A STUDY OF THE PHYSICAL PROPERTIES OF SLAB COHESION AND ITS IMPACT ON THE STABILITY OF THE SNOW COVER

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ABSTRACT: Unconsolidated snow, particularly during or immediately following a storm, is often expected to release as loose avalanches. However, there are numerous instances of slab avalanches releasing from conditions where the snow was more cohesive than expected. These types of avalanches, often termed a 'soft slab', or similar, are inconsistently reported using various terminology. This research project proposes a threshold value of cohesion, based on measurable snowpack properties. Snowpack test results from Extended Column Tests and Compression Tests are presented and correlated to snowpack properties, measured using the InfraRed Integrating Sphere (IRIS), Blade Hardness Gauge (BHG), and Hand Hardness (HH) observations. Based on these results, a threshold value for identifying slab cohesion is proposed, to aid in determining whether storm snow is more likely to release as a dry loose or slab avalanche.

KEYWORDS: Cohesion, Slab Development, Storm Slab, Dry Loose, Soft Slab, Unconsolidated Snow

1. INTRODUCTION

When forecasting avalanche problem types during, or particularly in the days following, a storm, slab cohesion is a topic of conversation in forecaster meetings, predicting whether an avalanche may release as a Storm Slab avalanche or a Dry Loose avalanche, as classified in the Observation Guidelines and Recording Standards for Weather, Snowpack, and Avalanches (OGRS) (Canadian Avalanche Association (CAA), 2024). However, while cohesion is a term used within the description of each avalanche problem type, it is not defined in OGRS (CAA, 2024).

According to the Avalanche Handbook (McClung and Schaerer, 2006), "The strength property that determines the *type* of avalanche that will occur once failure has taken place is called *cohesion*. Loose-snow avalanches are caused by a *lack* of snow cohesion, while slab avalanches *require* {cohesion}." McClung and Schaerer go on to relate cohesion to bond strength between snow grains and crystals, as well as the shape of snow grains, and density. While they discuss the role these factors (and many more) play in the release of slab and loose avalanches, there are no clear or defining values for what constitutes enough cohesion to produce a slab.

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When examining descriptive InfoEx summaries of snowpack structure or avalanche observations, there is often terminology used to further classify the slab, particularly in an effort to alert others to the subtlety of the snow presenting itself at the surface as lacking enough cohesion to produce a slab avalanche, however observations indicated that slab avalanches did indeed occur.

In some contexts, forecasters sub-classify a slab as 'very soft' or 'soft' to imply that it may present itself to an observer as lacking in cohesion, however it may likely exhibit characteristics of a slab (in terms of promoting avalanche release).

The Conceptual Model of Avalanche Hazard (CMAH) (Statham et al, 2018) classifies Avalanche Problem Types, with Storm Slab Avalanches listed as having Slab Hardness from "Very Soft to Medium (F–1F)", and Dry Loose Avalanches described as "cohesionless dry snow", and no associated slab hardness.

Though the significance of this may seem trivial, the resulting hazard is non-trivial. Haegeli and McClung (2003) describe dry slab avalanches as the most dangerous release type. If we take the example of a skier, and assess their vulnerability when presented with an avalanche, we can say that, as long as terrain traps are not a factor, cohesionless snow is much less hazardous than a dense slab. Slab avalanches are more hazardous than Dry Loose avalanches because they can be much larger and release in friendly looking (lower angle) terrain, making it more likely to surprise and injure a skier. Additionally, a Dry Slab avalanche involves snow with a higher density than a Dry Loose avalanche, with typical slab densities ranging from 100-350kgm^{-3} (McClung and

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Schaerer, 2006). Furthermore, due to slab mechanical properties and depending on the location of the trigger point, the slab may release upslope from the skier, and then break up into large blocks, making it more hazardous. On the other hand, a Dry Loose avalanche is typically less hazardous to a skier: due to the low density of snow and lack of cohesion, it is relatively easy to ski or ride out of (depending on the depth and density of the snow, as well as the skier's ability). Therefore, the likelihood of skier injury is much greater for a Slab avalanche than a Dry Loose avalanche, assuming terrain traps and other features (i.e. cliffs) are not a factor.

