AVALANCHE SCIENCE

Investigating the Relationship between Slab Hardness and the Stuffblock Stability Test

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Author's note: The American Avalanche Association generously provided financial support for the completion of this MS research at Colorado State University through their Graduate Grant program. Much of this work was presented at the 2002 ISSW (Kozak et al. 2002) and more of it is contained in an article currently under review (Kozak et al., submitted). This short article provides some additional information about my research.

In the winter of 1999-2000 at Jackson Hole Mountain Resort, we investigated the relationship between slab hardness and the stuffblock stability test (Birkeland et al., 1996) as an index of skier triggering. The research was based on the hypothesis that, if slab hardness is related to stability, a positive relationship should exist between slab hardness and the stuffblock stability test.

Schweizer (1993) found that slab thickness, slab hardness, and the layering within the slab to be the primary slab properties affecting skier triggering. Hardness, which is defined as the initial resistance to deformation per square unit area, controls how deformation results in a layer (McClung and Schweizer, 1996; McClung and Schweizer, 1999). Failure occurs when deformation, resulting from a load to the snowpack causes the weak layer below the slab to initially fail in shear. If the deformation occurs at a rate fast enough to provoke fracture, the slab can separate from the snowpack and avalanche down the hill (Gubler and Bader, 1989).

The stuffblock stability test provided two functions in this research: 1) to be a quantifiable load to the snowpack in the form of a stability test and 2) to define slab boundaries. A failure in the weak layer anywhere within the isolated column from a drop height of 40 cm or less defined the slab boundary. The 40-cm drop height was used for the maximum drop height to determine slab boundaries since the 50-cm stuffblock drop, the next highest drop height for the test, is not typically associated with skier-triggered slab release (Birkeland et al., 1996).

Using a ram penetrometer at north, south, east, and west study sites between January 1 and March 14, 2000, we obtained hardness profiles of the snowpack. Because of the influence of incoming shortwave radiation on snowpack structure, we compared the relationship between hardness and the stuffblock stability by aspect (Kozak, 2002). Once slab boundaries were determined with the stuffblock stability test, a weighted-value of hardness was determined for each slab.

We used simple linear regression analyses to predict stuffblock stability test results based on slab hardness. In theory, these models would allow a field worker to measure slab hardness and estimate the stuffblock drop height (or rather a stability index) associated with the hardness of that particular slab. We analyzed data from all aspects separately to determine whether results were influenced by aspect. Logarithmic transformations were also performed on the slab hardness data in order to normalize and improve the linear fit of the data. Table 1 provides descriptive statistics to further describe the hardness data.

The trend on all aspects was that as slab hardness increased, stuffblock drop height also increased. The most successful model using the log of slab hardness to predict stuffblock stability test drop height occurred on the north aspect. The models that described the relationship between the log of slab hardness and stuffblock drop height for the west and east aspects were also significant and similar. The south model explained the least amount of variability among all the models (Table 2).

hardness	range	mean	standard deviation
R_{SOUTH}	1 to 144	21	28.0
R_{NORTH}	1 to 33	6	6.5
R_{EAST}	1 to 73	11	14.0
R_{WEST}	1 to 77	14	17.8

Table 1. Summary statistics for slab hardness on south, north, east, and west aspects. R is in N

aspect	R^2	p-value	n
south	0.40	< 0.0005	85
north	0.64	< 0.0005	58
east	0.50	< 0.0005	59
west	0.49	< 0.0005	36

Table 2. A summary, by aspect, of the model results for predicting stuffblock drop height using slab hardness.

drop height					
aspect	0 cm	10 cm	20 cm	30 cm	40 cm
south	2	7	13	21	42
north	2	2	6	6	12
east	2	5	5	9	18
west	2	5	6	17	29

Table 3. Mean slab hardness associated stuffblock test drop heights on south, north, east, and west aspects. Slab hardness is in N.

Although a reasonably strong relationship (R^2 of 0.64) exists between slab hardness and the stuffblock stability test on the north aspect, slab hardness cannot be as successfully predicted on the other three aspects for one of two possible reasons: stability is a combination of factors that are not entirely tested by the stuffblock stability test or stability is related to a number of factors, not just slab hardness. Results from this research suggest that the influence of incoming shortwave radiation--the major energy balance difference between aspects (Kozak, 2002)--on slab development creates greater heterogeneity and, therefore, complexity within the snowpack. Incoming shortwave radiation tends to complicate slab development with the formation of melt-freeze crusts and the development of near-surface facets above these crusts on south and east aspects. Heterogeneity was even more pronounced on the south aspect in comparison to the east. According to calculated incoming shortwave radiation results, the south aspect also received considerably more incoming shortwave radiation than the east aspect, particularly early in the study period (Kozak, 2002).

