CHARACTERISTICS OF WEAK SNOW LAYERS OR INTERFACES

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ABSTRACT

Weak layers or interfaces are a necessary condition for slab formation. In order to gain more insight into the characteristics of such weak layers or interfaces roughly 300 snow pit and shear measurment data sets have been analysed. Detection of weak layers/interfaces happened by slab inspection or executing "Rutschblock"-tests on potential avalanche slopes.

40 % of the total were weak layers of thickness 1-60 mm, 60 % weak interfaces, where no distinct layer texture could be found. Weak layers consisted most often of aged surface hoar (40 %), faceted particles (25 %) and depth hoar (15 %). The other basic particle shapes contributed to a minor extent. The frequency distribution of the weak layer ages displays a exponential form with a time constant of 15 to 20 days, i.e. the main part of such layer is "younger" than 20 days, but a certain percentage keeps their danger pontential up to several months. The mechanical parameters as cohesion and shear strength of these layers depend slightly on age and overburden pressure, however various grain types show controversial behaviour. The frequency distribution of calculated S' (stability with ski loading) for an "a priori" unstable group of weak layers peaks at 1.3, the one of a more stabler group at 1.8, which yields a glimpse on the predictive potential of "in situ"-measurements and concurrent stability evaluations.

INTRODUCTION

Thin weak layers or interfaces are a prerequisite for slab formation, as long as new snow slab formation may be excluded. Consequently the detection of weak layers/interfaces as well as the knowledge of their material properties are of central interest for anybody who is forced to forcast avalanches or to forsee at least avalanche situations.

Several valuable studies have been executed in the past to clarify the "weak layer"-situation with respect to occurrence, physical properties (mainly shear strength) and towards grain structure and texture. Reports of Mc Clung (1977), Stethem and Perla (1980), Perla (1982), Ferguson (1984) and Akitaya (1987) have to be named in this context. Whereas the majority of information of these studies has been gained by inspecting snowpit profiles on level plots or on inclined slopes near avalanches after

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avalanche occurence, the present study concentrates on snowpit profiles which were executed on slopes before or during avalanche prone situations. Such measurements are since years part of the Swiss avalanche warning program and will be used here to analyse the occurence and the characteristics of weak layers/interfaces. By using mainly the "Rutschblock"-method or the shear shovel test to detect these layers (cf. Föhn, 1987), one assures that their snow structure stays unchanged (no aging) and that the primary shear surface and not a subsequent gliding plane of a slab may be choosen as weak layer.

MEASUREMENTS

Data for this analysis came from roughly 300 field campaigns, carried out over 10 winters (1980/81 to 1989/90). During periods of questionable stability, snowpits are dug on inclined slopes near avalanche starting zones to investigate potentially unstable snowpack structure. In order to have representative and rather critical conditions, slopes of mainly northern aspect and with slope angles generally larger than 30° have been choosen. Behind the snowpit a "Rutschblock" was excavated in order to find potentially weak layers/interfaces by the sliding test. Loose surface layers have been inspected by shear shovel tests. If slab avalanches occured nearby, the testsite was selected close to the slab flanks. However it may be noted here, that only 20 % of the weak layers/interfaces have been detected by avalanches, the majority of 80 % has been found by the mentioned tests.

The following parameters have been measured during such campaigns: altitude, aspect, slope angle, snow layering, ram hardness, snow temperature; if there was a sliding plane, distinction between a weak layer and a weak interface was made, additionally the method of discovering these layers was noted (natural avalanche, slab triggered by skiers or explosives, Rutschblock with loading degree, shear shovel test).

Above the weak layer/interface the depth and density of the slab layers was measured, as well as the ram hardness and snow structure (grain shape and size) of the layer adjacent to the weak layer.

In the weak layer the snow structure (grain shape and size) was observed and the cohesion was measured with a shear frame of 0,05 m^2 area, applying a fast pull ($0 < t \leqslant 1$ sec). The thickness of the weak layer was estimated on the pit wall, because thin layers of some mm are rarely measurable in a strict sense. The same holds for the density of the weak layers. In the case of a weak interface the cohesion on this interface was also measured. The distinction between a weak layer and a weak interface is somehow arbitrary, because a weak layer of a thickness less than 1 mm, where no distinct grain forms may be seen, is called an interface.

Below the weak layer/interface the ram hardness and the snow structure (grain shape and size) of this base layer have been observed.

