ROUGH CORRELATIONS OF COMMON SNOWPACK STABILITY TESTS

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ABSTRACT: Because each different layer of snow can respond to applied stress in a variety of ways, and because the mechanical properties of snow layers often change dramatically over space and time, it is difficult if not impossible for one simple mechanical test to determine whether or not a slope can avalanche. Often this can only be definitively answered by actually skiing, riding, hiking, climbing or boarding the slope in question–which is <u>not</u> recommended as a mechanical test except in the context of slope cuts or ski testing, preferably on small safe(r) slopes. However, there are a variety of simple field tests available that can safely aid in the stability analysis process, and these include the Rutschblock, Stuffblock, Compression (or tap) Test, and Shovel Shear. When these tests are used in combination with all the other snowpack, weather and terrain factors out there–and when they are repeated often enough to appropriately sample the spatial and temporal variability of snow–then they can help to determine avalanche potential and promote safe travel.

For practical purposes in many applications, common snowpack stability tests can be categorized into three basic stability levels. In addition to the internationally accepted test descriptors and classifications, these levels can be approximated in the Red-Yellow-Green or GO / NO GO rating system (Fesler and Fredston, 1994[2]) that gives ***<u>rough</u>*** correlations between various tests and the estimated stability level(s) of red (NO-GO) yellow (Caution) or green (GO):

- Red light (No Go) — another time, another day or try another place
- Yellow Light (Caution) — be conservative, more tests recommended
- Green Light (Go) — proceed, but don't stop thinking and updating

Be aware that the strength test table below provides ROUGH test correlations, and proper application involves practice and consideration of all factors in the data triangle (snowpack, weather, terrain and the human factor).

Useful snow stability information is hardly ever derived from just one test or one snowpit. It involves a process—an evolution of stability assessment—with snow profiles and strength tests being just one component. Avalanche potential is part of a strength-energy-structure continuum, and stability tests relate primarily to the strength portion. Hence other important considerations include knowledge about snowpack energy (related to the shear or fracture quality of stability tests) and snowpack structure (McCammon and Schweizer, 2002[3]).Accident research has shown that human triggered avalanches occasionally occur with stability (Rutschblock) scores of 6 and 7 and an apparent Green/Go rating level. In these events, consideration of other instability indicators such as poor structure (more lemons) or more available energy (high quality shears) can be essential in helping to avoid or mitigate avalanche danger.

Keywords: stability test, snowpack strength, avalanche danger, snowpack structure, snow profile, shear test

1. INTRODUCTION

During the recent past an increasing body of knowledge has developed about how to best test for snow stability, and how to apply this information to maximize safe mountain travel and minimize avalanche related danger. These tests have presented the back country enthusiast with a larger array of stability information, but not necessarily a more easily applied methodology for making appropriate travel decisions. Despite these advances in field snow strength assessments, no single test offers the "one pill" or "silver bullet" that will ensure safety.

It has become increasingly accepted that while some strength tests may be considered as more of

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[2] Fesler, Doug and J.A. Fredston, *Snow Sense*, Alaska Mountain Safety Center, Anchorage, AK, 1994.

[3] McCammon, Ian and Jürg Schweizer, *A field method for identifying structural weaknesses in the snowpack*, Proceedings, International Snow Science Workshop, Penticton, BC, 2002.

a universal standard (e.g., Rutschblock), information from a variety of sources often needs to be compared or correlated to obtain the most reliable stability analysis. The most applicable strength test for the snowpack may also vary from region to region and from time to time within the same region, depending on the overall snowpack structure and how it evolved.

Yet no matter what the results of such snow testing are, this knowledge of strength should not be taken in isolation. Insight into snow strength should always be considered in the context of snowpack structure and energy information to help reduce uncertainty and gain the most accurate and applicable snow safety analyses. What is really most desired from field tests is the most objective and complete information in the shortest time possible (so that we minimize test time and maximize pleasure time). It is hoped that the rough strength test correlations presented below, when used as part of a structure/energy/strength matrix of information, will provide back country users with an easier to apply framework for making safe travel decisions.

