Cornices: Their Growth, Properties and Control

by

Doug McCarty[1]
R. L. Brown[2]
John Montagne[3]

ABSTRACT

Two types of programs were recently conducted to learn more about snow cornices. The first of these involved a month long study of a cornice to determine in detail the mechanical properties of the cornice and how the cornice responds to its meteorological environment. The second study compared the use of aerial explosives and buried explosives for dislodging cornices. While results are somewhat premature, the air method appeared to be more reliable, since its success rate was roughly double that of the standard method of placing the explosive in the snow.

INTRODUCTION

Snow cornices form on mountain ridges under the effects of wind-aided transport of snow particles toward the lee side of a ridge. These particles are transported up the windward side close to the surface and, once in the wind shadow, attach to the snow surface. In many cases the particles can adhere to the leading edge of the snow surface without being in the wind shadow. Given sufficient wind, snow transport, and time, extremely large cornices can develop, often in excess of 100 Mg of mass. The classic cornice, which is most easily recognized by the casual skier, has a substantial mass overhanging the lee slope as illustrated in Figure 1. However, they can also develop without this large overhang and can still pose a threat to the area below.

When a cornice breaks off and drops onto the slope below, its impacting mass can be more effective for initiating an avalanche than direct control by explosives. The strength of cornices may often be unpredictable. Under the right conditions, a cornice can exhibit a very fragile structure which readily fails after very little disturbance. On the other hand they can exhibit considerable strength, not failing even under the influence of explosives. They're unpredicatability is also evidenced by the variety of failure patterns. Most often, the overhanging portion merely breaks off just to the lee side of the apex (see Figure 1). However, sometimes the failure extends into the windward side, dragging a number of layers of the snowcover on the windward side with it.

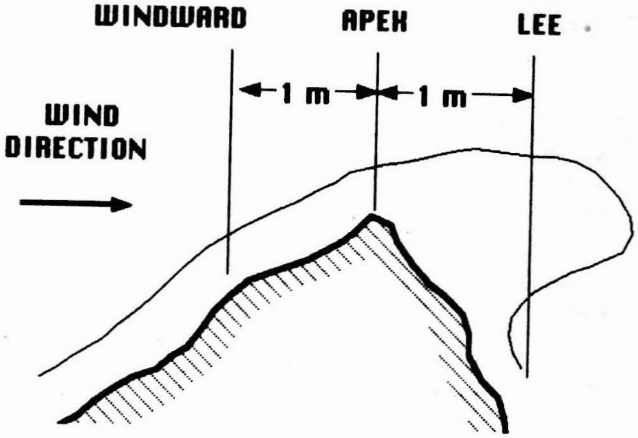

Figure 1. Schematic of the Bridger ridgeline cornice. The windward, apex and lee locations where profiling was done are shown.

There has been surprisingly little research on cornices. An exception to this is the work by Montagne (Montagne et al, 1968 and Latham and Montagne, 1970). These studies were concerned with the adhesion, deformation, and wind environment which is responsible for cornice formation. This work lead to the evaluation of snow fences, baffles, and jet roofs as methods to prevent the growth of snow cornices on mountain ridges. The wind baffles, for instance, have been used extensively in California. In the process of studying the growth of cornices, the electrostatic charge of the saltating snow particles was determined to be an influential mechanism for cornice growth. The saltating particles were found to have a electrical charge large enough to attach the particle to the cornice surface once stopped at the leading edge of the cornice.

The current study is not concerned so much with the formation process as with the properties of cornices once they have formed. Cornices are known to respond rather quickly to their meteorologic environmental. However little

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[1] Graduate Student, Geology Dept., University of Montana, Missoula, MT.

[2] Professor, C&AE Dept., Montana State University, Bozeman, MT.

[3] Professor Emeritus, Earth Science Dept., Montana State University, Bozeman, MT.

is known about their mechanical and physical properties. In particular there has been little quantitative work on the actual variation of cornice strength with the winter weather. Consequently this study attempts to answer some of these questions and to consider more effective use of explosives to control cornices.

FIELD STUDY TO EVALUATE PROPERTIES

A site in the Bridger Range just north of the Bridger Bowl Ski areas was chosen as the site for the cornice study. The summit area is, in part, a ridge running in a north-northwest direction at an elevation of approximately 2800 m. Since the winds are predominantly from the west, and since orographic precipitation is a significant contributor to snowfall in the Bridger Range, the ridgeline is a natural location for growth of a large number of cornices each winter.

