Snowpack Observations

2.1 Introduction

Information on the structure and stability of the snowpack within an area is essential to assessing current and future avalanche conditions. In certain applications, starting zones may be inaccessible and snowpack properties can be estimated with careful analysis of past and present weather and avalanche events. Snowpack parameters vary in time and space and observation schemes should address these variations. Snowpack information is generally observed and recorded separately from the snow and weather observations outlined in Chapter 1. However, some basic weather observations are typically made in conjunction with snowpack observations.

Broad objectives are outlined in Section 2.2. A set of standard parameters to be collected with any snowpack observation follows in Section 2.3. Snow profiles and snowpack measurements are described in Sections 2.4 and 2.5. In Section 2.6 methods for observing and recording shear quality are discussed. Section 2.7 presents column and block stability tests, slope cuts are described in Section 2.8, non-standardized tests are described in Section 2.9, and instrumented measures are listed in Section 2.10.

2.2 Objectives

The primary objective of any observer working in avalanche terrain is safety. Secondary objectives may include observing and recording the current structure and stability of the snowpack. Other objectives will depend on the type of operation.

Specific measurements and observations will be dependent on the type of operation, but in general the objective is to observe and record the current structure and stability of the snowpack. More specific objectives are listed in the sections that follow.

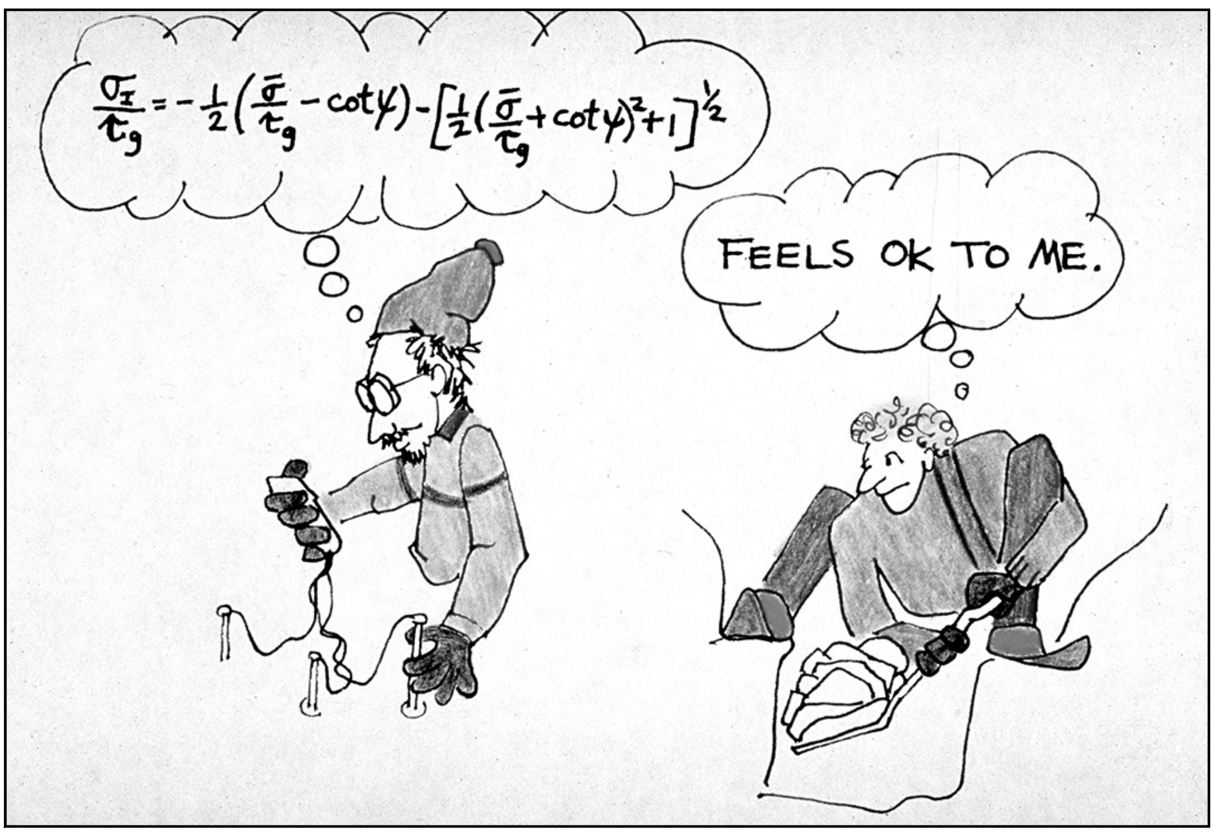

Figure 2.1 There are many different approaches to observing snowpack properties.
(illustration by Sue Ferguson).

2.3 Standard Snowpack Observation

The snowpack parameters observed and the detail of those observations will depend on the particular forecasting problem. This section presents an outline for daily snowpack observations. Parameters one through five and seven will be useful for most avalanche forecasting programs. Individual programs and field workers should select snow properties from those listed in this chapter (parameter six listed below) to supply the information needed for their specific application.

1) *Date* – record the date on which the observation was made (YYYYMMDD).
2) *Time* – record the local time at which the observation was begun (24-hour clock).
3) *Observer* – record the name or names of the personnel that made the observation.
4) *Site Characteristics*
    a. *Observation Location*- record the nearest prominent topographic landmark (mountain, pass, drainage, avalanche path, etc.), political landmark (town, road mile, etc.), or geographic coordinates (latitude/longitude or UTM and datum). If observing a fracture line profile, note the location within the avalanche path.
    b. *Aspect* – record the direction that the slope faces where the observation was made (i.e. N, NE, E, SE, S, SW, W, NW, or degrees azimuth).
    c. *Elevation* – record the elevation of the observation site in feet (meters).
    d. *Slope Angle* – record the incline of the slope where the observation was made (degrees).
5) *Current Weather*
    a. *Sky Conditions*- record the sky conditions as Clear, Few, Scattered, Broken, Overcast, or Obscured (Section 1.12).
    b. *Air temperature* – record the current air temperature to the nearest 0.5 °C (or whole °F).
    c. *Precipitation Type and Rate* – record the precipitation type and rate using the scale and data codes in Section 1.13.
    d. *Wind* – record the wind speed and direction (Section 1.26)
    e. *Surface Penetration* – record the surface penetration using one of the methods described in Section 1.18.
6) *Snowpack Properties* – observe and record the necessary snowpack properties as described in this chapter.
7) *Avalanche Potential* – record one or more of the parameters as applicable to the operation (see Appendix G). Avalanche conditions can be grouped by region, aspect, slope angle range (i.e. 35°-40°), or obvious snow properties (such as recently wind loaded or amount of new snow). In this case a separate stability, danger, or hazard rating should be given for each group.
    a. *Snow Stability*
        i. *Forecast* – record the snow stability stated in the morning meeting or current forecast.
        ii. *Observed* – record the snow stability observed at this location
    b. *Avalanche Danger*
        i. Forecast – record the avalanche danger stated in the current avalanche advisory.
        ii. *Observed* – record the avalanche danger assessed at this location
    c. *Avalanche Hazard*
        i. *Forecast* – record the avalanche hazard currently stated by the program
        ii. *Observed* – record the avalanche hazard assessed at this location.

2.4 Snow Profiles

Snow profiles are observed at *study plots, study slopes, fracture lines* and *targeted sites*. This section outlines two types of snow profiles: *full profiles* and *test profiles.* A full profile is a complete record of snow-cover stratigraphy and characteristics of individual layers. A test profile is a record of selected observations.

Full Profiles

Full snow profiles are frequently observed at study plots or study slopes in time series to track changes in the snowpack. They require that all, or most, snowpack variables be measured (Section 2.5). Full profiles are time consuming and not always possible at targeted sites.

Test Profiles

Test profiles are the most common type of snow profile. There is no fixed rule about the type and amount of information collected in a test profile. Each observer must select, observe and record the parameters needed by their operation. These parameters may change in both time and space. Test profiles are commonly observed at targeted sites and fracture lines.

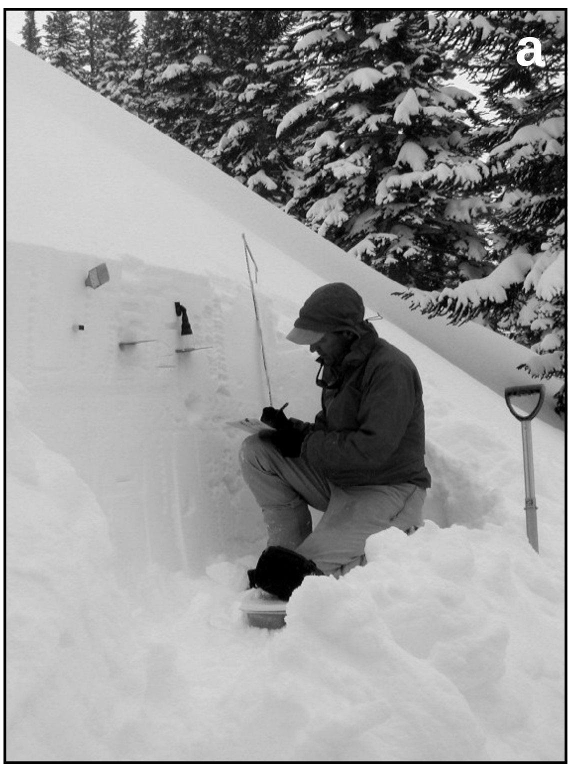

Figure 2.2 Different types of snow profiles: a) Full Profile, b) Test Profile c) Fracture Line Profile. Snow profiles will vary depending the information needed to support a particular application (photographs by Mount Shasta Avalanche Center (a), Bruce Tremper (b), and Ben Pritchett (c)).

The objectives of observing *full profiles* are to:

a) Identify the layers of the snowpack
b) Identify the hardness and/or density of the layers in the snowpack
c) Identify weak interfaces between layers and to approximate their stability
d) Observe snow temperatures
e) Monitor and confirm changes in snowpack stability
f) Determine the thickness of a potential slab avalanche
g) Determine the state of metamorphism in different snow layers
h) Observe and record temporal and spatial changes in snow properties

A *test profile* would address one or more of the above objectives.

In addition, this information can be used for climatological studies, forecasts of snow-melt runoff, engineering applications, and studies of the effect of snow on vegetation and wildlife.

Typical Full Profile

A typical full profile may include the following observations:

- Total Depth
- Temperature by depth (Section 2.5.1)
- Identification of layer boundaries (Section 2.5.2)
- Hand hardness of each layer (Section 2.5.3)
- Grain type and size of each layer (Sections 2.5.4 and 2.5.5)
- Water content of each layer (Section 2.5.6)
- Density of each layer (Section 2.5.7)
- Stability tests (Sections 2.6, 2.7, 2.9, and 2.10)
- Comments

2.4.1 Location

Snow profiles can be observed at a variety of locations depending on the type of information desired. Typical locations include study plots, study slopes, fracture lines, or targeted sites. Full profiles are usually conducted at study plots, study slopes, and fracture lines; however, full profiles and test profiles can be completed at any location.

Study Plot

Study plots are used to observe and record parameters for a long-term record. They are fixed locations that are carefully chosen to minimize contamination of the observations by external forces such as wind, solar radiation, slope angle, and human activity (See Appendix D). Study plots are typically flat sites and can be co-located with a meteorological observing station.

Observations are carried out at a study plot by excavating each snow pit progressively in a line marked with two poles. Subsequent observation pits should be at a distance about equal to the total snow depth, but at least 1 m from the previous one. After each observation, the extreme edge of the pit is marked with a pole to indicate where to dig the next pit (i.e. at least 1 m from that point). When the observations are complete, the snowpit should be refilled with snow to minimize atmospheric influences on lower snowpack layers.

Study plots and study slopes should be selected and marked before the winter and the ground between the marker poles cleared of brush and large rocks. Some operations will require multiple study plots to adequately track snowpack conditions.

Study Slope

The best snow stability information is obtained from snow profiles observed in avalanche starting zones. Since starting zones are not always safely accessible, other slopes can be selected that are reasonably representative of individual or a series of starting zones. Choosing a safe location for a study slope is

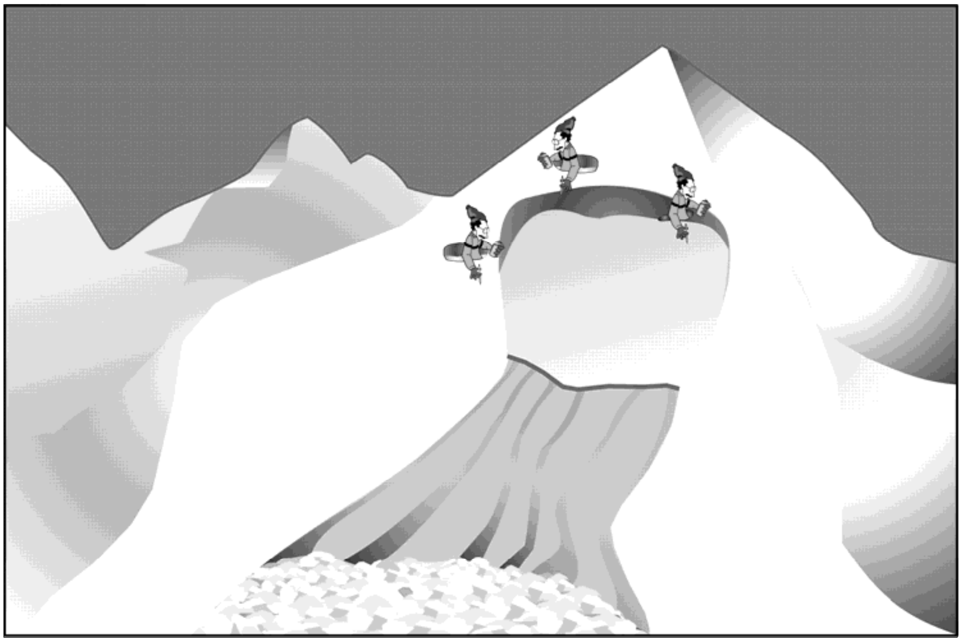

Figure 2.3 Possible locations for a fracture line profile. From left to right: undisturbed snow in the flank, undisturbed snow in the crown, on the crown face.

critical. The study slope should be relatively uniform in aspect and slope angle, and with the exception of the observations should remain undisturbed during the winter. The study slope may be pre-selected and marked in the same manner as study plots; however, marker poles on slopes will be tilted by snow creep and may have to be periodically reset. Some operations may find it advantageous to collect their time series observations on a study slope in addition to, or in place of, a study plot. Multiple study slopes may be useful.

Fracture Line

Observing snow profiles near an avalanche fracture line can provide valuable information about the cause of the slide. Safety considerations are paramount when selecting a site for a profile. Before approaching a site, observers must evaluate the potential for and consequences of further releases. Snow profiles can be observed on a crown face or flank as well as areas where the weak layer did not fracture. When possible, profiles should be observed at a fracture line and at least 1.5 m away from the crown face or flank in undisturbed snow.

Fracture line profiles should be observed at as many locations as possible, including thick and thin sections of the fracture line. In addition, use a sketch or camera to document the location of prominent features and location of fracture line profiles. Carefully note terrain, vegetation, solar, and wind effects on the snowpack. Note any evidence of past avalanche activity which may have influenced the structure of the snowpack.

> *Note: The snow that remains following an avalanche can be either stronger than what slid or dangerously weak. Care should also be taken to choose a location where average crown depth is not exceeded. It is preferable to examine the snow along a fracture line at as many places as possible as time allows.*

Figure 2.4 A targeted site for a snow profile (photograph by Doug Richmond).

Targeted Site

A targeted site is selected to satisfy a particular observer's objectives. The site should be selected to target parameters of interest. Keep in mind that exposure to wind, solar radiation, elevation, and other factors produce variations in snowpack characteristics.

