Mechanism of dry slab avalanche release – a look under the hood

Ron Simenhois

The Friend of The North Douglas Avalanche Center,
Coeur Alaska, Juneau, AK 99801, United States of America.
Thanks to:

Ned Bair

Joachim Heierli

Alec van Herwijnen

Karl Birkeland
Dry slab avalanches begin when a fracture in a weak snowpack layer undercuts a large portion of the slope.

Photo: Mike Bartholow
In this presentation...

- Fracture mechanics lite (very lite)
  - Cracks
  - Energy
- The mix mode anticrack
- What bring fractures to arrest
- Crack face friction
- Practical implications
Fracture mechanics:
Cracks:

Cracks weaken the material more than you would expect from the reduction in intact cross-section.
The Energy: (Equations for Wendy)

- The energy balance approach (Griffith 1920):
  - $U = U_F + U_M$, $U_M = U_G + U_E$

Video: Alec van Herwijnen
Weak layer collapse

\[ N_{\text{total}} = 89 \]

\[ \nu_y (\text{cm}) \] vs. Propagation distance (m)

Alec van Herwijnen
The Energy: (Equations for Wendy)

- The energy balance approach (Griffith 1920):
  
  \[ U = U_F + U_M, \quad U_M = U_G + U_E = -U_E \]

- \( U_M(r) = C \frac{\sigma^2 r^2}{E} \)

Video: Alec van Herwijnen

\( C \) – constant, \( E \) – elastic modulus, \( E = \frac{\sigma}{h_f} \)
The Energy: (Equations for Wendy)

- The energy balance approach (Griffith 1920):
  - $U = U_F + U_M$, $U_M = U_G + U_E$
  - $U_M(r) = C \frac{\sigma^2 r^2}{E}$
  - $U_F = W_f r$

- The elastic energy grows faster than the work it takes to fracture material

$C$ – constant, $E$ – elastic modulus, $E = \frac{\sigma}{h_f}$
The Energy: (Equations for Wendy)

- Energy release rate (rate – per area, not time):
  \[ G = \frac{dU_E}{dr} = C \frac{\sigma^2 r}{E} \]

- Fracture propagation
  \[ \frac{dU_F}{dr} = w_f = \text{constant} \]

- If \( G \geq W_f = \text{fracture propagation} \)

- Fracture toughness
  \[ \sigma_f = \sqrt{\frac{EW_f}{rC}} \]

\[ C - \text{constant}, \ E - \text{elastic modulus}, \ E = \frac{\sigma}{h_f} \]
In theory once a self propagation fracture starts, it can go for ever

Photo: Mohan Rasiah
Take home message (fracture mechanics):

- Loading is critically important
- Soft slab avalanches are easier to trigger than hard slab
- Crack size counts.
Mix Mode Anticrack:
Mix Mode Anticrack has both compression and shear components in it.

\[ U_M(r) = \frac{\pi \gamma r^2}{4E_{slab}} (\sigma^2 + \tau^2) - \frac{r^3}{6E_{slab} D} \left[ \lambda_{\tau\tau} \tau^2 + \lambda_{\sigma\tau} \sigma \tau + \lambda_{\sigma\sigma} \sigma^2 \right] \]

Joachim Heierli 2008
How does slope angle affect ECT results?
Field areas
Field area - Montana
Field area – Chugach Alaska
Field area – SE Alaska
Slightly modified ECT

> 2(slab depth) + shovel width

*Only considered ECTPs*
Other data

- Slope angle measured by looking upslope with a Suunto clinometer (±1°)
- Weak layer depth at each test
- One manual profile/day
Snowpack structure

- Surface hoar weak layer for all four datasets (4 to 10 mm xtals)
- Mean slab depths from 24 to 30 cm (sd = 1-4)
- Mean slab densities from 160 to 180 kg/m³
Snowpack structure (SE AK)

- SS over 4F- PP ~28cm deep.
Results – Montana:

Dataset 1:
ECTP taps vs slope angle

Dataset 2:
ECTP taps vs slope angle
Results – Chugach Alaska:

Dataset 3:
ECTP taps vs slope angle

Slope angle
ECTP taps

Dataset 4:
ECTP taps vs slope angle

Slope angle
ECTP taps
Results – Southeast Alaska:

Slope angle
Take home message (Mix mode anticrack):

- If the snow conditions are reasonably similar, observers can conduct tests on low angle slopes before committing to steeper terrain
Fracture arrest:

In theory it shouldn’t happen, but in reality it happens often. Why?

