LOVELAND PASS AVALANCHE MITIGATION

Fanny Bourjaillat*[1], Ethan Greene[2], Tyler Weldon[3], Ray Mumford[4], Philippe Berthet-Rambaud[1]

[1]Engineerisk, Sainte Hélène du Lac, France
[2]Colorado Avalanche Information Center, Boulder CO,USA
[3]Colorado Department of Transportation, Denver CO, USA
[4]Dillon, CO, USA

ABSTRACT: Close to Denver, Loveland Pass is part of the route that provides access to some famous ski resorts such as Vail and Keystone and is among of the more frequently used passes in Colorado. The pass is the primary route for trucks transporting hazardous materials (not authorized to travel through the Eisenhower Tunnel) to return to I-70 on either side of the Eisenhower Tunnel.
It is also kept opened on a regular basis while being situated at an elevation of about 11,900 feet. Due to this situation, the exposure to heavy snowfall and strong winds leads to a major snow avalanche hazard. There is not less than 30 avalanche paths that threaten or could reach Loveland Pass and I-70 in the area. This highway presents a real management problem for the Colorado Department of Transportation (CDOT) which is responsible for the safety of the highways.
This paper presents the risk assessment analysis and mitigation strategy key points prior to the installation of the first protections during the summer and fall of 2015

KEYWORDS: Avalanche mitigation, Loveland Pass, Protection strategy

1. INTRODUCTION

CDOT wanted to improve the safety on Loveland Pass for both the users and the highway technicians, and to avoid the closures of this road as much as possible. The goal was to find the most appropriate protection scheme for each avalanche path in regards to the snow avalanche hazards (Fig.1).

Figure 1: Location of avalanche paths to be studied for Loveland Pass and I-70 (missing Vail Narrows)

* Corresponding author address:
Fanny Bourjaillat, Engineerisk
PA Alpespace, Bat Cleanspace, 73800 STE HELENE DU LAC - FRANCE
tel: +33 6 23 75 06 42
email: fanny.bourjaillat@engineerisk.com

An exhaustive study was conducted based on traditional field investigations, expert analysis and avalanche modeling thanks to RAMMS software. The results were used to classify possible mitigation strategies to find the most optimal solutions based mainly on artificial releases, but on other active protections (snow fences , bomb tram…) as well.
First, during the summer and fall of 2015, Gazex exploders were installed in the 7-Sisters avalanche paths, one of the most dangerous areas.

2. INPUT DATA

2.1 Study context

The principal goal of CDOT is to keep the roads (I-70 and US 6) open as much as possible while maintaining a safe environment for its workers and the public. The challenge now is that it's not always possible to manage the risk sufficiently and quickly when conditions change rapidly and become dangerous. Either the weather doesn't permit helicopter use for heli-bombing or the time required to install the avalauncher and / or artillery is too long and avalanches are already naturally triggered. It's then necessary to close the road to finalize artificial release operations, recover a sufficient safety level and clear the snow to reopen the road.

CDOT would like to reduce the risk of avalanches impacting the road by managing the hazard as soon as possible (according to the risk/path priority). The strategy, here applied at least to the concerned paths, is to release small avalanches before the snow accumulates enough to cause a significant release able to reach the road. Steep slopes (over 35°) are the most suitable to allow this strategy which will reduce snow clearing operations on the road and the closure periods.

The most adapted devices in such cases are fixed and remotely controlled systems like Gazex® or O'Bellx® (Berthet-Rambaud & al, 2010) (Fig. 2).

Figure 2: O'Bellx® at Chamonix (left) and Gazex® at 7 Sisters (right, Source: R.Mumford)

Effectively, they are operational regardless of the weather conditions and at any time because they are remotely controlled. They can be adapted to the starting zone's surface thanks to the different sizes of exploders and the use of a gas mixture which induces less constraints than solid explosives regarding deployment, environmental impact or the recreation user's safety (no UXO problems). Avalanches can be released when the snow accumulation is sufficient to control the avalanche flow resulting in less volume and possibly a shorter runout. Operators can also take adapted precautions before a mission (close the road, prepare …) as procedures and time will be managed.