Further, from an avalanche control perspective, the difference between cohesionless snow and a ("soft") slab avalanche could mean the difference between triggering an avalanche through initial avalanche control work or leaving the problem to 'set up' for a little longer – for example if slab metamorphism occurs at a sufficient rate, it could be enough to trigger an avalanche after a time interval. This could be between multiple attempts of avalanche control, if the area is kept closed, or, if the area is opened after the avalanche control finishes, this could be exposing a member of the public to an accidental avalanche release. Thus this is relevant to how forecasters treat the outcome of a non-result in avalanche control work: does the non-result imply that the slope is safe?

The relationship between snow cohesion and slab properties remains poorly understood, particularly in low-density snow, and is therefore a primary focus of this research project. This research project studies properties of dry snow such as resistance and specific surface area of snow grains, and correlates these with positive snowpack test results that indicate the existence of a slab. The immediate goal is to identify a threshold value for slab cohesion, above which the snow is classified as having enough cohesion to produce a slab avalanche, and below which it can be expected that the snow is lacking enough cohesion to release as a slab and therefore will release as a dry loose avalanche. Future goals also include using these measured snowpack properties to further refine the description of reported slab avalanches and snowpack conditions, allowing for a standardized communication scheme for communicating slab avalanche characteristics along with the likely destructive potential associated with the snow properties above the weak layer. Another target of investigation is the rate of slab development, or slab metamorphism, and how this relates to slab stability, particularly during and immediately following new snowfall. This will involve measuring the above listed slab properties along with their rate of change, and associated snowpack test results.

2. STUDY SITES

Study sites are located in Glacier National Park (GNP) and Kicking Horse Mountain Resort (KHMR) in the Columbia Mountain Range of British Columbia, and in two coastal communities in Nunavik, Québec.

Study sites in GNP included sites at Mount Fidelity, Hermit Meadow, and Balu Pass. Study Sites in KHMR included sites in Rudi's Meadow. The snow climate in the Columbia Mountain Range is classified as transitional, with both continental and maritime influences (McClung and Schaerer, 2006, Haegeli and McClung, 2003). Typical total snowpack depths of 2.5 to 5m are measured in March-May, and average winter temperatures are -5°C to -15°C from December through February (Bellaire et al, 2016, McClung and Schaerer, 2006).

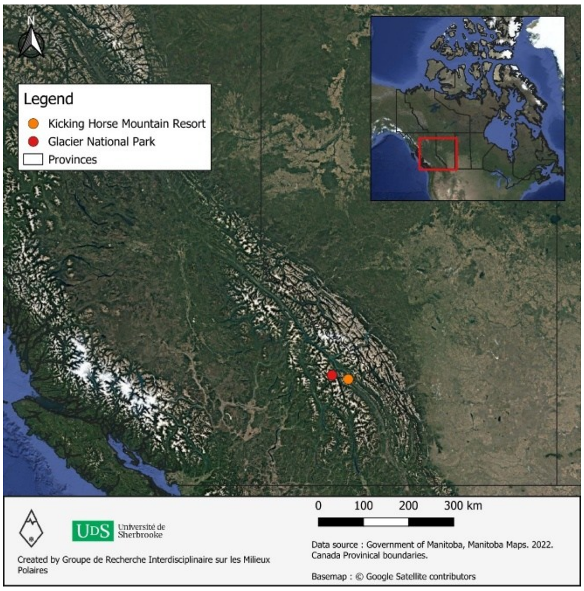

Figure 1: Study Site Locations in BC.

