Preliminary Investigations of Glide/Creep Motion Sensors in Alta, Utah

Bob Rice[1], Dan Howlett[2], Rand Decker[1]
[1]Department of Civil Engineering, 3220 MEB University of Utah,Salt Lake City, Utah 84112
[2]Snow Safety, Alta Ski Lift Co. And Chairman, Center for Snow Science at Alta, P.O. Box 8007, Alta, Utah 84092

Key Words: Creep, Glide, Slab Avalanche, Forecasting

ABSTRACT

Creep and glide in an alpine snowpack can lead to snowpack failure including snow avalanching. With a rapid rate of change in creep or glide with respect to time without an increase in snow strength, avalanches may be expected. Deformation in the snowpack by creep and glide are necessary measurements in determining stress in snow slabs. In order to detect in real time the creep and glide in an alpine snowpack, the use of creep/glide sensors are utilized. These sensors are capable of detecting deformation rates and avalanche events. The sensors are connected by hardwire to a multiplexer and a datalogger where real time data are collected on creep and glide motion. This motion deflects the sensors which are fixed within a one meter poly vinyl chloride pipe which is attached to a coaxial spring. The deflections are monitored on two axis. Voltages corresponding to angle of tilts are recorded. These voltages are produced by a solid state accelerometer. Preliminary testing during the winter of 1995-1996 was carried out on Mt. Baldy in Alta, Utah. Valuable lessons were learned during the winter that will be implemented next winter. A number of significant events were captured by the sensors. These events included both the elastic response of the snowpack when explosives resulted in widespread avalanching and the rapid increase in creep rates which preceded avalanching. The cause and effect between successful avalanche control with explosives and corresponding high creep rate events warrant further field investigation. The goal of the project is to improve or optimize avalanche forecasting and control using creep/glide motion sensors.

1. INTRODUCTION

Measuring instabilities in an alpine snowpack have been ongoing for many years by researchers. Evaluating and predicting these changes in slopes have been approached by examining acoustic emissions and various methods of measuring creep and glide. Researchers have concluded that these phenomena indicate the development of instabilities. However, by examining these phenomena in real time, this information could prove invaluable in assisting avalanche forecasters.

During the Winter of 1995/1996 three glide and creep(C&G) sensors where installed on Mt. Baldy in Alta, Utah. These sensors are designed to measure differential creep and glide motion in real time in an alpine snowpack. By monitoring creep and glide in real time, rapid changes in the deformation of the snowpack can signal approaching instabilities and avalanching. The preliminary testing focused on site selection, laboratory calibration and repeatability of the A/D sensor signal, installation, initial snowpack measurements and climatic effects on the instrumentation.

2. METHODS AND PROCEDURES

2.1Objective of the Creep and Glide Sensor

The sensor is designed to measure snow creep and glide characteristics in avalanche starting zones. The sensor is a poly vinyl chloride (PVC) pipe one meter in length. Within the PVC pipe an accelerometer and temperature sensor are fixed to measure the angle of deformation of the sensor and the temperature of the surrounding snowpack. The signals are measured in milliamps. The current is converted to a voltage which is then calibrated over -90 to 0 to +90 degrees angle from vertical in both longitudinal and traverse directions. The deflections are monitored on two axes to detect skew and lateral motions. The sensor is attached to a coaxial steel spring that acts as a return mechanism. The sensor is then threaded onto an 1.27 cm diameter ready rod (all thread) that is fixed to the ground.

Deflections are calculated by:

$$D = h\sin\Theta \quad \textit{Eq. (1)}$$

where:
D=deflection
h=hypotenuse length of 1m
Θ =angle of tilt

Snow movement accelerations are calculated:

$$A = \frac{d^2 D}{dt^2} \quad \textit{Eq. (2)}$$

where:
A=snow movement acceleration
D=deflection
t=time

2.2 Location of Creep and Glide Sensors in Alta

The C&G sensors were installed on Mt. Baldy in Harold's slide path. The starting zone of Harold's is located at an elevation of 3,110 meters with a slope aspect of 40 degrees, a slope steepness of 37 degrees and a length of 122 meters. This slope was chosen because the starting zone is relatively undisturbed by area skiers and could be accessed and monitored frequently. Furthermore, the sensors are in close proximity to high resolution weather data collection sites.

