Using a checklist to assess manual snow profiles

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1. Background

In recent years it has become increasingly apparent that our favorite snowpack stability tests are better indicators of whether a skier is likely to *initiate* a fracture in a weak layer than whether – once initiated – the fracture will propagate. Since in most cases, fracture propagation in a weak layer on a sufficiently steep slope leads to slab avalanche release, we could write

Fracture initiation + fracture propagation = slab release

Probably because stability test scores are primarily indicators of fracture initiation and because they can exhibit substantial spatial variability (e.g. Campbell, 2004), practitioners and researchers have been seeking tests and indicators of fracture propagation (e.g. Jamieson, 2003) other than whumpfs and slab avalanches.

2. Progress

For decades, avalanche practitioners have been observing and communicating the appearance of fractures, e.g. clean and fast. In 1995, Jürg Schweizer and others concurred with such observations, and emphasized observation of the portion of the block that released in rutschblock tests, e.g. whole block, most of block, only an edge. Seven years later, Schweizer proposed that rutschblock tests were large enough for their *fracture characteristics* to be indicative of fracture propagation potential, e.g. the release of the whole block suggests that propagation is possible. In the same year, Ron Johnson and Karl Birkeland suggested at the 2002 ISSW that the *appearance* of the fracture in stuffblock and other small column tests might be indicative of fracture propagation. They classified the fracture appearance in three classes known as Shear Quality, which is similar to Fracture Character (Birkeland, 2004). In a recent article in *The Avalanche Review*, Ian McCammon and Don Sharaf (2005) interpreted *sudden* fractures (Quality 1, or Sudden Planar and Sudden Collapse fractures) as indicating that the release of energy was favourable to fracture propagation. In his 2004 ISSW paper and recent thesis, Alec van Herwijnen showed that weak layer and interface properties for a large dataset of *sudden* fractures were associated with weak bonding and stress concentrations favourable for fracture initiation and propagation. So it seems that sudden fractures may be indicative of fracture propagation potential in weak snowpack layers.

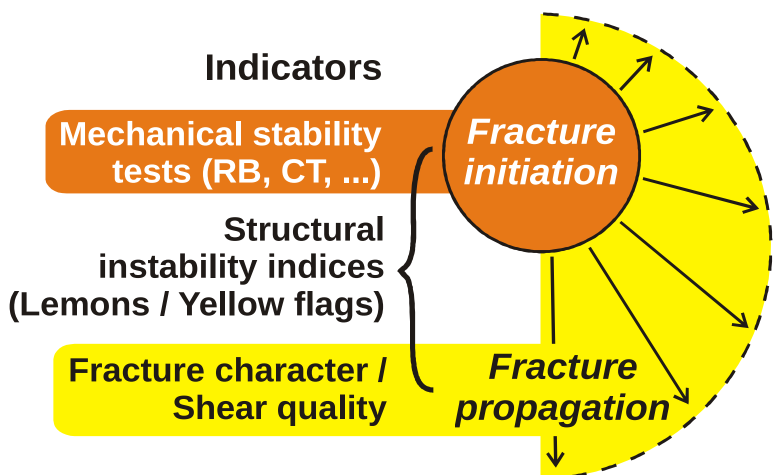

Figure 1. Recent studies suggest that stability test scores are primarily indicative of fracture initiation, and fracture character or shear quality are primarily indicative of propagation, whereas structural instability indices may indicate whether fracture initiation **and** *fracture propagation are likely.*

Of course, two indicators can be better than one. In a poster at the 2002 ISSW, Ian McCammon and

Jürg Schweizer developed a simple method for scanning snow profiles and flagging certain characteristics associated with instability of the interfaces between adjacent layers. These five instability flags, called "Lemons", include the hardness difference and grain size difference across interfaces. The Lemon count for the profile is the maximum number of Lemons for any interface in the profile. The Lemon count for profiles correlated with the stability assessment on similar slopes, i.e. more Lemons, lower stability. In 37 of 41 profiles on slopes that had avalanched, the bed surface had the most Lemons, or was tied for the most. Ian and Jürg proposed that the Lemon count was a good indicator of instability, partly because it selected interface characteristics favourable to propagation.

Using a large dataset from the Columbia Mountains of western Canada in his thesis, Alec showed that snow layer and interface characteristics similar to Lemons (more on these later) were favourable to fracture initiation *and* fracture propagation. This means we may have two indicators of fracture propagation potential, as shown in Figure 1, which is based on the "stability circle" developed by Ian McCammon and Don Sharaf. In the diagram, we show that while stability test scores may be primarily indicative of fracture initiation, structural instability indices, such as the Lemon count in a profile, are likely indicative of fracture initiation *and* propagation.

