

RELATIVE IMPORTANCE OF WEATHER FACTORS CREATING

SLAB AVALANCHES IN COLORADO

By

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INTRODUCTION

The first organized attempt in the United States to make operational decisions based on current avalanche conditions coincided with the development of alpine ski areas on National Forest land. In the winter of 1937-1938, the first full-time snow ranger was employed to carry out snow safety work at Alta, Utah. Later, in 1946, a program of applied avalanche research was initiated at Alta. The main objective of this study was to develop techniques leading to the recognition and reduction of avalanche hazard (LaChapelle, 1960).

W. M. Borland established the avalanche station at Berthoud Pass in 1949 in cooperation with the U. S. Army 5002nd Organized Reserve Research and Development Unit (Tng.) headquartered in Denver, Colorado. R. M. Stillman took over the observational program in 1950 as an avalanche hazard forecaster with the U. S. Forest Service. The writer worked as an assistant to Mr. Stillman during the winter of 1961-1962.

The data at this station have been taken in accordance with the procedures outlined in the U.S.D.A. Handbook No. 194 entitled, "Snow Avalanches" (U. S. Forest Service 1961). A summary of weather factors relating to direct-action slides for the winter of 1961-1962 is presented.

LOCATION

Berthoud Pass is located on the Continental Divide in north-central Colorado, 45 miles west of Denver at an elevation of 11,314 feet m.s.l. The pass is oriented north-south since it is situated on an east-west section of the Divide.

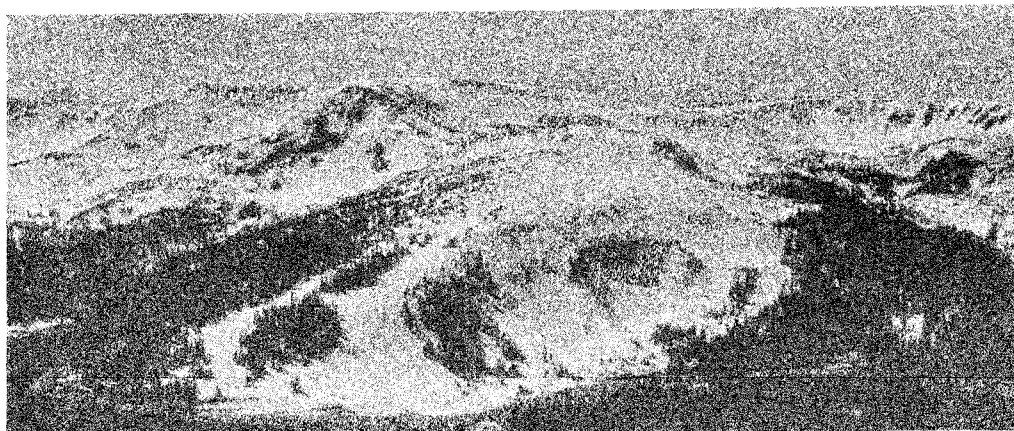


Figure 1. View looking west over Berthoud Pass, April 23, 1963.

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Peaks to the east and west rise from 1,000 to 2,000 feet above the pass. The dominant vegetation is mature Engelmann spruce and subalpine fir. Timberline is about 500 feet above the pass.

CLIMATE AND WEATHER

Temperature and Precipitation

The period November through April is relatively cold, with only 6 percent of the January maximum temperatures exceeding 32° F. The mean temperature for the period December through February is 12° F. ^{1/} Snow falls on 50 percent of the days. ^{2/} Twenty-four-hour amounts exceed 12 inches only 3 percent of the time; however, daily new snowfall depths up to 42 inches have been recorded. The mean annual snowfall for the period of record is 359 inches with an average of 291 inches falling in the November through April period. Rain has never been recorded in the winter months.

Wind

Average monthly windspeeds at or near the 12,000-foot level in the central Rockies of Colorado compare with those recorded at other mountain areas of the Western United States and Europe (table 1). Average hourly windspeeds exceed 30 m.p.h. only 3 percent of the time at Berthoud Pass; they occasionally exceed 40 m.p.h. ^{3/}

The highest recorded windspeeds in the Colorado Rockies are found in a narrow, north-south band along and east of the Continental Divide. This area is often under the influence of the strong winds associated with the chinook (Cook and Topil, 1952). Under these conditions, average hourly windspeeds up to 84 m.p.h. (corrected) ^{4/} have been recorded (U. S. War Department Signal Office, 1885). Climatological data for Berthoud Pass are shown in table 2.

AVALANCHE TYPES

For our purposes, avalanches will be classified as slab or loose snow avalanches depending on the presence or absence of cohesion in the avalanching snow.



Figure 2. Hard slab avalanche descending cliffs at Berthoud Pass, April 14, 1964.

**See following page for footnotes.

Table 1

Mean monthly windspeeds (m.p.h.) at various mountain weather stations. November through April 1962-1963 season.