Three C&G sensors were installed in Harold's starting zone. In order to measure the differential creep and glide movements the three sensors were placed at varying heights from the surface of the ground. Sensor #1 was placed at the ground, sensor #2 was placed 1 meter above the ground and sensor #3 was placed two meters above the ground. The ready rods were fixed to the ground and plumb to slope angle. Rod lengths were increased with couplers.

2.3 Calibration of Creep and Glide Sensors

Prior to installing the C&G sensors, the sensors were benched tested and calibrated. The sensors were calibrated, so that a voltage would correspond to a specific angle of tilt. Once seven corresponding angles were known in the x and y directions, and repeatability established, a linear relationship is established to derive the remaining angles of tilt. The linear equation derived for sensor #3 in the x-direction is:

$$y = 0.0054x + 0.1543 \quad \textit{Eq. (3)}$$

where:
y = voltage
x = angle of tilt of sensor

By knowing the voltage produced by the sensor, the angle of tilt of the sensor is derived from Eq. (3). For each of the three sensors a linear equation was derived in both the x and y direction.

2.4 Instrumentation

Once the C&G sensors are in place in the starting zone, the data collection station was installed. The station consisted of a datalogger, multiplexer and 12 volt dc solar power supply. The station and data is accessed by radio telemetry. A solar panel was pointed at 25 degrees aspect due to the terrain and tilted slightly toward the ground so that the energy from the snow reflectivity would charge the battery. A program was downloaded to the datalogger via RF telemetry to monitor the sensors every 15 seconds. Also, capabilities at the site allow for real time monitoring. The program retrieved the maximum and minimum angles and calculated the average over a fifteen minute interval. The sensors were connected to the hardware via 50 meters of cable. Since the sensors were installed in January the cable was laid on the snow surface.

2.5 Data retrieval

The data was downloaded from the datalogger via RF telemetry every week for analysis. During a storm cycle data was downloaded and analyzed more frequently. This allowed examination of snowpack strength and activity on a real time basis.

3. PRELIMINARY RESULTS

The preliminary results obtained from the creep and glide sensors showed promise. The major problem was the installation and operation of the sensors. Since the sensors became operational in late January, sensors #1 and 2 were buried under 2.5 meters of snow. Sensor #3 was the only working sensor once the system was operational. Two important results were obtained from the data. The elastic response of the snowpack to explosives and the increase in creep rates due to loading were recorded that preceded widespread avalanching.

On February 20, 1996 an explosive charge (2kg / PETN) tied to a bamboo pole was detonated 1 meter above the new snow surface to create an airblast in Harold's slide path at 1200 hours. The elastic response of the snowpack due to the explosive charge was captured by the C&G sensors. This is evident with an increase in creep rate or deflection of the sensor. This rapid increase was followed

