The Compression Test for Snow Stability

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ABSTRACT

The compression test is a quick stability test. It involves tapping on a shovel placed on top of a column of snow and noting the failures in weak layers that appear on the smooth walls of the column. Limited data show a correlation for compression scores (number of taps) with rutschblock scores and with the frequency of skier triggering on avalanche slopes.

The effect of various experimental factors on compression scores are assessed. Two different designs of shovel blades (varying in size and shape) did not appear to affect the compression scores. Increasing the cross-sectional area of the columns increased the compression scores. Different operators generally obtained a score in the same range identified as easy, easy-moderate, moderate, moderate-hard and hard.

BACKGROUND

The test method used for this study was developed by Parks Canada wardens in the 1970's although similar tests may have been developed elsewhere. Weak layers are identified when they fail and become visible on the walls of the column of snow either while tapping on a shovel placed on top of the column, or occasionally while initially cutting the column.

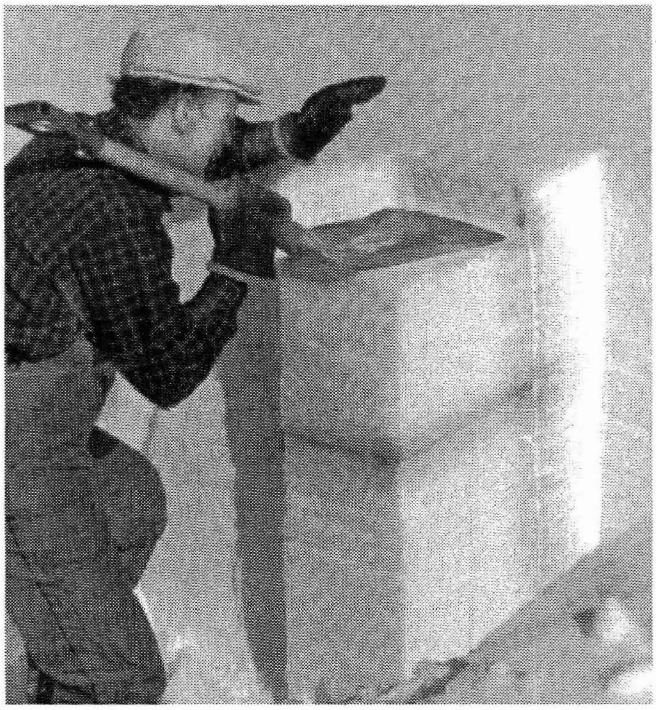

Figure 1 Compression test

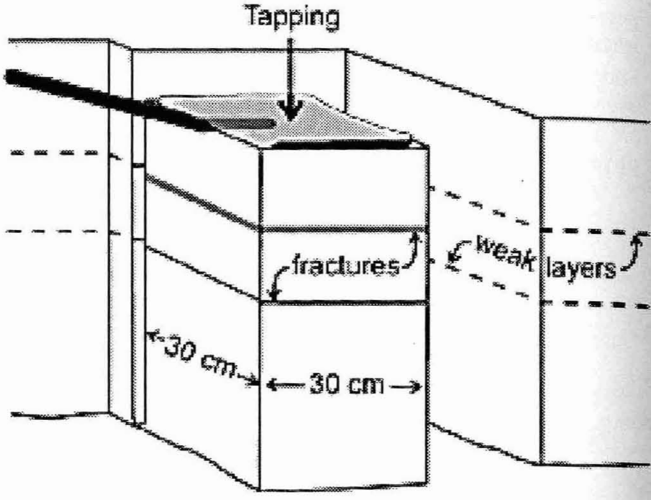

Figure 2 Compression test showing failures in two weak layers

TECHNIQUE

Isolate a 30 cm by 30 cm column of snow deep enough to expose potential weak layers on the smooth walls of the column (CAA, 1995, p. 44-45). Rate any failures that occur while isolating the column as "very easy". Place a shovel blade on top of the column. Tap with finger tips, moving hand from wrist and rate any failures as "easy". Tap with the knuckles from elbow and rate any failure as "moderate". Finally hit the shovel blade with open hand or fist and rate any failures as "hard". In practice, 5-10 easy or moderate taps are applied before increasing the force. For the purposes of the following field studies, 10 taps were applied before increasing the force. For scores from adjacent tests, variability is typically ±2-3 taps 65% of the time (Jamieson and Johnston, 1995).