To summarize these recent ideas:

- Scores from stability tests such as the rutschblock, compression test or stuffblock test are indicators of whether skiers are likely to *initiate* fractures. These scores vary considerably over the terrain, and false stable scores are not uncommon.
- Fracture character or shear quality are indicators of whether fracture propagation in the weak layer or interface is likely or not. Cam Campbell (2004) showed that sudden fractures are often quite consistent within avalanche start zones.
- *Structural instability indices* such as McCammon's Lemons correlate with skier triggering probably because they are indicative of fracture initiation *and* fracture propagation.

3. Yellow flags

At the 2004 ISSW, Jürg Schweizer and others developed a set of critical layer and interface properties, similar to McCammon's Lemons, but based on several hundred profiles from the Swiss Alps and Columbia Mountains. They showed the maximum count of these critical snowpack properties in any interface of a profile could distinguish most profiles on skier-triggered slopes from most profiles on slopes that had been tested by skiers but not triggered.

The optimal critical ranges for these properties were different for profiles from the Swiss Alps and from the Columbia Mountains of western Canada. In this article, we'll use the set of Columbia Mountain profiles from the ISSW paper by Schweizer and others, and modify the critical ranges to make them easier to use. Because the approach is different from but based on McCammon's Lemons, each layer or interface with a property in the critical range is marked with a Yellow Flag.

Table 1: Yellow flag criteria for identifying potential failure layers

Property	Critical range (Columbia Mtns)
Layer properties	
Average grain size	> 1 mm
Hardness*	< 1F (3*)
Grain type	Persistent (SH, FC or DH)
Interface properties	
Difference in grain size	> 0.5 mm
Difference in hardness*	> 1 *
Depth of interface	20 to 85 cm

* hand hardness F, 4F, 1F, P, K is assigned values of 1, 2, 3, 4, 5, respectively. Fractional values are allowed, e.g. 4F+ and 1F- are 2.3 and 2.7, respectively.

Although based on data, the approach and the ranges have similarities to assessments by experienced practitioners and by expert systems (e.g. McClung, 1995).

4. Method

There are three layer properties and three interface properties to check (Table 1). Start with the first layer property: average grain size. In a column, put a flag (or checkmark) beside each layer with average grain size *larger* than 1 mm (Table 1). (For crusts without a reported grain size, use 1 mm.) In the second columns, flag each layer that is softer than 1F (1-finger), and in the third, flag each layer that consists of persistent weak grains (surface hoar, facets or depth hoar). In three more columns, flag each interface that is critical according to each of the interface properties in Table 1. See Figure 2 for an example.

Now scan down the interfaces, add the number of flags for each interface and for the adjacent layer that has the most flags. For example, suppose an interface has one flag, the layer above has two flags and the layer below has one; the total for that interface is three. This gives each interface in the profile a number (count of flags) between 0 and 6. The predicted failure interface(s) are those with the maximum number of flags, and there can be more than one interface with the same maximum. Similarly a rutschblock or other snowpack test can identify more than one critical interface.

The maximum number of flags for any interface is the structural instability index for the profile.