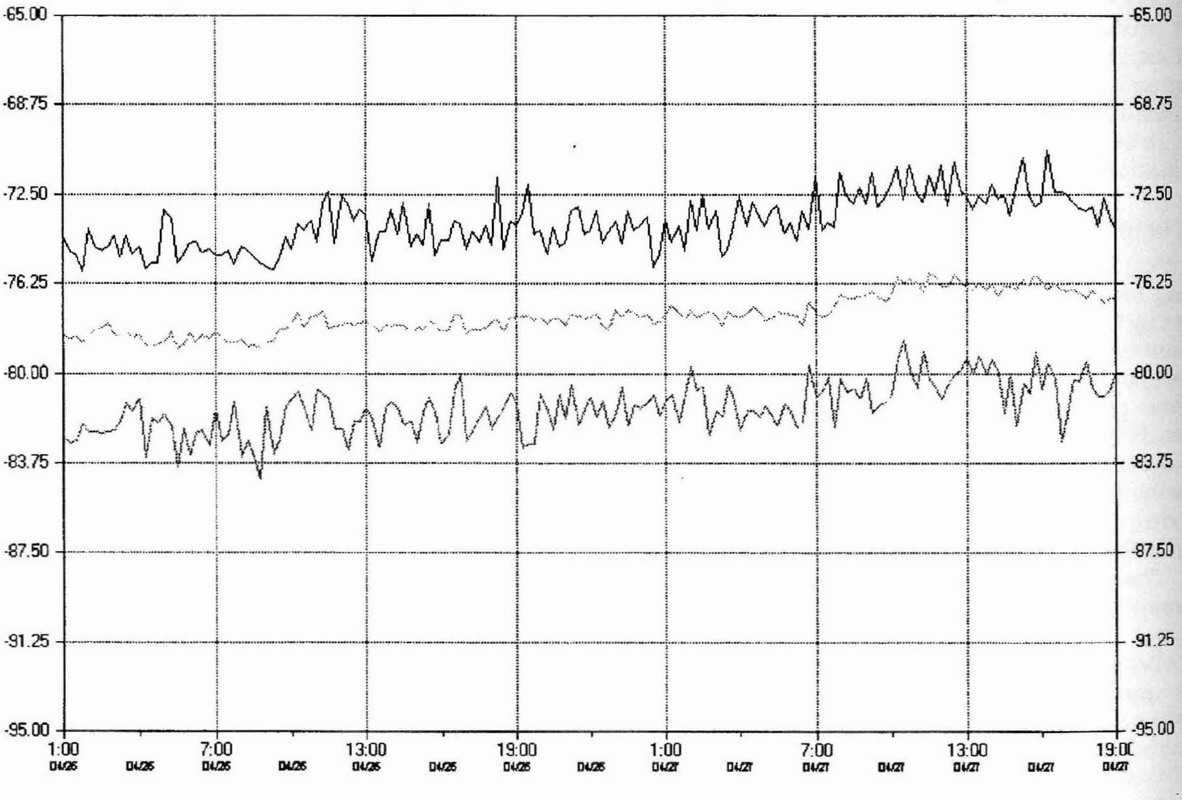

Figure 1. Probe #1 reflecting no creep movement.

by a slow stabilization of the snow. This is evident by the angle of the sensor moving back toward normal. In starting zones adjacent to Harold's slide path, control routes reported the same results. All avalanche activity was confined to the new snow within the ski resorts boundaries.

On February 22, 1996, during a significant storm event, the precipitation intensity increased and widespread natural snow avalanching occurred. During this period an avalanche released from White Pine #3 and crossed Highway 210. White Pine #3 starting zone is located at an elevation of 3,000 meters with a slope aspect of 90 degrees and a slope steepness of 37 degrees. This avalanche path is located 2,560 meters from the C&G sensors. The C&G sensors during this period of increased activity, indicted a rapid increase in creep rates. The creep rate spiked at about the time White Pine #3 crossed the highway.

In April sensor #3 was excavated and examined. RECCO Avalanche Rescue Reflectors were attached to the sensors prior to field installation. These reflectors were used to locate the sensors. Sensor #3 was found parallel to the slope. The force of the gliding snow bent the ready rod to and angle of 40 degrees. The coaxial steel spring was damaged. Once the pressure around the ready rod and sensor were released the steel spring was bent at an angle of 15 degrees. Also, the tension in the wiring caused by the gliding snow created a downslope force on the sensor and ready rod. This tension contributed to a moment about the sensor and ready rod.

DISCUSSION AND CONCLUSION

4.1 Storm Data

The data presented represents significant highlights during the winter of 1995-1996. The winter of 1995-1996 began slowly with no significant snowfall till after the first of the year. The sensors were not operational till after the first two significant storm cycles. At this time, the snowpack at Harold's slidepath was 200 cm in depth. This completely buried sensors # 1 and 2 and left sensor #3 able to record surface movements in the snowpack. There was no deep slab avalanche in the slidepath after installation.

The eighth storm of the year arrived on February 19, 1996. Between 0400 hours on February 19 and 0400 February 20 the Collins snow study plot at an elevation of 2,990 meters had received 53 cm of snow with 5.91 cm of water (11% density). The winds were from the Northwest at 51 km/hr. During this storm cycle the tilt sensors were monitored.

