AVALANCHE EVALUATION AND SAFETY IN THE BACK-COUNTRY

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Introduction

Avalanche burials within developed ski area boundaries are rare; fatalities are quite rare. Almost all ski areas can boast a record of less than one avalanche fatality per 10^6 skier days. The fine safety record of the ski-area industry is due to the conscientious efforts of avalanche control teams supported by area management. For example, in 40 years of operation, the Alta Ski Area, which was built on the site of a ghost-mining town with a historical record of about 100 avalanche fatalities, has had only two avalanche fatalities within the ski area boundary, and one of these was in violation of a closure sign. Another good example is the Snowbird Ski Corporation, which, despite having an intense avalanche problem within and around the ski area, has had only one avalanche fatality in seven years of operation, serving over 10^6 skiers. Avalanche safety planning at Snowbird started during the earliest planning stage of the area. Snowbird avalanche teams continuously monitor the hazard, and use ample amounts of explosives to test and stabilize slopes (5000 charges per season). As soon as a slope is stabilized, it is opened to the public to receive the full benefit of ski-compaction. Should precautionary measures fail, avalanche teams are on standby at the top of the tram-lift to make the quickest rescue possible.

The skiing public is accustomed to this high level of protection, and an avalanche fatality within a ski area boundary is apt to lead to a court case against management. In at least one instance (Berg vs Park City, Utah), the ski area was found negligent.

In contrast, the avalanche safety record in back-country travel (away from developed areas) is poorer by a large factor. Ski-tourers, mountaineers, helicopter skiers, and others who travel on uncontrolled slopes in virgin powder take a far greater risk than the skier protected by a commercial area. It is the purpose of this paper to comment on the few things that we know about back-country safety, and the many things that we don't know. Our theme is a negative one--that there are really very few guidelines that permit safe travel on steep, uncompacted slopes, and that stability evaluation in the back-country does not boil down to simple cookbook rules.

The first thing that the back-country skier must realize is the great difference between compacted and uncompacted slopes.

Slab Failure on Compacted and Uncompacted Slopes

The compaction of slopes by skis, boot-packing, or machines is the main tool within developed ski areas for alleviating the problem of deep slab instability. Compaction accomplishes the following: it breaks up the slab so that a single continuous slab is no longer joined to a smooth sliding surface; it makes the snow denser and hence stronger; and by making the snow denser, it slows down the recrystallization process of depth-hoar formation (temperature-gradient metamorphism). On a well-compacted slope, instability is generally confined to surface layers deposited by a new snowfall. Surface instability is detected by the ski-test or by the shattering action of high-speed explosive charges placed on the snow surface.

On an uncompacted slope, instability may be near the surface or hidden at some depth. A particularly dangerous situation occurs when a relatively stiff slab bridges over a weak, uncompacted layer of depth-hoar because the lack of compressive support under the slab results in a hair-trigger state of tension around the slab boundaries. An unsuspecting skier may traverse into the centre of a slab, which could collapse as shown in Fig. 1A and fracture suddenly around the tension boundaries. Since the fractures propagate near the speed of sound, the skier may have little chance to escape from the trap. A skier may also trigger instability by pushing the slab downslope in shear (Fig. 1B) or undercutting the slab (Fig. 1C). The fact that a skier does not obtain a release with the test shown in Fig. 1B is not a guarantee that the slab will not fail subsequently according to the mechanism of either Figs. 1A or 1C.

Slab Geometry

As just discussed, slab failure may initiate with a subtle and hidden shear failure or a sudden collapse. The spectacular tension fracture may, in some cases, be the last line across which the slab fails. On the other hand, the back-country skier should be aware of the potential line of tension fracture (the upslope or crown fracture line) since this delineates the safe and unsafe portion of the slope, and is also the ski traverse line which is used to test for surface instability according to the mechanism of Fig. 1B. The ability to recognize slab boundaries develops along with experience in avalanche control (test skiing, explosive targeting), and is not something learned from reading this paper or attending an avalanche school. However, one serious misconception should be clarified: too much emphasis has been placed on the fact that a tension zone is most apt to be at a slope convexity. Numerous observations indicate that the slab crown line may be on the steep portion of the slope beneath the convexity (Fig. 2A), on a concave portion of a slope (Fig. 2B), and beneath cliff bands (Fig. 2C). One must be careful not to generalize that the slab crown is at the top of the slope since, in some cases, the crown line will occur in the middle of an apparently flat slope.

It is interesting that crown fractures are observed to follow almost identical paths each winter. These paths are predetermined by slope geometry, and often connect trees and rock protrusions which act as pinpoints.

