Where to dig? – On optimizing sampling strategy

Jürg Schweizer and Sascha Bellaire*
WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

ABSTRACT: Snow slope stability evaluation is often based on a single test location within a slope. However, we know that snow cover properties and stability may vary at the slope scale. Reliably estimating the slope scale variability requires many samples, probably up to 100. As this is unpractical, it has been proposed to do at least two tests – about 10 m apart – on a given slope. In addition, if small column stability tests are used (such as the compression test), it seems reasonable to perform two tests at each of the two locations. Differences between the two tests at one location allow one to assess the small scale variability (and/or the test uncertainty), whereas differences between the pairs at different locations may hint at the slope scale variability. We analysed 22 slopes each with four pairs of stability tests. In 61-73% of the cases the two stability tests at a specific location provided consistent results. Comparing the different sampling locations on a given slope (~10 m apart) showed that in many cases (59-75%) differences between sampling locations were rather small. Based on our analysis, we suggest an interpretation scheme and an adjusted sampling procedure.

KEYWORDS: snow avalanche release, snow stability evaluation, snow stability test

1 INTRODUCTION

Information on snowpack instability is crucial for assessing avalanche risk in backcountry operations as well as for operational forecasting of the regional avalanche danger. Manual observations of snow stratigraphy combined with stability tests are presently the method of choice – in absence of obvious signs of instability. These measurements are time consuming and sometimes dangerous for the field crew. Consequently, theses snow stability data are available only with low resolution in space and time. In the future, simulated snow stratigraphy data may complement manual observations (e.g. Schirmer et al., 2009). In addition, snow cover properties are spatially variable at various scales which affects the avalanche release probability and, in particular, questions the validity of single measurements. However, reliably measuring slope scale variability is too time consuming as a large number of measurements is required – even if using, for example, a snow micro-penetrometer.

Accordingly, it has been proposed (e.g. (Birkeland and Chabot, 2006) to do a second observation at a representative site beyond the correlation length from the first test and choosing the least stable of the two test results. As the correlation length is unknown, at least about 10 m have been proposed as the distance between two tests (Jamieson and Johnston, 1993; Schweizer et al., 2008). Furthermore, performing two tests side by side at one location can significantly decrease the uncertainty of test results and may indicate the small scale variability (0.1 – 1 m).

As independent estimates suggest that the critical size for a self-propagating fracture is on the order of 1 – 10 m (Schweizer et al., 2003) it can be assumed that a fracture can propagate (and avalanche release is possible) if at one of the two test (~10 m apart) locations initiation is possible. On the other hand, significant variations at the scale of 0.1 – 1 m rather indicate conditions unfavourable for fracture propagation.

The aim of the present study is to evaluate whether performing two pairs of tests about 10 m apart improves our ability to predict snow slope stability.

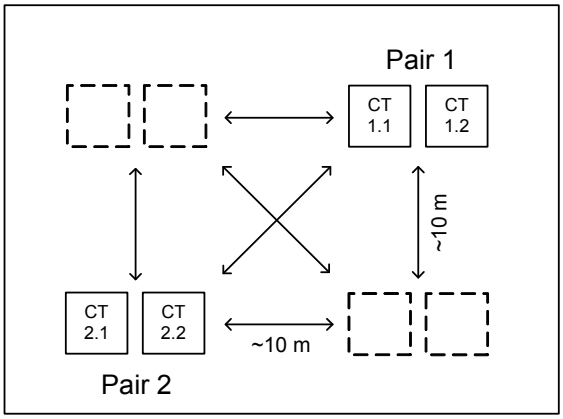

Fig. 1: Measurement set-up. At four locations on a slope, about 10-15 m apart, 2 compression tests (CT) were performed.