2. RESEARCH & APPLICATION

Recent snowpack stability research by McCammon and Schweizer (2002), Jamieson and Schweizer (2003), Johnson and Birkeland (2002), and Jamieson, Fierz & Schweizer (2004) stress that the most reliable snow stability information may result from consideration of more than just strength test results. Indeed, it appears that careful consideration of information from three primary snowpack properties—structure, strength and energy—seems likely to give the most meaningful safety knowledge, as combining all three factors of the snowpack may help to overcome effects of spatial variability and minimize chances of “false stable” results (McCammon and Sharaf, 2005).

Structure, strength and energy may all be viewed as pieces of the “snow stability pie” (Figure 1), with each piece contributing to the overall stability of a particular slope or snowpack.

2.1 Structure

The five most important snow structure or layering parameters as presented by McCammon and Schweizer (2002) relate to: depth of the failure plane, weak layer thickness, hardness transition, grain type and grain size. These instability indices can be expressed as “lemons” or negative contributors to snow stability. The more lemons the snowpack contains, the more likely it is to be unstable and result in avalanche release, no matter what field strength tests indicate. As Ian McCammon describes it, “the more lemons, the more efficiently the snowpack concentrates shear stress at the weak layer”. For example, a Rutschblock test of 6 or 7 may be considered a relative sign of stability, but if 4 or 5 lemons are also indicated from structure considerations, then the slope should still be considered as potentially unstable (a “false stable” condition). Furthermore, the bed surface for any avalanche release will often be at the layer having the maximum number of lemons. In fact, this has been shown to be the case by McCammon and Schweizer (2002) in several human triggered avalanche events.

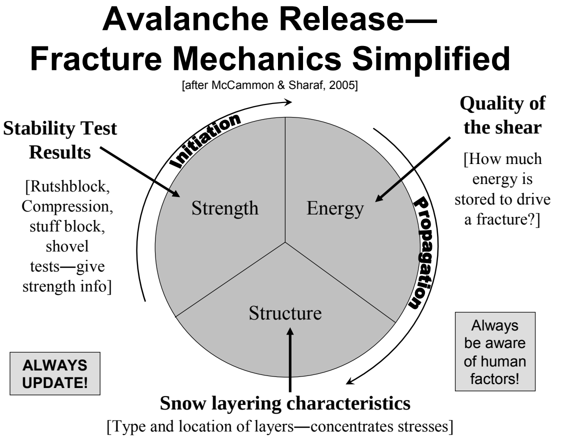


Figure 1. Primary snowpack components affecting avalanche release. Adapted from McCammon & Sharaf, 2005

More specifically, McCammon and Schweizer (2002) identified the following threshold structure values (lemons) in potential fracture planes:

- **Depth of failure planes** (≤1m)—96%
- **Weak layer thickness** (≤10cm)—78%
- **Hardness change across failure planes** (≥1 hand hardness test or more)—90%
- **Persistent grain type** (facets, surface or depth hoar)—86%
- **Grain size change at fracture planes** (≥1.0 mm)—65%

The percentages listed above indicate the proportion of accidents in the study occurring with the threshold value for the indicated parameter.

2.2 Strength

As a result of such structure based accident data, whenever snow strength tests are performed and used to judge slope stability, they should always be interpreted in light of both structure characteristics (above) and energy information (described below), as well as the human factor.

In addition to significant personal experience utilizing a variety of stability tests, input on rough stability test correlations has been solicited from a variety of members of the professional snow and avalanche community. Table 1 resulted from this effort and it has experienced considerable evolution over time. However, the comparison framework shown must still be considered as a work in progress and is by no means definitive. It presents an operational synthesis of what the author and others have found to be repeatable, relatable and applicable through a variety of tests in many field locations.

