

SENSOR FREQUENCY, WAVE GUIDE ORIENTATION AND TYPE, AND THEIR
INFLUENCE ON ACOUSTIC EMISSION MONITORING OF SNOW PACK STABILITY

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Abstract.--Acoustic emission monitoring of the snow pack indicates that 1) acoustic emission rate is related to settlement, creep and snow loading rate; 2) snow attenuation values are a function of snow density, frequency of the sensor and snow anisotropy; 3) skiing activity produces erratic acoustic emission activity; 4) avalanche releases were identifiable.

INTRODUCTION

In conjunction with Alpine Meadows Ski Resort, Tahoe, California, and utilizing acoustic emissions equipment, avalanche prone slopes at the ski resort were instrumented during the winter ski seasons 1982-1985. The main intent was to determine 1) the feasibility of detecting avalanches by analysing acoustic emissions (micro-seismicity) from within the snow pack, and 2) perform experiments using two types of sensors and different types of wave guides.

An automatic chart recorder and processor station was established near an avalanche track zone with wave guide, sensor, and preamplifier buried in the avalanche track. Acoustic signals from the sensor were transmitted via a cable to the processor.

During the monitoring phase, continuous weather records were maintained of snow fall, snow moisture, pack settlement, and air temperature. Correlations were made between acoustic emission rate and, the foregoing pack conditions, ski activity on the instrumented slope, and natural and controlled avalanche releases.

Previous research into the use of acoustic emission monitoring of avalanche activity has been published by St. Lawrence (1976) and more recently by Sommerfeld and Gubler (1982). An acoustic emission (A.E.) is a transient elastic wave that has been produced within a material by the very rapid release of energy. In geologic materials, energy release processes include fracturing or sliding of minerals and rock. In snow, degradation

and dilation, settlement, compaction and glide produce the majority of A.E.'s. Monitoring the changes in A.E. signal (the electrical signal produced from the transducer in response to the elastic wave) levels, enables correlations to be made between A.E. levels and snow deformation, ski activity and avalanche phenomena.

SITE LOCATION

The ideal site for experimentation is an area where steep snow slopes exist, which avalanche regularly, and with easy access to the slopes. These conditions exist at Alpine Meadows ski resort, California. Alpine Meadows is located approximately 40 miles southwest of Reno, Nevada on State Route 89 in northern California. Alpine Meadows, with some of the best downhill skiing in the Sierra Nevada, also has some of the best avalanche country in the Sierra Nevada. Consequently, their avalanche control personnel are experienced at controlling avalanche activity through explosives and ski release techniques. Even with utilization of their experience and all known techniques, major avalanches have occurred at Alpine Meadows, the most notable occurring on March 31, 1982, killing seven people.

A snow slope called High Yellow Run was selected for monitoring. This slope which experiences both natural and controlled avalanche releases is south of Ward Peak, 8637 feet, the high point of the ski resort. High Yellow Run has avalanche releases which cover a vertical distance of about 800 feet. The instrumentation was installed in the avalanche track of the slope, between the starting and runout zones (Fig. 1).

Prior to, and during the monitoring of the snow pack for instability, field tests were performed. These tests were executed to assess snow attenuation, wave guide orientations, and the effectiveness of using sensors which respond to different signal frequencies.

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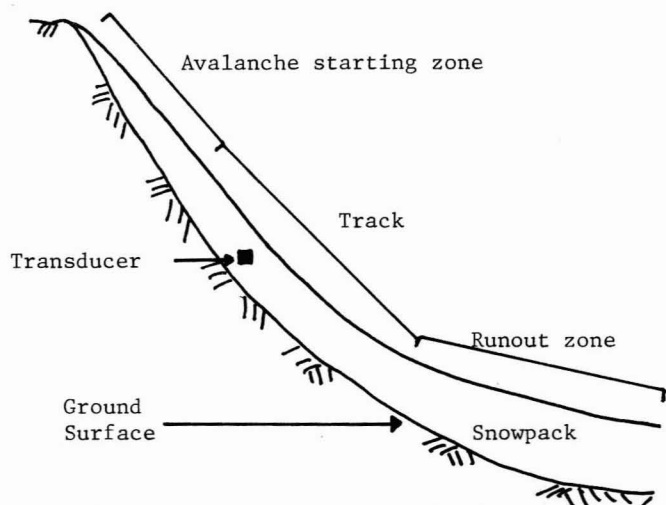


Figure 1.---Location of monitoring equipment on High Yellow ski run.

