ACOUSTIC EMMISSIONS IN THE INVESTIGATION OF AVALANCHES 633-77

By

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Introduction

Over the past several years we have been investigating the role of acoustic emissions in the deformation and failure of snow. Our investigations began in the laboratory by studying the acoustical activity associated with snow subjected to various states of stress. The frequency range monitored in our laboratory experiments ranged from 30 KHZ to 300 KHZ.

The results obtained in these experiments indicate that snow is a copious emitter of acoustic emissions when subjected to stress. When various loadings are applied to snow in the laboratory, patterns of acoustical activity are produced which are indicative of the applied load. Observation of the time response of these acoustical patterns suggests that this acoustical phenomenon plays an important role in the stress deformation response of snow. With the experience and knowledge gained from our laboratory work, we have been able to apply acoustical emission techniques in the field to investigate the stability of avalanche prone snow slopes.

For the purpose of this paper we will describe in general terms the methods and equipment used in our investigation and some of the results we have obtained to date. Although we are working with snow, many of the processes involved in the failure of snow slopes should relate directly to the failure of soil and rock slopes.

Acoustic Emission Monitoring System

The basic system used to detect ultrasonic emissions from snow is in general similar to systems employed to monitor acoustic emissions in other fields of material science. Considerations regarding the design and employment of acoustic emission monitoring systems are reviewed extensively in the literature. For a detailed analysis of such systems the reader is referred to papers by Liptai et al (1971) and Dunegan et al (1969).

The acoustic emission system used in our investigations utilized a commercially available transducer in conjunction with a low noise preamplifier with a numerical gain of 1000. Depending on the manner in which the signal is to be processed, various signal conditioning units are used. For our purposes, signal conditioning consisted of post amplifying and filtering the signal between 30 KHZ and 300 KHZ, discriminating each incoming noise burst in terms of voltage amplitude, generating a digital pulse and then counting these pulses and displaying them in terms of noise rate or accumulated noise versus time.

It is of some importance to note that the transducers used in these investigations generally do not exhibit a flat response with frequency. It is common in high frequency acoustic emission studies to monitor the acoustic activity in the range of the transducers resonant frequency. In this manner the sensitivity of the transducer is increased at the cost of a major degradation in signal fidelity. Figure 1 shows the response versus frequency curve for one of the transducers used in our experiments.

In working with a soft material such as snow, some care must be taken when mounting the transducer to the snow to insure that the transducer does not influence the response of the snow. To accomplish this in the laboratory the transducer is mounted on a stand which holds the transducer away from the snow. The face of the transducer is then covered with a thick layer of silicon lubricant and pressed lightly against the snow sample. In this manner the transducer is kept physically away from the snow with coupling to it being achieved by the lubricant.

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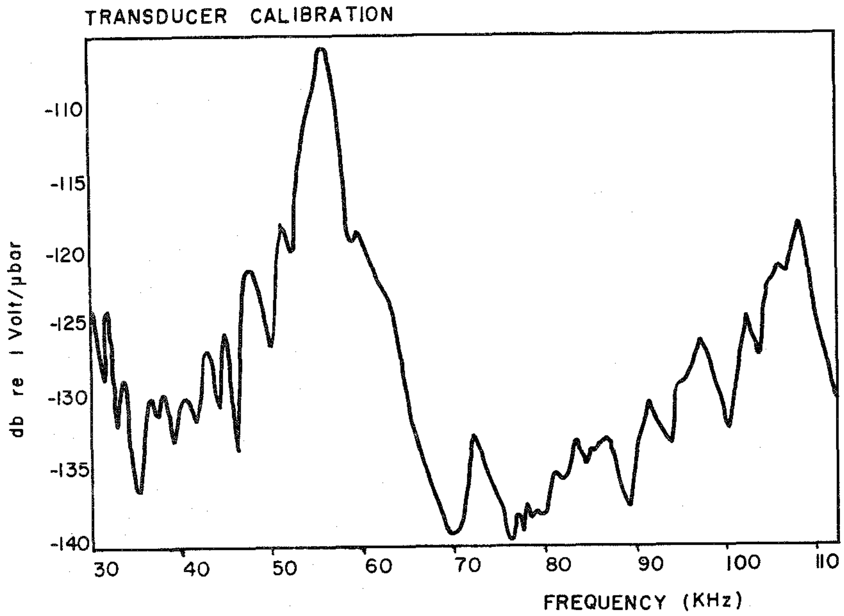

Figure 1. Response versus frequency curve for a typical acoustic emission transducer used to monitor acoustic emissions from snow.