Permanent protections such as snow fences, also presents a good alternative in such a context. If they are designed correctly regarding maximum snowpack (Margreth, 2007), they fix the full depth of the snowpack, avoiding any avalanche releasing during a winter season. Questions for this type of protection are essentially the financial cost and/or the environmental footprint.

Of course, there are other technologies of remote systems for preventive triggering which are available for consideration but they are not as reactive. Bomb tram, hand charges, Howitzer etc require an "on site" intervention by CDOT operators instead of remote control.

2.2 Methodology

There is no unique methodology to reach the best avalanche mitigation method, the methodology used for Loveland Pass was based on several points.

First, it was about setting priorities. The most dangerous and most active paths won't be managed the same as others, they will require more attention and investments. It was a question to deal with in both the avalanche paths and banks on Loveland Pass.
There were 3 main sites threatening Loveland Pass and I-70, each had their own particularities: the 7 Sisters on Loveland Pass, the West Portal Loop road located close to the Eisenhower tunnel on I-70, and Vail Narrows on I-70 Vail Pass which consists mainly of banks.

On site visits from roads and aerial pictures using a helicopter defined the whole/global configuration of each path (Fig. 3).
It was very important to exchange information with local technicians and engineers who manage these roads all winter long. They are very familiar with the accurate (and historical) on site conditions: 1. How the wind is loading the snow on the slopes. 2. The locations of the start zones and the most common release areas. 3. The conditions that most often result in an avalanche. 4. How they are currently being mitigated (avalauncher, howitzer heli-bombing) …
Trying to understand what the main problems are, what is the behavior of a path according to its configuration and knowing the weather phenomena in order to address, as best as possible, the manager's problems is one of the most important and interesting part of an avalanche mitigation study.

It's also important to collect as much information as possible, such as testimonies and snow data in order to be as pertinent as possible.

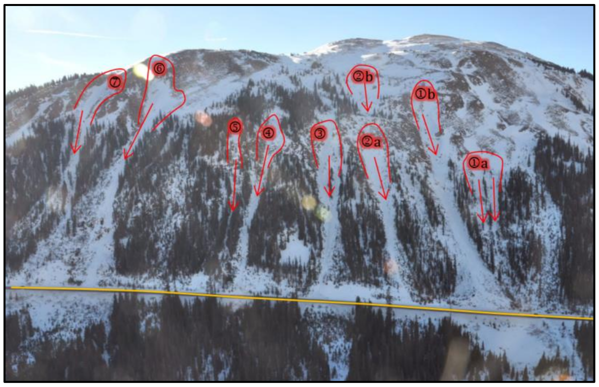

Figure 3: Definition of each avalanche paths for 7 Sisters

Map analyses and meteorological statistics are more ''quantitative'' and more accurate about starting zone(s) definition notably with the determination of all specific parameters such as slopes gradient, snow height etc.
Available DEM allows as well to propose avalanche modeling. RAMMS software (SLF, 2013) was used for the Little Professor and Black Widow paths on Loveland Pass (Fig. 4). The context was specific here, with two main issues, since these two paths threaten both the highway and the Arapahoe Basin ski resort. The ski resort, on the other side of the road, was impacted by an avalanche the 20th of February 1986 destroying a chairlift and covering the current visitor parking. The question was to evaluate if avalanches could again reach the ski resort infrastructures taking into account the potential preventive release thanks to Gazex®. Avalanche modeling is a good tool to help in the understanding of avalanche flow by comparing results influenced by some parameters.