General rules for choosing a targeted site include:

- Always evaluate the safety of a location prior to observing a snow profile.
- To minimize the effects of trees, dig the snow pit no closer to trees than the height of the nearest tree (draw an imaginary line from the top of the tree at a 45 degree angle to the snow surface). In high traffic areas, or when evaluating forested slopes this criterion may not be practical.
- Avoid depressions such as gullies or other terrain traps.
- Avoid heavily compacted areas such as tree wells, canopy sluffs, and tracks made by humans or other animals.

2.4.2 Frequency of Observations

No firm rules can be set on how frequently snow profiles should be observed. Frequency is dependent on climate, terrain, access to starting zones, recent weather, current snow stability, type of avalanche operation, and other considerations. Full profiles should be conducted at regular intervals at study plots and study slopes. Profiles at fracture lines and targeted sites can be completed on an as-needed basis.

2.4.3 Equipment

The following equipment can be useful when observing snow profiles:

a) Probe
b) Snow shovel (flat bladed shovels are preferred)
c) Snow thermometer (calibrated regularly)
d) Ruler or probe graduated in centimeters
e) Magnifying glass (5x or greater)
f) Crystal card
g) Field book
h) Two pencils
i) Gloves
j) Snow saw
k) Inclinometer
l) Compass (adjusted for declination)
m) Density kit
n) Brush
o) Altimeter (calibrated regularly)
p) Topographic map
q) Global positioning system (GPS) unit

The thermometers should be calibrated periodically in a slush mixture after the free water has been drained. Glass thermometers must be checked for breaks in the mercury or alcohol columns before every use.

2.4.4 Field Procedure

Equipment

Equipment used to measure or observe snow properties should be kept in the shade and/or cooled in the snow prior to use.

Observers should wear gloves to reduce thermal contamination of measurements.

Checking Snow Depth

Check the snow depth with a probe before digging the observation pit and make sure the pit is not on top of a boulder, bush or in a depression. Careful probing can also be used to obtain a first indication of snow layering. Probing prior to digging is not necessary in a study plot, or when the snow is much deeper than your probe.

Digging the Snow Pit

Make the hole wide enough to facilitate all necessary observations and to allow shoveling at the bottom. Remember to examine the snow as you dig the pit as valuable information can be obtained during this process. In snow deeper than 2 m it may be advantageous to dig first to a depth of about 1.5 m, make the observations (such as stability tests) and then complete excavation and observations to the necessary depth. The pit face on which the snow is to be observed should be in the shade. Cut the observation face in an adjacent sidewall vertical and smooth. On inclined terrain it is advantageous to make the observations on a shaded sidewall that is parallel to the fall line

Recording

If there are two observers, the first observer can prepare the pit, while the second observer begins the observations (see Figures 2.7 and 2.9 for examples of field notes):

a) Record date, time, names of observers, location, elevation, aspect, slope angle, sky condition, precipitation, wind, surface penetrability (foot and ski penetration), and total snow depth.

b) Observe the air temperature to the nearest 0.5 degree in the shade about 1.5 m above the snow surface. Use a dry thermometer, wait several minutes, and then make several readings about a minute apart to see if the thermometer has stabilized. Record the temperature if there is no change between the two or more readings.
c) Convention for seasonal snow covers is to locate the zero point on the height scale at the ground. However, when the snow cover is deeper than about 3 m it is convenient to locate the zero point at the snow surface. Setting 0 at the snow surface, for test pits, eases comparisons with other snowpack observations made throughout the period. Observers should use whichever protocol fits their needs. In either case the total depth of the snowpack should be recorded when possible.

2.5 Snowpack Observations

2.5.1 Snowpack Temperature (T)

Observe snow temperature to the nearest fraction of a degree based on the accuracy and precision of the thermometers. Most field thermometers can measure snow temperature within 0.5 °C.

Measure the snow surface temperature by placing the thermometer on the snow surface; shade the thermometer.

The temperature profile should be observed as soon as practical after the pit has been excavated.

Push the thermometer horizontally to its full length parallel to the surface into the snow (use the shaded side-wall of the pit on a slope). Wait at least one minute, re-insert close by and then read the temperature while the thermometer is still in the snow. Shade the thermometer in order to reduce influence of radiation. One method is to push the handle of a shovel into the snow surface so that the blade casts a shadow on the snow surface above the thermometer. Shading the snow above your thermometer is important when you are making temperature measurements in the upper 30 cm of the snowpack.

Measure the first sub-surface snow temperature 10 cm below the surface. The second temperature is observed at the next multiple of 10 cm from the previous measurement and from there in intervals of 10 cm to a depth of 1.4 m below the surface, and at 20-cm intervals below 1.4 m. Measure the snow temperatures at closer intervals when needed, as may be the case when the temperature gradients are strong, significant density variations exist, or when the temperatures are near to 0 °C. When measuring relatively small temperature variations, as is common around a crust or density discontinuity, greater accuracy and reliability in measurements may be possible by using a single thermometer/temperature probe.

Begin the next observation while snow temperatures are being measured.

> *Note: Compare thermometers first when two or more are used simultaneously. Place side-by-side in a homogenous snow layer and compare the measurements. If they do not agree, only one of the thermometers should be used.*
>
> *Punch a hole in the snowpack with the metal case or a knife before inserting the thermometer into very hard snow and at ground surface.*
>
> *It is important to regularly check the accuracy of all thermometers by immersing them in a slush mixture after the free water has been drained; each should read 0 °C. Prepare this mixture in a thermos and recalibrate or note variation from 0 °C on the thermometer.*

2.5.2 Layer Boundaries

Determine the location of each major layer boundary. Brushing the pit wall with a crystal card or a soft bristle paint brush will help to bring out the natural layering of the snowpack. Identify weak layers or interfaces of layers where a failure might occur. Record the distance from the layer boundary to the ground or snow surface depending on the convention being used.

Figure 2.5 The layered nature of a seasonal snow cover (photograph by Bruce Tremper).

Many operations find it useful to track specific features within the snowpack. Persistent weak layers or layers that are likely to produce significant avalanche activity (such as crusts, surface hoar, or near-surface facets) can be named with the date that they were buried. Some operations also find it useful to number each significant precipitation event and reference potential weak layers with these numbers or as interfaces between two numbered events.

2.5.3 Snow Hardness (R)

Observe the hardness of each layer with the hand hardness test. Record under "R" (resistance) the object that can be pushed into the snow with moderate effort parallel to the layer boundaries.

> *Note: Fierz and others (2009) suggests a maximum force of 10 to 15 newtons (1 to 1.5 kg-force or about 2 or 3 pounds) to push the described object into the snow.*
>
> *Wear gloves when conducting hand hardness observations.*

Slight variations in hand hardness can be recorded using + and - qualifiers (i.e. P+, P, P-). A value of 4F+ is less hard than 1F-. Individual layers may contain a gradual change in hand hardness value. These variations can be recorded in a graphical format (Figures 2.8 and 2.9), or by using an arrow to point from the upper value to the lower value (i.e. a layer that is soft on top and gets harder as you move down would read 4F+ → 1F).

Table 2.1 Hand Hardness Index

Symbol	Hand Test	Term	Graphic Symbol
F	Fist in glove	Very low	
4F	Four fingers in glove	Low	/
1F	One finger in glove	Medium	X
P	Sharp end of pencil	High	//
K	Knife blade	Very high	⋇
I	Too hard to insert knife	Ice	■
N/O	Not observed		N/A

2.5.4 Grain Form (F)

The International Classification for Seasonal Snow on the Ground (Fierz and others, 2009) presents a classification scheme composed of major and minor classes based on grain morphology and formation process. This scheme is used throughout this document. Primary classes are listed in the table below. Subclasses are listed in Appendix F.

Table 2.2 Basic Classification of Snow on the Ground

Symbol	Basic Classification	Data Code
+	Precipitation Particles (New Snow)	PP
◎	Machine Made snow	MM
/	Decomposing and Fragmented Particles	DF
●	Rounded Grains	RG
□	Faceted Crystals	FC
Λ	Depth Hoar	DH
V	Surface Hoar	SH
○	Melt Forms	MF
▬	Ice Formations	IF

Note: Modifications to Fierz and others, 2009:
The use of a subscript "r" modifier is retained to denote rimed grains in the Precipitation Particles (PP) class and its subclasses except for ***gp***, ***hl***, ***ip***, ***rm***, *and all of Decomposing and Fragmented Particles (DF) class (Example: PP-r).*
Subclasses for surface hoar are listed in Appendix F.

The major class of Precipitation Particles can be divided into minor classes that represent different forms of solid precipitation according to the *International Classification for Seasonal Snow on the Ground*. Commonly, the Precipitation Particles class (graphic symbol "+") may be replaced by one of the following symbols. Snow layers often contain crystals from more than one class or that are in transition between classes. In this case the observer can select primary and secondary classes for a single layer and place the secondary class in parentheses (e.g. a new snow layer composed of mostly plates with some needles could be listed as ⊙(↔)).

Table 2.3 Basic Classification of Snow in the Atmosphere

Symbol	Description	Data Code
▭	Columns	cl
↔	Needles	nd
⬡	Plates	pl
✱	Stellars and dendrites	sd
⌒	Irregular crystals	ir
⩓	Graupel	gp
▲	Hail	hl
◬	Ice pellets	ip

In warm weather the crystals may melt and their shape may change rapidly on the crystal card. In this case, a quick decision must be made and repeated samples taken from various depths of the same layer.

Snow layers often contain crystals in different stages of metamorphism. The classification should refer to the predominant type, but may be mixed when different types are present in relatively equal numbers. A maximum of two grain forms may be displayed for any single layer. The sub-classification in Fierz, and others, 2009 has "mixed forms" classes that can be used by experienced observers who recognize grains that are in a transition stage between classes.

Illustrations of the various types of crystal shapes may be found in the following publications: LaChapelle, 1992; Perla, 1978; Colbeck and others, 1990; McClung and Schaerer, 2006, and Fierz and others, 2009.

Refer to the *International Classification for Seasonal Snow on the Ground* (Fierz and others, 2009) for complete descriptions of the grain forms listed here.

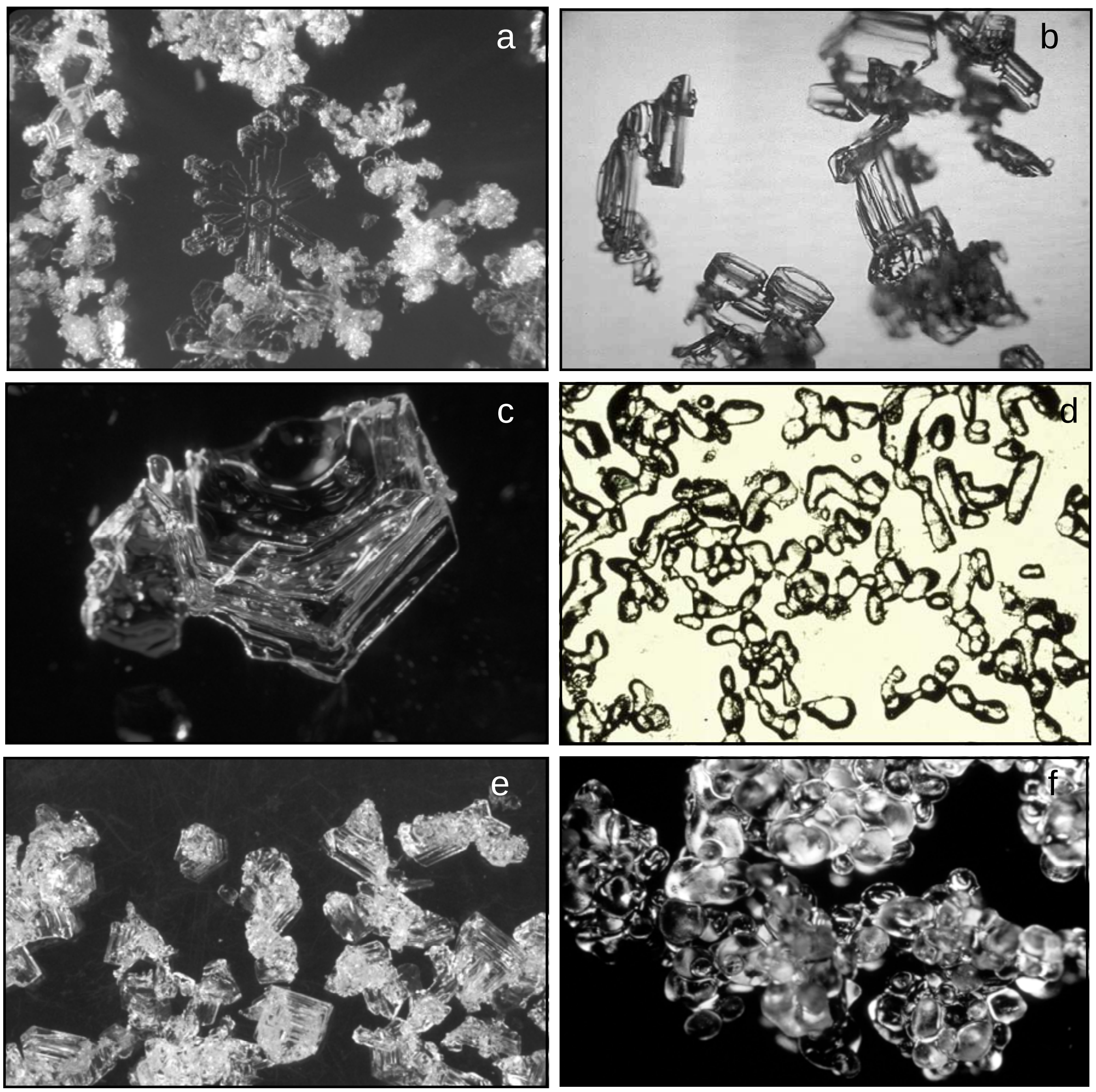

Figure 2.6 Snow crystal formations found in seasonal snow covers. a) Partially rimed new snow (+), b) Faceted grains formed near the snow surface (⧄), c) Depth hoar (∧), d) Rounded snow grains (●), e) Faceted snow grains (□), f) Clustered melt forms (⚘) (photographs by Kelly Elder (a,c), Joe Stock (b), courtesy of John Montagne (d), Ethan Greene (e), and Sam Colbeck (f)).

2.5.5 Grain Size (E)

Determine the grain size in each layer with the aid of a crystal card. In doing so, disregard the small particles and determine the average **greatest extension** of the grains that make up the bulk of the snow. Record the size or the range of sizes in millimeters in column "E". Record size to the nearest 0.5 mm, except for fine and very fine grains which may be recorded as 0.1, 0.3 or 0.5mm.

Where two distinct grain forms exist in a layer, list the size of the primary crystal form first followed by the size of the secondary class in parentheses.

Example: 0.3 (2.5)

Where a range in sizes exists for any single grain form, specify the average and maximum size with a hyphen.

Example: 0.5-1.5

The above notations can also be combined.

Example: 0.5-1.0 (2.5)

2.5.6 Liquid Water Content (θ)

Classify liquid water content by volume of each snow layer that has a temperature of 0 °C. Gently squeeze a sample of snow with a gloved hand and observe the reaction; record in the column headed "θ" (theta).

Table 2.4 Liquid Water Content of Snow (adapted from Fierz and others, 2009)

Class	Definition	Water Content (by volume)	Symbol	Data Code
Dry	Usually the snow temperature (T) is below 0 °C but dry snow can occur at any temperature up to 0 °C. Disaggregated snow grains have little tendency to adhere to each other when pressed together. Difficult to make a snowball.	0 %		D
Moist	T = 0 °C. Water is not visible even at 10 x magnification. When lightly crushed, the snow has a distinct tendency to stick together. Snowballs are easily made.	<3 %	|	M
Wet	T = 0 °C. Water can be recognized at 10x magnification by its meniscus between adjacent snow grains, but water cannot be pressed out by moderately squeezing the snow in the hands (Pendular regime).	3 - 8 %	||	W
Very Wet	T = 0 °C. Water can be pressed out by moderately squeezing the snow by hand, but there is some air confined within the pores (Funicular regime)	8 – 15%	|||	V
Slush	T = 0 °C. The snow is flooded with water and contains a relatively small amount of air.	>15%	||||	S

2.5.7 Density (ρ)

Measure density of the snow in layers that are thick enough to allow insertion of the snow sampling device. Small samplers are more suitable for measuring the density of thin layers and larger samplers are better suited for depth hoar.

