The Stuffblock Snow Stability Test

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6E62A95--Stuffblock Correlation Test

Introduction

This report introduces the stuffblock snow stability test, provides information on its application and interpretation, and presents data that validate its usefulness in evaluating avalanche conditions. It is important to realize that avalanche conditions cannot be assessed strictly on the basis of stability tests. A large number of factors relating to the terrain, weather, and snowpack must be considered, factors that are covered in detail in a variety of texts (Daffern 1992; Fredston and Fesler 1994; McClung and Shaerer 1993). Further, locating a "representative" site for the test is difficult. Despite these concerns, snowpack stability tests are recognized as critical tools for avalanche workers and backcountry travelers evaluating the stability of a particular slope (LaChapelle 1980), and for scientists attempting to test various aspects of the snowpack.

This report will discuss various stability tests, their respective shortcomings, and how those shortcomings led to the development of the stuffblock test. An extensive discussion on performing and interpreting the test is provided, followed by an evaluation of the effectiveness of the stuffblock test in different snow climates and a comparison of the test with the widely accepted rutschblock test.

Snow Stability Tests and Their Limitations

Most stability tests currently in use by backcountry skiers, snowmobilers, and avalanche workers have significant drawbacks. Simple shovel shear tests have been used widely. They are fast, easy, and require nothing more than an avalanche shovel (although many people also use a snow saw). While the shovel shear test effectively locates weak interfaces, the results of the test are not easy to communicate between various observers (a "moderate" shovel shear can mean entirely different things to different people), and one person may need to perform several tests to reliably rate the shear strength (Shaerer 1988). A test that takes more time, but is still relatively quick, is the "loaded column" test. Blocks of snow are placed on top of an isolated column until the column fails (McClung and Shaerer 1993). It is easier to communicate the results of this test (saying for instance, "The column failed when loaded with 250 mm (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 it is difficult to cut blocks out of cohesionless snow (such as new or faceted snow). The authors have used a "hasty" version of this test where the observer isolates a column, puts a shovel on top of it, and beats on the shovel until the column fails. Failure is rated as easy, moderate, or hard. The Canadians use a similar test, dubbed the "tap test" (Tremper 1994). The column is isolated and the shovel is placed on top of it. The shovel is alternately tapped with a motion beginning at the observer's wrist, then the elbow, and finally the shoulder until the column fails. Still, all of these tests leave ample room for error between observers who might interpret the amount of force applied to the column differently.

The Swiss rutschblock test (Föhn 1987) has steadily gained popularity in North America among researchers and backcountry skiers. This test, which is described in detail later in this paper, involves isolating a column about 2 m (6.5 ft) long and 1.5 m (4 ft) wide. The block is loaded by a skier who steps onto the block, and then jumps on it until the block fails. The rutschblock has been used in several studies (Föhn 1988; Jamieson and Johnston 1993), and work has indicated that it can be roughly correlated to slope stability (Jamieson and Johnston 1992). The test analyzes a much larger area of snowpack (about 3 m2) than other tests. Since the use of specialized snow saws and other techniques have shortened the time needed to perform a rutschblock test, backcountry skiers increasingly are using the test. Still, rutschblock results depend on how well the block is isolated, the weight of the person jumping on the block, and how hard the person jumps. Results are given a value between 1 and 7 on a scale of increasing difficulty to failure. Although these results are easier to compare than the "easy, moderate, or hard" values given shovel shears, they are still somewhat biased and are more difficult to compare than less subjective values. Finally, it is difficult for snowboarders, snowshoers, and snowmobilers to apply the rutschblock test with confidence. Snowboarders could jump on the block with their board, and snowmobilers could walk or crawl onto the block, but it is unclear what the results would mean or how they would compare to a rutschblock tested by a skier.

To address these concerns, the stuffblock test was developed at the Gallatin National Forest Avalanche Center in Bozeman, MT. This test has been used for operational avalanche forecasting for three seasons in southwestern Montana. The test consists of:

1. *Isolating a small block of snow on an inclined slope*
2. *Dropping a nylon stuff sack full of a known mass of snow onto the block from varying heights until the weak layer fails.*

The stuffblock test has many desirable attributes: it is easy to learn, it can be performed quickly, the equipment is easy to carry and inexpensive, it can be applied by skiers, snowboarders, and snowmobilers, and it provides numerical results that are easy to compare between different observers (Johnson and Birkeland 1994). Results indicate a positive statistical relationship between stuffblock results and the more time-consuming rutschblock test in several different snow climates. Thus, the stuffblock test is another useful tool for avalanche workers and backcountry recreation enthusiasts attempting to evaluate slope stability.