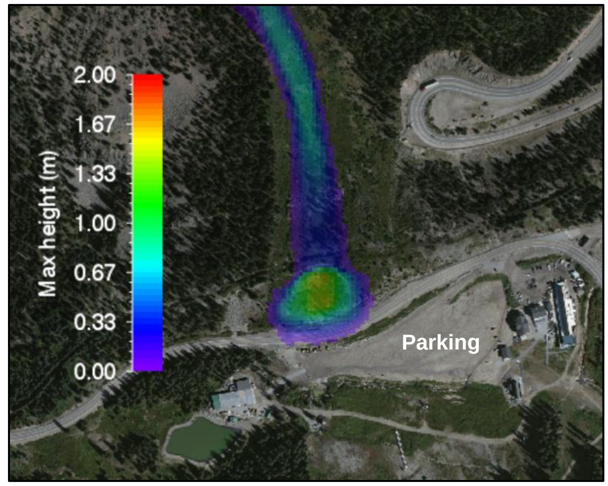

Figure 4: RAMMS modeling, Maximum height in preventive release conditions in order to evaluate how avalanches could reach Arapahoe Basin ski resort

3. CLIMATE AND SNOW DATA

3.1 Snow accumulation

There are at least three zones, each designated by different climatic characteristics in the Western United States. From West to East, they include: the Coastal Alpine Zone of the Sierra-Cascade Crest along the West Coast, the Intermountain (zone) of the Wasatch and Sawtooth Ranges and the Continental (high alpine zone) of the Continental Divide areas in the Rocky Mountain chain.

The High Alpine Zone is dominated by a continental climate. It includes the northern Colorado Rockies and so Loveland Pass (Cary J. Mock and Karl W. Birkeland, 2000):

- Relatively shallow snowpack with settled mid-winter snow depths less than 5 feet (1.5 m)
- Less frequent storms with lower-density snow (than the coastal climate)
- Long periods of drought with very cold temperatures during winter
- Variable temperatures throughout winter, leading to more varied layers within the snowpack
- Both direct-action avalanches and delayed-action avalanches are common and often involve layers deep within the snowpack; the pack can remain unstable and avalanches may be triggered even weeks after the last significant storm.

Avalanche forecasts in these areas depend heavily upon observations of structural weaknesses in the snowpack as well as ongoing weather observations.

Four main snow study stations are used to gather weather data around Loveland Pass and I-70. CDOT has recovered accurate data from the winters of 2009-2014.
The maximum at each station are shown in next the following figure (Fig. 5) both for fresh snow accumulation (for one day, in cm) and snowpack, Tab.1. This data gives the maximum ranges of snow conditions in the corresponding avalanche paths:

- Loveland Pass East: 7 Sisters, Outward Bound, Boy Scout, Big Windy…
- Loveland Pass West: Black Widow, Little Professor
- I-70 Tunnel: West Portal Loop road, Batch Plant, Whistlers…
- Vail Pass: Vail Pass Narrows

I-70 TUNNEL (3 396 m)

	New snow	Snow base
2009-2010	45	135
2010-2011	35	240
2011-2012	15	85
2012-2013	20	200
2013-2014	30	225

LOVELAND PASS EAST (3 429 m)

	New snow	Snow base
2009-2010	30	110
2010-2011	40	200
2011-2012	20	120
2012-2013	20	175
2013-2014	30	230

LOVELAND PASS WEST (3 355m)

	New snow	Snow base
2009-2010	20	115
2010-2011	40	235
2011-2012	20	115
2012-2013	25	160
2013-2014	35	210

VAIL PASS NARROWS (2 918 m)

	New snow	Snow base
2009-2010	20	130
2010-2011	40	200
2011-2012	20	115
2012-2013	25	150
2013-2014	45	190

Figure 5: Maximum daily snowfall (new snow) and snowpack (snow base) in cm

These data shows rather similar maximum snowfalls (around 40 to 45 cm) and maximum snowpack (between 230 and 240cm except at Vail Pass narrows but which can be explained by a lower altitude).

