THE SYSTEMATIC SNOW COVER ANALYSIS: A PRACTICAL TOOL FOR INTERPRETING AND ASSESSING SLOPE STABILITY

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ABSTRACT: Avalanche professionals rely often on direct snowpack information to determine slope stability or assess the avalanche danger of a specific site or avalanche path. However, the interpretation of snowpack observations is not always unambiguous. Previously presented interpretation schemes of direct snowpack information (e.g. snow profiles) require a full snow stratigraphy with a distinct stability test, which makes them often unattractive among practitioners – mainly due to lack of time. We will present a fast and systematic approach on how to reliably interpret snowpack observations and judge the release probability of a single slope based on a stability test, the characteristics of the slab and the weak layer stratigraphy. For the winter seasons 2008-2009 to 2010-2011, various observers performed snow profiles including a stability test and evaluated avalanche release probability. With a classification tree, we investigated which properties of the snow profile and the test led to which avalanche danger assessments. The tree revealed that situations with high release probability had always a prominent weak layer, a sudden or planar fracture and low test scores. The decision path of the resulting tree was then applied and tested using a second, independent data set that included objective measures of stability, i.e. skier-triggered avalanches, shooting cracks or whumpfs. The predictive skills of the tree were reasonable, but significantly improved if more information on the slab, i.e. hardness, and weak layer stratigraphy were introduced. The results were encouraging and will help practitioners to assess slope stability more reliably.

KEYWORDS: snow cover, slope stability, danger estimate.

1. INTRODUCTION

The problem of exactly forecasting the timing and extent of a slab avalanche on a particular slope is unsolved and no methodology is known, which could deliver such a result. However, since this is a very practical problem, which you need to solve if you want to move safely in avalanche terrain or if you need to decide on road closures or evacuation of houses, many suggestions have been made, how to best approximate a solution. Two trends developed over the course of the last decades and offered several standard techniques to estimate slope stability: (1) Risk and probability based methods (e.g. reduction method by Munter (2003) or the SnowCard or Avaluator), which heavily rely on an issued danger level and (2) an analytical, expert-based method, which relies on direct field observations (e.g. snow pit and stability test) to estimate snow slope stability (Schweizer and Wiesinger, 2001). Among recreationists, the risk-based approach is very popular, since it does not require any knowledge on the physical properties of snow and its mechanical behaviour. However, if applied for road closures or evacuation management, the risk-based approach is not feasible, since it is very conservative and includes a large margin for errors. With other words, a practical safety management is not possible and therefore the Bavarian avalanche warning service has promoted as early as 1989, the idea of a process-based judgement. Since the 1990ties the Bavarian avalanche warning service has taught a method tailored to expert use, the so-called systematic snow cover analysis (Kronthaler and Zenke, 2006). The key component of this tool is finding the most prominent weak layer, test the weak layer - slab combination with a fast test and interpret the result. Kronthaler et al. (2013) presented first results on the effectiveness of this tool for estimating slope stability. Although results were promising with high probability of detection and non-events, they concluded that still the problem of how to forecast an avalanche on a single slope is not solved with this methodology. However, it was felt that the systematic snow cover analysis might be

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a practical alternative to include local snow cover properties in an expert danger rating system.

In order to bring this tool a step further, we wanted to test the outcomes of Kronthaler et al. (2013) with this follow up analysis and applied their results on a second independent data set of slope stability estimates and used different input parameters for the tree, respectively.

2. METHODS AND DATA

Kronthaler et al. (2013) presented a classification tree, which analysed the properties of the systematic snow cover analysis. The tree was performed using field data of stable and unstable slopes. Stable – unstable meant that a slope was investigated and then skied. If signs of instability (avalanche release, shooting cracks or whumpfs) were observed during skiing, the slope was judged as unstable, and stable otherwise. The resulting tree indicated that unstable slopes had always a prominent weak layer, a smooth fracture plane and low test scores (we call this model ORIG). All these values were provided with the small test block, which represents the core of the tool (Kronthaler, 2009).

However, the tree used none of the additional features of the snow cover analysis (mainly snow stratigraphy) to classify into stable and unstable. Other work though showed that structural differences play a vital role in estimating stability (Schweizer and Jamieson, 2003; Schweizer et al., 2008) and therefore we re-run the classification tree including new data and forcing the usage of structural properties (i.e. grain size, hand hardness) with prior probabilities in the tree (Breiman et al., 1998). We further reference to this model as STRUCTURE.

In Bavaria the observers must estimate the danger based on the systematic snow cover analysis into four different levels: (1) Spontaneous release of dry slab avalanches expected, (2) release under small additional loading (one skier) expected, (3) release with large additional loading (group of skiers) expected and (4) generally stable conditions. We therefore applied the estimates on the stable/unstable dataset and refer to this model as ESTIMATE.

