SNOWPACK TEMPERATURE AND DECREASES IN TENSILE STRENGTH

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ABSTRACT. In an effort to understand post-control and other natural avalanches that occur shortly after rain begins or the sun's rays start to warm the starting zone, several experiments were conducted. The use of inexpensive, commercially available data-loggers for in-situ temperature data acquisition and recording is presented. By monitoring the snowpack temperature at various depths we found warming from the sun to reach as deep as 50 cm within hours after the sun's rays reached the slope. At shallower depths the sun's radiation warmed the snowpack (not just the surface) to temperatures well above the air temperature much more rapidly. Under conditions artificially created to simulate rain, the snowpack temperature was found to increase at depths of as much as 20 cm as the rain crust froze on the snow surface above. Finally, by conducting in-situ tensile strength tests on the upper snow layers during simulated rain we found average decreases in snow strength of 15% to 30%. We theorize that a snow slab over an extensive weak shear layer that is being supported mostly by the slab tensile strength could fail as it warms within a brief period of time after the onset of the sun's radiation or a rain event.

KEYWORDS: rain-on-snow, snow temperature, snow strength

BACKGROUND

Snow avalanche forecasting can be divided into two groups. First, the so-called easy forecasting of new snow avalanches, when it snows enough, the avalanche frequency increases. Second, the harder to forecast old snow avalanches. Natural avalanches that occur without an obvious trigger when there has been no new precipitation to increase the load are likely caused by a decrease in snow strength. An avalanche control team might label these as post-control avalanches. At Alta, Utah, we have observed avalanches on East through South and West exposures occurring 10 to 30 minutes after the sun's rays have reached a particular slide path. Several researchers in other locations have reported avalanching within a few minutes after the onset of rain, before enough rain has fallen to increase the loading, or penetrate to the weak layer (Conway, 1996; Heywood, 1988; and many others). During the 1996-1997 season Alta had three rain events; however, because of the change to snow during the storm and lack of direct observations, no avalanching could be directly attributable to the rain. These two conditions, sun and rain, can cause a sudden warming of the snowpack resulting in changes to the mechanical properties. This will alter the stress-strength balance and may create the right conditions for avalanching.

EXPERIMENTS

Initially we wanted to see if we could actually measure a decrease in tensile strength associated with the relatively brief period of time following the onset of rain. The trapezoid tensile test, developed by Rosso, 1986, was chosen for these experiments. An undisturbed snowfield with a 30° to 35° slope was selected for each set of tests. A day with air temperatures near, or slightly above freezing was chosen because we felt it would represent the conditions when rain could occur. Several tensile tests were conducted on the upper 15 to 20 centimeters of the snowpack, without adding any water. Next, tests were conducted by preparing the trapezoid sample and sprinkling water on the snow surface to simulate rain. By comparing the results from these two sets of tests we hoped to establish whether the addition of liquid water not only increased loading but also decreased slab tensile strength.

During January, February and March of 1997 several days of testing resulted in procedures that could yield fairly consistent results. First the

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trapezoid shape was prepared and the saw/support pad positioned without undercutting the sample. Water was sprinkled over the entire surface of the sample during a 3 to 5 minute period. The amount of water was considered significant enough to have a measurable effect, but not so much that it would soak through the entire depth of the test sample. Within the next 5 to 10 minutes the sample was undercut to remove all shear support until tensile failure occurred. A series of density tests were conducted to determine a density profile and load for each test. This included the added water in the "wet" tests. The density profile and the volume calculation were used to determine the amount of weight contributing to the load. We could not establish the added load of the water by recording the amount of water added because water was sprinkled over a larger area than the unpredictable area that finally was included in the failed sample.

Early testing, although somewhat inconsistent, showed a decrease in tensile strength for the wet samples of about 15%. The results of later tests conducted on March 9, 1997 were consistent enough to convince us we had refined our procedures and could be confident of our measurements. They are presented in Table 1. The large range of strengths for the wet tests may be the result of nonuniform density profiles throughout the sample area. To narrow the range of strength measurements for the wet tests the highest and lowest (flyers) were thrown out. These results show a 30% decrease in tensile strength after the application of simulated rain.