SNOW ATTENUATION

The more important parameters on which attenuation of elastic waves are dependent include density of the material, degree of coupling, and frequency of the acoustic emissions. Steel has an attenuation of about 0.1 dB/ft at 30 kHz, whereas a dry fine grained soil has an attenuation in the region of 50dB/ft. Wave guides, therefore, in geologic materials are normally composed of steel, with a low attenuation loss compared to the medium in which they are placed.

The sensitivity of the monitoring is highly dependent on the distance of the wave guide from the acoustic emission source. As this distance increases, attenuation rapidly reduces the A.E. strength. The locality for the test was the same as used for the avalanche studies. The wave guide and transducer was about 4 feet below the snow surface and 15 feet above the ground surface at the time of the test. Energy was put into the snow via a hammer and plate arrangement; consequently a wide range of frequencies were introduced into the snow pack.

The maximum range of receiving the acoustic noise varied from 18-39 feet using 30 kHz sensors. As the snow pack in the monitored area is also a ski run, the snow undergoes different degrees of compaction, e.g., moguls are formed. This anisotropy explains the different attenuation rates in the snow pack due to compaction and metamorphism. Snow densities were found to be between 150 - 400 kg/m³, with occasional thin ice layers and ice

lenses in the monitored area. The variability in density affects the attenuation. Attenuation was calculated, using the very limited data, to vary from 6-10 dB/ft., though possibly it could be at least an order of magnitude greater in low density snow.

WAVE GUIDE ORIENTATION

In order to fabricate the optimum shape for a wave guide to be buried in the snow pack, tests were performed using different wave guide orientations with a steel rod acting as the guide (Fig.2)

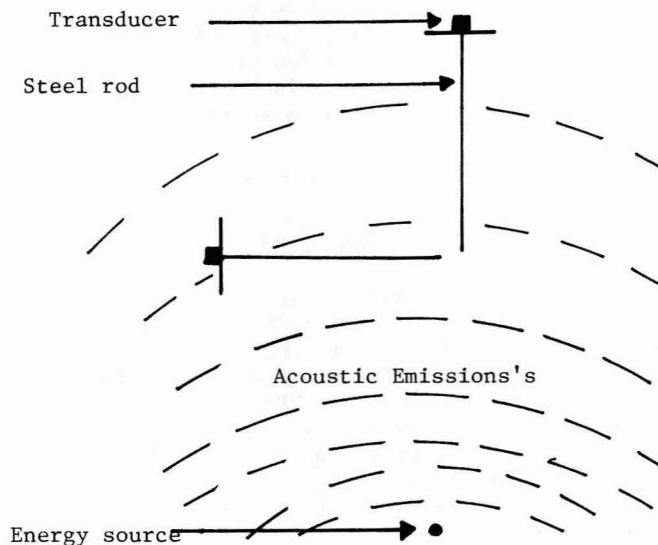


Figure 2.---Field tests performed using steel rods as wave guides, parallel and normal to the energy source and A.E. waves.

Two parallel snow pits were excavated about 10 feet apart. One pit was used to provide the energy source by hitting a steel plate attached to the pit sidewalls. The energy was measured in the other pit by having the steel rods with sensors attached installed in the pit walls, one rod normal, the other parallel to the direction of the energy source.

Ring down counts picked up by the wave guide normal to the energy source were approximately 60% greater than those obtained from the wave guide parallel to the source (Fig. 3). From the results of this test it was decided to produce a wave guide which had both types of orientation (Fig. 4). This type of configuration therefore would, it was hoped, pick up all available emissions from the snow.