Insert the sample cutter into the pit wall, compacting the sample as little as possible. On angled slopes, sampling on the pit sidewall will make it easier to sample a single layer. Samples used for bulk density calculations can contain more than one snow layer, otherwise be sure to sample one layer if possible. Trim the excess snow off the cutter and weigh. Either write down the mass under comments and calculate density later, or calculate density on site and note it in the column headed “ρ” (rho).

Calculate density as follows: Divide the mass (g) of the snow sample by the sample volume (cm^3) and multiply by 1000 to express the result in kg/m^3. The nomogram included on the final page automates this calculation. Record as a whole number.

$$\rho\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{\text{mass of snow sample (g)}}{\text{sample volume (cm}^3\text{)}} \times 1000$$

Practical methods for calculating snow density can be established based on the snow volume sampled. For example, when using a 500 cm^3 snow sampling tube multiply the mass of snow sample in the tube by 2, with a 250 cm^3 sampler, multiply the snow sample mass by 4, etc.

2.5.8 Strength and Stability Tests

Perform tests of strength and stability as appropriate (see Sections 2.6, 2.7, 2.9, and 2.10 for details on individual tests). It may be advantageous to perform multiple tests or iterations of a test.

2.5.9 Marking the Site

If additional observations are to be made at this site, fill the pit and place a marker pole at the extreme edge. Pits dug in areas open to the public should be filled back in with snow.

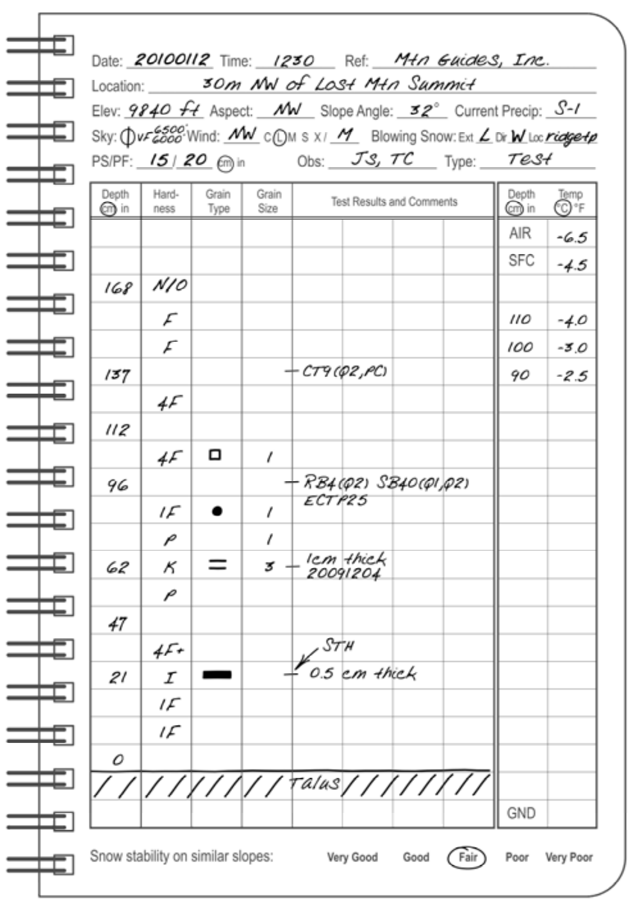

Figure 2.7 Example of field notes from a test profile.

2.5.10 Graphical Snow Profile Representation

Snow profiles can be represented graphically in a standard format for quick reference and permanent record (Figures 2.8 and 2.9).

a) Plot the snow temperatures as a curve; mark the air temperature above the snow surface and use a dashed line to connect the two.
b) Plot the height of the snow layers to scale.
c) Use graphic symbols for the shape of grains and liquid water content. Record N/O when the hardness or liquid water content can not be determined (a blank implies fist hardness or dry snow respectively). *Use of graphic symbols for hardness is optional.*
d) Tabulate grain size and density with the values observed in the field.
e) Include written comments where appropriate. If possible, label important layers by their date of burial.
f) Include the results of appropriate strength and stability tests in the comments column.
g) Document grain form and size of the failure layer. Draw an arrow at the height of each observed failure and use a shorthand notation to describe the test. When multiple tests are performed the results of every test should be included.

Examples:

STE (Q1) SH 2.5 (shovel shear test, easy shear, quality 1, on 2.5 mm surface hoar)
RB6 (Q2) FC 1.5 (rutschblock score six, quality 2, on 1.5 mm faceted crystals)
CT8 (Q1) DH 2.0 (compression test, on 8th tap, quality 1, on 2.0 mm depth hoar)
CT12 (Q1x2) (two compression tests on 12th tap, quality 1, on graupel)
SB30 (Q2,Q2) □ (two stuff block tests both 30 cm drop, quality 2, faceted grains)
SB20, 30 (Q2) (two stuff block tests, one on 20 cm drop, one on 30 cm drop, both quality 2)

h) Plot the hand hardness test results as a horizontal bar graph (Figures 2.8 and 2.9). If a snowpack layer has variable hand hardness, the length of the upper or lower ends of the bar can be shortened or lengthened and the connecting line angled or curved to reflect the variation (Figures 2.8 and 2.9). Changes in hardness category can be emphasized by using the bar lengths in Table 2.5. In regions where both weak layers and slabs are composed of very soft snow (1F or softer), it may be beneficial to plot the hard hardness index using the same distance to represent each category.

Table 2.5 Graphical Representation of Hand Hardness Index

Object in Hand Test	Length of Bar
Fist in glove	Base Length
Four fingers in glove	2 x Base Length
One finger in glove	4 x Base Length
Blunt end of pencil	8 x Base Length
Knife blade	16 x Base Length
Ice	20 x Base Length

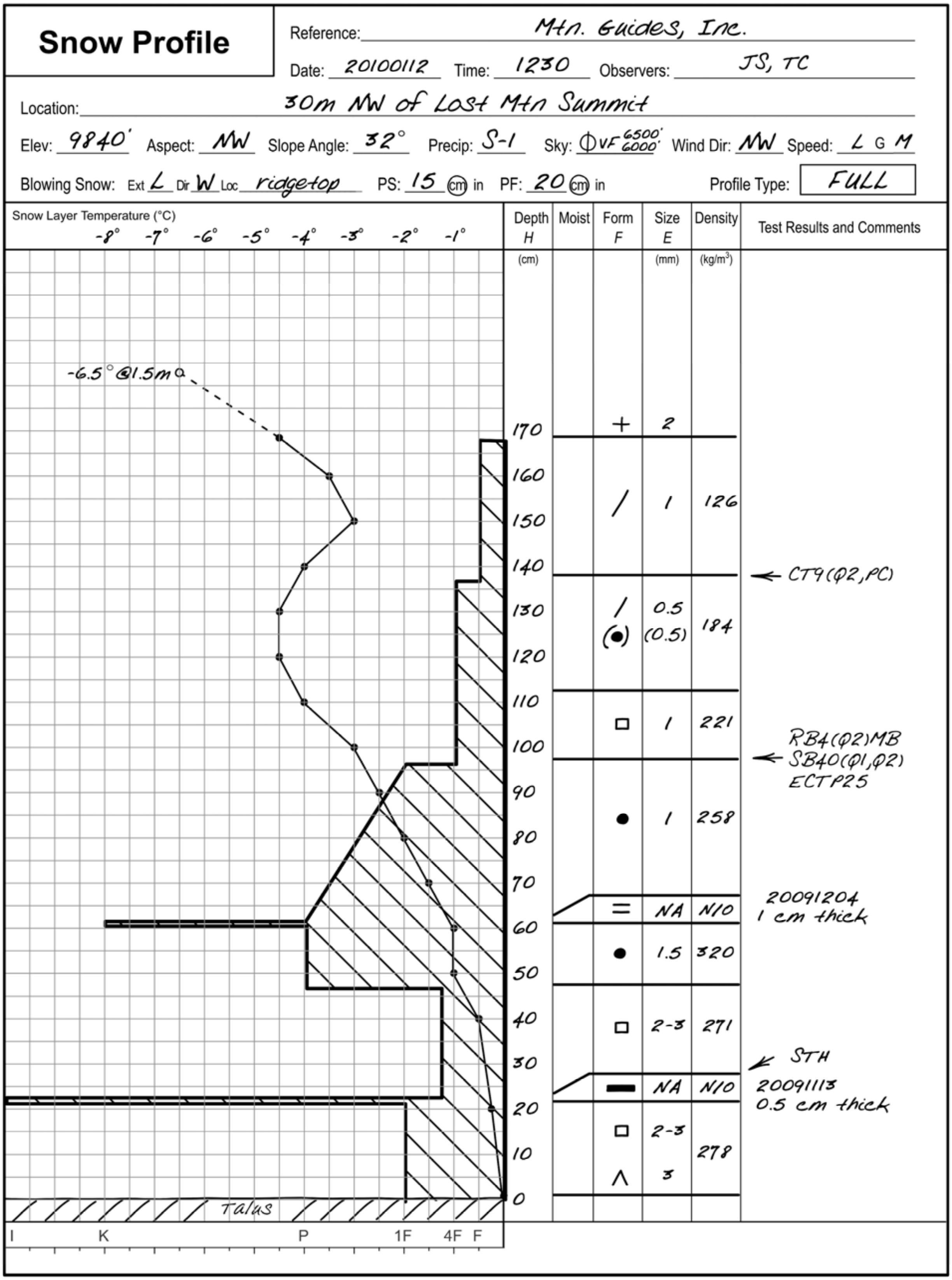

Figure 2.8 Hand drawn full snow profile. Snow profile forms are provided at the end of this manual.

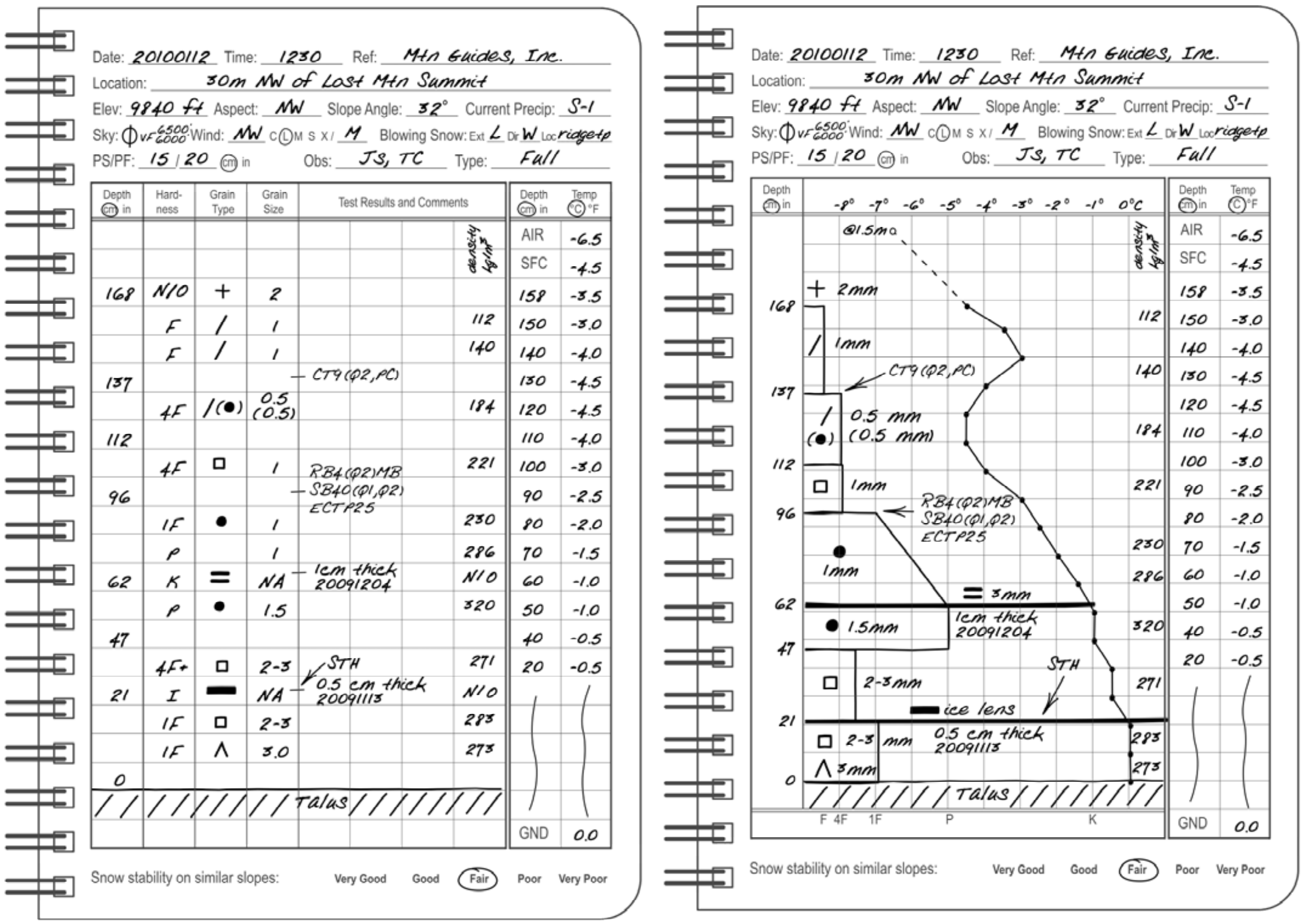

Figure 2.9 Two different methods for recording field notes from a full profile.

2.6 Characterizing Fractures in Column and Block Tests

Many of the stability tests described in the following sections yield some indication of the load required to produce a fracture. In addition to the magnitude of the load, observing the nature of the fracture can improve estimations of snow stability and can, in particular, reduce false-stable results (Johnson and Birkeland, 1998; Birkeland and Johnson, 1999; Johnson and Birkeland 2002; Birkeland and Johnson 2003; van Herwijnen and Jamieson, 2002; van Herwijnen, 2003). Both methods described below can be included with the results of a column or block test (see Section 2.7) and provide additional information about the stability of the snow slope. All the research with these methods has been conducted using compression-type tests such as the compression, stuffblock and rutschblock tests.

The methods described in this section provide a qualitative assessment of the fracture propagation potential. Although the definitions and approach differ, the phenomena they describe are essentially identical (Table 2.6). Both methods require experienced observers to make somewhat subjective assessments, especially when trying to determine whether a planar fracture is sudden (SP/Q1) or resistant (RP/Q2). Members of an operational program should select the method that works best for their application and periodically compare their ratings to ensure consistency.

Table 2.6 A comparison of the categories in the Fracture Character and Shear Quality scales (after van Herwijnen and Jamieson, 2003 and Birkeland, 2004).

Fracture Character Category	Fracture Character Data Code: Subclass	Fracture Character Data Code: Major class	Typical Shear Quality
Sudden planar	SP	SDN	Q1
Sudden collapse	SC	SDN	Q1
Resistant planar	RP	RES	Q2
Progressive compression	PC	RES	Q2 or Q3
Break	BRK	BRK	Q3

2.6.1 Shear Quality

Shear Quality was developed by avalanche workers at the Gallatin National Forest Avalanche Center (southwest Montana). It can be used with any of the stability tests in this chapter, but was developed primarily for use with the rutschblock, compression, and stuffblock tests.

Procedure

a) Conduct any of the stability tests described in this chapter.
b) Carefully observe how the fracture occurs and examine the nature of the fracture plane.
c) Record the results in accordance with the shear quality definitions (Table 2.7).

