INTEGRATING STRENGTH, ENERGY, AND STRUCTURE INTO STABILITY DECISIONS

"So you dig a pit and then what?"

By Ian McCammon and Don Sharaf

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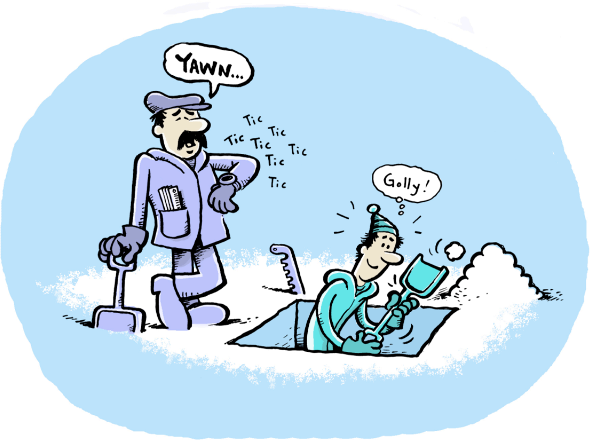


"You get in zee pit, you get zee information, you get out" – Peter Schaerer told one of us during a training course. Along with his advice that you should never stop observing changes within the snowpack was the stern admonition that snow pits should be focused, efficient, and QUICK.

For years, avalanche educators have taught students to dig snow pits to look at stratigraphy, identify snow crystals, and perform stability tests. But correlating snow profiles with stability has never been an exact science, and many students came away unsure of exactly how they were supposed to use snow stratigraphy in their stability decisions. Moreover, many of them lacked clear objectives for their pit analysis and ended up wasting time collecting tedious and semi-relevant information. The result fell far short of Peter Schaerer's sage advice. Rather than training people to make quick, informed decisions, we seemed to be creating an army of winter recreationists who could spend half an hour or more in one snow pit, but couldn't tell you how, why, or when they would use the information they found.

Two years ago, we began teaching a simple approach to interpreting snow profile results on upper level avalanche courses and professional training seminars. Many students said the approach produced an "a-ha!" moment for them and they were excited to learn a simple way to focus their efforts in their snow pits. In this article, we'll describe our approach and how we teach it, in hopes that others may find it useful in helping their students to make quick and informed stability decisions.

A three-part model

The discipline of fracture mechanics tells us that three things need to happen in order to produce the large-scale shear fracture that initiates a slab avalanche:

> 1) The fracture must begin at some point under the slab where the shear ***strength*** of the weak layer is overcome by applied stresses,
>
> 2) The shear fracture must liberate enough ***energy*** from the snowpack to sustain its own propagation, and
>
> 3) There must be a "path of least resistance" in the snowpack ***structure*** along which the shear fracture can propagate.

These three components of ***strength, energy,*** and ***structure*** are a simplification of the complex interrelationships that produce slab avalanches. But from a teaching standpoint, they provide an effective way of summarizing important stability information that students can gather from a few simple field procedures.

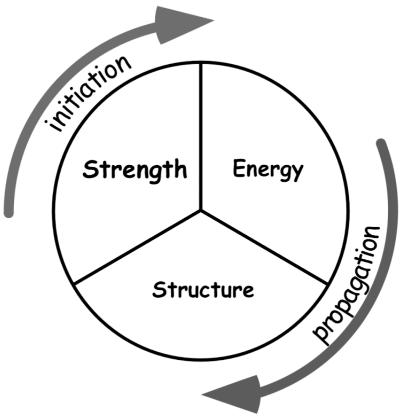


Figure 2. A fracture mechanical model of slope

Strength

The backbone of most Level 1 stability classes is the standard stress-strength model. This model says that a weak layer will fail when you apply enough stress to it. An important implication of this model is that when stress and strength are very nearly balanced, unstable conditions will exist and slabs may be easily triggered by the weight of a skier or snow machine. In this model, the role of stability tests is to assess whether stress and strength are in a critical balance. If your stability test scores are low, the weak layer is in a critical state of balance. But if your stability scores are consistently high, the weak layer is less likely to be triggered. Many students come away from avalanche courses with a simple rule of thumb: low scores are bad, high scores are good. Thus it's no surprise that some of them come to base their go/no go decisions almost entirely on cursory avalanche observations and test scores from one or two snow pits.

Research has shown that the stress-strength model works pretty well most of the time: high test scores generally do correlate with stable conditions. But not always. A disturbing number of accidents occur during "false stable" conditions, where tests indicated stability but avalanches were still triggered by a skier or rider. In these cases, practitioners in the know say "Well, that's spatial variability for you" and shake their heads in recognition of the tough job they have chosen. But for decision makers who rely on stability tests the message is deeply troubling – the stress-strength model is not the whole picture.

Energy

In 1998 , Ron Johnson and Karl Birkeland described a formal rating system for a phenomenon that field practitioners had noticed over the years: when stability tests fractured with a clean and fast shear, triggered avalanches were more likely. In 2001, Schweizer and Weisinger described a similar system used with rutschblock tests in Switzerland and in 2002, van Herwijnen and Jamieson described a system of fracture character used in Canada Exactly what these schemes are measuring remains unclear, but one trend stands out: fast and clean shears release their fracture energy quickly, and are more frequently associated with unstable conditions. See Karl Birkeland's article on stability, shear quality, and fracture character in the previous issue of *The Avalanche Review* for more details.