4.2 Sensor Data Results and Discussion

Sensors #1 and 2 indicated little to no movement in the

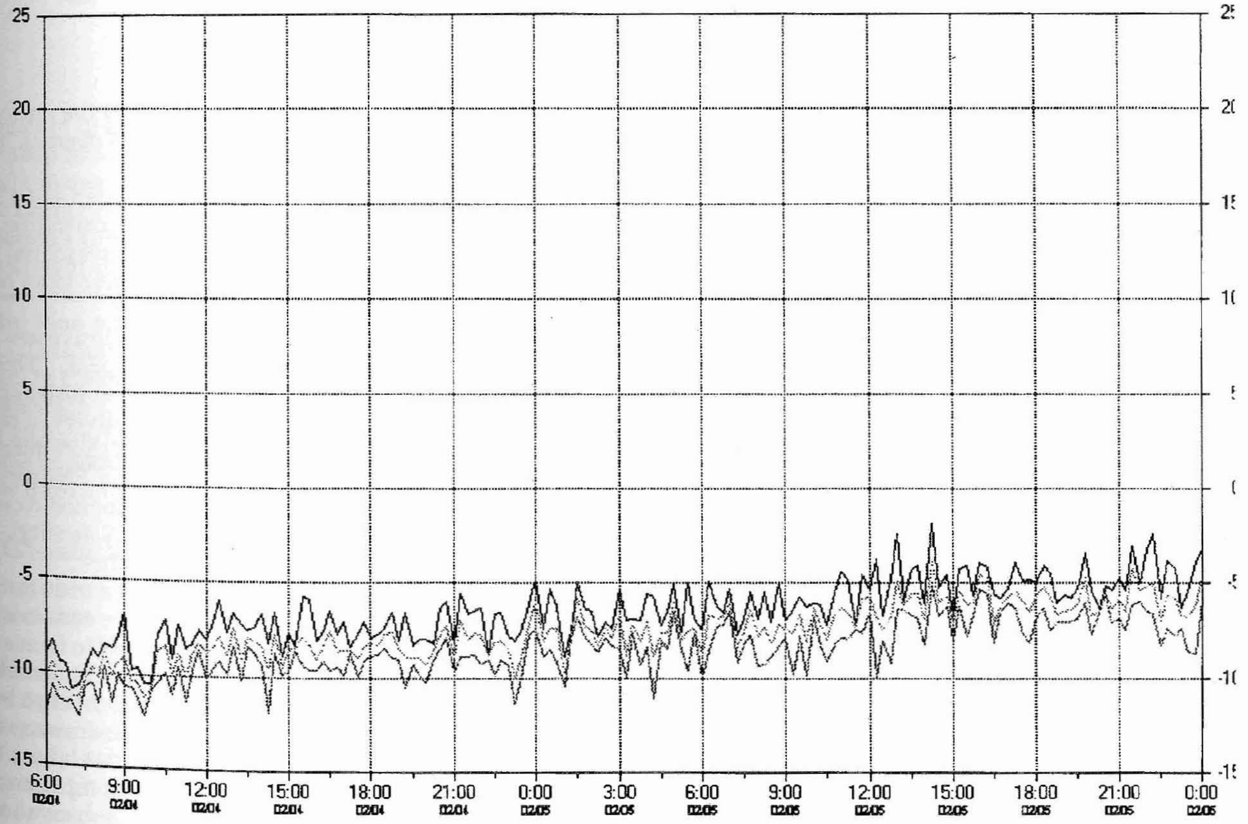

Figure 2. Probe #2 reflecting no creep movement.

