Persistent Deep Slab Avalanches

Introduction

Persistent deep slab avalanches are caused by a thick and hard cohesive slab of snow losing its bond to an underlying weak layer that is very deeply buried in the snowpack, often on or near the ground. They are highly unpredictable and destructive; essentially not survivable. It's common for persistent deep slab avalanches to become dormant for extended periods of time then "wake-up" again, weeks or sometimes months later when the weather changes or when warm spring weather arrives. When active, they often occur without warning or with light triggers. In dormant phases, they may require heavy triggers such as snowmobiles, cornice falls or smaller avalanches from above or on the slope which step down to deeper layers.

Development

Deep persistent slabs form when a persistent weak layer becomes deeply buried under a thick, hard slab of snow created by numerous storm events. Typically this takes weeks and the subsequent instability persists for extended periods of time.

Time of the Season:
The development of deep persistent slabs typically begins in the early season, the time when ideal conditions exist for creating the persistent facet, facet/crust, depth hoar, or depth hoar/crust weak layers. These are the most common layers upon which a persistent deep slab problem eventually forms.

In addition, early season persistent weak layers are more likely to become deeply buried under all or most of the subsequent winter snowpack.

Weather Patterns:
For a deep slab problem to develop, weak layers must be deeply buried by further snowfalls and they must be layers that are highly resistant to settlement and bonding. The persistent weak layers that created persistent deep slab problems generally form when an early season snowpack is exposed to periods of clear, dry weather. The persistence and propagation potential of the instability is greatly increased if the weak layer forms in conjunction with a rain crust.

Rain on snow events produce a wet surface layer. If this wet surface is buried by snowfalls before it freezes, development of facet on crust layers is common. Facet/crust layers can also develop if the surface freezes first and is then buried by subsequent snowfalls, but in general weak layers that develop under the latter conditions are not as severe. In either case, faceting above and/or below crusts is exacerbated if a clear, dry spell occurs after initial formation of a facet on crust layer but before it is deeply buried.

Basal facets and depth hoar form when a shallow, early-season snowpack combines with clear, dry weather to create strong temperature gradients in the snowpack, which in turn promote development of facets and depth hoar layers at or near the ground.

Deep slab problems occur when facet/crust layers or basal facets and depth hoar are buried by ongoing snowfalls throughout the winter. Deep slabs are more likely to develop if the early snowfalls burying the layers are low density, light accumulations of
cold snow.

Snow Climates:
Persistent deep slabs are uncommon (although not unheard of) in maritime climates. Warm temperatures, high density snow, large storm snow accumulations, and regular storm snow avalanche activity tend to prevent formation of or eliminate any persistent weak layers in the early season.

Persistent deep slabs are most common in an interior mountain climate where early season weather can produce facet/crust combinations followed by significant accumulations of snow which produce the thick slabs that deeply bury the weak layers. Occasionally, deep basal facet/depth hoar layers do form in the interior but this is not a common situation.

Persistent deep slabs are less common in the continental climate of Western Canada. Early season rain on snow events, which create facet on crust conditions are less common in these colder climates. While cold, dry, early season weather does promote regular formation of basal facets and depth hoar, winters are generally dry enough that the basal weak layers never become deeply buried. In these ranges, persistent deep slab avalanches are generally found only at high elevations lee areas where wind deposited snow accumulations are large enough to deeply bury basal weak layers.

In warmer continental climates (such as those in the United States) where greater snow accumulations occur, persistent deep slabs are more likely to occur and can be a more common problem. In these regions, the problem will likely display characteristics more like an interior climate

Spatial Distribution:
The persistent weak layers that underlie a deep slab can be widely distributed or quite isolated. How widespread a problem will be depends entirely on the weather pattern that created it. For example, if a rain on snow event is widespread, the weak layer that subsequently develops can span entire ranges, whole regions, or even multiple climatic zones. Conversely, isolated areas of facet on crust or basal facets/depth hoar are common if the snowpack and weather conditions that produce them are localized events.

Similarly, the extended periods of early season cold, dry weather required to form basal facets and depth hoar may be widespread or localized depending on the winter in question and the geographic region.