Recording

The results can be included at the end of any shear test result. Example: A rutschblock score of 2 with a shear quality of 1 would be recorded as RB2(Q1). A compression test that fractured with 5 taps from the elbow producing a rough shear plane would be recorded as CT15(Q3). A stuffblock test that fractured on the static loading step and produced a moderately clean shear would be recorded as SB0(Q2).

Table 2.7 Shear Quality Ratings

Description	Data Code
Unusually clean, planar, smooth and fast shear surface; weak layer may collapse during fracture. The slab typically slides easily into the snow pit after weak layer fracture on slopes steeper than 35 degrees and sometimes on slopes as gentle as 25 degrees. Tests with thick, collapsible weak layers may exhibit a rougher shear surface due to erosion of basal layers as the upper block slides off, but the initial fracture was still fast and mostly planar.	Q1
“Average” shear; shear surface appears mostly smooth, but slab does not slide as readily as Q1. Shear surface may have some small irregularities, but not as irregular as Q3. Shear fracture occurs throughout the whole slab/weak layer interface being tested. The entire slab typically does not slide into the snow pit.	Q2
Shear surface is non-planar, uneven, irregular and rough. Shear fracture typically does not occur through the whole slab/weak layer interface being tested. After the weak layer fractures the slab moves little, or may not move at all, even on slopes steeper than 35 degrees.	Q3

2.6.2 Fracture Character

Fracture Character was developed by the Applied Snow and Avalanche Research Group at the University of Calgary. It can be used with any of the stability tests in this chapter and other tests that load a small column of snow until a fracture appears.

Fracture character is best observed in tests performed on a small isolated column of snow where the objective is to load the column until a fracture (or no fracture) occurs. The front face and side walls of the test column should be as smooth as possible. The observer should be positioned in such a way that one side wall and the entire front face of the test column can be observed. Attention should be focused on weak layers or interfaces identified in a profile or previous snowpack.

Procedure

a) Conduct any of the stability tests described in this chapter.
b) Carefully observe how the fracture occurs in the target weak layer. For tests on low-angled terrain that produced planar fractures, it may be useful to slide the two fracture surfaces across one another by carefully grasping the two sides of the block and pulling while noting the resistance.
c) Record the results in accordance with the definitions in Table 2.8.

Recording

The results can be included at the end of any stability test result. Example: A sudden fracture in a rutschblock test with a score of 2 would be recorded as RB2(SDN). A compression test that fractured with 5 taps from the elbow producing a resistant planar fracture would be recorded as CT15(RP). A stuffblock test that fractured on the static loading step and produced a sudden collapse would be recorded as SB0(SC).

Table 2.8 Fracture Character Ratings

Fracture Characteristics	Subclass	Data Code	Major Class	Data Code
A thin planar* fracture suddenly crosses column in one loading step AND the block slides easily** on the weak layer.	Sudden planar	SP	Sudden	SDN
Fracture crosses the column with a single loading step and is associated with a noticeable collapse of the weak layer.	Sudden collapse	SC	Sudden	SDN
A fracture of noticeable thickness (non-planar fractures often greater than 1cm), which usually crosses the column with a single loading step, followed by step-by-step compression of the layer with subsequent loading steps.	Progressive compression	PC	Resistant	RES
Planar or mostly planar fracture that requires more than one loading step to cross column and/or the block does NOT slide easily** on the weak layer.	Resistant planar	RP	Resistant	RES
Non-planar; irregular fracture.	Non-planar break	BRK	Break	BRK

Note: ** "Planer" based on straight fracture lines on front and side walls of column.*
*** Block slides of column on steep slopes. On low-angle slopes, hold sides of the block and note resistance to sliding.*

2.7 Column and Block Tests

2.7.1 Site Selection

Test sites should be safe, geographically representative of the avalanche terrain under consideration, and undisturbed. For example, to gain information about a wind-loaded slope, find a safe part of a similarly loaded slope for the test. The site should not contain buried ski tracks or avalanche deposits. In general, the site should be further than about one tree length from trees where buried layers might be disturbed by wind action or by clumps of snow which have fallen from nearby trees (imagine a line drawn between a tree top and the snow surface, the acute angle between that line and the horizontal should be at most 45°). Föhn (1987a) recommends slope angles of at least 30º for rutschblock tests, but stability tests done on 25º - 30º slopes can yield some useful information. Be aware that near the top of a slope, snowpack layering and hence test scores may differ from the slope below.

Recently, interest in understanding and documenting spatial variations in the physical properties of snow has increased in both the research and applied communities (Schweizer et al., 2008). The general guidelines outlined in the paragraph above remain part of good field practice. However, there is increasing evidence that making more observations is an effective strategy for avalanche operations and can help minimize the frequency of false-stable situations (Birkeland and Chabot, 2006). Both scientists and field workers should maintain a high level of curiosity and continue to search for signs and areas of instability, even during periods when the snow appears to be stable.

2.7.2 Shovel Shear Test

Objective

The shovel shear test provides:

a) information about the location where the snow could fail in a shear; and
b) a qualitative assessment of weak layer strength. It is best applied to identify buried weak layers, and it does not usually produce useful results in layers close to the snow surface.

Equipment

A shovel is the only equipment required for the Shovel Shear Test. However, a snow saw will make cutting the snow column easier and more precise.

Note: Observers are cautioned that identification of the location of weak layers is the primary objective of the shovel shear test. The ratings of effort are subjective and depend on the strength and stiffness of the slab, dimensions of the shovel blade and handle, and the force applied by the tester.

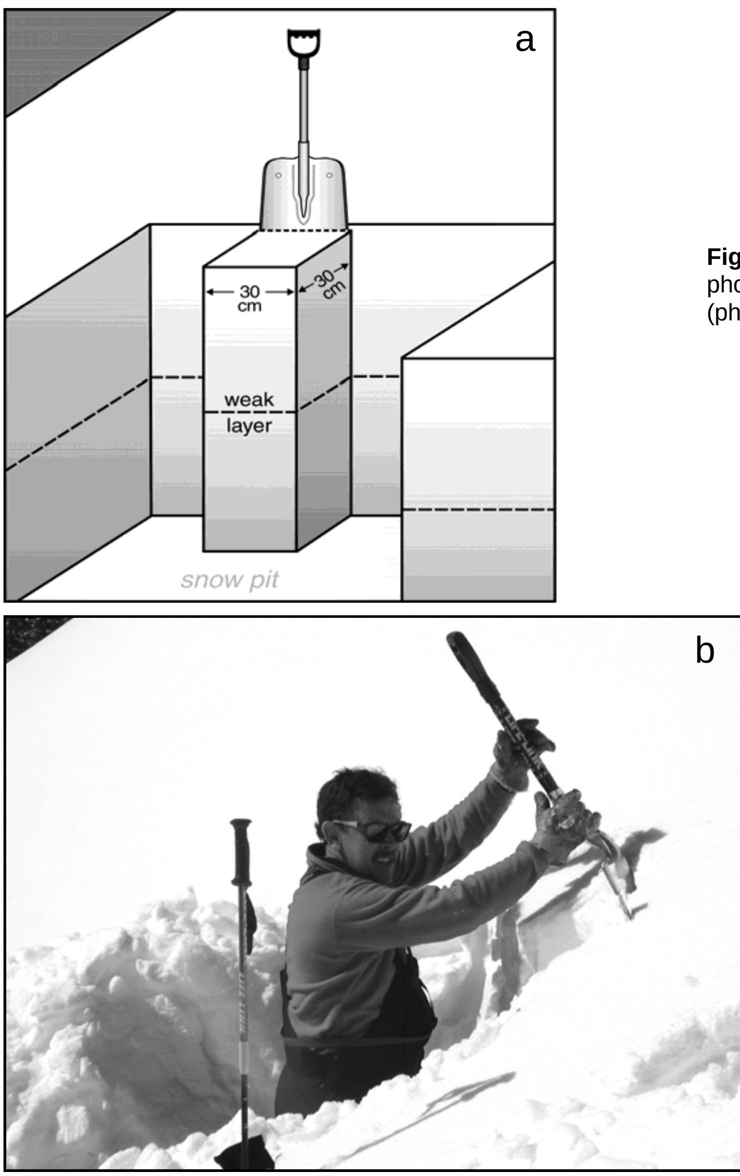

Figure 2.10 a) Schematic and b) photograph of the shovel shear test (photograph by Kelly Elder).

Procedure

a) Expose a fresh pit wall by cutting back about 0.2 m from the wall of a full snow profile or test profile.
b) Observers can remove very soft snow (fist hardness) from the surface of the area where the test is to be carried out if necessary.
c) On the snow surface mark a cross section of the column to be cut, measuring 30 cm wide and 30 cm in the upslope direction (approximately the width of the shovel blade to be used).
d) Cut a chimney wide enough to allow the insertion of the saw on one side of the column and a narrow cut on the other side.
e) Make a vertical cut at the back of the column and leave the cutting tool (saw) at the bottom for depth identification. The back-cut should be 0.7 m deep maximum and end in medium hard to hard snow if possible.
f) Carefully insert the shovel into the back-cut no farther than the heel of the shovel. Hold the shovel handle with both hands and apply an even force in the down-slope (slope parallel) direction. Be careful not to pry the column away from the snow pit wall.
g) When the column breaks in a smooth shear plane above the low end of the back-cut, mark the level of the shear plane on the rear (standing) wall of the back-cut.
h) After a failure in a smooth shear layer or an irregular surface at the low end of the back-cut, or when no failure occurs, remove the column above the bottom of the back-cut and repeat steps e) to g) on the remaining column below.
i) Repeat the test on a second column with the edge of the shovel 0.1 m to 0.2 m above the suspected weak layer.
j) Measure and record the depth of the shear planes if they were equal in both tests. Repeat steps c) to h) if the shear planes were not at the same depth in both tests.
k) If no break occurs, tilt the column and tap (see Section 2.9.4).
l) Use Table 2.9 to classify the results of the test.
l) Observe and classify the crystal shape and size at the shear planes. (Often a sample of the crystals is best obtained from the underside of the sheared block.)
i) Record the results of the test with the appropriate data code from Table 2.9 along with the height, and grain type and size of the weak layer (i.e. “STE@125cm↑□ 1mm” would be an easy shear on a layer of 1 mm faceted grains 125 cm above the ground).

Table 2.9 Loading Steps and Shovel Shear Test Scores

Term	Description	Equivalent Shear Strength (Pa)	Data Code
Collapse	Block collapses when cut		STC
Very Easy	Fails during cutting or insertion of shovel	<100	STV
Easy	Fails with minimum pressure	100 – 1000	STE
Moderate	Fails with moderate pressure	1000 – 2500	STM
Hard	Fails with firm sustained pressure	2500 - 4000	STH
No Shear	No shear failure observed		STN

2.7.3 Rutschblock Test

The Rutschblock (or glide-block) test is a slope test that was developed in Switzerland in the 1960s. This section is based on analysis of rutschblock tests in Switzerland (Föhn, 1987a; Schweizer, 2002) and Canadian (Jamieson and Johnston, 1993a and 1993b).

Equipment

Ski pole mounted saws or rutschblock cutting cords (eight meters of 3 to 4 mm cord with overhand knots tied every 20 or 30 cm) are great time savers for isolating the block in soft or medium hard snowpacks. However, it is often difficult to see the entire length of a cut made by these methods and extra care is needed to ensure the block has straight edges. Large rutschblock saws are useful to cut knife -hard crusts. The Rutschblock Test can be performed with either skis or a snowboard.

Figure 2.11 Stepping onto the block during a rutschblock test (photograph by Kelly Elder).

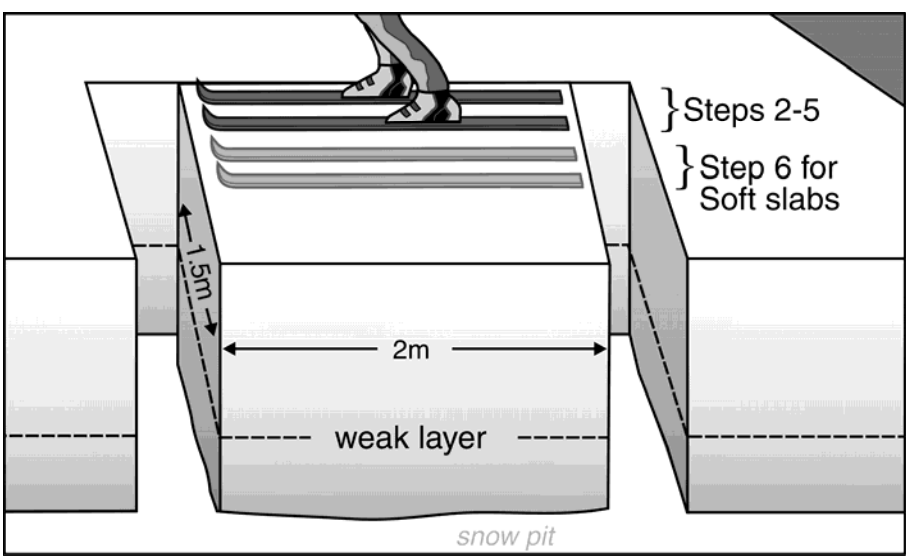

Figure 2.12 Schematic of the rutschblock test (after Jamieson and Johnston, 1993a).

Procedure

a) Select a safe site that has undisturbed snow and is geographically representative of the slopes of interest.
b) Observe a snow profile and identify weak layers and potential slabs.
c) Excavate a pit wall, perpendicular to the fall line, that is wider than the length of the tester's skis (2 m minimum)
d) Mark the width of the block (2 m) and the length of the side cuts (1.5 m) on the surface of the snow with a ski, ruler, etc. The block should be 2 m wide throughout if the sides of the block are to be dug with a shovel. However, if the side walls are to be cut with a ski, pole, or saw, the lower wall should be about 2.1 m across and the top of the side cuts should be about 1.9 m apart. This flaring of the block ensures it is free to slide without binding at the sides
e) Dig out the sides of the block, or make vertical cuts down the sides using the lines marked on the snow surface.
f) Cut the downhill face of the block smooth with a shovel.
g) Using a ski or snow saw make a vertical cut along the uphill side of the block so that the block is now isolated on four sides.
h) Rate any fractures that occur while isolating the block as RB1.
i) Conduct loading steps as described in Table 2.10, and record the results with the appropriate rutschblock score as well as the release type that occurred during the test (Table 2.11). A field book notation for recording rutschblock results is shown in Figure 2.13.
j) Rate any identified weak layers that did not fracture as no failure (RB7).

Record rutschblock results in a field book, along with pertinent site information using the method shown in Figure 2.13 or the data codes in Tables 2.10 and 2.11.

Table 2.10 Rutschblock Loading Steps and Scores

Field Score	**Loading Step that produces a Clean Shear Fracture**	**Data Code**
1	The block slides during digging or cutting.	RB1
2	The skier approaches the block from above and gently steps down onto the upper part of the block (within 35 cm of the upper wall).	RB2
3	Without lifting the heels, the skier drops once from straight leg to bent knee position (feet together), pushing downwards and compacting surface layers.	RB3
4	The skier jumps up and lands in the same compacted spot.	RB4
5	The skier jumps again onto the same compacted spot.	RB5
6	• For hard or deep slabs, remove skis and jump on the same spot. • For soft slabs or thin slabs where jumping without skis might penetrate through the slab, keep skis on, step down another 35 cm (almost to mid-block) and push once then jump three times.	RB6
7	None of the loading steps produced a smooth slope-parallel failure.	RB7

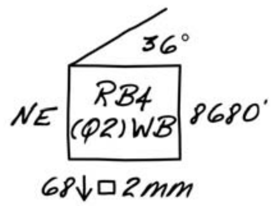

Figure 2.13 A field notebook method for recording a rutschblock score, release type, shear quality (center of box) along with the slope angle, elevation, crystal form and size, depth of weak layer, and aspect (clockwise from top). Arrows can be used to indicate whether the depth of the weak layer was measured from the snow surface or the ground (i.e. 68 cm below the snow surface).