* *Corresponding author address:* Sascha Bellaire, WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland.
tel: +41 81 417 0111; fax: 41 81 417 0110;
email: bellaire(at)slf.ch

2 DATA

We analysed compression test (CT) results from 22 slopes located above tree-line in the vicinity of Davos (Switzerland). The elevation of the test slopes was about 2400 m a.s.l. and the mean slope angle was 25°. About half of the slopes had northerly, the other half mainly south-westerly aspect. On each slope, four pairs of CTs were performed. Locations where two adjacent tests were done, were about 10-15 m apart (Fig. 1). These data were collected during the winters 2006-2007 to 2008-2009 in the course of a spatial variability study (Bellaire and Schweizer, 2008). On each slope, we also observed snow stratigraphy so that failures in CTs could be assigned to a specific layer boundary. Occasionally, the stratigraphy was too variable and the failure depth found with the CT could not be related to a corresponding depth in the manual snow profile.

3 METHODS

Compression tests were performed according to Jamieson (1999). The loading step at failure, failure depth and fracture character (van Herwijnen and Jamieson, 2007) were recorded. On 18 out of 22 slopes multiple failures occurred, i.e. the CT indicated several potential weak layers.

For assessing the variability within pairs as well as between pairs we considered (1) the CT score and the failure depth, and (2) the fracture character and the failure depth. Within a pair, we considered the two CTs as similar if (1) the difference in CT score was ≤ 2 for scores < 20 (and ≤ 4 for scores 20 and larger) and the same weak layer showed up, and (2) if the tests had similar fracture character and the same weak layer showed up. Similar fracture character meant that the fracture character was (a) either sudden planar (SP) or sudden collapse (SC), or (b) one of the following three types: progressive collapse (PC), resistant planar (RP), or break (B).

For comparing the CT score between pairs we considered the mean score. When checking whether the same failure layer showed up in a pair 10 – 15 m apart, it was sufficient for similarity that the same weak layer showed up in at least one of the two tests. In other words, we simply wanted to know whether the weak layer also existed 10 – 15 m away from the first sampling location.

Two pairs could be similar, even if the CTs within a pair were different – and of course vice versa.

We rated each pair in terms of stability. If the mean CT score for the first sudden failure was ≤ 13, we estimated the stability as 'poor', for CT score ≥ 20 as 'good', and 'fair' else.

4 RESULTS

On each of the 22 slopes, we assessed the within pair variability for the four locations, and the between pairs (slope) variability for the six combinations existing between the four pairs.

Considering the CT score, within pair variability was found in 34 cases (39%). The fracture character was less variable and agreed in 64 out of the 88 pairs (73%). Sudden failures dominated.

At the slope scale, the pairs (10 – 15 m apart) were judged as similar in 78 out of 132 cases (59%), if the CT score was considered. For the CT fracture character, a somewhat higher agreement was found (75%).

Considering the stability rating, 42% of the pairs were rated as 'poor', 42% as 'fair', and the remaining 16% were rated as 'good'. For the pairs rated as 'fair', in 32% of the cases the second pair was rated as 'poor', i.e. the sampling at the first location overestimated stability.

In general, the agreement between pairs was 61%. In the other 51 cases, one of the pairs was either rated as 'poor' and the other as 'fair', or alternatively as 'fair' and 'good'. No combination with a pair rated as 'poor' and the other on the same slope as 'good' occurred (which would have indicated large slope scale variation).

5 INTERPRETING SLOPE STABILITY

Obviously, performing two pairs of tests provides additional information. However, how this information should be interpreted is not clear, in particular if test results differ at the small scale (~1 m) and/or the large scale (~10 m). Very similar results, i.e. similar within pairs as well as between pairs, were only found in 27% if the CT score was considered and in 48% if the fracture character was considered. In about two thirds of these cases at least one of the pairs was rated as 'poor'. On the other hand, very different results, different within as well as between pairs, occurred in only 10 cases for the CT score and 6 cases for the fracture character. In about 90% of these cases at least one pair was rated as 'fair'. In other words, in <10% variability existed at the small as well as the large scale suggesting rather stable conditions. In the large majority of the cases, however, 'some' variability was found.

In principle, six possible situations exist: (1) no within and no between pairs differences: ssS; (2) no within pairs differences, but the pairs are different: ssD; (3) difference within pairs, but no difference between the pairs: ddS; (4) differ-

Tab. 1: Variability situations, their frequency separately for CT score (CT) and CT fracture character (FC) and a possible interpretation (see text for explanations).