Avalanche Activity Patterns

Seasonal Timing and Persistence:
In the unusual circumstance that a persistent deep slab condition occurs in maritime climates, avalanches on these layers are possible at almost any time of the winter due to high snowfall accumulations, which can deeply bury a persistent weak layer in a short period of time. In the interior climate, persistent deep slab avalanches are most likely to occur in mid to late winter or spring after weak layers have been buried by snowfalls from numerous storms. In a continental climate, they are most likely to occur in late winter or spring—fewer and less intense snowfalls here take longer to create the thick layer of slab on basal facets and depth hoar grains.

Because the grains that form the weak layers are buried so deeply and are extremely resistant to strengthening, deep slab problems persist for weeks or months. In extreme cases they can span seasons (e.g. in one case a problem that developed in November was the suspect layer in a fatal avalanche the following August).

Size and Propagation:
When the weak layer that underlies the slab is widely distributed, it’s common to see wide propagations where most or all of start zones clean out. In these situations, fracture lines can run great distances, may propagate across terrain features that generally stop fracture lines in other types of avalanches, and in extreme circumstances can connect multiple avalanche paths. These slides often overrun significant terrain features in the track or runout zone destroying mature timber and lengthening or widening existing paths.

When the weak layers are more variably distributed, fracture lines may be limited in length but the depth and hardness of the slab still produces highly destructive localized slides.

Spatial Distribution and Variability:
Persistent deep slab avalanches are most common above treeline where the snowpack is deeper. In continental climates, they are most likely to be found in lee areas of high alpine terrain. Persistent deep slabs are common on all aspects and show little preference for specific terrain features.

Persistent deep slab avalanche activity is often variable in distribution over terrain. That is, one mountain range, one drainage, one mountain, one slope on a mountain, a given elevation, or a particular aspect may have a persistent deep slab problem while adjacent ranges, drainage, mountains, slopes, elevations, or aspects do not.

The factors that drive variability include the weather pattern than caused the problem in the first place, subsequent weather that produced the snowfalls which bury the weak layer, and the amount of avalanche activity on the weak layer soon after burial. The more widespread the offending weather patterns and the less avalanche activity on the layer before it becomes deeply buried, the more widespread deep persistent slab activity will be later in the winter and vice versa.

Triggering:
Where the snowpack is deep and evenly distributed and when the weather is benign, deep persistent slabs generally require heavy triggers such as large explosive charges, large cornices, or icefall,. Stepdown triggering is also common, that is: a smaller or shallower avalanche on the slope in question or falling from above in turn triggers a deep slab. Remote triggering from shallow or weak spots in the snowpack is common.

A smaller, lighter trigger like a single skier is unlikely to trigger this type of avalanche on a slope where the snowpack is deep and evenly distributed when the weather is benign. The likelihood of a snowmobile and rider triggering a deep slab in this situation is probably higher than a skier but not as high as a larger trigger as described above.

Certain weather conditions promote increased sensitivity to triggering:

- Accumulations of wind driven snow or new snowfall loading on a slope at a rate of 3-5cm/ hour (3mm/hour water equivalent) or more.
- Rainfall of any amount.
- Total snowfall accumulations of 30-50cm or more (30mm of water equivalent) in a 12 hour period or less.
- Strong solar radiation or warm temperatures making the surface of the snowpack noticeably denser or moister.
- Air temperatures warming at a rate of 3^{o}C per hour or more, especially if the temperature rises above 0^{o}C as a result.

If more than one of these weather conditions occur together, the effect is greater than the sum of its parts. When weather conditions are conducive to increased sensitivity to triggering, lighter triggers, such as a single skier, may be enough to tip the balance and trigger an avalanche.

When the snowpack is unevenly distributed or contains discontinuities, all bets are off. Where shallow and deep snow exist adjacent to each other, slopes are more sensitive to light triggers. Similarly, a light trigger is much more likely to initiate an avalanche if rocks or trees are shallowly buried below or projecting through the snow surface.

Recognition and Assessment in the Field

Avalanche Activity:
Low probability, low frequency, high consequence avalanche activity is the norm. That is, it's difficult to trigger a persistent deep slab so few avalanches occur, but those that do are often large and destructive due to the volume and high density of snow in the slab.