INSTRUMENTATION AND TEST PROCEDURE FOR SNOW PACK INSTABILITY

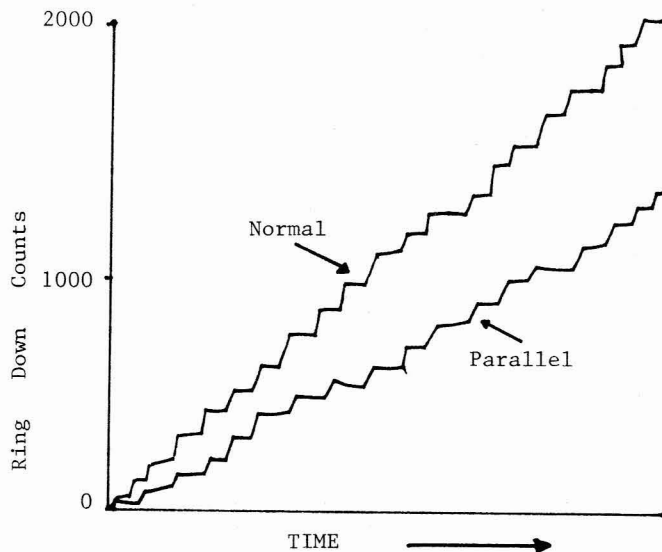


Figure 3.---Ring down counts obtained from wave guides normal and parallel to the energy source.

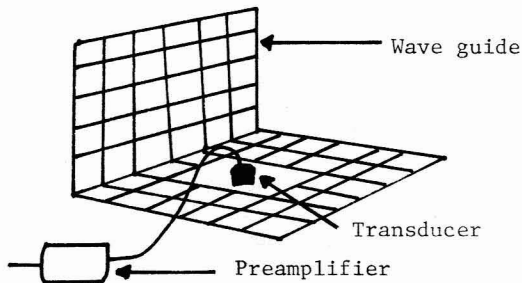


Figure 4.---Instrumentation configuration of the wave guide installed on High Yellow.

SENSOR FREQUENCY

Two sensor frequencies were tested. One sensor was resonant at 30 kHz, the other at about 28 Hz. Previous investigations by Sommerfeld (1981), indicated that using sensors resonant at low frequencies were successful at picking up acoustic emissions, which were interpreted as suggesting snow pack instability. Our own series of tests using both types of sensors, and a constant energy source, found that the sensitivity of the geophone (28 hz sensor) was too low to pick up our signals, the 30 kHz sensor worked well. Consequently, we utilized the 30kHz sensors in our testing program.

The acoustic emission system consisted of a sensor, preamplifier, processing unit, and strip chart recorder. The sensor used was an AET AC30L resonant at 30 kHz. The AET Model 140B preamplifier provided gain and a frequency bandwidth of 4.5 kHz to 47 kHz. An AET Model 204G functioned as the signal processing unit providing information on the threshold activity and signal strength to a one pen recorder. The signal processing unit and strip chart recorder were housed in a wooden box with 2" styrofoam insulation, and were powered by a 12VDC battery.

Previous investigations (Leaird and Plehn, 1983) at Alpine Meadows had utilized a sensor attached to a 6 foot long steel fence post, one end anchored in the ground. The fence post acted as a wave guide, the purpose of which was to decrease the attenuation loss experienced by the acoustic emission's passage through the snow. Leaird and Plehn established that as snow load increased, the acoustic signal level increased. However, as the depth of snow cover over the wave guide increased, the attenuation loss increased, and the snow pack glide distorted the wave guide.

To avoid similar problems, the transducer was attached to a 3x3 foot square hardware cloth wave guide (Fig. 4). The wave guide effectively "floats" in the snow pack, as it is not attached to the ground, but buried 1-2 feet below the snow surface, prior to renewed snow precipitation from storm activity.

The equipment box was firmly attached to a large tree, which was protected by a rock pinnacle from avalanches. The cable from the processor unit was buried 1 foot below the snow surface and extended for 80 feet to the middle of the avalanche track where the wave guide, transducer and pre-amplifier were buried 1 foot below the snow surface. Approximately two-thirds of the wave guide was buried so that it was parallel to the snow surface and one-third was normal to it.