Table 1
March 9, 1997 Trapezoid Tensile Tests

Water	Average Density Kg/cu. m	Fracture Area sq. m	Sample Volume cu. m	Tensile Strength N/sq. m	
dry	145	0.054	0.044	678	
dry	145	0.060	0.056	782	
dry	145	0.056	0.042	625	
			Average	695	
			Range	157	
wet	250	0.052	0.017	478	
wet	237	0.080	0.022	380	
wet	237	0.048	0.023	653	
wet	220	0.062	0.038	785	Highest
wet	237	0.066	0.032	670	
wet	225	0.064	0.023	465	
wet	227	0.040	0.014	458	
wet	210	0.080	0.019	293	Lowest
wet	200	0.062	0.021	388	
wet	210	0.060	0.018	362	
			Average	493	
			Range	492	
			Flyers tossed average	482	
			Flyers tossed range	308	

During the spring of 1998 we experimented with snowpack temperature measurements. Programmable temperature probes and data loggers from Onset Computer Corporation* were used. The Hobo Temp model H01-001-01 single

* Onset Computer Corporation, PO Box 3450, Pocasset, MA 02559-3450; tel: 508-759-9500

channel unit stores 1800 data points including date and time for each measurement. The unit is connected to an RS 232 serial data port on a personal computer and programmed using BoxCar software, also from Onset. During programming the data acquisition interval is set from 0.5 seconds to as much as 9 hours. The data acquisition begins as soon as the programming is complete. The Hobo is then disconnected from the computer and placed in the snowpack. When the test is complete, the Hobo is reconnected to the computer and the data is down loaded using the BoxCar software package.

One of our first tests consisted of simply burying three Hobos at depths of 5, 15 and 25 cm. and acquiring data as the morning shadow moved over the test site exposing the snowpack to the sun's radiation. The temperature sensors were inside the plastic Hobo case during this test, slowing the response time and possibly recording temperatures higher than the true snowpack. The Hobo cases may absorb more radiation, and heat up more, than the snow. The graph in Figure 1 shows warming at a depth of 5 cm as soon as the sun hits the snow surface, climbing 7° C in about 20 minutes. Some warming at 15 cm began after about 1.5 hours, climbing about 4° C in the next 1.5 hours. No warming at 25 cm was measured at all during the 3 hour period following first exposure to the sun's rays.