A lack of avalanche activity is not a reliable indicator of potential hazard. Avalanches often occur in cycles consisting of dormant periods where only a few isolated avalanches occur for extended periods of time interspersed with periods of activity where a number of events are clustered in a relatively short time frame. Dormant periods are generally associated with periods of benign weather. Deep slabs often "wake up" or reactivate when weather changes occur (see Triggering above).

Snowpack Layering, Tests, and Observations:
Persistent deep slab avalanches are characterized by 180-200 or more centimetres of hard to very hard snow over a persistent weak layer of facets, facet and crust combinations, or depth hoar.

Facets are angular grains with the look and feel of sugar crystals. They bond poorly to each other and to the layers above or below. Depth hoar grains are larger, hollow, cup-shaped, and often have striations visible to the naked eye on close inspection. Thick basal facet and depth hoar layers often pour out like grain when exposed in a snow profile pit wall. Facet on crust layers can be much more subtle. The crusts are generally relatively easy to identify, consisting of icy or crunchy hard layers often created by freezing rain or consisting of snow that has been wetted by rain or melting, then refrozen. However, the associated facet layers can be very thin, sometimes so thin that they are not visible to the naked eye, especially in the case of inexperienced observers. The faceted grains in persistent weak layers are often relatively small compared to basal facets.

There are few reliable bonding tests for deep persistent slab problems. Standard tests such as the shovel compression test and rutschblock test are not suitable for testing deeply buried weak layers, although they can indicate if failure might be triggered in shallow or weak spots in the snowpack. The propagation saw test (PST) has proven to be a fairly reliable indicator of whether a deeply buried weak layer might propagate if failure occurs. It should be noted that the PST does not quantify the force or load required to trigger an avalanche, it only indicates the likelihood that a fracture will propagate if triggered.

It should be noted that, while thick weak layers are more easily identified and appear more fragile, thin weak layers are generally more unstable than thick ones and should not be discounted. The biggest challenge in finding and testing deeply buried persistent weak layers is the depth at which they are buried. Digging two metres or more involves significant effort and even avalanche professionals often do not have the time or resources to make regular observations of these layers, relying instead on local knowledge and a wide range of other observations to assess the hazard presented by deep persistent slabs.

Ski cutting or any other form of testing that places a person on an actual avalanche slope are not recommended—even on small terrain features. Watch for signs of instability while travelling, such as whumpfing, cracking, and avalanches on similar slopes. These observations are a clear signal that conditions are at a critical state. However in the case of a known or suspected PWL, the absence of whumpfing or avalanches should never be interpreted as evidence that a layer is not active.

Surface Conditions:
Surface condition is not indicative of persistent deep slab avalanche potential. Because the underlying layer is buried so deeply in the snowpack and has been buried for such a long time, it's possible that almost any surface condition could be experienced in this avalanche character type.

Risk Management Strategies

Deep slab instabilities associated with PWLs are among the most difficult of all avalanche problems to assess, predict, and manage. Even professionals with extensive training and decades of experience struggle with the "low probability-low frequency high consequence" nature of the problem. It's generally difficult to trigger a deeply buried instability and the number of avalanches is low, but the consequences if caught are very serious due to the size and mass of the slide. Appropriate risk management relies on making decisions based on what you know about a slope: its history of avalanche activity over the season, slope use patterns (e.g. compaction), and/or stabilization (avalanche control) measures. In the absence of local knowledge the only reasonable way to manage your risk is by leaving a wide safety margin wherever a persistent deep slab is known or suspected.

Timing:
Choosing the time of exposure can reduce risk when deep persistent slabs are a concern.

- Avoid exposure to deep persistent slabs when weather factors likely to increase sensitivity to triggering exist:
    - Snowing, especially >3cm/hour.
    - Windloading.
    - Raining.
    - Strong solar radiation or air temperatures high enough to make the surface of the snow feel moist or wet.
    - Temperatures rising at more than 3^{o}C/hour, especially if the temperatures are going above zero.
- It takes time for persistent deep slabs to adjust to stress from changes in weather. Wait at least 36-48 hours after significant weather changes.
- It takes time for most non-persistent, storm snow instabilities (which might trigger a step-down avalanche) to settle out. Wait 36-48 hours after a storm ends.
- On clear days, warming and solar radiation can quickly destabilize slopes or cornices above, which might then trigger a persistent deep slab as a step-down avalanche. Even when in the shade in the valley below or on a "cold" slope such as a north or east aspect, keep looking up and don't underestimate how early the sun or warming temperatures might be affecting slopes or cornices far above.
- There's less tendency to stop and reassess current, local conditions in good weather. Stay alert and don't miss changes happening around or above you.