CALCULATIONS

The measured properties were applied to several mechanical approximation formulas to evaluate the balance between strength and stress on the sloping snowcover.

In a first stage the shear strength (τ_s) of each weak layer/interface has been calculated:

$$\tau_s = c + tg\,\phi\,\sigma_z \qquad (1)$$

where ϕ is the internal friction angle of the "weak layer"-snow, c denotes the measured cohesion and σ_z the normal pressure on this weak layer/interface. The friction angle was calculated by an empirical relation of Roch (1966):

$$tg\,\phi = 0.4 + 0.08\,c \text{ [c in kPa]} \qquad (2)$$

The normal pressure results from

$$\sigma_z = \rho g h \cos^2\psi \qquad (3)$$

where ρ is the density and h the vertical "height" of the over burden slab layers and ψ denotes the slope angle.

The calculation procedures for the natural stability index S as well the ones for the stability index S' (integrating human triggering) are described in an earlier paper (Föhn, 1987) and will not be repeated here. The question of representativity of such snowcover measurements and tests has also been treated in several papers (Conway and Abrahamson, 1988; Föhn 1989) and cannot be discussed here.

RESULTS

Even with obvious uncertainties, due to the present, preliminary data analysis, the available "weak layer/interface"- observations hold a wealth of information. On one side, practical information for the avalanche forecaster, who may relate his own data and conceptions with mean or extreme values of the study and who may verify or visualize certain relationships e.g. between snow structure and mechanical indices. On the other hand research oriented people may find some indications, how a typical weak layer and the neighbouring layers may be synthesized for modelling purposes.

The whole data set has first been divided into two categories:

1) A group of weak layers/interfaces detected by the inspection of real slab avalanches

2) A group of weak layers/interfaces detected by sliding tests

The following Figure 1 describes the differences.

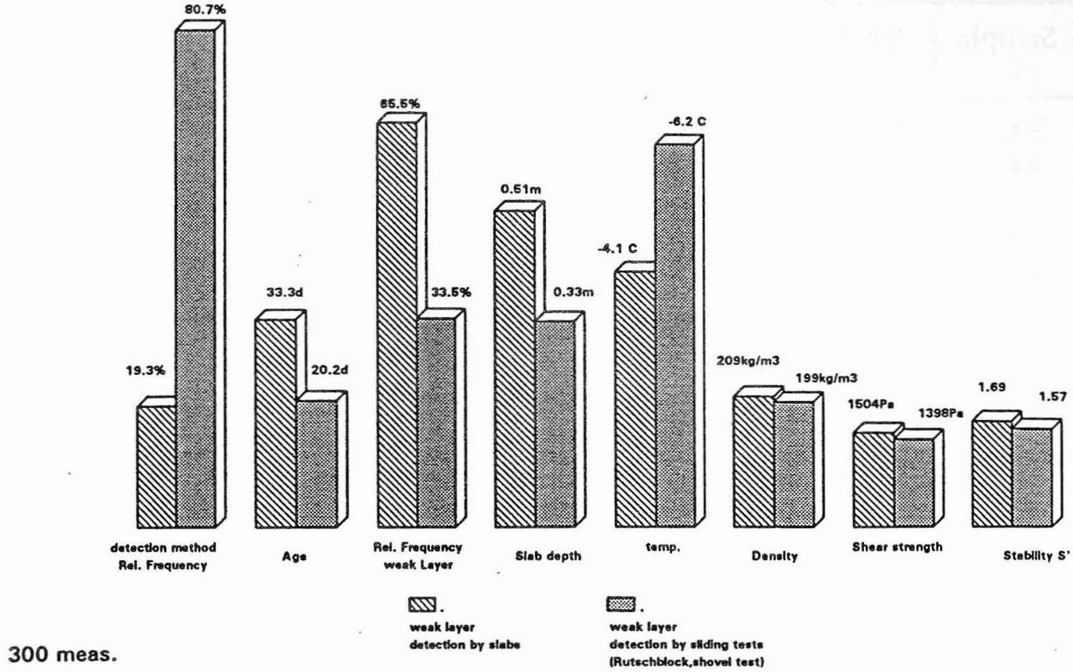

Figure 1: Comparison of various weak layer/interface properties, grouped according to the detection method. The left handed columns show cases detected by avalanche inspection, the right handed columns cases detected through sliding tests (Rutschblock or shear shovel test)

First of all it may be noted on Figure 1, that in this study roughly 80 % of the weak layers/interfaces have been detected by sliding tests and not by avalanche inspection. The age, the percentage of weak layers in contrast to weak interfaces as well as the slab depth is larger if these instabilities are found at the base of a real slab layer. The temperatures: at the weak layer position are higher in avalanches, probably due to warming up since slab release. Slab layer densities, shear strength and stability S' of these layers differ much less.

