STORM SNOW AVALANCHES: CHARACTERISTICS AND FORECASTING

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ABSTRACT: At ski areas, a majority of avalanches fail in storm snow. We investigate these avalanches using stability tests and avalanche observations from California and Alaska. Collapse amplitudes during fracture, measured using particle tracking, were 1 mm for a failure layer of precipitation particles and 7 mm for a layer of unrimed sectored plates. Stability test results showed little dependence on slope angle, suggesting that both precipitation particles and older faceted crystals (persistent weak layers) fail as described by the anticrack model, with collapse providing energy. Using observations from avalanche control work at Mammoth Mountain, CA USA, a large coastal ski area where 9/10 avalanches fail in storm snow, we examined Extended Column Test (ECT) results and their relation to avalanche activity. ECT propagation was a powerful predictor; days with ECTs that propagated had significantly more and larger avalanches. Since other studies have shown that the ECT is an effective predictor of avalanches involving persistent weak layers, we suggest that the ECT is an effective test to predict both types of avalanches, those that fail in storm snow and those that fail on persistent weak layers.

KEYWORDS: storm snow, ski area, Extended Column Test

1 INTRODUCTION

Avalanches that fail in storm snow (i.e. precipitation particles) are the most common type at ski areas and may be the most common avalanches worldwide. We know they are the most common type at ski areas because avalanche workers at US ski areas have been recording failure layers for decades (Williams and Armstrong 1998). Because storm snow avalanche cause fewer fatalities than those that fail on older faceted crystals, they have received limited study (Bair et al. 2012). Yet, storm snow avalanches are a significant hazard. For instance, the most deadly in-bounds ski area avalanche accident in North America failed in storm snow. It occurred at Alpine Meadows in March of 1982, killed seven people, and destroyed two buildings (Penniman 1986; Heywood 1992).

This paper reveals some basic insights into storm snow avalanches. One of the most salient findings is that storm snow avalanches share many properties with avalanches that fail on older faceted crystals, often called persistent weak layers (Jamieson 1995). For instance, storm snow avalanches fail in collapse, just like avalanches on persistent weak layers. Also, at a large coastal ski area, Extended Column Test (ECT) propagation was a powerful predictor of storm snow avalanche activity. This finding is similar to other studies (i.e. Birkeland and Simenhois 2008; Schweizer and Jamieson 2010) that have shown ECT propagation to be a powerful predictor of avalanches on persistent weak layers. This paper provides an overview of the main results in one published paper (Bair et al. 2012) and one paper under review (Bair in review).

2 RESULTS

2.1 *Universality of collapse*

A new theory of avalanche initiation, called *anticrack nucleation* (Heierli et al. 2008), emphasizes collapse in the avalanche process. The anticrack model accounts for whoompfing and remote triggering, phenomena which can not be explained using shear models that do not allow slope normal collapse (McClung 1979; Louchet et al. 2002; Bažant et al. 2003). Using Propagation Saw Tests (PST, Gauthier and Jamieson 2008) and markers inserted into the slab to track

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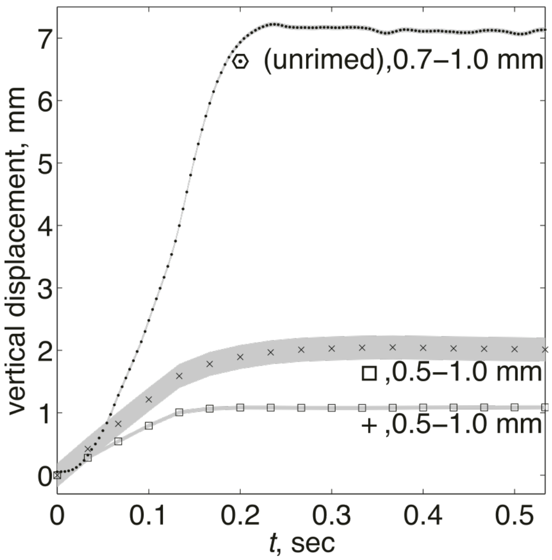

Figure 1 Collapse amplitude of three failure layers. The horizontal axis is time *t* since fracture. The two lower amplitudes were filmed at 30 fps while the higher amplitude was filmed at 240 fps. The gray shaded areas are error estimates. Snow symbols are from Fierz et. al (2009).

movement with sub-millimeter accuracy, we were able to measure the collapse amplitude for two failure layers of storm snow and one failure layer of faceted snow (Figure 1).

Collapse amplitude is the average vertical displacement of slabs that collapsed, but did not continue to slide downhill. In tests where the slab slides downhill, bed surface erosion becomes indistinguishable from the collapse amplitude (van Herwijnen and Jamieson 2005); thus, only tests where the block stops sliding were used.

