ENGINEER AND PRACTITIONER: A COMBINED EFFORT IN AVALANCHE HAZARD FORECASTING

William L. Harrison and Mike Wiegele

Abstract. Scientists, engineers, and practitioners use methods which appear to differ radically, when determining the hazard level of an avalanche prone slope. While the scientist and the engineer can find general agreement in methods and terminology, there is often an ability to communicate between the academic and the experienced practitioner.

The authors describe an attempt to merge two approaches in hazard forecasting; one based on engineering principles, and the other on years of practical experience. Intuitive and subjective parameters are examined for conversion into fundamental and quantitative parameters. The paper also describes the use of computer software and hardware to assist with hazard forecasting.

INTRODUCTION. (engineer)

To the casual observer, the forecasting of avalanche hazard is as varied as the number of forecasters involved. The degree of success achieved by the current practitioners strongly support the indications that there are numerous successful methods to predict avalanche hazard.

There are courses held periodically which offer excellent guidelines to forecasting and safety in avalanche areas. Yet, it has been my observation that each area concerned with forecasting for recreational or highway safety has its own technique which generally reflects the influence of an experienced practitioner with years of day to day exposure to the threat of avalanche activity. As is common in many disciplines where a "communications gap" exists between researchers and practitioners, it is difficult to find one of the latter who is willing, and able, to tell "how he does it". I have great respect for those whose position requires that during the winter seasons, they assume daily, the responsibility for the lives and well being of thousands. I also respect them because they are professionals in avalanche hazard forecasting.

As an engineer with a background in snow mechanics, I am aware that forecast parameters must all arrive at like conclusions; i.e., is the snowpack on slope "X" stable or is the avalanche potential high? So I have asked several practitioners and researchers "how do you do it? what do you do with snowpit profile information?" Perhaps the questions were so academic that the resulting discourses in mumbling were a form of politeness. Most practitioners get the same information from snowpits, while the frequency of digging snowpits and the relative importance placed on them varies. I have invested considerable time in discussing methodology with several practitioners,
INTRODUCTION. (practitioner)

I have been asked how do I predict avalanche hazard. As a practitioner who has developed techniques from years of experience in the mountains, both as an apprentice and later as a journeyman, I find it very difficult to put into a few paragraphs the subtle warnings, danger signals, and feelings which are likened to intuition but stems, I believe, from a mental filing system. What all of us fear is the avalanche which happens when experience, reasoning, and measurements indicate stability. So we (most of us) never rest on our successes or past records, but always try to reduce the unexpected.

There are differences in all areas of practice. The Sierras differ from the Colorado Rockies which differ from the Wasatch Front. Two important differences in methodology are in areas which can utilize artillery control procedures (and hand charges) and have heavy ski traffic, and areas where control is limited to dislodgement attempts with skis by the guides. In controlled areas, there are a limited number of avalanche slopes, or rather, the number is such that one becomes familiar with their characteristics and response to certain storm tracks and intensity. When in doubt, control procedures can be activated or areas are closed until stability is achieved. A history of control procedures and actions are generally maintained throughout the season. These records along with the periodic monitoring of snowpack conditions provide a valuable basis for improvement. Areas where these type of control procedures are impractical, if not impossible, present a different challenge. The area which falls within the realm of my responsibility covers 2600 square miles in the Cariboo and Monashee ranges of the Canadian Rockies. The procedures used for hazard forecasting is discussed in the following section.

FORECASTING METHODOLOGY. (practitioner)

My program begins each season with a thorough review of our strengths and weaknesses from past seasons. Special attention is centered on unexpected releases sited during periods of predicted stability. The basic mechanics of avalanche release are reviewed by lectures from invited experts in avalanche technology. Snowpack profile analyses are conducted at various mountain locations to review and refine past techniques. This week of orientation is considered to be very necessary and helpful in preparation for predicting avalanche hazard.

The daily prediction methodology is referred to as the "Five Step Avalanche Hazard Evaluation". Each of the five steps are discussed briefly in the following paragraphs:

1) Daily Weather Data.

Figure (1) shows an example of the weather data as received each morning. Factors noted and transferred to the forecast graph are as follows: Snow and wind for the past 24 hours are recorded as mm of water (20 mph wind load = 1mm of water). By noting the wind direction, it can be determined which slopes are loaded. An estimate (regarding elevation) is made of new snow depth and potential slab depths. Other factors provided for the forecast graph are maximum and minimum temperature, relative humidity, and barometric pressure.