With respect to slab geometry, there is one important and useful guideline for the back-country skier and guide -- the minimum slope angle for instability.

Slope Angle Guidelines

There is overwhelming evidence that initiation of slab avalanches requires a slope of at least 25°. Figure 3 shows slope angle measurements taken beneath the crown (upslope tension fracture) of 194 slabs. From available data (Perla, 1977), it is possible to conclude that less than 1% of all slabs occur on slopes inclined less than 25°. This does not mean that a slab fracture cannot propagate to a portion of a slope where the angle is less than 25°. It means that it is highly unlikely that avalanches can initiate on a slope that does not have at least a 25° portion. The data also indicate that, at the most, 5% of all slabs occur on slopes where the angle is less than 30°.

As a matter of interest, a 25° slope would be considered in the category of an advanced to an expert run in a commercial ski area, and a 30° slope is unquestionably for expert skiers. Most skiers would agree that enjoyable powder skiing can be found on slopes in the range of 15° to 30°. The standard of avalanche safety in the back-country could perhaps approach the standard in commercial ski areas if back-country skiers would totally avoid slopes steeper than 25° unless stability is certain (for example, early morning in the spring on a frozen snowpack). A decision to cross starting zones above 25° should be balanced against the risk that the closer the slope angle is to 40°, the greater the chance of instability, other factors the same.

What is the one indispensible instrument you should carry for avalanche hazard evaluation? A POCKET INCLINOMETER!

Cookbook Equation for Stability Evaluation

If you are determined to cross slopes steeper than 25°, you probably would like to have a cookbook equation that tells if a slope is stable. Sorry, there is no such equation. In practice, stability evaluation is a very general, subjective interpretation of a set of inputs: history of meteorological events; history of avalanche events; test-skiing results; results of throwing a few explosive charges, and information from a snow-pit, here and there. Each input by itself is strongly limited, but, taken together, there is general agreement that they provide a useful picture to someone experienced with conditions in a specific mountain range. However, there is more to the problem than experience. There is an intrinsic sensitivity to the signals of nature that you have or don't have, irrespective of your time in the mountains.

History of Meteorological and Avalanche Events

These must be followed from the beginning of the season, as the snowpack builds. A snowpack that builds gradually and consistently with almost daily increments of new snow tends toward self-compaction, at least more than the thin snowpack that grows due to storms interspersed with long periods of clear weather. In the first situation, one expects new snow instability, in the latter, both new snow and deep slab instability. Only experience in a given mountain range teaches us when to expect deep slab avalanches in response to a series of meteorological events. It is not possible to give numbers that in any way imply universal criteria.

Thus, we learn to suspect instability, and to look for confirmation in terms of avalanches that have run or are running. The fact that avalanches are running, or have run, is sufficient evidence that any slope that has not run, may be ready to run, especially if the slopes are related by a common aspect and elevation. However, do not drop your guard because there are no obvious signs of avalanche activity. Now the other inputs come into play.

Test Skiing and Its Limitations

Test skiing is the most realistic "strength test" that a ski mountaineer can make to determine the instability of top layers. Other tests which depend on gadgets (shear frame, lightweight penetrometer) are restricted to a small sample area and do not provide a realistic fracture disturbance compared to the push of a ski on a test slope. Usually, the smallest amount of cracking in response to a test ski traverse is indicative of slab instability. But the test has its limitations. A ski test result on a slope with a particular aspect and elevation may not represent conditions elsewhere on the mountain. Another important limitation is that test skiing is not a reliable indicator of deep slab conditions. Sometimes in early season, we hear beneath our skis a sudden settling noise which is almost always indicative of deep slab instability on a recrystallized base (depth hoar). However, slab collapse may occur suddenly without any pre-warning noises.

Explosives and Their Limitations

The high standard of avalanche safety in ski areas would not be possible without explosives. Unfortunately, there are rare but dangerous instances where ski area slopes have been controlled with explosives, and, although no avalanche occurred immediately in response to the blast, the slope avalanched later in the day when loaded with skiers. It is generally agreed that these "post-control" releases are connected with a weak substratum due primarily to insufficient ski compaction early in the season. There is also the possibility that an explosive blast could loosen a slope, and decrease stability, but this is controversial. Regardless of the amount, explosives do not always give reliable results.

