# THE EXTENDED COLUMN TEST:
# A FIELD TEST FOR FRACTURE INITIATION AND PROPAGATION

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ABSTRACT. For dry slab avalanches, fractures initiate and propagate in a weak layer or along an interface. Current field tests like compression or stuffblock tests are designed for assessing fracture initiation; however, these tests may not be as useful for assessing fracture propagation. Furthermore, in some cases these tests *may* identify layers that are most likely to initiate a fracture under stress, but not necessarily those layers that initiate *and* propagate the fracture as well, thereby occasionally “masking” those layers of real concern in a weak snowpack. This paper describes the development of a new field test that aims to assess both fracture initiation and propagation in an isolated column. Tested during the winters of 2005-06 in Colorado and 2006 in New Zealand, this test is a variation of the compression test and can be used in the same manner with the stuffblock. By tapping on one side of an extended column of 30 cm downslope by 90 cm in the cross slope direction, the extended column allows a slab to transmit stress across the width of the column. The fracture initiation results are collected as well as the results of the fracture propagation across the extended column. Out of 68 tests of unstable snowpacks (where avalanches recently occurred, or there was whumphing or shooting cracks) the fracture propagated across the entire block in 1 or 2 loading steps every time (100%) and 63 times (93%) it fractured with a compression test load of easy to moderate. Conversely, out of 256 pits where the snowpack was stable, only 4 cases (1.6%) propagated across the entire extended column through a single layer or interface. Thus, in stable snowpacks a fracture may be initiated, but it typically does not propagate across the column. For the snowpacks we tested the extended column test effectively discriminated between stable and unstable slopes.

KEYWORDS: stability test, avalanche forecasting, stability assessment, fracture propagation

## 1. INTRODUCTION

Avalanches consistently threaten people living in, recreating in, and traveling through mountains in the winter. Of the different types, slab avalanches account for most accidents [*Tremper*, 2001]. Slab avalanches result when a weak layer or interface underlying a stronger slab fractures. Recent Canadian research shows that fractures commonly initiate below skiers, but those fractures usually do not become avalanches [*van Herwijnen and Jamieson*, 2005]. Clearly, fractures must not only initiate, but they must also propagate to a critical size in order to form an avalanche.

Avalanche workers and backcountry recreationists use a variety of tests such as compression [*Jamieson and Johnston*, 1997], stuffblock [*Birkeland and Johnson*, 1999], and rutschblock [*Föhn*, 1987] tests to help evaluate snow stability. However, these tests are primarily designed to evaluate fracture initiation and not fracture propagation. A few indirect methods have been used to try to help predict fracture propagation. For example, many avalanche workers now assess shear quality [*Johnson and Birkeland*, 2002] and/or fracture character [*van Herwijnen and Jamieson*, 2004] in addition to stability test scores. The Swiss have long noted the type of release and what portion of the block releases with rutschblocks tests [*Schweizer and Wiesinger*, 2001]. Other methods like lemons [*McCammon and Schweizer*, 2002] and/or flags [*Jamieson and Schweizer*, 2005] are also gaining acceptance as tools for assessing whether the snowpack structure is conducive to fracture propagation. However, prior to the

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development of this test and recent work in Canada, we know of no tests specifically targeting fracture propagation.

Recently, Canadian researchers Dave Gauthier and Bruce Jamieson have been refining a test that focuses specifically on fracture propagation. In the first iteration of their test, they isolated a column 30cm across the slope by 3m up the slope, and loaded the column using a drop hammer tester at the upper end [*Gauthier and Jamieson*, 2006a]. This allows a flexural wave in the slab to develop as result of the dynamic load on the upslope side. Fracture length was measured and compared between unstable and stable slopes. Fractures lengths collected on a day with high fracture propagation propensity show a bimodal distribution with approximately 50% of the fractures having a similar fracture length as those in a stable snowpacks, and the other 50% having much longer fracture length [*Gauthier and Jamieson*, 2006a]. Subsequently they have refined the test. Their current test involves isolating the same long, thin beam, but they now initiate the fracture in the weak layer by cutting along the weak layer from the uphill side [*Gauthier and Jamieson*, 2006b, 2006c]. Results of this work indicate that under some conditions a critical cut length exists whereby propagation always propagates to the end of the column; their results are included in this proceedings volume [*Gauthier and Jamieson*, 2006d].

