CHANGES IN EXTENDED COLUMN TEST RESULTS WITH VARYING DEPTHS

Ian Hoyer[1]*, Ethan Greene[1], Doug Chabot[2] and Karl W. Birkeland[3]

[1]Colorado Avalanche Information Center, Boulder, CO, USA
[2]Gallatin National Forest Avalanche Center, Bozeman, MT, USA
[3]USDA Forest Service National Avalanche Center, Bozeman, MT, USA

ABSTRACT: Knowing the Extended Column Test's (ECT's) effectiveness at different slab thicknesses is critically important for practitioners. To better understand the limitations of the ECT, we used the SnowPilot dataset to investigate the utility of ECTs for providing an index of crack initiation and propagation on varying weak layer depths. The database currently contains 5013 ECTs conducted by 386, primarily professional, users worldwide between 2007 and 2016. The broad range of observers and snowpacks in the dataset allow us to examine variations in ECT results with changing weak layer depth across seasons and locations. We found 25% of ECTP (propagating ECT) results have weak layer depths of less than 30cm, 45% have depths between 30 and 70 cm, and 30% propagate on weak layers deeper than 70 cm. We also found an increasing ratio of ECTP to ECTN (non-propagating ECT) results as depth increased. The results make intuitive sense as fracture initiation takes more force and becomes more infrequent as slab depths increase, especially once depths exceed about 1.2 m. In addition, we used these same data to look at the repeatability of ECT results in individual snow pits. In the 582 pits where two ECTs were performed on the same weak layer, 86% have similar results (either two ECTPs or two ECTNs), showing a high degree of repeatability. Our results suggest the ECT can be effectively used over a fairly wide range of weak layer depths.

KEYWORDS: Extended Column Test, Snowpack Test, Propagation

1. INTRODUCTION

Simenhois and Birkeland (2006; 2009) developed the Extended Column Test (ECT) to index propagation propensity. The ECT is performed by isolating a 0.3 m by 0.9 m column of snow and tapping with your hand on a shovel placed on one side of the top of this column. The ECT provides information on propagation potential (ECTP (propagation) or ECTN (non-propagation)), as well as information on the force required for crack initiation (ECT test score (a range of 1-30)). An ECTP result indicates that the crack propagates all the way across the column, while an ECTN indicates that the fracture arrested before reaching the far end of the column (Simenhois and Birkeland, 2009).

The ECT was quickly adopted by the avalanche community. By the 2011/2012 winter it had become the most popular snowpack test in the SnowPilot database, being used in 80% of those snow pits (Birkeland and Chabot, 2012).

* *Corresponding author address:*
Ian Hoyer, Colorado Avalanche Information Center,
Boulder, CO 80305;
tel: 503.984.0722;
email: ian.hoyer@state.co.us

Previous studies found low false-stability rates for the ECT in comparison with other snowpack tests (Simenhois and Birkeland, 2009; Winkler and Schweizer, 2008). A false-stability rate is the percentage of snowpack tests that produce a stable result (e.g. an ECTN result), on slopes which are actually unstable. Simenhois and Birkeland (2009) found a false stable rate of only 1%, using a tightly controlled dataset, with all tests performed by the same highly skilled observer. They found a 6% false-stable rate using information from 311 ECTs submitted to the SnowPilot database between 2006 and 2008. They also found false-unstable rates of 2% and 18%, respectively, in these same two datasets (Simenhois and Birkeland, 2009). Winkler and Schweizer (2008), found much higher false-stable and false-instability rates, 21% and 17%, using a dataset of 225 ECTs performed by professional observers in the Swiss Alps. Winkler and Schweizer (2008) classified slopes as stable or unstable using the presence of recent avalanche activity, whumphing or cracking, and analysis of the snowpit hardness profile. Slope scale analysis indicates that while ECT results are homogenous on many slopes, there are also some slopes where false-stable or false-unstable rates approach 50% (Hendrikx and Birkeland, 2008; Hoyer, 2014).

Ross and Jamieson (2008) analyzed a dataset of 242 ECTs, primarily collected during the

2007/2008 winter season in the Columbia Mountains of interior British Columbia. They found that most tests on weak layers deeper than 70 cm ended with an ECTX result, although there were several ECTP results on weak layers up to 92 cm deep and some ECTN results down to 111 cm (Ross and Jamieson, 2008). In their conclusions, Ross and Jamieson (2008) suggest that because of the limited ECTP and ECTN results below 70 cm in their dataset, it is not a reliable indicator of propagation propensity below that depth. This conclusion has been widely cited in teaching materials and articles for the popular press (e.g. Goldie, 2016; Zacharias, 2013).

