A PRACTICAL USE OF HISTORIC DATA TO MITIGATE WORKER EXPOSURE TO AVALANCHE HAZARD

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ABSTRACT: In the forty-one seasons of avalanche mitigation at the Jackson Hole Mountain Resort, avalanche hazard reduction routes have been run from the top down. During the 2007/08 season, the resort's aerial tramway was being replaced and was inoperable. To gain access to the top of their routes ski patrollers would be required to pass beneath unmitigated avalanche terrain. The ski patrol director had a plan to address this challenge. Some members of the patrol were concerned about their safety and the patrol's ability to manage this hazard.

A search of an historical database with over 18,000 avalanche events was conducted to characterize the hazard on the avalanche paths of concern. Data analyses tools were created to perform this search and a Geographic Information System (GIS) was used to present a summary of this study along with operation modifications to the patrol during a preseason training session.

This methodology was extremely effective in characterizing the avalanche hazard and communicating the results of this effort to the staff. Operations were safely conducted with surety and confidence. This example highlights the value of historical data as a practical tool for mitigating worker exposure to avalanche hazards.

KEYWORDS: Avalanche hazard mitigation, historical database, geographic information system

1.0 INTRODUCTION

The Jackson Hole Mountain Resort is situated in steep avalanche terrain on the east slope of the Teton Range in Western, Wyoming. There are nearly 300 avalanche paths within the resort boundary that are managed on a daily basis during winter operations.

Since 1974 the resort has diligently kept detailed daily records of meteorological data, snow study plot observations and avalanche activity.

These hand written records have been entered into an electronic database. Outlines of avalanche paths and avalanche starting zones at the resort have been digitally delineated and can be viewed with topographic base maps or aerial photographs. These resources have become important tools for daily avalanche hazard management.

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2.0 PROPOSED OPERATION MODIFICATIONS

Since 1965 avalanche hazard at the resort has been mitigated by the deployment of explosive charges. Seven hand charge routes are run from the summit of Rendezvous Mountain.

The aerial tramway that transports patrollers to the summit of the resort was being replaced and was unavailable during the 2007/08 season. Without the aerial tramway, it is necessary to ride four lifts to get to the summit of the ski area. The third lift in this route (Sublette Chair) terminates in the run out zone of the East Ridge Avalanche Path. The route from the top of this lift to the bottom of the fourth lift (East Ridge Chair) passes through the lower potion of several avalanche paths.

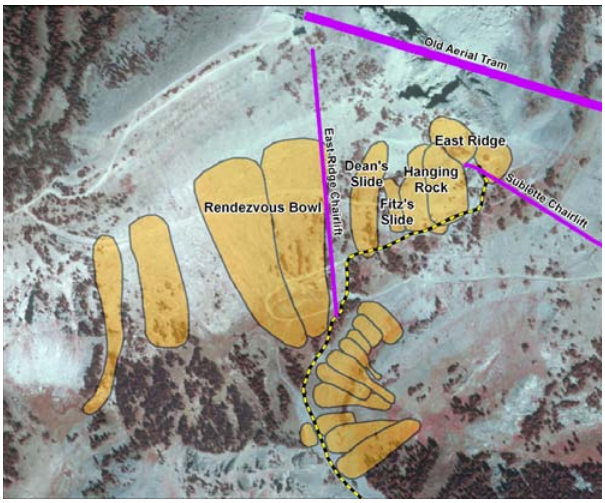

Figure 2: Outline of the extent of Class IV size (relative to the path) avalanches that affect the route from the Sublette to East Ridge Lifts.

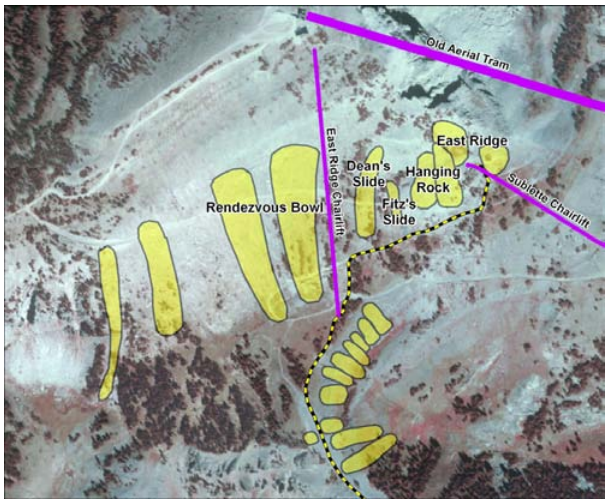

Figure 1: Outline of the extent of Class III size (relative to the path) avalanches that affect the safest patrol route from the top terminal of the Sublette Chairlift to the base terminal of the East Ridge Chairlift.

