# ON WET SLAB MECHANICS AND YELLOW SNOW: A PRACTITIONER'S OBSERVATIONS

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**Abstract:**

Wet slab avalanches remain a vexing phenomenon to theoreticians and practitioners alike. Empirically based studies that employ the same field methods commonly used by practitioners can have particular relevance to technicians and recreationists. This project seeks to expand fundamental knowledge of wet slab avalanches from a practical perspective, using common field methods: hand tests and dyes.

Specific analytical emphases include: a) temporal changes in the overall structure and strength of the snowpack -on a meso-scale, the course of one day, and a macro-scale, over the course of several weeks -during the transition from the ripening phase to the output phase; b) variations in propagation propensity correlated to shear and compression strength; and c) effects of water percolation through heterogeneous stratigraphy in a depth hoar climate snowpack in central Colorado. Preliminary data on strength tests and propagation propensity reveal consistent patterns in the strength of the snowpack, and direct correlations to recently developed propagation hand tests. Initial observations of dye percolation may indicate consistent percolation and wetting properties that relate to failure.

Final analysis of the data considers possible models for wet slab avalanches in a depth hoar climate during the ripening phase, at or before peak snow water equivalent; and during the output phase, after peak snow water equivalent or during decreasing snow water equivalent.

## 1. Introduction:

Recent attention has been drawn to wet slab avalanches. Much focus has been paid to the dynamics of free water flow through the snowpack, especially related to snow hydrology and run-off prediction. However, fewer studies –until very recently, have directly attempted to correlate free water flow properties to avalanche phenomenon, especially wet slab activity. Dye tests have been used since the earliest snow science studies to identify flow patterns and hydraulic conductivity within the snow matrix.

More recent studies have focused on relationships between free water production and infiltration in wet-slab and wet-loose avalanches. This project has sought to find fundamental associations between: slab layering, propagation propensity, shear and compressive strength, and water percolation in the depth hoar snowpack and climate of central Colorado.

The local climate consistently develops significant depth hoar, which is a constant basal weakness. In this climate depth hoar grain characteristics prevail until well into the output phase of the late-season, even in a large-grained, mature snowpack. Recent studies have implicated depth hoar or basal facets as a likely factor in wet slab activity. (Osterhuber, 2006; Reardon 2004 & 2008))

## 2. Procedure:

A series of snow pits were dug adjacent to snow survey SWE sampling sites. Timing was determined to represent periods of likely weakening in given conditions. Field days were chosen when weather was warm and sunny and SWE values were expected to be decreasing.

Special emphasis was placed on observing the transition from a ripening snowpack to a mature, large grained, melt/freeze snowpack. All locations were below tree line. Aspects and pit timing were chosen to represent maximum potential water generation at a given site on a given date and maximum probable weakening on each given day. All pits were dug in un-compacted snow.

The sampling period was from early April (4/1) until early May (5/6) 2008. Due to cold, cloudy, or snowy days; roughly half of the available time frame was suitable for

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testing. Because of a deeper than average snowpack and cool temperatures, potential sites that were at relatively lower elevations (~10,600 ft or 3230m ), below treeline, were in the appropriate window of transition from ripening to output phases. The testing was limited to such sites at the appropriate times. Temperatures were generally below freezing overnight, and above in the daytime.

Pit sampling included density (ρ) measurements for each layer, along with grain size and type. Strength, stability, and propagation propensity were gauged by common, simple practitioner field tests. These included: shovel shear, compression: tap and stuff block tests, and propagation tests: extended column and propagation saw tests.

<u>*2.1 Testing and Sampling Methods:*</u>

Densities were sampled with a 100cm$^3$ coring tube and weighed to .01 grams. No less than four samples per layer were collected. If variation was > ~10% then six or eight samples were collected to throw out high-low values in the analysis. Sample sets of four values per layer were used in the analysis. For the hand tests, all procedures were according to the *Snow, Weather, Avalanche, and Observational Guidelines*. (Green et al, 2004).