Putting aside the environmental question (if it is possible to put it aside), explosives can be used to some advantage in the back-country, especially in helicopter skiing, not only to stabilize a particular run but also to provide data on the overall stability of the area. The helicopter guide has the advantage over the ski-tourer that he can inspect from the air large areas for natural avalanche activity. With explosives, he can then check select paths to confirm his stability evaluation. Thus, explosives can be an important tool for helicopter guides, provided the above-mentioned limitation of explosives on uncompacted slopes is remembered.

Snow Pits and Their Limitations

Too much advice has been published telling skiers to check for instability by sticking their ski poles into the snow. Too many ski-tourers have pushed their poles into the snow, found nothing unusual, proceeded to cross a starting zone, and triggered an avalanche. Slabs often fail due to a thin shear discontinuity. The thickness of a surface hoar layer, for example, may be only a few millimeters -- hardly thick enough to respond to a ski pole thrust.

You may have a better chance to find the critical weakness if you dig a snow-pit, although, after all the years of digging snow-pits, and pulling and tugging on the snow, most avalanche workers (both field men and scientists) will agree that we still cannot draw the line between a potentially stable and unstable weakness. If we dig a snow-pit, we will probably find at depth some layer that is relatively weaker than adjacent layers. But is that layer critical? As a matter of interest, the same problem is not fully solved for other landslide materials (rock, soil, clay) which are considerably less time-and temperature-dependent than snow.

Even granting that we are quite clever in interpreting a particular snow-pit, the next question is: How representative is that pit of conditions on other slopes? This brings us right back to our other inputs, and our main point: all inputs must be blended together subjectively to form a useful picture that, in the final analysis, is interpreted through experience in a specific mountain range.

Avalanche Swimming Techniques and Rescue Gadgets

The penalty for making the wrong decision is severe -- one cannot count on surviving an avalanche without injury. If you are completely buried, the odds that you will be found alive are poor, to say the least. According to statistics compiled by Gallagher (1967) and Williams (1975), the odds of being found alive after a complete burial (no trace showing at the surface) is about one chance in four, or possibly as low as one chance in five. These statistics dramatize that avalanche safety depends first and foremost on avoidance and prevention, not on your avalanche swimming technique, nor on what you manage to do when you are buried under the snow.

True, you may increase your odds somewhat if your group is well equipped with probes, rescue transceivers, shovels, and possibly avalanche cords. There is only one recorded case in North America where a live victim was found quickly because his avalanche cord managed to end up on the surface. Rescue transceivers are considered superior to avalanche cords, and have saved several lives. However, victims with rescue transceivers have been recovered dead, owing to injuries or suffocation, and there are not yet enough case histories to know how much the odds shift in the victim's favour if he or she carries a transceiver.

One tragic case has taught that rescue receivers must be at the same frequency. There is no convincing reason at present to depart from the Skadi and Pieps frequency of 2275 Hz. Another tragic case proved the helplessness of making a transceiver rescue without a shovel to dig down to the victim. It is not safe practice if the guide is the only member of the party carrying a shovel.

Re-emphasizing the point: rescue equipment and techniques are for emergency back-up protection and should not in any way give the skier added confidence to enter an avalanche slope.