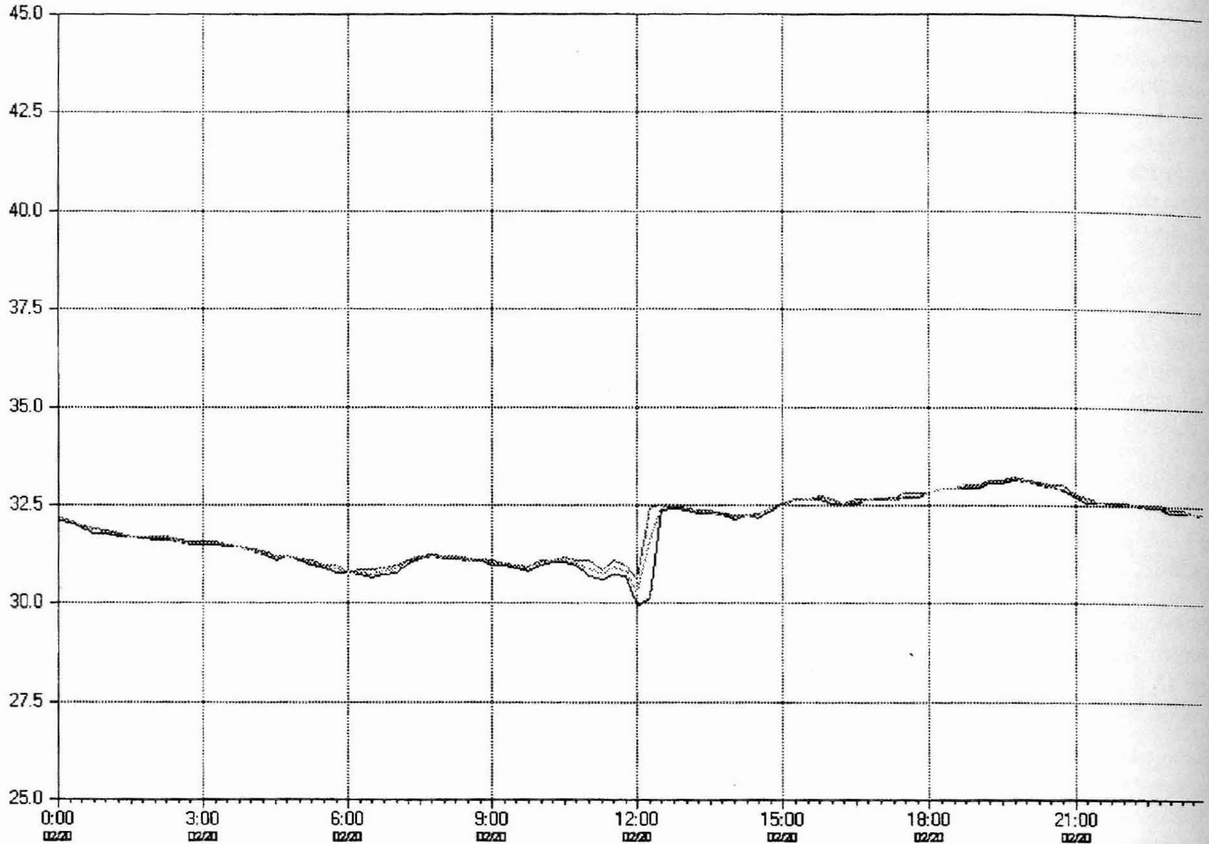

Figure 3. Accelerated creep in probe #3.

snowpack. It is believed that those sensors were deflected beyond the 90 degree range and were parallel to the slope. This extreme deflection would cause any movement of the snow to creep or glide over the sensors. Therefore, no measurements are considered valid in lower sections of the snowpack. Figures 1 and 2, which represents Sensor #1 and 2 respectively, indicate no movement. The negative angles that are shown in the figures represent a deflection greater than 90 degrees. This is possible due to the sensors being mounted plum to the slope.

Though problems were evident in sensors #1 and 2, sensor #3 produced the following data at a higher confidence level. Sensor # 3 monitors the snowpack in the top meter of the snowpack. As the storm progressed sensor #3 showed little movement. The sensor was bent at an angle of 35 degrees (2 degrees less than perpendicular to the slope) and began to decline at a slow rate until 30 degrees. This tends to indicate that the stress in the snowpack was declining during the storm. At about 1130 hours an avalanche control team began progressing out to stabilize the slidepath's around Mt. Baldy. At 1200 hours a explosive charge (2 kg / PETN) tied to a bamboo pole was detonated 1 meter above the new snow surface to create an airblast. This explosive created a class 2 avalanche with an crown depth of 46 cm, width of 254 cm and ran 10 m. This indicated some instability within the new snow.

At the time the explosive was detonated the creep rate accelerated in sensor #3. At 1200 hours the sensor was bent at an angle of 30 degrees and at 1215 the angle was 32.5 degrees. The sensor stabilized at 32.5 degrees. Refer to Figure 3.

From equation 1 the deflection was calculated as 4.12 cm. Using equation 2 the snow movement acceleration was 7.32 cm/hr^2. Over the next 18 hours the sensor moved back to an angle of 30 degrees. This corresponds to an acceleration of $1.35\text{x}10^{-2}$ cm/hr^2.

The accelerated creep rate from the explosive was a result of the elastic response in the snowpack. This increased creep rate after the delivery of the explosive charge could signal a weaker snowpack. The delivery of an explosive could weaken the snowpack for a short duration.

The ninth storm of the year arrived on February 22, 1996. By 1100 hours the Collins study plot had received 45.7 cm of snow with 3.38 cm of water (7% density). The winds were from the northwest at 41 cm/hr^2 .

