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Theo Meiners works the sharp end of stability evaluation, hunting for weak layers. In April of 2010 in Alaska's Chugach Range, surface hoar managed to survive and get buried on west aspects and more protected areas, but it was not to be found on this exposed, easterly facing slope. After hard compression test results with poor shear quality and an ECTN, Theo led his group down the slope without incident. The Wrangells provide stunning background topography. *Photo by Karl Birkeland*

The Effect of Changing Snowpack and Terrain Factors on ECT Results

Story by Ron Simenhois and Karl Birkeland

Since this issue of *The Avalanche Review* focuses on fracture, Lynne Wolfe asked us to summarize our work with the Extended Column Test (ECT). The ECT was designed to test not only what it takes to get a block to fail, but whether or not a fracture fully crosses the block. As such, we believe that the ECT gives us some information about snowpack fracture. However, we have to be careful in interpreting our results since the scale of the ECT is obviously much smaller than the scale of a fracture leading to an avalanche. In this short paper we will first put forth our definition of fracture, which is different than the snow community has been using, but which is consistent with the terminology of materials scientists. Then we briefly discuss some recent ECT research demonstrating how changing slab thickness, changing slope angle, increasing loading, and wetting the snow surface affect ECT results.

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How would you feel if someone who didn't know much about skiing tried to teach you to ski safely in avalanche terrain? What would your response be if they made you feel like shredding steep powder slopes was stupid?

—Chris Lundy, *Shredders Teaching Sledders*, pg 17 snow science

CSI: FRACTURE MECHANICS

Investigating the who, what, when, where, and why – a series of articles that examine propagation

Ron Simenhois performs yet another ECT in his research. A strong work ethic leads to robust results.
Photo by Karl Birkeland

SNOWPACK, TERRAIN, AND ECT RESULTS

continued from cover

Defining Fracture

Before discussing fracture, we need to agree on some basic terminology. The snow community has long used terms like fracture propagation and fracture propagation propensity. However, this terminology is not consistent with that of materials scientists. In their terminology, fracture is not a thing but is rather a process. The thing we are talking about is a crack, while fracture is the process of expanding or propagating the crack. Thus, talking about fracture propagation doesn't make sense because – by definition – fracture is crack propagation. Thinking about fracture using this new vocabulary won't be easy, especially for those of us who have written articles using the old terminology (for an example of how we've misused these terms, check out *(Simenhois and Birkeland 2009)*). However, using terminology consistent with materials science is important since it allows us to better communicate and share ideas with scientists working with other materials. Therefore we will use the above definitions in this article.

Changing Slab Thickness

At the 2008 ISSW we presented results on the effect of changing slab thickness on ECT results *(Simenhois and Birkeland 2008a)*. In 52 pits we did a set of side-by-side ECTs where we first loaded the column at the end where the slab was thick and then at the end where the slab was thin. The snowpack on all our tested slopes was capable of sustaining fracture over considerable distance, as evidenced by recent avalanche activity (33 of the 52 pits) or by standard ECTP results. In 20 pits the slab thickness above the weak layer changed naturally within a column width and in the other 32 pits where the slab thickness above the weak layer was consistent, we reshaped the slab above the weak layer with a snow saw. Change in slab depth across the column varied from 12 cm to 50 cm, with an average change of 30 cm. In all 52 pits in our dataset fractures that initiated under the thin part of the slab always advanced along the weak layer to the thicker end of the column. However, fractures that initiated under the thick slab consistently arrested before crossing the entire column to the thinner side.

Our limited data and field observations show that sizable slope-scale fractures are also often more likely to advance from areas with thinner slabs toward areas of the slope where slab above weak layer is thick, than in the other direction. We know of cases where explosives large enough to create large cracks in the weak layer did not trigger avalanches when placed in thicker areas of the slab, while smaller loads placed in thinner areas released the entire slope. Though our dataset does not contain cases where fractures propagated from under thick slab toward a thinner slab, it would be wrong to assume that fractures initiating under thicker slab areas will not propagate toward areas of thinner slabs. We and many others have observed slopes fracture from thicker slab areas toward thinner slab areas under some conditions. Further, it is also possible that under some conditions that we haven't observed yet, fractures in our propagation tests may come to an arrest when propagating from thin to thick areas.

See Simenhois and Birkeland, 2008 for more information at www.fsavalanche.org/NAC/techPages/articles/08_ISSW_Simenhois_ChangeSlabDpth.pdf

Changing Slope Angle

At the 2010 ISSW we presented a study on the effect of changing slope angle on ECT results *(Birkeland et al. 2010)*. For this study we collected four datasets from three different slopes with slope angles ranging from 7° to 44°. The snowpack structure was reasonably similar for all four of our datasets, with a 25-40 cm slab overlying surface hoar. In all cases, the number of shovel taps required for weak layer fracture remained reasonably constant or increased slightly, with increasing slope angle. Our results provide strong evidence that ECT triggering of persistent snowpack weak layers such as surface hoar does not vary, or increases slightly, as slope angle increases. Though counter intuitive to most of us, our results are consistent with the anticrack model for weak layer fracture *(Heierli et al. 2008; Heierli et al. 2010a, 2010b)*.