Unaware of Gauthier and Jamieson's work, the senior author on this paper independently began working on his own version of a test that could help assess both fracture initiation and propagation called the extended column test (ECT). This paper describes the test method and procedure, and then evaluates the test's effectiveness in discriminating between stable and unstable slopes by comparing test results on a number of such slopes. We also look at the spatial variability of the test on one stable slope. Our results show that the ECT effectively discriminates between stable and unstable slopes for our limited data from Colorado and New Zealand, suggesting that it might be a valuable additional tool for assessing snowpack stability.

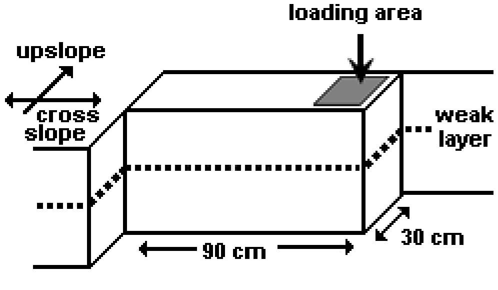

Figure 1: The preparation of the ECT involves isolating a column 90 cm across the slope by 30 cm upslope. The column is then loaded from one side using the same technique as the compression test.

## 2. CONDUCTING AND INTERPRETING THE EXTENDED COLUMN TEST

The Extended Column Test aims to test the likelihood of fracture initiation and propagation by extending the size of a small column test beyond the size of the loading area. The extended column allows the slab to transmit stress across the column, and we assume that fractures that are initiated will quickly propagate across the column if conditions are favorable for fracture propagation. In this test a vertical column of 90 cm across the slope by 30 cm downslope is isolated (Figure 1). One end of the column is dynamically loaded like the compression test in 30 steps - 10 taps from the wrist, 10 taps from the elbow and 10 taps from the shoulder [*Greene, et al.*, 2004]. The tester notes the number of taps required to initiate a fracture and the number of additional taps it takes for the fracture to propagate across the entire column. If a fracture is initiated but does not propagate across the column (Figures 2 and 3), the tester continues to load the edge of the column until either a fracture propagates across the entire column (Figure 4) or the column has been loaded with 30 taps.

Observers note the number of taps required to initiate a fracture (mark as I), the number of taps it take for the fracture to cross the entire column (mark as P) and the depth of the fracture from the surface (mark as D) in the format of: ECT I/P@↓D. For example if a fracture initiates at 25 cm from the surface on the 13th tap and crosses the entire column on the 14th tap it is recorded as: ECT 13/14@↓25. Fractures that initiated but never propagated beyond the boundary of a shovel are recorded as NP (for no propagation). Fractures that propagated, but never crossed the entire column we record as PP (for partial propagation).

Figure 2: Example of a fracture that initiated but didn't propagate beyond the boundary of the loading area (shovel).

Figure 3: Example of a fracture that propagated beyond the boundary of the shovel, but didn't propagate across the entire column.

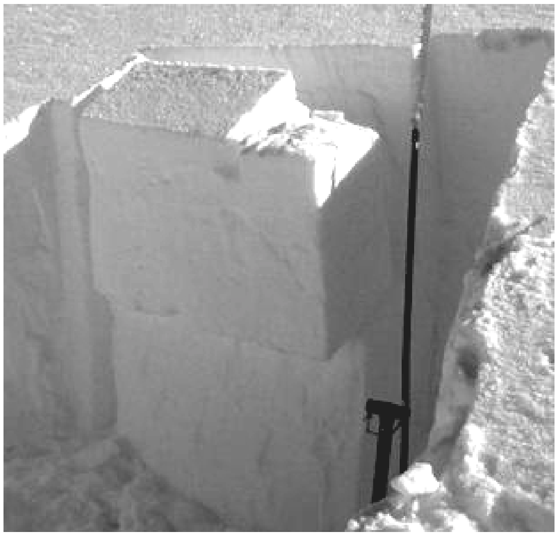

Figure 4: Example of fracture that propagated across the entire column. The test score was ECT19/19@↓51.