Situation	Frequency CT	Frequency FC	Variability	Initiation	Propagation	Stability interpretation (depending on CT score (sudden fracture)
ssS	35	64	no	possible	likely	'poor', 'fair' or 'good'
ssD	12	8	slope scale	possible	likely	'poor', 'fair' or 'good'
ddS	7	5	small scale (consistent)	rather unlikely	rather unlikely	'fair' or 'good'
ddD	10	6	small scale and slope scale	rather unlikely	rather unlikely	'fair' or 'good'
sdS	36	30	some small scale	possible	likely	'poor', 'fair' or 'good'
sdD	32	19	some small scale and slope scale	possible	possible	'poor', 'fair' or 'good'

ences within and between pairs: ddD; (5) one of the pairs shows within pair variability, but the pairs are similar: sdS; (6) one of the pairs shows within pair variability and the pairs are different: sdD. Table 1 attempts to interpret these situations of differing variability.

6 CONCLUSIONS

We explored the value of a simple sampling scheme that attempts to capture the small (~1 m) as well as the large (slope) scale variability (~10 m). Considering the two essential avalanche release processes: initiation and propagation, we suggest the following procedure. If at a sampling location on a slope two stability tests show similarly low scores and sudden fractures, no further sampling is required. However, if either the two scores are similar and indicate rather 'fair' or 'good' stability, or the two scores are different, a second pair of tests on the same slope about 10 m beyond the first sampling location can be useful. If at the second location similarly low scores are found, stability is expected to be rather 'poor'. If as well intermediate scores, dissimilar scores or a different weak layer are encountered the stability is at least 'fair', and in the case of consistent small scale variability maybe even 'good'.

When stability was rated as 'poor', less variability was found. Also, the fracture character was less variable than the CT score.

For our dataset, proceeding to a second sampling location about 10 m apart would have been necessary in about 58% of the cases. In about two thirds of the cases, results at the second location would have confirmed the findings at the first location. In other words, in about 20% of all cases the results at one location overestimated stability – which is obviously not desired. Accordingly, if no instability was found at the first sampling location, a second pair of measurements can clearly reduce the number of false-stable predictions.

ACKNOWLEDGEMENTS

We would like to thank Alec van Herwijnen, Christoph Mitterer, Sina Schneider, Michael Schirmer and Charles Fierz for help with the field work. We gratefully acknowledge financial support by the European Commission (FP6-STRep-NEST, Project no. 043386: TRIGS).

REFERENCES

Bellaire, S. and Schweizer, J., 2008. Deriving spatial stability variations from penetration resistance measurements. In: C. Campbell, S. Conger and P. Haegeli (Editors), Proceedings ISSW 2008, International Snow Science Workshop, Whistler, Canada, 21-27 September 2008, pp. 188-194.

Birkeland, K.W. and Chabot, D., 2006. Minimizing "false stable" stability test results: Why digging more snowpits is a good idea. In: J.A. Gleason (Editor), Proceedings ISSW 2006. International Snow Science Workshop, Telluride CO, U.S.A., 1-6 October 2006, pp. 498-504.

Jamieson, J.B., 1999. The compression test - after 25 years. The Avalanche Review, 18(1): 10-12.

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

Schirmer, M., Schweizer, J. and M. Lehning, 2009. Regional stability evaluation with modelled snow cover data. In: Proceedings ISSW 2009, International Snow Science Workshop, Davos, Switzerland, 27 September – 2 October 2009, this issue.

Schweizer, J., Jamieson, J.B. and Schneebeli, M., 2003. Snow avalanche formation. Rev. Geophys., 41(4): 1016.

Schweizer, J., Kronholm, K., Jamieson, J.B. and Birkeland, K.W., 2008. Review of spatial variability of snowpack properties and its importance for avalanche formation. Cold Reg. Sci. Technol., 51(2-3): 253-272.

van Herwijnen, A. and Jamieson, J.B., 2007. Fracture character in compression tests. Cold Reg. Sci. Technol., 47(1-2): 60-68.