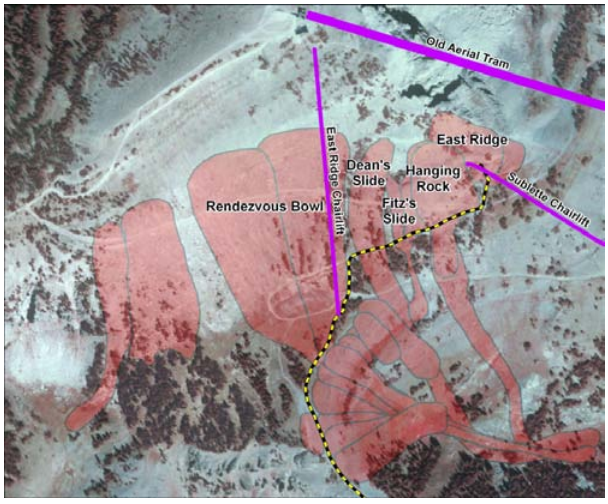

Figure 3: Outline of the extent of Class V size (relative to the path) avalanches that affect the route from the Sublette to East Ridge Lifts.

Normal operations require 12 to 24 ski patrollers to reach the summit of Rendezvous Mountain to conduct avalanche hazard reduction efforts.

Without the aerial tramway, the East Ridge Chairlift is the only lift access to the summit of the resort. The base terminal of this chairlift and a couple of its lift towers lie within the eastern limits of a Class V slide in Rendezvous Bowl. The dashed line on Figures 1-3 is the safest route for patrollers to reach the base of the East Ridge Chairlift.

Without the aerial tramway it was proposed that 13 patrollers be transported from the base of the resort to the base the East Ridge Chairlift in an enclosed snow coach. This tracked personnel carrier would follow the dashed line in the lower portion of Figures 1-3. This route runs beneath the Rendezvous Bowl avalanche paths as it approaches the bottom of the East Ridge Chairlift.

The rest of the patrol was to ride ski lifts from the base of the resort to the summit. These patrollers, on skis, were to follow the dashed line on Figures 1-3 from the top of the Sublette Lift to the base of the East Ridge Lift.

Figure 1 shows that Class III size events on the paths of concern would not impact either of the proposed routes to the base of the East Ridge Lift. Figure 2 shows that Class IV size avalanche events would run to the proposed routes. Figure 3 shows that Class V size slides in these paths would overrun the proposed routes.

Operation modifications for this season were conceived by the ski patrol director who had over 30 seasons of empirical knowledge regarding the nature of the avalanche hazard on these paths. Based on accumulated knowledge he believed that the planned routes would be safe in all but the most extreme conditions. Should extreme conditions occur it was his belief that these conditions could be easily recognized.

Some members of the patrol with less experience of the historical occurrence of avalanche activity on these paths were understandably concerned about exposure to this avalanche hazard.

3.0 HISTORICAL DATABASE SEARCH

To address worker concerns, and to confirm or refute the validity of the thoughts of the patrol director a search of the historic database was conducted for the avalanche paths of concern.

The database is comprised of observations made on 5,256 days over the course of 33 seasons. There were 18,831 avalanche observations in the database during this period. Of these 17,546 were recorded as slab avalanches. None of the loose snow avalanches in this database were greater than Class III in size (relative to the path) and none of those Class III loose snow avalanches were greater than one meter deep at their point of failure.

The attributes of the avalanche paths of concern were identified using GIS technology.

Avalanche Starting Zone	**Elevation (m)**	**Aspect (º)**	**Angle (º)**
High East Ridge	3,076	162	38
Low East Ridge	2,885	148	37
Hanging Rock	3,037	160	45
Fitzs Slide	3,021	169	36
Deans Slide	3,050	178	33
Rendezvous Bowl	3,059	170	34

Table 1: Avalanche starting zone attributes for the slide paths of concern.