Table 1. **Rough** Comparison of Common Snowpack Tests

Meaning/ Stability	**Numeric rating**	**Common rating**	**Type of Test** **---------------- Strength -------------|---Shear---**			
		(Abbreviation)	**Rutschblock RB**	**Compression CT**	**Stuff block SB**	**Shovel shear ST**
Unstable (similar slopes may fracture when skied)	**1 Red**	Collapse (C)	Fractures when isolating block	Fractures when isolating column or laying shovel on column	Clean shear while isolating column or with weight of sack	Block settles when cut
			RB1	**CTC**	**SBC**	**STC**
Unstable	**2 Red**	Very Easy (V)	Fractures approaching or stepping on block	1-6 taps (articulate from wrist)	Fractures cleanly with weight dropped from 10 cm (4 in.)	Fractures cleanly during cutting or insertion
			RB2	**CTV**	**SBV**	**STV**
Unstable	**3 Red**	Easy (E)	Fractures with sharp knee bend / unweight	7-12 (wrist + elbow)	Fractures with weight dropped from 20 cm (8 in.)	Fractures with minimum pressure
			RB3	**CTE**	**SBE**	**STE**
Fair or Marginal (marginally stable)	**4 Yellow**	Moderate (M)	One jump (large)	13-18 (elbow)	Fractures with weight dropped from 30 cm (12 in.)	Fractures with moderate pressure
			RB4	**CTM**	**SBM**	**STM**
Fair or Marginal	**5 Yellow**	Moderate to Hard (MH)	A second jump (large)	19-24 (elbow + arm)	Fractures with weight dropped from 40 or 50 cm (16 or 20 in.)	Fractures irregularly with moderate pressure
			RB5	**CTMH**	**SBMH**	**STMH**
More stable (lower potential for triggering)	**6 Green**	Hard (H)	Jump ½ way down or multiple large jumps	25-30 (arm)	Fractures with weight dropped >50 cm (>20 in.)	Fractures after firm, sustained pressure
			RB6	**CTH**	**SBH**	**STH**
More stable	**7 Green**	No fracture (N)	No fracture	No fracture	No fracture	No fracture
			RB7	**CTN**	**SBN**	**STN**

In the rough guideline stability/meaning column of Table 1:

- **Unstable** indicates that avalanche slopes with similar conditions (including aspect and slope angle) are likely to be triggered by a skier; recreating here might best be considered on another day or another time, or try another place

- **Fair or Marginal** indicates marginally stable conditions. Human triggered slab releases are possible and more tests are indicated to assess stability; conservative route selection is recommended

- **More Stable** indicates a low (but not negligible) potential of a skier-triggered avalanche on a similar slope; proceed, but don't stop thinking and updating

For a color version of Table 1, please link to www.nwac.us and consult the avalanche education page and rough stability correlations document.

Table 2. General comments on Strength Tests

Test	Comments
General	• All tests need repeatability to increase confidence in results; Always note slope angle and aspect; • Most tests decrease/increase 1 level for each 10 degree increase / decrease in slope angle; • Quality of shear [1-clean and fast (paper), 2-normal (scissors), 3-uneven & irregular (rock)] is important to note and apply to test interpretation—see below • Need to identify weak layers and correlate with past weather to estimate aerial distribution (local vs widespread) • Always consider these strength results along with all other snowpack, weather and terrain information, including structure/layering pattern and energy information
Rutschblock (RB)	• Limited to upper 1 m of snowpack; • Not for deeply buried weak layers; • Normal size 1.5m upslope x 2 m across slope, slightly angled in at top; • Must cut back wall to be meaningful as Rutschblock or else notate; • Size and orientation may be modified for boarders, snowshoers and snowmobiles—note change in shape under comments; • May be roughly related to red light (RB1-3), yellow light (RB4-5) and green light (RB6-7) conditions • May not be representative or meaningful for hard near-surface crusts, hard slabs or more deeply buried persistent weak layers (e.g., surface hoar, faceted grains)
Compression (Tap) (CT)	• Limited to upper 1.2 m (120cm) of snowpack; • Good correlation with Rutschblock; • Good for new snow instability; • Average decrease of 1.1 taps for each 10° decrease in slope angle (varies from 0.2 to 3 taps) • Quantifiable—normally more consistently repeatable results than shovel shear • Very rough correlation with red light (1-12), yellow light (13-24) and green light (≥25 taps) conditions • Results may vary between testers and force applied
Shovel Shear (ST)	• Small sample size—need repeatable results • Size normally ~30x30 cm—25x25 cm okay and little effect; • Shape and size of shovel has limited effect; • Location and strength of layers only—not a true strength/stability test; • Use care not to lever column with shovel; insert and pull entire shovel toward tester • Better than compression for locating old snow and buried weak layers > 100-120 cm deep
Stuff block (SB)	• Small sample size—need repeatable results; • Size 30 x 30 cm; weight of 4.5kg (10 lbs); • Quantifiable results like compression test; • Results approximate Rutschblock scores • Works best with near surface / new snow instability
Loaded column (LC)	• Small sample size—need repeatable results; • Quantifiable results like compression test, but difficult to gage quantity (snow density) of loading applied