The east and west results fall between those of the north and south. These results may, in part, represent the transition of the influence of incoming shortwave radiation between north and south aspects. Despite the fact that the west aspect (faced slightly northwest) did not receive as much incoming shortwave radiation as the east aspect and did not experience the same melt-freeze crusts, it displayed greater heterogeneity than the north aspect. We hypothesize that this heterogeneity results from high wind speeds that often occurred at the west study site.

We also performed a one-way analysis of variance on the stuffblock test results and the log of slab hardness in order to determine the mean slab hardness associated with each 10 cm interval drop height per aspect. The results for the south, north, east, and west aspects are summarized in Table 3 and in Figure 1.

Without knowing more about the strength of the weak layer, it is difficult to explain why the mean slab hardness values are so different for a given drop height between the south and north aspects. The values for the north and south average hardness were regressed and plotted against each other to further understand the relationship between the two aspects (Figure 2). The resulting model is: $R_S = 3.49R_N - 2.34$ (1) where R_S represents slab hardness on the south aspect and R_N represents slab hardness on the north aspect. This model has a R^2 of 0.97 with an associated p-value = 0.003, although these results should be viewed cautiously since the sample size is small (n=5).

On average, the slabs on the south aspect are 2.8 times harder than slabs on the north aspect, yet they have the same stability rating (Figure 2). While it is difficult to make any assumptions without weak layer data, we speculate that the two have the same rating because stability is a combination of slab and weak layer strength. It is possible that weak layers on the south aspect are weaker than weak layers on the north aspect. It is also possible that the difference in hardness between the weak layer and the slab is more important than the absolute strength of the weak layer. Schweizer and Camponovo (2001) found that fracture propagation becomes more likely as the difference in stiffness between the slab and the weak layer increases.

The stratigraphic profiles for the south and north aspects were distinctly different. The profile on the south aspect tended to be more heterogeneous than the profile on the north aspect. The south aspect possessed many hard melt-freeze layers with easily identifiable near-surface faceted layers above and below the melt-freeze layers. These faceted layers tended to lack cohesiveness. On the contrary, the north aspect appeared more homogeneous with generally unidentifiable weak layers or interfaces. Slabs on the north aspect tended to be defined by storm events. Slabs on the west aspect were heavily influenced by high wind speeds.

We expected to find a relationship between the stuffblock stability test and slab hardness since the property of hardness ultimately determines whether strain reaches the weak layer and causes it to fail. The results of these models show that harder slabs are associated with high-

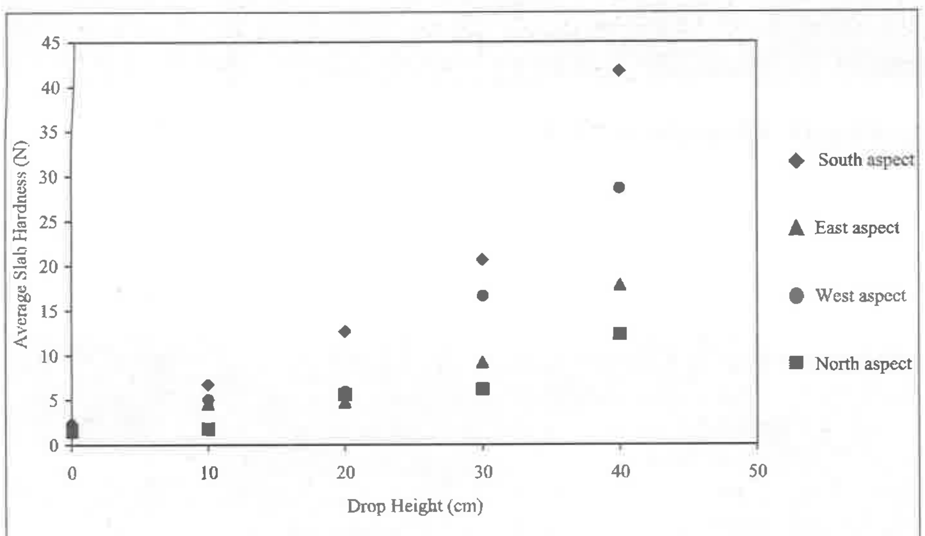

Figure 1. Average slab hardness vs. stuffblock stability test drop height. Average slab hardness values associated with specific drop heights for slabs on north, south, east, and west aspects.

er stuffblock drop heights. These results suggest that strain may result to the weak layer more efficiently with softer slabs than with harder slabs and that as soft slabs compress, the effective depth between the stuffblock and the weak layer decreases. After a few drops, the stuffblock may be much closer to the weak layer with a soft slab in comparison to a hard slab. Even though these tests are being conducted on only a 0.3 m x 0.3 m column of snow, results suggest that hardness helps to control skier triggering.