3.2 Wind context

The two main causes of high winds in Colorado during the winter season are the air pressure difference between strong low pressure and cold high pressure systems, and Chinook winds developing across the Front Range and other eastern mountain ranges.

A strong, very cold high pressure system moving from the north and setting up west of the Rockies can generate a damaging wind down the leeward slopes of the mountains, known as a bora. These episodes feature widespread high winds from the west or northwest into the adjacent plains at speeds which can exceed 100 mph. Much rarer are those episodes when low pressure is across the Rockies, and strong, cold high pressure is across the Great Plains. The result is damaging winds from the east across the western slopes of mountain ranges and adjacent valleys.

Mid and upper level winds over Colorado are much stronger in the winter than in the warm season, because of the huge difference in temperature from north to south across North America. West winds, under certain conditions, can bring warm, dry chinook winds plowing down the slopes of the eastern mountains. These winds can exceed 100 mph in extreme cases, bringing the potential for widespread damage. Winds of 60 to near 100 mph will occur in and near the foothills in areas such as Fort Collins, Boulder, Denver, Colorado Springs, Canon City, Westcliffe, Walsenburg and Trinidad areas. The areas around Boulder and Westcliffe are especially prone to these extreme wind episodes.

Concerning Loveland Pass, the prevailing wind is coming from the West/North West, with a sufficient velocity resulting in regular snow drift, Fig. 6. Slopes exposed to the west will be eroded whereas snow accumulations will usually be located on east-facing slopes.
Wind events from the east happens only a few times a winter.

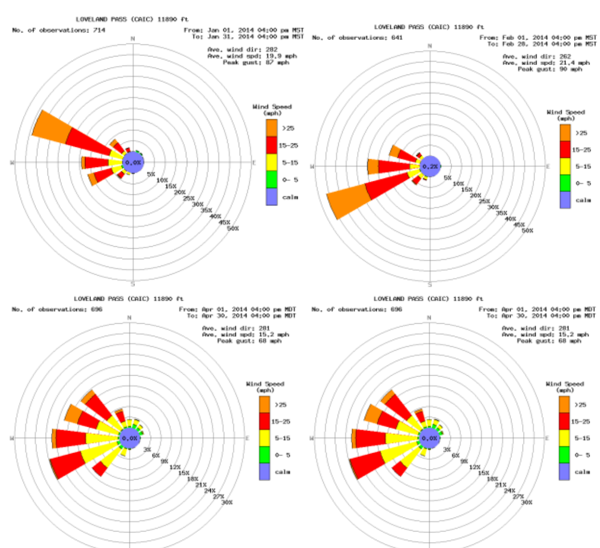

Figure 6: Loveland Pass Wind roses from January to April 2014

4. PROTECTION STRATEGY

4.1 Sites description

Two different sites will be detailed below, each with its own particularity regarding the protection approach: The West Portal Loop road which was among the first priorities and the ''South Banks'' particularly exposed to the wind.
Similar analysis (depending on priority) was performed for each path.

West Portal Loop is situated just above the access to the Eisenhower tunnel (Fig. 7). It consists in several path/gullies that are quite tight leading directly to the loop road which is often used by snow removal vehicles, trucks transporting hazardous materials …
It also includes the protection of the water tank access as well. They are both situated further north from the tunnel and are reachable thanks to a small pathway directly below avalanche paths.
CDOT releases avalanches using the Avalauncher, about 15 times a winter (just 2/3 times for the upper part), the road is reached 3, 4 times. In 1996, it affected the CDOT tunnel roof.
The starting zones are often influenced by snow drift. There can be about 2m of snow in gullies when the wind is coming from the West.
According to the wind direction, the starting zones location can be also different.
Usually, the main starting zones are situated in gullies, around an altitude of 3,500 and 3,600 meters. However, when the wind comes from the east, fresh snow accumulations are also on the upper part of the slope, between 3,700 m and 3,800 m. It rarely happens (2/3 times a winter), the snow is then rapidly transported by the west wind the day after, but, in the meantime it can lead to avalanches releasing.
The crown line can be 1m high after preventive releasing operations.