The station was activated one day prior to storm activity, enabling records to be obtained of ski-activity, avalanche releases both natural and artificial, and background level acoustic activity.

RESULTS

Together with the weather information, avalanche activity both natural and artificially induced by Alpine Meadows avalanche control team was recorded. A complete record of prevailing weather conditions and avalanche activity on the instrumented slope could therefore be compared with the acoustic emission signals recorded on the strip chart.

The most interesting and informative record of acoustic emissions occurred during the period February 22 to March 24. This time period saw heavy snowfalls and avalanches, which were

correlative to acoustic emissions. In addition to the A.E. relationships recorded by Leaird and Plehn (1982), which were also found, previously discussed, three other main areas were identified.

ACOUSTIC EMISSION AND SKI ACTIVITY

Skier activity on the instrumented slope was very recognizable (Fig.5). The figure shows a background A.E. level of about 8000 counts per hour, with no skiing or snow precipitation. With skier activity the count levels increase to between 20-24,000 counts/hour. The maximum level occurring after lunch.

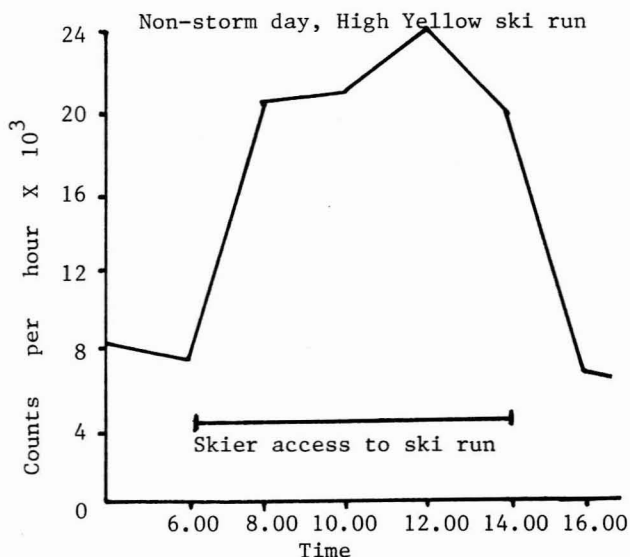


Figure 5.---Skier induced A.E. activity compared to background level.

ACOUSTIC EMISSION AND NATURAL AVALANCHE RELEASES

The monitoring showed many large increases in acoustic activity during storm activity. Inspection of the avalanche reports indicated when avalanches were caused by artificial techniques. However, at other times specifically in the evening or early morning when no avalanche control occurred and no persons or skiers were present, similar large increases in acoustic activity were recorded.

Figure 6 contains the record of total counts against time for such activity in the evening. Background A.E. level is about 5000 counts per hour, but two parts of the graph show activity levels of 1000 and 500 counts at 21.10 and 20.18 hours respectively occurring "instantaneously". Weather records show high snow fall during the night with 2-3 feet of new snow recorded on Ward Peak as noted in the morning by the avalanche control crews. The jump in acoustic activity is interpreted as snow slides originating above the instrumentation, and passing over the wave guide assembly as the moving snow slid down the avalanche track.

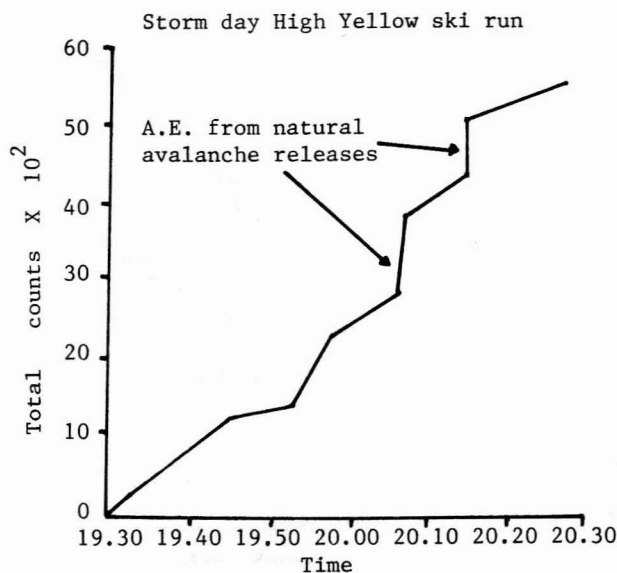


Figure 6.---Effect on A.E. count rate of avalanche passing over wave guide.

