CLIMATE EFFECTS ON SNOW AVALANCHE TRAVEL DISTANCES

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Abstract.--Avalanches with the 10 smallest $\alpha$-angles found in a coastal climate near Anchorage, Alaska were compared with the 10 smallest examples found in central Colorado. The Colorado examples had a significantly smaller mean value ($16.8^\circ$ compared with $21.3^\circ$ in Alaska). The higher mobility of the Colorado avalanches is attributed to (1) easily-dispersed dry soft slab releases, (2) a dry, erodable snowcover found throughout the paths in Colorado, and (3) denser vegetation found in the Alaskan runout zones.

INTRODUCTION

Snow-avalanche travel distance is known to be dependent on many variables which can be grouped into two main categories: terrain and snow type. The effect of the terrain variables on travel distance has been the subject of considerable research in recent years (Bovis and Mears, 1976; Lied and Bakkehoi, 1980; Bakkehoi et. al., 1982). This research has developed statistical models that correlate measurable terrain features such as starting-zone size, vertical path displacement, and path inclination with the runout distance or with the mean path gradient ($\alpha$-angle). The $\alpha$-angle, or mean path gradient is the vertical angle measured from the end of the runout zone to the top of the starting zone, and is the most objective measure of travel distance.

Snow type and climate are not explicitly considered in analysis of avalanche travel distance. During a long time period optimum snow conditions will develop and avalanches will run to maximum potential in response to these optimum conditions. Because engineering applications must usually consider long return periods, within a given area, the climate and snow conditions are treated as constant while analysis of terrain provides all the independent variables used in analysis of travel performance. However, the prevailing climate of an area also has a profound effect on the travel performance of avalanches. Study of avalanche paths in the maritime climate of Juneau, Alaska in the early 1970's (H. Frutiger, pers. comm.), demonstrated large discrepancies between the observed maximum travel distances of avalanches and the distances predicted by applications of the equations of motion used in Swiss engineering practice (Voellmy, 1955). Similar discrepancies between predicted and observed avalanche maxima were also observed during a 1982 avalanche-zoning study of Anchorage, Alaska (Mears, unpubl.). This paper compares the minimum $\alpha$-angles found in two different climates to determine if climate and snow type appear to be important variables controlling travel distance.

AVALANCHE PATH SAMPLE AREAS

A study of this type must minimize the effect of terrain variables on travel performance and maximize the effect of snow and climate. In order to minimize the effect of terrain variables, only the longest-running avalanches (smallest $\alpha$-angles) were selected for analysis. In each of the two climate regions studied, the paths sampled represent only approximately 1% of the entire population of avalanches. Presumably, these avalanches were located on terrain best suited to producing long travel distances. In contrast, climatically-induced snowpack differences between each sample area were maximized by comparing the smallest $\alpha$-angle examples from an Alaskan "maritime" area with a Colorado "continental" area.

The maritime area is located in the Chugach and Kenai Mountains approximately 50 to 80 kilometers southeast of Anchorage, Alaska. The 500 km² area studied is located on the walls of fiords and other glacial valleys. The number of avalanche paths in the area is unknown, but is very large, probably exceeding 1000. The 10 paths with the smallest $\alpha$-angles are listed in Table 1. These paths have the following characteristics in common:

1) All avalanches sampled were 100-year return period events (an "order-of-magnitude" estimate), as deduced by dating destroyed trees at the path boundaries;
2) Starting zones are above treeline and probably are accumulation areas during prevailing wind conditions;
3) Longitudinal path profiles gradually decrease in gradient rather than being sharply inflected;
4) Major avalanches in the paths sampled...
result from massive \(10^6\) to \(10^7\) kg releases of dry, strongly-bonded wind slab;

5) The low-elevation (Table 1), runout zones support a dense, wet snowcover; and

6) Runout zones usually support dense conifer forests.

This area is well known for producing highly variable snowpacks. Rain at sea level is often accompanied by vigorous snowstorms and high winds at elevations in excess of 600m. Fairly large avalanche releases occur somewhere in the area nearly every winter, but most of these deposit on steep slopes before reaching runout zones. Dry cold storms sometimes deposit at or near sea level, but a cold, low-density snowpack rarely persists throughout the entire snow season at low elevations. All the avalanches listed in Table 1 begin at high elevation (roughly 1000m), and descend to near sea level, therefore; major avalanches encounter a varied snowpack during descent.