Performing a Stuffblock Test

Locating a Snow Pit Site

Snow pit location is crucial for evaluating snow stability. Pits should be located in areas representative of the slope you wish to evaluate (similar aspect, elevation, slope angle, and exposure to wind) without endangering the sampling team. Often a nearby small slope can be used, or a small area on the side of a larger slope. Choice of an appropriate slope angle is particularly important for stuffblock tests. Since the slope angle determines the amount of shear stress on the weak layer, stuffblocks will fail more easily on steeper slopes, while on slopes that are too flat, it may be difficult or impossible to get the block to fail. Ideally, you should test a slope angle that corresponds to the steepest part of the slope you wish to evaluate. At a minimum, stuffblocks must be applied on slope angles typical of slab avalanche formation (30 to 45° slopes), although slopes as gentle as 25° can be used when conditions are particularly unstable.

Stuffblock Equipment

The equipment required to perform the stuffblock test is easy to acquire, inexpensive, and lightweight. The necessary tools (Figure 1) include:

- Snow shovel (a flat-bladed shovel works best)
- Snow saw (not essential, but the saw helps to isolate consistent columns)
- Nylon stuff sack
- Scale (capable of measuring 4.5 kg (10 lb))
- Nylon cord.

The equipment necessary for the stuffblock test includes a medium-sized nylon stuff sack with nylon string marked off in 100-mm (4-in) increments tied to the bottom, a small spring scale capable of measuring 4.5 kg (10 lb), and a snow shovel. A snow saw is useful, although the back of a ski can also be used in its place.

Since most avalanche workers and many backcountry skiers carry snow shovels and saws, only the stuff sack, scale, and cord need to be added to a typical snow pit kit.

These items can be picked up at a sporting goods store for less than $15; they weigh just 0.5 kg (1 lb). The scales we used for the test are made to weigh fish and cost about $10. The nylon cord should be about 800 mm (32 in) long, and should be marked off in 100-mm (4-in) increments. When the cord is attached to the bottom of the stuff sack, drop heights can be easily determined.

Stuffblock Procedure

1. Completely isolate a column of snow from the wall of the snow pit (Figures 2a, b, and c). The top of the column should be 300 mm (12 in) square (approximately the size of the shovel blade). A snow saw is the best tool for isolating a column of snow, but the tail of a ski will also work. Isolating the block on both sides and the back ensures that the test measures only the shear strength along the weak layer, the most critical strength when evaluating avalanche potential.
2. The stuff sack is filled with 4.5 kg (10 lb) of snow (measured with the scale) (Figures 3a, b).
3. The shovel blade is placed on top of the isolated column, and the full stuff sack is gently placed on the shovel blade (Figure 4).
4. If shear failure does not occur when the stuff sack is placed on the shovel, the block is loaded dynamically by dropping the stuff sack from a height of 100 mm (4 in) (measured by looking at the marked string that is tied to the bottom of the stuff sack). The height is increased by 100-mm (4-in) increments until shear failure occurs. Note the location of failure and the drop height (Figures 5 a, b).
5. If more than one weak layer is present in the snowpack, remove the snow from the first failure and continue dropping the stuffsack from increasing heights until the next layer of interest fails.

Figure 2a--A block of snow 300 mm (12 in) square is isolated from the snow pit wall by cutting out the sides.

Figure 2b--Then, begin cutting out the back . . .

Figure 2c--. . . isolating the column completely.

Figure 3a--The nylon stuff sack is filled with 4.5 kg (10 lb) of snow.

Figure 3b--Use the spring scale to measure the weight.

Figure 4--The sack is gently placed on top of the isolated column of snow.

Figure 5a--If the column does not fail when the sack is gently placed on top of the isolated column, the block is loaded dynamically. The stuff sack is lifted in increments of 100 mm (4 in) . . .

Figure 5b--. . .and dropped onto the column until it fails.

Maintaining consistency in the testing procedure is an important part of any stability test. 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 of the column, and the stuff sack should be dropped onto the middle of the shovel blade.

Performing a stuffblock test adds only a few minutes to the time spent analyzing the snowpack in a snow pit. Once the stuff sack is filled with snow, it is easy to perform several stuffblock tests in the same snow pit. Several tests analyze a larger area of snow and help validate the results for a particular location.