	East Ridge	Hanging Rock	Fitzs	Deans	Rendezvous	All Paths
Total Slabs	78	758	17	56	22	931
Class I	48	340	8	20	5	421
Class II	22	336	6	19	9	392
Class III	**5 (0)**	**68 (3)**	**3 (1)**	**7 (1)**	**3 (0)**	**86 (5)**
Class IV	**1 (0)**	**13 (0)**	**0 (0)**	**8 (0)**	**3 (0)**	**25 (0)**
Class V	**1 (0)**	**1 (0)**	**0 (0)**	**2 (0)**	**2 (0)**	**6 (0)**
(2) = denotes number of natural releases						

Table 2: Number of slab avalanches, by size relative to the path, for the paths of concern. The value in parentheses represents the number of events that released naturally.

3.1 East Ridge Slide Path

Avalanches on the East Ridge originate from starting zones located above the top terminal of the Sublette Chairlift (Figure 1). A Class III avalanche event from these starting zones would not reach the top of this lift, or the proposed route to the base of the East Ridge Chairlift. A Class IV slide would run to these areas. A Class V avalanche from these starting zones would run over run this route and the top terminal of the lift (Figure 3).

The database search identified 78 slab avalanche events from the East Ridge area during the previous 33 season (Table 2). Table 3 lists attributes of the seven large (Class III, IV or V) slides in the database. The attributes listed include date of occurrence, slab type, mechanism of release, size relative to the path and depth of the crown at its highest point.

Date	Type	Trigger	Size	Crown Depth(m)
12/6/1982	HS	AE	4	1.5
12/15/2000	SS	AB	3	1.1
1/11/1997	SS	AB	3	0.3
1/12/1998	**SS**	**AB**	**5**	2.1
2/26/1982	SS	AE	3	0.8
3/17/1996	SS	AE	3	0.6
3/24/1995	SS	AE	3	0.6

Table 3: East Ridge Class III, IV and V avalanche attributes.

During the period of 1974 to 2007 there were five Class III slides, one Class IV slide and one Class V side in this area. All seven of these slabs were explosively triggered. Only one of these events, a Class V slab on 1/12/98, reached the lift. The debris from this slide partially buried the top terminal of Sublette Chairlift but caused no structural damage.

3.2 Hanging Rock Slide Path

Slab avalanches on this path originate from two adjacent starting zones located above and gunners left of the top terminal of the Sublette Chairlift (Figure 1). A Class III slide would not run to the proposed route from the top of the Sublette Lift to the base of the East Ridge Lift. A class IV event would run to this route and a Class V event could overrun this route with a large volume of fast moving snow (Figures 1-3).

Due to its steep starting zone angle (45 degrees), this is one of the resort's most active slide paths. As shown in Table 2, there were 758 slab avalanches on this path in the database. Of these, 68 were Class III in size, 13 were Class IV and one was a Class V.

Date	Type	Trigger	Size	Crown Depth(m)
12/6/1978	HS	AE	4	1.2
12/6/1978	SS	AE	4	1.2
12/7/1983	HS	AE	4	0.9
12/12/2004	HS	AE	4	1.2
12/21/1996	SS	AB	4	0.6
12/24/2008	SS	AE	4	1.5
1/6/1982	HS	AE	4	1.8
1/7/1995	SS	AE	4	0.4
1/11/1997	SS	AB	4	0.4
1/13/1976	HS	AE	4	1.8
1/15/1980	SS	AE	4	1.5
1/16/1998	**SS**	**AB**	**5**	**1.8**
1/26/1997	SS	AB	4	1.2
2/13/2000	SS	AB	4	0.5
Class III = 68 events of which only three released spontaneously				

Table 4: Hanging Rock Class IV and V avalanche attributes.

All of the Class IV and Class V events listed in Table 4 were explosively triggered. Only three of the 68 Class III events in the database released naturally. The crown depths of the three Class III size natural slides were less than 0.7 meters deep.

All but two of the Class IV and V events occurred in December or during the first half of January. During this period the first avalanche hazard reduction efforts are conducted while the snow transitions from an undisturbed backcountry scenario to a ski-compacted resort snowpack. The Class V event occurred on 1/16/98, four days after the only Class V event on the East Ridge, during one of the longer sustained storm cycles experienced at the resort.

3.3 Fitzs Slide Path

This path originates from a starting zone to the gunners left of the Hanging Rock slide path (Figure 1). Some potential exist for a Class V event on this path to cross the proposed ski route from the top of the Sublette Chairlift to the bottom of the East Ridge Chairlift.

There were only 17 slab avalanches on this path in the database (Table 2). Only three of these avalanches were Class III in size. There no Class IV or V size events. One of these Class III events occurred naturally after the resort had closed on 4/30/95.