Clearly visible weak layers are found twice as often, if the instable layer has been found by inspection of real slabs as in the case of layer detection by sliding tests. The importance of this fact is not yet clear but the percentage (60 - 70 %) of weak layers at inspection of slabs is once more verified (Föhn, 1980; Ferguson, 1984).

The following Table 1 summarizes some important features of weak layers or interfaces. It has to be noted here, that "weak" does not necessarily imply that such layers would easily fail in shear, because a large number of these layers/interfaces has been detected only after applying strong surcharges (explosions, "Rutschblock"-degrees 4 to 6 or shovel shearing). Layers/interfaces, which failed with no or slight surcharges (natural slabs, slabs triggered by skiers, "Rutschblock"-degrees 1 to 3) are later on called "very weak layers".

Table 1: Main characteristics of the analysed weak layers/interfaces

Sample N	Parameter	mean + std. dev.	range
300	slope angle	35.7 ± 4.1°	15 < ψ < 45°
300	depth of slab	37 ± 25 cm	2 < h < 180 cm
299	density of slab	201 ± 58 kg/m^3	56 < ρ < 388 kg/m^3
114	thickness weak layer	11.9 ± 10.8 mm	1 < h < 60 mm
285	temp.weak layer	-5.9 ± 3.4° C	-20.4 < T < 0° C
114	grain size weak layer	2.1 ± 1.4 mm	0.3 < ⌀ < 8.0 mm
298	age weak layer	22.7 ± 23.7 d	1 < A < 145 d
298	shear strength	1418 ± 878 Pa	105 < τ_s < 5668 Pa
298	stability S	4.1 ± 1.2	0.4 < S < 115
298	stability S'	1.6 ± 1.0	0.04 < S' < 5,7

The sample number differs slightly because sometimes certain properties could not be measured or analysed. The table shows clearly that the depth of the slab layers is generally low: Dry snow slabs are rather triggered at places with little snow, a fact which has to be kept in mind. The mean age, which is defined as the number of days elapsed since this layer/interface has been buried by new snow on top, is rather large (22.7 days). A dangerous slab situation may last for weeks, if the weak layer/interface is not deeply buried by new snow layers. Deep and heavy overloading favors compaction, temperature gradient decrease and results e. g. in lower triggering stress peaks by skiers, all in favor of a stability increase. Figure 2 yields some details of the age distribution.

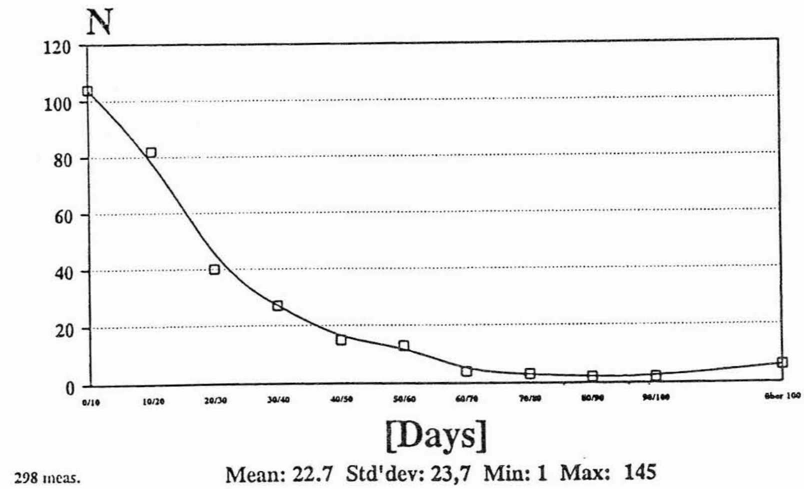

Figure 2: Frequency polygon of the age of all weak layers/interfaces.

The exponential decrease of the age distribution is obvious, however it takes approximately 20 days until half of the weak layers/interfaces disappear as dangerous discontinuities.