Station	Location	Anemometer : elevation : in ft. m.s.l.	Month					
			Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Mt. Fuji	Japan	12,388	42	42	47	37	43	34
Mt. Washington	N. H.	6,262	25	36	39	49	41	36
Niwot Ridge ^{1/}	Colorado	12,200	21	25	26	24	22	21
Sonnblick	Austria	10,191	22	16	18	15	18	15
Berthoud Pass	Colorado	11,880	15	15	17	17	16	17
Zugspitze	Germany	9,718	13	20	15	14	17	11
Sandberg	California	4,517	12	13	15	13	16	14
Sexton Summit	Oregon	3,836	14	13	11	15	13	11
Stampede Pass ^{2/}	Washington	3,958	12	11	13	13	11	11
Weissfluhjoch	Switzerland	8,835	13	13	12	8	11	9
Arapaho Basin	Colorado	12,400	--	--	--	15	14	15
Bald Mountain	Idaho	9,000	--	--	12	9	13	--
Peak Eight	Colorado	11,600	--	12	11	12	9	--

^{1/} Station operated by the Institute of Arctic and Alpine Research with headquarters at the University of Colorado at Boulder, Colorado

^{2/} M.P.H. entries based on the monthly mean of the mean 1-minute windspeeds taken once each hour from 0400 to 1900 PST daily.

Slab avalanches will be subdivided into hard or soft slabs depending on the amount of cohesion.

A second criterion for classification is based on how long the avalanching snow had been on the avalanche path prior to release. Direct-action avalanches involve only the snow of the last storm. They may be either loose snow or slab types. Delayed-action avalanches involve snow that has accumulated from two or more storms. Delayed-action avalanches in Colorado may consist of either soft or hard slabs.

^{1/} Temperature data taken at 11,314 feet m.s.l.

^{2/} Includes traces.

^{3/} Greatest recorded one-hour average windspeed was 55 m.p.h.

^{4/} Recorded on the summit of Pikes Peak (14,110 feet m.s.l.) on March 26, 1884. Correction was made using the Robinson 4-cup hemispherical anemometer calibration curve by (Brevoort and Joyner, 1935). Uncorrected anemometer reading was 112 m.p.h.

This discussion will be concerned primarily with direct-action slab avalanches. The more common delayed-action slab avalanche is a much more complex phenomenon and will be the subject of later studies.

Table 2
Climatological data for Berthoud Pass, Colorado, for November
through April 1949-1963.

Item	Unit	Amount
Mean temperature, December through February	° F.	12
Average days with precipitation	Number	90
Maximum 24-hour precipitation	Inches	2.38
Limits of 24-hour precipitation amounts from 10-90 percent deciles	Inch	0.04 to 0.52
Limits of the 6-hour average windspeeds from 10-90 percent deciles ^{1/}	m.p.h.	6.8 to 24.3
Maximum recorded 6-hour average windspeed	m.p.h.	49.0
Maximum recorded 1-minute windspeed	m.p.h.	95.0

^{1/} Anemometer located 24 feet above the ground on an exposed ridgetop at an elevation of 11,880 feet m.s.l.

AVALANCHE FORECASTING TECHNIQUES

The basic approach to avalanche hazard forecasting in the United States utilizes 10 factors known to contribute to the development of avalanche hazard. Reasonably good results have been obtained with this method in areas where direct-action slides are prevalent (Atwater, et al., 1954, 1955). The Swiss use a slightly different approach which emphasizes the physical properties of the surface and internal layers of the snow on the ground (Schaerer, 1962). Actually, a combination of both methods is used at avalanche stations in the United States.

AVALANCHES AT BETHOUD PASS DURING THE WINTER OF 1962-1962

During the winter of 1962-1962, 106 avalanches occurred on the Berthoud Pass ski area. Forty-six of these were direct-action slides. Only four slides were natural releases; the others were released by either skis or explosives. The number of slides occurring this winter was roughly double the average number, due to a more intensified control program. The winter itself, with the exception of heavy snows in September and October, was not an unusual one. Table 3 shows the occurrence of slides for the winter 1961-1962.

Table 3

Avalanche occurrence at Berthoud Pass, Colorado, winter 1961-1962

Type	Type of release			Total Slides	
	Artificial		Natural		
	Skier	Explosives		Number	Size 2 ^{2/} and greater
Direct action ^{1/}					
Soft slab	15	6		21	10
Hard slab	3	3		6	4
Loose	15	2	2	19	6
Subtotal	33	11	2	46	20
Delayed action					
Soft slab	17	15		32	12
Hard slab	1	25	2	28	17
Subtotal	18	40	2	60	29
Total	51	51	4	106	49

^{1/} Snow involved in avalanches was less than 48 hours old.^{2/} Medium and large size avalanches.

WEATHER FACTORS ASSOCIATED WITH DIRECT-ACTION AVALANCHES

Wind

A study of weather factors associated with the 27 direct-action slab avalanches (table 4) at Berthoud Pass during the winter of 1961-1962 showed wind to be the most important single factor. All of these direct-action slabs were released following two or more 6-hour periods when the windspeed averaged 18 m.p.h. or more. The 18 m.p.h. figure seems to be the threshold for slab formation at the site of this anemometer (24 feet above the ground on the ridge crest). However, this value is probably 12 m.p.h. or lower for less exposed anemometers. For instance, an anemometer located 4 feet above the snow surface in the upper section of one of the slide paths averaged between 10 and 12 m.p.h. when the upper anemometer recorded 18 m.p.h. The horizontal distance between the two anemometers was about 500 feet; both were above timberline.