Interpretation

No single measure is enough to determine the stability of a particular slope. The results of any stability test must be coupled with snowpack and weather histories, shear quality, snow structure, and other observations before the stability can be assessed.

Research in the Canadian Rocky Mountains has shown that:

Field score of 1, 2, or 3: The block fails before the first jump. The slope is unstable. It is likely that slopes with similar snow conditions can be released by a skier.

Field score of 4 or 5: The block fails on first or second jump. The stability of the slope is suspect. It is possible for a skier to release slab avalanches on slopes with similar snow conditions. Other observations or tests must be used to assess the slab stability.

Field score of 6 or 7: The block does not fail on the first or second jump. There is a low (but not negligible) risk of skiers triggering avalanches on slopes with similar snow conditions. Other field observations and tests, and safety measures remain appropriate.

Schweizer, McCammon and Jamieson (2008) found that rutschblock scores combined with release type correlated well with observed avalanche occurrence. Johnson and Birkeland (2002) found that combining rutschblock scores with shear quality ratings reduced the number of false-stable results.

Limitations

The rutschblock is a good slope test but it is not a one-step stability evaluation. The test does not eliminate the need for snow profiles or careful field observations nor does it, in general, replace other slope tests such as slope cutting and explosive tests.

The rutschblock only tests layers deeper than ski penetration. For example, a weak layer 20 cm below the surface is not tested by skis that penetrate 20 cm or more. Higher and more variable rutschblock scores are sometimes observed near the top of a slope where the layering may differ from the middle and lower part of the slope (Jamieson and Johnston, 1993b). Higher scores may contribute to an incorrect decision. The rutschblock may not effectively test weak layers deeper than about 1 m below ski penetration.

Table 2.11 Release Type Ratings for the Rutschblock Test

Term	Description	Data Code
Whole block	90 — 100% of the block	WB
Most of block	50 — 80% of the block	MB
Edge of block	10 — 40% of the block	EB

2.7.4 Compression Test

The compression test was first used by Parks Canada Wardens working in the Canadian Rockies in the 1970s. The following procedure was developed by the University of Calgary avalanche research project in the late 1990s. Similar tests have been developed elsewhere.

Objectives

The compression test identifies weak snowpack layers and is most effective at finding weak layers in the upper portion of the snowpack (~1 m). The tester taps a shovel blade placed on top of an isolated snow column causing weak layers within the column to fracture. These fractures can be seen on the smooth walls of the column. Compression test are typically performed on sloping terrain. Tests of distinct, collapsible weak layers can be performed on level study plots.

Equipment

A shovel is the only piece of equipment required for the Compression Test. However, a snow saw will make cutting the column of snow easier and more precise.

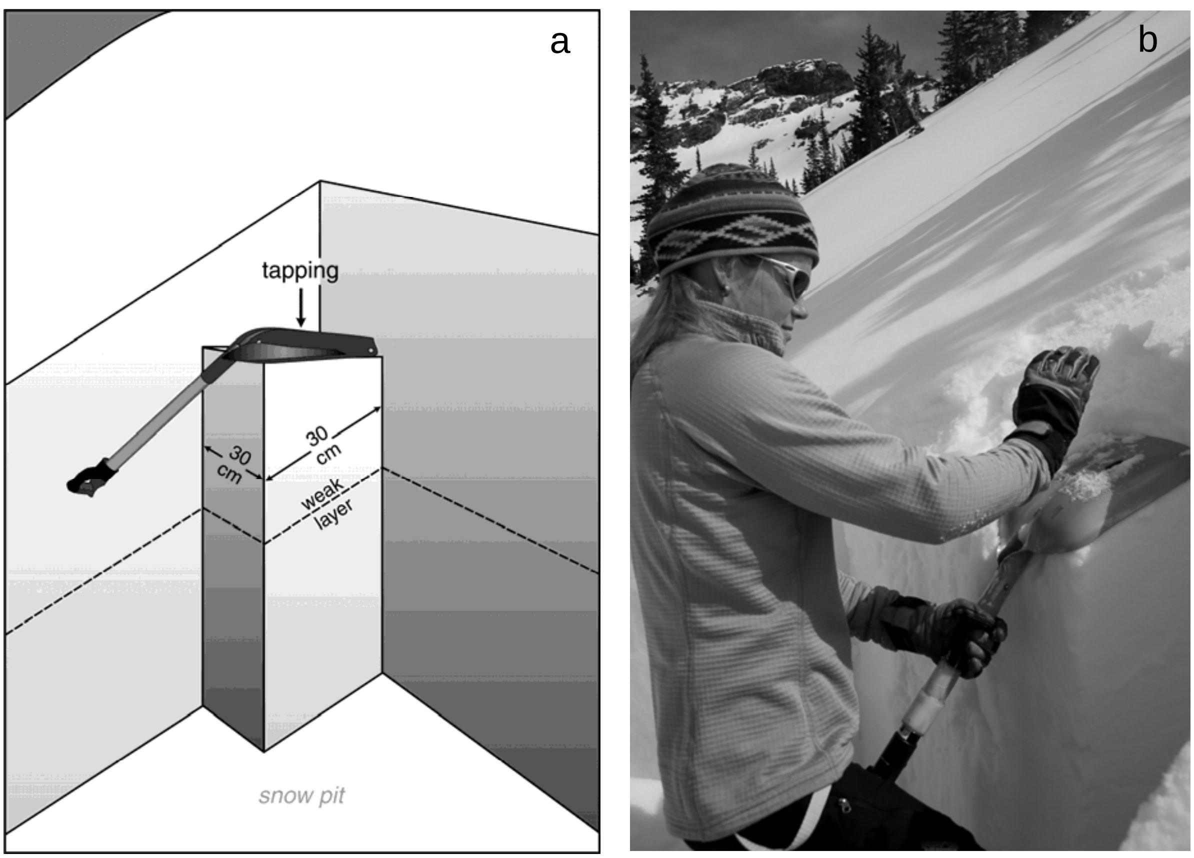

Figure 2.14 a) Schematic and b) photograph of the compression test (photograph by Bruce Tremper).

Procedure

a) Select a safe site that has undisturbed snow and is geographically representative of the slopes of interest.
b) Isolate a column of snow 30 cm wide and with a 30 cm upslope dimension that is deep enough to expose potential weak layers on the smooth walls of the column. Field tests have indicated that the size of the shovel blade to be used has minimal impact on test outcome (Jamieson, 1996). A depth of 100-120 cm is usually sufficient since the compression test rarely produces fractures in deeper weak layers. Also, taller columns tend to wobble during tapping, potentially producing misleading results for deep weak layers (Jamieson, 1996).
c) Rate any fractures that occur while isolating the column as very easy.
d) If the snow surface slopes, remove a wedge of snow to level the top of the column.
e) Place a shovel blade on top of the column. Tap 10 times with fingertips, moving hand from wrist and note the number of taps required to fracture the column (1 to 10).
f) If during tapping the upper part of the column slides off or no longer "evenly" supports further tapping on the column; remove the damaged part of the column, level the new top of the column and continue tapping.
g) Tap 10 times with the fingertips or knuckles moving forearm from the elbow, and note the total number of taps required to fracture the column (11 to 20). While moderate taps should be harder than easy taps, they should not be as hard as one can reasonably tap with the knuckles.
h) Finally, hit the shovel blade moving the arm from the shoulder 10 times with open hand or fist and note the total number of taps required to fracture the column (21 to 30). If the moderate taps were too hard, the operator will often try to hit the shovel with even more force for the hard taps – and may hurt his or her hand.
i) Rate any identified weak layers that did not fracture as no failure (CTN).
j) Record the depth of the snowpack that was tested. For example, if the top 110 cm of a 200 cm snowpack was tested (30 taps on a column, 110 cm tall) and the only result was a failure on the 15th tap, 25 cm below the surface, then record "CT15 @↓25 cm; Test depth 110 cm, or TD 110". This clearly indicates that no fracture occurred from 25-110 cm below the surface and that the snowpack between 110 cm and 200 cm was not tested with the Compression Test. Operations that always test the same depth of the snowpack, (e.g. top 120 cm) may omit the test depth.

Table 2.12 Loading Steps and Compression Test Scores

Term	Description	Data Code
Very Easy	Fractures during cutting	CTV
Easy	Fractures within 10 light taps using finger tips only	CT1 to CT10
Moderate	Fractures within 10 moderate taps from the elbow using finger tips	CT11 to CT20
Hard	Fractures within 10 firm taps from whole arm using palm or fist	CT21 to CT30
No Fracture	Does not fracture	CTN

Interpretation

The objectives of the compression test are to locate weak layers in the upper snowpack (approximately 1 m) and provide an indication of their triggering potential on nearby slopes with similar snowpack conditions. Deeper weak layers are generally less sensitive to the taps on the shovel resulting in higher ratings. Similarly, deeper weak layers are less sensitive to human triggering. Experience and research in the Rocky and Columbia Mountains of Western Canada indicates that human-triggered avalanches are more often associated with "easy" (1 to 9 taps) fractures than with "hard" (20 to 30 taps) fractures or with layers that do not fracture (Jamieson 1996). Sudden fractures (SC, SP, Q1) that show up on the column walls as straight lines identify the failure layers of nearby slab avalanches more often than non-planar or indistinct fractures (BRK, Q3) (van Herwijnen and Jamieson, 2003). The results of any stability test should be interpreted in conjunction with snowpack and weather histories, fracture type, and other snowpack and avalanche information

Limitations of the compression test include sampling a relatively small area of the snowpack and a variation in force applied by different observers. A greater understanding of these limitations can be gained by conducting more than one compression test in a snow profile and performing side by side tests with other observers at the beginning of the season.

2.7.5 Deep Tap Test

The Deep Tap Test was developed by the Applied Snow and Avalanche Research group at the University of Calgary. The test was developed to address very deep weak layers that are difficult to assess with other column and block tests.

Objective

The primary objective of the deep tap test is to determine the type of fracture that occurs in a weak layer that is too deep to fracture consistently in the Compression Test. In addition, it is possible to observe the tapping force required for fracture to occur.

Equipment

A shovel is the only piece of equipment required for the Deep Tap Test. However, a snow saw will make cutting the column of snow easier and more precise.

Table 2.13 Loading Steps and Deep Tap Test Scores

Term	Description	Data Code
Very Easy	Fractures during cutting	DTV
Easy	Fractures within 10 light taps using finger tips only	DT1 to DT10
Moderate	Fractures within 10 moderate taps from the elbow using finger tips	DT11 to DT20
Hard	Fractures within 10 firm taps from whole arm using palm or fist	DT21 to DT30
No Fracture	Does not fracture	DTN

Procedure

a) Using a profile or other means, identify a weak snowpack layer, which is overlaid by 1F or harder snow and which is too deep to fracture consistently in the Compression Test.
b) Prepare a 30 cm x 30 cm column as for a Compression Test (note that the same column can be used after a Compression Test of the upper layers, provided the Compression Test did not disturb the target weak layer). To reduce the likelihood of fractures in weak layer below the target layer, such as depth hoar at the base of the snowpack, it may be advantageous not to cut the back wall more than a few centimeters below the target weak layer.
c) Remove all but 15 cm of snow above the weak layer, measured at the back of the sidewall. This distance should be constant, regardless of the slope angle.
d) Place the shovel blade (facing up or facing down) on top of the column. Tap 10 times with fingertips, moving hand from wrist and note the number of taps required to fracture the column (1 to 10).
e) Tap 10 times with the fingertips or knuckles moving your forearm from the elbow, and note the total number of taps required to fracture the column (11 to 20). While moderate taps should be harder than easy taps, they should not be as hard as one can reasonably tap with the knuckles.
f) Finally, hit the shovel blade moving arm from the shoulder 10 times with open hand or fist and note the total number of taps required to fracture the column (21 to 30). If the moderate taps were too hard, the operator will often try to hit the shovel with even more force for the hard taps – and may hurt his or her hand.
g) Record the results as described in Table 2.13. Observers may also include the total depth of the weak layer below the snow surface at the location of the test.
h) Use one of the methods in Section 2.6 to describe the type of fracture observed during the test. This information is important for deep, persistent weak layers.

Limitations

While very effective for testing deeper weak layers, the number of taps required to initiate a fracture in the Deep Tap Test has not been correlated with human-triggered avalanches or avalanches on adjacent slopes.

2.7.6 Stuffblock Test

The Stuffblock test was developed at the Gallatin National Forest Avalanche Center (southwest Montana) during the mid 1990's. The test has become a popular forecasting tool that can be conducted with minimal additional equipment.

Table 2.14 Loading Steps and Stuffblock Test Scores

Term	Description	Data Code
Very Easy	Fractures during column isolation	SBV
Easy	Fractures during static load	SB0
Easy (drop height of 10 or 20 cm)	Fractures during dynamic load	SB drop height number (SB10, SB20, etc.)
Moderate (drop height of 30 or 40 cm)		
Hard (drop height of 50 cm to 70 cm)		
No Fracture	Does not fracture	SBN

Objective

The test identifies weak snowpack layers and is most effective at finding weak layers near the snow surface. A known mass is dropped from a known height to produce a dynamic load on a snow column. The fracture can be seen on the sides of the column. The stuffblock test is generally performed on sloping terrain steeper than about 25 degrees (Birkeland and Johnson, 1999).

Equipment

a) Snow shovel (a flat-bladed shovel works best)
b) Snow saw
c) Stuff sack with graduated cord (10 cm (~ 4 in) increments) attached to the bottom. The stuff sack diameter should be no larger than the width of the shovel blade.
d) Weighing scale capable of measuring 4.5 kg (~ 10 lb)

Procedure

a) Select a safe site that has undisturbed snow and is geographically representative of the slopes of interest.
b) Pack 4.5 kg (10 lb) of snow into a stuff sack.
c) Isolate a column of snow 30 cm wide and with a 30 cm upslope dimension that is deep enough to expose potential weak layers on the smooth walls of the column. The test column is generally no more than 100-120 cm (~ 50 in) in height, although the Stuffblock Test can be used to test deeper weak layers. Taller columns tend to wobble during loading, potentially producing misleading results for deep weak layers.
d) Rate any fractures that occur while isolating the column as very easy (record as SBV).
e) Place the shovel blade on top of the column so that the blade is horizontal and the handle points upwards (Figure 2.15). Support the handle with one hand.
f) Gently place the filled stuff sack onto the shovel blade, and record any resulting fractures.
g) Raise the stuff sack 10 cm above the shovel blade and drop it onto the shovel.
h) Continue to drop the stuff sack onto the shovel blade incrementing the drop height by 10 cm each time (ie: 10 cm, 20 cm, 30 cm, etc.). After each drop examine the column for a fracture. If a fracture occurs, record the depth of the sliding plane and stuff sack drop height. Then remove the loose block of snow and continue the test on the sliding surface. The depth of snow removed at each fracture should be recorded. Test results from the shortened column will not accurately reflect the absolute strength of weak layers deeper than the initial fracture.
i) Any identified weak layers that did not fracture after a drop of 70 cm should be rated as SBN.
j) Test results should be recorded with the test identifier and the drop height that produced the fracture (example: If the column fractured with a static load, record as SB0. If the column fractured after a drop from 10 cm, record as SB10).
k) Record the depth of the snowpack that was tested. For example, if the top 110 cm of a 200 cm snowpack was tested and the result was a fracture 25 cm below the surface produced by a 20 cm drop, then record “SB20 @↓25 cm; Test depth 110 cm, or TD 110”. This clearly indicates that no fracture occurred from 25-110 cm below the surface and that the snowpack between 110 cm and 200 cm was not tested with the stuffblock test. Operations that always test the same depth of the snowpack (e.g. top 120 cm) may omit the test depth.

