THE STUFFBLOCK: A SIMPLE AND EFFECTIVE SNOWPACK STABILITY TEST[1]

Ron Johnson[2] and Karl Birkeland[3]

Abstract

The stuffblock is a new snow stability test developed and used operationally by the Gallatin National Forest Avalanche Center during the 1993-94 winter. Shortcomings of other stability tests, including the inability to effectively communicate results, the complexity of the test, and the time necessary to collect a measurement make the development of a new test desirable. The stuffblock is performed on an isolated column of snow about 0.30 m (1 ft) square which is cut out of the wall of a snow pit. A nylon sack (stuff sack) is filled with 4.5 kg (10 lbs) of snow, which is measured with a lightweight scale. An avalanche shovel blade is placed on top of the isolated column and the stuff sack is first placed, then dropped onto the shovel from increasing heights. The drop height is increased in increments of 0.10 m. When shear failure occurs, the drop height is noted. Initial results from the 1993-94 field season indicate that, for snowpack conditions found in southwest Montana, a positive relationship exists between stuffblock drop heights and rutschblock numbers. While the stuffblock is not perfect, it is inexpensive, quick, easy, and provides numbers that can be readily compared between observers. This latter attribute is especially useful for regional avalanche forecasters who must often compare the results of several different observers with differing avalanche skills. For the individual avalanche worker, the stuffblock provides one more useful tool for snowpack stability evaluation.

Introduction

Applying a stability test to a given slope is problematic. There are many tests to choose from, and little guidance about how to employ and interpret some of them. Due to the subjective nature of several tests, comparisons between various observers are often difficult. Further, locating a "representative" site for the test is complex, as emphasized by recent field studies which have documented the spatial variations in snowpack properties (Conway and Abrahamson, 1984; Föhn, 1988; Birkeland, 1990; Logan, 1992; Jamieson and Johnston, 1993; Birkeland, *et al.*, in press). In spite of the difficulties, snowpack stability tests are recognized as critical tools for avalanche workers trying to evaluate the stability of a particular slope (LaChapelle, 1980), and for scientists attempting to test various aspects of the snowpack.

---

[1]Paper presented at the 1994 International Snow Science Workshop, Snowbird, Utah.
[2]Gallatin National Forest Avalanche Center, P.O. Box 130, Bozeman, MT 59771
[3]Gallatin National Forest Avalanche Center, P.O. Box 130, Bozeman, MT 59771 and Department of Geography, Arizona State University, Tempe, AZ 85287-0104

Before reviewing the available snowpack stability tests, it is instructive to list the properties desired in a so-called "ideal" test. First, and most importantly, an ideal test would provide an accurate representation of snow stability. Second, it would be so simple that it could easily be explained in an avalanche course and so fast that ski area workers and backcountry skiers and forecasters would use it. Third, the equipment used would be inexpensive enough to make the test accessible to everyone. Fourth, the test should be field portable, since few backcountry skiers or avalanche workers are willing to carry much extra weight or equipment. Fifth, the test could be equally applied by various backcountry user groups, including skiers, snowboarders, snowshoers, and snowmobilers. Finally, the ideal stability test would provide unbiased, replicable, and quantifiable results that could be easily communicated between avalanche workers. This latter attribute would be especially useful for backcountry avalanche forecasters dealing with large amounts of information from a variety of sources, and for scientists seeking to quantify snowpack properties.

Although numerous stability tests currently exist, all of them have shortcomings. The following discussion is not meant to be an exhaustive examination of all stability tests and variations that have been used and developed, but rather a sampling of some of the tests that we are most familiar with. Shear frames, which are utilized primarily in scientific work, will first be examined, followed by those tests used primarily by operational forecasters, avalanche workers, and backcountry recreationalists (shovel shear, loaded column, tap test, and rutschblock), realizing that some tests (notably the rutschblock) have been used for both.

Although scientists have used a variety of instruments to evaluate snowpack properties (including acoustic sensors, radar, and a number of penetrometer-type devices), only the shear frame can be regarded as a true stability test. Shear frames have been used extensively to index the shear strength of thin weak layers which are typically responsible for avalanche release (Föhn, 1988;1992). Although shear frames have yielded valuable and quantifiable shear strength data for scientists, they are time consuming and difficult to use (Perla and Beck, 1983), making their acceptance by backcountry skiers and forecasters unlikely.