The results of these models have shown that harder slabs may be associated with higher stuffblock drop heights and that the levels of hardness vary by aspect. These results also suggest that softer slabs may have allowed strain to result to the weak layer more efficiently than did harder slabs. These models emphasize the importance of slab hardness and how it relates to skier-triggered slab release. If this study were to be repeated, we would measure the shear strength as well as the hardness of the weak layer in conjunction with the stuffblock stability test measurements. Additional hardness and shear strength data may make it possible for more conclusive deductions to be made concerning the effectiveness of the stuffblock stability test in testing stability.

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Mark Kozak is Snow Safety Director for Dean Cummings H2O Heli Guides in Valdez, Alaska. He recently completed an M.S. at Colorado State University.

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A Few Notes on "The Exploding Whale Video"

For those explosive control fans who requested copies of the Exploding Whale video shown at the highly energy charged ISSW2002 video night, Tom Stringfield of Portland Mountain Rescue put together this little informational article on the event and how and where to obtain your very own video. Thanks, Tom! Of course no AAA certified avalanche professional would ever be linked to anything involving explosives and avalanche mitigation as weird as this—or would we now?? Anyway, enjoy—Mark Moore

The Oregon Highway Division's 1970 attempt to blow up a beached whale lives on a quarter-century later.The Portland TV station that filmed the event (KATU, Channel 2) farms out requests for copies to a local video service (MOBAMedia, 503/223-1677) who charge $55.00 for a copy of the original tape.

Copies are also available on the Internet for downloading. Hopefully, one of these will get you what you need. Two of the many sources are:

http://www.manbottle.com/video/Exploding_Whale.htm
http://perp.com/whale/video.html

A Google search for "exploding whale" will give you more.

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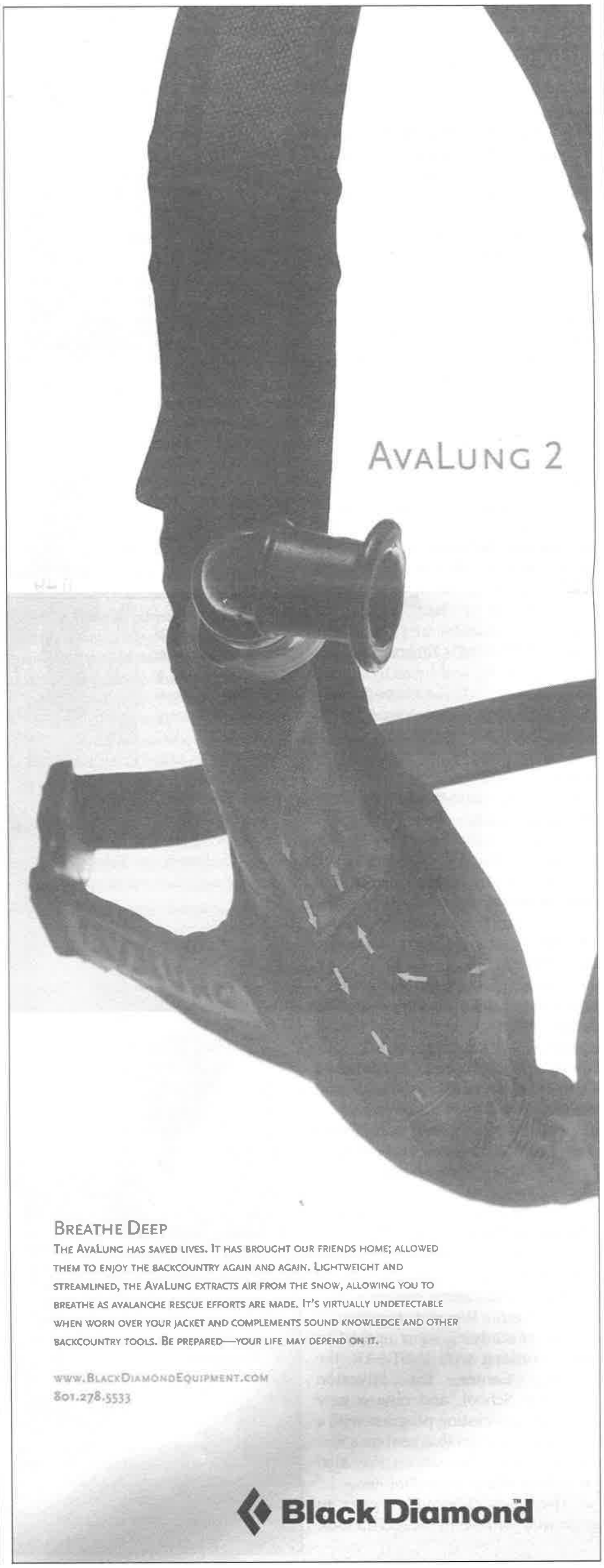
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