According to the CAA Guidelines (CAA, 1995, p. 44-45), if the snow surface slopes, a wedge of snow should be removed to level the top of column "after surface layers have been tested". Since we observed wobbling of very tall columns (> 1.5 m) when the moderate and hard blows were applied to columns with sloping top surfaces, we decided to level the top of the column after the easy taps from the wrist. This ensures that the moderate and hard taps are directed vertically down the column.

SCORING

The CAA Guidelines give four levels (very easy, easy, moderate or hard) for rating the failure of weak layers in response to tapping with increasing force on the top of the column. However, some field workers use "easy-moderate" and "moderate-hard" to describe the transitions. Using our practise of 10 taps per force level, Table 1 gives a six-level rating scheme that includes the easy-moderate and moderate-hard transitions. Although further experience is required with this scheme, it is used in several of the discussions in this paper.

Table 1 Rating Schemes for Compression Test

	Four-Level Rating Scheme (CAA, 1995)				Six-Level Rating Scheme (for discussion only)					
Rating	VE	E	M	H	VE	E	E-M	M	M-H	H
No. of Taps	0	1-10	11-20	21-30	0	1-7	8-12	13-17	18-22	23-30

INTERPRETATION

Sudden failures that appear on the column walls as distinct lines ("pops" or "drops") are more likely to be the failure plane for avalanches than "rough" or indistinct failures. Indistinct failures are sometimes the result of a soft layer "pressing out" next to a harder layer. Experience in the Canadian Rockies suggests that layers with "very easy" or "easy" distinct failures are more often associated with human or explosive triggering than are "moderate" or "hard" failures (G. Israelson, personal communication).

EXPERIMENTAL OBJECTIVES

During the winter of 1996, we conducted field studies of the compression test concerning:

- effect of different operators
- effect of slope inclination
- effect of varying cross-sectional area of the column
- effect of shovel size and shape
- effect of shovel facing up or down
- correlation with rutschblock scores
- correlation with skier-triggering

Preliminary results for these studies are presented in this paper.

EFFECT OF DIFFERENT OPERATORS

To determine if different operators tend to get the same or different results, compression tests were repeated with different operators testing adjacent columns of snow. On 95-12-28, three operators tested two weak layers in 24 columns yielding 12 comparisons (Table 2). On 96-03-06 and on 96-03-14, two operators tested one weak layer in 20 pairs of columns.

Compression test results (scores) are compared based on the number of taps required to cause failure. However, since the taps increase progressively in force and the depth of damping snow tends to decrease, compression scores are ordinal data. Consequently, the matched pairs of tests with difference operators are assessed with a Wilcoxon test for matched pairs in Table 2 rather than a t-test.

As shown in Table 2, the difference in the mean number of taps required to cause failure is significant ($p < 0.05$) in 7 of the 8 comparisons or marginally significant (0.05 £ p < 0.01) in the remaining case. Hence, differences between operators can often be determined by repeating the compression test 20 or more times.

To assess whether the differences in compression scores between operators are likely to affect decisions regarding stability, the comparisons from Table 2 are also plotted in Figure 3 using box and whisker graphs. The standard error of the number of taps is shown with a box and the standard deviation with a whisker. The scores from an individual compression test are expected to fall in the