Other tests more commonly used by backcountry skiers also have their drawbacks. Simple shovel shear tests have been used widely, probably because they are fast, easy, and only require an avalanche shovel (although many people prefer to also use a snow saw). While the shovel shear test is effective at identifying the location of weak interfaces, the results of the test are not easily communicable between various observers (a "moderate" shovel shear can mean two entirely different things to two different people), and it may take one person several tests to reliably rate the shear strength (Shaerer, 1988). A slightly more time consuming, but still relatively quick test is the "loaded column" test whereby blocks of snow are placed on top of an isolated column until the column fails (McClung and Shaerer, 1993). An advantage of this test is a better ability to communicate results (i.e., "the column failed when loaded with 25 cm (10 in) of old snow with a density of around 30%"). Still, block size may not be uniform, estimates of snow density may vary, and cutting reasonable blocks out of the snow when it is cohesionless (such as with new or faceted snow) is difficult. The authors have also used a "hasty" version of this test whereby the observer simply isolates a column, puts a shovel on top of it, and beats on the shovel until failure, coming up with a relative rating of an easy, moderate, or hard failure. The Canadians have taken a similar test one step further and dubbed it the "tap test" (Tremper, pers. comm., 1994). In this test the column is isolated and the shovel is placed on top of the column. The shovel is alternately tapped with a motion beginning at the observer's wrist, then his/her

elbow, and lastly the shoulder until failure occurs. Still, these latter two tests leave ample room for error between observers who might interpret the amount of force applied to the column differently.

A final test that has steadily gained popularity in North America by both researchers and backcountry skiers is the Swiss rutschblock test (Föhn, 1987). In this test the isolated column is about 2 m long and 1.5 m wide. The block is loaded by a skier who slides onto, and then jumps on the block until failure occurs. The rutschblock has been used in several studies (eg., Föhn, 1988; Jamieson and Johnston, 1993), and work has indicated that it can be roughly correlated to slope stability (Jamieson and Johnston, 1992). A primary advantage is that it analyzes a much larger area than other tests (about 3 m^2). Although rutschblocks were originally time consuming, the use of specialized snow saws and other techniques have shortened their preparation time to the point that backcountry skiers are increasingly using them. Still, rutschblock results depend on how well the block is isolated, the weight of the person jumping on the block, and how hard they jump. Results, which are given a value between 1 and 7 on scale of increasing difficulty to failure, are easier to compare than the "easy, moderate, or hard" values given to shovel shears, but they are still somewhat biased and are more difficult to compare than numerical values. Finally, it is difficult for snowboarders, snowshoers, and snowmobilers to apply the rutschblock test with confidence. Snowboarders can jump on the block with their board, and snowmobilers can walk or crawl onto the block, but it is unclear what their results would mean or how comparable they would be to a skier tested rutschblock.

In order to address these concerns about various stability tests, the stuffblock was developed over the past two seasons at the Gallatin National Forest Avalanche Center. Last season it was used operationally for avalanche forecasting in southwest Montana. The test consists of: 1) isolating a small block of snow on an inclined slope, and 2) dropping a nylon sack full of a known mass of snow onto the block from varying heights until the weak layer fails. While the stuffblock may not be the perfect stability test, it does have many desirable attributes: it is simple to learn, it is reasonably fast, the equipment required is field portable and inexpensive, it can be equally applied by skiers, snowboarders and snowmobilers, and it provides numerical results that are easily compared between observers. Initial results indicate a positive statistical relationship between stuffblock results and the more time consuming rutschblock test. Thus, the stuffblock is another useful tool for avalanche workers and backcountry recreationalists attempting to evaluate slope stability.