Sudden Planar: SP
Sudden Collapse: SC
Resistant Planar: RP
Progressive Compression: PC
Non-Planar Break: B

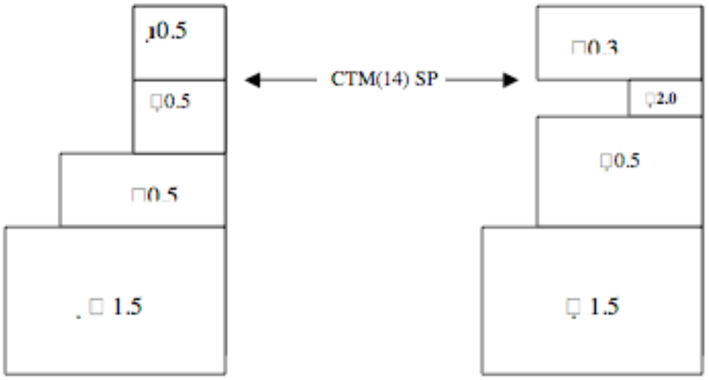
Canadian Fracture Character Classifications

Fracture mechanics tells us that the higher the fracture energy release rate, the greater potential the fracture has for propagation. Shear quality and fracture character may only provide a very rough estimate of the fracture energy release rate, but when used in conjunction with stability tests, shear quality seems to provide valuable information regarding the likelihood of avalanche triggering.

Structure

Imagine two snow profiles. In one, an interface between light-density storm layers produces a moderate and sudden planar fracture 30 cm from the surface. In the second, a layer of facets beneath a hard wind slab produces the same fracture character and score at the same depth. Even though the two weak layers have the same strength and release their energy at the same rate, few practitioners would treat the two snow packs the same.

Figure 3: Two profiles with similar strength and energy, but different structural properties



In an effort to characterize some of the “red flags” that professionals use in comparing such profiles, McCammon and Schweizer (2002) described five stratigraphic features of weak layers that statistically correlate with skier-triggered avalanches (Table 1). These features, referred to here as “lemons”, appear to be rough indicators of how well a snowpack might concentrate shear stresses in a weak layer. The more lemons in a weak layer, the more structurally weak the snowpack.. Schweizer et al. (2004) extended the initial concept, and refinement of the system continues.

Weak Layer Depths ≤ 1m
Weak Layer Thickness ≤ 10cm
Hardness Difference ≥ 1 step
Weak Layer Grain Type: Persistent (SN, DH, FC)
Grain Size Difference ≥ 1mm

Table 1: Five Structural “Lemons”

Taken alone, ***strength***, ***energy*** and ***structure*** only do a fair job of predicting skier triggered avalanching. But fracture mechanics tells us that when all three factors are present, shear fractures are more easily initiated and are more likely to propagate large distances. Bruce Tremper uses the analogy of a combination lock; when all three tumblers of strength, energy and structure fall into place on a particular slope, conditions are primed for avalanching. False stable conditions exist when the tumblers of energy and structure are present, but strength tests indicate stability. Under these conditions, wandering onto an isolated weak spot can cause localized fracture that can propagate into an avalanche.

Teaching

The standard way that we approach teaching mechanics and stability assessment using strength, energy and structure typically goes like this:

1) Review the stress-strength model and its limitations
2) Describe shear quality as a way of quantifying elastic energy release
3) Introduce the lemons as a method of analyzing snow structure
4) Incorporate the lemons into a quiz for strength, energy, and structure
5) Introduce the concept of the 'Test +' pit as an efficient way to analyze snow strength, energy and structure in a snow pit

The Test + Pit

In *Snow Sense*, Jill Fredston and Doug Fesler describe three questions to ask when digging a test pit:

1) What is the weakest (significant) layer?
2) How much force does it take to make that weak layer fail?
3) What is the depth and distribution of that weak layer?

These are very good questions to help focus snow pit observations and keep the observer from analyzing layers that are unimportant for an immediate go or no go decision. A test + pit takes the three questions and then asks you to get more structural information about the weak layer. To answer the five lemon categories, you need this additional information about the weak layer only. Obtaining this information shouldn't take more than a few minutes .

1) What is the hardness of the weak layer and the layer immediately above it?
2) What is the grain size of the weak layer and the layer immediately above it?
3) What is the grain type of the weak layer? Persistent?
4) What is the weak layer depth (answered before with the previous questions)
5) What is the weak layer thickness?

Helpful hint: When teaching about the lemons we strongly encourage the students to write down the lemons into the back of their field books (along with the three objectives of a standard test pit).

As always, information from a snow profile shouldn't override class 1 information (natural avalanches, recent loading, shooting cracks). However, we have found that when students look at snow profiles within a larger mechanical framework, their efforts are more focused, efficient, and productive. So get in those snow profiles and then… get out!

Test results	*Strength*	*Energy*	*Structure*	*Stability*
RB6 Q3 L2	Strong	Slow	Strong	Good
RB2 Q1 L4	Weak	Fast	Weak	Poor
RB6 Q1 L5	Strong	Fast	Weak	False stable?

Table 2. Examples used in introducing the fracture mechanics model of slope stability. Students are encouraged to consider all three

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