Table 2 Effect of Different Operators on Compression Scores

Date	Layer	Depth (cm)	Operators	No. of Taps		Wilcoxon Test	
Date	Layer	Depth (cm)	Operators A & B	Opr A Mean±SD	Opr B Mean±SD	No. of Pairs	p
951228	FC DF 1	6	1 & 2	5.1±1.4	4.5±2.1	24	0.07
951228	FC DF 1	6	1 & 3	5.1±1.4	2.2±0.6	24	10^{-5}
951228	FC DF 1	6	2 & 3	4.5±2.1	2.2±0.6	24	10^{-5}
951228	FC RG 0.5	22	1 & 2	18.5±2.2	21.9±1.2	24	10^{-4}
951228	FC RG 0.5	22	1 & 3	18.5±2.2	20.0±2.1	24	0.02
951228	FC RG 0.5	22	2 & 3	21.9±1.2	20.0±2.1	24	10^{-3}
960306	FC 1	14	4 & 5	18.4±1.9	16.3±1.1	20	10^{-4}
960314	FC 0.5	27	4 & 5	11.6±0.6	7.1±3.3	20	10^{-3}

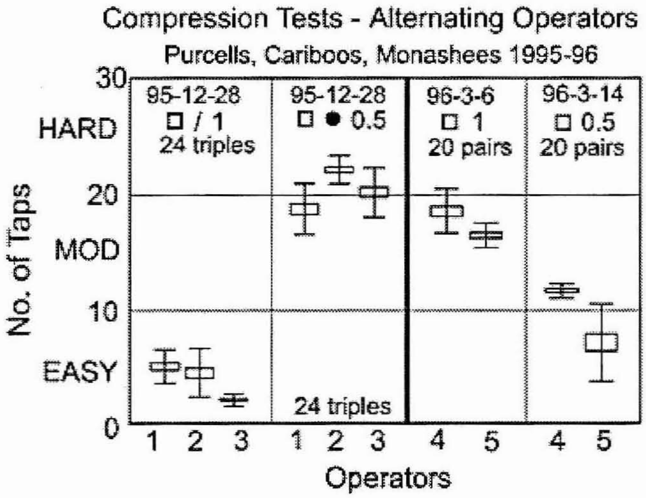

Figure 3 Effect of different operators on compression scores

range marked by the whiskers approximately two-thirds of the time. Using the leftmost box and whisker in Figure 3 as an example, two-thirds of the scores obtained by Operator 1 on 95-12-28 for the shallow layer (FC DF 1) probably lie between 4 and 7 taps. More importantly, most of the scores obtained for the shallow layer by both operators are in the easy range. Similarly, the for the second set of comparisons on 95-12-28, most of the scores lie in the moderate-hard range. For the compression scores compared on 96-03-06, most of the scores range between moderate and moderate-hard. For the compression scores compared on 96-03-14, most of the scores range between easy and easy-moderate. Compression scores obtained from different operators generally fall in the same range, or occasionally within an adjacent range (e.g. moderate to easy-moderate). It is not common for scores from different operators to spread over three ranges (e.g. easy to easy-moderate to moderate). This variability of compression scores is roughly comparable to rutschblock variability where repeated scores vary within 1 of 7 steps, two-thirds of the time (Jamieson and Johnston, 1993).

EFFECT OF SLOPE INCLINATION

To assess the effect of slope inclination on compression scores, same-day comparisons were conducted on four slopes where the inclination varied from as low as 0º to as much as 40º. At each slope, 3 to 5 compression tests were done at 3 to 5 siteswith different slope inclinations. The compression scores (number of taps to cause failure) for each site are given in Table 3. The results for 3 of the 4 slopes are also shown in Figure 4 along with the depth of the weak layer at each site. The scores on 96-02-13 and 96-02-14 show a tendency to decrease with increasing slope inclination except for at the steepest sites where the increase may have been due to the observed increase in depth of the weak layer. Only 3 tests were done at each site on 96-02-09 (Table 3 and Figure 4) and 96-01-24 (Table 3) and an effect of slòpe inclination on these compression scores is not apparent. More tests per site are recommended for future studies of slope effects.