Interpreting Stuffblock Results

As would be expected, higher drop heights are associated with more stable conditions on slopes of similar elevation, aspect, and slope angle. This correlation was observed by comparing stuffblock results with snowpack information from a variety of observations such as recent avalanche activity, ski cutting tests, other snowpack stability tests, and the "general feel" of the snowpack. Although this information is difficult to quantify, avalanche workers understand that it is "real" data. As a loose guideline, drop heights of about 0 to 200 mm indicate mostly unstable snowpack conditions, 300 to 400 mm indicate moderately stable snowpack conditions, and drop heights of 500 mm and higher indicate the snowpack is mostly stable. One important limitation of the stuffblock is that it only tests a small area. Since the surrounding snow may be stronger or weaker than the area tested (Birkeland and others 1995; Jamieson and Johnston 1992), several tests will increase the confidence in the result. In the end, results from the stuffblock test, like all stability tests, are not definitive. They simply provide one more piece of information for a forecaster or backcountry traveler to contemplate when evaluating the stability of a slope.

Validating the Usefulness of the Stuffblock Test

Usefulness in Various Snow Climates

The stuffblock test was developed and tested in the snow climate of southwestern Montana. We found that the test gave us a good indication of snow stability and that the test results were much easier to communicate between observers than the results of other tests. We have used the stuffblock test as an integral part of our operational backcountry avalanche forecasting program for three full seasons. In addition, the Bridger Bowl Ski Patrol found the test to be effective for their snowpack evaluations during the past two seasons. We were unsure, however, how the test would work in the denser snows of the coastal climates, and the generally weaker snowpacks of continental areas.

Snowpack characteristics in the Western United States have been classified into three general snow climates. Coastal snow climates found in Washington, Oregon, and California are characterized by generally warmer temperatures, higher snowfall, higher snow density, and less faceted snow crystal growth than areas farther inland. The continental snow climate of Colorado has colder temperatures, lower snowfall, lower snow density, and more faceted crystal growth (LaChapelle 1966). Areas between these two extremes, such as the mountains of southwestern Montana, are considered to belong to an intermountain snow climate (Mock 1995; Birkeland and Mock, in press).

During the winter of 1995-1996, the stuffblock test was evaluated by experienced avalanche professionals in other snow climates. In the continental climate of Colorado, Andy Gleason, Nick Logan, and Knox Williams of the Colorado Avalanche Information Center agreed to use the stuffblock. Comments returned by the evaluators were positive, indicating that the test was effective in the Colorado snowpack. Gleason, who used the test most frequently, was the most enthusiastic. He especially liked the comparability of results among different field workers.

In Washington, Aaron Horwitz, a mountain guide who also works for the Washington Department of Transportation, evaluated the stuffblock test. His results also show a strong positive statistical correlation between the stuffblock and other stability tests. Horwitz was less enthusiastic about the test, and indicated that he tends to rely more heavily on other factors for evaluating the avalanche conditions rather than trust any of the available stability tests. At Alpine Meadows, CA, another coastal site, Gary Murphy and Gene Urie of the Alpine Meadows Ski Patrol performed several stuffblock tests during the 1994-1995 season. They were quite pleased with the results and felt that the stuffblock test was good at picking up weaknesses near the surface of the snowpack. They noted that the test might not be useful for wet snow influenced by rain. This is not a major drawback since all stability tests are difficult to apply in wet snow conditions.

In summary, the stuffblock test worked well in coastal, intermountain, and continental snow climates. The relationship between drop heights and a rough estimation of instability was similar for all three climates. However, all evaluators noted that experience with this test is necessary before informed decisions can be made about overall snowpack stability. This is the case with all available snow stability tests.

Although evaluators generally agreed that the stuffblock test was effective, we compared stuffblock results with the more widely accepted rutschblock test to further validate its usefulness. We will briefly discuss the rutschblock test and interpretation of its results.

Rutschblock Equipment and Procedure

The rutschblock test is described in detail by P.M.B. Föhn (1987). A brief overview will suffice here. As with the stuffblock test, a column of snow is isolated. However, with the rutschblock test this column is 2 m (about 6.5 ft) long and 1.5 m (about 4.5 ft) wide. This size can be approximated with skis and ski poles (Figure 6). Sides of the block are isolated by digging, cutting with a special snow saw, or cutting with the tail of a ski (Figure 7). The back of the block must be cut to ensure an accurate test. It can be cut with the tail of a ski, a special snow saw, or a piece of knotted nylon cord sawed back and forth by two people.