In applying the acoustic emission method to *in situ* investigations of avalanche slopes the method of coupling the transducer to the snow becomes somewhat more involved. Since ultrasonic signals attenuate rapidly with distance from their source a method is required which will extend the range of surveillance. To obtain this extended range, in our current work we have coupled the transducer to a wave guide which is placed in the slope. The wave guide which is used is a small diameter (3 mm) metal wire 25m in length. This wire is coiled and then extended to form a helix 0.5m in diameter. One end of this helix is then attached to the transducer. The wave guide is implanted in the snow slope by laying it on the existing snow surface and allowing it to become buried in subsequent storms.

Origin of Acoustic Emission in Snow

To understand the nature of acoustic emissions from snow we must give consideration to its structure and how it behaves under stress. Snow on the ground is a low density, highly porous granular material formed of individual ice grains or groups of ice grains sintered together to form a coherent aggregate mass.

When snow is subjected to an applied load two mechanisms of deformation predominate. The ice grains which constitute the snow matrix deform and flow, and simultaneously the ice grain matrix undergoes a geometric rearrangement. The degree to which these two mechanisms participate is to a large extent a function of the applied stress. For low stresses the predominant mechanism of deformation is intragranular flow while at higher stresses intergranular movement becomes increasingly more significant.

During intergranular flow and to a less extent under low applied loads the sintered bonds between ice grains rupture. It is the fracturing of these grainbonds that are detected as acoustic emissions. At a given stress level snow that is well sintered may emit relatively few acoustic emissions while snow with poorly developed grainbonds may emit a large number of acoustic emissions. In terms of relating the acoustic activity to the deformation of snow we can consider it as a measure of the mobility of the ice grains making up the snow matrix. Since snow is such a highly porous material, this grain mobility becomes important in describing the deformation of snow.

Figure 2 shows a photomicrograph of a thin section of snow. This section is from a sample of snow which had a density of 300 $Kg.m^{-3}$. This photo shows the characteristic structure of snow.

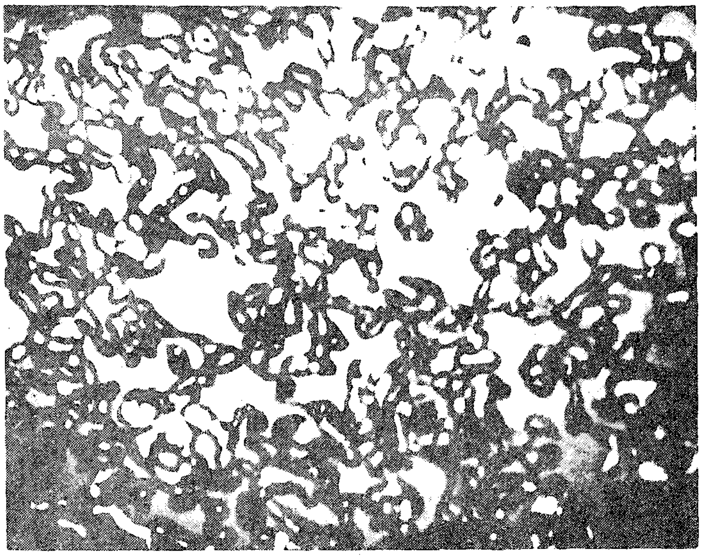

Figure 2. Photomicrograph of a thin section of snow with a density of 300 $Kg.m^{-3}$. This photo shows the characteristic structure of snow on the ground.

Results of Laboratory Experiments

Our initial work with ultrasonic emissions from snow was conducted in the laboratory to determine under what conditions snow would emit acoustic signals. The format for these experiments was a series of creep tests and constant deformation rate tests.

The material character of snow shows dramatic differences depending on the degree of metamorphism it has experienced. For the purpose of our laboratory experiments we have confined our work to equitemperature snow. This is an equilibrium form of snow that develops in the absence of temperature gradients.

In uniaxial compression at constant stress snow exhibits only primary and secondary creep. In uniaxial tension at constant stress snow may also exhibit a tertiary creep stage. This later effect is developed only after the applied stress reaches some critical value. The acoustic emission pattern for snow subjected to constant stress levels is quite indicative to this type of loading.

Normally, the acoustic activity shows an initially high rate of activity as the load is applied. The rate of acoustic activity then decays rapidly to zero within a few tens of minutes after application of the load. This emission pattern suggests that the intergranular flow regime is established rapidly in the snow sample by the initial fracture of a certain number of grainbonds. The snow structure is thus geometrically rearranged in a manner such that a flow pattern can be achieved which is consistent with the applied stress.

In the case where a tensile load is applied that is high enough to eventually cause tertiary creep and rupture the acoustic emission pattern is somewhat altered. After application of the load the emissions show an initially high rate, but decay with time in this instance does not go to zero but to some lower steady rate. As the creep strain increases into the region of tertiary creep the emissions show a marked increase in rate.