Interpretation

The objectives of the stuffblock test are to locate weak layers in the upper snowpack (approximately 1 m) and provide an indication of the potential for human triggered avalanches on nearby slopes with similar snowpack conditions. Deeper weak layers are generally less sensitive to drops of the stuff sack, which results in higher test scores. Similarly, deeper weak layers are less sensitive to human triggering. Research conducted in the United States has shown that stuffblock test scores correlate to rutschblock

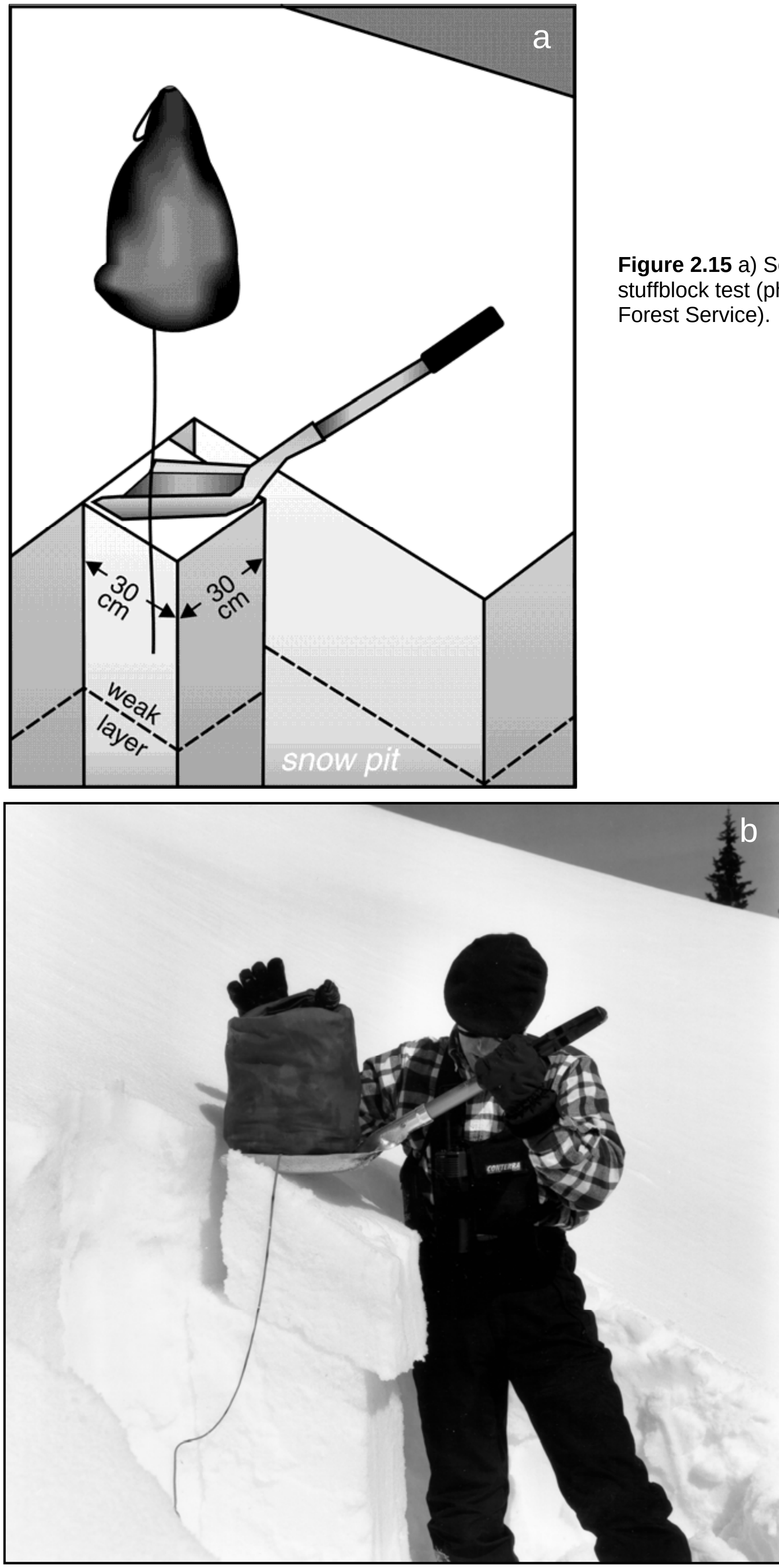

Figure 2.15 a) Schematic and b) photograph of the stuffblock test (photograph courtesy of the USDA Forest Service).

test scores in a variety of snow climates (Birkeland and Johnson, 1999). The results of any stability test should be interpreted in conjunction with snowpack and weather histories, shear quality and other snowpack and avalanche information.

2.7.7 Extended Column Test

The Extended Column Test (ECT) was developed in Colorado and New Zealand in 2005 and 2006. The ECT has been tested in the continental and intermountain snow climates of the U.S. (Simenhois and Birkeland 2007; Hendrikx and Birkeland, 2008;Birkeland and Simenhois 2008), the Swiss Alps (Winkler and Schweizer 2009), the Spanish Pyrenees (Moner et al. 2008) and New Zealand's Southern Alps (Simenhois and Birkeland 2006, Hendrikx and Birkeland 2008).

Objective

The Extended Column Test (ECT) is a snowpack test that aims to test the fracture propagation propensity of slab/weak layer combinations in the upper portion of the snowpack (< 1m). The tester dynamically loads the snowpack by tapping on a shovel blade placed at one end of an isolated extended column in order to initiate a fracture (Figure 2.16). Once initiated, the key observation in the test is whether or not the fracture immediately propagates across the entire column.

Equipment

The equipment required for the ECT includes:

a) A snow shovel.
b) One or two collapsible probes or ski poles, 2 meters of 3-4 mm cord with knots every 20-30 cm or a snow saw with extension.

Procedure

a) Select a safe site that has undisturbed snow and is geographically representative of the slope of interest.
b) Isolate a column of snow 90 cm wide in the cross slope dimension and 30 cm deep in the upslope dimension that is deep enough to expose potential weak layers. Depth should not exceed 100 – 120 cm since the loading steps rarely affect deeper layers.
c) Rate any fractures that cross the entire column, while isolating it, as ECTPV.
d) If the snow surface slopes and the surface snow is hard, remove a wedge of snow to level the top of the column at one edge.
e) Place the shovel blade on one side of the column. Tap 10 times moving hand from the wrist and note the number of taps it takes to initiate a fracture and whether or not the fracture immediately propagates across the entire column on that or the next loading step (1 to 10).
f) Tap 10 times with the fingertips or knuckles moving forearm from the elbow and note the number of taps it takes to initiate a fracture and whether or not the fracture immediately propagates across the entire column on that or the next loading step (11 to 20).
g) Finally, hit the shovel blade moving arm from the shoulder 10 times with open hand or fist. Note the number of taps it takes to initiate a fracture and whether or not the fracture immediately propagates across the entire column on that or the next loading step (21 to 30).
h) If no fractures occurred within all loading steps, rate the test as ECTX.
i) If a fracture initiated on a weak layer on the ## tap but did not propagate across the entire column on the same or the next loading step, rate that layer as ECTN##.
j) If a fracture initiated and propagated across the entire column on the ## tap *or* it initiated on the ## tap and propagated on the ## + 1 tap, rate that layer as ECTP##.

Recording and Results

ECT recording describes if fractures initiated during the loading steps and whether or not those fractures immediately propagated across the entire column.

Interpretation

Test interpretation is straightforward. ECTPV and ECTP## results suggest unstable conditions, while ECTN## or ECTX are generally indicative of stable conditions. However, the objective of this test is to assess the propagation potential of the snowpack, therefore, ECTX should not necessarily be considered a sign of stability. In these cases other stability tests should be conducted to assess snowpack stability.

Strengths and Limitations

Two strengths of the ECT are its ease of interpretation (does the fracture propagate or not?) and the low false-stability ratio for the test, which is generally less than that for other typical tests. It is limited in that it is not a good tool to assess weaknesses in soft (F+ or less) upper layers of the snowpack or in mid-storm shear layers. In these cases the shovel edge tends to cut those soft layers. Further, the ECT is not a good tool to asses fracture propagation potential on a weak layer deeper than 100 – 120 cm because fracture initiation in these cases can be difficult or impossible (ECTX). In cases where a fracture is not initiated, other stability tests should also be conducted or a snowpit in different location should be considered.

Table 2.15 Extended Column Test Scores

Description	Data Code
Fracture propagates across the entire column during isolation	ECTPV
Fracture initiates and propagates across the entire column on the ## tap *or* the fracture initiates on the ## tap and propagates across the column on the ## + 1 tap	ECTP##
Fracture initiates on the ## tap, but does not propagate across the entire column on either ## or the ##+1 tap. It either fractures across only part of the column (observed commonly), or it initiates but takes more than one additional loading step to propagate across the entire column (observed relatively rarely).	ECTN##
No fracture occurs during the test	ECTX

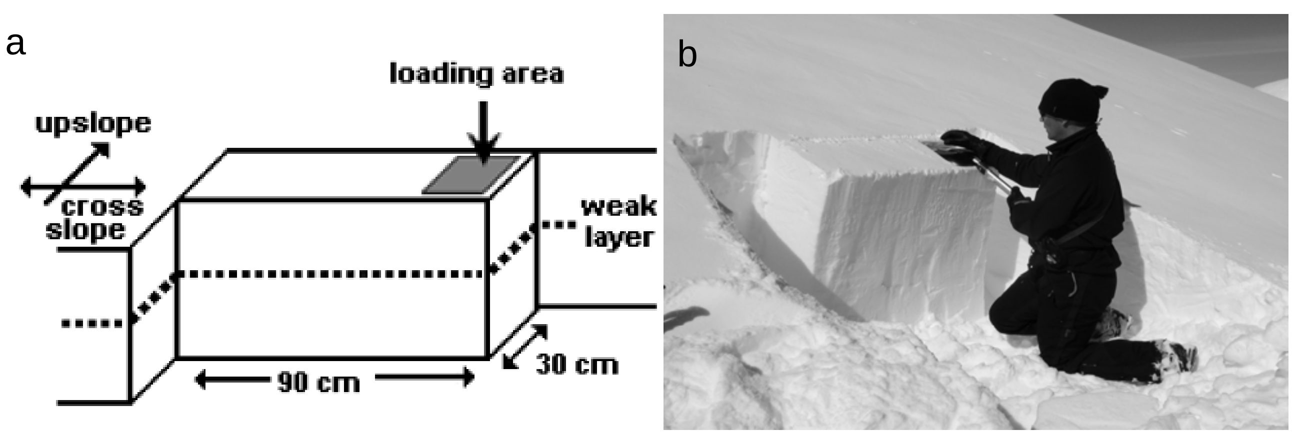

Figure 2.16 a) Schematic and b) photograph of the Extended Column Test (photograph courtesy of Ron Simenhois)

2.7.8 Propagation Saw Test

The Propagation Saw Test (PST) was simultaneously developed in Canada (Gauthier and Jamieson, 2007) and in Switzerland (Sigrist, 2006). The PST has been tested in Canada since 2005 – mostly in the Columbia Mountains, in the Swiss Alps and in Colorado's continental snowpack (Birkeland and Simenhois, 2008). The PST has been shown to indicate propagation propensity in persistent weak layers (PWL) buried 30 cm to over 100 cm and occasionally up to 250 cm deep.

Objective

The Propagation Saw Test is a snowpack test that aims to indicate the tendency (propensity) of a pre-identified slab and a PWL combination to propagate a fracture. The tester uses an isolated column and initiates a fracture by dragging a snow saw along the weak layer in the uphill direction.

Equipment

The equipment required for the PST includes:

A snow shovel.

A snow saw with a blade at least 30 cm long and approximately 2 mm thick.

For layers much deeper than the saw is long, the following are recommended:

- One or two collapsible probes.
- Three to five meters of four to 3-4 mm cord with knots every 20 – 30 cm.

Procedure

The PST procedure involves three main steps (after Gauthier and Jamieson, 2007): Identifying the weak layer of interest within the snowpack, isolating and preparing the test column, performing the test, and noting the results.

a) Select a safe site that has undisturbed snow and is geographically representative of the slope of interest.
b) Isolate a column 30 cm wide across the slope and 100 cm long upslope when the weak layer is less than 100 cm deep. (For layers deeper than the saw is long, two adjacent walls can be cut with a cord between probes.) When the weak layer is >100 cm deep the column length is equal to the weak layer depth in the upslope direction. The column should be isolated to a depth greater than the tested layer's depth.
c) To identify the weak layer clearly, mark the weak layer with a glove, a brush or a crystal card along the exposed column wall.
d) Drag the blunt edge of the saw upslope through the weak layer at a 10-20 cm/s speed until the fracture propagates (jumps) ahead of the saw, at which point the tester stops dragging the saw and marks the spot along the layer where propagation began.
e) After observations are complete, remove the column and check that the saw scored the weak layer in the wall behind the test column. If the saw deviated from the weak layer, the test should be repeated.

Results

Once the fracture propagates ahead of the saw, one of three results can be observed as noted in Table 2.16.

Interpretation

Fracture propagation is considered to be likely only if the fracture propagates to the end of the column, along the same layer and when the length of the saw cut is less then 50% of the column length when propagation begins (Gauthier and Jamieson, 2008). Otherwise, fracture propagation is considered unlikely (i.e. the propagating fracture fails to reach the end of the column or propagation begins when saw cut is greater than 50% of the column length).

(a)

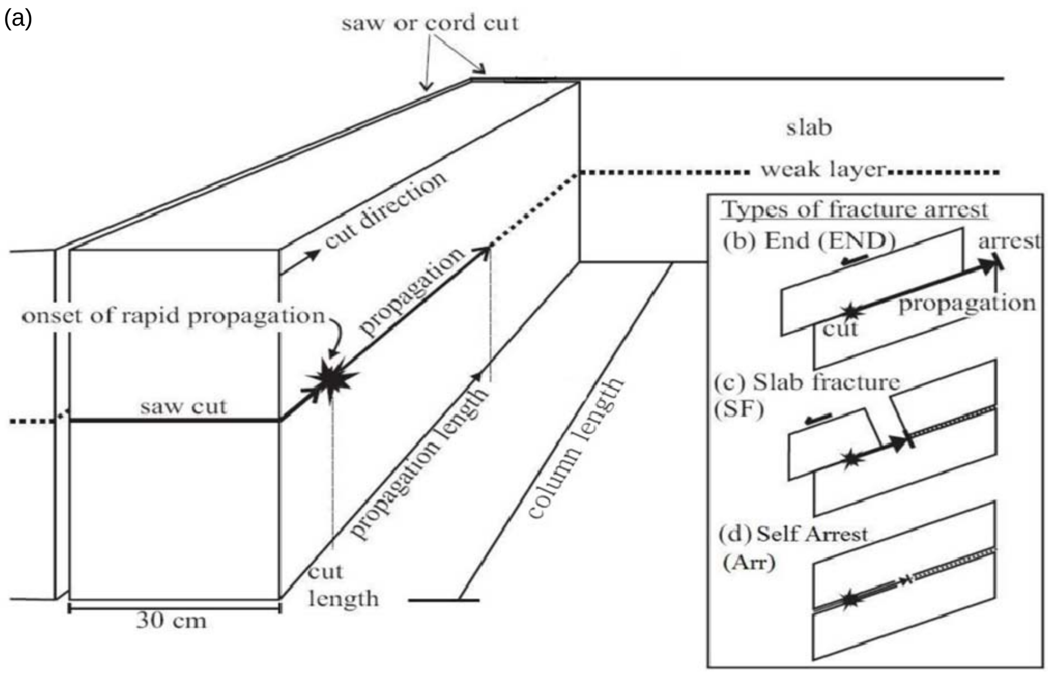

Figure 2.17 Schematic showing the PST column (a) and the observable results of propagation to end (b), slab fracture (c), and self arrest (d) (after Gauthier and Jamieson, 2007).

