The Compression Test – after 25 Years

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Summary

The compression test is a snowpack stability tests developed by Parks Canada wardens in the 1970's. In recent years its use has spread throughout the mountains of western Canada. Research on the compression test began in the winter of 1995. Based partly on this research, refinements and clarifications to the technique are suggested. Experience suggests that thin-planar failures (shears) or sudden collapses (drops) are associated with slab avalanching more than non-planar breaks or indistinct failures. In the latter case, the weak layer progressively compresses with additional taps. Using results from 121 skier-tested dry slabs, the frequency of skier triggering drops from about 90% for compression scores of *easy* to 10% for scores of *hard*. The technique appears effective for weak layers within a metre of the snow surface, and perhaps deeper. As rutschblock scores increase from 2 to 7, scores from adjacent compression tests usually increase from *easy-to-moderate* to *hard*. Compression scores tend to increase by about 3 taps for each 10 cm increase in the length of the column sides. The size and shape of the shovel blade as well as the orientation of the blade (facing up or down) has little effect on the results although a larger effect for weak layers close to the top of the column is possible. Different people doing adjacent tests usually obtain scores within 3 taps of the other's score for the same weak layer. Compression scores decrease by about 0 to 3 taps for each 10° increase in slope angle, and average 1 less tap per 10°. Compared to shovel test results, compression test results are less variable, much less sensitive to the length of the back cut, better for testing soft weak layers near the surface and easier to learn. However, experience indicates that the shovel test has its place. It works reasonably well for weak layers located between snowpack layers of 1-finger hardness or more, and is often better than the compression test for locating weak layers deeper than 1 metre.

History

Parks Canada wardens developed the compression test in the mid-1970's. Other variations on the test may be even older. Although the published research only dates back about four years, the test has been helping avalanche forecasters and their staff assess snow stability for about 25 years.

Use of the test west of the Rocky Mountains was delayed by

- a rumour that it was a test for the Rocky Mountain snowpack, and
- the fact that the shovel test works better in the more consolidated snowpack to the west than in the weaker snowpack of the Rockies. Conse-

quently, avalanche workers in the Rockies were more interested in an alternative to the shovel test than their counterparts in the Columbia and Coast Mountains.

In recent years, more avalanche professionals and recreationists in the Columbia and Coast Mountains have started to use the compression test. The Canadian Avalanche Association's InfoEx probably helped this westward migration.

In this article, I will summarize some experience and research on the compression test and contrast it with the shovel test.

Technique

One early variation of the compression test involved pushing down, with increasing force, on a shovel blade placed on top of a column of snow. This technique probably gave the test its name. Some folks have, quite reasonably, suggested that now that we tap on the shovel blade, we should call it the "tap test."

The following technique is largely taken from the *Observation Guidelines and Reporting Standards for Weather, Snowpack and Avalanches* (CAA, 1995). However, in the four winters since the Guidelines were published, the University of Calgary avalanche research project has done about 3000 compression tests. Based on this experience, I have included some proposed clarifications and refinements to the technique. These suggested changes are underlined.

1. Isolate a 30 cm by 30 cm column of snow deep enough to expose potential weak layers on the smooth walls of the column. <u>A depth of 100 to 120 cm is usually sufficient since the compression test rarely produces failures in deeper weak layers. Also, taller columns tend to wobble during tapping, potentially producing misleading results for deep weak layers.</u>

2. Rate any failures that occur while isolating the column as *very easy.*

3. Place a shovel blade on top of the column. Tap <u>*10*</u> times with fingertips, moving hand from wrist and rate any failures as *easy*.