ACOUSTIC EMISSION AND ARTIFICIAL AVALANCHE RELEASES

A major advantage of controlled avalanche release is that the exact time of the event is known and can be compared to the recorded acoustic levels for that time interval. Plotting the A.E. counts against the time interval when avalanche control was underway (Fig. 6), it is apparent that at about 9:00 a.m. the A.E. level jumped from a background of 5000 counts per hour to a value in excess of 100,000 counts per hour. If the A.E. level is assessed similar to Figure 7, the value would correspond to "instantaneous" count of 1840.

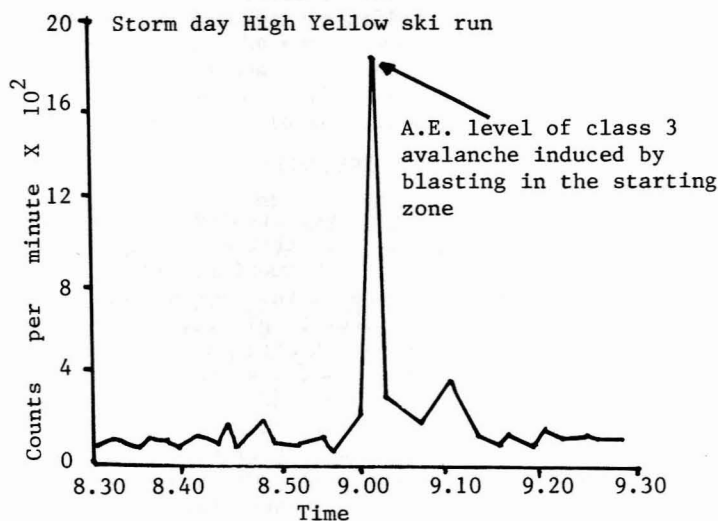


Figure 7.---Effect on A.E. count rate of avalanche passing over wave guide.

Inspection of the avalanche control teams records for that day and time interval, reveals that the slope above High Yellow Ski Run was controlled. The control consisted in using hand thrown charges at the top of the face, which triggered a soft snow slab which ran down the track, over the instrumentation before stopping in the runout zone. The slab ran for a vertical distance of 675 feet, leaving a crown fracture of 1 to 1-1/2 feet. The time of the avalanche was 9:00 a.m. This time coincides with the large recorded jump in the A.E. activity. Interestingly, after the passage of the avalanche, the background count remains about 8000 count/hour, compared to 5000 counts/hour prior to the avalanche.

Not all blasting produces avalanches, and where blasting has occurred, it does not show up as an increase in A.E. level, due to the distance the wave guide is from the blast area.

Not all controlled avalanches produce such an excellent correlation. As the depth of snow over the wave guide increases, attenuation of the acoustic emissions with high energy loss occurs, with consequently an increase in preamplification required. This unfortunately also increases the background A.E. signals. Eventually an avalanche cannot be discriminated from the background unless it is within a certain distance from the wave guide.

CONCLUSIONS

Utilization of acoustic emission techniques can show when releases occur, and give insight into snow pack deformation. Comparing the A.E. "instantaneous" counts of 1000 and 500 for the natural releases and about 1800 counts for the controlled slide, the different count levels are probably related to the size of the avalanches. The larger the avalanche, the higher the number of counts. More detailed research is required to confirm this and produce a workable relationship.

The major problem with the technique is determining the frequency to monitor. The higher the frequency, the greater the attenuation, and loss of resolution. Laboratory and field research using an isotropic snow pack to determine optimum frequency for different snow densities and snow deformation modes is required. Wave guide orientation and shape in relation to the A.E. source should be pursued to increase receiver efficiency. Further investigation is needed to determine if A.E. could be a useful and practical tool for snow avalanche prediction.

ACKNOWLEDGMENTS

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