The test program involved monitoring the evolution of a particular cornice during a one month period in the 1979-80 winter. Density, strength, temperature, and physical property profiles were taken at regular intervals in order to evaluate how the cornice responds to its meteorological environment. It would have been desirable to conduct this type of study for several winters in order to acquire a data base for a wider range of winter conditions. Unfortunately this could not be done. The one study reviewed here did, however, demonstrate how quickly a cornice responds to changes in winter weather.

On January 15, 1980, an existing cornice on the ridge crest was destroyed with explosives, and all snowcover in the windward side of the apex was completely removed with shovels. In this way the snowcover and the cornice itself could be monitored as it reformed and developed to a mature stage. Succeeding site visitations were made on the dates of February 1, 5, 9, and 21 which, respectively, were 17 days, 21 days, 25 days, and 37 days after removal of the original cornice on January 15.

On each visitation three strength profiles with a ram penetrometer were made at, respectively, 1 meter windward of the apex, the apex, and 1 meter leeward of the apex (see Figure 1). The ram profiling was then followed with temperature profiles at the same three sites. Finally a Mt. Rose snow sampler was used to extract cores from the three sites indicated in Figure 1. Five-centimeter samples from the cores were weighed to determine density profiles. After weighing, these samples were viewed with a hand held lense to determine the crystal classification.

Figures 2, 3, and 4 show the ram profiles at for February 5, 9, and 21. Finally, Figure 5 demonstrates the overall statigraphy of the cornice as it existed on February 9.

The temperature probe used to obtain a temperature profile failed to work satisfactorily. This was most unfortunate, since temperature gradient metamorphism appeared to play a role in the variation of the mechanical and physical properties of the cornice.

The temperature from January 15 to February 15 was fairly cold with the air temperature seldom reaching 0°C during the daytime. This period was therefore favorable for the development of temperature gradient (kinetic growth) forms.

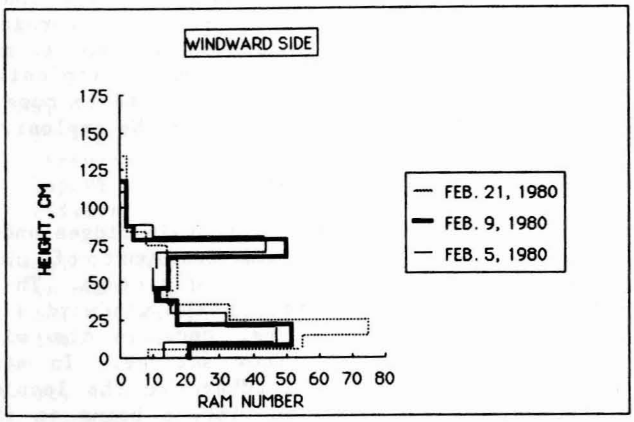

Figure 2. Ram profiles on the windward location.

From February 15 to February 21, a warming trend was experienced with the daytime air temperatures reaching 3 - 8°C during this period. This therefore provided an excellent opportunity to study the manner in which an established cornice responds to its thermal environment.

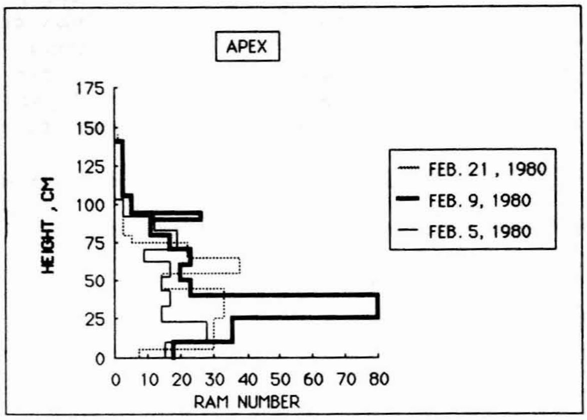

Figure 3. Ram profiles at the apex.

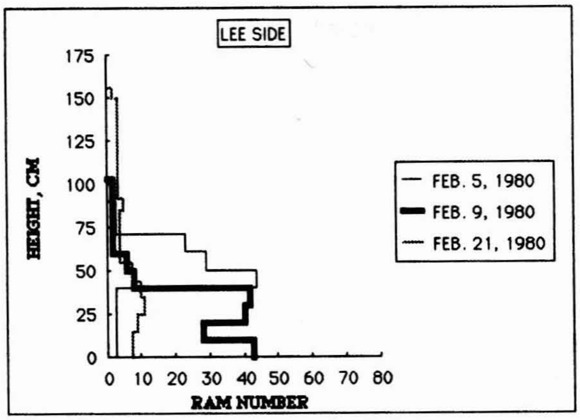

Figure 4. Ram profiles at the lee side.