To assure consistency, and an adequate volume of data, density samples were taken no less than four times per layer; the primary hand tests: shovel shear (ST) and compression tap test (CT) were commonly repeated two or three times per test pit–with some exceptions. Verification of CT scores was made by stuffblock (SB) tests. (Fig.1)

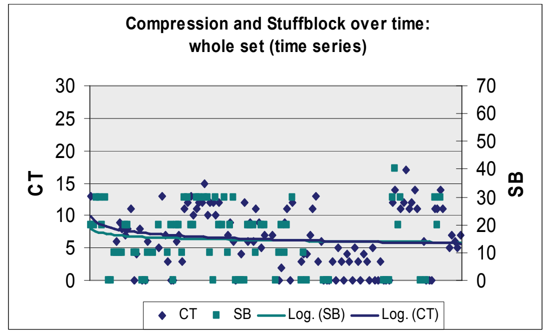


Fig. 1: Compression hand test (tap test) scores correlated well with stuffblock values.

Of the sixteen field days, four were identified as ‘Red Flag’ days due to classic observations of instability such as widespread large areal collapses or natural activity (wet-slab and wet-loose avalanches) observed or reported in the general area.

The four ‘Red Flag’ days were additionally considered in comparison to eight ‘event’ days (wet slab activity) in terms of twenty-four hour temperature trends and one month SWE trends. These twelve days were also compared as a set.

After focusing analytical goals and excluding outliers, the following quantities of field collected data were considered in the field data analysis:

| | Total | Pits | ST | PST | CT | SB | ECT | ρ |
|---|---|---|---|---|---|---|---|---|
| Field Days | 16 | 47 | 140 | 187* | 109 | 78 | 90 | 488 |
| ‘Red Flag’ days | 4 | 17 | 54 | 37 | 53 | 22 | 30 | 220 |

Table1: Total sample set analyzed after outliers were removed and analysis focused.

* Most of the PST scores analyzed in the graphs (128) were taken from tests performed at the basal layer or at the interface between faceted basal layers and the snowpack above. While several examples of ‘PST = yes’ results were observed when mid or upper layers were being actively wetted, especially for the first time, in most cases the mid and upper layer interfaces resulted in ‘PST = no’ -especially when ice masses were present.

*2.2 Densities and Dyes:*

Within the first few days of sampling it was apparent that densities and moistness/ wetness (hand test and loupe) of various layers did not fit any simple pattern, nor did it seem likely that an initial hypothesis of small over coarse grain capillary barriers, densification of small grain layers, and slab failure behavior would correlate.

Density and wetness observations indicated that water was being transferred through the snowpack and was being retained in various layers at various times, but not in easily discernable patterns. It was decided to continue sampling densities (though less frequently) for later analysis.

It was also decided that dyes may help identify percolation patterns as relating to failure and propagation. After 4/13, powdered dyes were added to the surface of the snow on nine field days. Generally, dry powder dyes were placed on the snow prior to softening. As pits were dug on site, some were dug into dye affected areas to attempt to observe any possible relations between the conductivity of liquid water and failure and propagation. Several colors were used, but yellow was chosen most often with the idea of reducing solar heating effects.

## 3. Analysis

*3.1 Field Data:*

Data were entered into spread sheets from field books and graphed in various plots assess for patterns or correlations.

For temporal trends in the weakening of the snowpack, time series plots and time sorted plots were graphed to asses for strength and propagation propensity patterns over time. For propagation tests only simple yes or no values were considered.

Other observations were hand tabulated from field notes. Photos of dye infiltration patterns were taken. Composite representations of the two types of snow stratigraphy that were observed repeated and consistently were assembled and graphed.

Temperature and SWE trends were reviewed for the project area and time, and were compared to temperature and SWE trends for other recorded wet slab events. SWE values from Snotel sites and snow course measurements were used for analysis.

*3.2 Temperature and SWE Trends:*

Temperature trends for twenty-four hour periods on 'Red Flag' days and eight reported wet slab avalanche events were compared and graphed, as were the one-month SWE trends for the same events and timeframes. Similarities, correlations, and patterns for the SWE and temperature trends were considered.

## 4. Findings

*4.1 Densities, Wetness, and Grain Size:*

No discernable patterns in the densities of a given layer over time could be drawn relating directly to liquid water within that layer. Density values were assessed for consistency, to check for sampling errors. The mean standard deviation per layer was .0141 g/cm$^3$.