This is illustrated in Figure 3 for a snow sample which failed forty-six hours after application of the applied load. It is interesting to note that the failure of snow in this manner appears to be related to the failure of intergranular bonds as indicated by the level of acoustic activity.

For constant rate deformation tests where stress is the dependent variable the acoustic emission pattern is considerably different than for creep. In this case, the noise rate increases rapidly with time and then decays to a constant rate. This is illustrated in Figure 4 with both the stress and acoustic rate response shown versus time. The particular stress and acoustic response shown is for a snow specimen subjected to a constant rate of extension of 1.54 X 10-4m.min-1.

It is interesting to note here the stress response when snow is subjected to either constant rates of extension or compression. As can be seen in Figure 4, snow exhibits a noticeable geometric softening in tension as indicated by the negative stress rate after the stress has reached a maximum. Conversely, when snow is subjected to constant compressional deformation rates a marked geometric hardening effect is observed in which the stress rate is always positive and the stress never achieves a maximum value.

In the present context this geometric hardening has to do with an increase in the interaction of ice grains with increased strain for compression. In tension the geometric softening represents a decrease in the interaction between ice grains. By considering the deformation of snow at the structural level and by considering the grain geometry and amount of acoustic activity, St. Lawrence and Bradley, (1974) have developed a constitutive law for snow which describes these phenomenon.

For snow subjected to constant rates of deformation we observe two basic patterns of acoustic emissions related to failure. For snow which has not been subjected to a prior stress and for which the deformation rate exceeded approximately 5% hr^{-1}, failure occurred during the rapid initial rise of the stress time curve. This held for both tension and compression tests. If failure occurred in this manner the acoustic activity also showed a very high, or more precisely, saturation rate. The acoustic saturation rate is the rate at which the acoustic activity can no longer be monitored as single burst of acoustic energy. For snow, this level is about 400 to 500 bursts per second but can vary considerably depending on the trigger level used for discriminating the acoustic bursts.

It is hypothesized that when snow fails in this manner, intergranular fracture occurs at such a high rate that the ice grains cannot shift to a configuration that will permit further flow. In this instance, the snow simply undergoes catastrophic failure. This type of failure has been classified as a type I brittle failure by Kinosita (1966).

A second mode of failure which takes place in tension under constant rates of deformation occurs after the stress has exceeded its maximum value and the acoustic emission rate becomes relatively constant. In this case, failure occurs in the snow sample with no detectable change in the rate of acoustic activity. It is felt that in this instance the limit of flow in the snow sample is reached and the snow fractures.

Acoustic Emission Field Investigation

During the winters of 1974-75 and 1975-76, an avalanche slope in the Bridger Range of southwestern Montana was instrumented. As with many natural phenomenon some patience is required when conducting an investigation of this type. During the first field season one major slab avalanche occurred on our test slope and several smaller wet and loose snow avalanches took place. During the second field season 1975-76 no major slab avalanches took place, but again several loose and wet snow avalanches did occur. The results obtained from these field experiments, although preliminary; do indicate that ultrasonic activity does occur in natural snow slopes.

The intent of our research program was to determine if the acoustic patterns associated with the failure of snow in the laboratory would also be detected *in situ*. Our initial findings indicate that in the field the patterns of acoustic activity are not as clearly defined as those observed in the laboratory. Also, since we do not have a large number of events on which to base our analysis, further field experimentation will be required. In this regard, the results presented must be considered as preliminary in lieu of more complete data.

The general pattern of acoustic response observed throughout the winter shows periods of generally low background noise interrupted by periods of higher acoustic activity. A typical record of a three-day period in early March 1975 is shown in Figure 5. In this figure the acoustic rate (events per hour) is plotted against time. It was common to observe several days of low activity between periods of high noise rate. It was also observed that as the winter progressed the time between quiescent periods became shorter.

On two occasions during monitoring, after extended periods of relatively low activity instability developed which led to the release of several large slab avalanches. In one instance a major slide released directly over the waveguide.

Although our primary interest is the mechanism of failure of the delayed action slab avalanche, we have found that the ultrasonic activity is also related to instabilities which produce wet snow avalanches. Unlike the slab avalanche in which the snow fails as a coherent mass, the wet snow avalanche represents the failure of individual bonds between snow grains. The wet snow avalanche generally involves only a portion of the upper snow surface and may start from a point source.

In our studies we have found a high correlation between the development of wet snow avalanches and a rapid rise in the rate of acoustic activity preceding the release of these avalanches. In the area of our field station these avalanches generally occur in mid-afternoon and are related to the amount of radiation incident on the slopes as well as to snow conditions.