One final test that should be mentioned is a new test that is similar to, but was developed entirely independently of, the stuffblock. Half-way through last season we learned that Swiss researchers have been developing a "rammrutsch" test (Schneebeli, pers. comm., 1994). With this test a 0.50 m square block is isolated, an apparatus consisting of a plate with ram-penetrometer type guide is set on the block, and a 5 kg mass is set, and then dropped, onto the plate (Schweizer, *et al.*, in press). Initial results with the rammrutsch appear promising, and this test would undoubtedly be more controlled and provide more consistent scientific data than the stuffblock. However, the additional equipment required would compromise its field portability and affordability, making its use by the general public in the backcountry improbable. The stuffblock provides an inexpensive and lightweight alternative to the rammrutsch for backcountry skiers and avalanche workers.

Methods

Stuffblock Development

In our work as backcountry avalanche forecasters over the past several years, we have increasingly relied on snowpit tests that allow us to better communicate test results. The most effective tests have been the loaded column and the rutschblock. However, while we can easily compare results between ourselves, communication with a wide variety of volunteer observers is not so easy. Loaded columns have been reported as failing with "one or two blocks of snow", and rutschblocks have failed with "a couple small jumps", leaving us scratching our heads and wondering exactly what was observed. As a result, in 1992 we set out to modify the loaded column test.

We first attempted to improve the loaded column test by placing a nylon stuff sack filled with a known mass of snow on the isolated column. By increasing the amount of snow in the stuff sack (in increments of 0.9 kg (2 lbs)) until shear failure occurred, we hoped to acquire more replicable and reliable data. Unfortunately, this technique was not only time consuming (since it required filling and weighing the stuff sack several times), but we found that shear failure for many columns would not occur even when the mass placed on the column was greater than 4.5 kg (10 lbs). This was problematic when other observations on the same slopes indicated the snowpack stability was often suspect. We found, however, that once the loaded column was dynamically loaded by gently tapping with a shovel blade or hand, shear failure readily occurred. This latter observation led to the idea of the stuffblock test, whereby a known mass is dropped from a known height onto an isolated column of snow. The dynamic load on the column provided by the falling stuff sack provides a much better correlation with the observed snowpack stability.

Stuffblock Equipment and Procedure

The equipment required to perform the stuffblock test is easy to acquire, inexpensive, and lightweight. The necessary tools include a snow shovel (a flat bladed shovel works best), a snow saw (not essential, but helps for consistent isolated columns), a nylon stuff sack, a scale (capable of measuring 4.5 kg (10 lbs)), and a nylon cord. Since snow shovels and saws are carried in the field by most avalanche workers and many backcountry skiers, typically only the stuff sack, scale, and cord need to be added to a snow pit kit. These can all be picked up at a sporting goods store for less than about $15 US, and they weigh about 0.5 kg (1 lb). The scales we used for the test are used to weigh fish and cost about $10. The nylon cord should be about 0.80 m long, and should be marked off in 0.10 m increments. By attaching the cord to the bottom of the stuff sack, drop heights can be easily determined.

The procedure for conducting a stuffblock test is straightforward and does not require extensive snow removal from the snow pit wall. A column of snow, with a surface area which approximates the size of the shovel blade (about 0.30 m square), is isolated from the wall of the snow pit, and the stuff sack is filled with 4.5 kg (10 lbs) of snow. The shovel blade is then placed horizontally on top of the isolated column, and the full stuff sack is statically placed on the shovel blade. If shear failure does not occur, then the block is loaded dynamically by dropping the stuff sack from a height of 0.10 m onto the shovel blade. The

drop height is increased by 0.10 m increments until shear failure occurs, and the observer notes the location of failure and the drop height.

An important part of any stability test is to maintain consistency in the testing procedure, and the stuffblock is no exception. To ensure dependable results, the isolated column of snow should have vertical sides and a uniform shape, the shovel blade should be held horizontally with the tip of the blade resting on the upslope side, and the stuff sack should be dropped onto the middle of the shovel blade.

We found that performing a stuffblock test added only a few minutes to the total amount of time spent analyzing the snowpack in a given snow pit. In fact, once the stuff sack is filled with snow, it is easy to perform several stuffblock tests in the same snow pit. Performing several tests analyzes a larger area of snow and helps to validate the results for a particular location.