Time Series Plots did not reveal any consistent patterns of change in density of the snowpack, or a given layer within the snowpack. There was no correlation that could be drawn between grain size and liquid water retention from density readings or the standard field 'squeeze test' and (10x loupe) visual inspection for liquid water.

*4.2 Temperature and SWE Trends:*

Data analysis of temperature trends was somewhat consistent over the set of twelve days (four 'Red Flag' days and eight 'event' days) in that steep temperature increases were noted in all cases. Of the twelve cases considered, five had not frozen overnight and seven had. In three of ten examples: $\Delta T > 10°C$ in ~2 Hrs. (Fig. 2)

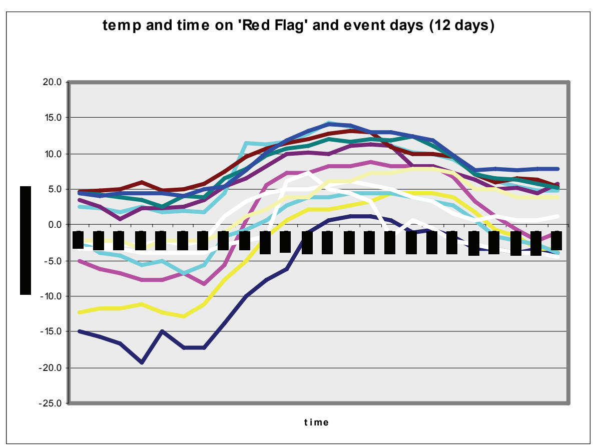


Fig. 2: 24 hour temps on 'event' and 'red flag' days.

SWE trends were also somewhat consistent. Ten days were associated with some loss of SWE. Two of twelve were not; gradual or no SWE loss possibly associated more closely with the moist-mid-pack-slab ripening regime. (Fig. 2)

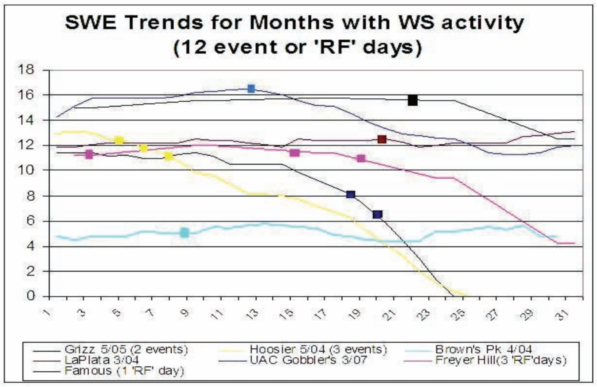


Fig 3: Monthly SWE trends, event and 'RF' days marked

In five other instances, out of the total set of twelve, the SWE dropped precipitously during or following avalanche activity cycles. (Fig. 3) These events were associated with wet slab activity in a mature, output phase snowpack, especially considering that the cycles were all associated with shallow or no freeze (four had no freeze) and occurred in May when the snowpack would be mature, large grained, and subject to M/F re-crystallization in all layers.

| | Overnight Freeze? | Rapid SWE loss? |
|---|---|---|
| 'RF' day | Yes | Yes |
| 'RF' day | Yes | No |
| 'RF' day | Yes | No |
| 'RF' day | Yes | No |
| Event day | Yes | No |
| Event day | Yes | No |
| Event day | Yes | Yes |
| Event day | No | Yes |
| Event day | No | Yes |
| Event day | No | Yes |
| Event day | No | Yes |
| Event day | No | No |

Table 2: For the 12 days where Temp and SWE trends were considered, there was a distinct split between days that either showed steady SWE and freezing or days with no freeze and a rapid SWE loss for the month.

## <u>4.3 Layering and Stratigraphy:</u>

Two very distinct types of layering were observed consistently. Every snow pit observed and recorded could be placed into one or the other of the two distinct types of strata. Both types of layering involved basal depth hoar and basal facets that, though wetted, retained a distinctive faceted shape.