Simenhois and Birkeland (2009) and Hoyer (2014) both found propagating ECT results in their datasets on weak layers at depths greater than 1 meter. Simenhois (2009) states that he "rarely uses the ECT to test layers deeper than 120 cm," and suggests that at that point initiating a fracture becomes less likely. In terms of thinner slabs, the authors have seen ECTs propagate hard slabs as thin as 5 cm, and then subsequently observed small avalanches on those weak layers, suggesting that the ECT was effectively capturing that propagation potential in those cases. This earlier work and our field experience suggest that the ECT may be effective at depths substantially shallower and deeper than the 30 – 70 cm range suggested in some teaching materials.

2. METHODS

2.1 Data

In this study, we analyze data submitted to SnowPilot between 2007 and 2016. SnowPilot is a free software program that allows users to record and graph their snow profiles (Chabot et al., 2004). Users can submit their data into a database for research purposes. A total of 386 users submitted 5013 ECT results and associated snow pits over these 9 years. While these users are diverse in geography and experience, most SnowPilot users identify themselves as avalanche professionals (Birkeland and Chabot, 2012). This database has been used for a number of previous studies (Birkeland and Chabot, 2006; Simenhois and Birkeland, 2009, Birkeland and Chabot, 2012).

2.2 Analysis

To look for general trends in our dataset, we plotted a scatterplot with weak layer depth on the x-axis and ECT score on the y-axis, with different symbols for ECTP and ECTN results. This provides a visual overview of our entire dataset, and also allows for direct comparison to earlier research via a similar figure in Ross and Jamieson (2008). We used Simple Linear Regression to test for a trend in the relationship between ECT score and weak layer depth. To examine changes in propagation results with changing weak layer depths, we plotted the ratio of ECTP to ECTN results (# of ECTP results / # of ECTN results) over a range of weak layer depths. This plot provides a simple and clear view of the trend in this relationship. We use a stacked histogram to provide another view of the data that is summarized in the ratio plot.

ECTX results are used to examine changes in the distribution of non-results at increasing weak layer depths. ECTX results don't have a depth associated with them, as they indicate that no fracture initiated on any layer in the column. To allow a comparison of ECTX results, we assigned them the depth of the "layer of greatest concern", a value selected by the observer. We then compared ECTX results to ECTN and ECTP data from ECTs performed on the "layer of greatest concern" in the profile. A histogram and stacked barplot show changes in the absolute number of ECTP, ECTN, and ECTX results as well as proportions of those results at differing depths.

We also used the same SnowPilot data to analyze the repeatability of ECT results in an individual snow pit. To do this, we examined the 582 pits where two ECTs were performed on the same weak layer. Pits were then categorized by whether the two tests gave the same result (either two ECTP results or two ECTN results), or gave different results (one ECTP result and one ECTN result). The proportion of tests in these two categories indicates the likelihood that the result of a second ECT performed in a snowpit will match the result from the initial ECT in that pit. In order to focus on the ECTs with the highest value for decision making, this analysis was also repeated on the subset of the data where two ECTs were performed on the "layer of greatest concern" in a pit.

3. RESULTS

3.1 Changes with Depth

A scatterplot of ECT score versus depth for ECTN and ECTP results shows propagating ECTs on both very shallow and deep weak layers (Fig. 1). For both ECTP and ECTN results, there is a trend

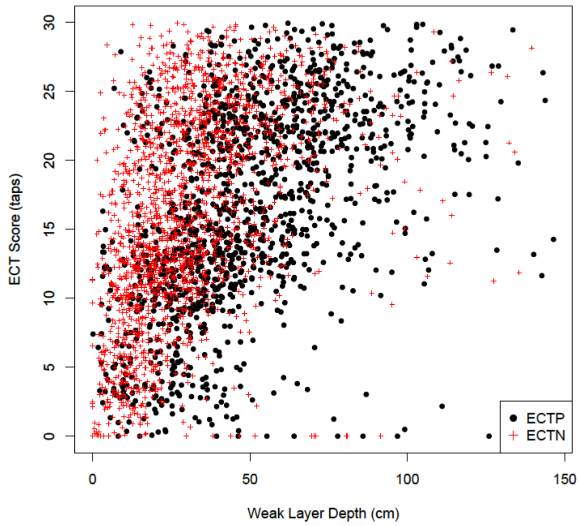

Fig. 1: Scatterplot of ECT score and weak layer depth for ECTP and ECTN results

of increasing ECT scores with increasing depth (p-value < .01). The proportion of ECTP to ECTN results also increases with increasing depth (Fig. 2).

A stacked histogram (Fig. 3) provides another view of these relationships, showing that 25% of ECTP (propagating ECT) results have weak layer depths less than 30cm, 45% have depths between 30 and 70 cm, and 30% are on weak layers deeper than 70 cm.