The heaviest intensity occurred between 0100 through 1500 hours. During the storm cycle sensor #3 was monitored. Figure 4 shows the creep rate began to increase at 0000 hours. As the intensity of the snowfall increased at 0600 hours the creep rate also accelerated. At 0615 hours the creep rate accelerated dramatically. Increasing from 33 degrees at 0615 hours to 34 degrees at 0945 hours. This relates to a snow movement acceleration of 0.124 cm/hr^2.

Over the next hour and half the C&G sensor showed the snowpack stabilizing as the angle of tilt was decreased to 31 degrees. This decline in the creep rate correlates to

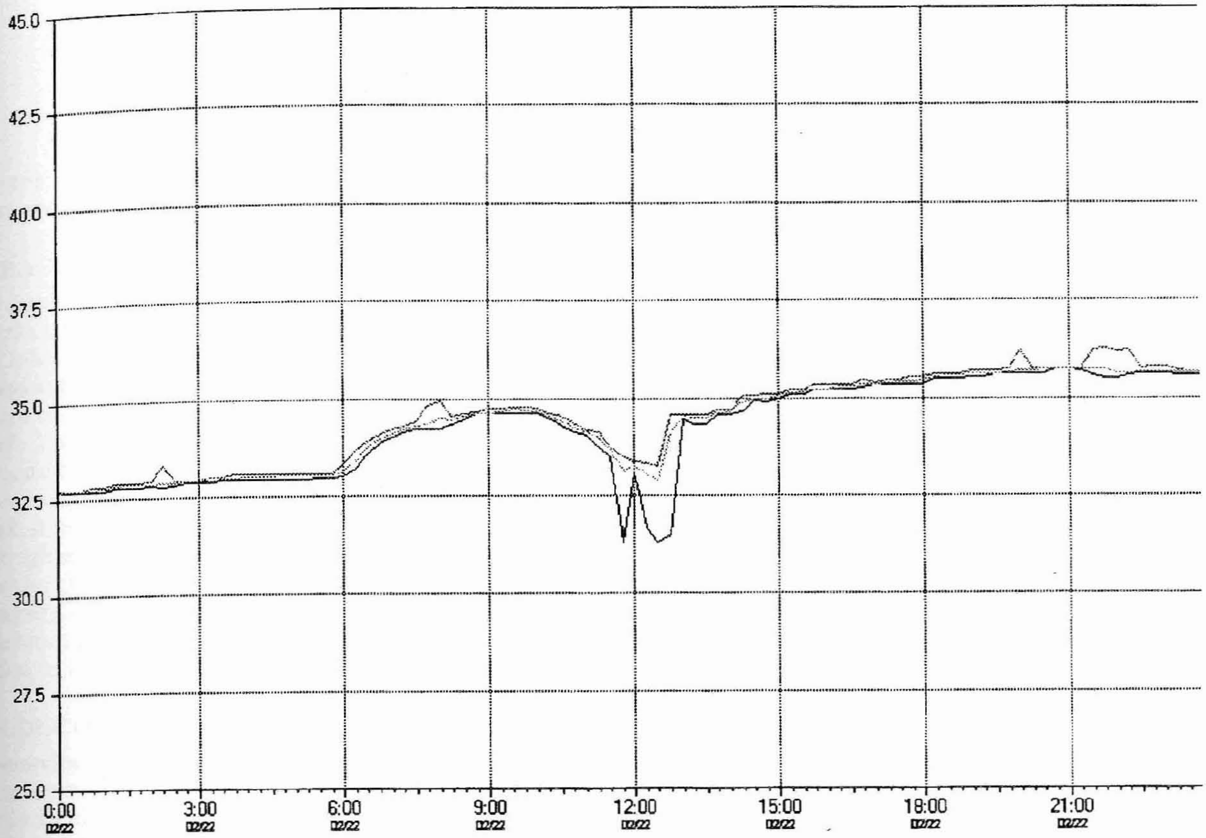

Figure 4. Accelerated creep rates.

a decrease in snowfall intensity. However, at 1145 hours the creep rate accelerated to 35 degrees at 1215 hours and slowly increased to 36 degrees at 2200 hours.