References

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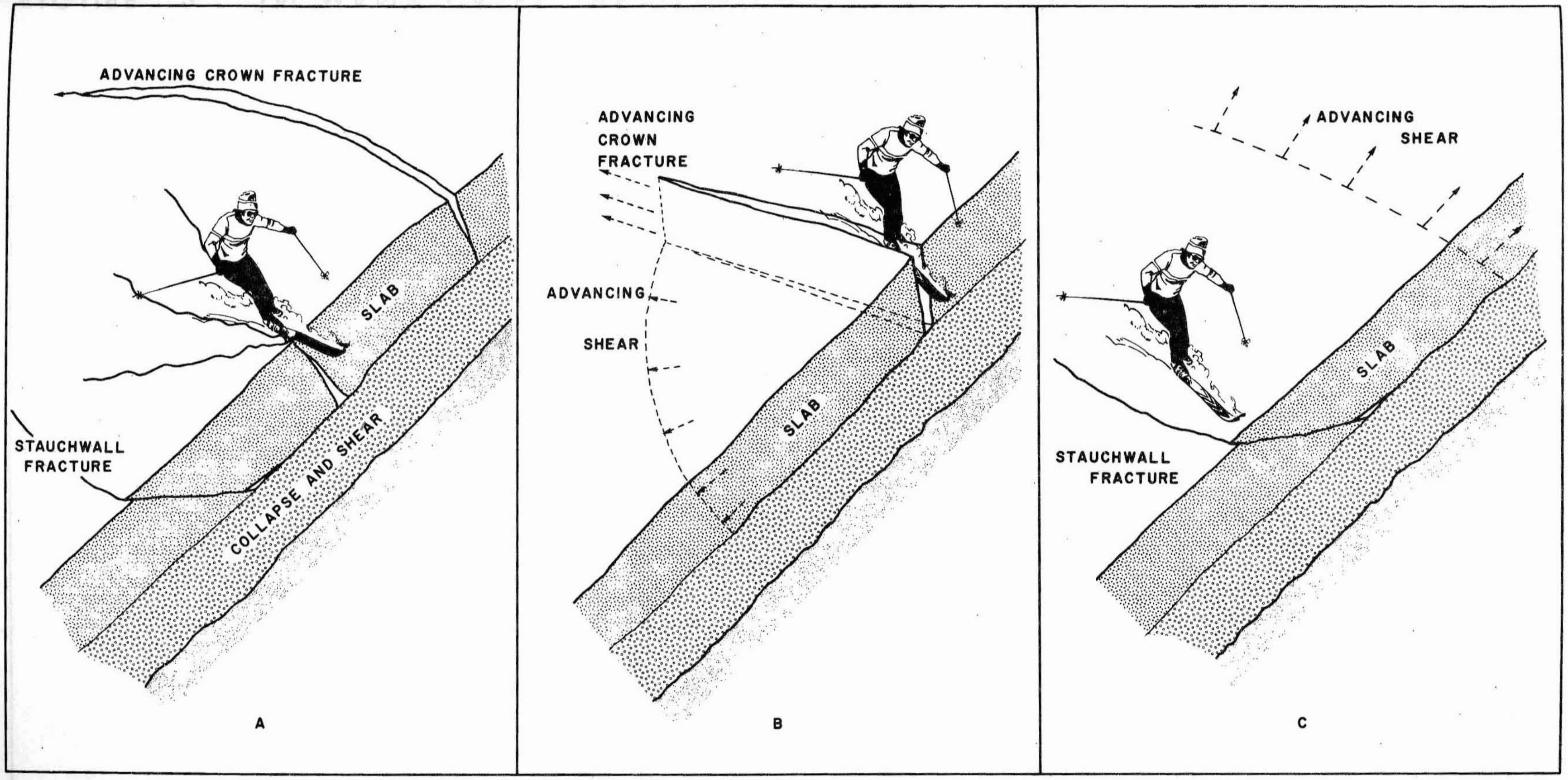

FIGURE 1 EXAMPLES OF A SKIER INITIATING SLAB FAILURE AT VARIOUS SLOPE POSITIONS: A, COLLAPSE AND SHEAR NEAR THE SLAB CENTRE; B, SHEAR AND TENSION FAILURES INITIATING NEAR THE SLAB CROWN; C, SHEAR FAILURE INITIATING NEAR THE STAUCHWALL