Some insight into the relationship between the calculated stability index S' and the slab layer depth is given in Figure 3.

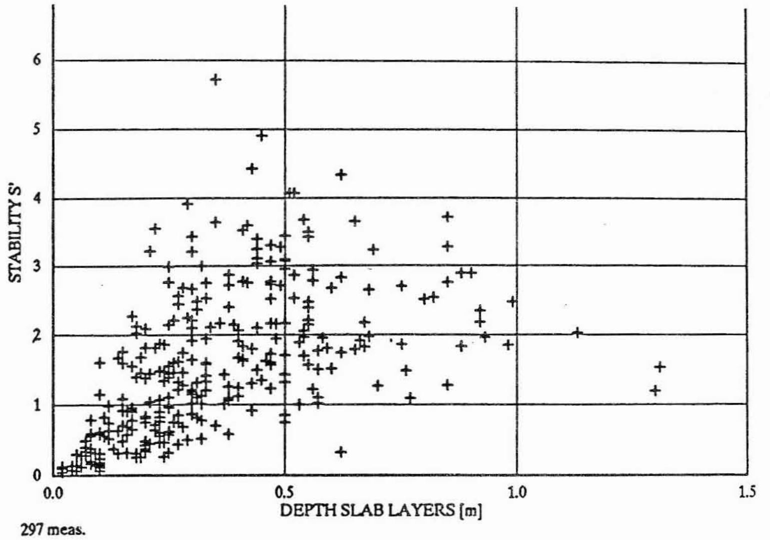

Figure 3: Stability S' versus slab layer depth

The large scatter of the data points is not surprising in view of the many different layers or interfaces, which are represented by these data points. The stability S' (integrating human triggering) is a strong function of the slab layer depth (h), but also dependent on cohesion (c), slab layer density (ρ) and slope angle (ψ) beside an assumingly constant skier weight:

$$S' = f(h, c, \rho, \psi) \qquad (4)$$

The stability S' increases fast with increasing slab depth (h), reaches a plateau at h ≈ 0.5 m and drops gradually with increasing h-values. Data points aside of this general course are influenced by extreme values of c, ρ, ψ.

In order to document here a few of the additionally analysed parameters, Figure 4 yields some frequency distributions.