Interpreting the test is fairly straightforward. Our results indicate that fractures will typically propagate across the entire column within one or two additional loading steps of fracture initiation on unstable slopes. Thus, noting the difference between ECTI and ECTP is key. It is also important to observe whether or not the fracture is propagating along the same layer throughout the column. If the difference between ECTI and ECTP is less than 2 but the fracture is propagating across more than one layer, or is broken, our results suggest that fracture propagation is unlikely.

The ECT does have some important limitations. First, the ECT may overestimate snowpack instability in some cases where a weak layer sits under a thick hard slab. Second, the ECT is not a good tool to assess soft (F+ or less) upper layers of the snowpack or in mid-storm shear layers. In these cases the shovel edge tends to cut those soft layers and sink through. Finally, as with any other stability test, site selection is critically important in order to sample an area that is representative of the slope of concern.

## 3. TESTING THE EFFECTIVENESS OF THE EXTENDED COLUMN TEST

### *3.1 Methods*

During the winters of 2005/06 the senior author dug 202 pits in Colorado's continental snowpack and 122 pits in the maritime snowpack of New Zealand's Southern Alps and Mt. Hutt range. Pit data included all the typical snowpit observations following the techniques described by *Greene, et al.* [2004], and included all the data necessary to assess structural weaknesses using lemons [*McCammon and Schweizer*, 2002]. Stability test data included a compression test score with its associated shear quality, and an ECT test. Of the 202 pits from Colorado, 49 (24%) were on unstable slopes and 153 (76%) were on stable slopes. Of the 122 pits from New Zealand, 19 (16%) were on unstable slopes and 103 (84%), were on stable slopes. We defined “unstable” slopes as those with obvious signs of instability like cracking, collapsing, or recent avalanche activity. Our “stable” slopes are steep enough to slide ( 30°) and were tested by skiers or explosives, but did not present any of the above signs of unstable slopes. Out of the 68 unstable pits 12 (18%) were dug one day after the avalanches occurred, 1 pit (2%) was dug about 4 hrs after avalanche occurrence, 6 pits (12%) were dug about 3 hrs after avalanches occurrences, 5 pits (10%) were dug about 2 hrs after avalanches occurrences, 3 pits (1%) were dug about 1 hr after avalanche occurrence and 38 (56%) of the pits were dug either before or within 10 minutes from the time when a sign of instability in the snowpack was observed, or were dug on an adjacent slope. Our analyses compared ECT test data from stable and unstable slopes.

### *3.2 Results and Discussion*

The ECT effectively discriminated between our stable and unstable slopes. Of 68 tests on unstable slopes, every test (100%) propagated across the entire column in two or less additional loading steps after the fracture initiated (e.g., ECTP - ECTI less than or equal to 2) (Figure 5). On the other hand, out of 256 tests on stable slopes a fracture crossed the entire column only 25 times (10%). Further, in only six cases did the facture cross the column during the same step, or the next loading step after the fracture initiated. The important point is that *in only four cases (2%) did the fracture cross the column through one layer and during the same or the next loading step as when the fracture initiated*. Thus, for our limited dataset the ECT showed strong promise as a tool to discriminate between unstable and stable slopes with very few misclassifications. In all four of the cases of misclassification the hardness of the layer above the fracture layer was P or harder. In these cases the test result suggests that the snowpack may have the propensity to propagate a fracture, but we did not make observations of instability on these particular slopes. Perhaps the slab strength in these cases dominates, causing the entire column to fracture after a fracture is initiated.

Comparing ECT results with other methods shows how much more effectively it discriminates between our stable and unstable slopes. For example, median compression test scores are only slightly lower on our unstable slopes, and there is considerable overlap in CT scores between stable and unstable slopes (Figure 6). Likewise, lemon counts using the snow structure factors identified by *McCammon and Schweizer* [2002] are higher on our unstable slopes (Figure 7) and shear quality is predominantly Q1 on our unstable slopes (Figure 8), but again there is much more overlap in stable/unstable classifications than with the ECT test. The overlap between stable and unstable slopes using existing techniques points to the need to develop additional tests or techniques and is the reason the senior author developed the ECT.