This storm cycle produced no natural or artificial releases at Harold's slidepath. An early morning shoot by the Utah Department of Transportation produced small sluffs on the south facing avalanche paths. However, at 1145 hours White Pine #3 naturally released and crossed Highway 210. This natural release corresponded to the rapid increase in creep rates at 1145 hours. The snow movement acceleration for the period between 1145 and 1215 hours was 20.8 cm/hr^2. Potentially, this rapid rise in creep rate relates to possible widespread instability within the new snow during this storm.

4.3 Climatic Effects on Instruments

During the winter of 1995-1996 valuable lesson were learned that could lead to more accurate and viable data collection. The creep and glide of the snowpack had a profound effect on the ready rods, sensors and wiring.

In April sensor #3 was excavated and examined. The sensor was bent at an angle of 135 degrees from plumb. The ready rod was bent at an angle of 45 degrees. The snow was gliding around the sensor. Since the sensor was bent beyond 90 degrees, readings on snowpack creep and glide were invalid. The condition of sensor # 3 lead to low confidence in the data received from sensors #1 and 2. Also, apparent was the tension that built up on the wires that ran up hill to the datalogger. The tension from the wires pulled downhill on sensor #3 and could be a cause of some deflection in the sensors. By April the depth of snow in Harold's was over 4 meters. Based on the examination of sensor #3, this depth of snow rendered the sensors useless for the remainder of the winter. The snowpack was hard, cold and deep.

4.4 Modifications to Instrumentation

For the winter of 1996-1997 a few changes will be implemented to avoid the aforementioned problems. In order to prevent the ready rods from bending under the pressure of creep and glide, angle irons will be welded on the uphill side of the ready rods. This should prevent any bending of the mounting equipment. The wires that run from the instrumentation downhill to the sensors will be buried underground. These alterations will allow the sensor to make readings that are solely based on the angle of the sensor not both the ready rod and the sensor.

Location of the sensors is under review. The current site at Alta provides a good location. However, other sites may provide better conditions for the project. A site with a shallower snowpack would assure creep and glide readings throughout most of the winter.

4.5 Summary

It is an eventual goal to use this sensor as a tool for avalanche forecasting. This sensor could aid the forecaster in determining the stability of the snowpack during rapid loading. Also, it is a hope that these sensors will be able to capture an avalanche event. This should be evident when the avalanche releases and the data will record the sensor moving back to a zero angle of tilt. Another primary goal is to capture a deep old snow avalanche that is induced by the loading of new snow. This could hopefully lead to the detection of the failure plane within these slabs.

The 1995-1996 data sets are inconclusive and no absolute conclusions can be drawn from this first winter of research.

ACKNOWLEDGMENT

The authors would like to extend its gratitude to Alta Ski Lift Company and the Center for Snow Science at Alta. Their generous support for providing the facilities and equipment has made this project possible.

REFERENCES

Brown, C.B., R.J. Evans and D. McClung. The incorporation of glide and creep measurements into snow slab mechanics, Unpublished.

Clarke, J.A. and D.M. McClung, 1994. Correlation of fast rates of snow glide with full-depth avalanche occurrence. Proceedings of the International Snow Science Workshop in Snowbird, Utah, October 30 - November 3, 1994, ISSW '94 P.O. Box 49, Snowbird, Utah 84092 USA, p. 405-407.

Gubler, H., 1979. Acoustic emission as an indication of stability decrease in fracture zones, Journal of Glaciology, Vol. 22, No.86, p.186-188.

Peal, R.I., 1972. Generalization of Haefeli's creep-angle analysis, Journal of Glaciology, Vol. 11, No. 63, p.447-450.

St. Lawrence, W.F., 1980. The acoustic emission response of snow, Journal of Glaciology, Vol. 26, No. 94, p. 209-216.

Sommerfeld, R.A., 1977. Preliminary observations of acoustic emissions preceding avalanches, Journal of Glaciology, Vol. 19, No. 81, p. 399-409.

Sommerfeld, R.A.,1975. Continuous measurements of deformations on avalanche slopes, Proceedings of the Grindelwald Symposium, April 1974.

Walker, Walter, 1994. Snow creep movement in the San Juan Mountain snowpack Red Mountain Pass. Proceedings of the International Snow Science Workshop in Snowbird, Utah, October 30 - November 3, 1994, ISSW '94 P.O. Box 49, Snowbird, Utah 84092 USA, p. 408-413.