EFFECT OF VARYING CROSS-SECTIONAL AREA OF THE COLUMN

During the winter, seven trials were conducted in which cross sections of columns ranged from 20 x 20 cm to 40 x 40 cm as shown in Tables 4a and 4b and Figure 5. (In several cases, more than 30 taps were applied to prevent the distribution from being truncated.) The figure clearly shows the mean number of taps increasing with the length

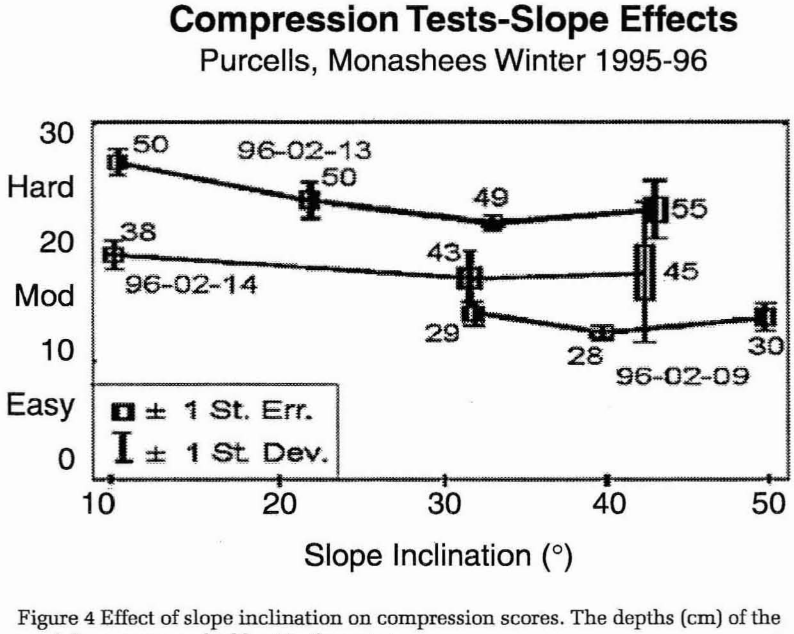

Figure 4 Effect of slope inclination on compression scores. The depths (cm) of the weak layers are marked beside the points.

Table 3 Effect of Slope Inclination on Compression Scores

96-02-13			96-02-14			96-01-24			96-02-09		
Slope (o)	No. of Tests	Mean ±SD	Slope (ö)	No. of Tests	Mean ±SD	Slope (o)	No. of Tests	Mean ±SD	Slope (o)	No. of Tests	Mean ±SD
0	5	26.6±1.1	0	5	19.0±1.9	4	3	15.7±2.3	22	3	14.0±1.0
12	5	23.4±1.5	22	5	17.0±2.3	10	3	18.3±1.5	30	3	12.3±0.6
23	4	21.5±0.6	33	6	17.5±6.0	16	3	17.0±1.0	40	3	13.7±1.2
33	5	22.6±2.4				19	3	20.3±0.6			
						23	3	17.7±1.2			

of the column sides and hence the advantage of keeping columns a consistent size. (The three decreases apparent at 35 x 35 cm all occurred late on 9 March 1996 when it began to drizzle.)

During these trials, operators were encouraged to report subjective preferences concerning column size. Their preference was for 30 x 30 cm columns except for one layer which seemed to produce "cleaner" shears for 25 x 25 cm columns. Overall, the 30 x 30 cm column size specified by the CAA (1995) appears well chosen.

EFFECT OF SHOVEL SIZE AND SHAPE

To assess the effect of shovel design, tests with a relatively flat metal blade were alternated with tests using a smaller curved plastic blade on 14 March 1996. The weak layer consisted of 0.3-0.5 mm faceted crystals 24 cm below the surface. A Wilcoxon test was used to compare the compression scores from adjacent tests with the different blades (Table 5). For operator 4, the difference in scores from the two shovel blades is marginally significant ($p = 0.09$). For operator 5 and when both sets of alternat