In the first type of strata (A) there was a mid-pack slab layer that was *moist* by definition, not *wet* according to standard. This layering pattern is consistent with wet slab configurations proposed by others, (Reardon 2004, 2008 and Peitzsch 2008) and produced strength test failures and propagation test results consistently to indicate wet slab hazard potential. (Fig. 3 & 4)

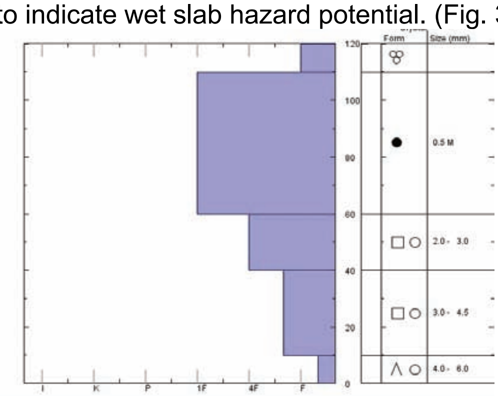

Fig. 3: one typical stratum (A) with a moist-mid-pack-slab present.

The moist-mid-pack-slab layering was common with or without ice being present in the upper pack. (Fig. 4)

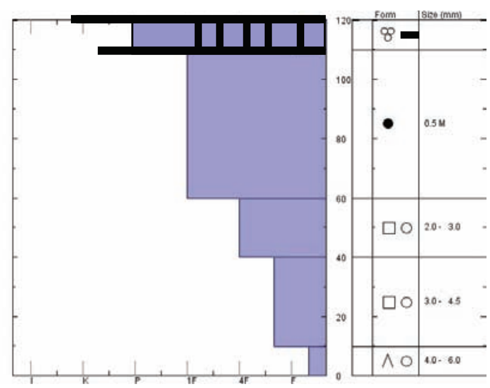

Fig. 4: Another typical stratum (A) where a moist-mid-pack-slab is present with some surficial ice layering.

The second type of layering pattern (B) involved a slab layer present in the top 20-40 cm of the snowpack that had abundant vertical and horizontal ice masses present from diurnal melt/freeze cycles. This M/F 'slab' typically sat on top of large M/F poly-crystals that were poised above the wetted basal facets or depth hoar. (Fig. 5)

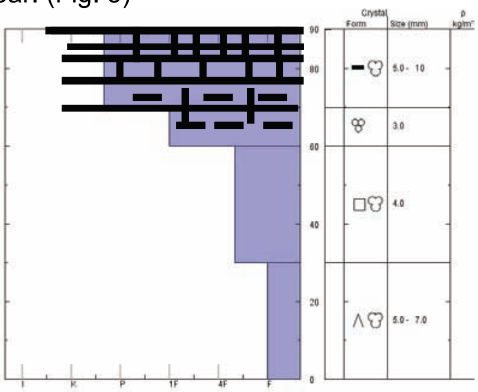

Fig. 5: Typical type (B) stratum. In a well matured, output-phase snowpack the 'slab' of vertical and horizontal ice bodies is poised over facets and depth hoar.

The stratigraphy seen in pattern (B) would be associated with a 'mature' old well wetted snowpack. The pattern (A) layering would still be in the ripening phase.

Ice masses were present in 83% of the total set. Small round grains associated with a moist-mid-pack-slab stratigraphy were present in ~63% of the snow profiles; and ~37% of the profiles represented a fully mature, output snowpack with a complete absence of round grains. In half of the 'Red Flag' conditions, small rounds were present, and half had only M/F poly crystals.

Field tests and observations indicate that in a depth hoar snowpack <u>both</u> strata are capable of producing wet slab avalanches.

*4.4 Shear, Compression, and Propagation Propensity:*

The trends that relate to strength and propagation propensity were the most consistent aspect of the entire project. A pattern of consistently low shear strength at the basal facets was observed on field days. This was corroborated in the analysis. PST propagation, which associates with shear, correlated well with the low shear failure scores. (Fig. 6)

A pattern of compressive strength decrease throughout the day was observed in the field and supported by the data analysis. ECT propagation, which is associated with compressive failure, correlated well with the declining compressive failure strength scores. (Fig. 7)

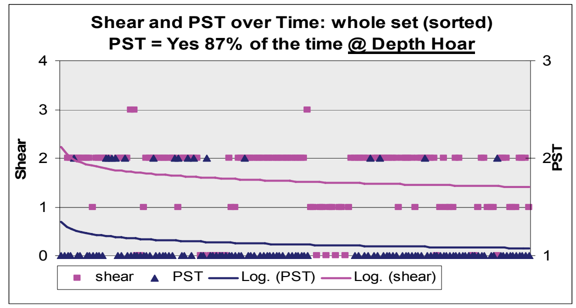


Fig. 6 Weak shear and PST = Y were consistent, with a trend toward weakening and more propagation propensity in the afternoons.