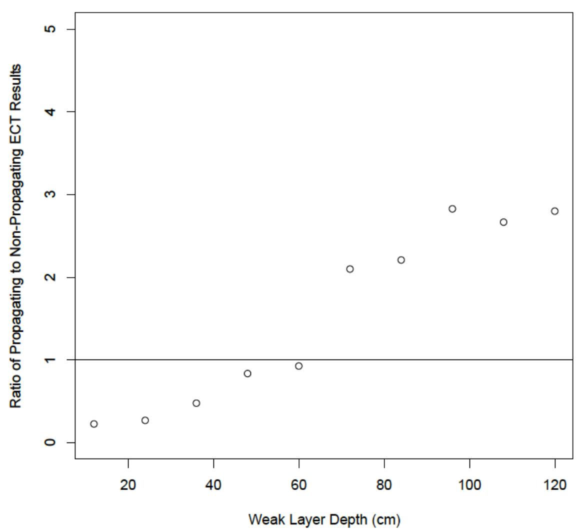

Fig. 2: Ratio of ECTP to ECTN results (# of ECTP results / # of ECTN results) over a range of weak layer depths

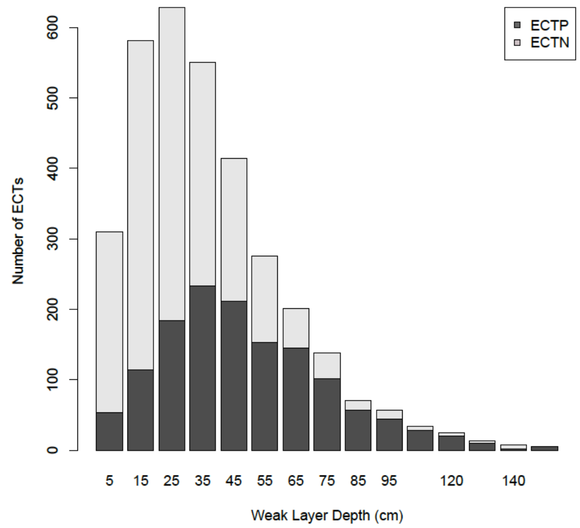

Fig. 3: Weak layer depth histogram of ECTP and ECTN results

Above ~35 cm, the frequency of ECT results decreases with increasing depth. However, this is a gradual trend, with 245 ECTs initiating a fracture deeper than 100 cm. A total of 137 (55%) of these were ECTP results, which is 9% of all ECTP results in the database.

One possible explanation for these changes is that there are simply fewer tests being attempted on deeper weak layers. To examine this element of the dataset, we looked at the distribution of ECTX results. A histogram shows ECTP, ECTN, and ECTX results all decreasing in frequency with depth (indicating fewer "layers of greatest concern" at greater depths), but ECTN results decrease in frequency first, then ECTP results, with ECTX results decreasing at a much lower rate (Fig. 4).

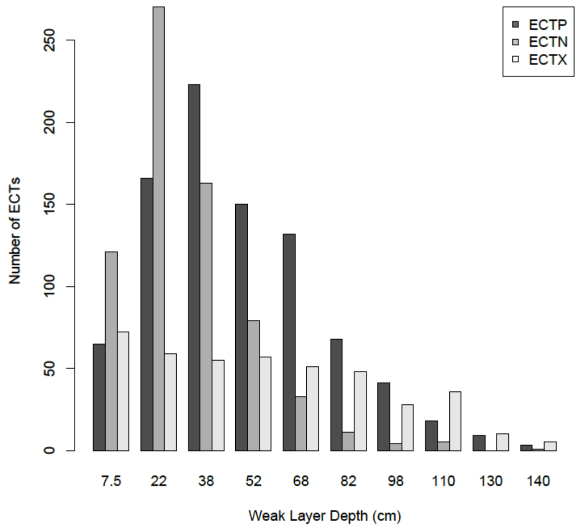

Fig. 4: Weak layer depth histogram for ECTP, ECTN, and ECTX results

A normalized stacked barplot shows the changing proportion of ECTP, ECTN, and ECTX results (Fig. 5). The proportion of ECTX results increases steadily as depth increases. The proportion of ECTN results steadily decreases as weak layer depth increases. The proportion of ECTP results increases until ~80 cm and then decreases slightly as ECTX results increase. At depths around 100 cm, 67% of ECTs initiate a fracture. Even at depths of 120 cm, about 40% of ECTs initiate a fracture on the layer of greater concern, with a high proportion of those tests propagating.