It is of interest to note that although our waveguide was located several meters beneath the sliding layer, a rise in the emission rate was still detected. This leads us to the hypothesis that the deterioration of stability in the surface layers is causing a significant change in the state of stress throughout the snow pack.

Discussion

In this paper, we have presented a brief review of the results obtained in applying the acoustic emission technique to studies of snow and avalanche mechanics. From our initial observations it appears that acoustic emissions represent an important variable in describing the deformation and failure properties of snow. In the laboratory we have achieved a preliminary understanding of the acoustic phenomenon which has allowed us to develop a constitutive law using the acoustic activity as a primary variable. Our in situ investigations have not led us to an understanding which can be readily quantified at this time. We can, however, develop an initial hypothesis relating acoustic activity to the occurrence of delayed action avalanches.

Acoustic emissions in snow are a measure of the amount of energy that is dissipated when the snow is subjected to a change in its state of stress. Thus if a load is applied to snow, the internal structure is rearranged to accommodate this load. Generally, this internal rearrangement of the structure represents a strengthening of the material.

To illustrate this point, we can cite the following example. If we have several snow samples which have all been subjected to the same stress history, we can determine roughly a particular deformation rate or stress level which will cause these samples to rupture. If, however, we load the snow sample at some level below that which we had initially determined would cause fracture and then reload it at the initial fracture rate we find that this level is no longer sufficient to cause rupture. Actually, in this manner we may double to triple the strength of the material.

In these terms, we can consider the occasional rise in the rate of acoustic activity observed in the field as an overall strengthening of the snow pack. If, however, we observe that an extended period of time elapses at which the acoustic activity is at a minimum, then it is possible that the snow slab is storing energy and is thus more susceptible to massive catastrophic failure.

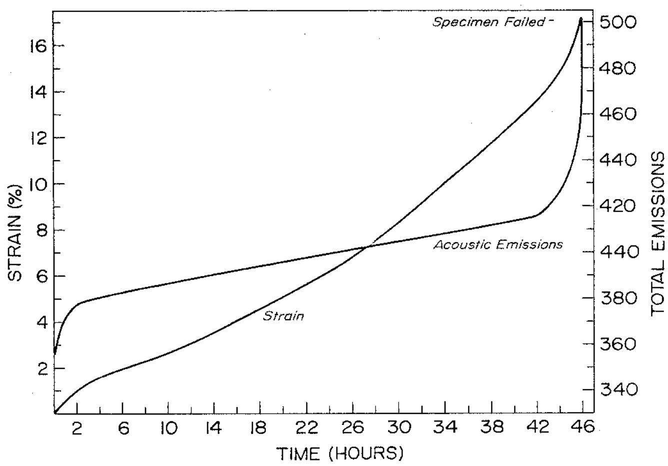

Figure 3. Strain and acoustic response of a snow sample subjected to a constant uniaxial tensil stress of 20.5 kilonewtons per square meter.

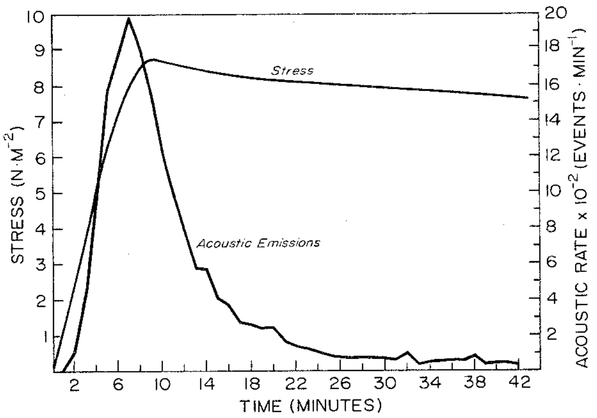

Figure 4. Stress and acoustic rate response for a snow sample deformed at a constant rate of 1.54×10^{-4} m.min^{-1}.

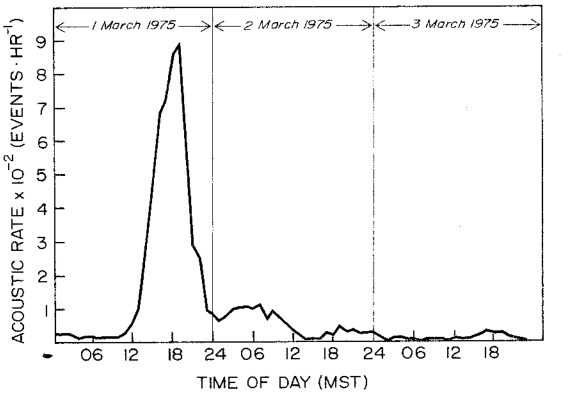

Figure 5. Acoustic rate response observed over a three-day period in early March 1975. This record is typical of the acoustic activity observed throughout our winter field testing program.

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