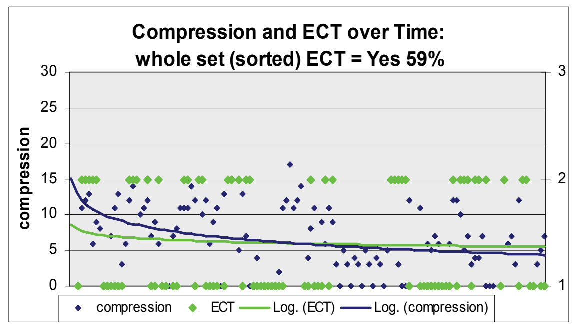


Fig. 7 The trend toward PM weakening in compression is more pronounced for compression. The distribution of ECT =Y is more even and correlates with lower CT scores

*4.5 Temporal Strength Trends:*

On a macro-scale time frame, over the course of the month, there was a slight trend toward weakening. (Fig 8) On a meso-scale there was a consistent strong trend toward weakening each day in the afternoon. (Fig. 9)

A decline in shear strength was more pronounced on 'Red Flag' days, reflected by steeper trend line curves, weakening from STE to STV or STC. (Fig. 10 & 6) 'Red Flag' days were also marked by weaker compression test scores in the morning. (Fig. 11 & 7) On seven of the sixteen field days there was an almost simultaneous drop in shear and compression values. (Fig. 12)

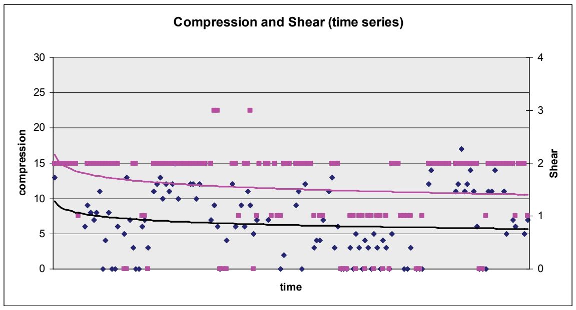


Fig. 8: A general trend toward weakening over the course of the whole month

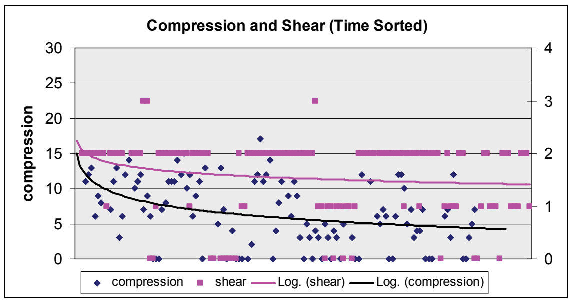


Fig. 9: The daily weakening trend is steeper for compression than shear

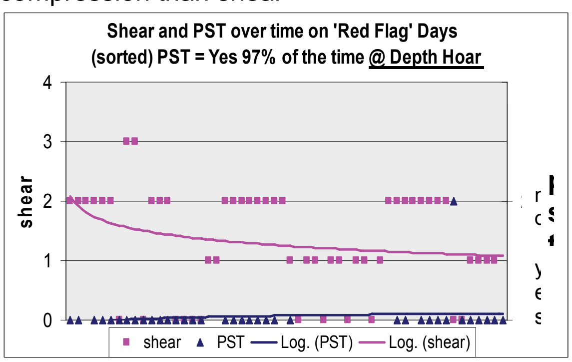


Fig. 10: On 'Red Flag' days the trend toward weakening in the course of the day was steeper and PST = 'Y' 97% of the time. (Compare to Fig 6, the whole set)