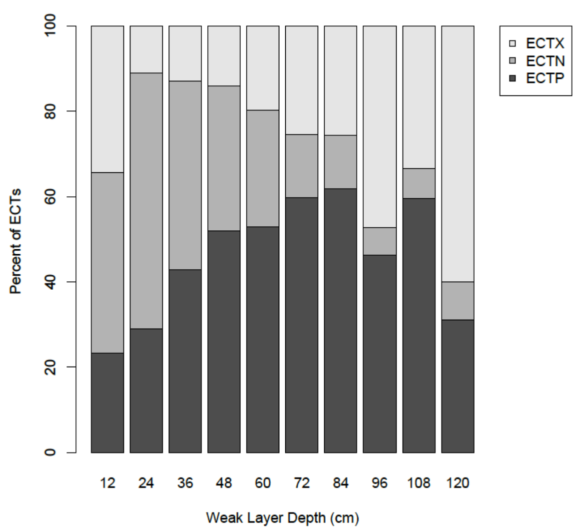

Fig. 5: A normalized stacked barplot showing the weak layer depth distribution of ECTX, ECTN, and ECTP results.

3.2 Repeatability

In 86% (500) of the pits where two ECTs were performed on the same weak layer, both ECTs gave the same propagation result (either two ECTPs or two ECTNs). This indicates that although results are largely repeatable, there is still a 14% chance that a repeat test will provide contradictory results. Similar results were found in the subset of the data where two ECTs were performed on the "layer of greatest concern" in a pit. In 83% (229) of these 275 pits with two ECTs on the layer of greatest concern the propagation results matched.

4. DISCUSSION

Our results show that cracks routinely initiate and propagate in ECTs on weak layers shallower than 30 cm and deeper than 70 cm. More than half of the ECTPs in our dataset were on layers outside that range, and we found nothing in our results to suggest that the ECT was less reliable at shallower or deeper weak layer depths. Our results are consistent with the work by Simenhois and Birkeland (2009), which shows the ECT performing well on slabs up to 100 cm thick in Colorado and New Zealand. In our dataset, the ECT appears to be effectively capturing propagation for slab thicknesses significantly greater than the 70 cm maximum proposed by Ross and Jamieson (2008). Although the number of tests in the Snowpilot dataset decreases at greater depths, there is no indication of a clear cutoff depth where ECTP results are no longer possible.

A large proportion of ECTP results (25%) were on weak layers less than 30 cm deep. This suggests that the ECT effectively captures propagation at shallow depths. The higher proportion of ECTN results at shallow depths is likely a function of the snow settlement process. Cracks can propagate below a thin slab when it is relatively stiff compared to the weak layer. In a snowpack with a harder surface slab, even a shallow slab can remain intact and produce an ECTP result, or break in a shallow avalanche. The increasing proportion of ECTN results at deeper depths makes sense because thicker, stronger slabs are more conducive to propagation (Schweizer et al., 2014; van Herwijnen and Jamieson, 2007).

The increasing proportion of ECTX results at deeper depths also fits well with earlier research indicating the increasing difficulty of initiating a fracture at depth (van Herwijnen and Jamieson, 2007). However, even at depths of 1 m, two thirds of ECTs on concerning weak layers give ECTN or ECTP results. This suggests that in a snowpack with a known deep-weak-layer concern, the ECT may still provide valuable data. If the test results in an ECTX on the layer of concern, it should be treated as a non-result and practitioners should look for other ways to test the potential for a crack to propagate through that layer.

The high degree of repeatability in ECT results in this dataset suggests that performing more than one ECT in a snowpack may be of limited value. Performing multiple tests may decrease the incidence of false-stable or false-unstable results. However, the high number of repeatable test results suggest that time and energy may be better spent on other forms of snowpack assessment to further understand the avalanche potential.

5. CONCLUSIONS

Our results show no evidence to suggest that the reliability of the ECT is limited to a specific depth range. The probability of initiating a fracture decreases as depth increases, but even at depths of greater than 1 m, fractures are initiated in the majority of ECTs. Like all compression-type tests such as the Compression Test or Rutschblock test, it becomes more difficult to initiate fractures when slabs are deep and hard. While shallow, soft, slabs may be less likely to show crack propagation in the ECT, they are also less likely to produce an avalanche. The ECT appears to capture at least some of the propagation potential of shallow slabs, and it certainly captures the potential for cracks to propagate under thin hard slabs of snow.

Ron Perla famously declared that the only rule of thumb for avalanche forecasting is that there are no rules of thumb. The same can be said for the application of snowpack tests. Rather than a set of rules for the appropriate application of the ECT (or any snowpack test), we suggest a more nuanced approach. Observers should understand the strengths and limitations of the tests, and apply them accordingly when assessing the snowpack. Limiting use of the ECT to a narrow band of slab thicknesses could mean missing potentially valuable data.

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