In a last approach we applied the ORIG model to the independent stable/unstable dataset and applied afterwards the snow stratigraphy variables of the systematic snow cover analysis. We call this model ORIG+STRUCT.

The results of the four statistical models used in this study were classified into correct stable, misses, false alarms and hits. We then calculated the probability of detection (POD), the probability of non-events (PON) and the false-alarm rate (FAR), the success rate (SSR) and the true-skill score (HSS) according to Schweizer and Jamieson (2007).

3. RESULTS AND DISCUSSION

Tbl. 1 shows the results of our analysis. The best performance in terms of predictive skills was obtained with the ESTIMATE model. All unstable slopes were correctly identified, and only 3% of the stable slopes were wrongly classified as unstable. Worst results were obtained with the STRUCTURE model: POD dropped to 0.53, PON was still high and the FAR decreased slightly compared to ORIG. Applying first the ORIG tree and continuing with snow stratigraphy variables was as nearly good as the ESTIMATE model, but produced three misses and more false alarms. Compared to the ORIG the ORIG+STRUCT model improved slightly with the PONs and significantly with the FAR by halving the false alarms.

The results of the statistical approach based on a snow cover test (ORIG) were still promising. POD and PON were very high with 0.89 and 0.93, respectively. FAR, however, was also considerably high. Of course, false-stable predictions, i.e. misses, can have more serious consequences than false alarms, but too many false alarms will not provide meaningful stability predictions. It is very interesting that the model ESTIMATE was capable of correctly classifying all unstable slopes. With other words, the observers managed somehow to hit the three misses, which the two best statistical models (ORIG and ORIG+STRUCT) were not able to detect.

Tbl. 1: Models to classify unstable and stable slopes with their predictive performance.

Model	*Correct stable*	*Misses*	*False alarms*	*Hits*	*POD*	*PON*	*FAR*	*SSR*	*HSS*
ORIG	327	3	22	25	0.89	0.93	0.47	0.53	0.67
STRUCTURE	341	13	8	15	0.53	0.97	0.34	0.66	0.58
ESTIMATE	341	0	8	28	1	0.97	0.22	0.78	0.87
ORIG+STRUCT	339	3	10	25	0.89	0.97	0.28	0.72	0.79

With our dataset, it was not possible to reveal what observes motivated to correctly classify these three cases, although all objective variables hinted towards stable conditions. With other words, these cases represent other observations (e.g. recent avalanche activity), intuition and expert knowledge. In addition, these results clearly indicate that the proposed methodology requires a certain expert knowledge and is hard to handle for novices.

Based on these findings we suggest the following steps (Fig. 1): (1) Perform stability tests and applying the rules of the ORIG classification model. (2) Continue with applying critical thresholds for structural differences within the snow profile (Kronthaler, 2009; Schweizer and Jamieson, 2007). (3) Adjust the resulting danger estimate using other observations, e.g. recent avalanche activity (Jamieson et al., 2010), and your expert knowledge for the local situation.

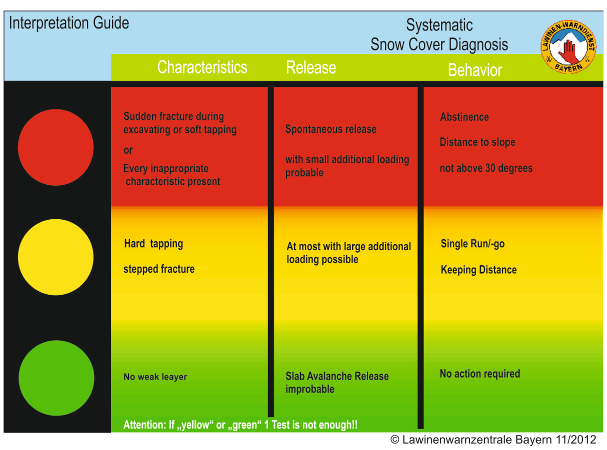

Fig. 1: Interpretation guide for the systematic snow cover analysis.

4. CONCLUSIONS

We presented a following up analysis on the reliability of the snow cover analysis. In a previous work, we showed with a classification tree that a prominent weak layer, smooth fracture plans and low test scores were important to correctly classify skier-tested slopes. We again tested this classification tree and other approaches, which included also snow stratrigraphy to stable/unstable slopes. In addition, we tested the danger estimates of observes for the same slopes.

Results showed that the statistical approach with the presented rules performed fairly well and slightly improved if snow stratigraphy information was added afterwards. This lowered the FAR. Nevertheless, this combination missed three unstable events and still produced ten false alarms. The estimates of the observes hit all unstable slopes and produced only eight false alarms and was therefore superior to the model. It is difficult to detect what this discrepancy determined. Reasons might be additional observations and expert knowledge. The outcomes underline that the presented tool is valid and represents a practical application for experts to determine snow stability on single slopes.

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