4. If the snow surface slopes, remove a wedge of snow to level the top of column.

5. <u>If, during tapping, the upper part of the column slides off, or crushes so that it no longer "evenly" supports further tapping on the column, remove the damaged part of the column, level the new top of the column and continue tapping. Do not remove the portion of the column above a failed weak layer, provided it that evenly supports further tapping, since further tapping may cause failures in shallower weak layers.</u>

6. Tap <u>*10*</u> times with the fingertips <u>*or knuckles*</u> moving forearm from the elbow, and rate any failure as *moderate*. <u>While *moderate* taps should be harder than *easy* taps, they should **not** be as hard as one can reasonably tap with the knuckles.</u>

7. Finally hit the shovel blade moving arm from the shoulder *10* times with open hand or fist and rate any failures as *hard.* <u>If the *moderate* taps were too hard, the operator will often try to hit the shovel with even more force for the *hard* taps – and may hurt his or her hand.</u>

8. Rate any identified weak layers that did not fail as *no failure* (CTN).

9. <u>Record the depth of the snowpack that was tested. For example, if the top 110 cm of a 200 cm snowpack was tested (30 taps on a column, 110 cm tall) and the only result was an *easy* failure 25 cm below the surface, then record "CTE @ 25 cm; Test depth 110 cm, or TD 110". This clearly indicates that no failure occurred from 25 to 110 cm below the surface and that the snowpack between 110 cm and 200 cm was not tested with the compression test. Operations that **always** test the same depth of the snowpack, e.g. top 120 cm, may omit the test depth.</u>

Ratings

Some operations record **five** levels of results for weak layers or interfaces: *very easy*, *easy*, *moderate hard* or *no failure*. Other operations prefer to record failures that occur during taps 8-12 as CTE-M or *easy-to-moderate* and taps 18-22 as CTM-H or *moderate-to-hard*. This gives seven levels of compression scores. These intermediate scores can also be obtained by averaging two or more results for the same weak layer. For example, if a weak

Table 1 Character of Failures for the Compression and other Tests					
Name	Progressive Compression	Thin Planar	Sudden Collapse	Non-planar Break	No Failure
Code	PC	TP	SC	B	NF
Description	Layer compresses, failure advances through weak layer with additional taps	Sudden failure of an interface or weak layer, usually less than 1 cm thick	Sudden failure of a layer, usually > 2 cm thick, with noticeable downward displacement of the overlying snow	Failure is not confined to a plane or layer in the column	Does not fail with 30 taps.
Other terms	Indistinct, rough, slow	Shear, pop, fast	Collapse, drop	Break, rough	

layer fails at 21 taps in the first test, and 17 in the second test, the average number of taps to cause failure is 19 and some operations would record this as *moderate-to-hard*.

What if a weak layer only fails on one of two tests? For research purposes we assign the result with no failure a rating of 35 “taps.” So if a layer failed at 27 taps on the first test and did not fail on the second test, we would calculate the average (27 + 35)/2 = 31 and consider the average result to be *no failure* since the average is greater than 30. However, if the layer failed at 23 taps on the first test, then the average would be (23 + 35)/2 = 29 and we would consider the average result to be *hard*.

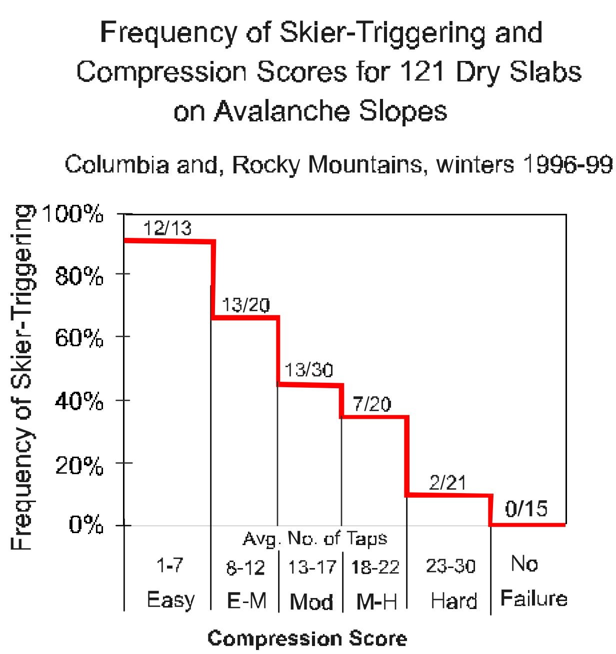
The character of failures

There is no standard way to describe and record the failure character. For research purposes, we have used the system in Table 1 for several years.