3.4 Deans Slide

The Deans Slide avalanche path is located to the gunner's right of the East Ridge lift line (Figure 1). A Class IV event on this path could make it to the proposed ski route from the top of the Sublette Lift to the bottom of the East Ridge Lift (Figure 2). A Class V event would cross this route and continue into Cheyenne Bowl (Figure 3).

On 12/2/85 ski patroller Paul Driscoll died in this avalanche path. On this day, avalanche hazard reduction efforts consisting of the deployment of one kilogram hand charges were conducted in the morning. On the last run of the day, Paul and several other patrollers were setting up signs when this slope failed under their weight.

This fatality occurred on the first day avalanche hazard reduction routes were run in this area for that season. Backcountry conditions existed. There was new snow and wind transport of available snow between the morning work and this tragic event. The two meter deep hard slab that killed Paul failed on a buried weak layer of well developed faceted snow that sat upon on a hard October crust.

Since this fatality occurred, large explosive charges have been very effective triggers in this lower angle (33 degrees) starting zone when deep slab instability exists.

There were 56 slab avalanche events on this path in the database (Table 2). On these, seven were Class III, eight were Class IV and two were Class V in size.

Date	Type	Trigger	Size	Crown Depth(m)
11/29/1988	HS	AO	4	1.5
12/2/1985	HS	AS	4	1.8
12/2/1996	SS	AO	3	0.5
12/3/2005	SS	AE	3	0.5
12/4/1981	HS	AE	4	1.2
12/4/1992	SS	AO	3	1.2
12/5/1978	**HS**	**AE**	**5**	**2.1**
12/5/1979	HS	AE	4	1.2
12/5/1979	HS	AB	3	0.6
12/7/1983	HS	AE	4	0.9
12/8/1975	**HS**	**AE**	**5**	**1.8**
12/12/2004	HS	AE	4	0.9
12/21/1996	SS	AS	4	0.3
1/5/1980	SS	AE	3	0.9
1/15/1980*	SS	AE	4	1.8
2/17/1976	SS	AE	3	0.6
3/6/1996	SS	N	3	0.5
* Aerial Tram opened on January 7				

Table 5: Deans Slide Class III, IV and V avalanche attributes.

The information provided in Table 5 shows that all of the Class III or larger avalanches on this path were explosively triggered except the Driscoll fatality, one shallow slab on 12/21/96 and one natural event on 3/6/96 with a 0.5 meter crown.

The AO trigger designation means the trigger was a large (12 or more kilograms) explosive charge. This list of data also shows that Class IV and V size slides on this path are likely to be hard slabs.

Most significant is the timing of the occurrence of large avalanches on this path. All but three of the avalanches listed in Table 5 occurred on the first day of the season that avalanche hazard reduction efforts were conducted on this path.

3.5 Rendezvous Bowl Slide Paths

The Rendezvous Bowl slide paths originate from avalanche starting zones located to the gunners left of the East Ridge Lift (Figure 1). A Class III size event would not reach the proposed travel routes. A Class IV size event would run to these routes, and a Class V size event would overrun these routes, the East Ridge base station and could impact lift towers.

There were 22 slab avalanche events for these avalanche paths in the 33 year database (Table 2).

Date	Type	Trigger	Size	Crown Depth(m)
11/29/1995	HS	AO	4	0.9
11/30/1988	SS	AO	3	*
12/4/1985	**HS**	**AO**	**5**	**1.2**
12/4/1992	SS	AO	3	0.6
12/24/1984	SS	AE	4	1.2
1/11/1998	**SS**	**AB**	**5**	**0.9**
1/12/1998	SS	AO	4	*
2/21/1980	HS	AE	3	1.2
* Depths not recorded				

Table 6: Rendezvous Bowl Class III, IV and V avalanche attributes.

The data provided in Table 6 shows there have been only eight Class III, IV or V size avalanches on the Rendezous Bowl slide paths in the past 33 seasons.

One of the Class V size events and one of the Class IV size events occurred during the same historic storm cycle that also produced the only Class V size events on the East Ridge and Hanging Rock avalanche paths.

All of these Rendezvous Bowl slides were explosively triggered and all but two were triggered by a large explosive charge or an airblast. Most occurred during the first avalanche hazard reduction efforts conducted at the onset of the season or during an historic deep slab avalanche cycle.

4.0 DISCUSSION OF SEARCH RESULTS

A database search was very effective in characterizing the history of large avalanches in the study area.

This search identified and investigated 931 slab avalanches on the slide paths of concern that occurred during the previous 33 seasons. Six of these were Class V in size and 25 were Class IV in size (Table 2).