No matter what level of expertise is used in applying Table 1, it must be emphasized again that no rating level is definitive regarding avalanche occurrence. Additional confirmation and observations should always be sought for any test based decisions, with continual updates a mandatory process along with proper consideration of potential heuristic traps (McCammon, 2002). Indeed, while McCammon and Schweizer (2002) showed that the likelihood of skier triggered slabs gradually decreased as stability and the associated numeric rating increased, this percentage did not become negligible at scores of 6 and 7 (statistics showed triggering percents of 12 and 8 % respectively).

In order to be consistent and present the same number of rating level steps for each test, Table 1 deviates slightly from strength test guidelines presented by Greene et al (2004) in the recently released *Observational Guidelines for Avalanche Programs in the United States*. However, in light of significant documented spatial variability of snowpack properties (Kozak et al, 2000, Landry et al, 2002 & Birkeland et al, 2004), the fact that these strength tests are given as "rough correlations", and the recommended application of these results only after also assessing structure and energy information, this correlation seems a reasonable liberty, especially if it can help field users make better decisions. For practical field use a simplified version of Table 1 is given in Appendix A.

Table 2 offers comments and limitations on strength tests in general as well as some application guides for the specific tests listed. It should be noted that one of the most important results hoped for with any mechanical stability test is repeatability, since redundant results help reinforce the validity and trustworthiness of any test outcome, especially if the redundancy extends from pit to pit and slope to slope.

2.3 Energy

Most avalanche professionals feel that energy stored within the snowpack is closely related to how easily and cleanly fractures occur when performing strength tests. Furthermore, this fracture character for weak layers seems to provide additional information to consider when evaluating the potential for human triggered avalanche release. Several studies of *shear quality* (Johnson and Birkeland, 2002) or *fracture character* (Herwijnen and Jamieson, 2004) have been recently presented, and both suggest that the "nature of the shear" provides important stability information to include when assessing numerical strength test scores (especially regarding snowpack energy). It must be noted that "the *energy* part of the circle refers to the rate at which stored fracture energy is released, rather than the total amount of energy" (see McCammon & Sharaf, 2005).

Hence "nature of the fracture" is the third significant snowpack property to consider when making safety choices relating to potential avalanche release. This fracture or shear quality tells a great deal about the bonding at the shear plane, as well as how much energy may be available to help propagate fractures once they initiate. For instance, an irregular shear surface indicates some bonding and strengthening has begun between layers, while a clean shear surface suggests a weak attachment between snow layers. Likewise, a sudden or unusually quick, smooth fracture during a test suggests stored energy is releasing. When the smoothness of the fracture surface is considered in combination with the relative speed of fracture, both layer bonding and snowpack energy enter into the picture, and fracture initiation is more likely to be followed by fracture propagation.

The broader *shear quality* description and the more specific *fracture character* system capture the nature of the fracture in slightly different ways; however, the various levels of fracture can be related. This comparison is given in FractCharNotes.pdf by Jamieson at http://www.eng.ucalgary.ca/Civil/Avalanche/Papers; summary Table 3 below also gives a brief description of commonly accepted US shear quality values and their field interpretation, as well as the Canadian equivalent.