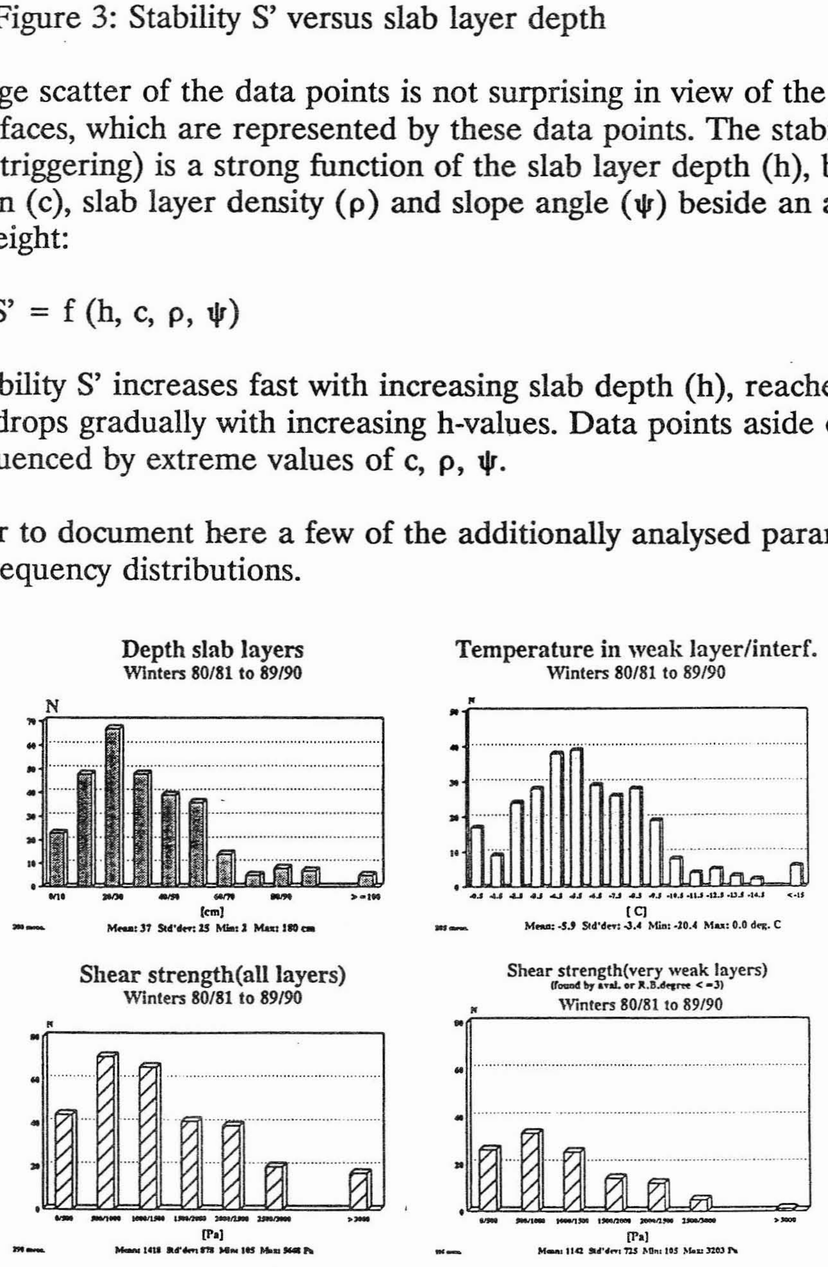

Figure 4: Frequency distributions of slab layer depth, temperature, shear strength of all layers and of very weak layers.

Whereas the two upper figures are self-explanatory, the lower ones document clearly that only about one third of the weak layers/interfaces may be called "very weak" layers and that the "a priori" discriminating conditions for "very weak" layers were justified by the "a posteriori" calculated, lower shear strength values for this special group.

Figure 5 shows the typical layering of a slab in our climatic conditions.

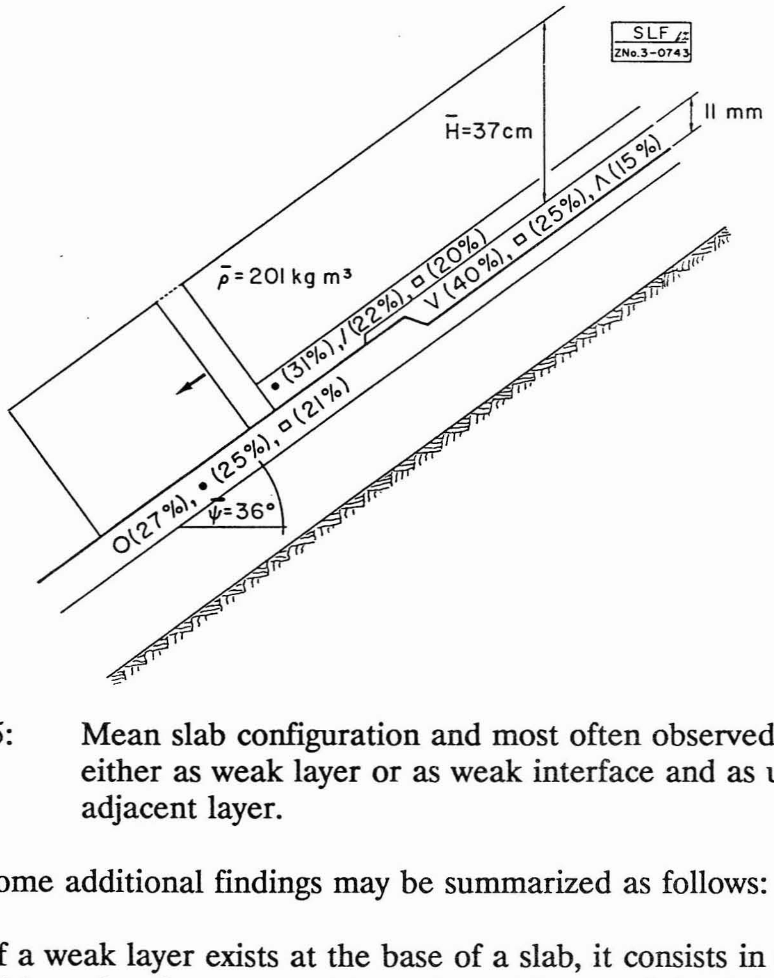

Figure 5: Mean slab configuration and most often observed grain forms, either as weak layer or as weak interface and as upper and lower adjacent layer.

