Melt-Induced Deformation in an Isothermal Snowpack

Simon A. Trautman[1], Stephan G. Custer[1], Karl W. Birkeland [1,2]

[1]Dept. of Earth Sciences, Montana State University, Bozeman, MT 59717 USA

[2]U.S. Forest Service National Avalanche Center, P.O. Box 130, Bozeman, MT 59771 USA

Contact: simont@montana.edu

1. Abstract

Bridger Bowl Ski Area outside of Bozeman, MT, USA, has encountered annual problems forecasting large, wet loose avalanches that occur during warming events in the spring. These avalanches terminate within the ski area boundary and create a potential hazard to skiers and equipment alike. A study is being conducted at Montana State University in order to further understand wet snow processes the Intermountain Climate Zone and their relation to melt-induced avalanche activity. We believe that creep plays a significant role in wet-loose avalanche events. This poster discusses methods employed in the documentation of creep in the Bridger Range, as well as the timing and rate of deformation in March and April of 2004.

During the spring of 2003, sawdust filled boreholes showed accelerated down-slope movement near the surface of the snowpack. The depth of accelerated motion was similar to the depth of melt-water accumulation and surficial instability. In March of 2004 we used an array of string potentiometers in an attempt to quantitatively document creep during melt events. Preliminary results show snow moving differentially at three levels in the snowpack, with the highest velocities being near the surface, and the lowest being near the ground. The maximum velocity logged throughout the period is ~1.0 cm/day, while glide rates ranged from 0 to 3mm/day. Borehole excavations show that in an isothermal snowpack, surficial melt layers deform at rates higher than in underlying snow and that stratigraphic boundaries such as ice layers can control local rates of deformation.

2. Background

Although warm days and above freezing nights are good indicators of wet snow instability, it is very difficult to determine the timing and size of melt-induced wet avalanches. Wet snow does not respond well to explosive testing and due to the dynamic nature of snow affected by liquid water, instabilities may be transient in nature and require a significant time commitment by patrol personnel.

The strength of wet snow depends on snow structure, stratigraphy, and water content. Certain layers may concentrate, or inhibit, water movement throughout the pack, allowing for a different metamorphic history and overall strength between layers.

Goals:

- Build a device that can quantitatively document creep in a melting snowpack
- Determine if layers with significant melt-water accumulation cause differential creep
- Determine if increased surficial creep rates precede wet-loose avalanche activity

3. Study Site / Experimental Setup

Figure 1. Creep monitoring equipment was set up adjacent to Bradley Meadows just north of Bridger Bowl Ski Area outside Bozeman, Montana. The study site is south-east facing and has a slope of 34 degrees.

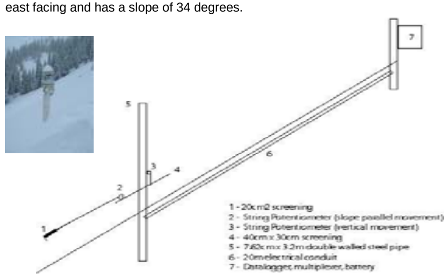


Figure 2. Experimental setup used to monitor creep at the South Bradley study site in March of 2004. String potentiometers were configured to track vertical and horizontal components. Readings were taken at 15 minute intervals for the period of the study. Three pairs of sensors were placed at different levels within the snowpack prior to the melt event depicted. Sensor 1 was located at the ground-snow interface and measured snowpack glide. Sensors 2 and 3 began measurements at 61 cm and 100 cm from the ground respectively. Settlement was not measured independently during this period.

Figure 3. Vertical boreholes were used to document snowpack deformation during April of 2004. Holes were placed in groups of three, 1 meter apart, and perpendicular to the fall-line of a 30-degree slope. They were set using a vertical avalanche probe and filled with 8mm nylon utility cord. Boreholes were placed April 13th, and excavated April 16th, 19th, and 23rd. Deformation was determined by aligning a vertical probe with the ground-borehole interface and measuring the perpendicular distance from the probe to the center of the 8mm cord.