From a practical perspective, our results show that, as long as the snow structure remains reasonably consistent in space, observers can conduct dependable tests on persistent weak layers such as surface hoar in gentler, safer terrain before committing themselves to more exposed areas. Of course, it is still critically important for observers to carefully assess whether or not the snowpack structure in that lower angled terrain is sufficiently similar to the snowpack structure on the surrounding steeper slopes. The bottom line for avalanche practitioners is that being able to conduct at least some initial tests in safer locations has the potential to greatly increase the safety of stability assessments.

See Birkeland et al., 2010 and Heierli et al., 2010b for more information at www.fsavalanche.org/NAC/techPages/articles/10_ISSW_ECT_SlopeAng.pdf and www.fsavalanche.org/NAC/techPages/articles/10_ISSW_Heierli_etal.pdf

Increased Loading

At the 2010 ISSW we presented a study on the effect of increased loading on ECT results *(Simenhois and Birkeland 2010)*. We collected data from before and after 11 different loading events in Colorado utilizing 50 pits on 45 different slopes that we specifically targeted for being on the verge of instability before the loading event. In each pit we collected two ECTs before and after each loading event. In 64% of the tests results changed from ECTN before the snow loading event to ECTP afterwards, while in 12% our results were ECTP both before and after the loading, and in remaining 24% of the cases (12 pits) results were ECTN before and after the loading event. Thus, although it does not hold in all cases, increased loading generally increases the probability the fracture will completely cross the ECT. Two case studies from southeast Alaska confirm these conclusions.

The technique used for some of this work involved placing additional blocks of snow on an ECT before testing it. Further refinement this technique, along with additional data collection, might allow us to develop a rough test that will give an estimate of the load required for cracks to begin to freely propagate along the weak layer.

See Simenhois and Birkeland (2010) for more information at www.fsavalanche.org/NAC/techPages/articles/10_ISSW_Simenhois_ECT_loading.pdf

Surface Warming / Setting

Avalanche workers have consumed many pints of beer while discussing the possible role of warming in changing the avalanche potential. At the 2008 ISSW we presented some data showing changes in ECT results when warm temperatures had caused the snow surface to become wet *(Simenhois and Birkeland 2008b)*. During four relatively warm days we collected data from 28 pits in different locations around Copper Mountain, Colorado. We especially targeted slopes on the verge of instability. We conducted a variety of Extended Column tests, tracking changes in ECT and modified ECT results during the day. The weak layer was buried near surface facets.

In all four datasets, fractures crossed the entire columns after the snow surface became wet in the afternoon while in the same pits in the morning when the snow surface was frozen those fractures arrested before the end of the column. In addition we witnessed two cases where slopes tested with explosives or skiers early in the morning did not release, but later avalanched when the snow surface become wet. A possible reason for these results is that increased deformation in the slab near the surface increases the strain rate down to the weak layer, thereby decreasing the propensity for fracture arrest *(Schweizer and Jamieson, 2010)*. However, the snow structure must already be close to critical. In our data, ECT results in three pits (more than 10% of our data) were ECTN in the morning and in the afternoon.

See Simenhois and Birkeland (2008b) for more information at www.fsavalanche.org/NAC/techPages/articles/08_ISSW_Simenhois_SurfWarm.pdf

Conclusions

Our recent work shows that many factors affect ECT results. We have not definitively shown that these same factors affect the slope scale fractures resulting in avalanche release, so be careful about extrapolating our results out to the slope scale. However, a few field observations suggest that some of our observations might hold for avalanche slopes, such as the increased propensity for fractures to both initiate and propagate from thinner to thicker areas of the slab.

Acknowledgments

Many thanks to Joachim Heierli for numerous discussions that helped us better understand fracture, fracture mechanics terminology, and the physical processes that occur during an ECT test. Thanks also to Alec van Herwijnen for his help in clarifying the wording in our fracture definition.

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Ron Simenhois just moved his entire family to Juneau, AK, where he forecasts for the Kensington Mine and thinks about snow. His work on the ECT has given the practitioners among us an incredibly useful tool for assessing propagation propensity.

Karl Birkeland is not only the avalanche scientist for the National Avalanche Center, he is also a perennial cheerleader for The Avalanche Review. His clear eye and ongoing support are greatly appreciated.