Air Temperature During the Initial Stages of a Storm

The air temperature at the start of each storm that produced slides was below 25° F. in every case. Assuming that the surface temperature of the snow is normally colder than the air temperature 4 feet above the snow surface, it appears that this factor is relatively unimportant with regard to the bonding strength of the new and old snow layers at this altitude in Colorado. (Stronger bonds are thought to develop during the early part of a storm if the new snow is damp and the air temperature is near the freezing point.)

Table 4

Direct-action slabs with lifespans^{1/} of 48 hours or less and
24 hours or less.

Item	Lifespan	
	48 hours or less	24 hours or less
	Number	
Days with slides	14	8
Total avalanches	27	13
Avalanches with at least two 6-hour average windspeeds ≥ 18 m.p.h.	27	13
Avalanches when the fastest 6-hour average windspeed < 18 m.p.h.	0	0
Avalanches when the air temperature at the start of the storm was $> 25^{\circ}\text{F.}$	0	0
Avalanches when the air temperature at the time of release was $< 28^{\circ}\text{F.}$	27	13
Avalanches when the total precipitation for the lifespan preceding release was		
Less than .14 inch	3	3
Less than .50 inch	17	9
Maximum precipitation preceding release	0.97 in.	0.85 in.
Avalanches classed as: soft slab	21	10
hard slab	6	3
Avalanches classed as size 1	13	8
size 2 and greater	14	5
Average of the four 6-hour mean temperatures preceding release: soft slab		14.5°F.
hard slab		6.5°F.
Range of the four 6-hour mean temperatures preceding release: soft slab		+8°F. to +25°F.
hard slab		-2°F. to +20°F.

^{1/} Lifespan - the age of the avalanching snow prior to release.

Air Temperature at Release

The data in table 4 confirm the opinion that slab avalanches are more prone to re-lease when temperatures are low. No slides were released when the air temperature was above 27°F.^{5/}

^{5/} No sun releases occurred during the study period.

Precipitation

Precipitation amounts prior to avalanching were light. Only 10 of the 27 slabs were accompanied by more than 0.50 inch of water equivalent in the 48 hours prior to release. The greatest precipitation in the 48 hours prior to release was 0.97 inch.

Type of Slide

Seventy-eight percent of the direct-action slab avalanches were soft slabs. This is the usual case, since hard slabs are thought to be a product of age hardening, and generally more than 24 hours are needed for their formation. There are certain conditions that are not understood, however, in which hard slabs have formed at this site in less than 12 hours.

It is interesting to note in table 4 the mean temperature and ranges associated with soft and hard slab avalanches. The data suggest that hard slabs form at lower temperatures than soft slabs.

THE CONTRIBUTORY FACTORS

For various reasons, this study included only three of the factors that contribute to avalanche formation. The following factors were not included.

1. Old snow depth. The snow depth during these direct-action slabs was sufficient to cover all terrain barriers.
2. Condition of the base.
 - a. Due to a lack of manpower, data on snow surface conditions were not taken on a daily basis, so surface conditions prior to each storm were not known.
 - b. Data on snow surface conditions for south and west facing avalanche slopes was not available.
 - c. An ice lens caused by a rain has never been recorded in the 15 years of data at this station.
3. New snow depths. This factor becomes important when the water equivalent is not known; however, the writer elected to use the water equivalent of the snow, since it was available.
4. New snow type. Available data for this factor could not be correlated with avalanche occurrence because:
 - a. There was no record of the relative amounts of new snow types.
 - b. The time of observation was not recorded.
 - c. Data were not taken for all snowfalls.
5. New snow density. New snow densities seldom depart widely from normal at this station.
6. Snowfall intensity. While this is a useful guide in making operational decisions, the data at hand were insufficient for a formal analysis.
7. Precipitation intensity. Again, this is important in making operational decisions regarding avalanche control, but it is very difficult to handle analytically for an area subjected to rigorous control action. This factor is more important in areas where large, direct-action natural avalanches occur (Atwater, 1952).

8. Settlement. This factor has not proven to be significant in this area because low temperatures prevail. It becomes more important during April.

CONCLUSION

Wind is the most important factor influencing the formation of direct-action slab avalanches in the high alpine zone of Colorado. This confirms the opinion of Stillman (1964) and others familiar with conditions in this climatic zone. The noticeable lack of rime ice and high-density snow crystals in this area gives the wind a more important role in snow transport than in warmer climates, even though the winds at 12,000 feet in the central Rockies are not much stronger than those in other western mountain ranges. The combination of moderate winds above 18 m.p.h., low temperatures, and light precipitation leads to a rapid development of avalanche risk in Colorado.

It is doubtful that any fully objective method can be developed for integrating the 10 contributory factors for areas open to skiing. The frequent avalanche control action necessary in areas of public use, together with the stabilizing effect of skier use on slide paths, create changes in the snowpack which are extremely difficult to evaluate.

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