USING A HIGH-RESOLUTION PARTICLE TRACKING METHOD TO ANALYZE EXTENDED COLUMN TESTS

Arden Feldman[1]*, Ladean R. McKittrick[2], and Edward E. Adams[2]

[1] *Leadville, CO, USA*
[2] *Montana State University, Bozeman, MT, USA*

ABSTRACT: The Extended Column Test (ECT) has become a very popular tool for assessing snowpack stability, yet its mechanics are still not well understood. Using a high-resolution particle tracking method, we analyzed high-speed video of propagating ECTs to better understand the mechanics of the test. This digital image correlation method allowed us to analyze deformation on the entire front face of the column, giving us data that lower resolution methods would have missed. Using this high-resolution technique, we reaffirm previous research and provide new insights into the crack propagation process. For the cases analyzed, tapping on one side of the column only deformed the slab directly underneath the shovel. No deformation was observed in the weak layer or on the other side of the column until a crack initiated and propagated. These results correspond with previous research validating the ECT as a measure for crack propagation propensity. Based on a small number of test cases, it appears that during the propagation of ECTs, varying amounts of both collapse and shear occur at the weak layer. The shear can precede collapse during propagation of ECTs, but generally they seem to occur simultaneously. The shear found in this study occurs on flat slopes and is not the conventional slope angle dependent shear found in various slab avalanche models. Similar high-resolution particle tracking methods should continue to be used to enhance our understanding of the stability analysis tools that we rely on.

KEYWORDS: collapse, shear, crack propagation, particle tracking, Extended Column Test

1. INTRODUCTION

Dry snow slab avalanches are the cause of most avalanche accidents. They occur when a weak layer of snow fractures underneath a stronger, more cohesive slab of snow. The crack must both initiate and propagate for the avalanche to occur.

Both avalanche professionals and recreationalists use snowpack stability tests to analyze the propensity for weak layer crack initiation and propagation. The Extended Column Test (ECT) is unique in its ability to simply measure both initiation and propagation (Simenhois and Birkeland, 2006). The ECT involves isolating a 30 x 90 cm column of snow and incrementally loading it on one side until either a crack forms or a predefined maximum load is reached. Slab avalanche instabilities are associated with weak layer cracks that propagate through the entire column. The ECT has proven to be very useful and popular, but the mechanics of the test have seen relatively minimal research.

The goal of this study is to further understand the mechanics of the ECT using a novel high-resolution particle tracking method and high-speed video. Using the GOM Correlate 2017 software we are able to analyze deformation on the entire front face of the column. Particle tracking techniques have been used previously to study the ECT (e.g. Birkeland and van Herwijnen, 2012; van Herwijnen and Birkeland, 2014; van Herwijnen et al., 2016), but this approach provides data that lower resolution methods would have missed. We hope that our results and innovative technique can improve our understanding of the ECT and lead to better snowpack stability tests and models in the future.

2. METHODS

During the 2017/18 winter we collected data of propagating ECTs (ECTPs) in the backcountry in central Colorado. Specific locations were chosen depending on the day's conditions, prioritizing safety and finding propagating ECTs. At each site, we conducted a full snow profile and one or more ECTs (Table 1). Once the ECT was set up, we used a spray bottle and diluted black food coloring to spray a fine dot pattern onto the entire front face of the column (Figure 1). One of the biggest problems we faced was the spray bottle freezing in the cold weather. This limited the days and locations we could collect data. We conducted each ECT according to the procedure outlined in

* *Corresponding author address:*
Arden Feldman, Leadville, CO, USA
Tel: +1 (617) 930-1715
Email: ardenf@gmail.com

American Avalanche Association (2016). A high-speed digital camera on a tripod filmed the front face of the column during the ECT, and we tapped from the side of the column to avoid blocking the camera's view. The videos of the ECTs were then uploaded to a computer and relevant frames of the video were chosen for data analysis. The frames were uploaded into the GOM Correlate 2017 software and analyzed. GOM Correlate 2017 tracks changes in the dot pattern during the ECT and can be used to make a wide array of calculations based on the results.

Table 1: Snow profile data from each test site.