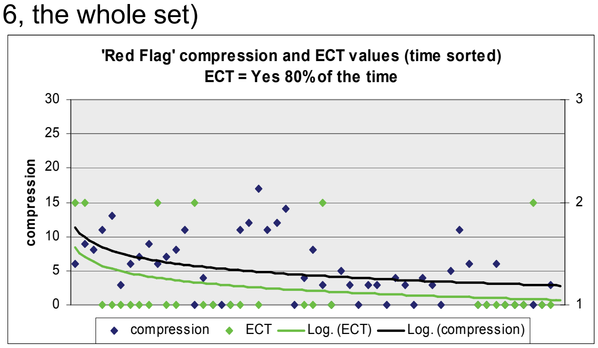


Fig. 11: The trend towards PM weakening on 'Red Flag' days: weaker to begin with and lower over all. (Compare to Fig. 7)

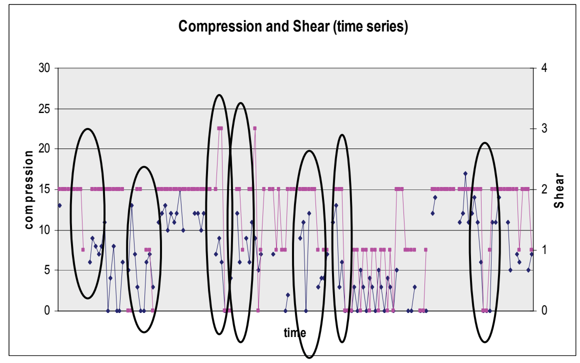


Fig. 12: On seven field days (all four 'RF' days and three others) the shear and compression test scores fell simultaneously.

*4.6 Dyes or (the dreaded) Yellow Snow:*

Obvious preferential wetting with vertical (column) and horizontal (planar) flow was observed in moist small grained layering -type (A) ripening snowpack. (Fig. 13) Uniform wetting was observed in the mature (B) output layering patterns. (Fig.14)

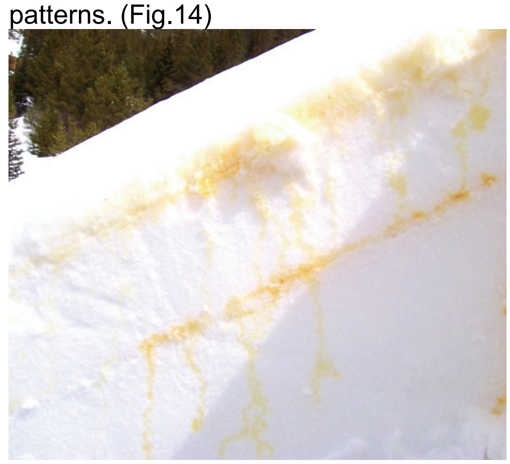

Fig. 13: Vertical and planar wetting in moist fine grained snow.

Fig.14: More uniform wetting in older, large, coarse grained, mature, output snowpack

There were several instances of active wetting between layers (planar Fig. 13) that was weak in shear and produced PST= 'yes'.

Unfortunately these dye related observations are suspect as it was discovered, after the field days, that a freezing point depressor was in the dye ingredients.

**5. Conclusions:**

Though the sample size is limited and much of the data collected proved 'noisy' and scattered, there were some consistent patterns:

*5.1 Shear and Compression Strength:*
Shear strength observed in a wet depth hoar regime was low overall. Though it did sometimes drop from STE to STV or STC in the afternoons, it was generally less subject to diurnal weakening than compression strength.

Compression values are more subject to diurnal weakening in the melt phase of the melt/freeze cycle. Shear and compression strength may drop precipitously together.

| Shear value | frequency |
|---|---|
| STH | 0% |
| STM | 2% |
| STE | 65% |
| STV | 20% |
| STC | 13% |

Table 3: Shear strength in a wetted, depth hoar regime was consistently low.

*5.2 Propagation Propensity:*

Each of the recently developed propagation propensity field tests correlates well with its corresponding strength tests i.e. the PST is associated with shear, and when shear values are low, 'PST = Yes' is likely; when CT scores are moderate 'ECT = No' is more likely and if CT values are low 'ECT = Yes' is more common. The potential propagation under compressive or shear stress seems a suitable compliment to its comparable strength test.

*5.3 Dyes*

Though the results from this cycle of field tests were suspect, they were consistent. While the dyeing agent may have proven a poor choice, the practice seems sound and full of potential. Adding a dye prior to softening and then digging pits into the dye affected snow may reveal weakening patterns that correlate to the arrival of liquid water at an interface or in a layer.

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