2. Forecast Graph.

The forecast graph, shown in figure 2, is used as a summary presentation of weather data and daily observations. The graph includes the output from the Lev "Avalimeter" indicating the hazard level based on "tidal effect". The graph has the prime purpose of visually displaying trends and changes in the weather parameters which may be an indication of conditions leading to snowpack instability on certain slopes. The graph also shows sightings of avalanche activity noted while flying and skiing on the previous day.
CARIBOO HELICOPTER SKIING

AVALANCHE & WEATHER FORECASTING - DAILY REPORT

DATE: March 10, 1983

BY: Scott

0600 OBSERVATION

1. Present temperature - 1.0
2. Maximum temperature - 6.8
3. Minimum temperature - 0.3
4. Wind: Direction - IRBL
   Total miles - 25
5. Barometer - 926.3
6. Present weather - F
   Ceiling - 400
   Lower cloud layer - ---
7. Relative Humidity - 100%
8. Total snow depth - 0.63m
9. New snow depth - nil
10. New snow type - ---
11. Water content - 1.2 rain
12. Density - ---
13. Old snow surface - ---
14. Stratigraphy: new snow -1
dean slab -2

UPPER AIR DATA at 0400 PST

<table>
<thead>
<tr>
<th>STATION</th>
<th>700mb</th>
<th>700mb</th>
<th>700mb dew</th>
<th>1700mb</th>
<th>upper winds</th>
<th>height</th>
<th>temp. pt. spread</th>
<th>R.H.</th>
<th>9000'</th>
<th>12000'</th>
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<tr>
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<td>240/17</td>
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</table>

Skiing Zone: Non-skiing day due to weather.

ESTIMATE OF AVALANCHE HAZARD: High! Bad wind slabs! At lower elevations caution of sliding on rain crust, about 0.6m below surface. Watch out for large cornices! Warm temperatures and high freezing level causes increase in avalanche hazard!

FIELD OBSERVATIONS & REMARKS: none

AVALANCHE ACTIVITY: no observations due to weather.

Figure 1. Daily Weather Forecast.

3. Snowpack Profile.

A great effort is being generated to obtain snow profiles on a daily basis from slopes having different aspects. A computer software package has been activated to assist with presentation, analysis, and filing of the profile data. Special attention is given to weak layers and potential slab formation. Weak layers are determined by the "shovel shear test". Major gliding and weak layers of concern are:

- Depth and surface hoar
- New snow; graupel
- Faceted snow crystal
- Upside-down powder
- Sun glaze
- Rain glaze
- Wind packed surface

An example of profile data is shown in figure (3).
WEATHER FORECAST

SYNOPSIS: A very shallow arctic front from near Williams Lake to Terrace this morning will move to 50 miles North of Prince George tonight. A series of frontal systems will move across the region over the next two days. The leading system will lie over SE B.C. this afternoon, followed by another system lying along the coast range Wednesday morning. Precipitation will generally be intermittent and increase ahead of the frontal systems.

NORTH COLUMBIA MOUNTAINS:

<table>
<thead>
<tr>
<th>Freezing Lvl.</th>
<th>Mountain top winds</th>
<th>Snowfall amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>1400 meters</td>
<td>SW 35 km/hr</td>
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<tr>
<td>Tonight</td>
<td>1600 meters</td>
<td>SW 45 km/hr</td>
</tr>
<tr>
<td>Tomorrow</td>
<td>1800 meters</td>
<td>SW 50 km/hr</td>
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</tbody>
</table>

Cloudy, occasional rain or snow

CARIBOO MOUNTAINS:

<table>
<thead>
<tr>
<th>Freezing Lvl.</th>
<th>Mountain top winds</th>
<th>Snowfall amount</th>
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<tr>
<td>Tonight</td>
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<tr>
<td>Tomorrow</td>
<td>1400 meters</td>
<td>SW 50 km/hr</td>
</tr>
</tbody>
</table>

Cloudy, occasional rain or snow

Figure 1. Daily Weather Forecast. (cont.)

4. Field Observations.

Each guide and helicopter pilot records sightings of avalanche activity in terms of location, fracture length, and runout length. Also recorded are cornice buildup and cornice release activity. As stated previously, this data is entered on the forecast graph.

5. Slope Test.

This is a method of ski cutting on representative starting zones or small rolls and slopes to get a final or confirmation of slope stability before skiing.

SUMMARY.