Figure 5 and some additional findings may be summarized as follows:

1) If a weak layer exists at the base of a slab, it consists in 80 % of all cases, either of surface hoar, of faceted particles or of depth hoar (only main forms have been considered).

2) A very thin, weak layer (< 5 mm) consists in 66 % of all cases of surface hoar or a combination of surface hoar and some other forms.

3) An interface contains generally less friable corn forms, both in the upper and the lower layer. Henceforth it may be supposed, that an interface also contains after some minute, fragile particles (surface hoar?), which cannot be detected by visual inspection. A sliding test ("Rutschblock", shear shovel test) proves to be the only fast and reasonable detection method for the occurence of such fragile interfaces.

Figur 6 yields some shear strength values for eight main forms of snow

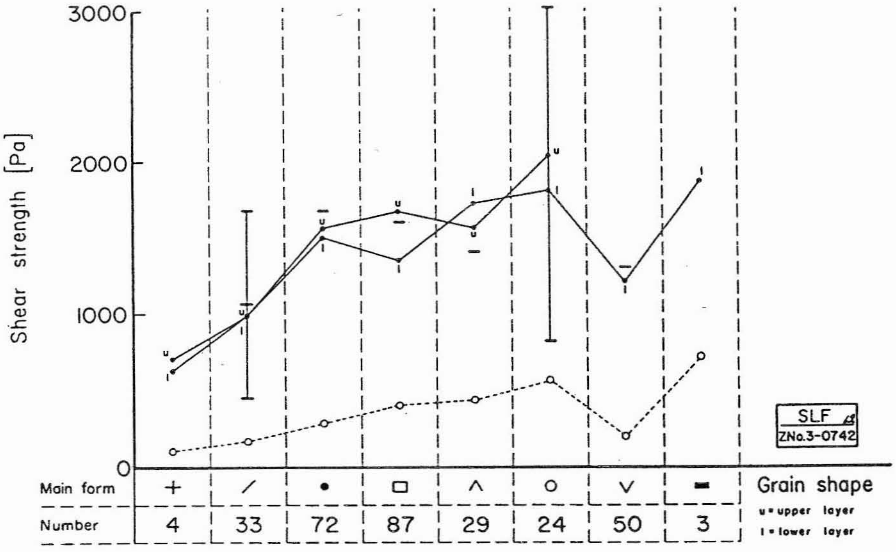

Figure 6: Mean and minimal values of shear strength for main grain shapes. The mean values in weak layers are given by horizontal bars (besides two values of stand. dev.). The measured mean values at interfaces are denoted by dots. The minimal values are denoted by small circles.

The limited data and the preliminary analysis show 3 things:

1) The differences in shear strength are small between "weak layer" samples and "interface" samples. The larger stress concentration in interfaces seems to outweigh the brittleness of well developped weak layers.

2) The mean and minimum values for the various snow forms show rather small differences (0 : 0.1 - 2 kPa). However the generally supposed fragility for the various snow forms is well documented. The only exception are the values for depth hoar.

3) The only up to now published values relating snow forms with a shear strength index (Perla et al., 1982) are of the same magnitude for new snow, felt-like snow and surface hoar, but 4 to 5 times larger for other forms.

Because the density of these thin weak layers could not be measured, a correlation of shear strength with this generally important parameter was not possible. I agree with Perla et al. (1982), that "crystal size is not a good predictor of the strength index", at least in comparison to crystal form. The reason is, that every main crystal form has a rather narrow range of grain sizes, thus an additional differentiation into size categories seems not to improve the prediction situation (the observation errors with hand lenses do certainly contribute to a large extent to this result).

A final goal of weak layer/interface inspection in the field or of its synthetic generation by snow cover modelling will be a stability evaluation. Figure 7 enlights the outlook for this procedure.

