ASSOCIATIONS BETWEEN SHEAR STRENGTH OF A BURIED SURFACE HOAR LAYER AND STRATIGRAPHIC, TOPOGRAPHIC AND VEGETATION CHARACTERISTICS ON A "UNIFORM" SLOPE

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EXTENDED ABSTRACT

In this study we quantify 1) changes in spatial and aspatial characteristics of the shear strength of a buried surface hoar layer, and 2) identify characteristics in terrain, vegetation and snow stratigraphy that can help clarify some of the variation in shear strength. The study site is a relatively uniform 31 m by 31 m slope in southwest Montana. A local coordinate system linked terrain, vegetation and snow information.

We generated a sub-meter (0.5 m) resolution terrain models from over 2000 total station elevation points collected in summer and autumn of 2005. A vegetation surface model was generated from total station and inclinometer measurements acquired during summer 2006. All trees within 30 meter proximity of the field site were modeled based on tree locations, heights, crown diameters, and crown forms. An ArcInfo-based geographic information system was developed to use these models to estimate spatial variations in environmental conditions that may influence surface hoar growth and preservation. Since re-radiation from trees may hinder surface cooling and associated surface hoar growth, the percent unobstructed sky exposure and its counterpart (the percent sky obstructed by trees) was calculated for all observation locations on the slope. Since sun exposure and intensity affect surface hoar growth and preservation, the daily sunlight exposure time and maximum intensity was estimated for clear days during the surface hoar growth period. This was done by calculating 1) the shading effects of trees and terrain and 2) the three-dimensional angle of incidence of in-coming solar radiation accounting for sun trajectory and terrain geometry.

We collected shear strength and snow structure data during five sampling days over a three week period during the 2004-2005 winter. Over 350 shear strength measurements quantify the strength changes of a buried surface hoar layer. More than 800 SnowMicroPen (SMP) and probe measurements track changes in a number of stratigraphic variables. Two main signal criteria were used to manually delineate the weak layer in SMP profiles: 1) the load and fracture signature typical of large hoar crystals interacting with the sensor tip (Johnson and Schneebeli, 1998), 2) a flat line signal indicative of air pockets, typically between large hoar crystals. Since the adjacent layers were composed of closely-spaced small facets which produce smaller and more frequent loads in resistance signals, the above criteria could be safely assumed. The hardness of the weak layer and the adjacent layers was analyzed using summary statistics of central tendency and spread. Special interest was given to the 5mm segment directly above the weak layer, the stratigraphic location where the base of the shear frame was located.

Plot 1, spanning the entire slope, was examined for cross-slope and up-slope trends at initial conditions. Shear strength decreased significantly in the up-slope direction, with the

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strongest values at the base of the slope ($p = 0.007$, $r^2 = 0.18$). Weak layer thickness increased significantly in the up-slope direction, with the thinnest dimensions at the base of the slope ($p < 0.001$, $r^2 = 0.40$). This indicates that at initial conditions an inverse relationship existed between weak layer thickness and shear strength. When coupled with adjacent shear frame measurements, weak layer thickness observations account for 16% of the variation in shear strength ($p = 0.014$). Significant ($p < 0.0001$) relationships exist between the modeled environmental variables and weak layer thickness and shear strength. Most notably, at plot 1 the estimated daily sunlight exposure time model explains 41 % of the variation in weak layer thickness and 18% of the variation in shear strength.

On the four remaining sampling days, shear strength increased significantly ($p <= 0.05$). While strengthening definitely occurred, it would be imprudent to view this strengthening as purely a temporal phenomenon. Variations in environmental variables and weak layer thickness values from plot 1 indicate that at initial conditions the weak layer was likely thinner in the lower plots (plots 2 and 5) than it was in the upper plots (plots 3 and 4). Hence, instead of viewing plots 2 through 5 as points-in-time that describe a temporal process on a uniform slope, we analyze changes between the lower plots separately from those identified between the upper plots. Although this limits the temporal analysis, it reduces the likelihood for false interpretation of the strengthening process.

In both the upper and lower slope comparisons significant increases in shear strength are accompanied by increases in microstructural snow hardness at the base of shear frame. Interestingly, the thickest weak layer was observed in the locations where the modeled environmental variables indicated surface hoar growth and preservation would be greatest; i.e. where the sun exposure and intensity was at a minimum and the unobstructed sky exposure was near its maximum. Conversely, the weak layer was thinnest where sun exposure was greater and down-slope trees obstructed nearly 40 % of the sky exposure.

These findings demonstrate the variability that exists in environmental and snowpack characteristics on so-called “uniform” slopes. These findings suggest that at a given point in time, a portion of the variation in weak layer structure and strength across a slope may be estimated on hand predefinable environmental variables. For practitioners and recreationalists, this type of modeling may prove useful for identifying and visualizing potential weak spots or zones on slopes. Such models are largely limited by the selected environmental variables. Future work may improve such models by integrating meteorological and atmospheric variables and by identifying such associations with other types of weak layers.

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