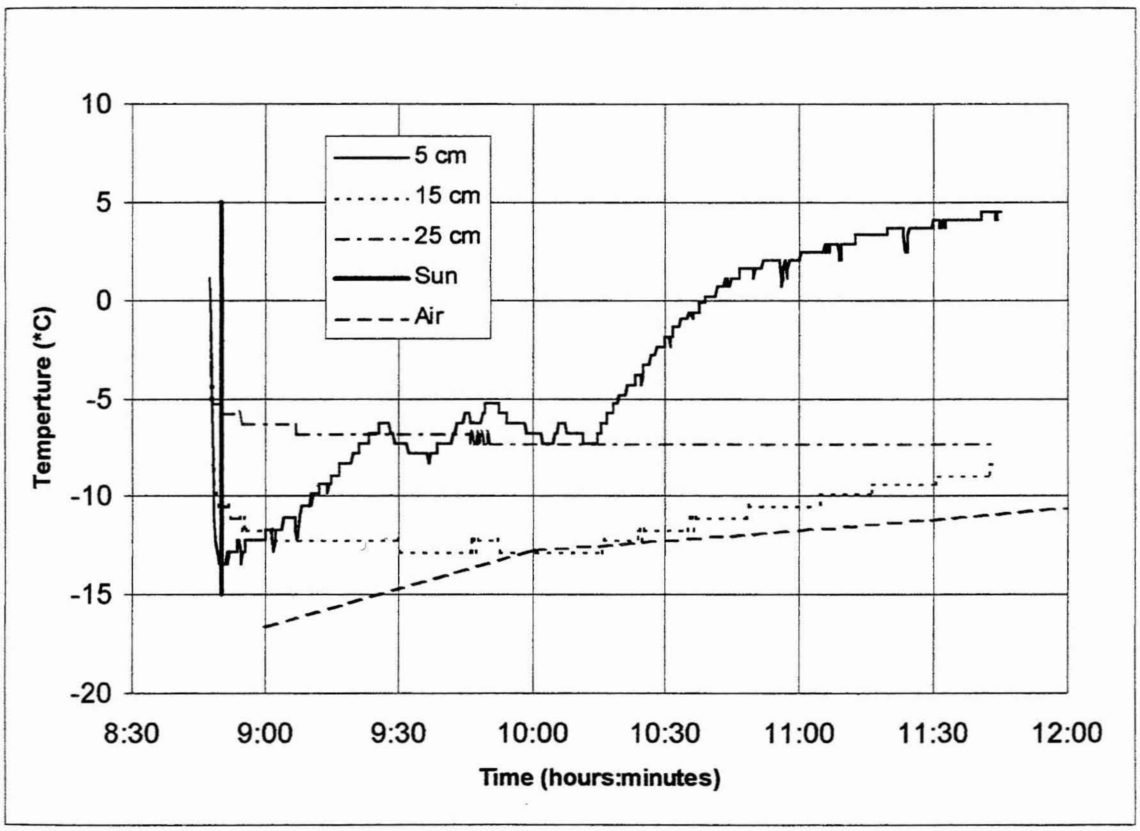

Figure 1. Snowpack exposure at sunrise

We then removed the sensors from inside the plastic cases, but kept them in the plastic bags. This improved the response time, but may not have reduced errors due to different radiation absorption rates. The three Hobo's were placed at the same depths on an East facing slope. The graph in Figure 2 shows a 24 hour period when warming at all three depths occurred as the sun's rays hit the site. Cooling during the clear night was also measured. Recorded temperatures at both 5 and 15 cm depths warmed during the day to temperatures as much as 10° C above the air temperature.

In a test conducted on a South exposure during a warm March period, a sensor 50 cm deep detected a rise of 1° C four hours after the sun first reached the slope. Temperatures on this exposure reached 8° C at a depth of 20 cm at a time when several wet slab avalanche releases were observed in the area.