All of the Class IV and V size slab avalanches on these paths, except the slide that killed patroller Paul Driscoll, and one other very shallow slab were explosively triggered. The death of ski patrollers Paul Driscoll and Tom Raymer during the 1985/86 season instigated the idea of using large explosives charges. The data indicates this practice is an effective tool for mitigating deep slab instability especially in lower angle avalanche starting zones.

The vast majority of these large events occurred on the first day of avalanche hazard reduction efforts of the season or during an historic storm/avalanche cycle.

A review of meteorological and snow pack structure records indicate the potential for these early season events to occur is related to deep slab instability associated with buried layers of faceted snow.

This data search confirmed the thoughts of thought of the patrol director and supported the proposed operation modifications.

5.0 OPERATION MODIFICATIONS TALKING POINTS

The data compiled using database & GIS technology was incorporated into a power point presentation and presented to the patrol during its preseason training exercises. This presentation discussed the following concepts.

- Preseason observations are necessary to monitor the potential development of basal weak layers of faceted snow.

- A cautious approach to early season avalanche hazard reduction efforts is necessary and should consider the use of large charges.

- A continued cautious approach would be necessary if early season conditions indicated the potential for deep slab instability, and large charges fail to trigger deep slabs in the areas of concern.

- Continuous monitoring for extended storm cycle activity that could lead to a cycle of deep slab avalanche activity is necessary.

- Diligent monitoring for unusual conditions that could result in a deep slab avalanche cycle would be necessary.

- The historical data and empirical knowledge indicated that unless an unusual or historic storm cycle occurred it would be unlikely for Class IV or V size avalanche events to occur once daily avalanche hazard reduction efforts had been conducted on a routine basis.

- Above all, the patrol was provided the directive that if conditions warranted, all operations in this area of the resort would be ceased until the hazard abated. Based on the information reviewed, there was a strong feeling that these conditions could be easily identified.

Practically speaking, the thoughts discussed applied to routine operations whether the aerial tramway would be functional or not. This exercise provided an opportunity to discuss these concepts in regard to the operation modifications proposed.

6.0 2007/08 OPERATIONS

The 2007/08 season began with some early snow in October that was followed by mostly dry conditions and cold temperatures in November. During the 128 days the resort was open (December 1 to April 6) there were only 21 days when it did not snow. By June 13, 2008 over 700 inches of new snow had fallen at the resort's upper snow study plots. The last day of avalanche hazard reduction efforts occurred on June 13 and produced slab avalanches with 0.6 to 1.3 deep crowns.

The fall setup was the perfect scenario for the development of deep slab instability in the Deans Slide starting zone. On December 4, 2007, the first day of avalanche hazard control in this area, the patrol explosively triggered Class III size, one-meter deep slab avalanches, in the Deans Slide and Fitzs Slide paths. These slabs failed on a buried weak layer of early season faceted snow.

Figure 4: Photograph of the crown of a hard slab avalanche that was explosively triggered from the Deans Slide Avalanche Starting Zone on the first day of avalanche hazard reduction efforts on this path during the 2007/08 season.

Class Size	**I**	**II**	**III**	**IV**	**V**
Dean's Slide	0	1	1	0	0
East Ridge	1	0	0	0	0
Fitz's Slide	0	0	2	0	0
Hanging Rock	20	18	3	0	0
Rendezvous Bowl	0	0	0	0	0

Table 7: Number of slab avalanches by size that occurred on the slide paths of concern during the 2007/08 season.

During this season there were 46 avalanche events observed and recorded on the slide paths of concern. The vast majority, 41 events, occurred on the Hanging Rock Slide Path.

There were no Class IV or V events on any of these paths. There were six Class III slides. All of these Class III slides were explosively triggered. This season's avalanche activity was consistent with the expectations garnered from this study.

7.0 CONCLUSIONS

This methodology was very effective in characterizing the avalanche hazard and communicating the results of this effort to staff.

As a result of this study, avalanche hazard management operations during the 2007/08 season were conducted with surety and confidence.

This example highlights the value of historical data and GIS technology as practical tools for the mitigation of avalanche hazards.

The results of this study will be useful during future avalanche hazard reduction efforts regardless of the means patrollers use to access their routes. The application of this methodology to the other slide paths in the historic database would provide useful insight into the character of the avalanche hazard of each of these paths.

As of August 2008 the new aerial tramway is expected to be completed before the start of the 2008/09 season. This completion will allow the patrol to return to routine "from the top" operations.