This has been a brief description of our methods. There are a number of other factors which come into play while on the slopes during the course of the day: solar effects, wind, changes in humidity, noticeable changes in temperature, and sensory perceptions which I cannot at this time put into words. We are looking towards the installation of a weather station to provide data more local to our operation. We will tie this station into our computer facility providing direct information into our hazard forecast software. The program includes a data bank capability with which we hope to be able to formulate trends from data collected over the past years and updated, seasonally.
Figure 2. Forecast Graph.
SNOW PIT DATA

Date: 03/15/84    Site: STEINBOCK    Observer: Willi
ELEVATION: 6000 FT    ASPECT: N    SLOPE ANGLE: 35    SNOW SFC TEMP (C) -10.0

FIGURE 3. PLOT OF SNOW PROFILE DATA.

FORECASTING METHODOLOGY. (engineer)

This methodology which I refer to as the "engineering approach" for lack of a better title is not a personal derivation but an application of basic mechanics and work that has been performed by many researchers over the past years. If there is any uniqueness in the method, it is that it has been formulated expressly for micro-computer application. The so-called engineering approach is divided into three operations:

1) Determining strength and stress levels of the snowpack as a function of slope angle.

2) Speculative analyses based on increased loading.

3) Speculative analyses based on climatic influences.
The snowpack is considered as consisting of a number of distinct layers resting on a slope having a known angle. Strength and stress forces are computed from snowpack properties measured in the snowpit. Snowpit data includes density and temperature profiles, depth of significant layers from the snow surface, shear strength along layer boundaries from shear frame measurements, tensile strength of each layer, as well as other documentary data such as grain size and metamorphic classification. At this reading, there are two choices offered by the computer program for entry of tensile strength; (1) from measurements taken in the snowpit using the beam method, (Rosso, 1982), or (2), from the relationships established by Sommerfield (1971, 1972) based on density and metamorphic class. The second choice requires only a reply to program prompting since the relationships and necessary data are part of the program and on file, respectively. An analysis is made of the downslope forces on each layer interface as a function of slope angle.

The critical slope for each layer is output with the profile data shown in figure (4).

The next operation presents an option to examine if and at what slope angle a selected layer will go into tension due to new snowfall. To eliminate density estimates of projected new snowfall, a family of curves representing water equivalents of new snow depths is superimposed over the current snowpack state. An example of this plot is shown in figure (5). The horizontal line on the graph represents the shear strength at the base of layer number 1. The intersection of this line with the family of curves representing the increased load caused by projected snowfall, shows the slope angles at which the layer will go into tension.

The final operation speculates on the change in layer boundary shear strength and layer tensile strength due to projected changes in atmospheric and climatic conditions. These speculative

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**SNOW PIT DATA**

**DATE:** 03/15/84  
**SITE:** STEINBOCK  
**OBSERVER:** WILLI  
**ELEVATION:** 6000 FT  
**ASPECT:** N  
**SLOPE ANGLE:** 35  
**SNOW SFC TEMP (°C):** -10.0

<table>
<thead>
<tr>
<th>LAYER</th>
<th>THICKNESS</th>
<th>DENSITY (g/cc)</th>
<th>BASE TEMP (°C)</th>
<th>TEMP GRAD (°C/cm)</th>
<th>SHEAR STRENGTH (g/cm²)</th>
<th>TENSILE STRENGTH (g/cm²)</th>
<th>CRITICAL SLOPE (°)</th>
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<td>20.0</td>
<td>55</td>
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</tbody>
</table>

**Figure 4. Snow Profile Data Output From Computer Entry.**
analyses are based on a large number of studies on changes in snowpack properties as functions of changes in various climatic parameters (see bibliography). Since most of the relationships developed lack ample validation, this part of the methodology will improve over the coming seasons as the database becomes substantial.

SUMMARY.

Presentation of the above methodology has been brief but hopefully sufficient to describe the basic approach. Although the snowpack model used in the first step is basically fundamental, it is realized that the measurement of snowpack properties for exercising the model has inherent shortcomings in the form of data scatter and accuracy. It is reasoned that in spite of these shortcomings, measurements obtained in physical units are better, or in the least, no worse than subjective measurements. Furthermore, the models as such, require physical units.

On the subject of tidal effect, it is apparent that many practitioners favor the existence of cyclic phenomena. Without attempting to relate these cycles to some physical phenomenon, if in fact they do exist, they can be determined for a particular locality from an extensive database. The variation in weather patterns experienced in recent winters and still in progress seems to offer faint hope for cycles. Frequent monitoring of snowpack properties offers a sound alternative.

REFERENCES AND BIBLIOGRAPHY