Study Sites in Nunavik are located in 2 communities: Kangiqsualujjuaq, and Kangiqsujuaq, located on the northern coast of Québec, above arctic treeline, and within the continuous permafrost zone. The snow climate in northern Nunavik is classified as arctic, with winter temperatures typically varying from -10°C to -30°C from December through March, typical snowpack depths of 60cm to 125cm, and wind speeds exceeding 150km/h (Filion et al., 2025).

Figure 2: Study Site Locations in Nunavik, Qc.

3. METHODS

A series of snowpack observations, measurements, and snowpack tests were performed during the 2025-2026 winter season. Standard observations were made and snowpack tests were conducted in accordance with OGRS (CAA, 2024), with the addition of measurements using the Snow Scope Probe (SSP), Blade Hardness Gauge (BHG), and the InfraRed Integrating Sphere (IRIS) (Montpetit et al, 2012).

After choosing an undisturbed, representative, and safe location, and prior to disturbing the area by digging, the SSP was used to probe the snow immediately in front of where the test wall would be, a minimum of 3 times (Figure 3). After digging the snow pit, snowpack layers and correlating Hand Hardness values were identified prior to the measurements made with the BHG and IRIS to prevent confirmation bias from occurring. After the measurements were made on the observation wall, snowpack tests including Compression Tests (CT), Extended Column Tests (ECT) and Shovel Tilt Tests (TT)* were conducted on the test wall**. (*Shovel Tilt Tests were added late in the data collection season) (**if the slope angle was 0, then the observation wall was combined with the test wall and had the same aspect.)

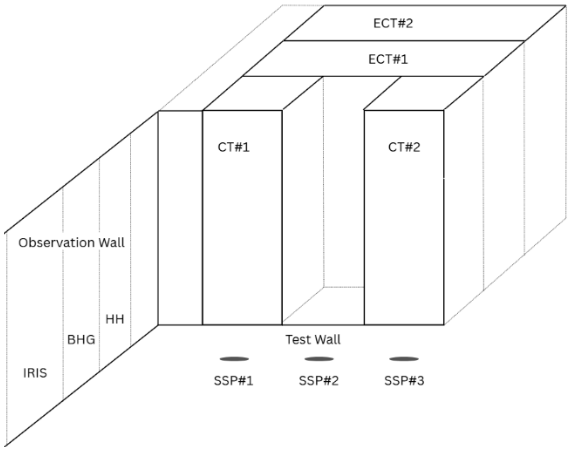

Figure 3: Snow Pit Layout.

4. DATA

The following data was retrieved from study sites: snowpack layer stratigraphy (including resistance), reflectance, which can be translated to specific surface area, and snowpack test results.

4.1 Snowpack stratigraphy

Snowpack stratigraphy was collected in accordance with OGRS (CAA, 2024).

4.2 Horizontal resistance: Blade Hardness Gauge and Hand Hardness (BHG, HH)

Horizontal resistance measurements were made with the Blade Hardness Gauge (BHG) and the Hand Hardness (HH) scale. HH measurements were made in accordance with OGRS (CAA, 2024). The Blade Hardness Gauge is a pocket-sized instrument with a blade similar to a paint-scraper, which measures the force required to insert the blade into the snow in Newtons (N), similar to the procedure for Hand Hardness. Results can be correlated to Hand Hardness values using the table presented in *Snow Hardness Measuring and Analysis Techniques With the Blade Hardness Gauge* (Barsevskis, 2024), although as noted in this publication, the Hand Hardness Scale is subjective, with inconsistent values reported across Avalanche Practitioners. In contrast, the Blade Hardness Gauge is an objective measurement tool, providing a precise numerical output.

Figure 4: The Blade Hardness Gauge (From Barsevskis, 2022).

4.3 <u>Reflectance and Specific Surface Area (R, SSA): Infrared Integrating Sphere (IRIS)</u>

The Infrared Integrating Sphere (IRIS) is a scientific instrument which measures the Reflectance (R) of a sample of snow by illuminating the surface of a snow sample presented by the collection cylinder, using an infrared laser with wavelength 1330nm. This snow reflects the laser beam into the spherical cavity that makes up the reflection chamber; the reflected light is collected by a photodiode and converted to a voltage, corresponding to a percentage of the incident infrared beam.