Site	Slope Angle (°)	Slab Height (cm)	Slab Hardness	Weak Layer
A	25	62	F - P	FC
B	25	51/93	F – 1F	FCxr/DH
C	8	37	F – 4F	FC
D	30	27	F – 4F	DH
E	23	35	F – 4F	FC
F	25	27	F - P	FC

Figure 1: A picture of the E1 ECT after the dot pattern was sprayed onto the face of the column, but before any tapping occurred.

3. RESULTS/DISCUSSION

From 6 field sites (Table 1), we gathered data from 10 ECTs. The slope angle at the sites ranged from 8° to 30°, and the slab depths ranged from 27 cm to 93 cm. Weak layers tested include facets, rounding facets, and depth hoar. The slabs consisted of various combinations of facets, rounding facets, rounds, precipitation particles, wind deposited grains, and melt freeze crusts.

Our results agree with previous studies showing that prior to crack initiation in the weak layer, tapping on the ECT progressively compresses the slab directly under the shovel (Birkeland and van Herwijnen, 2012; van Herwijnen and Birkeland, 2014). This can be seen in the E1 ECT (Figure 2) where only the areas near the shovel show displacement or blank space (due to the dot pattern being damaged too much for the software to track it). No deformation was observed in the weak layer or in other parts of the slab. This indicates that the ECT does measure the propensity of a crack to propagate.

The GOM Correlate 2017 software provides a detailed view of the crack initiation and propagation process (Figure 3). The Y displacement of the slab is equivalent to the amount of collapse in the weak layer. Downwards Y displacement of the slab starts on the shovel side of the slab and works its way to the opposite side during crack propagation (Figure 3a). The downward slab displacement coincides with a distinct area of compressive vertical strain in the weak layer that propagates from the shovel end of the column to the other end (Figure 3c). Maximum collapse amounts occur on the shovel side of the slab and range from 1.4 mm to 24.4 mm (Table 2). In all of the tests the vertical displacement on the far end of the column is significantly less than near the shovel, often reaching near zero (Table 2). In the F1 ECT, the vertical displacement at the far end actually is zero, yet it is still an ECTP due to the horizontal displacement near the weak layer (Figure 4).

Weak layer crack propagation also causes horizontal displacement in the slab during ECTs (Figure 3b). The horizontal displacement has two distinct characteristics. The top of the slab moves towards the shovel and the bottom of the slab moves away from the shovel. These displacements are first seen on the shovel side of the slab, and make their way to the other end of

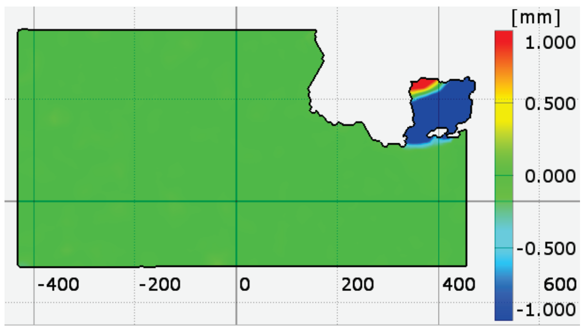

Figure 2: Particle tracking displacement Y data of E1 ECTP just before crack initiation and propagation. Positive X direction is to the right and positive Y direction is up.

Table 2: Overview of the particle tracking data from each test. Both vertical displacement (ΔY) and horizontal displacement (ΔX) values are the maximum and minimum values from the undamaged part of the slab, not directly underneath the shovel. Negative ΔY is downwards and negative ΔX is away from shovel.

Test	Result	ΔY (mm)	ΔX (mm)
A1	ECTP 29	-1.4 – (-0.2)	-0.3 - 1.0
A2	ECTP 19	-2.8 – (-0.2)	-0.8 – 1.6
B1	ECTP 14	-5.3 – (-1.1)	-1.2 – 2.0
B2	ECTP 17	-17.8 – (-4.4)	-0.5 – 8.8
C1	ECTP 14	-3.0 – (-0.3)	-1.0 – 1.1
C2	ECTP 14	-4.1 – -(0.4)	-1.5 – 1.3
C3	ECTN 12	-4.6 – 0	-1.0 – 2.3
D1	ECTP 11	-24.4 – (-0.1)	-6.6 – 13.8
E1	ECTP 13	- 4.0 – (-1.1)	-1.2 – 1.5
F1	ECTP 11	-2.7 – 0.0	-1.5 – 1.5

the slab during propagation. Magnitudes of horizontal displacement away from the shovel near the weak layer range from 0.3 mm to 6.6 mm (Table 2). Magnitudes of horizontal displacement towards the shovel at the top of the slab range from 1.0 mm to 13.8 mm (Table 2). At the far end of the column, near the weak layer, the magnitude of horizontal displacement is often similar or even greater than the vertical displacement.