If the block fails while being isolated, it is given a rutschblock score of 1. If it does not fail, it is progressively loaded by a person on skis. First, the skier gently steps onto the block (Figure 8). Failure at this point indicates a rutschblock score of 2. Then the skier bends their knees, settling their weight on the block (score of 3) (Figure 9). This is followed by a moderate jump (score of 4), a large jump (score of 5), several large jumps (score of 6), and no failure (score of 7). Research in Switzerland and Canada has shown that rutschblocks that fail before the first jump (scores of 1, 2, or 3) indicate that avalanche slopes with similar conditions are likely to be triggered by a skier, while rutschblocks that fail on the first or second jump (scores of 4 or 5) indicate marginally stable conditions. Rutschblocks failing after two jumps (scores of 6 or 7) indicate a low potential of a skier-triggered avalanche on a similar slope, although it is still possible to trigger an avalanche (Föhn 1987; Jamieson and Johnston 1992).

Figure 6--The size of the rutschblock (2 m (6.5 ft) long and 1.5 m (4.9 ft) wide), can be approximated using skis and poles.

Figure 7--The entire rutschblock must be isolated. Sides can be shoveled out or cut with a ski or special saw. The back of the block can be cut with a ski or saw, or it can be sawed by two people using a knotted nylon cord.

Figure 8--If the rutschblock does not fail when it is isolated, it is progressively loaded by a person on skis. First, the person gently steps onto the block. A failure at this point would indicate a rutschblock score of 2.

Figure 9--If the rutschblock does not fail when a skier steps onto it, the skier bends his knees and "settles" his weight onto the block. When the block fails, as it did here, the rutschblock score is 3.

Relationship of Stuffblock and Rutschblock Results

During the 1993-1994 season, a significant, positive correlation between stuffblock and rutschblock results was found in southwestern Montana (Spearman rank order correlation coefficient of 0.77, $p < 0.0001$) (Johnson and Birkeland 1994). During the winter of 1995-1996 a study was conducted in a coastal snow climate (Washington), an intermountain snow climate (Montana), and a continental snow climate (Colorado) to see if the same relationship could be observed. Stuffblock and rutschblock tests were performed adjacent to each other in a snow pit to control for variations in slope angle, aspect, and elevation, although small-scale variability in snow strength may still have been present. Since the data are not ordered, the nonparametric Spearman rank order correlation coefficient was used to test the significance of the relationship (Zar 1984).

Table 1--Spearman rank order correlation coefficients comparing side-by-side stuffblock and rutschblock results from data collected during the winter of 1995-1996 in Washington, Montana, and Colorado. The p refers to the probability that the particular relationship is due to chance and N is the number of side-by-side tests. All snow climates showed a highly significant relationship between stuffblock drop height and rutschblock score.

Area	**Snow climate**	***Spearman r***	***p***	***N***
Washington	Coastal	0.72	0.0000	57
Montana	Intermountain	0.71	0.0000	64
Colorado	Continental	0.67	0.0001	27
All sites	**--**	***0.73***	***0.0000***	***148***

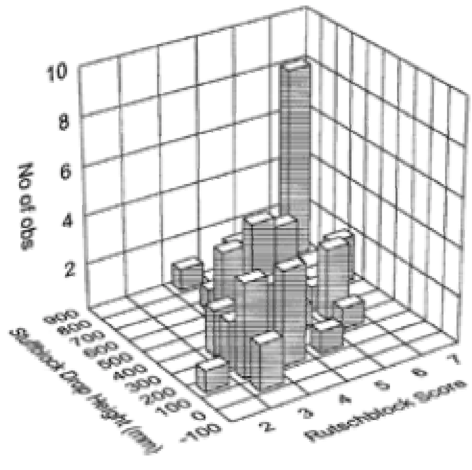

Figure 10a--Three-dimensional frequency diagram for Washington for data collected during the winter of 1995-1996. The frequency is the number of times that a certain rutschblock number was associated with a specific stuffblock drop height.

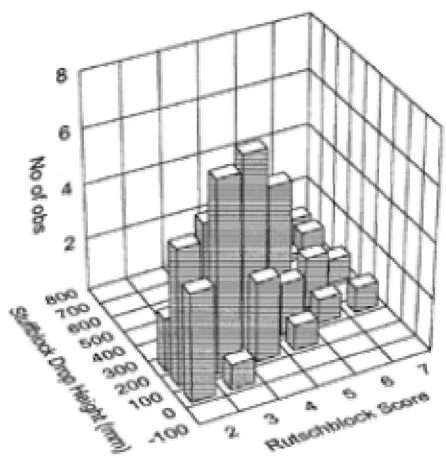

Figure 10b--Three-dimensional frequency diagram for Montana for data collected during the winter of 1995-1996. The frequency is the number of times that a certain rutschblock number was associated with a specific stuffblock drop height.