If any of the above factors is at play, and especially if more than one are a potential, you should very carefully examine your motivation for exposing yourself to slopes where persistent deep slabs are known or suspected to exist. It is strongly recommended you back off and go to slopes where persistent deep slabs are not an issue or choose low angle, simple terrain that is not exposed to slopes above. If you feel you must expose yourself to slopes that might contain persistent deep slabs, give them several days to adjust to new stresses before reconsidering them as an objective. Consider using those several days to obtain as much information as possible from credible local sources about the slope you want to tackle and continue to question your motivation.

Human Factors:
It has been noted that:

- People are more willing to push into bigger, steeper, more complex terrain when the weather is good.
- People ride more aggressively on blue-bird days.
- People tend to discount their intuition or "gut feel" more on blue bird days. If something doesn't feel right, they are more willing to push on a clear warm day than on a cold, foggy, snowy day.
- Examine your own motivation and that of others in your group. Check out this article: http://www.mec.ca/AST/ContentPrimary/Learn/Snowsports/AvalancheSafety/HumanFactors.jsp.
- Assess the training and experience of your party.
- Employ a structured decision making process or use tool like the Avalanche Canada Avaluator™ to aid in trip planning

- Ensure all members of the party play an active role in all aspects of planning, preparation, and execution of the trip.
- Talk to the others in your party. Listen to what they have to say. Respect their concerns. Make sure lines of communication remain open between all members of the party at all times.
- Use the information in this discussion and from regional avalanche forecasts to assess general conditions for the area where you will be.
- Talk to credible local experts such as guides, ski patrollers, avalanche professionals, etc. to get a handle on local conditions.
- Avoid making snap decisions in the field that put you at risk for triggering a persistent deep slab avalanche. Because there are often no visible signs of instability related to persistent deep slab avalanche conditions, it is easy to be lulled into a false sense of security while in the field. Generally, the best decisions regarding persistent deep slab avalanche are made during planning and prior to going out in the mountains. When dealing with a known or suspected persistent deep slab instability, it is not a good idea to let the lack of signs of instability lead you to choose to travel on more aggressive terrain than originally intended.

Terrain:
Deep persistent slabs are associated with high uncertainty and low confidence. With persistent deep slabs don't ask: "Will it slide?" Rather you should ask: "If it slides, what will happen to me or my partners?" This approach leads to greater margins for error and more conservative terrain choices, which are the best way to manage the risk presented by deep slabs. Be conservative when choosing terrain and manage your group carefully. For example:

- Take a more conservative overall approach when dealing with deep persistent slab problems.
- Use a slope assessment tool or process like that provided by the Avaluator™ to assess each slope before you expose yourself to avalanche terrain.
- Avoid areas where the snowpack is shallow (less than 200cm on average).
- Avoid terrain where the snowpack depth is variable (shallow areas mixed with deep areas).
- Avoid slopes that have rocks and scattered trees sticking out of the snow.
- Avoid steep unsupported terrain features especially if there is a pronounced convexity.
- Minimize or eliminate exposure to terrain traps.
- Stay on slopes that have less than 30 degree incline.
- Stay on smaller slopes.
- Stay on simpler terrain (www.avalanche.ca/CAC_Avaluator_TerrainRating).
- Avoid avalanche start zones and tracks if possible.
- If you must travel in or through start zones or tracks, go one at a time from safe spot to safe spot.
- Spread out or go one at a time when travelling in or through avalanche runout zones.
- Regroup only in safe areas where avalanches will not start or where terrain features or ground cover provide protection, such as:
    - High points.
    - Ridges above start zones.
- Dense timber well away from the sides or bottom of the track or runout zone.

USE AT YOUR OWN RISK

Mountain travel is dangerous and can involve exposure to avalanches and other hazards. The advice and decision guidelines provided in this field book cannot eliminate these hazards, but they can help you understand and manage them. This field book is no substitute for training, experience, and choosing skilled and responsible travel partners.

To find an avalanche training course near you, visit www.avalanche.ca.

CITATION

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