The continental climate area is located in the West Elk and Elk Mountains of central Colorado. The 500 km² area studied is located primarily between 3000m and 4000 elevation and, similar to the Alaska area, was heavily glaciated. The total number of avalanche paths in central Colorado is undetermined, but probably exceeds 1000. The 10 paths with the smallest \(\alpha\) angles are identified on Table 2, and have the following characteristics in common:

1) Boundary forest destruction suggests all events had return periods on the order of 100 years;
2) Starting zones are at or near treeline and accumulate snow during prevailing wind conditions;
3) Longitudinal path profiles gradually decrease in gradient rather than being sharply inflected;
4) Major avalanches are generally smaller than those in the Alaskan examples and usually result from releases of dry, soft slabs;
5) The high-elevation runout zones usually contain a dry, low-density snowcover; and,
6) Runout zones usually support a conifer forest with a poorly-developed understory.

This area is well known for maintaining a dry snowcover above the 2500m to 3000m elevation range throughout most of the snow season. Rain or wet snowstorms are rare during winter and the snowcover is usually weak, dry, and easily erodable. Large avalanches descend several hundred meters (Table 2), and commonly encounter a similar dry snowcover throughout most of the descent.

### DATA ANALYSIS

Data obtained in the study are summarized in Table 3.
Table 3.—Data Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>Mean $\alpha$</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>21.3°</td>
<td>2.2°</td>
</tr>
<tr>
<td>Colorado</td>
<td>16.8°</td>
<td>0.9°</td>
</tr>
</tbody>
</table>

Application of a "t-test" shows that the mean values differ at the 1% significance level. The observed difference in $\alpha$-angles cannot be attributed to randomness within the data set. Therefore, the samples appear to belong to different populations of avalanche travel performances which suggests there should exist physical causes for this difference.

DISCUSSION

Small $\alpha$-angles result when an avalanche has a small effective frictional resistance or when the deposit is dispersed longitudinally over long distances. Frictional resistances are complex and depend on several interacting factors, as discussed by Salm (1966), Mears (1980), Perla et. al. (1980), and Korner (1980). Factors influencing friction include roughness at the avalanche/running surface interface, overall path shape in transverse and longitudinal directions, snow type, particle-sizes and size distribution, air density, velocity, and combinations of these and other factors. The tangent of the $\alpha$-angle (tan $\alpha$, Tables 1 and 2), is one approximation to the average overall friction acting on an avalanche from all effects combined. This measure of friction is only an approximation because the center-of-mass displacement will in general have vertical angle that is different from the $\alpha$-angle.

The $\alpha$-angle will also be affected by the dispersability of an avalanche. Wet-snow avalanches, and avalanches consisting primarily of large blocks derived from fracture of a dry, hard slab both tend to develop large internal frictional forces due to momentum exchange between the blocks and between the avalanche and the running surface. The large frictional forces cause rapid deceleration and shorten the runout distance (increase the $\alpha$-angle). Dry-snow avalanches derived from fracture of soft slabs quickly become pulverized into small chunks and particles of snow with small free-fall velocities. The avalanches entrain air and become at least partly fluidized into a deep, diffuse aerosol. Internal frictional forces are relatively small because particle interaction is less important than in hard slab avalanches; consequently, the deposit is dispersed over long distances, and the $\alpha$-angle is small.

The snow conditions existing in the starting area are near sea level and usually contain damp or wet, high-density snow that absorbs avalanche energy, mixes with the dry snow descending from higher in the path, and shortens runout distances. The Colorado examples usually traverse dry snow even in the runout zones which are located at roughly 3000m elevation. This low-density snow can be entrained as other parts of the avalanche are deposited. As a result, material is dispersed in a thin deposit over long distances, another possible cause for small $\alpha$-angles.

Runout-zone vegetation may also be an important factor in controlling runout length and the $\alpha$-angle. The large trees and well-developed understory in the Alaskan coastal climate may serve to dissipate energy more quickly than the open forests at high Colorado elevations.

As mentioned in the introduction, terrain is also known to have an important influence on the $\alpha$-angle. The paper by Bakkebo et. al. (1982), demonstrated that the mean gradient measured from the 10$^\circ$ inflection to the top of the starting zone has a dominant effect on $\alpha$-angle. However, a 10$^\circ$ inflection point was absent in many of the paths studied here. Other terrain factors that have not yet been identified may favor the small Colorado $\alpha$-angles.

CONCLUSIONS

The simple statistical test applied in this study supports the hypothesis that one particular Colorado area produces avalanches with smaller $\alpha$-angles than one Alaskan coastal area. This difference is to be expected because the two areas were deliberately chosen to contrast known climate and snowpack differences. The conclusion also supports informal observations made by avalanche observers and consultants for at least a decade. The contrast in the data obtained from these two climate populations is attributed to climatically-induced differences in the snowpack and vegetation during major and rare avalanches. Because a significant difference in avalanche performance is demonstrated here, similar differences between other areas may also be encountered.

Consequently, a consultant who is equipped with a set of physical or statistical relationships that
predict avalanche travel performance in one climate may not necessarily be able to apply these relationships to other areas. Climatically-induced variables may, in fact, be more important in determining runout potential than some easily-measured terrain variables.

LITERATURE CITED