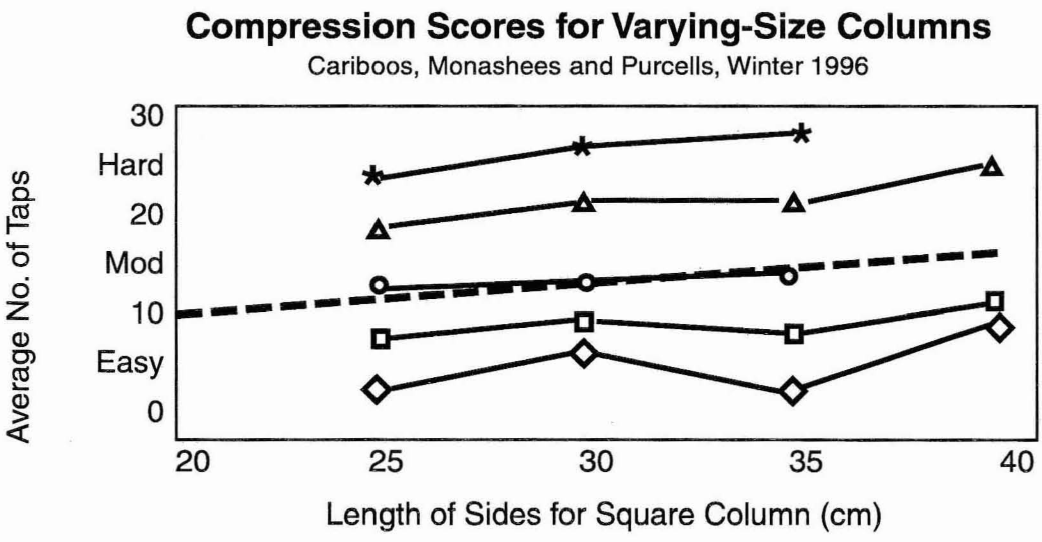

Figure 5 Effect of column size on compression scores

Table 4a Effect of Cross-Sectional Area on Compression Scores											
96-03-09 Layer down 7-11 cm			96-03-09 Feb. 17 SH			96-03-09 Layer down 40-43 cm			96-03-09 Layer down 46-48 cm		
Sides (cm)	No. of Tests	Mean ±SD	Sides (cm)	No. of Tests	Mean ±SD	Sides (cm)	No. of Tests	Mean ±SD	Sides (cm)	No. of Tests	Mean ±SD
25	5	5.2±3.0	25	5	10.4±1.3	25	5	21.8±1.6	25	5	26.6±1.9
30	4	9.3±2.6	30	5	12.4±0.9	30	5	24.4±1.5	30	5	29.8±1.8
35	3	5.0±1.0	35	5	11.0±1.4	35	5	24.4±1.1	-	-	-
40	4	12.5±1.3	40	5	13.6±1.5	40	5	28.6±3.1	-	-	-

Table 4b Effect of Cross-Sectional Area on Compression Scores								
96-03-09 Layer down 48-51 cm			95-12-16 Layer down 23 cm			96-01-25 Layer down 27 cm		
Sides (cm)	No. of Tests	Mean ±SD	Sides (cm)	No. of Tests	Mean ±SD	Sides (cm)	No. of Tests	Mean ±SD
25	5	27.0±2.0	25	15	15.5±1.4	20	8	13.0±0.8
30	4	30.3±1.7	30	15	16.1±1.2	30	8	16.1±1.6
35	4	31.5±2.4	35	15	17.1±1.0	40	8	19.0±0.8

ing tests were combined there was no significant difference in compression scores with the different blades ($p > 0.1$). However, the above average variability of the scores from operator 5 make it difficult to detect differences (Figure 6). Further comparisons are planned to assess the effect of shovel shape on weak layers closer to the shovel.

EFFECT OF SHOVEL FACING UP OR DOWN

Some field workers prefer tapping a shovel blade that faces up whereas others prefer the blade facing down. To assess this effect, tests were alternated with the two orientations of the shovel blade. For the tests on 16 January 1996, 4-5 pairs of tests were done with a relatively flat metal blade (Table 6 and Figure 7). On 21 March 1996, 15 pairs were done with a smaller more curved blade. Only this latter comparison yielded a significant difference in the number of taps with the different blade orientations ($p < 0.05$). Nevertheless, since the mean difference is only one tap, the scores from matched tests fall within the same range (easy, easy-moderate, moderate, moderate-hard or hard). The effect of shovel orientation appears not to affect the scores based on ranges.