Collapse amplitudes were quite different for the two storm snow layers, 1 mm for the mixed precipitation particles (+) and 7 mm for the unrimed sectored plates (⊙). The faceted crystals (□) collapsed about 2 mm, within the 1-40 mm range of published values for persistent weak layers (Johnson 2001; van Herwijnen and Jamieson 2005; van Herwijnen et al. 2010). More amplitudes are needed, but these three tests support the idea that all slab avalanches, whether occurring on persistent weak layers or in storm snow, undergo collapse. In fact, to our knowledge, there are no published measurements on failure layer fracture without collapse.

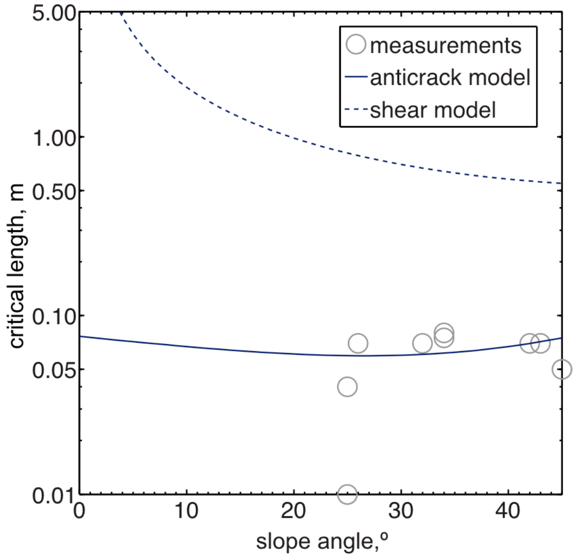

Figure 2 PST critical length vs. slope angle. Critical length is cut length from the edge of the block before self-propagation. The lines show the shear model (McClung 1979) and the anticrack model (Heierli et al. 2008).

2.2 Slope angle independence for triggering

One prediction of the anticrack model is that triggering is relatively insensitive to slope angle, since collapse contributes significant energy to the fracture process. Indeed, this has been verified with tests involving persistent weak layers using ECTs (Birkeland et al. 2010; Heierli et al. 2011) and PSTs (Heierli et al. 2008). Similarly, PSTs (Figure 2) and ECTs (Figure 3) on storm snow failures show little dependence on slope angle. This contrasts with shear models, which predict that triggering should ease with increasing slope angle.

2.3 Predictive power of the ECT

The ECT was a powerful predictor of avalanche activity at Mammoth Mountain, CA, where 9/10 avalanches fail in storm snow. Days with ECT propagation at a flat study plot had significantly more and larger avalanches (KW-test $p<0.01$, Figure 4).The median R-size sum for days with ECT propagation was 49 vs. 0 for days without ECT propagation.

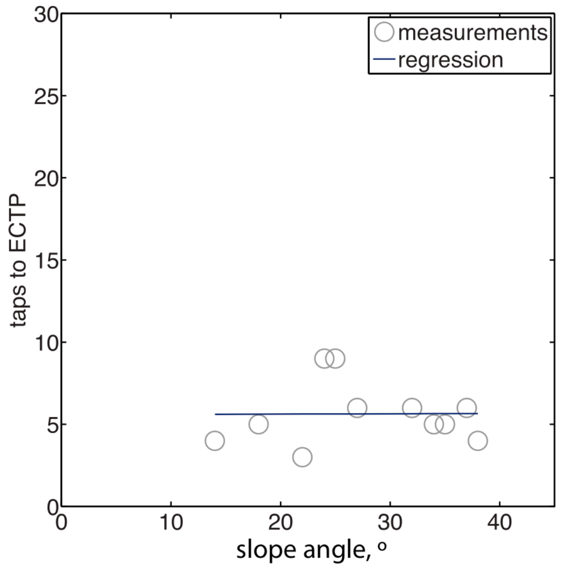

Figure 3 ECT taps to propagation versus slope angle. The vertical axis is number of taps required for self-propagation to begin (ECTP). The solid line is a linear regression showing no trend.

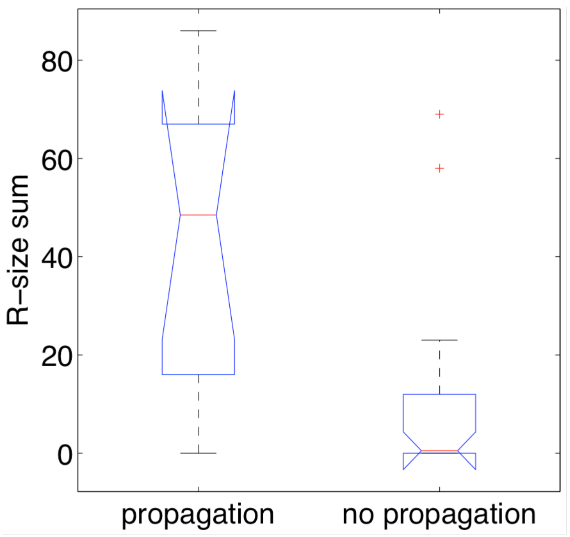

Figure 4 Sum of daily relative class sizes for 92 selected avalanche paths grouped by ECT propagation. Line at center is the median, boxes are 25th and 75th percentiles, whiskers are non-outlier ranges, and crosses are outliers. Non-overlapping notches indicate statistical significance at *p*=0.05, based on the Kruskal-Wallis test.