Voltage values can be read from a multimeter in the field to visually verify the accuracy of the instrument when making measurements; this also allows measurements to be recorded by hand as a backup. The measured value is also recorded to an internal memory using the button located on the side.

The recorded voltage can be converted to the Specific Surface Area (m2 kg–1) (SSA) using the Kokhanovsky and Zege (2004) model (Gallet et al, 2009). This model was tested by Montpetit et al (2012) using a SWIRcam to verify the results. From this, we can see that it is possible to correlate snow grain types to measured IRIS values, with expected SSA for Precipitation Particles (PP): 39 m2 kg–1 < SSA < 55 m2 kg–1, (dense) Rounded Grains (RG): 17.0 m2 kg–1 < SSA < 27.0 m2 kg–1, Melt-Freeze Crusts (MFcr): 5.0 m2 kg–1 < SSA < 13.0 m2 kg–1, and Depth Hoar (DH): 8.0 m2 kg–1 < SSA < 16.0 m2 kg–1 (Montpetit et al, 2012).

Figure 5: The IRIS displayed along with the calibration discs, collection cylinder and the multimeter used to display the recorded reflectance value.

Figure 6: The IRIS displayed in use in a snow pit, with the collection cylinder showing the layer of snow of interest.

4.4 <u>Vertical resistance: Snow Scope Probe (SSP)</u>

Vertical resistance measurements were made with the Snow Scope Probe (SSP). The SSP is inserted vertically into the snowpack in the same way as an avalanche probe is inserted. A sensor on the end of the SSP records the force in (kPa) required to push the probe through the snow. The SSP is paired to a cell phone via Bluetooth, which allows a visual snow profile to be displayed immediately after the probe insertion.

Figure 7: The SSP sensor displayed along with a visual representation of a snow profile conducted using the SSP.

4.5 Snowpack test results

Snowpack tests conducted included Compression Tests (CT), Extended Column Tests (ECTs), and Shovel Tilt Tests (TT).

CT and ECT tests were conducted according to procedures described in OGRS (CAA, 2024). TT procedures, while not yet standardized in OGRS, are presented in the Avalanche Journal (Klassen, 2006).

5. ANALYSIS

Snowpack test results were grouped according to fracture characteristics (CT), or by propagating vs non-propagating results (ECT), along with the properties of the snow overlying the test result weak layers, including HH, BHG, and IRIS values. SSP values were compared with BHG values to ensure consistency of measurements.

For this research, the primary result of interest is the fracture characteristic of the test result. Planar CT test results (SP, RP, SC) and propagating ECT test results (ECTP) indicate the existence of enough cohesion in the snow within the layer above the failure plane to support the existence of a slab. Non-planar CT test results (BRK), or non-propagating ECT test results (ECTN), or no result suggest that the layer above the failure plane lacks enough cohesion to support the existence of a slab. However, due to the nature of the CT and ECT tests: when the snow is soft, these layers of soft snow are often compressed during the execution of the snowpack test, and therefore the result is not fully representative of the cohesion of the layer (Klassen, 2006). In these cases, a Tilt Board (Brown and Jamieson, 2008), (Alei-Gonzalez and Eskeland, 2025) at study plots or a Shovel Tilt Test (TT) (Klassen, 2006) would allow for a positive, planar test result, where a CT may produce results such as progressive compression (PC) or non-planar break (BRK), or no results, and an ECT may produce either non-propagating or no results. The TT was introduced to the methodology late in the season with few test results which have been excluded from this report.