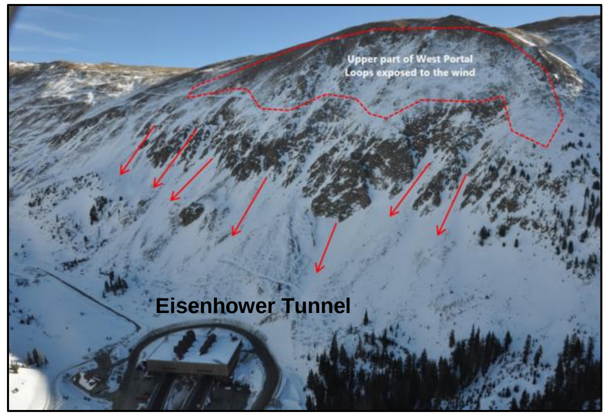

Figure 7: West Portal Loops

South Banks (Including Big Windy, Outward Bound, Boy Scoot and No Brains) are situated on the south part of Loveland Pass just after crossing the summit in the direction of Arapahoe Basin. They consist in several slopes with small positive elevation but significant slope gradients (Fig. 8).

Contrary to the East banks, the South banks are mostly affected by snow drift and accumulates a large amount of snow on their slopes. About 8 meters of snow accumulation along the road are possible when the wind is coming from the North West.

All these banks are often preventively released by case charges or hand charges: between 20 and 30 times a winter. Due to their proximity to the road, the amount of avalanche debris on the road can be significant despite their small surface area.

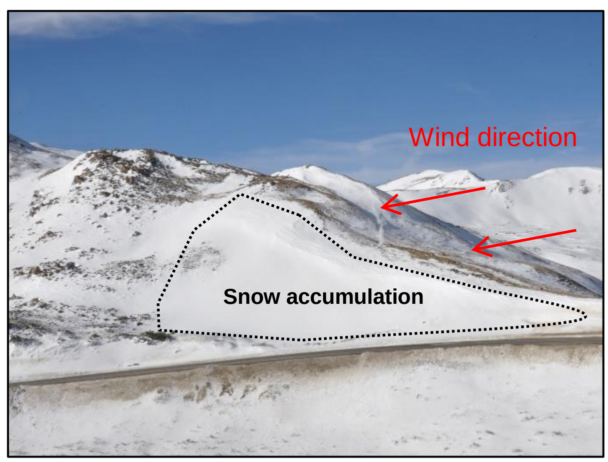

Figure 8: Snow accumulation on Outward Bound bank due to wind

4.2 Protection strategy

Due to their own particularities, there may be several solutions (when it's feasible) for one path, each with their drawbacks and/or advantages as explain in 2.1.

Several preventive release systems were proposed for the protection of Loveland Pass. Sometimes they can be replaced by case charges and/or snow fences depending on the protection level desired.

For the West Portal Loop road, the upper part and lower parts of the slope were separated.
The lower parts can be protected using fixed systems. These ''lower '' points are effectively released often during control operations, due to the main snow accumulations in gullies. Shot points have been determined during the field visit, they are the most frequent and will permit to secure all the main slopes. About 7 shot points are necessary to protect the tunnel access (including two points which would need an additional winter of observation before confirmation) and about 4 shot points to secure the water tank.
Concerning the upper part, CDOT conducts preventive release operations about 2/3 times a winter on these slopes. Regarding this low frequency, the most appropriate solution would be to continue to release avalanches using the avalauncher.
The other options could be to install 5 Gazex® systems or snow fences (about 2km). The investment would be difficult to justify according to this context.