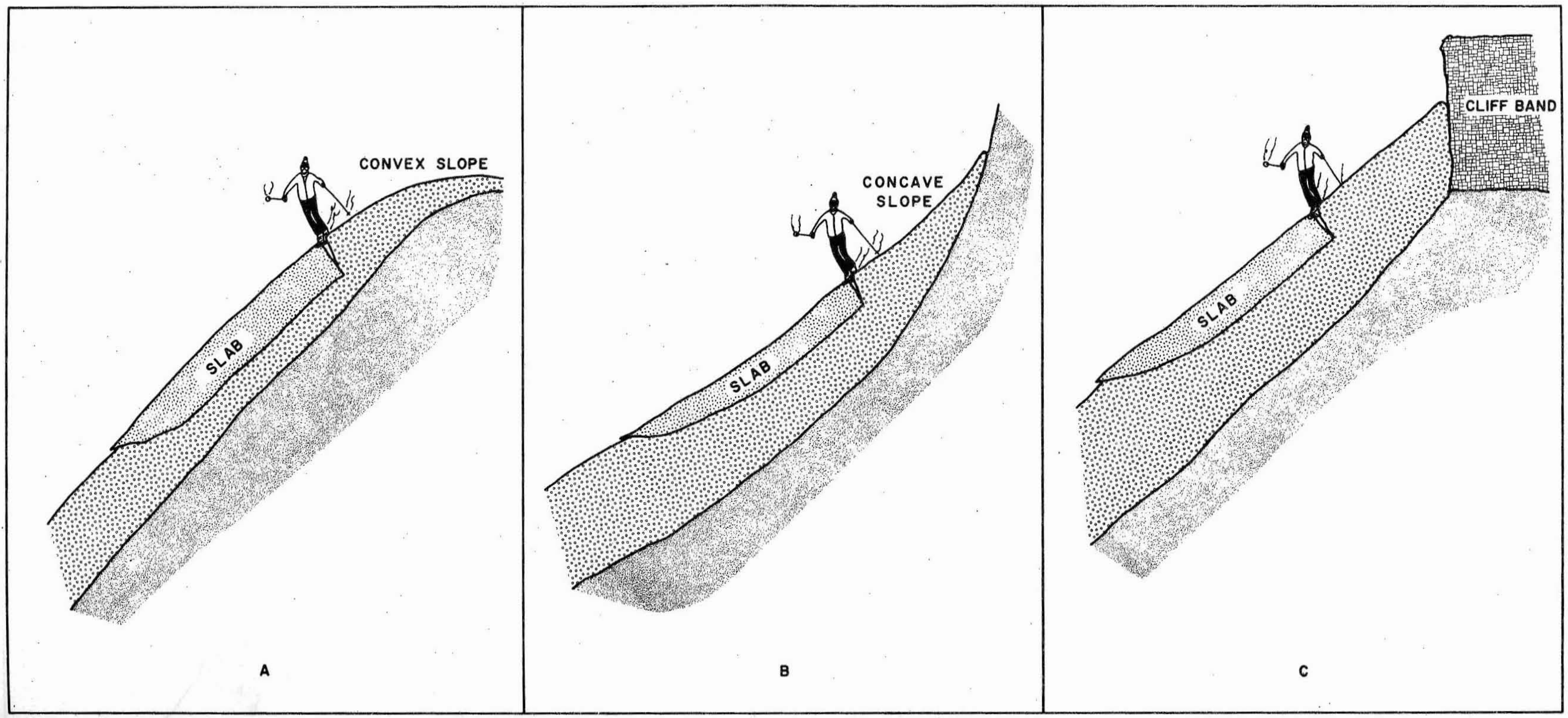

FIGURE 2 IN MANY CASES THE SLAB CROWN IS FOUND: A, ON THE STEEP PORTION OF THE SLOPE BENEATH A CONVEXITY; B, ON A CONCAVE SLOPE; C, BENEATH CLIFF BANDS

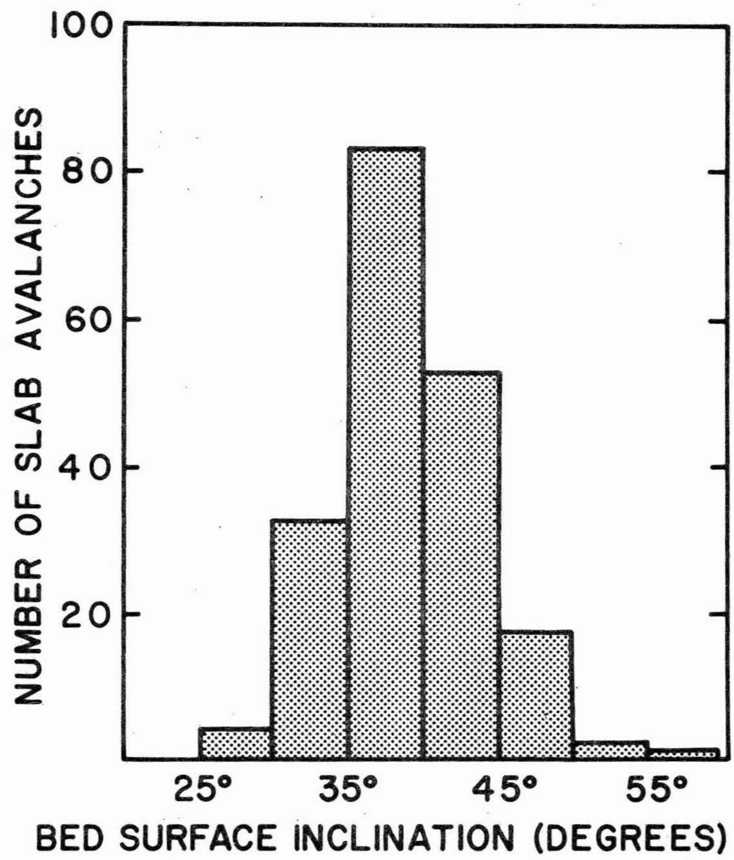

FIGURE 3 NUMBER OF SLAB AVALANCHES VS BED-SURFACE INCLINATION, 194 CASES (FROM PERLA, 1977)