WET SNOW AVALANCHES
STABILITY EVALUATION AND CONTROL

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INTRODUCTION

Although wet snow avalanches account for only a small percentage of the total number of avalanches occurring annually in North America, they pose a real problem in many areas. Maritime snow climates experience a variety of wet snow avalanche problems throughout the winter and spring seasons. These include rain caused avalanches, mid-winter thaw avalanches, and spring thaw avalanches, In contrast, wet snow avalanches in a continental snow climate are generally limited to springtime thaw induced avalanches.

The study of wet snow stability has received less attention than dry snow stability. It has been suggested most wet snow avalanches result from a decrease in shear strength while most dry snow avalanches fail due to an increase in shear stress. Although many springtime thaw wet snow avalanches have resulted from a decrease in shear strength new evidence suggests other factors may be responsible for some wet snow avalanches.

WET SNOW METAMORPHISM

Wet snow is made up of a matrix of frozen water (ice), air, and liquid water. In contrast dry snow contains only frozen water (ice) and air. The addition of liquid water to the snowpack adds another element which effects its metamorphism, strength and stability. Wet snow can vary from damp snow with a liquid water content of less than 1% by volume to a snow matrix which may be made up mostly of liquid water. Generally for liquid water to be present in snow the snow temperature must be 0.0 C or above. Rainfall and snowmelt are the two primary sources of liquid water found in a mountain snowpack.

Wet and dry snow share some characteristics which play a large role in the metamorphism of wet snow. A brief review of these properties may lead to a better understanding of wet snow stability and wet snow avalanches. When liquid water is added to dry snow both grain growth and grain rounding increase. This is obvious when rain water or melt water are added to dry snow. Snow is a mixture of different grain sizes, each with a slightly different temperature. Large grains have a slightly higher temperature than small grains. Heat flows from the large (warm) to the small (cold) grains. Since small grains have a lower melting temperature than large grains this heat flow results in a melting of small grains as the large grains increase in mass. This process can lead to a snow matrix made up mostly of large grains.

Snow scientists have divided wet snow into two regimes, the pendular (low water content) and the funicular (high water content). The rates of metamorphism, water flow rates and mechanical strengths differ considerably between the two regimes. As the liquid water content of snow increases, metamorphism increases slowly until the liquid water content reaches 7% by volume at which time the growth rate increases rapidly. This liquid water content marks the point when wet snow metamorphism shifts from the pendular to the funicular regime. In the pendular regime air is in continuous paths throughout the pore space. In the funicular regime the snow grains are surrounded by liquid water. This difference leads to different heat flow rates which effect rates of metamorphism and mechanical strength. Generally snow in the pendular regime is characterized by strong grain attraction and higher mechanical strength. Snow in the funicular regime can be characterized as large grains with little grain to grain contact resulting in lower mechanical boundaries strength. The funicular regime occurs over impermeable boundaries, at interfaces and flow drains.

MECHANICAL PROPERTIES OF WET SNOW

A well-known Swiss avalanche researcher has suggested our understanding of wet snow mechanics is not as well developed as for dry snow. My studies have supported this premise. Literature on wet snow in general and wet snow avalanche in particular is limited. Only a few researchers have tackled the wet snow avalanche problem. Nevertheless, a few observations have been made which give us some clues as to why, how and when wet snow avalanches might release.

Selignan, in his 1936 "Snow Structure and Ski Fields," noted the cohesiveness of snow decreased as the liquid water increased. This is evident in very wet spring surface snow. Snow of this type tends to sluff off moderate to steep slopes as loose snow avalanches. Other observations of wet snow have shown the angle of repose of snow decreases as its liquid water content increases and snow layers experience an increase of creep and glide velocities with an increase in liquid water content. Austrian avalanche workers observed an increase of avalanche activity when the surface snow liquid water content reached 7%.

WATER FLOW AND SNOWPACK STRESS

A brief discussion of water percolation through the snowpack may help explain the cause of some wet snow avalanches. Considerable research has been done to study the effects and nature of water percolation through the snowpack although most of this work has been conducted on flat surfaces. These observations have shown water flow through old snow tends to be funneled into vertical drainage channels. These flow fingers can be very effective in transmitting liquid water down through the snowpack. Ice layers within the snowpack can restrict the vertical downward flow of water. These ice layers often redirect the water flow downslope along the top of the ice layer. The snow above the ice layer may become very saturated. This layer can be relatively weak and a possible failure layer. Texture changes within the snowpack, such as changes in snow grain type and density, can also redirect the vertical downward flow of water to downslope flow. Those layers also become very saturated and can be potential failure layers.