CORRELATION WITH RUTSCHBLOCK SCORES

To determine a possible correlation between rutschblock scores and compression scores, three compression tests were done adjacent to one or two rutschblock tests. At some of the sites, more than one weak layer failed, each

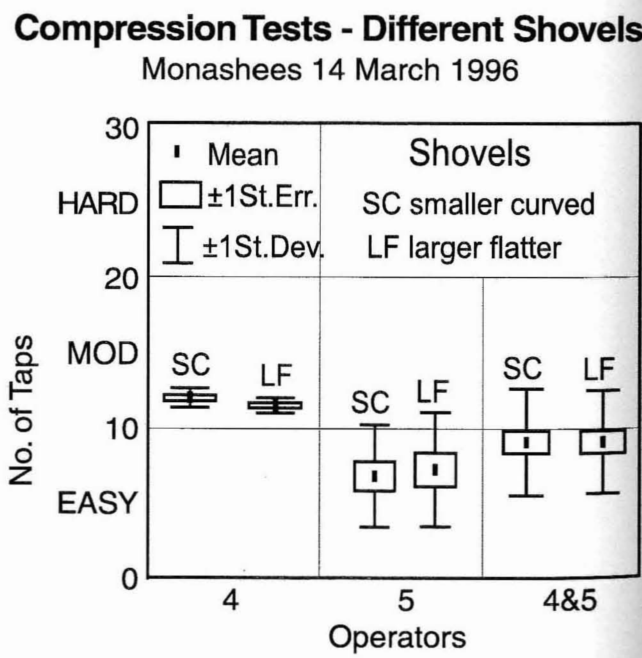

Figure 6 Effect of different shovels on compression scores

Table 5 Effect of Shovel Size and Shape on Compression Test Results						
	No. of Pairs	Number of Taps				Wilcoxon Test p
		Metal Shovel		Smaller Curved Plastic Shovel		
		Range	Mean±SD	Range	Mean±SD	
Operator 4	10	11-12	11.3±0.5	11-13	11.8±0.6	0.09
Operator 5	12	2-13	7.3±3.8	2-12	6.8±3.4	0.92
Operators 4 and 5	22	2-13	9.1±3.4	2-13	9.2±3.5	0.43

resulting in a compression score that corresponded to a rutschblock score. The median and range of compression scores for 52 rutschblock scores ranging from 2-7 are plotted in Figure 8. For rutschblock scores of 2, the two compression scores are in the easy-moderate range. For rutschblock scores of 4, compression scores are generally in the moderate range. For rutschblock scores of 5 or 6, compression scores range from moderate to moderate-hard. And for rutschblock scores of 7, compression scores are generally in the hard range. Except for five rutschblock scores of 3, median compression scores increase as rutschblock scores increase from 2 to 7. Based on these limited and preliminary data, there appears to be a correlation between rutschblock and compression scores. Further field studies are planned.

Although the compression test is considerably faster than the rutschblock test, it is unlikely to prove to be as good an index of slab stability for skiers as the rutschblock which tests an area over 30 times larger and loads the area with a skier.

CORRELATION WITH SKIER-TRIGGERING

During the winter of 1996, compression tests were done at 21 skier-tested slopes, eight of which produced dry slab avalanches. For each slope, the compression tests were done at a site judged typical of the start zone. On some slopes where skier-testing did not release avalanches, the compression test found more than one weak layer, thereby providing more than one skier-tested slab for the correlation.