The horizontal displacement away from the shovel along the bottom of the slab coincides with XY shear strain in the weak layer that propagates away from the shovel side of the column (Figure 3d). Some tests show a distinct area of shear strain in the weak layer (Figure 4d), while others do not (Figure 5d). The latter occurs when there is less horizontal displacement near the weak layer, and the noise in the data interferes with the low magnitudes of shear strain. The discrepancies in the shear strain results are most likely due to different initial snowpack characteristics. Further testing should be done to determine which snowpack characteristics correlate with higher amounts of shear strain.

The shear and collapse in the weak layer appear to propagate approximately simultaneously in most of the tests. In many of the tests, the noise in the data makes it difficult to definitively say which comes first, and therefore where the crack tip is. The one exception is the F1 ECT where the shear strain reaches the far end of the column significantly earlier than the collapse (Figures 4c and 4d). This shear poses a problem for measuring propagation speeds solely based off of the collapse, as has been the norm for previous studies (e.g. Birkeland and van Herwijnen, 2012).

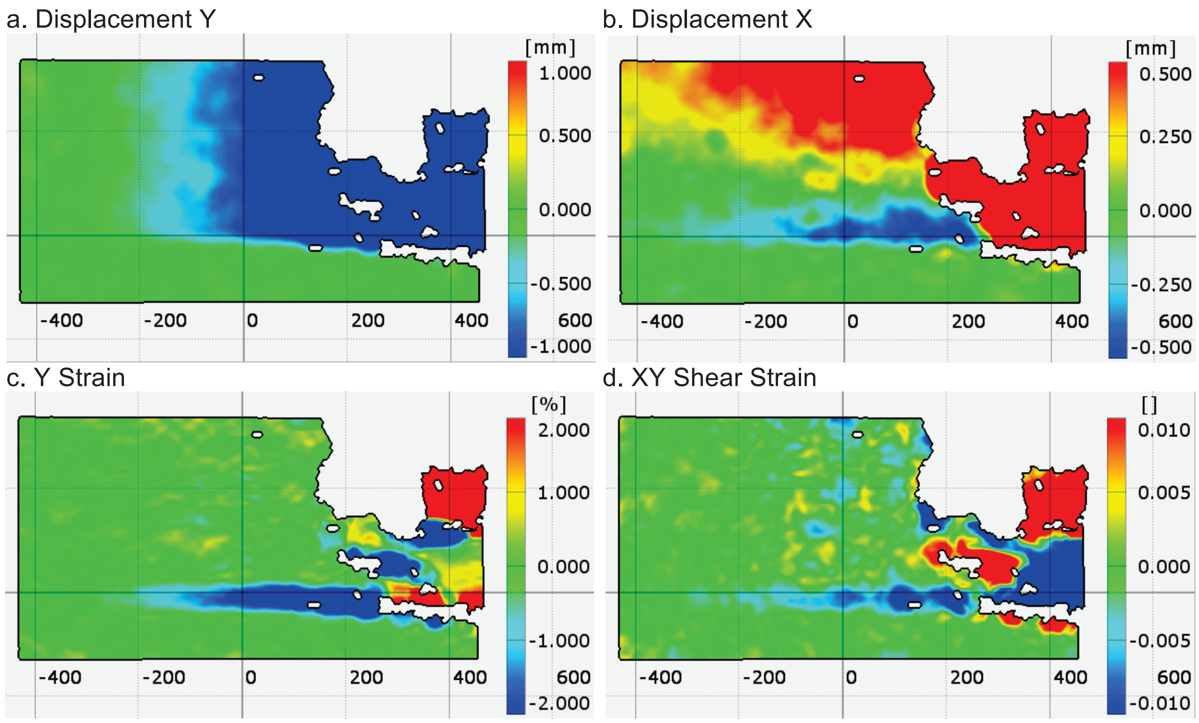

Figure 3: Particle tracking data of the E1 ECTP during crack propagation. Positive X direction is to the right and positive Y direction is up.