There is widespread agreement that thin planar failures (shears or pops) and sudden collapses (drops) are of interest for assessing slab stability and should be recorded. In our experience, progressive compressions (indistinct failures) are common in shallow soft layers and rarely, if ever, associated with avalanche activity in the same layer. Should they be recorded? Such failures may not be important for current stability evaluation but some operations track them and report that that they may develop over time into thin planar failures (shears). For persistent weak layers or weak layers that have released avalanches or failed in other tests, it is often useful to record non-failures (CTN). Such results may suggest stability for the particular layer. However, stability is always assessed based on a variety of factors.

Relative frequency of skier-triggering

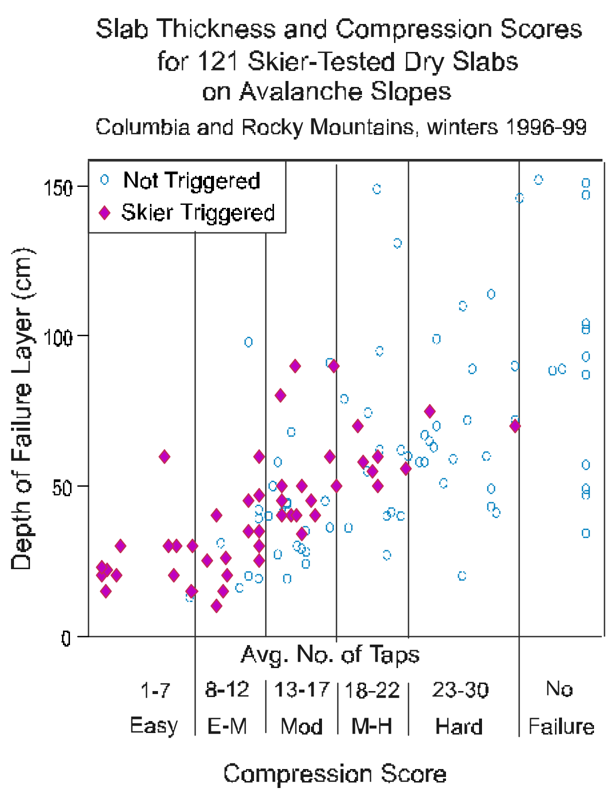
In the last four winters, we have done compression tests on avalanche slopes where 121 slabs were ski-tested. Forty-seven of these were triggered. We did compression tests on each of these slopes at a



site that appeared typical of the start zone. The graph on the previous page shows the decreasing frequency of skier triggering as the average compression score increases, which is what we expect from a stability test. While the decreasing trend is encouraging, notice that about 10% of the slabs with *hard* compression scores were skier triggered. Some of these results are from intensive backcountry skiing where the slab was triggered from an isolated weakness; however, we always do the compression tests at a place that is typical of the start zone. The fact that 10% of slabs with *hard* compression scores are skier triggered emphasizes that, when assessing snow stability, we must not place too much confidence on any *point* observation of the snowpack.

What is the maximum effective depth for the compression test?