4. Electronic Results

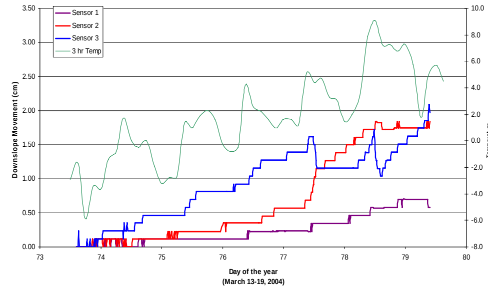


Figure 4. Graphical representation of creep March 13 – 19, 2004. Creep rates increase as temperature increases. The upper layers of the snowpack respond to increased temperature more rapidly than underlying layers. On days 77 and 78 there is apparent upslope motion (slip) in sensor 3 resulting from the ability of the potentiometer spring to overcome the shear strength of snow near the surface.

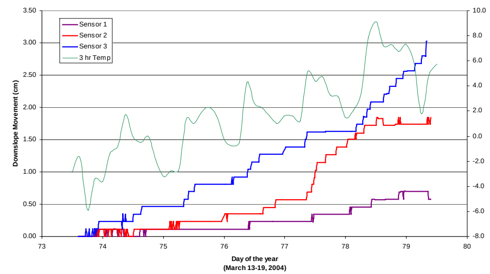


Figure 5. Creep March 13 -19, 2004 corrected for slip in sensor 3. The onset of movement shown by sensor 3 (snow surface) corresponds very well to warming temperatures.

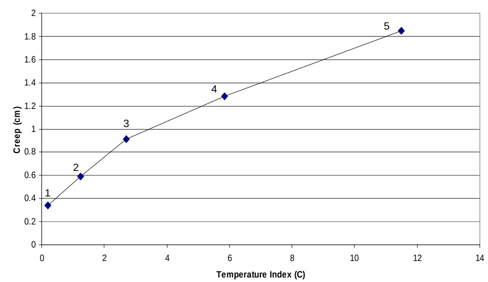
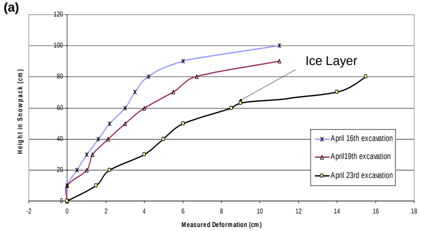


Figure 6. Total creep per day vs. a calculated temperature index (cumulative daily average of temps above 0°C) shows a relationship between cumulative heating and overall snowpack deformation. However, the correction depicted in the previous graph is illustrated by the change in slope at point three. The correction may underestimate creep occurring on days 77 and 78 by assuming periods of no movement during slip in sensor 3. A more accurate representation would probably show a steeper slope between points three, four, and five.

5. Borehole Results

Figure 7. Borehole excavations April 16th, 19th, and 23rd. The April 23rd excavation suggests significantly higher creep (or possible glide) rates immediately above a pervasive ice layer (63cm), the upper surface of which was ponding a significant amount of free water.

(a)



(b)

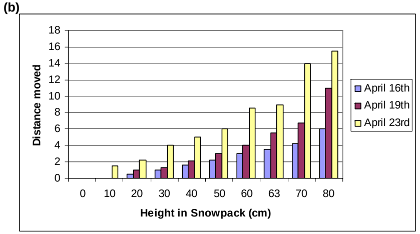


Figure 8. (a,b) Results from borehole excavations on April 16th, 19th, and 23rd; excavations show that surficial melt layers deform at higher rates than underlying snow and highlight the structural control stratigraphy plays in snowpack deformation. Graphical depiction does not reflect actual creep, but a representative measurement described in Figure 3.

6. Acknowledgements

The American Alpine Club

american avalanche association

Friends of the Gallatin National Forest Avalanche Center

UniMeasure — Linear Position Transducers —

Special Thanks to Howard Conway at the University of Washington for lending equipment and advice.

Thanks to Spencer Logan, Eric Lutz, Kalle Kronholm, Chris Lundy, Ladean McKittrick, Hayes Buxton, Andy Toth, and Mark Schaefer.