Concerning the South Banks on Loveland Pass, it would first be necessary to install snow barriers/wind drift control structures (Naaim-Bouvet, 2013) to limit and significantly decrease the height of the accumulated snow on the slopes due to the wind. It's not possible to install a fixed system or snow-fences in such condition as they will be rapidly buried and/or damaged because of the snow accumulation and would no longer be effective.
It's quite easy to install this kind of ''wind protection'' when there is enough space uphill, that's the case for Boy Scout and Big Windy.
It will be a greater challenge for Outward bound which is situated at the Loveland Pass summit, close to hiking trails and site seeing, and with consequent slopes behind the ridge…
After the prevailing wind direction is verified, definitive snow barriers can be installed to allow complementary protections thanks to snow fences or Gazex® systems (or continue with Case Charges) for Boy Scout and Big Windy.

For Outward Bound, if snow barriers are conceivable, snow fences or Gazex® could be installed there as the main protections. If not, it will be necessary to install 2 Gazex® or 2 O'Bellx® combined with jet roofs which will reduce the snow accumulation above the 2 systems.

5. CONCLUSION

The Loveland Pass is a very interesting case study for avalanche mitigation.

All of the avalanche paths present different configuration and particularities. It was a question of finding the right compromise between expectations and what could be done for each situation according to snow and particular wind conditions.

Finally, several possibilities were proposed for each avalanche paths (Fig. 9).

		Keep the current management	Snow fences	GAZEX® 0.8 m³ or Obell'x®	GAZEX® 1.5m³	GAZEX® 3m³	Necessity of wind systems
WEST PORTAL LOOPS	upper	X	-	-	-	-	-
	lower	-	-	4 + 2	5	-	-
VAIL NARROWS		-	≈ 660 m/ 2 200 ft +zone 1	-	-	-	-
LITTLE PROFESSOR		-	-	-	5	-	
BLACK WIDOW		-	-	-	4	-	X
GRIZZLEY		X	-	-	-	-	
BATCH PLANT		-	-	1	-	1	-
WHISTLERS			-	2	3	-	-
A-SIDE		X	-	-	-	-	-
B-SIDE		X	-	-	-	-	-
226		-	≈ 100 m/ 330 ft OR	2	-	-	-
EAST BANKS		-	≈1 km/ 3 300 ft	-	-	-	-
BIG WINDY/BOY SCOUT		-	≈ 200 m/ 660 ft OR	2	1	-	X
OUTWARD BOUND		-	≈ 210 m/ 690 ft OR	2	-	-	X
NO BRAINS		-	≈ 40 m/ 130 ft	-	-	-	-

Figure 9: Summary of most appropriate solutions for each paths

In total, about 30 Gazex® (twelve 0.8m³, eighteen 1.5m³ and one 3m³) and about 7 000 feet of snow fences were proposed in this analysis.

During the 2015 summer and autumn, two Gazex® 0.8m³ exploders and nine Gazex® 1.5m³ exploders were installed in the 7-Sisters with good results during the mitigation work last winter.

REFERENCES

Berthet-Rambaud P, Farizy B, Juge A, Gallot Lavalee X, Bassetti E, 2010: A new environmentally friendly device for avalanche preventive release. Proceedings of the *International Snow Science Workshop*, Squaw Valley, CA.

Cary J. Mock and Karl W. Birkeland, 2000: Snow avalanche climatology of the Western United States Mountain Ranges, *Bulletin of the American Meteorological Society Vol. 81. No 10,* pp.2367-2392

Margreth S (SLF Davos), 2007: Defense structures in avalanche starting zones, Technical guideline as an aid to enforcement, Federal Office for the Environment FOEN, 136pp

Naaim-Bouvet F, UR ETNA, RTM, 2013: Technical handbook, Wind drift control structures in mountain areas. Proceedings of the *International Snow Science Workshop,* Chamonix-Mont-Blanc, France, pp.134-139

SLF, 2013. RAMMS, rapid mass movements simulation. A numerical model for snow avalanches in research and practice, User Manual v1.5 and new RAMMS version 1.6