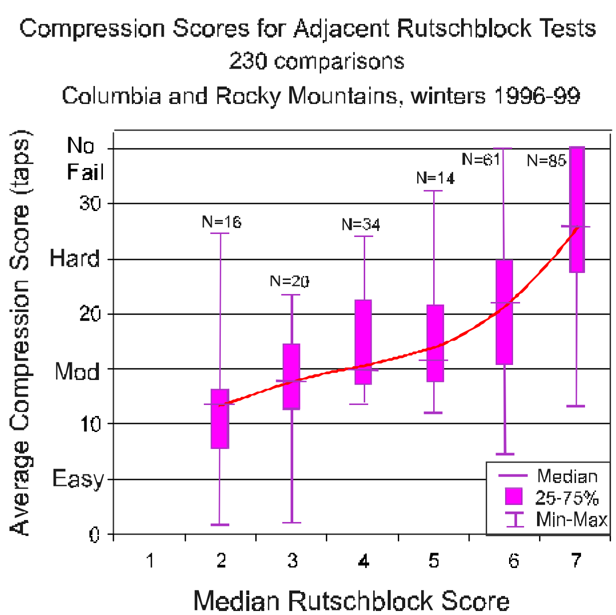
The slab thickness for the 121 skier-tested slabs is shown in the following graph. Notice that all the skier-triggered slabs were less than 100 cm thick. Although the two skier-triggered slabs with *hard* scores were 70 to 80 cm thick, the test distinguishes between most triggered slabs (low scores) and slabs not triggered (high scores or no failure).



Although we only have tested 6 slabs that were more than 110 cm thick, the compression test gives appropriate scores for these slabs. While this graph does not show any misleading scores for slabs between 100 and 160 cm thick, the practical limit of the test is often 100 to 120 cm. For columns taller than 120 cm, tapping becomes awkward and we have observed wobbling of the columns.

Compression scores compared with rutschblock scores

For this comparison, we did three compression scores beside one or two rutschblock tests 230 times in the last four years. The graph shows that the average compression score increases as the median rutschblock score increases. Beside rutschblock with scores of 2, we usually obtained *easy-to-moderate* compression scores. Beside rutschblock scores of 7 we usually obtained compression scores of *hard* or *no-failure.* Note that we often obtained *moderate* compression scores beside rutschblock scores of 3, 4, or 5 and sometimes 6. So which test is better? Well, since the rutschblock involves skier-triggering and a much larger specimen, one rutschblock is likely a better index of stability than one compression test. However, in the time required for one rutschblock test, we can often do two or three compression tests. If these tests are done at various well chosen locations, we probably get better information about snow stability and its variation over the terrain



from the compression tests. For introductory avalanche courses with students that have not seen many slab avalanches, the rutschblock is a valuable teaching tool.

Effect of column size

At the 1996 International Snow Science Workshop in Banff, Colin Johnston and I presented results of six series of compression tests in which the size of the column was varied in the range from 20 cm by 20 cm to 40 cm by 40 cm. For each series, three to 15 tests were done for each size of column. Overall, the average compression score increased by 3 taps for each 10 cm increase in the side of the square column. Currently, the Canadian Avalanche Association (CAA, 1995) recommends 30 cm by 30 cm columns. However, I have met several avalanche workers who prefer to use 25 cm by 25 cm columns because that is closer to the area of their shovel blade. Columns that are 5 cm narrow are likely to get scores that are 1 or 2 taps lower. For weak layers close to the top of the column, a column with reduced cross-sectional area (that is similar to the area of the shovel blade) may get cleaner or more obvious failures. However, for weak layers at least 10 cm below the blade, the only effect of the smaller column is likely to be lower scores. Since weak layers located so close to the surface are usually less important for assessing slab stability, there appears to be a small advantage to always using 30 cm by 30 cm columns.

Effect of shovel shape and size

In the winter of 1996, Jill Hughes and Ken Black completed ten and twelve pairs of tests to assess the effect of shovel size and shape. Each pair consisted of one test with a relatively small curved plastic shovel blade and a test with a larger flatter metal shovel. Since the average difference was less than one tap, it appears that the shape of the shovel blade has little effect on compression scores. However, it is possible that there may be a greater difference for weak layers located close to the top of the column (perhaps within 10 cm).

In the winter of 1996, avalanche research staff working in the Monashees near Blue River and in the Bobby Burns completed seven sets of compression tests to assess the effect of shovel orientation. Each set consisted of 4 to 15 pairs of tests, one test with the shovel facing up and one with the shovel facing down. For six comparisons with a relatively flat metal blade, there was no significant difference in the average scores (4 or 5 pairs). However, using a relatively small curved plastic blade, the average score was about 1 tap less when the shovel blade faced up compared to the score when the shovel blade faced down (15 pairs). The effect of shovel orientation appears to be small, and shovel orientation can be left to personal preference.