Table 3. "*Nature of the fracture*"—shear quality or fracture character

Shear Quality	Description	Fracture Character
Q1	Unusually clean, planar, smooth and fast shear surface; weak layer may collapse during fracture and slab typically slides into pit after weak layer fracture on slope angles > 35°, and sometimes on slopes as gentle as 25°	**SC** (sudden collapse) or **SP** (sudden planar)
Q2	Average" shear; mostly smooth shear surface but slab does not slide as readily as Q1; fracture occurs throughout most of slab but some small irregularities possible—not as many as Q3	**PC** (Progressive compression) or **RP** (resistant planar)
Q3	Non-planar shear surface, uneven, irregular and rough; shear fracture typically not through the whole slab/weak layer interface. After fracture, slab may experience only slight if any movement.	**B** (non-planar break)

With either system, it is common practice to examine and identify snow grains scraped from either the bottom of the block that failed or from the top of the bed surface or weak layer remnants left behind following the fracture. Recording the *shear quality* (Q1, Q2 or Q3) or *fracture characte*r when recording stability test results can give important information about the presence and persistence of suspected weak layers. For instance, smooth fast shears often indicate stored energy and the presence of surface hoar, facets or very weak bonding to a smooth bed surface (like a rain crust or ice lens)—weakness that may last awhile. [Note that a more stable test number (e.g., higher Rutshcblock score) combined with a Quality 1 shear may often be more important than a less stable test number (e.g., lower Rutschblock score) with a Quality 3 shear, since the weak layer or bonding of the potential slab is really what is most important along with the energy needed to drive fracture propagation.] Refer to the above references for a more complete analysis and description of shear quality.

3. CONCLUSIONS

An abundance of problems face anyone desiring to use snowpack observations for determining snowpack stability, potential avalanche release and resultant safe travel. These problems include spatial variability, inconclusive tests, false stable results, and difficulties with interpreting regional forecasts at the local level, just to name a few. While these are significant challenges, a combination of structure, strength and energy information about the snowpack can help to minimize risk and limit danger exposure. Although no single test will give all the information desired, correlation and combination of multiple test results that examine all slices of the *snow stability* pie will help produce a more knowledgeable picture of the current state of snowpack stability. It is hoped that the rough correlation of common snowpack stability tests presented (in both Table 1 and in the simplified version of Appendix A) will help to bridge the gap between the tests and their interpretation and/or application.

ACKNOWLEDGEMENTS

The author is grateful to all of those who have so diligently worked on finding the best and most effective way to test snowpack stability. While spatial variability is a fact, and snowpack stability test results can be misleading, the expansion of such testing and analyses to encompass all properties of the snowpack seems to be providing better and more reliable information on which to base avalanche control, route finding or other stability related decisions. Inclusion of such snowpack information into our psyche should be habit, as omission of such data may make for very short, very long, and/or very unpleasant trips.

REFERENCES

Birkeland, K.W. 2004. Comments on using shear quality and fracture character to improve stability test interpretation. *The Avalanche Review*, Vol. 23, No. 2.

Birkeland, K., K. Kronholm, M. Schneebeli, and C. Pielemeier. 2004. Changes in the shear strength and micro-penetration hardness of a buried surface hoar layer. *Annals of Glaciology* 38, 223-228.

Greene, Ethan et al. 2004. Snow, Weather and Avalanches: Observational Guidelines for Avalanche Programs in the United States. Working Group on Observational Guidelines, American Avalanche Association, Pagosa Springs, CO.

Jamieson, Bruce. 1999. The compression test - after 25 years. *The Avalanche Review 18(1), 10-12*

Jamieson, B. and J. Schweizer. 2005. Using a checklist to assess manual snow profiles. (*yellow flags) Avalanche News 72, Canadian Avalanche Association, Revelstoke, BC., 62-71.*

Johnson, R.F. and K.W. Birkeland. 2002. Integrating shear quality into stability test results. *Proceedings of the 2002 International Snow Science Workshop*, Penticton, BC, Canada, 508-513.

Kozak, M., K. Elder, and K. Birkeland. 2000. The spatial and temporal variability of slab hardness. *Proceedings of the 2000 International Snow Science Workshop*, Big Sky, Montana, 115-120.