The Ram profiles show that the cornice is heavily stratified. This is to be expected, since cornices form and develop under variable and often harsh conditions. The windward side, is regularly subjected to strong wind scour effects and periods of strong solar insolation. This section never did reach the thickness of the apex.

As indicated in Figure 2 for the windward side, two hard layers formed during the growth period (January 15 - February 15). During this period these hard layers continued to acquire additional strength, while at the bottom a weak zone of kinetic growth crystals developed and continued to weaken. However, once the warm period (February 15-20) established itself, the upper hard layer nearly disappeared, while the lower hard layer and the weak bottom layer retained their properties. What is seen here is not at all uncharacteristic of a normal shallow snowcover. The two hard layers were probably formed by a combination of wind and solar insolation.

The apex showed similar but less well defined trends. A thickness of approximately 1.50m was ultimately achieved. A very hard crust overlying a weak TG layer was again found to exist near the ground. The TG layer continued to loose strength throughout the period, but the hard lower layer lost strength during the warm period. In addition the upper hard layer was not as well defined at the apex as it was at the windward station.

The lee side of the cornice showed the most dramatic response to the changing weather environment. This is to be expected, since the cornice snow is subjected to warming or cooling from three surfaces (top, right end, and bottom). This is clearly illustrated in Figure 4. The February 5 and 9 profiles show a weak upper section, a hard inner core and a bottom layer exhibiting some strength by February 9. This could be the result of densification of the lower snow produced by flexural effects due to the overhanging section.

Figure 5 provides a general view of the cornice statigraphy prior to the warming period.

The two hard layers extend all the way from the windward side into the lee side. In all there were three weak layers, the bottom one exhibiting kinetic growth forms and fairly well developed TG snow. The layering in the lee side is not as well defined as at the apex and windward station. Since the snow mass tends to bend over under the effects of gravity, successive Ram profiles, if not made at exactly one meter from the apex may give substantially different results. This may explain some of the inconsistent results in the three profiles shown in Figure 4. Also, more profiles, say at 0.5, 1.0, and 1.5 m beyond the apex would be needed in order to obtain a clearer picture of the statigraphy on the lee side.

The profile for February 21 shows substantial deterioration in the strength. By this time the lee side of the cornice had essentially turned isothermal and the general strength of the entire mass had been reduced to a small fraction of its former reading. This is in contrast to the windward and apex sites which were subjected to warming only from the upper surface. As seen in Figure 5, the lee side has substantial surface area (top, right end, and bottom), therefore providing warming from the air.

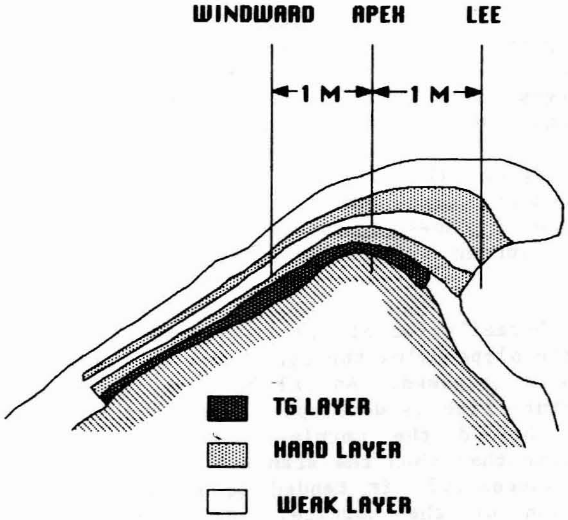

Figure 5. A general depiction of the cornice stratigraphy on February 9, 1980.

CORNICE CONTROL STUDY

In earlier studies at Bridger Bowl (Decker and Brown, 1982: Jurgens, 1984), aerial explosives have been shown to be an effective means of controlling avalanches. It was decided to investigate the merits of aerial explosives for dislodging snow cornices. Figure 6 illustrates the placement of the explosives. The standard placement procedure involved burying the explosive near the apex between 0.5 and 1.0 meters below the surface. The air explosive was emplaced by either one of two methods. In the first, detonation cord was used to suspend it from the free end of the cornice, usually between one and two meters from the lower surface of the cornice. In the second, a bomb wire strung in front of the cornice was used to suspend the explosive. This was not always possible since sites available to anchor the wire for appropriate location of the explosive was not always available. During the 1980-85 periods, a total of 12 shots were set off. Two pound charges were used for all of the six air tests. For the six standard tests, two pound charges were used on four tests and six pound charges were used on the remaining two. The aerial shots were 100 percent successful at dislodging the cornice, whereas the standard placement tests had a 50 percent success rate. Figure 6 shows a successful standard placement test, and an air placement test is shown in Figure 7.