Differences scores for different folks?

In the winter of 1995-96, avalanche research staff alternated doing compression tests (Jamieson and Johnston, 1997). Each comparison consisted of 20 or 24 paired tests. For all eight of the comparisons, the average scores were significantly different ($p < 0.05$). However, the average compression scores fall with the same range (e.g. *moderate*) six of eight times or within adjacent ranges (e.g. *easy-to-moderate* and *moderate*) on the remaining two comparisons.

Effect of slope angle

Eleven series of compression tests, each consisting of repeated tests on the same slope at two, three or four sites with substantially different slope angles (inclinations), are summarized in Table 2. For each series the compression scores are correlated with the slope angle. The correlations are significant in seven of the eleven series ($p < 0.05$). Ten of the eleven correlation coefficients are negative, indicating that the number of taps tends to decrease as the slope angle increases. The last column of Table 2 shows the effect, which is the coefficient of slope angle from linear regressions. This effect ranges widely from –3 taps per 10° increase in slope angle to 0.2 taps per 10°. Although field staff tried to select sites with uniform snowpack properties, the reason the effect varies from about 0 taps per 10° to 3 taps per 10° is probably due to variability in the slab properties and thickness. The average effect is –1.1 taps per 10° indicating that compression scores may typically decrease by about one tap as the slope angle increases by 10°. While this typical effect is small, the effect can be three times as large. At the extreme, it appears that scores could decrease by twelve taps – possibly from *moderate*

Table 2 Effect of Slope Angle on Compression Scores								
Date	Depth (cm)	Slope (°)	No. of Tests	No. of Taps	Corr. Coef. *r*	*p*	Std. Err of Est.	Effect (taps/ 10°)
96-02-09	28-31	22,30,40	9	12-15	-0.09	0.83	1.2	-0.1
96-02-13	48-56	0,12, 23,33	19	20-28	**-0.67**	0.002	1.8	-1.3
96-02-14	38-49	0,22,33	16	13-28	-0.19	0.49	3.9	-0.5
99-01-19	5-9	0,15,30	14	1-3	**-0.56**	0.04	0.5	-0.3
99-01-19	14-19	0,15,30	15	3-10	-0.15	0.60	1.7	-0.2
99-01-19	30-39	0,15,30	14	14-26	**-0.69**	0.006	3.7	-2.6
99-01-19	37-42	0,15,30	9	17-22	0.15	0.69	2.0	0.2
99-02-18	16-18	0,15	10	1-3	**-0.75**	0.01	0.5	-0.7
99-02-18	20-28	0,15,30	14	4-13	**-0.58**	0.03	2.5	-1.3
99-02-18	28-32	0,15,30	14	1-12	**-0.80**	0.001	3.1	-3.0
99-02-18	38-46	0,15,30	15	11-28	**-0.61**	0.02	4.0	-2.3

to *easy* – as the slope angle increases from 0° to 40°.

Comparison with the shovel test

First, we have no comparison of compression scores with shovel test scores. However, Jill Hughes and I started this comparison using three compression tests beside three shovel tests at a number of sites and dates during the winter of 1995. We gave up because we had difficulty getting the shovel test to identify the same weak layer in at least two of the three tests. I have not seen any results comparing the scores from these two tests.

Repeatability

As indicated above, we found that the compression test located weak layers much more consistently than the shovel test. For a particular weak layer, scores from repeated tests are within 2-3 taps of the mean 13 times out of 20 and within 5 taps of the mean 19 times out of 20 (Jamieson and Johnston, 1995). Coefficients of variation for compression scores ranged from 8% to 20% and averaged 13%. For the shovel test, coefficients of variation ranged from 20% to 41% and averaged 28% (Schaerer, 1992). So, the results of shovel tests are twice as variable as compression scores.