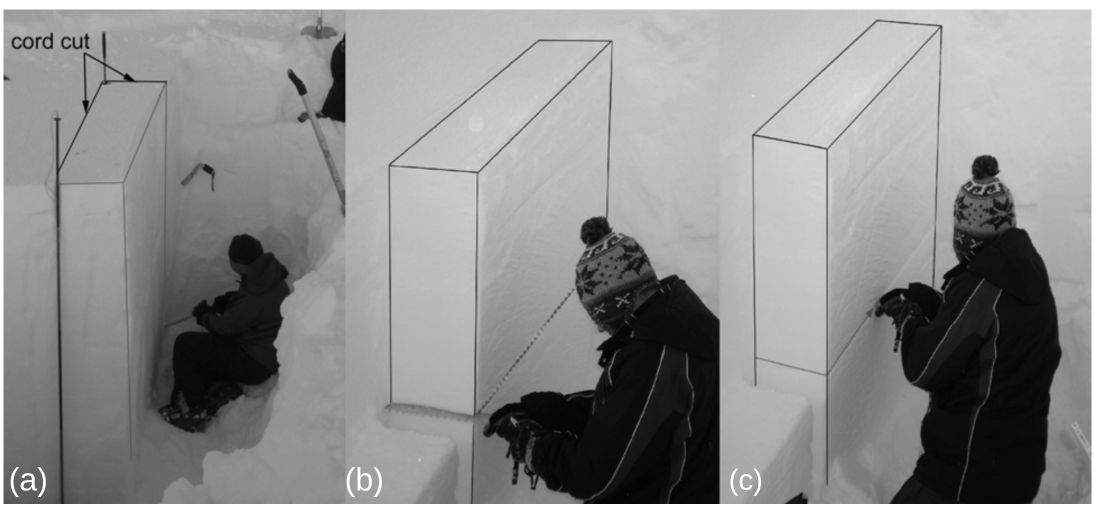

Figure 2.18 The PST process: (a) isolating the column with probes and cord; (b) identifying the weak layer and preparing to cut; (c) dragging the saw along the weak layer until the onset of propagation. Lightly brushing the weak layer with a glove or brush before cutting helps the operator follow the layer along the column (photo: ASARC).

Table 2.16 Propagation Saw Test Description and Data Codes

Observed Result	Description	Data code
Propagation to end	The fracture propagates in the weak layer in front of the saw uninterrupted to end of column.	End
Slab fracture	The fracture propagates in the weak layer in front of the saw and stops where it meets a fracture through the overlying slab	SF
Self-arrest	The fracture propagates in front of the saw but self-arrests somewhere along the weak layer before reaching the end of the column.	Arr

Recording

The recording standard for the PST is as follows: '**PST x/y (Arr, SF or End) down z on yymmdd**' where *x* is the length of the saw cut when propagation starts, *y* is the length of the isolated column, *z* is the depth to the tested weak layer, and *yymmdd* is the weak layer identification typically dated by when the layer was buried. All lengths are given in centimetres (cm). An example of a result that indicates high propagation propensity is 'PST 34/100 (End) down 56 cm on 080223'. It is recommended to comment on slope angle at the test site if it is not done on a 30-40° slope, as the cut distance (**x**) may depend on slope angle.

Strengths and Limitations

Because the PST is not dependent on surface loading, it is capable of assessing the propagation propensity of deeply buried weak layer and slab combination (deep instability). The PST is limited in that it has been shown to indicate a higher number of false-stable results than other common snowpack tests (around 30% for the PST versus approximately 10% for CTs, RBs and SBs), particularly for soft shallow slabs and when the weak layer is too hard to cut with the saw's blunt edge (Birkeland and Simenhois, 2008; Gauthier, D., Jamieson, J.B., 2008). Pre-selecting and identifying the layer of concern for testing can be challenging. Propagation to End occurs on flats as well as on incline slopes; however, as mentioned above, the cut distance (**x**) may depend on the slope angle.

2.8 Slope Cut Testing

Slope cutting can provide valuable information on snowpack stability. Safety must be the primary concern when attempting slope cuts, and inexperienced observers should not conduct this type of testing. Slope cut testing is typically applied to weak layers fairly near the snow surface, and soft snow slabs. Deeply buried weak layers and hard slab conditions often produce dangerous avalanches that break in less predictable locations and could prove dangerous, or fatal, to the tester.

There are many different approaches and "tricks of the trade" that can be applied to slope cutting. All of them are beyond the scope of this discussion. Slope cutting techniques should only be taught in the field or as "on the job training". More information on slope cuts can be found in Tremper (2008), McClung and Schaerer (2006) and Perla and Martinelli (1976).

Table 2.17 Slope Cut Testing Scores

Term	Description	Data Code
No release	No result	SCN
Whumpfing	Slope cut produces a collapse in the snowpack	SCW
Cracking	Slope cut produces shooting cracks	SCC
Avalanche Slab	Slope cut produces a slab avalanche	SCS
Avalanche Loose	Slope cut produces a loose snow or sluff avalanche	SCL

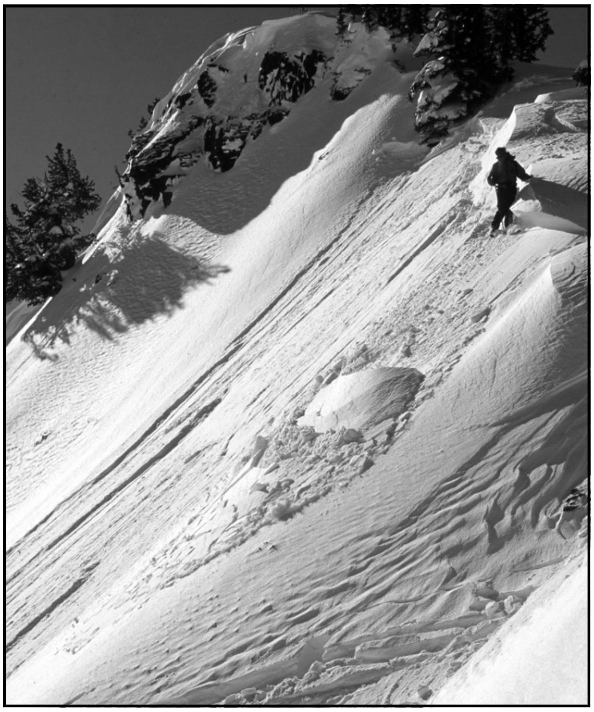

Figure 2.19 Slope cut producing a small slab avalanche (photograph by Bruce Tremper).

Procedure

- Choose a relatively small slope that is representative of the starting zones you wish to learn about.
- Place one or more people in zones of safety that allow them to observe the entire cut and avalanche path if possible.
- Begin from a zone of safety.
- Examine the starting zone and choose a line that crosses relatively high on the slope and ends in a zone of safety.
- Travel along the line chosen maintaining enough speed to cross the slope in one fast motion. The tester can bounce or jump during the cut to increase the load on the slope.
- Record the results of the test as described in the following section.

Recording Slope Cuts

Record the results of the test using the data codes listed in Table 2.17 along with the aspect and slope angle of the slope. When a ski cut produces a slab avalanche the Avalanche Size (Relative and/or Destructive) can be included in the data code. Additional information about the terrain and resulting avalanche can be recorded in comments as needed.

Example:

SCW35NE—Test produced a collapse (whumpf) on a 35° northeast facing slope
SCL40S—Test produced a sluff on a 40° south facing slope
SCN30N—Test produced no result on a 30° north facing slope
SCS45NWR3D2—Test produced a slab avalanche on a 45° slope that faces to the northwest. The avalanche was only medium in size, for the size of the path, but was large enough to injure or kill a person.

2.9 Non-Standardized Snow Tests

All of the stability tests described in chapter two were developed from many years of work by many observers. Each test went through several iterations before a standard procedure was established. Field practitioners and researchers eventually wrote protocols and conducted research on these tests to provide information on their response and suitability.

In addition to the standardized tests, there are many other tests that do not have specific field protocols. In this section, some of the more common non-standardized snow tests and suggested methods for communicating their results are presented. Field workers who are not satisfied with the standardized tests are encouraged to seek additional methods for determining physical properties of the snowpack. As new methods evolve and we learn more about their response and limitations, those methods may become standard practice.

2.9.1 Communicating the Results of Non-Standardized Snow Tests

There is no standard method for communicating the results of non-standardized tests. A common method is to rate the amount of energy required to produce a fracture using the descriptors Easy, Moderate, or Hard (with easy being the smallest amount), and note the height of the resulting fracture. Suggestions for communicating specific tests are presented below.

2.9.2 Cantilever Beam Test

Most of the standardized snow tests examine a weak snow layer or interface between snow layers. This type of information is critical for determining the snow stability. However, the weak layer is only one component of a slab avalanche and knowing more about the mechanical properties of the slab is also useful.

Several investigators have used cantilever beam tests to examine mechanical properties of snow beams and snow slabs (Johnson and others, 2000; Mears, 1998; Sterbenz, 1998; Perla, 1969). Sterbenz (1998) describes a cantilever beam test developed for avalanche forecasting in the San Juan Mountains of Colorado and that test is presented below.

Procedure

a) Select a geographically representative site and dig a test profile.
b) Collect snowpack data as needed and conduct stability tests as desired.
c) Identify weak layer or interface and potential snow slab.
d) Above a smooth pit wall, mark a horizontal section of the slab 1 m (or 40") in length on the snow surface.
e) Mark 1 m (or 40") lengths perpendicular to the pit wall so a 1 m x 1 m square block is outlined on the snow surface.
f) At the identified weak layer, remove the supporting snow from below the slab to be tested (1 m x 1 m square block).
g) Using a snow saw, make a vertical cut 0.5 m (or 20") along one side of the block.
h) Using a snow saw, make a vertical cut 0.5 m (or 20") along the other side of the block.
i) Using a snow saw, extend the first cut an additional 0.5 m (or 20") so that one side of the 1 m x 1 m square block is isolated.
j) Using a snow saw, extend the second cut an additional 0.5 m (or 20") so that the other side of the 1 m x 1 m square block is isolated.
k) At this point the block should be suspended, with its only connection point along the uphill edge of the block. Place a shovel along the downhill side of the block and strike it with successive blows until the beam breaks.
l) Record with the data codes in Table 2.18.

Cantilever Beam Test References

Johnson, B.C., J.B. Jamieson, and C.D. Johnston. 2000: Field studies of the cantilever beam test. *The Avalanche Review,* **18**, 8-9.

Mears, A., 1998: Tensile strength and strength changes in new snow layers. *Proceedings of the International Snow Science Workshop*, Sunriver, Oregon, 574-576.

Perla, R.I., 1969: Strength tests on newly fallen snow. *Journal of Glaciology,* **8**, 427-440.

Sterbenz, C., 1998: The cantilever beam or "Bridgeblock" snow strength test. *Proceedings of the International Snow Science Workshop*, Sunriver, Oregon, p. 566-573.

Table 2.18 Cantilever Beam Test from Sterbenz (1998)

Loading Step	Block Breaks When
0	Removing snow from below the block.
1	0.5 m cut along one side.
2	0.5 m cut along the second side.
3	1 m cut along the first side.
4	1 m cut along the second side.
5	Loading the block that is isolated on three sides.

2.9.3 Loaded Column Test

The loaded column test (Figure 2.20) allows an observer to estimate how much additional mass a weak layer might support before it will fracture. Although this test can produce a finite mass that will produce fracture, the results of this test should be regarded only as a general indicator of the additional load 90 that the snowpack can sustain. As stated previously, operational decisions should not be made on a single number or test.

Procedure

a) Select a geographically representative site and dig a test profile.
b) Collect snowpack data as needed and conduct stability tests as desired.
c) Identify weak layer or interface and potential snow slab
d) Using a snow saw isolate a column 30 cm wide and 30 cm in the upslope direction.
e) Excavate blocks of snow and stack them on the column until the column fractures.
f) Note the level of the fracture, shear quality, and amount of load that caused the test column to fail.
g) The mass of each block can be measured and a total load calculated.

2.9.4 Burp-the-Baby

This test is generally used to identify shear layers missed by the shovel shear test. Buried thin weak layers (often surface hoar) gain strength over time and their presence may be obscured or missed by the shovel shear test.

Procedure

When an isolated column remains intact after it breaks on a deeply buried layer, pick it up and cradle it in your arms. Burp the reclining column across your knee or with a hand. Clean shear planes can often be located above the original shovel shear plane.

Figure 2.20 Two non-standardized snow tests: a) the shovel tilt test (photograph by Howie Garber) b) the loaded column test (photograph by Andy Gleason).

2.9.5 Hand Shear Tests

These tests can be used to quickly gain information about snow structure. They should not be used to replace stability tests, but can be used to estimate the spatial extent of a relatively shallow weak layer (Figure 2.22).

Procedure

a) With your hand or a ski pole make a hole in the snow deeper than the layer you wish to test.
b) Carve out an isolated column of snow.
c) Tap on the surface or pull on the column of snow in the down slope direction.
d) Record your results with the name of the test, weak layer depth, and rate the result as Easy, Moderate, or Hard (example: Hand Easy or Hand-E). Also include pertinent terrain parameters such as slope angle, aspect, and elevation.
e) Use other methods to investigate the weak layer or interface as needed.

2.9.6 Ski Pole Penetrometer

The ski pole can be used like a penetrometer to look for or estimate the spatial extent of distinct weak layers or significant changes in layer hardness (Figure 2.21). In harder snow, an avalanche probe can be used.

Procedure

a) Place the ski pole perpendicular to the snow surface and push it into the snow (Basket end down for soft snow, handle down for harder snow).
b) Feel for changes in resistance as the ski pole moves through the snowpack.
c) Feel for more subtle layers as the pole is removed from the snowpack by tilting it slightly to the side.
d) Record the depth, thickness and spatial extent of buried layers.
e) Use other methods to investigate the snowpack as needed.

Figure 2.21 The ski pole poke, aka ski pole penetrometer (photograph by Bruce Tremper).

2.9.7 Tilt Board Test

This description follows material published in McClung and Schaerer (2006). The Tilt Board Test is typically used to identify weaknesses in new snow or storm snow layers. The test is generally conducted at an established study plot. It can be used to identify weak layers that will be tested with a shear frame.

Equipment

- Thin metal plate 30 cm x 30 cm
- Tilt Board – a board painted white and mounted on a frame. The frame is mounted to a joint that allows it to rotate in the vertical plane. The Tilt Board can be locked in the horizontal position or tilted about 15 degrees. This allows the test block to fracture in shear without sliding off the lower portion of the block.

Procedure

a) Cut a block of snow that is deeper than the suspected weak layer or that contains all of the new or storm snow. McClung and Schaerer (2006) recommend using a block no deeper than 0.4 m.
b) Using a thin metal plate, lift the block on to the Tilt Board.
c) Tap the bottom of the board until the snow fractures.
d) Record your results with the name of the test and rate the result as Easy, Moderate, or Hard (example: Tilt Board Easy or Tilt Board-E).
e) Use other methods to investigate the weak layer or interface as needed.

2.9.8 Shovel Tilt Test

The shovel tilt test is the field worker's version of the Tilt Board Test but requires no additional equipment be taken into the field (Figure 2.20).

Procedure

a) Isolate a column of snow of similar dimensions to your shovel blade.
b) Insert the shovel blade horizontally into the side of the column below the layers you wish to test (limited to about 0.4 m from the surface).
c) Lift the shovel and snow sample into the air and hold the shovel handle and bottom of the snow column in one hand,
d) Tilt the shovel blade about 5 to 15 degrees steeper than the slope angle of the sample.
e) Tap the bottom of the shovel blade with increasing force until fracture is observed.
f) Record the force required to produce the fracture as Easy, Moderate, or Hard.
g) Shovel tilt may be increased and angle recorded if no fracture occurs at 15 degrees.
h) Use other methods to investigate the weak layer or interface as needed.

Figure 2.22 A hand shear test (photograph by Bruce Tremper).