6. PRELIMINARY RESULTS

15 snow pits were dug over the 2025-2026 winter season, with N = 54 planar or propagating results. These preliminary results suggest a cohesion threshold value of 0.3N as measured by the BHG, correlating to a HH value of F, and 0.834mV as measured by the IRIS, corresponding to approximately 41% reflection. Values above this cohesion threshold repeatedly produced planar results in Compression Tests (SP, RP, SC), and propagating results in Extended Column Tests (ECTP). Below this threshold, snowpack tests either produced no results, non-planar or non-propagating results, or inconsistently produced planar or propagating results.

It should be noted that due to the subjectivity of the Hand Hardness scale, that this value is not necessarily reliable prior to an individual Avalanche Practitioner Calibrating their own HH values using the BHG (Barsevskis, 2024). Additionally, the range for which Fist density is applied includes BHG values both above and below the proposed cohesion threshold value, according to the table proposed by Barsevskis (2024).

Figures 8, 9, 10, and 11 show snowpack test results which produced planar results: SP, RP, SC for CT tests; or propagating results: ECTP for ECT tests.

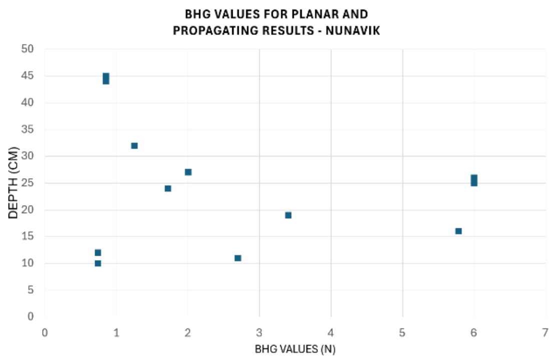

Figure 8. BHG values for planar snowpack test results collected in Nunavik (CT: SP, RP, SC; ECTP).

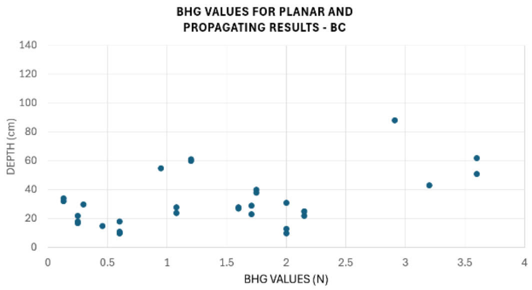

Figure 9. BHG values for planar snowpack test results collected in BC (CT: SP, RP, SC; ECTP).

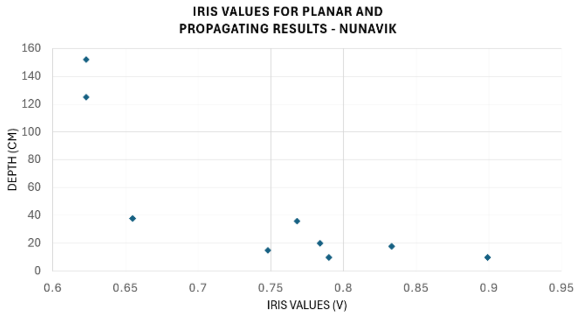

Figure 10. IRIS voltage values for planar snowpack test results collected in Nunavik (CT: SP, RP, SC; ECTP).

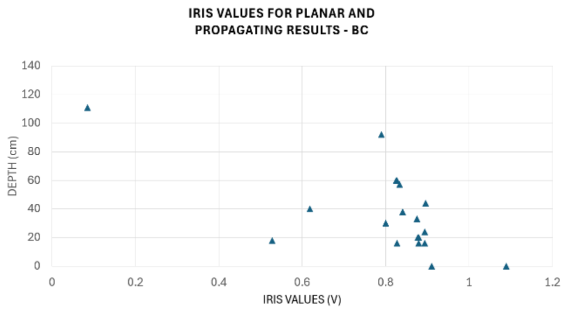

Figure 11. IRIS voltage values for planar snowpack test results collected in BC (CT: SP, RP, SC; ECTP).