3 CONCLUSION

This paper presents new findings about avalanches that fail in storm snow. First, during fracture, storm snow failure layers collapse, just as persistent weak layers. This means that, as previous research has shown with persistent weak layers, triggering is insensitive to slope angle. This is a prediction of the anticrack model that has been confirmed with ECTs and PSTs.

Second, ECT propagation was a powerful predictor of avalanche activity at Mammoth Mountain. Since 9/10 avalanches at Mammoth fail in storm snow, we suggest the ECT is a strong predictor of storm snow avalanches in general. Previous research has also shown the ECT to be an effective predictor of avalanches that fail on persistent weak layers (i.e. Birkeland and Simenhois 2008; Schweizer and Jamieson 2010), thus we suggest the ECT is a powerful predictor of both types of avalanches, those that fail in old snow and in those that fail in storm snow. We always advocate using multiple sources of information and more than one stability test, but the ECT can be used to predict avalanches without a priori knowledge of whether avalanches are likely to fail in storm snow or on older persistent weak layers.

4 REFERENCES

Bair, E., in review: Forecasting artificially-triggered avalanches in storm snow at a large ski area. Cold Regions Science and Technology.

Bair, E. H., R. Simenhois, K. Birkeland, and J. Dozier, 2012: A field study on failure of storm snow slab avalanches. Cold Regions Science and Technology, 79-80, 20-28, doi:10.1016/j.coldregions.2012.02.007.

Bažant, Z. P., G. Zi, and D. McClung, 2003: Size effect law and fracture mechanics of the triggering of dry snow slab avalanches. Journal of Geophysical Research, 108, 2119, doi:10.1029/2002JB001884.

Birkeland, K. W., and R. Simenhois, 2008: The Extended Column Test: Test effectiveness, spatial variability, and comparison with the Propagation Saw Test. Proceedings of the 2008 International Snow Science Workshop, Whistler, BC, Canada, 401-407.

Birkeland, K. W., R. Simenhois, and J. Heierli, 2010: The effect of changing slope angle on extended column test results: Can we dig pits in safer locations? Proceedings of the 2010 International Snow Science Workshop, 55-60.

Fierz, C., and Coauthors, 2009: The International Classification for Seasonal Snow on the Ground, IHP-VII Technical Documents in Hydrology N°83, 90.

Gauthier, D., and B. Jamieson, 2008: Evaluation of a prototype field test for fracture and failure propagation propensity in weak snowpack layers. Cold Regions Science and Technology, 51, 87-97, doi:10.1016/j.coldregions.2007.04.005.

Heierli, J., P. Gumbsch, and M. Zaiser, 2008: Anticrack nucleation as triggering mechanism for snow slab avalanches. Science, 321, 240-243, doi:10.1126/science.1153948.

Heierli, J., K. W. Birkeland, R. Simenhois, and P. Gumbsch, 2011: Anticrack model for skier triggering of slab avalanches. Cold Regions Science and Technology, 65, 372-381, doi:10.1016/j.coldregions.2010.10.008.

Heywood, L., 1992: Alpine Meadows: March 31, 1982 the story. The Avalanche Review, 10.

Jamieson, J. B., 1995: Avalanche prediction for persistent snow slabs. Ph.D., Department of Civil Engineering, University of Calgary, 258 pp.

Johnson, B. C., 2001: Remotely triggered slab avalanches. Department of Civil Engineering, 109.

Louchet, F., J. Faillettaz, D. Daudon, N. Bédouin, E. Collet, J. Lhuissier, and A.-M. Portal, 2002: Possible deviations from Griffith's criterion in shallow slabs, and consequences on slab avalanche release. Natural Hazards and Earth System Sciences, 2, 157-161, doi:10.5194/nhess-2-157-2002.

McClung, D. M., 1979: Shear fracture precipitated by strain softening as a mechanism of dry slab avalanche release. Journal of Geophysical Research, 84, 3519-3526, doi:10.1029/JB084iB07p03519.

Penniman, D., 1986: The Alpine Meadows avalanche trial: conflicting viewpoints of the expert witnesses. 1986 International Snow Science Workshop, 189-194.

Schweizer, J., and B. Jamieson, 2010: Snowpack tests for assessing snow-slope instability. Annals of Glaciology, 51, 187-194.

van Herwijnen, A., and B. Jamieson, 2005: High-speed photography of fractures in weak snowpack layers. Cold Regions Science and Technology, 43, 71-82, doi:10.1016/j.coldregions.2005.05.005.

van Herwijnen, A., J. Schweizer, and J. Heierli, 2010: Measurement of the deformation field associated with fracture propagation in weak snowpack layers. Journal of Geophysical Research, 115, F03042, doi:10.1029/2009jf001515.

Williams, K., and B. Armstrong, 1998: Westwide Avalanche Network electronic database: avalanche observations.