2.10 Instrumented Methods

2.10.1 Ram Penetrometer

Objectives

The ram penetrometer is used to obtain a quantifiable measure of the relative hardness or resistance of the snow layers. It can be applied on its own as an index of snow strength, but it is not recommended as the sole tool for determining snow stability. When used in combination with a snow profile, a ram profile should be taken about 0.5 m from the pit wall after observation of the snow profile, but before any shovel shear tests are performed. It is a valuable tool for tracking changes in relative hardness over time at study plots and slopes, or for measuring many hardness profiles over an area without digging pits.

Note: The ram profile describes the hardness of layers in the snowpack. However, it often fails to identify thin weak layers in the snowpack. Surface hoar layers or other weak layers that are one centimeter or less are difficult to detect. Its sensitivity is dependent on the hammer weight, particularly when used in soft or very soft snow. The magnitude of this problem may be reduced by using a lightweight hammer (500 g or less), or by using a powder or "Alta" ram (Perla, 1969).

Refer to Chapter 7 of *The Avalanche Handbook* (McClung and Schaerer, 2006) for a complete discussion on ram profiles.

Equipment

The standard ram penetrometer, also called ramsonde, consists of:

a) 1 m lead section tube with 40 mm diameter cone and an apex angle of 60°.
b) Guide rod and anvil.
c) Hammer of mass 2 kg, 1 kg, 0.5 kg, 0.2 kg or 0.1 kg.
d) One or two (1.0 m each) extension tubes.

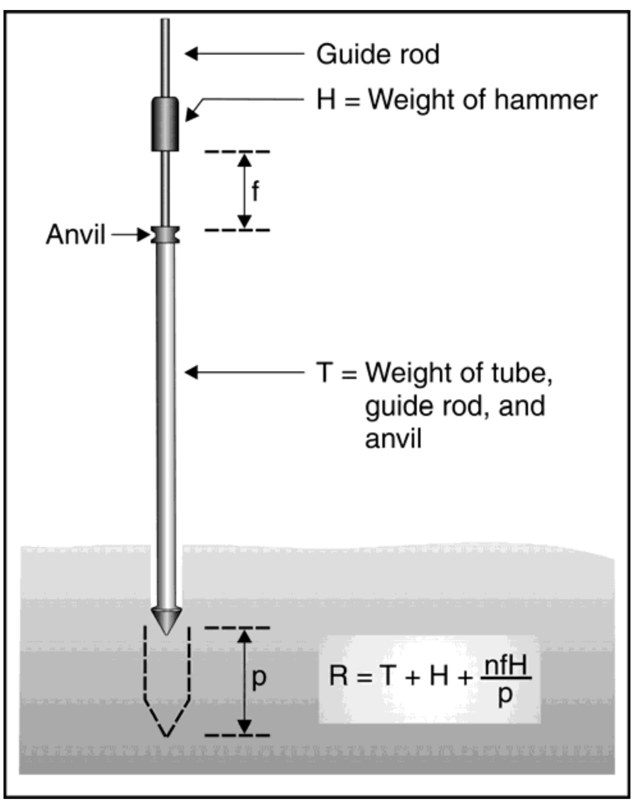

Figure 2.23 Schematic of the ram penetrometer (after Perla and Martinelli, 1976).

The powder ram, also called an Alta Ram (Perla, 1969), consists of:

a) 0.50 m to 1.0 m lead section and guide rod and anvil weighing 100 g
b) A hammer of mass 0.1 kg
c) Lead section cone has the same dimensions as a standard ram

The mass of hammer chosen depends on the expected hardness of the snow and desired sensitivity.

Unit of Measure

A ram profile depicts the force required to penetrate the snow with a ram penetrometer. The mass of the tubes, the mass of the hammer, and the dynamic load of the falling hammer all contribute to the applied force. Ram profiles can display two different quantities: *ram number* (*RN*), which is a mass (kg), and *ram resistance* (*RR*), which is a force (N).

Weight is a gravity force that is calculated by multiplying mass by the acceleration due to gravity (9.81 m/s^2). Although not strictly correct, most practitioners multiply by 10 to simplify the calculations. Since the ram number is an index of hardness, there is little danger in rounding this value. Force, and consequently the ram resistance, are measured in newtons. A mass of 1 kg has a gravity force (weight) of 1 kg x acceleration which is approximately 10 N (1kg x $10m/s^2$ =10N).

Procedure

Record the location, date, time, observers, slope angle, aspect, and ram type at the head of the data sheet. Also record any notes that will be pertinent to data analysis after leaving the field.

Work in pairs if possible. One person holds the ram penetrometer in a vertical (plumb) position with the guide rod attached. This person drops the hammer, counts the number of blows, and observes the depth of penetration. The other person records the information. The person holding the ram and dropping the hammer calls three numbers to the recorder: the drop number, drop height and penetration. For example, “5 from 20 is 143”, means 5 drops from a drop height of 20 cm penetrated to 143 cm (Figure 2.24).

a) Hold the first sectional tube with the guide rod attached directly above the snow surface with the point touching the snow. Let the instrument drop and penetrate the snow under its own weight without slowing it down with your hand. You will need to guide it in many cases so it does not fall over. Record its mass in column $T + H$. Read the penetration (cm) and record in column p (see Figure 2.24 for field data sheet example). Note that many people carry out this first step without attaching the guide rod first. However, since the tube weight T is 1.0 kg with the guide rod, it should be attached before the surface measurement is taken. Sometimes a greater sensitivity of the surface layer is desired. Dropping only the lead section without the guide rod will reduce the weight and may cause less of an initial plunge through the surface layers since the total mass will be lighter. If this method is used, then the weight of the lead section alone should be recorded for the T value, not the combined lead section and guide rod value of 1.0 kg.
b) Carefully add the hammer, or guide rod and hammer if using the lead section only for the surface measurement. Record the mass of the tube + hammer under $T + H$. Read the new penetration and record under p. If the ram does not penetrate further, as is often the case in this step, record the previous p value again.
c) Drop the hammer from a height between 1 cm and 5 cm; record the penetration. The low drop height (1-5 cm) is appropriate for near-surface layers. Larger drop heights (20-60 cm) and increased hammer weights may be desired as depth, and therefore, resistance increases. Continue dropping the hammer from the same height until the rate of penetration changes. Record fall height f, number of blows n, and penetration p up to the point. Some experience will allow the user to anticipate changes in the structure of the snow and record measurements before the rate of penetration changes. Continue with another series of blows; choose a fall height that produces a penetration of about 1 cm per blow. Do not change fall height or hammer weight within a series of measurements. Record the series then adjust fall

height or change hammer weight if desired before beginning another series. Resolution of the profile depends on the frequency of recorded measurements and the snowpack structure. Many recorded measurements in a homogeneous layer will provide no more resolution than fewer measurements since the calculated *RN* will be the same for both. However, resolution will be lost in varied layers if too many drops are made between recordings as the layer will receive a single *RN* over the entire range of p for that layer.

c) Add another section of tube when necessary and record the new $T + H$.
d) Repeat the measurements (b and c) until the ground surface is reached.

RAM DATA SHEET				
Location: Glory Bowl, Teton Pass, Wilson, WY				
Date: 19930312	Time: 0750 MST			
Observer: Newcomb/Elder				
Total depth: 239 cm	Equipment: Standard Ram			
Slope: 28°		Aspect E 80°		
Notes: 30 m south of GAZEX 1 Snowing 3cm/hr - wind SW 10m/s				
Tube and hammer wt $T + H$ (kg)	Number of falls n	Fall height f (cm)	Location of point L (cm)	Comments
1 + 0	0	0	23	tube & guide rod only, new snow deposited last 18 hr
1 + 0.5	0	0	25	add 0.5 kg hammer - no drop
	6	1	32	
1 + 1	0	0	32	change to 1 kg hammer
	4	5	37	
	11	10	49	
	7	20	52	crust
	5	10	64	
	15	10	87	
2 + 1	0	0	87	add 2nd tube section
	10	20	108	
	13	30	141	
	6	30	148	
3 + 1	0	0	148	add 3rd tube section
	25	30	181	
	22	30	209	
	1	30	215	
	3	10	239	

Figure 2.24 Sample field book page for Ram profiles.

Calculation

a) Calculate the increment of penetration p for each series of blows by subtracting the previous p value from the present p value (Figure 2.25).

b) Calculate ram number (RN) or ram resistance (RR) with the following equations:

$$RN = T + H + \frac{nfH}{p}$$

$$RR = RN \times 10$$

where:

RN = ram number (kg)
RR = ram resistance (N)
n = number of blows of the hammer
f = fall height of the hammer (cm)
p = increment of penetration for n blows (cm)
T = mass of tubes including guide rod (kg)
H = mass of hammer (kg)

c) Plot on graph paper the ram number or resistance vs. depth of snow (see Figure 2.26).

RAM CALCULATION SHEET								
Location: Glory Bowl, Teton Pass, Wilson, WY								
Date: 19930312	Time: 0750 MST							
Observers: Newcomb/Elder								
Total depth: 239 cm		Equipment: Standard Ram						
Slope: 28°		Aspect: E 80°						
Notes: 30 m south of GAZEX 1 Snowing 3cm/hr - wind SW 10m/s					*RN = T + H + (nfH)/p* (kg) *RR = RN x 10* (N)			
Tube and hammer wt *T* + *H* (kg)	Number of falls *n*	Fall height *f* (cm)	Location of point *L* (cm)	Penetration *p* (cm)	*(nfH)/p* (kg)	*RN* (kg)	*RR* (N)	Height above ground (cm)
								239
1 + 0	0	0	23	23	0.0	1.0	10	216
1 + 0.5	0	0	25	2	0.0	1.5	15	214
	6	1	32	7	0.4	1.9	19	207
1 + 1	0	0	32	0				207
	4	5	37	5	4.0	6.0	60	202
	11	10	49	12	9.2	11.2	112	190
	7	20	52	3	46.7	48.7	487	187
	5	10	64	12	4.2	6.2	62	175
	15	10	87	23	6.5	8.5	85	152
2 + 1	0	0	87	0				152
	10	20	108	21	9.5	12.5	125	131
	13	30	141	33	11.8	14.8	148	98
	6	30	148	7	25.7	28.7	287	91
3 + 1	0	0	148	0				91
	25	30	181	33	22.7	26.7	267	58
	22	30	209	28	23.6	27.6	276	30
	1	30	215	6	5.0	9.0	90	24
	3	10	239	24	1.3	5.3	53	0

Figure 2.25 Sample work sheet page for calculating Ram profiles.

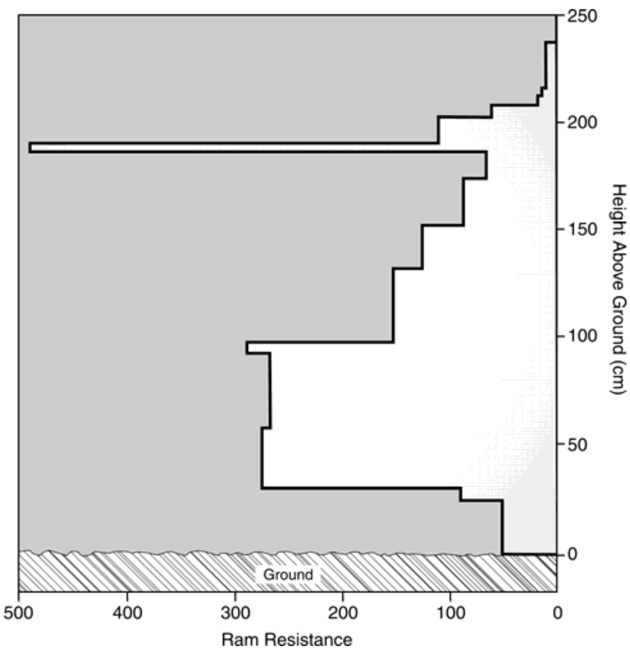

Figure 2.26 Graphical representation of a ram profile from data listed in Figures 2.22 and 2.23.

2.10.2 Shear Frame Test

The shear frame test is used to measure the shear strength of snow layers and interfaces between snow layers. The shear frame test requires experience, but provides useful information when done correctly and consistently. The test combined with a stability ratio is a useful tool for assessing the strength of snow layers. Discussions of shear frame methods can be found in Jamieson, 2001; Jamieson, 1995; Fohn, 1987b, Perla and Beck, 1983, and Roch, 1966.

Equipment

The shear frame test requires the following equipment:

1) Putty knife
2) Metal cutting plate about 30 cm x 30 cm
3) Shear frame, usually 100 cm^2 or 250 cm^2
4) Force gauge, maximum capacity 10 to 250 N (1 to 25 kg).

If you are calculating the stability ratio, you will also need the following equipment:

5) Sampling tube, 50 to 80 cm
6) Weighing scale

Procedure

The shear frame test can be performed on storm snow layers and persistent weak layers. Typically 100 cm^2 frames are used for storm snow layers and 250 cm^2 are used for persistent weak layers. Observers generally perform 7 to 12 consecutive tests and average the results. Once a series of measurements is started it is important to not switch frame sizes.

1) Identify weak layer using tilt board or other method.
2) Remove the overlying snow to within 4 or 5 cm of the layer or interface being measured.
3) Carefully insert the shear frame into the snow so the bottom of the frame is 2 to 5 mm above the layer.
4) Pass a thin blade (putty knife) around the shear frame to remove snow that was in contact with the frame.
5) Attach an appropriate force gauge and pull so that fracture occurs within 1 second. This method ensures brittle fracture. It is essential that the operator loads the force gauge at a constant rate and is consistent between all measurements.

Figure 2.27 Measuring the shear strength of a surface hoar layer with a 250 cm^2 shear frame and force gauge (photograph by Greg Johnson).

Shear Strength Calculation

Once you have obtained the average shear force for the weak layer or interface, calculate the shear strength from the formula:

$$T_{\text{frame}} = \frac{F_{\text{average}}}{A_{\text{frame}}}$$

where F_{average} is the average shear force in newtons (N), A_{frame} is the area of the shear frame in m^2, and T_{frame} is the shear strength of the layer in pascals (Pa). This calculation produces a shear strength that is dependent on the shear frame size ($T_{\text{frame}=}$ T_{250} or T_{100}). For a value of shear strength that is independent of frame size use the following equations (Föhn, 1987b; Jamieson, 1995):

$$T_{\infty} = 0.65\,T_{250}$$
$$T_{\infty} = 0.56\,T_{100}$$

where T_{∞} is the shear strength independent of shear frame size and T_{250} and T_{100} are the shear strengths measured with a 250 cm^2 and 100 cm^2 shear frame respectively.

Stability Ratios

The stability ratio is the shear strength of a layer divided by the overlying slab's weight per unit area. The stability ratio has a complex relationship with avalanche occurrence, but in general the lower the ratio the greater the likelihood of avalanches.

$$\textit{Stability Ratio (SR)} = \frac{\textit{shear strength}}{\textit{weight per unit area}}$$

To determine the slab's weight per unit area, slide a small plate such as a putty knife or crystal card horizontally into the pit wall at a depth equal to the sampling tube length. Now slide the sampling tube vertically down through the surface until it strikes the plate. Excavate the sampling tube, taking care not to lose any snow out of the end of the tube. Transfer the contents of the sampling tube to a plastic bag for weighing. Divide the sample weight by the cross sectional area of the tube to calculate the slab weight per unit area. For weak layers deeper than the sampling tube length, use a stepped sampling method.

Limitations

The shear frame works best for thin weak layers or storm snow interfaces. Thick weak layers (i.e. depth hoar) tend not to produce consistent fracture planes. The shear frame works poorly in situations where very hard layers (i.e. wind slabs and crusts) are directly above weak layers. The problem is inserting the shear frame into the hard layer without fracturing the weak layer below. In addition, there is little operational experience and literature on the use of shear frames with wet snow. The shear frame is also sensitive to user variability.

Shear Frame References

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