7. DISCUSSION

It should be noted that the lowest value observed that produced a relevant result was 0.1 on the BHG, corresponding to F on the HH scale, and 0.528mV on the IRIS, corresponding to approximately 20% reflection. However, due to the small sample size there are not enough results to justify choosing the lowest values collected, as they could be an anomaly.

With a larger dataset consisting of more snow pits and with a particular emphasis on near surface layers, including values recorded during and immediately following snowfall events, it is possible that the resulting BHG values for cohesion could consistently remain near 0.1N.

8. LIMITATIONS

Due to the small number of 15 snow pits dug during the 2025-2026 season, the resulting sample size of 54 positive snowpack test results across all Hand Hardness values, of which 13 were in snow that might be classified as a “soft” slab, indicates that these results are anecdotal only; cohesion threshold values are approximate and require further validating. Therefore, more research is required, particularly in low density and/or freshly fallen snow, to further refine this value for a cohesion threshold.

9. RECOMMENDATIONS

More data will be collected over the 2026-2027 winter season, allowing the determination of a more statistically relevant value for a threshold of cohesion.

The addition of a Tilt Board (Brown and Jamieson, 2008), (Alei-Gonzalez and Eskeland, 2025) at study plots, and a standardized Shovel Tilt Test (Klassen, 2006) will allow further refinement of the cohesion threshold, particularly allowing the collection of data in soft (i.e. recently fallen) snow near the surface of the snowpack, which type of snow typically does not produce results in shovel compression-type tests such as the CT and ECT due to compression of this layer.

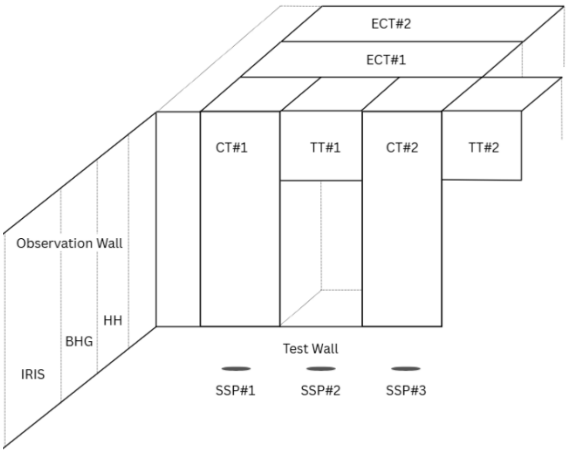

Figure 12: Proposed Snow Pit Layout for 2026-2027 Data Collection Season.

Another target of future investigation is the rate of slab development and how this relates to slab stability, particularly during and immediately following new snowfall. This will involve measuring the above listed slab properties along with their rate of change, and associated snowpack test results.

10. CONCLUSION

In this research project, snowpack properties such as Resistance and Specific Surface Area of snow grains were studied using the Blade Hardness Gauge (BHG) and InfraRed Integrating Sphere (IRIS), amongst other instruments, and snowpack tests including Compression Tests (CT) and Extended Column Tests (ECT) were conducted. Additionally, the Shovel Tilt Test was considered. Snowpack test results were examined for relevancy in indicating the existence of a slab, with fracture characteristics of Sudden Planar (SP), Resistant Planar (RP), and Sudden Collapse (SP) being chosen to indicate a positive test result for CT, and Propagating results (ECTP) being chosen to indicate a positive test result for ECT. These positive test results were then correlated to the measured values and examined for trends.

A value of 0.3N for the BHG and 0.834mV as measured by the IRIS (which corresponds to approximately 41% reflection) were chosen as a threshold of cohesion, above which snowpack tests consistently produced planar or propagating results, and below which snowpack tests either produced no results, non-planar or non-propagating results, or inconsistently produced planar or propagating results. Due to the small sample size of snowpack test results in low density and/or freshly fallen snow, more research is required to further refine this value for a cohesion threshold, for which the use of a Tilt Board and/or the Shovel Tilt Test is highly recommended.

11. ACKNOWLEDGEMENTS

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