Stuffblock/Rutschblock Comparison

After the development of the stuffblock early last season, it was used operationally by the Gallatin National Forest Avalanche Center for backcountry avalanche forecasting in southwest Montana. Although we quickly developed a qualitative "feel" for what the test was telling us by comparing stuffblock results to observed avalanches, fracturing or collapsing snowpacks, and other signs of instability, we wanted to compare the stuffblock to a more widely used stability test to further validate its effectiveness. The rutschblock was chosen for comparison due to its increasing acceptance among North American avalanche workers, scientists, and backcountry skiers.

Fifty-four stuffblock and rutschblock measurements were taken next to each other on a wide variety of avalanche starting zones typical of southwest Montana. Snow profiles were analyzed to insure that both tests failed on the same weak layer. All aspects were represented, and only dry slab conditions were considered. Test slope elevations ranged from about 2300 m to 3200 m (about 7500 to 10,500 ft), and slope angles varied from 28° to 38° (average slope angle of 33°). The depth to the weak layer tested ranged from about 0.10 m to 1.0 m (4 to 40 inches), with an average of about 0.40 m (16 in). Weak layers tested were typical of those found in southwest Montana and included new snow interfaces, small faceted crystals, surface hoar, and depth hoar. Spearman rank order correlation (Zar, 1984) was used to statistically compare stuffblock drop heights and rutschblock numbers.

Results/Discussion

The Stuffblock as a Stability Test

For the snowpack conditions that existed in southwest Montana during the 1993-1994 season, the stuffblock supplied valuable snow stability information. In general, higher drop heights are associated with more stable conditions on slopes of similar elevation, aspect, and slope angle. This correlation was observed from a comparison of stuffblock results with snowpack information gained from a variety of observations such as recent avalanche activity, ski cutting tests, other snowpack stability tests, and the "general feel" of the snowpack. Though this information is difficult to quantify, avalanche workers understand

that it is "real" data. As a loose guideline, drop heights of about 0 to 0.20 m indicate mostly unstable snowpack conditions, 0.30 to 0.50 m indicate moderately stable snowpack conditions, and drop heights exceeding 0.50 m indicate the snowpack is mostly stable. However, results from the stuffblock test, like all stability tests, are not definitive and simply provide one more piece of information for a forecaster or backcountry traveler to contemplate when evaluating the stability of a slope.

In addition to its usefulness in evaluating the stability of a particular slope, the stuffblock has been an excellent addition to our backcountry avalanche forecast program in southwest Montana for several reasons. First, since the stuffblock relies on a known mass being dropped a known height rather than a decision by the observer (such as how hard to jump on a rutschblock), variability between observers is minimized. The subjective nature of most other stability tests makes the comparison between a wide variety of observers problematic for backcountry forecasters. Second, the stuffblock does not require skis. This is an important consideration for southwest Montana since many of the backcountry users are snowmobilers and, to a lesser extent, snowboarders. Valuable information may be obtained from these user groups who are not be able to perform a "normal" rutschblock. Finally, the stuffblock test is capable of locating weak snow interfaces in the upper 0.30 m of the snowpack, and assessing their stability. These weak layers are often missed by the rutschblock test when the skier sinks through a fragile slab. While these interfaces may not pose an immediate hazard, being able to identify and get a sense for how weak they are is useful for forecasting the amount of new snow loading that may be required for failure to occur in upper snowpack layers.

Stuffblock/Rutschblock Comparison

The relationship between the stuffblock and rutschblock tests is represented by a three dimensional plot showing the frequency that we observed a specific stuffblock drop height to be associated with a certain rutschblock number (Figure 1). These data clearly show that increasing stuffblock heights correspond to increasing rutschblock numbers. This positive relationship is further confirmed by statistical analysis. For the 54 observations, the Spearman rank order correlation coefficient is highly significant at 0.77 ($p < 0.0001$), indicating the relationship observed is highly unlikely to occur by chance.

