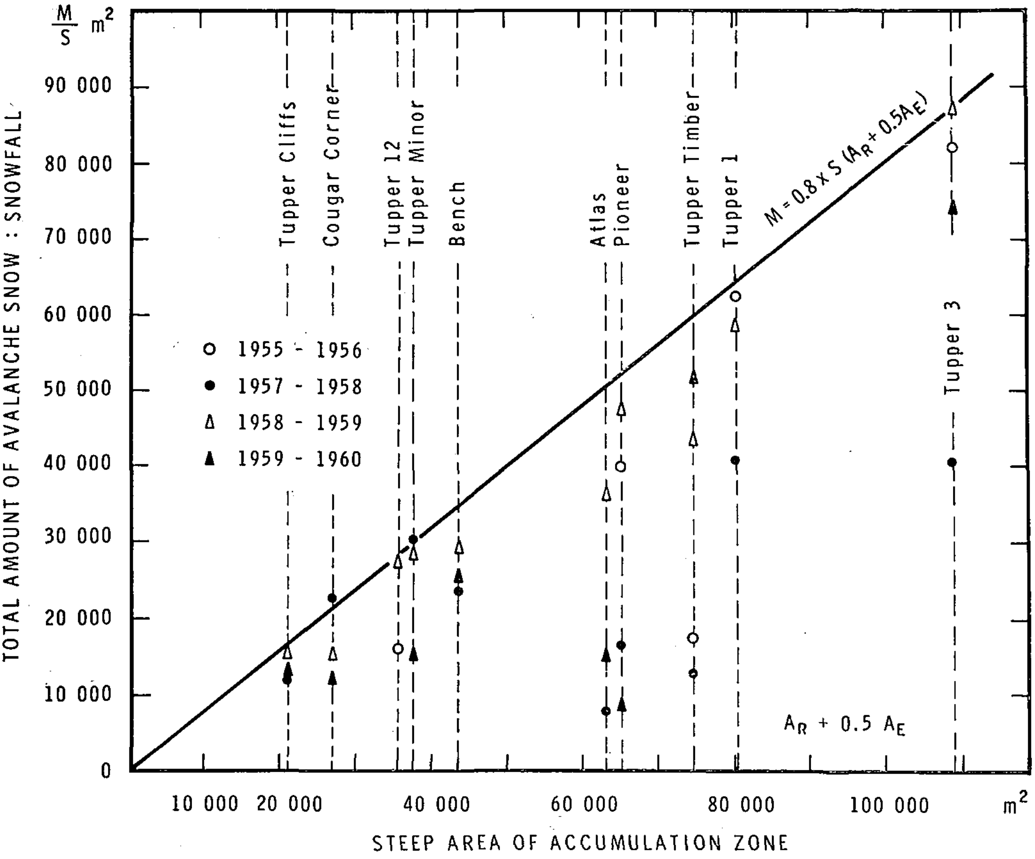

Fig. 3. Total amount of deposited avalanche snow

M is total amount of avalanche snow in one year, m^3 water equivalent,
S snowfall in the accumulation zone, measured from the beginning of the winter until the last avalanche had occurred, m water equivalent,
A_R area of accumulation zone having slope angles greater than 42 degrees, which is mainly the area with exposed bedrock, m^2,
A_E areas exposed to wind and from which snow could be expected to drift into the areas A_R, m^2.

Because of the complex relation between weather, terrain and occurrence of avalanches the points on the graph are widely scattered. There appears however to be an upper limit, as shown by the straight line. This line indicates that the greatest quantity of snow that could be deposited by avalanches is about 80% of all the snow that falls or is drifted by wind on slopes in the accumulation zone steeper than 42 degrees. This fact was confirmed by observations in the field. In spring, after the largest avalanches had occurred, the steep, rocky zones appeared to be bare, whereas there was still snow remaining on the flatter slopes between.

V. Conclusion

The study has indicated that it may be possible to determine empirically the greatest total amount of snow that could be deposited by avalanches at sites with known terrain characteristics and snowfall. It is possible that a relation between the size of the largest single avalanche, and terrain and weather could be found in a similar way. The results of the present study indicate that it might be extremely difficult to predict also the total amount of avalanche snow for specific years because of the many inter-related factors which influence the occurrence of avalanches.

Acknowledgments

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