Results from coastal, intermountain, and continental snow climates were similar. In all cases, the Spearman rank order correlation was highly significant and positive (Table 1), indicating strong statistical evidence that increasing stuffblock drop heights are correlated with increasing rutschblock scores. Three-dimensional frequency diagrams demonstrate the results (Figures 10a, b, and c).

To determine which rutschblock scores were associated with different stuffblock drop heights, data were categorized by rutschblock score. The median stuffblock drop height and the upper and lower quartiles were computed for each rutschblock score (Table 2) and graphed in a box-whisker plot (Figure 11). Data show that rutschblock scores of 2 and 3, which are usually associated with unstable snowpacks (Jamieson and Johnston 1992), generally correspond to stuffblock drop heights of 200 mm or less. Rutschblock scores of 4 and 5, which are associated with moderately unstable snowpacks, correspond to stuffblock drop heights of approximately 200 mm to 500 mm, with medians at 300 mm (score of 4) and 400 mm (score of 5). These numerical values correspond well with our qualitative observations.

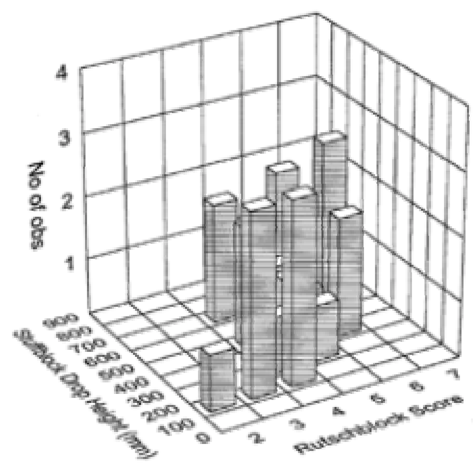

Figure 10c--Three-dimensional frequency diagram for Colorado for data collected during the winter of 1995-1996. The frequency is the number of times that a certain rutschblock number was associated with a specific stuffblock drop height.

Rutschblock score	*Stuffblock drop height (m)*			*N*
	Median	Lower quartile	Upper quartile	
2	0.10	0	0.10	13
3	0.10	0.10	0.20	27
4	0.30	0.20	0.40	44
5	0.40	0.30	0.50	28
6	0.40	0.30	0.60	20
7	0.80	0.60	0.80	16

Table 2--Stuffblock drop heights associated with rutschblock scores for all data from the winter of 1995-1996. The number of times a given rutschblock score was observed is represented by *N*.

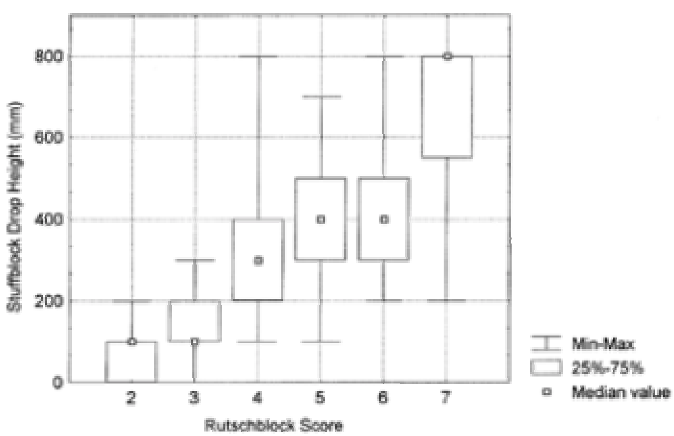

Figure 11--Box-whisker plot for all data collected during the winter of 1995-1996, categorized by rutschblock score. Median stuffblock drop heights, upper and lower quartiles, and the range of stuffblock values are shown for each rutschblock score.

Summary

The stuffblock snow stability test is a new test that provides valuable and quantifiable information about the strength and location of weak layers in the snowpack. This information can be used in combination with other factors when evaluating the avalanche potential of a particular location. Results from testing in the three distinct snow climates of Washington, Montana, and Colorado indicate that the test is effective at identifying the strength and location of weak layers. A positive, and highly statistically significant, 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. Comparability is especially useful for regional avalanche forecasters who must compare the results of several different observers with differing avalanche skills. For avalanche workers and winter backcountry travelers, the stuffblock provides another useful tool for snowpack stability evaluation.

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