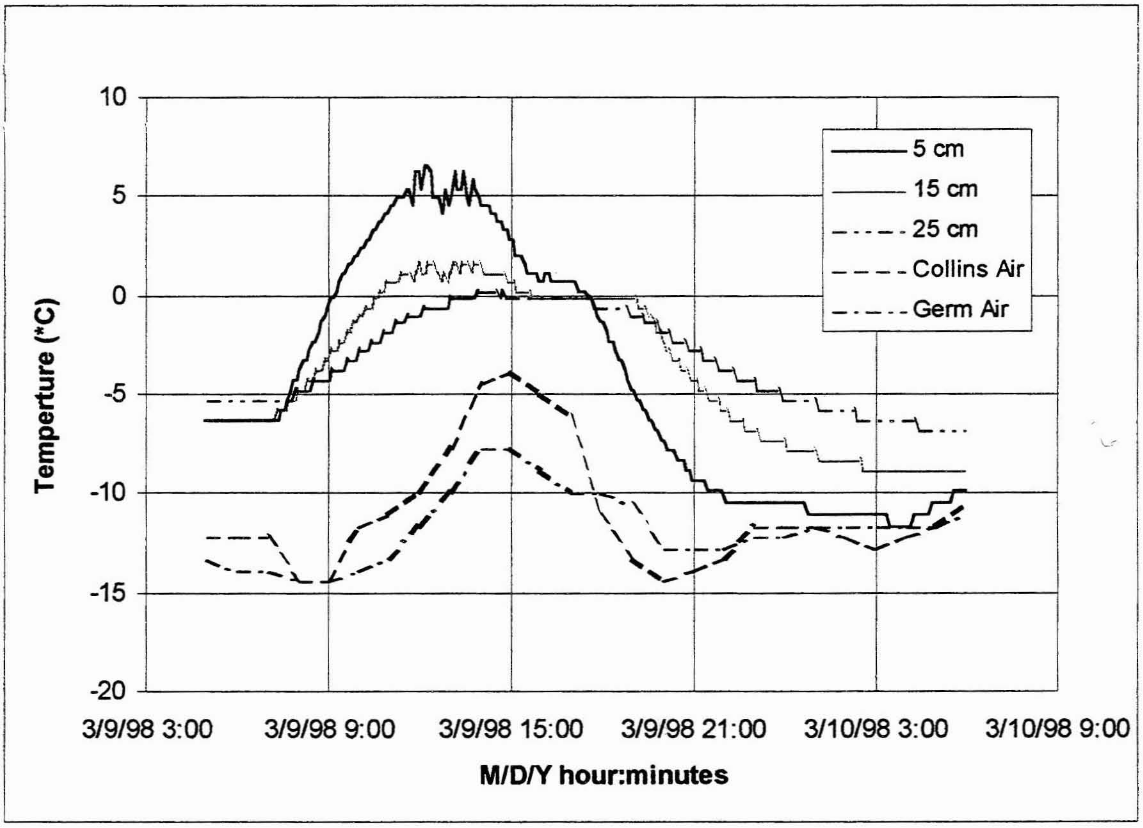

Figure 2. Snowpack and air temperatures on an East exposure.

Next we experimented with snowpack warming due to rain. A shaded location with a north exposure was chosen for each test. A small rectangular area 70 cm by 50 cm was marked off. Two Hobos were placed in different locations within the rectangle and at different depths of 10 and 20 cm. A third Hobo was placed at a depth of 10 cm outside the rectangle as a control sensor. Three liters of water were sprinkled evenly over the rectangle during an 18 minute period, for a total simulated rainfall of 0.86 cm.

We experimented with the Hobo units in several configurations. The best results were obtained by extending the small temperature sensor outside the case fastened to a wooden tongue depressor for support. The case was placed in a plastic bag to protect it from the environment. The results of a simulated rain test conducted with the sensors in this configuration are shown in Figure 3. The quick response of the temperature sensors in this configuration is demonstrated by the steady state reached in a few minutes before the simulated rain is started. Within 10 minutes after the first water application the temperature at 10 cm started to increase. After another 20 minutes the temperature at 10 cm increased over 2° C. At a depth of 20 cm the snowpack also warmed due to the simulated rain. Approximately one hour after the first rain application an increase greater than 1° C was measured. During the two-hour test period the control sensor measured a basically constant temperature. It can be concluded that the increasing temperatures measured under the simulated rain were entirely due to the effects of the water on the snow surface. At the end of the two-hour test period the water had frozen into an ice crust about 1 cm thick.