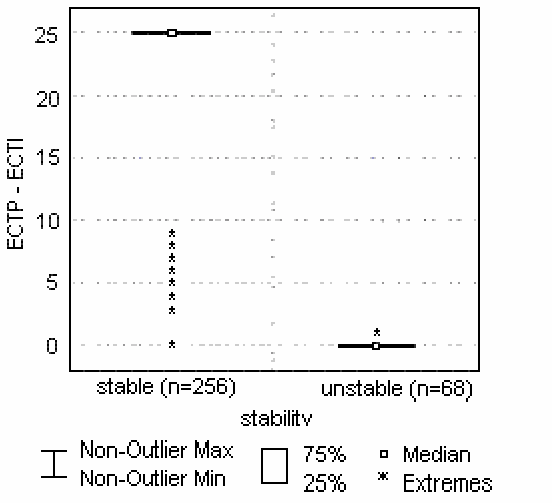

Figure 5: Boxplot showing the distribution of the difference between fracture propagation (ECTP) and fracture initiation (ECTI) for the extended column test on our stable and unstable slopes. Fractures that did not propagate across the column were given a value of 25. For all tests on unstable slopes the difference between the initiation and propagation of the fracture was two or less loading steps. The ECT effectively discriminated between our stable and unstable slopes with little overlap.

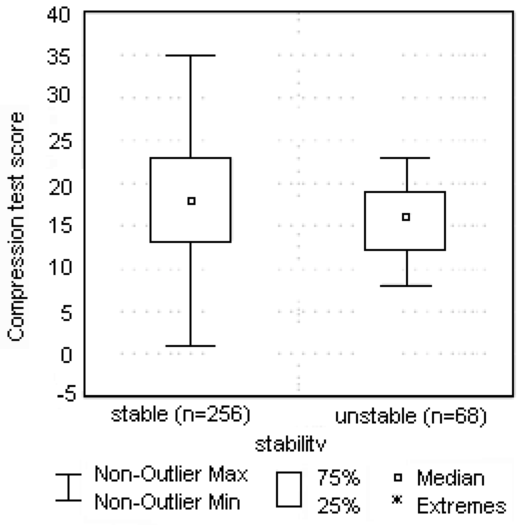

Figure 6: Compression test results for the slopes we used to test the ECT. This graph shows that the compression test does not effectively discriminate between our stable and unstable slopes.

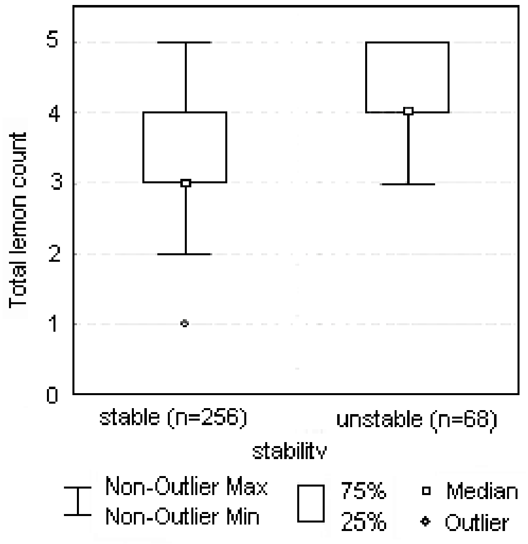

Figure 7: More than 75% of our unstable pits had a total lemon count of 4 or 5 at the critical interface, while 75% of the stable cases have 4 lemons or less. Lemons are a helpful discriminator between our stable and unstable slopes, but there is some significant overlap.