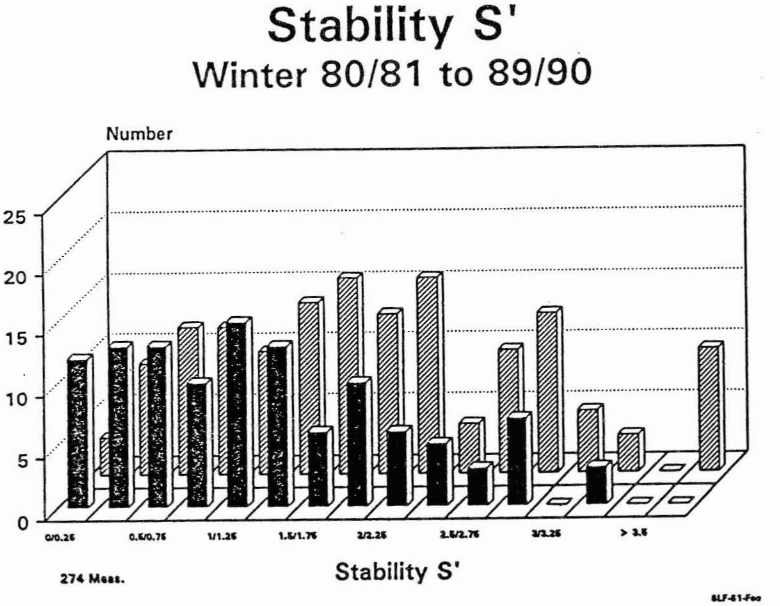

Figure 7: Stability S' is calculated for all available data sets. The front row contains the sample of "very weak layers/interfaces", the back row the remaining sample of the total (274 data sets.)

The displacement along the x-axis between the two frequency distributions is clearly visible. The instable sample (front row) peaks at 1.3, the stabler sample (back row) at 1.8. Although the two samples would not yet allow a highly confident discrimination between dangerous and safe layers, they show some predictive potential. A tentative discrimination limit would be around S' = 1.5. This limit has already been used in a earlier paper (Föhn, 1987).

CONCLUSIONS

1. In our climatic conditions slab avalanches start probably as often on weak interfaces as in weak layers. According to the observed layer structures, a weak interface may be defined as a weak layer of minute thickness (The layer grains are no longer visible). Therefore in a forecasting situation - weak interfaces may only be detected by "Rutschblock"-tests.

2. The large majority of weak layers (80 %) is composed of the most fragile snow forms (surface hoar, faceted particles, depth hoar), whereas only main forms have been considered. The mean grain size was 2.1 ± 1.4 mm. The mean thickness of these layers amounts to 11.9 ± 10.8 mm. The thickness range was 1 - 60 mm.

3. Interfaces contain most often less fragile snow forms (small rounded grains, melt/freeze grains, felt-like forms and faceted particles).

4. Relationships between shear strength and weak layer density - a few times described in literature (cf. References) - were helpful for stability evaluations, if such thin layer densities could be measured or synthesized. Unfortunately this is not possible. Hence here a relationship has been established based solely on grain shapes. These tentative figures for each main grain shape have to be further verified and may serve meanwhile as order of magnitudes.

Due to the wealth of informations contained in these large data sets, not all aspects and relationships between parameters have yet been studied. The influence of slab layer hardness, aging of weak layers and the mechanical behaviour of specific grain combinations at the interface have to be analysed furtheron.

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REFERENCES

Akitaya, E. and Shimizu, H. (1987) "Observations of weak layers in a snow cover", Low Temperature Science, Ser. A, 46, p. 73 - 75.

Conway, H. and Abrahamson, J. (1988) "Snow-slope stability - a probabilistic approach". J. of Glaciology, Vol. 34, No. 117, p. 170 - 177.

Ferguson, S. (1984) "The role of snowpack structure in avalanching, Ph. D. thesis, Univ. of Washington, USA, 150 pp.

Föhn, P. (1981)" Schneefeldsprengungen und Stabilität der Schneedecke". Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft, Heft 8, p. 51- 67.

Föhn, P. (1987) "The stability index and various triggering mechanims", IAHS Publ. No. 162, p. 195 - 214.

Föhn, P. (1989) Snowcover stability tests and the areal variability of snow strength". Proceedings of the Intern. Snow science workshop in Wistler, Canada, Oct. 12-15, p. 262 - 273.

Mc Clung D.M. (1977) In-situ estimates of the tensile strength of snow utilizing large sample sizes", J. of Glac., Vol. 22, No. 87, p. 321 - 329.

Perla, R. et al. (1982) "The shear strength index of Alpine Snow Cold Regions Science and Technology, Vol. 6, p. 11 - 20.

Roch, A. (1966) "Les Variations de la résistance de la neige", AIHS-Publ. No. 69, p. 86 - 99.

Stethem C. and Perla R. (1980) "Snow slab studies at Wistler mountain, British Columbia", J. of Glac., Vol. 26, No. 94, p. 85 - 91.