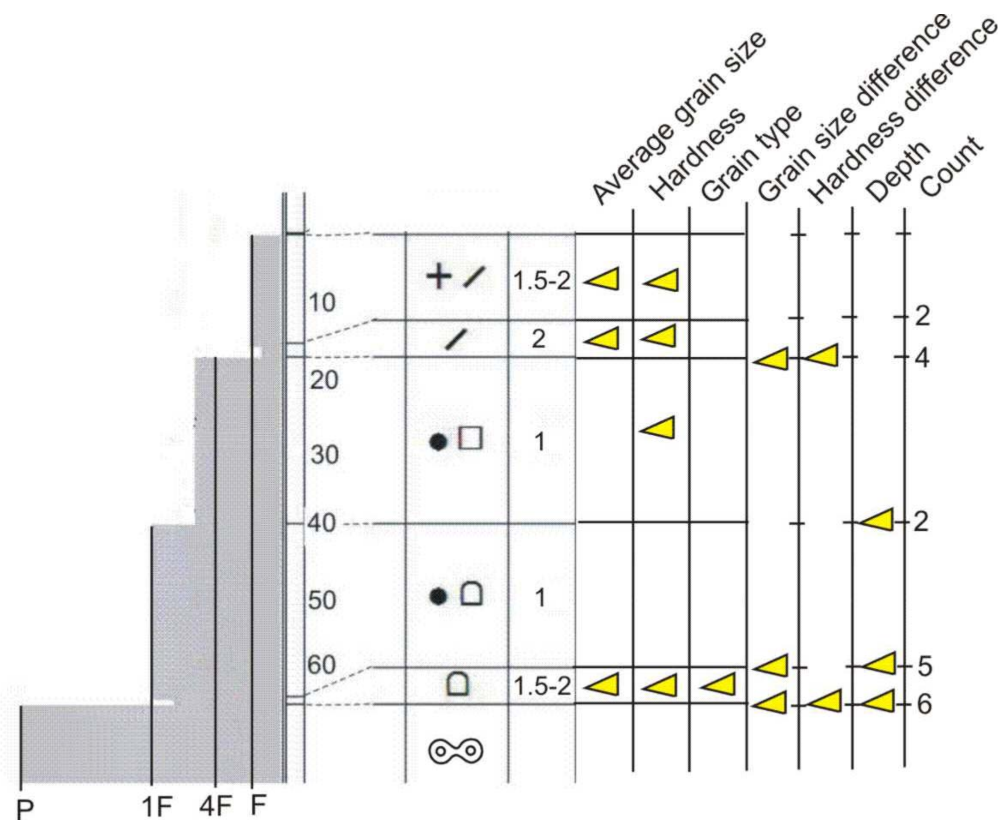

Figure 2. Example of using flags to find critical interfaces (those with higher scores more likely to release slab avalanches and fracture in stability tests) and to assess the profile (skier triggering likely if at least one interface has 5 or 6 flags). The flag count for this profile is 6, and the observer triggered a whumpf on the adjacent slope. The fracture occurred on the layer of rounded facets 64 cm below the surface.

5. Results

Two hundred and sixteen profiles from skier-tested slopes in the Columbia Mountains were used to optimize the critical ranges of the yellow flags. One hundred and seventeen of these were on slopes triggered by skiers and the others were on slopes that had been skier tested but not triggered. A separate set of 54 profiles was used to test the yellow flag method, 16 of these were on skier-triggered slopes. (For more on the learning and test samples, see Schweizer and others, 2004).

On the slopes that were not triggered, Table 2 shows 59% of the profiles in the learning sample and 66% of the profiles in the test sample had no interfaces with 5 or 6 flags. For the slopes that were skier triggered, at least one interface had five or six flags in 67% of the profiles in the learning sample and in 75% of the profiles in the test sample. Apparently, using the critical ranges in Table 1, the method recognizes unstable slopes better than stable slopes.

Table 2. Accuracy of Yellow Flag method for Columbia Mountain profiles on skier-tested slopes

Sample	Slopes not triggered by skiers	Skier-triggered slopes
Learning	59% (58 of 99) flag count of 4 or less	67% (78 of 117) flag count of 5 or 6
Test	66% (25 of 38) flag count of 4 or less	75% (12 of 16) flag count of 5 or 6

6. Limitations

The method only identified 67% to 75% of unstable slopes. This means it did **not** identify 25% to 33% of the unstable slopes! The inaccuracy is partly because the count of Yellow Flags is too simple to capture all the information relevant to skier triggering, and partly because profiles are point observations of the snowpack—and some avalanches are triggered from a point where snowpack properties are different from the profile site. Site selection is important, although perhaps less critical than for common stability tests.

The profiles were quite detailed. Research is required to determine the accuracy of the method when applied to less detailed profiles.

Like the count of McCammon's Lemons, the maximum number of Yellow Flags in a profile is a promising objective index of instability. However, its value in making decisions about avalanche risk is unclear, especially for experienced avalanche practitioners. Decisions regarding avalanche risk should include terrain as well as proven indicators such avalanche observations, recent weather and ─ where available and applicable ─ snow profile information and snowpack tests.

7. Summary

A set of layer and interface properties was proposed to objectively assess manual snow profiles, i.e. to find the most critical interfaces. The maximum number of flags for any interface is the structural instability index for the profile.

The simplistic interpretation of the index summarized above (5 or 6 flags indicative of instability) was correct for about 67% to 75% of skier-triggered slopes in the Columbia Mountains. The critical ranges of the layer and interface properties presented in Table 1 are based on dry snow profiles from this range. They were evaluated *only* for skier triggered avalanches, and may not be relevant for other types of triggers. For similar approaches to assessing profiles from other snow climates, see McCammon and Schweizer (2002) and Schweizer and others (2004).

While skill and experience are required for site selection and snow profile observation, experienced and inexperienced people and computer programs should calculate the same index from the same profile. The index does not require a rutschblock or other stability test, although such tests remain valuable as independent indicators of instability.

The method can be used in training for snow profile interpretation.

While site selection for profiles is important, structural instability indices such as the count of Lemons or Yellow Flags are probably less sensitive to site selection than results of stability tests such as the rutschblock test.

Structural instability indices such as the Yellow Flag count provide an objective index (0 to 6) that can be averaged (or otherwise aggregated) to identify differences in *structural instability* between drainages, aspects, elevations, zones, etc.

Structural instability indices are an active research topic. The described method is likely to be updated as more profiles from more areas become available.

Acknowledgements

Our thanks to Ian McCammon, Alec van Herwijnen, Charles Fierz and Ian Tomm for stimulating discussions on structural instability indices, and to the many ASARC staff and graduate students who observed the profiles. The Canadian contribution to this paper was supported by the Natural Sciences and Engineering Research Council of Canada, the BC Helicopter and Snowcat Skiing Operators Association, Mike Wiegele Helicopter Skiing, the Canadian Avalanche Association and Canada West Ski Areas Association.

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