Some observations have illustrated rain and melt water concentrates in the upper section of a new snow layer on an inclined surface. This liquid water also flows downslope within the same upper section of the new snow layer. For some time interval the liquid water does not percolate vertically down; thus the lower section of new snow remains relatively dry. If the angle of repose of snow decreases with an increase in liquid water and the glide and creep velocities increase with an increase in liquid water, it follows that within the new snow layer the upper portion with a higher liquid water content may be travelling downslope faster than the lower dry section.

If the above assumptions are correct, the snow layer moving downslope at a higher velocity than the layer below would result in additional stresses in the snowpack possibly leading to avalanches. The accelerated creep rate of the upper section of the new snow layer could transmit stress deeper into the snowpack, particularly if there was some bond between the new wet snow and the new dry snow. In effect the upper wet snow layer would be pulling the lower snow layer downslope with it. Should there be a weak layer in the new dry snow or the older snow below, this pulling may increase the stress on the weak layer and produce a shear failure.

STABILITY EVALUATION AND CONTROL

Maritime snow climates such as the Sierra Nevada Mountains where I work are subject to several types of wet snow avalanche problems. To better understand the nature of wet snow avalanches, to assess the potential for them and possibly control them it is necessary to divide them into three major groups. These are springtime thaw induced avalanches, mid-winter rapid warming avalanches, and avalanches caused by rain or snow. Each group has its own unique characteristics, but also share many common traits. The similarities result from the mechanical properties of wet snow, in particular the lack of cohesiveness and strength of snow with a high liquid water content, the low angle of repose of snow with a high liquid water content, the increased creep and glide velocities of snow with a high liquid water content, and the water percolation characteristics of fine and course grained snow. By applying our understanding of these properties we can better evaluate wet snow stability, assess the avalanche hazard and apply appropriate control measures.

Artificial release with explosives on wet snow avalanches has been found to be ineffective. Wet snow does not respond to explosive control as does dry snow. The physical properties of wet snow suppresses the propagation of explosive shock waves through the snowpack. Wet snow tends to be less brittle and more fluid than dry snow. This property appears to lessen the effectiveness of explosive control. Most wet snow avalanche forecasting is done for wet springtime avalanches. For this type of forecasting of wet avalanches, meteorological factors, particularly temperature, must be used. Generally the snow cover must have a temperature of 0.0 C and liquid water must be present. Often this type of avalanche runs naturally when liquid water lubricates and weakens a basal layer.

RAIN INDUCED AVALANCHES

Avalanches resulting from rainfall on snow are common in a maritime climate. This type of avalanche is defined as a wet snow avalanche although dry snow may also be involved. Avalanche occurrence appears to be dependent on the age and grain type of snow on the ground. Avalanches of this type were responsible for the destruction of thousands of trees in the northern Sierra Nevada during a large storm in February, 1986.

An analysis of twenty rain on snow events at Alpine Meadows showed a relationship between the time interval since the last new snow and avalanche activity produced by rainfall. All avalanche days had new snow within the three days preceding rainfall. The analysis also showed the more new snow within the three days prior to rainfall, the less rain it took to produce avalanches. No avalanches were produced by rainfall intensities of less than .09" per hour and large rainfall totals did not always produce avalanches. New snow had to be present.

Observations of avalanches produced by the rainfall in the twenty events analyzed demonstrated many avalanches occur after the onset of rain. In some events, the avalanches ran within minutes of the commencement of rainfall. This quick response of the snowpack to rain water eliminates the possibility of rain water percolating to some lower snow layer, lowering the sheer strength and producing an avalanche.

Rain on snow avalanche events must be divided into two categories. The first category is similar to wet springtime avalanches. Rain falling on old snow can create an isothermal snowpack with snow temperatures of 0.0 C. During these conditions, water may percolate and develop lubricating layers resulting in wet slab avalanches. For this type of avalanche, explosives are usually ineffective and these avalanches must be forecast with the same methods used for springtime wet avalanches. Predicting the timing of these avalanches is difficult as the pathway of liquid water through the snowpack is often difficult to determine. Large safety margins must be used when forecasting these events.

The second category of rain on snow avalanches occurs when rain falls on new snow. In these situations explosive control is often effective in releasing slab avalanches. Timing of explosive use is critical. The snowpack during these periods often consists of wet snow on the surface with dry snow below. Explosives must be used early in the rainfall period while the snowpack is subjected to the additional stress of accelerated creep in the new snow layer. Explosive control performed later usually will not produce avalanches. One researcher found the detention of rain water on new snow high during the immediately after the precipitation period. This high detention capacity was only temporary. Four hours after the cessation of rain, most of the water had drained from the new snow. The percolation of the rain water may relieve the additional temporary stress in the new snow. Additionally, the percolating water appears to wet the snow below, thereby suppressing the propagation of the explosive shock waves.