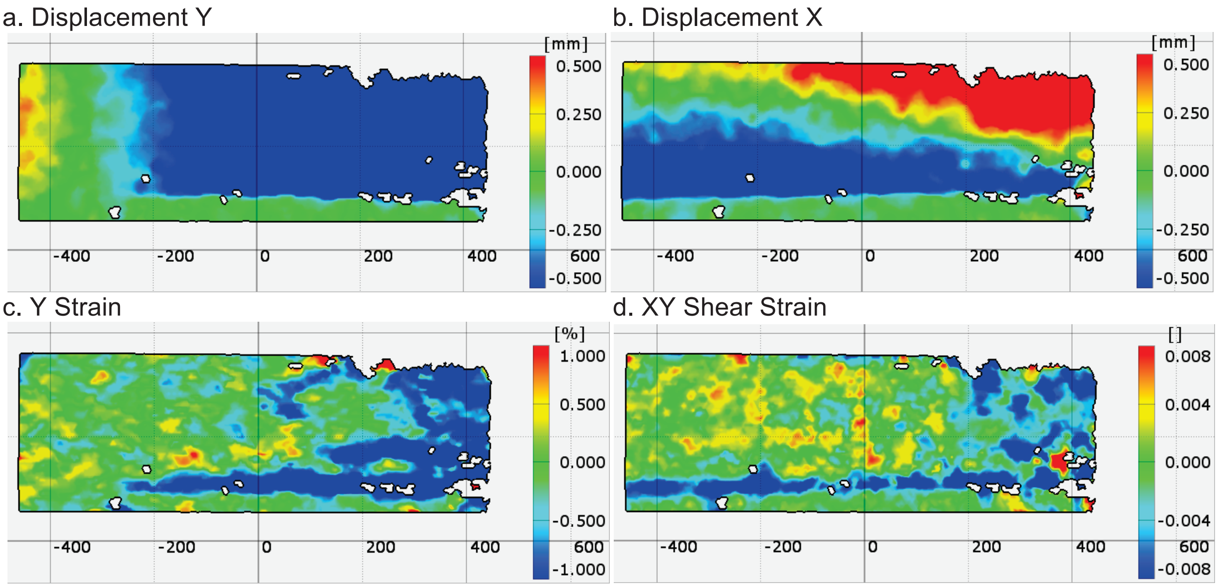

Figure 4: Particle tracking data of the F1 ECTP just after the shear strain reaches the far end of the column. In this example, the shear strain reaches the far end of the column before the collapse does. Positive X direction is to the right and positive Y direction is up.