Although a relationship between stuffblock drop heights and rutschblock numbers exists, it is not strong enough to be used for absolute prediction of one variable given the other. This is not surprising since the impact energy applied to the snow surface varies linearly with stuffblock drop height, while no such relationship exists for rutschblock numbers (Schweizer, *et al.*, in press). With the stuffblock:

$$PE = mgh$$

where PE is the potential energy (in Joules) of the stuff sack, m is the mass of the stuff sack filled with snow (4.54 kg), g is the acceleration due to gravity (9.8 m/s^2), and h is the stuffblock drop height (in meters). Energy is conserved as the stuff sack is dropped, with potential energy being converted into kinetic energy. Thus, a drop height of 0.40 m will impact the shovel with twice the energy of a 0.20 m drop height. So, since the rutschblock and stuffblock tests are not exactly comparable, the imperfect relationship we have observed

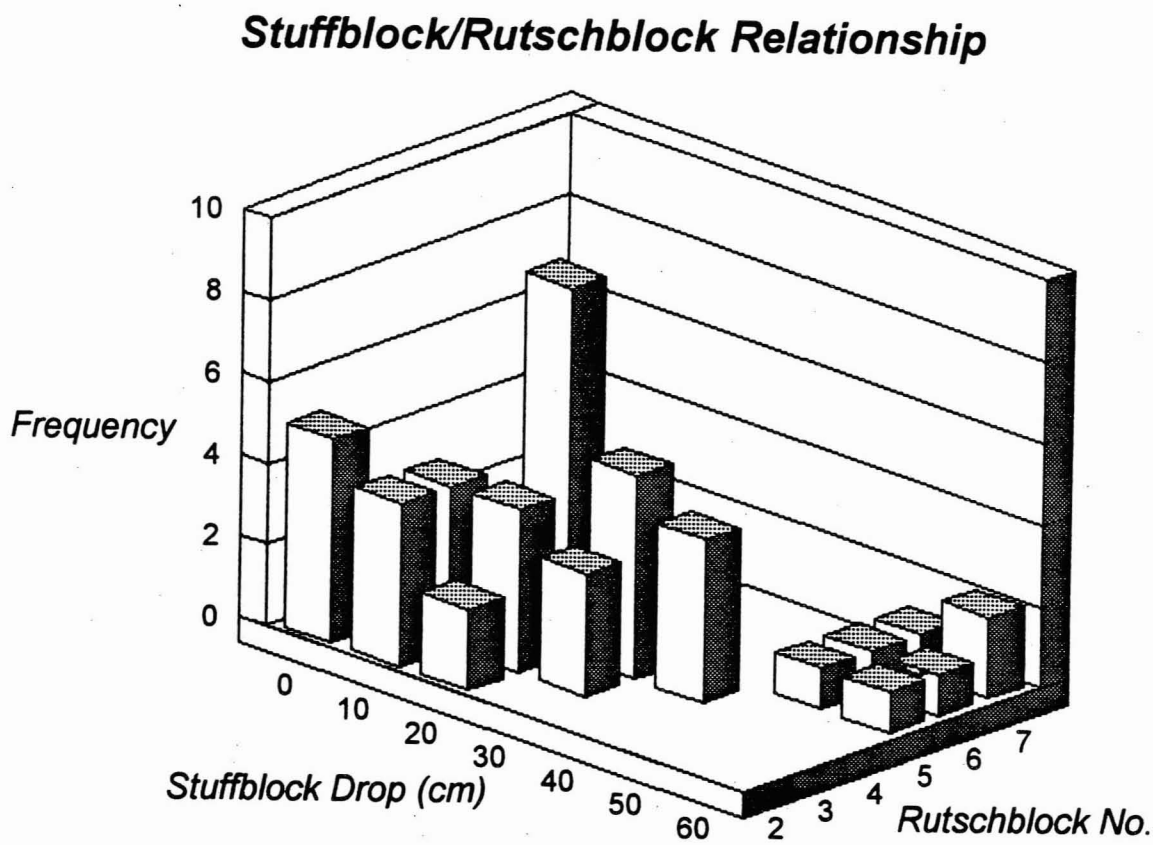

FIGURE 1: Results of rutschblock and stuffblock tests conducted side-by-side in a variety of dry snowpack conditions in southwest Montana. Frequency is the number of times that a certain rutschblock number was associated with a specific stuffblock drop height.

---

between the two tests should not be a cause for concern among avalanche workers.