A good example of the short time period of explosive effectiveness occurred at Alpine Meadows on December 9, 1987. 50 cm of new snow fell during the night of December 8 and the morning of December 9. This snowfall was followed by rainfall at daybreak on December 9. With the onset of rainfall, a few small natural slab avalanches fell. Explosive control was performed with an avalauncher shortly after the rain began. All explosive charges brought down slab avalanches. Several hours later slopes with similar aspect and steepness were shot. No avalanches were released. There was no evidence these slopes had avalanched naturally.

RAPID MIDWINTER THAW

In maritime climates many mid-winter snowfalls are followed by warm sunny days. Sub-freezing air temperatures during the snowfall can rocket to 50 F within a few hours of the storm breaking. These high air temperatures, along with high levels of solar radiation on south facing lopes can result in rapid melting of the upper section of the new snow layer. During these events it is common to observe the top 1 to 2 inches on new snow become saturated with liquid water while the new snow below retains its original grain type, density and temperature. Both loose and slab avalanches have resulted from this condition.

Generally air temperature and cloud cover are the factors used to recognize the development of this condition. Warm air temperature alone usually will not result in enough melt for an instability to develop. Lack of cloud cover with direct solar radiation must normally be present. If these conditions are present other indicators of instability will quickly develop. The most obvious indicators of this condition are small loose snow sluffs and snow rollers. Examination of the snow will most likely reveal the top few inches of new snow as very wet small round grain. The original new snow crystal shape in this wet layer will have been altered. It is during this period when the instability appears to be highest.

Most avalanches resulting from this condition tend to be loose snow avalanches. Ski checking during this condition often results in loose snow avalanches initiating form the skier's tracks. On occasion this condition produces slab avalanches. Although the mechanism for the release of slab avalanches is not clear, it appears to be similar to the differential creep stress which leads to avalanches when rain falls on new snow. Since it is not always possible to determine whether an event will lead to the more dangerous slab avalanche condition safety margins should be large.

Skiers and ski checking often produce loose snow avalanches during this condition large enough to bury an individual. At times ski checking can eliminate the hazard. Should slab avalanches result from ski checking it may be necessary to consider other control methods. The most commonly used method at Alpine Meadows is closure. Since this condition often results during business hours while skiers are present explosive control may not be an option. Limited experience has demonstrated explosives can be effective if applied during the critical differential creep period.

SPRING THAW AVALANCHES

Of the three types of wet snow avalanches discussed in this article spring thaw avalanches have been the most widely studied and written about. This type of avalanche is common in most snow climates and accounts for the highest number of wet snow avalanches. Spring thaw avalanches result from the gradual warm up and melt of the snowpack in spring. For avalanches of this type to be produced the snowpack must be isothermal with snow temperatures of 0.0 C and liquid water must be present. Both loose snow and slab avalanche may result.

This type of avalanche can often be forecast using meteorological factors. At Alpine Meadows once the snowpack is isothermal, wet snow avalanches of this type usually require nighttime lows above freezing. Generally nighttime cloud cover is also present. The cloud cover lessens the radiation loss resulting in warmer snow temperatures, increased melt and liquid water. Snow temperature is also a good indicator for instability of this type. Generally snow temperature of 0.0 C is required before avalanches occur.

Experience has shown that if the wet surface snow layer can be ski checked off the potential for a slab release may be reduced. This is usually performed mid-day. Ski checkers traverse and side slip down the slope. This often produces loose snow avalanches, sometimes of considerable size. On occasion this act will trigger slab avalanches. Slab avalanches usually result when percolating liquid water pools in some discontinuity within the snow layers. The pooling water reduces the strength of the snow within the layer thereby reducing the shear strength.

As mentioned earlier explosives are often ineffective in wet snow. Experience has shown conventional avalanche blasting usually will not produce avalanches during spring thaw. Two explosive techniques have proven to be effective in producing avalanches. At Lake Louise Ski Area avalanche workers bury 1 lb. explosive charges along the fracture zone. These are linked with det cord. The charges are buried while the snow is frozen. As the snow warms during the day snow temperatures in the area are monitored. When the snow temperature reaches 0.0 C the explosives are detonated. This often produces avalanches. Another method was developed to protect roads and mine sites. This involves large charges of 100 Kg plus. This also usually produces avalanches.

CONCLUSION

We still have a long way to go before we can accurately predict wet snow avalanches. A better understanding of wet snow mechanical properties such as differential creep and liquid water percolation on an inclined pack should lead to better forecasting methods. For now we must continue to apply the tools we have to this interesting type of avalanche.

FURTHER READING

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