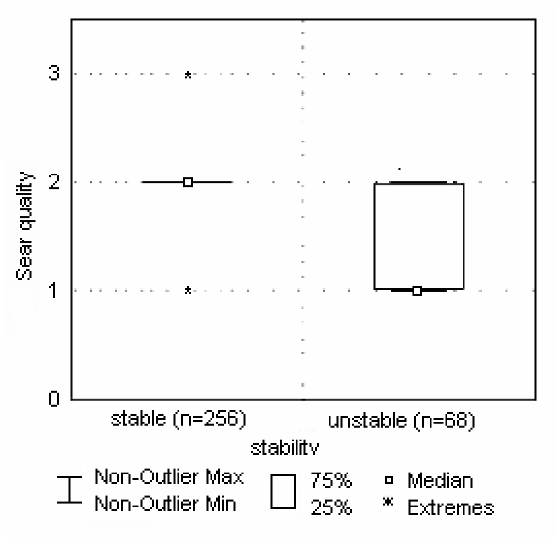

Figure 8: A comparison of shear quality on the critical interface on our stable and unstable slopes shows that Q1 fractures are more commonly associated with unstable snowpacks than Q2 or Q3. Still, there is sizable overlap, especially at the Q2 level.

## 4. SPATIAL VARIABILITY OF EXTENDED COLUMN TEST RESULTS

Given the encouraging results of the ECT during Colorado's 2005/06 winter, the senior author conducted additional tests while ski patrolling in New Zealand later in 2006. One focus of those tests was to try to assess the spatial variability of ECT results. On 27 June he collected data from 21 stable snowpack pits in the Mount Hutt range. In a grid spanning an area 30 m across the slope by 15 m down a relatively planar 32° slope, ECT results were spatially uniform (Figure 9). In no case did the fracture propagate across the column in 2 or less additional loading steps following fracture initiation. In 17 cases the fracture did not propagate at all (NP), and in four cases in the top row of tests the fracture partially propagated (PP) across the column. Even in those partial propagation cases the fracture never propagated more than 10 cm beyond the edge of the shovel, and in this part of the slope the overlying slab was slightly thicker and stronger than across the rest of the slope.

The spatial uniformity of ECT fracture propagation results is encouraging since many stability test results are quite spatially variable. In fact, the fracture initiation scores (ECTI), which are often similar to CT scores, varied on this slope from ECTI 11 to ECTI 18 (Figure 10). However, these results are from only one

Figure 9: The ECTP scores from 21 pits on a stable 32° slope at Mount Hutt range in New Zealand. None of the tests propagated across the entire column in two or less additional loading steps after fracture initiation. In four cases in the upper row, there was partial propagation (PP), but in those cases the fracture did not propagate more than 10 cm beyond the edge of the shovel. In all other cases the fracture did not propagate beyond the edge of the shovel (NP).

Figure 10: The ECTI scores from the 21 pits in Figure 9.

stable slope. We do not know how ECT fracture propagation results vary spatially across a variety of slopes or under unstable conditions. Still, these results are consistent with the idea that the potential for fractures to propagate is more spatially uniform than stability test scores [*Johnson and Birkeland*, 1998], an idea reinforced by the work of *Campbell and Jamieson* [2003] that showed that fracture character across avalanche start zones was often spatially uniform.

## 5. CONCLUSIONS

Many different techniques exist to evaluate snow stability. Our initial results suggest that the ECT might be a valuable additional tool for stability assessment. In particular, we are encouraged by how effectively the ECT discriminated between our stable and unstable slopes. Further, on one stable slope the ECT demonstrated spatial uniformity in its fracture propagation results, with none of the tests fracturing across the extended column. Despite the promising results, we caution that our results are preliminary. The test has only been used by a few people in a couple areas, and the study of spatial variability was only on one slope. In coming seasons we hope to investigate the use of the ECT in other locations, with other snowpacks, and with a variety of observers to further validate its usefulness. Also, we remind readers that all stability evaluation techniques must be supplemented by additional information such as detailed avalanche and weather observations to effectively evaluate the snowpack stability. We encourage others to try the ECT in addition to their other tests, evaluate its effectiveness, and to share their results and experiences with us.

## Acknowledgements

The authors would like to thank Dan Moroz and Tim Shinn from Copper Mountain, Colorado and John Hooker from Mt. Hutt, New Zealand for their help and useful comments during 2005/06 seasons. Chris Landry provided a valuable review of the paper with many constructive comments.

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