- Not heavily researched
- Dynamic system
  - $G < W_f \neq \text{fracture arrest}$
- Spatial variability is to blame, but...
Fracture arrest:

Two main reasons:

- Increase in $W_f$
- Decrease in $U_M$
  - Slab fracture
  - Decrease in wave length
  - Decrease in slab thickness
  - Decrease in collapse magnitude.

Photo: ASARC
Fracture arrest:

Slab Fracture

- “The race”
- Transition from SS to HS can create similar effect

Gauthier & Jamieson 2010
Fracture arrest:

Decrease in wave length:
- Crack size is limited \((2r \approx l)\)
- Effective wave length \((l > 2r_c)\)
  - Decrease in elastic modulus
  - Decrease in slab thickness

Joachim Heierli 2008
Fracture arrest:

Decrease in gravitational energy (or load)

Ned Bair
The effect of changes in slab thickness:

- In 2007/2008 winter in Colorado and winter of 2008 in New Zealand we collected data on fractures along weak snowpack layers.
Methods:

- ECT length was between 200 – 300 cm to capture slab thickness variations.
- In some of the pits we modified the slab thickness with a snow saw.
Results:

- In all 116 side by-side tests from 52 pits:
Results:

- In all 116 side by-side tests from 52 pits:
Take home message (fracture arrest):

- Hard slab avalanches likely to be larger than soft slab avalanches
- Fractures are more likely to propagate from areas of thin slab to areas of thick slab than the other way around. ⇒ Wise route selection / escape route

Photo by Garrett Grove
Downslope motion...

- Different types of weak layers have different “preferred" avalanche release angles

From McCammon I., 2009 (TAR Vol. 27, NO 4)
Methods (Friction coefficient measurements):

Procedure field work:
Methods (Friction coefficient measurements):

Procedure: Deriving the friction coefficient

For every frame in the video {
- \((u_x(t), u_y(t))\)
- \((v_x(t), v_y(t))\)
- \(v(t) = v_0(t) + at\)
- \(a = \frac{v(t) - v_0(t)}{t}\)
- \(aM = F = \frac{(F_g - \mu F_n)}{M}, \) (Newton’s 2nd)
- \(a = \frac{1}{M(F_g - \mu F_n)} = g(sin\theta - \mu cos\theta)\)
- \(\mu = tan\theta - \frac{a}{g cos\theta}, \theta \neq 0\)
}  
- Get average \(\mu\)
Results (Friction coefficient measurements):

PWL vs. NPWL:

Friction Coefficient ($\mu$):

PWL ($N=34$) (from van Herwijnen and Heierli [2009])

NPWL ($N=7$)

Weak layers type
Results  (Friction coefficient measurements):

![Graph showing friction coefficient measurements against slab hardness.](image_url)
Results (Friction coefficient measurements):

![Graph showing the relationship between friction coefficient and h_{below} - h_{above} with n=57 data points.]

- The graph illustrates the trend of friction coefficient measurements.
- The data points are plotted on a linear scale.
- The formula n=57 is noted on the graph.

The diagram visualizes the sliding friction data, where the friction coefficient decreases as the difference between h_{below} and h_{above} increases.
Take home message (friction):

- Avalanches releasing on non-persistent weak layers tend to release on steeper slopes mainly due to crack face friction.
- Ski cutting newly fallen soft snow can be deceptive if not carried to the steeper part of the slope.
- Hard slab avalanches are more likely to “pull” into flatter areas.
- Relying on crack face friction for stability evaluation is impractical.
Take home message (important):

- The fundamentals of avalanche forecasting shouldn’t change.
- The snowpack doesn't care how much you know
  - Use your knowledge to understand why you need to maintain margins of error rather than narrowing them down.
Thanks!