Knowing the amount of energy applied to the snowpack, the next logical step would be to calculate the forces applied to the weak layer. However, since the dissipation of the applied energy depends largely on the density and cohesion of the snowpack layers above the weak layer, calculations of applied forces quickly become complicated and are well beyond the scope of this paper. Still, in human-caused avalanches, it is the energy applied to the snow surface which triggers the avalanche. Thus, stability tests which apply energy to the snow surface (such as the stuffblock, rutschblock, or the new rammrutsch) are appropriate tools to use when evaluating the susceptibility of a slope to a human-triggered slide.

Conclusion

Our work shows that, while the stuffblock test may not be perfect, it is an effective snow stability test. The stuffblock meets many of the goals set forth for an ideal test, including simplicity, speed, and portability. It can be used by all backcountry recreationalists, including skiers, snowmobilers and snowboarders. Perhaps most importantly, our observations show that the stuffblock provides a reasonably accurate representation of the snowpack stability for conditions observed in southwest Montana. We hope to work on testing its effectiveness in other snow climates this coming year. Finally, the stuffblock test provides quantifiable results, and is therefore useful for both avalanche workers comparing a wide variety of observations and scientists measuring snowpack properties. Overall, the stuffblock test provides backcountry skiers and avalanche workers with an inexpensive and portable means of assessing snowpack stability.

Acknowledgements

We would like to thank the National Avalanche Center, which provided some monetary support for this project, and the Gallatin National Forest, which allowed us to experiment with this test for the past two seasons.

Literature Cited

Birkeland, K.W. 1990. The spatial variability of snow strength on potential avalanche slopes. Unpublished MS thesis, Dept. of Earth Sciences, Montana State University, 99 pp.

Birkeland, K.W., K.J. Hansen, and R.L. Brown. In press. The spatial variability of snow resistance on potential avalanche slopes. *J. Glaciology*, accepted for publication, July, 1994.

Conway, H. and J. Abrahamson. 1984. Snow stability index. *J. Glaciology*, 30(106):321-327.

Föhn, P.M.B. 1987. The "Rutschblock" as a practical tool for slope stability evaluation. In: *Avalanche Formation, Movement, and Effects, IAHS Publ. No. 162*, 223-228.

Föhn, P.M.B. 1988. Snowcover stability tests and the areal variability of snow strength. *Proceedings of the 1988 International Snow Science Workshop, Whistler, BC, Canada*, 262-273.

Föhn, P.M.B. 1992. Characteristics of weak snow layers or interfaces. *Proceedings of the 1992 International Snow Science Workshop, Breckenridge, CO*, 160-170.

Jamieson, J.B. and C.D. Johnston. 1992. Experience with rutschblocks. *Proceeding of the 1992 International Snow Science Workshop, Breckenridge, CO*, 150-159.

Jamieson, J.B. and C.D. Johnston. 1993. Rutschblock precision, technique variations and limitations. *J. Glaciology*, 39(133):666-674.

Logan, N. 1992. Snow temperature patterns and artificial avalanche release. *Proceedings of the 1992 International Snow Science Workshop, Breckenridge, CO*, 37-46.

LaChapelle, E.R. 1980. The fundamental processes in conventional avalanche forecasting. *J. Glaciology*, 26(94):75-84.

McClung, D. and P. Shaerer. 1993. *The Avalanche Handbook*. The Mountaineers, Seattle, WA, 271 pp.

Perla, R.I. and T.M.H. Beck. 1983. Experience with shear frames. *J. Glaciology*, 29(103):485-491.

Schneebeli, M. 1994. Personal communication. Swiss Federal Institute for the Study of Snow and Avalanches, Davos, Switzerland.

Schweizer, J., M. Schneebeli, C. Fierz and P.M.B. Föhn. In press. Snow mechanics and avalanche formation: Field measurements onto the dynamic response of the snow cover. *Surveys in Geophysics*.

Shaerer, P. 1988. Evaluation of the shovel shear test. *Proceedings of the 1988 International Snow Science Workshop, Whistler, BC, Canada*, 274-276.

Tremper, B. 1994. Personal communication. Director, Utah Avalanche Forecast Center.

Zar, J.H. 1984. *Biostatistical Analysis*. Prentice Hall, Englewood Cliffs, New Jersey, 718 pp.