Figure 6. Successful dislodging of a cornice using the standard placement technique with a six pound charge.

Normally the air shots released the snowcover on the slope below the cornice at the same time the cornice released. As can be seen in Figure 7, a fracture line is developing along the crown region just beyond the cornice. It should be noted however that when the standard placement technique was successful, it tended to knock off a larger portion of the cornice. For this method the fracture occurred near the apex where the bomb was placed. I the case of the air shots, usually only the actual overhang was released. Figure 8 illustrates typical fracture lines for these two methods.

CONCLUSIONS

The field studies reported here demonstrate that the overhanging portion of the cornice responds rapidly to changing temperature environment. During a warm period, only a few days are required to turn the overhanging mass into an isothermal condition. The rate at which this occurs depends on the mass of the overhang, its geometry (which determines the surface/mass ratio) and the temperature. Once the mass becomes isothermal, the material strength is quickly destroyed to the point where the overhang is relatively easily knocked off.

For cornice control air placement of explosives appears to be more effective than placement of the explosive in the snow near the apex. However, only a very few limited number of tests were made, and these were all on cornices of small or intermediate size. The relative merits of these two techniques for large cornices is to the authors' knowledge, still an open question.

In light of the limited data, the authors would caution the reader to not make any hard and fast conclusions. Rather the results are presented as "food for thought" with the hope that more research on this topic will be forthcoming.

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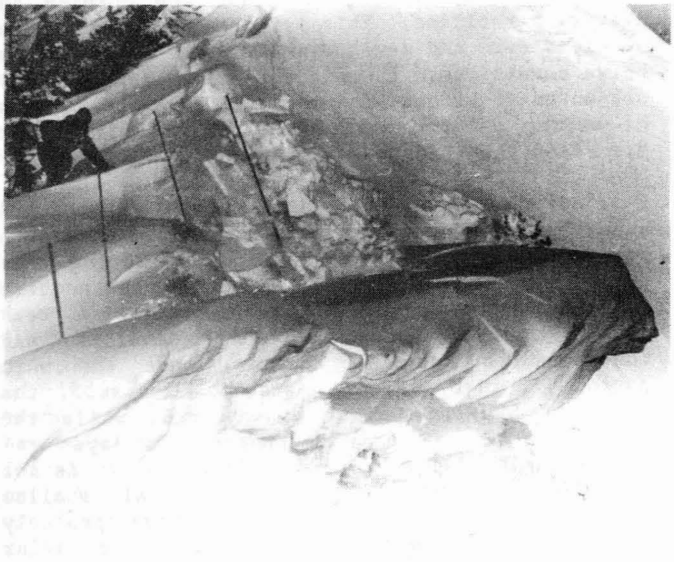

Figure 7. A successful dislodging of a cornice using the aerial placement technique.

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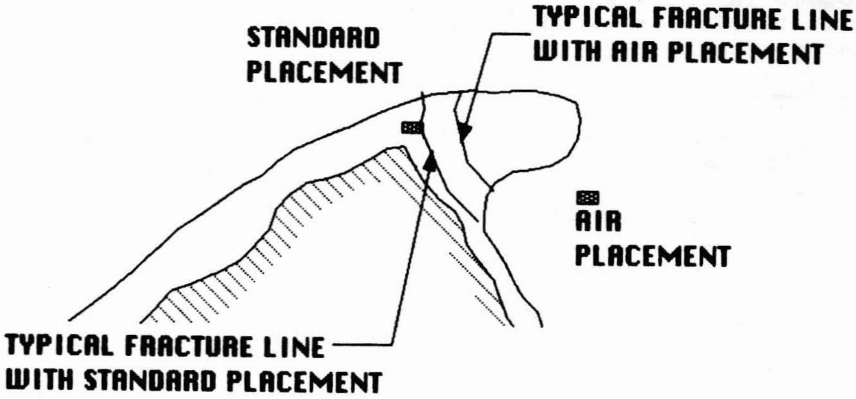

Figure 8. Typical fracture lines for the standard placement and the aerial placement techniques.