The depths of the weak layers for the skier-tested slabs are plotted against the average number of taps required to cause failures in the weak layers (Figure 9). There was only one skier-tested slab with an easy compression score (1-7 taps). Most of the skier-triggered slabs fall in the easy-to-moderate (8-12 taps) or moderate (12-17 taps) ranges. The graph also identifies one slab that was triggered remotely (17 taps) and one that was triggered from near the bottom of the slope (30 taps). Although the site chosen for the

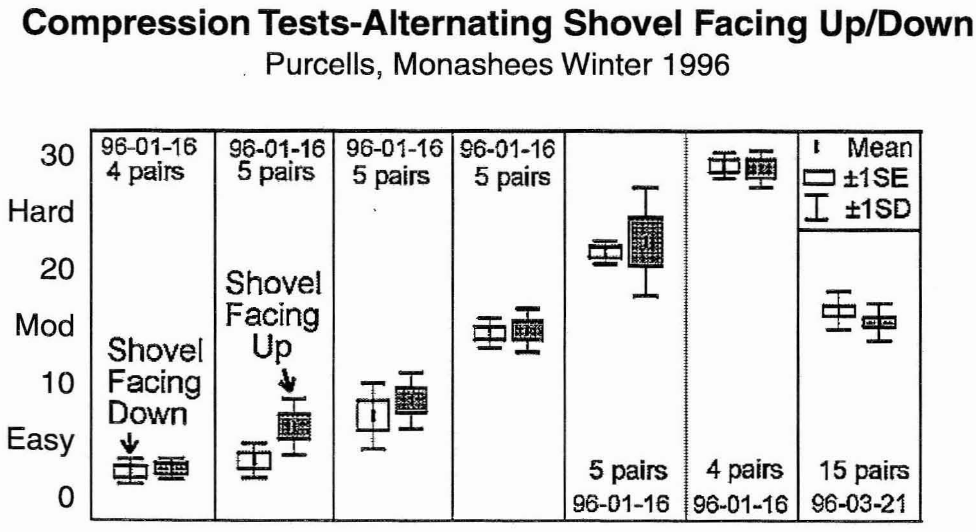

Figure 7 Effect of shovel orientation on compression scores. Boxes and whiskers show ±1 standard error and ±1 standard deviation respectively.

Table 6 Effect of Shovel Orientation on Compression Test Results						
	Average Depth of Layer		Number of Taps		Shovel Blade	Wilcoxon Test
			Facing Down	Facing Up		p
Date	(cm)	N	Mean±SD	Mean±SD		
960116	10	4	3.8±1.0	4.0±0.8	flat metal	0.72
960116	14	5	4.6±1.3	7.2±2.2	flat metal	0.07
960116	24	5	8.0±2.6	9.2±2.2	flat metal	0.35
960116	35	5	14.4±1.1	14.6±1.7	flat metal	0.86
960116	41	5	20.6±0.9	21.4±4.2	flat metal	0.69
960116	52	4	27.3±1.0	27.0±1.4	flat metal	0.59
960321	31	15	16.1±1.5	15.3±1.4	smaller curved	0.01
All Pairs	-	43	14.0±7.1	14.3±6.7		0.55

compression tests on the bottom-triggered slope appeared typical of the start zone, the high score (30 taps) suggests that the slab was more stable at the top of the slope than at the trigger point 80 m down-slope.

Using the six ranges of compression scores (very easy, easy, easy-moderate, moderate, moderate-hard and hard), Figure 10 shows the frequency of skier triggering decreasing from 50% (2 of 4 skier-tested slabs) to 9% (1 of 11) with increasing compression scores. Based on these preliminary data, the compression test shows promise as a index of slab stability for skiers. However, because of natural snowpack variability, no stability test done at one or two sites on a start zone can provide a definitive index of stability for the slope (Jamieson 1995, p. 185-194).

Nevertheless, since the compression-tested slabs range up to 1 m in thickness (Figure 9), the compression test appears to have the potential to test slabs over much of the range for which skier-triggering is common.