Depth of back cut

The shovel test is very sensitive to the depth of the saw cut down the back wall. Non-planar fractures that start at the bottom of the saw cut are common, especially if the cut is much deeper than the bottom of the shovel. The compression test is not sensitive to the depth of the saw cut for column heights up to about 120 cm. Taller columns may wobble during tapping and – potentially – crack or damage snowpack layers, resulting in misleading results.

Deep weak layers

Since the compression test loads the top of the column, and the stress waves from tapping the shovel blade dissipate with depth, the test does not appear suited to locating weak layers deeper than about 120 cm. In contrast, the shovel test can be repeated for deeper weak layers – as deep as you care to dig.

Soft near-surface layers

The compression test works for soft snow layers near the surface and for old snow layers up to about 120 cm below the surface. For the shovel test, soft snow layers – certainly fist layers and perhaps 4-finger layers – should be removed (CAA, 1995). These soft layers can be tested with the burp test as the first part of the shovel test.

Shovel shape and size

The compression test results do not appear sensitive to the size or shape of the shovel (Jamieson and Johnston, 1997) except perhaps for weak layers located near the shovel. Since the shovel test is not used for soft layers, the shovel size or shape should not affect the results for columns of harder layers. (Schaerer, 1992). However, for curved shovels, a wide slot should be made for the back cut to ensure that inserting the shovel does not pry on the column, resulting in bending failures (often at the bottom of the back cut) instead of shear failures in weak layers.

Objectivity of results

The *easy, moderate* or *hard* ratings from the shovel tests are certainly subjective. Compression scores are more objective since the force applied is moderated by

- using the fingertips and moving from wrist for *easy* taps,
- tapping with the fingertips or knuckles and moving from the elbow for *moderate* taps, and
- tapping with an open hand or fist and swinging from the shoulder for *hard* taps.

However, subjectivity cannot be eliminated in the compression test. [See Johnson and Birkeland (1995) for the information on the stuffblock test which is a more objective test of slab stability.]

Time required

Although we have not used a stop watch to compare the time required by these tests, they both require about the same time for testing the top metre of the snowpack.

Learning curve

Again no data, just experience. At the end of a CAA Level 1 course, most students can do a reasonable compression test. However, shovel test technique is often wanting, particularly with regard to the back cut which is often cut too deep. As a result of technique and repeatability problems with the shovel test, students get far more consistent results with the compression test.

A strength test or a stability test?

A strength test provides an index or measurement of the strength – usually shear strength – of a weak snowpack layer. So the shovel (shear) test is a strength test. A stability test provides an index or measurement of the ratio of weak layer strength to load, where the load is usually due to gravity pulling on the slab and may also include the load due to a skier or the dynamic load due to hand taps, etc. Clearly, the compression test is, like the rutschblock, a stability test. However, before we conclude that the shovel test is about apples and the compression test is about oranges, consider the study by Föhn and Camponovo (1997). They showed that skier stability, similar to what the compression test indexes, is linearly related to the strength of weak layers, which is what the shovel test measures. The reason is that the strength of a weak layer adjusts to the overlying load through settlement and metamorphism. So, strength is a function of load, and both the numerator and denominator of the strength to load ratio are functions of load. Looked at this way, it is not suprising that the strength of a weak layer bears a linear relationship to the stability of the slab and weak layer. Consequently, we should generally expect low compression scores near easy results of the shovel test for the same layer, and high compression scores for weak layers near where shovel test results are *hard*. Of course, we have to say "generally" since the snowpack is variable, our technique is variable, and the tests are at least partly subjective indices.

Time to retire the shovel test?

While ski touring and interested primarily in weak layers within the top metre of the snowpack, I usually prefer the compression test. However, I don't think we should retire the shovel test. It works reasonably well in old snow, and it often works better than the compression test for weak layers deeper than 100 or 120 cm.

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