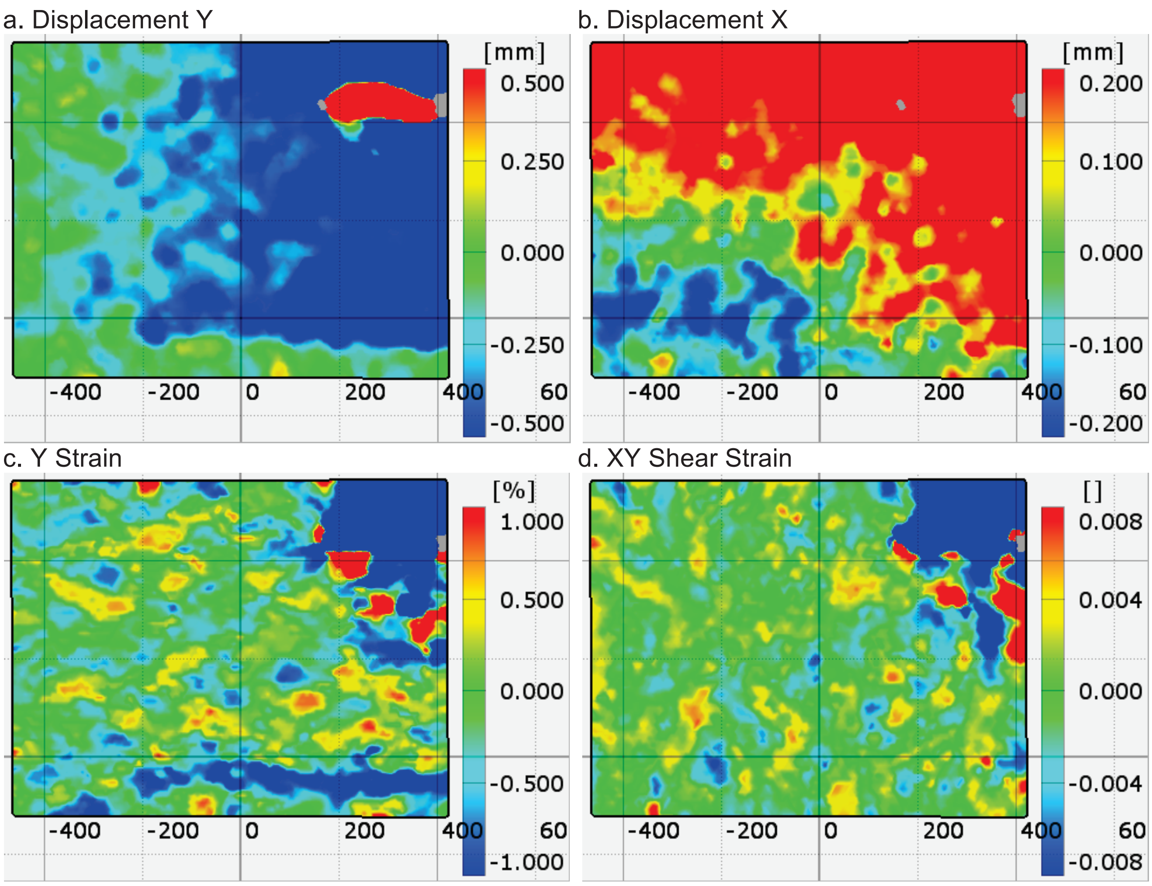

Figure 5: Particle tracking data of the A1 ECTP during propagation. In this example, the horizontal displacement along the weak layer is less significant than in other tests, and the shear strain is hard to pick out. Positive X direction is to the right and positive Y direction is up.

4. CONCLUSIONS

Using a high-resolution particle tracking method, we analyzed the mechanics of 10 ECTs. This method led to a number of conclusions:

1. Prior to crack initiation during ECTs, tapping on one side of the column only affected the slab directly underneath the shovel. We observe no evidence of deformation in the weak layer or on the far end of the column. This means that the ECT measures the propensity of a crack to propagate.
2. During the propagation of ECTs, varying amounts of both collapse and shear occur at the weak layer.
3. Shear can precede collapse during propagation of ECTs, but generally they seem to occur simultaneously in the tests performed in this study.

There is an ongoing debate regarding the importance of collapse versus shear during slab avalanche release (Bair et al., 2016). Recent theories use a mixed mode failure criterion for the weak layer, combining collapse and shear mechanisms to account for failure propagation (Gaume et al., 2016). The shear found in this study is not the conventional, slope angle dependent shear found in various avalanche models (e.g. McClung, 1981; Gaume et al., 2016). The shear in this study can and does occur in flat areas together with collapse. We would like to emphasize that our dataset is limited, and further testing needs to be done to confirm our results and to see if this shear only occurs in the ECT, or if it is a widespread phenomenon that actually occurs in avalanches. A good start would be to apply a similar high-resolution particle tracking method to the Propagation Saw Test, and to small test slopes, to reduce edge effects.

The noise in our data limited our ability to definitively determine the order of the shear and the collapse, and therefore the location of the crack tip. Using a higher quality high-speed camera with increased resolution would hopefully solve this. Unfortunately our camera compromises resolution when in the high-speed setting.

Similar high-resolution particle tracking methods should continue to be utilized and improved upon to enhance our understanding of the stability analysis tools that we rely on. The ability to track the entire front face of the column appears to be critical for catching the fine details of crack propagation.

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