Landry, C., K. Birkeland, K. Hansen, J. Borkowski, R. Brown, and R. Aspinall. 2002. Snow stability on uniform slopes: Implications for avalanche forecasting. *Proceedings of the 2002 International Snow Science Workshop*, Penticton, BC, Canada, 532-539.

McCammon, I. and Jürg Schweizer. 2002. A field method for identifying structural weaknesses in the snowpack. *Proceedings of the 2002 International Snow Science Workshop*, Penticton, BC, Canada, 477-481

McCammon, Ian.. 2002. Evidence of heuristic traps in recreational avalanche accidents. *Proceedings of the 2002 International Snow Science Workshop*, Penticton, BC, Canada. [See also *Avalanche Review Vol.* 22, No 2 and 3.]

McCammon, I and Don Sharaf, 2005. Integrating strength, energy and structure into stability decisions, *Avalanche Review*, 23 (3): 18–19.

Schweizer, J. and B. Jamieson. 2003. Snowpack properties for snow profile analysis. *Cold Regions Science and Technology* 37(3): Special issue, International Snow Science Workshop 2002, 233-241.

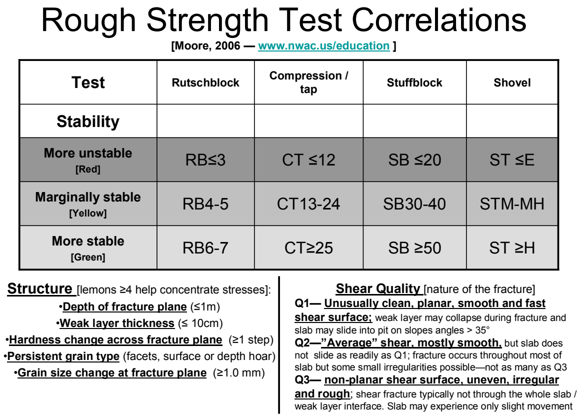
Schweizer, J., Fierz, C., Jamieson, B. 2004. Assessing the probability of skier triggering from snow layer properties. *Proceedings of the 2004 International Snow Science Workshop*, Jackson Hole, Wyoming. USDA Forest Service, Fort Collins, CO, 192-198.

van Herwijnen, A. and B. Jamieson. 2003. An update on fracture character in stability tests. *Avalanche News* 66. Canadian Avalanche Association, Revelstoke, BC, 26-28.

van Herwijnen, A.F.G. and B. Jamieson. 2004. Fracture character in compression tests. ISSW 2004 *Proceedings, Jackson Hole, Wyoming*. USDA Forest Service, Fort Collins, CO, 182-191.

APPENDIX A

Simplified Field Version of Table 1.This preliminary and **very rough** correlation guide is presented as a possible tool for comparing and applying field tests results only if energy and structure information is part of the stability assessment. See also www.nwac.us/education for color version of this chart.



Rough Strength Test Correlations

[Moore, 2006 — www.nwac.us/education]

Test	Rutschblock	Compression / tap	Stuffblock	Shovel
Stability				
More unstable **[Red]**	RB≤3	CT ≤12	SB ≤20	ST ≤E
Marginally stable **[Yellow]**	RB4-5	CT13-24	SB30-40	STM-MH
More stable **[Green]**	RB6-7	CT≥25	SB ≥50	ST ≥H

Structure [lemons ≥4 help concentrate stresses]:

- **Depth of fracture plane** (≤1m)
- **Weak layer thickness** (≤ 10cm)
- **Hardness change across fracture plane** (≥1 step)
- **Persistent grain type** (facets, surface or depth hoar)
- **Grain size change at fracture plane** (≥1.0 mm)

Shear Quality [nature of the fracture]

Q1— Unusually clean, planar, smooth and fast shear surface; weak layer may collapse during fracture and slab may slide into pit on slopes angles > 35°

Q2—"Average" shear, mostly smooth, but slab does not slide as readily as Q1; fracture occurs throughout most of slab but some small irregularities possible—not as many as Q3

Q3— non-planar shear surface, uneven, irregular and rough; shear fracture typically not through the whole slab / weak layer interface. Slab may experience only slight movement

The author is extremely interested in input and feedback regarding these strength test correlations. Please send your comments to the email or address listed.