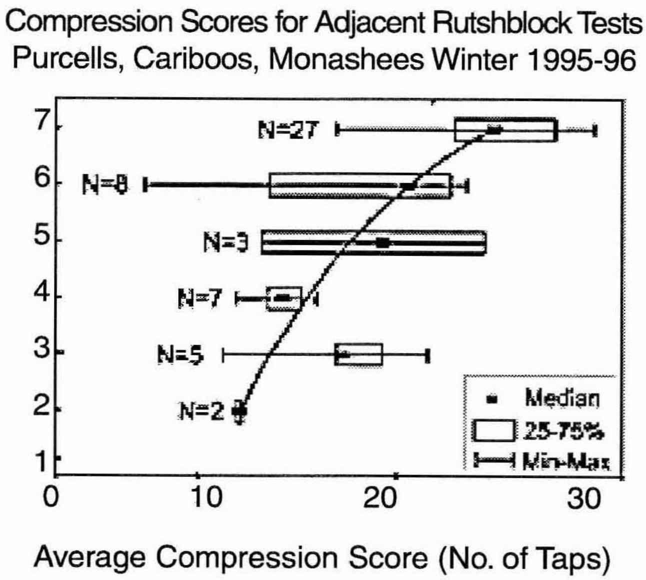

Figure 8 Compression scores adjacent to rutschblock tests

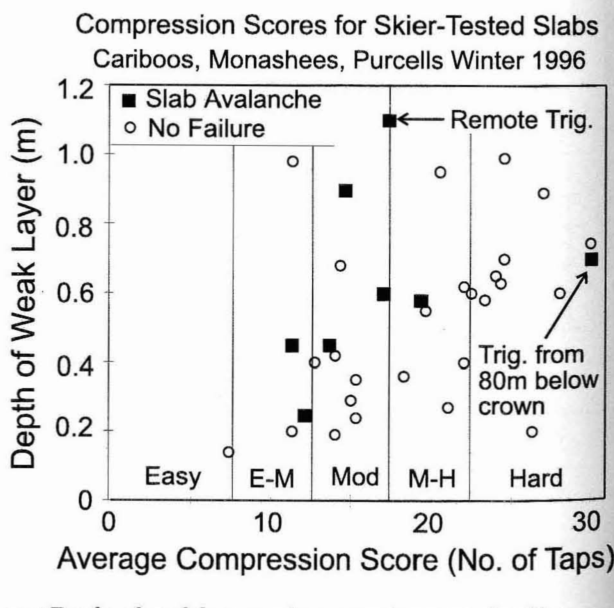

Figure 9 Depths of weak layers and compression scores for skier-tested slabs

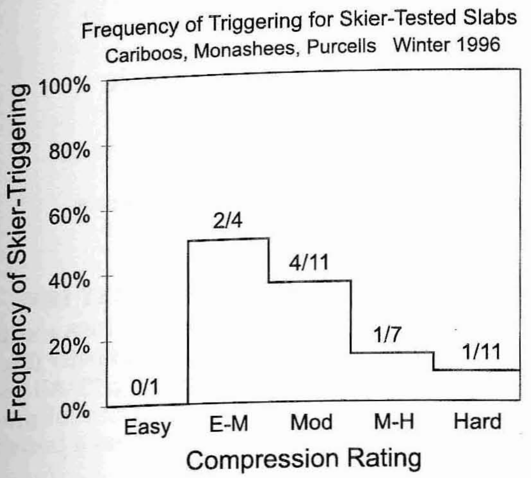

Figure 10 Frequency of skier-triggering for skier-tested slabs

LIMITATIONS & FUTURE STUDIES

This paper only presents limited data. It is not yet clear if the compression test can identify (and rate) all the weak layers that can produce slab avalanches. For example, on level terrain the compression test may miss certain weak layers such as a poorly-bonded crusts.

Also, the compression scores in this paper are based on the average number of taps required to cause failure in weak snowpack layers. Tests in which weak layers did not fail during the first 30 taps are excluded from the averages (except for the studies of column size). Non-failures should be included in a manner similar to the way rutschblock scores of 7 are included in median rutschblock scores.

Finally, more field studies are required to:

- identify the maximum effective depth for compression tests,
- clarify the effect of slope inclination on compression scores,
- better correlate compression scores with rutschblock scores and skier-triggering, and
- correlate compression scores from study sites with the frequency of skier-triggering on surrounding slopes.

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