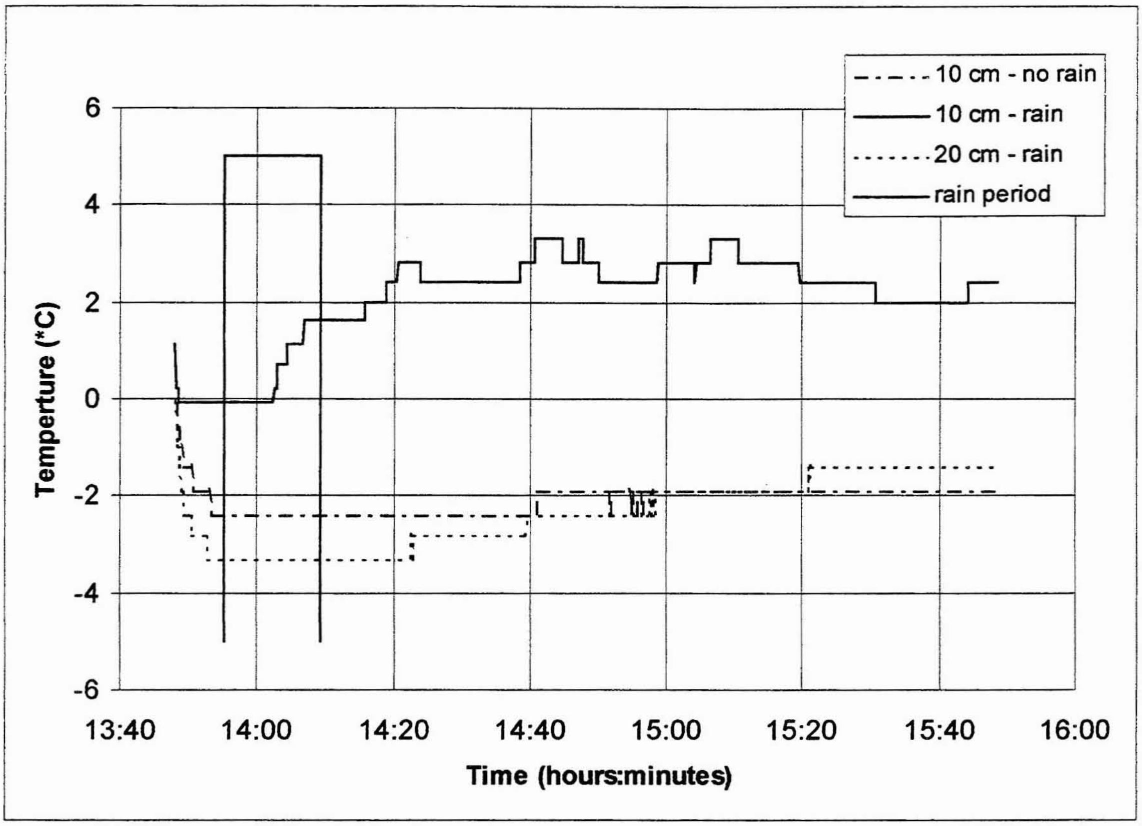

Figure 3. Snowpack temperatures following a simulated rain event.

DISCUSSION

Although the tensile strength data presented is limited and has a relatively large range, we feel our hypothesis of lower tensile strength due to rain on the surface can be supported. The temperature tests show increases in snowpack temperature, at depths well below the depth of any water, due to rain on the surface. This suggests the decrease in tensile strength is caused by increases in temperature due to the liquid water applied to the snow surface. The ice crust formed after the application of water to the snow surface is evidence of snowpack warming caused by the heat of fusion as the water freezes.

The tests to measure snowpack warming by the sun showed the depth of warming in the first hour of exposure to be limited to the top 5 or 10 cm. The mechanical properties of this part of a 30 to 40 cm thick slab can conceivably contribute to the creep rate and total strength of the slab.

Several previous studies support a relationship between snowpack temperatures and avalanche failure. Snowpack deformation, or creep, required before failure is dependent on temperature (Conway, 1996). Temperature also has an important affect on the fracturing of the weak layer (Mc Clung, 1995). Warming the slab causes an increase in creep deformation that can increase shear stress on the weak layer resulting in failure. Much of the previous work has been centered on the shear failure at the weak layer under the slab. Studies of other snowpack mechanical properties have shown an inverse relationship between temperature and snow tensile strength (Voitkovskii, 1987; and Zhidkov, 1992).

Snow avalanches are the result of both shear failure of the weak layer and the tensile failure of the slab itself. The depth of warming during the onset of sun or rain is limited to the upper 10 to 20 cm. For thicker slabs, warming of the weak layer is not a factor. Warming the slab that causes an increase in creep deformation and also decreases the slab tensile strength could certainly be the combination that results in avalanching shortly after the onset of sun or rain.

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