RANDOM SHOT PLACEMENT:
An Alternative Technique for Risk-Reduction Explosive Use

Story by Peter Carvelli

In western Colorado an effective snow-safety program spans the winter season, beginning with the first snowfalls. At Aspen Highlands we begin with weather and snowpack observations, moving into bootpacking and Strategic Application of Explosives (SAE) when appropriate depths are reached. Bootpacking and SAE disrupt layering of initial storms, thus greatly enhancing stability *(Carvelli ,2008)*. As soon as bootpacking and SAE are completed on a given slope, skiers are applied to increase strength through compaction AND to further layer disruption with each succeeding storm. Generally, after a storm, risk-reduction routes are completed prior to the introduction of skiers. This industry standard procedure traditionally utilizes explosives delivered to start zones followed by ski cutting each slope. During the season, large ANFO explosive charges are applied to select slopes at select intervals to further test ongoing stability. With the advent of spring conditions, ski runs may be closed as strong solar input and warming air temperatures combine to moisten and weaken the snow cover through bond erosion and other factors, which may be reopened as refreezing occurs.

As we all know, the Colorado snow cover is a product of a continental climate. The early season metamorphism of the snow cover provides a faceted basal layer to work with every year. The clear period between storms throughout the season produces surface facets for the next storm to fall on. Persistent weak layers (PWLs) exist throughout a Colorado snow cover. PWLs plus loading equal INSTABILITY. Absolute instability presents a readily solvable problem in ski areas. Conditional instability is a more difficult problem, and one we are employed to manage. Conditional instability brings uncertainty into the picture. This paper introduces a technique to reduce uncertainty: random shot placement.

Traditional storm risk reduction usually involves targeting start zones with a few shots followed by ski cutting, then opening to public. This has worked well for the industry over the years. However, many of us have experienced or know of so-called "post-control releases" on recently opened ski slopes. This may imply that our technique is incomplete.

Current avalanche fracture theory *(J Heierli, 2008)* states that an avalanche can occur when two conditions are met:

Condition 1

A crack, caused by stress on a flaw in a weak layer, must grow to a critical size, from which it will self propagate two dimensionally in all directions through the weak layer until stopped by a change in weak-layer boundary conditions. Once a crack begins to self propagate, and the slab is detached from the weak layer and has met a size condition of at least 100m2, condition one is met.

Condition 2

The frictional force between the two crack faces must be overcome. This force is determined by slope angle, slab mass, and weak layer grain geometry. When friction is overcome, condition two is met and an avalanche can occur. The stress on a flaw can be caused by new or wind transported snow, a skier, or an explosive pressure wave. Our understanding of the avalanche process, while improving, is also incomplete. In light of this fact, it makes sense to do all we can within reason to reduce uncertainty in our risk-reduction work.

Explosives can be used to accomplish four things:

- **To elicit avalanches.**
- **To test a slope for instability.**
- **To establish an array of deformation-resistant pillars of snow which may inhibit crack propagation.**
- **To disrupt layering of the snow cover.**

TRADITIONAL STORM SNOW RISK-REDUCTION TECHNIQUE

Generally speaking, the traditional risk-reduction technique for storm snow usually involves placement of a few 2-lb explosives in a given start zone, followed by ski cutting. If these tests prove uneventful, the slope is opened to public. The benefits of this technique are timely openings, low cost, and hands-on experience with current conditions.

In order to use this technique most effectively, snow-safety personnel must be familiar with their route(s), understand the concept of "sweet spots," and have a good bit of experience.

Often, a snow-safety team will have only one or a few routes they are familiar with, and they may run the same route for a season or many seasons. While familiarity with a route is desirable and necessary, it may lead to complacency, and it may result in explosive placements that are unvaried and ski cuts made from here to there every time.

Costs associated with this type of risk-reduction work are minimal, usually consisting of explosive cost, (currently about $20 per 2-lb round), protective gear costs (hearing protection), training costs, and wages. Explosive use with this technique is generally limited to a few shots placed high in the start zone, keeping costs down.

RANDOM SHOT PLACEMENT

The random technique is not new, but an enhancement of traditional methods developed to reduce uncertainty over time. The random shot technique differs from the traditional technique in two respects, which are:

- **The increased use of explosives.**
- **Intentionally varied placements of the additional shots, particularly in the lower portions of the path.**

The technique itself consists of the following steps:

1. **Observe conditions prior to the weather event.**
2. **Observe current conditions, i.e., HN, wind speed and direction, loading, temps, weather forecast, etc.**
3. **Make a stability forecast and risk-reduction plan and consider plans B and C.**
4. **Begin routes for the day in less hazardous areas when possible in order to verify conditions and stability forecast.**
5. **As information becomes available, tweak the plan as necessary.**
6. **Assign a greater number of shots to each team than the minimum, to be used randomly throughout the route. This addition may be two or five, or more or less, and is determined by the forecaster and/or the risk-reduction team, depending on path history for the season, demands of the day, HN and loading, near-future weather forecasts, and "intuition and experience."**

After making what could be considered the traditional shot placements, the additional shots may be utilized randomly throughout the path. Maybe one higher than usual, or in this corner, or on that bench, or as far down as can be thrown. Maybe above the convexity, maybe below. Maybe at mid-

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