AN EXPLOSIVE DELIVERY SYSTEM IMPLEMENTATION IN THE STEEP GULLIES AT THE ARAPAHOE BASIN SKI AREA

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ABSTRACT: Traditional methods of avalanche mitigation have been in use for many years at the Arapahoe Basin Ski Area. These methods include hand routes, use of multiple avalaunchers, ski cutting, ski/boot packing, compaction rollers[2] and a single bomb tram fixed wire. With an expansion planned for the 2017-2018 season and a move into additional avalanche terrain called the Steep Gullies, there became a need for alternative methods of avalanche mitigation and a more robust bomb tram system. With a design introduced by Unique Fabrication[2], the ski area was able to install a network of terminals and fixed wires called an Explosive Delivery System (EDS) that would allow us the capability to deliver explosive air blasts at many different slope elevations within these avalanche paths. Compared with traditional avalanche mitigation methods, the new system provides efficiency, accuracy and enhanced worker safety in this extreme terrain.

KEYWORDS: Bomb Tram, Air Blast, Avalanche Mitigation, Mitigation Methods, Worker Safety, Explosive Delivery System

1. INTRODUCTION

The Arapahoe Basin Ski Area operates under a special use permit through the USFS now offering 1428 acres of terrain to our guests. Located in the Northern Rockies of Colorado, the ski area functions within a continental snowpack and is known for its long operating season (typically October into June). The Beavers expansion began during the summer of 2017, in which 468 acres of new terrain would be added to our existing area over the next two operating seasons. Of the 468 acres, 129 acres of complex avalanche terrain known as the Steep Gullies would effectively be added for the 17/18 season (Fig.1). Prior to the integration of this terrain into our operation, the Steep Gullies 1-8 have had a broad history of being considered extreme out of bounds terrain popular to many backcountry enthusiasts. Yet the Steep Gullies have also killed 5 people since 1982.

With the expansion, the ski area now boasts over 150 avalanche paths and over the years has effectively utilized several methods or techniques of mitigation to reduce the avalanche hazard. These methods include hand routes, use of multiple avalaunchers, ski cutting, ski/boot packing, compaction roller[2], terrain closures, and a single bomb tram fixed wire.

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2. EXPANDING INTO THE STEEP GULLIES

The addition of the Steep Gullies to our operation took careful consideration because all of our guests entering "The Beavers" or effectively our entire expansion area, would have to egress out underneath the run out of the Steep Gullies to get back to a chairlift (2017/2018 season only). It became evident that in order for the Steep Gully terrain to be safely mitigated that the traditional methods or tools of avalanche mitigation would not be sufficient and worker safety would also be compromised without some changes to our procedures and infrastructure. In addition, Snow Safety needed to find a way to effectively deliver explosives into mid path areas where advanced faceting and persistent weak layers could be present (Ferrari and Mt. Rose Ski Patrol, 2008) or perhaps lack skier compaction. Throwing charges low in these paths would be impossible and hand routes would require supplemental mitigation efforts

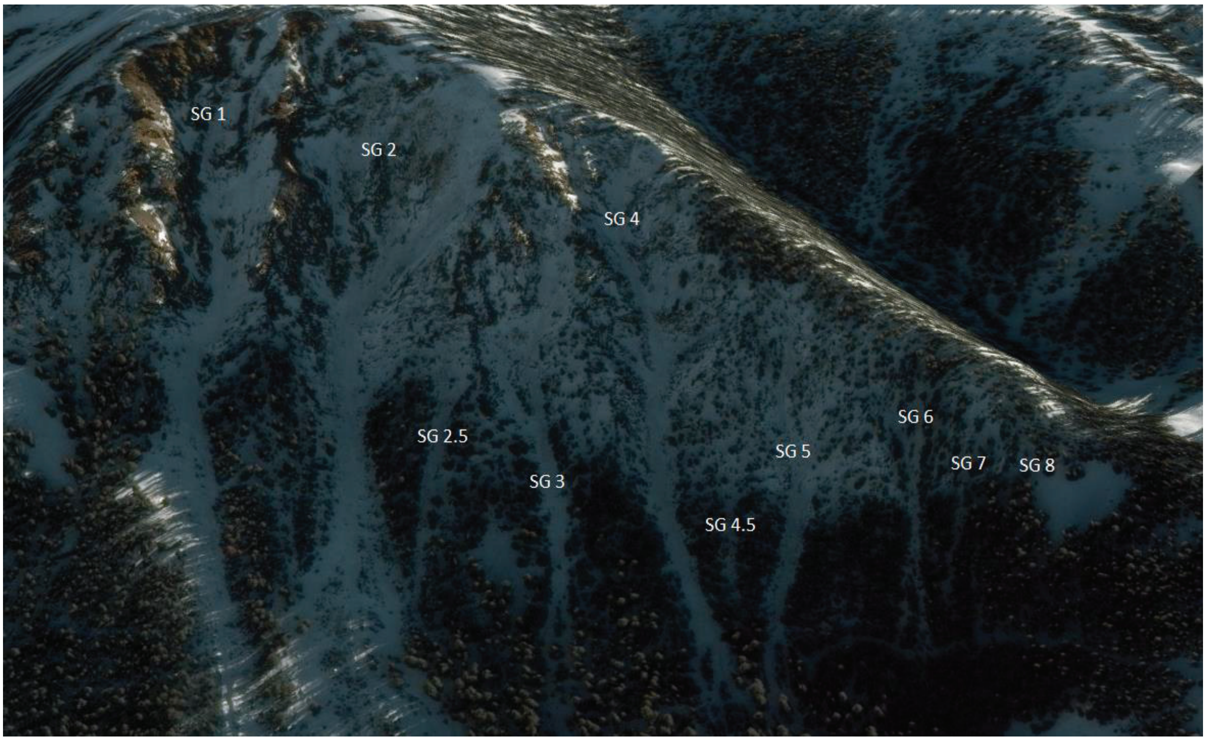

Figure 1: Steep Gullies 1-8

prior to traveling in high consequence terrain.

For years leading up to the expansion the ski area engaged in studying several trends and collected data on current backcountry usage, snow depths, skier/rider patterns and where to construct permanent snow fences. For the Steep Gullies, we continued to perform a detailed terrain analysis with constant site visits and touring sans explosives.

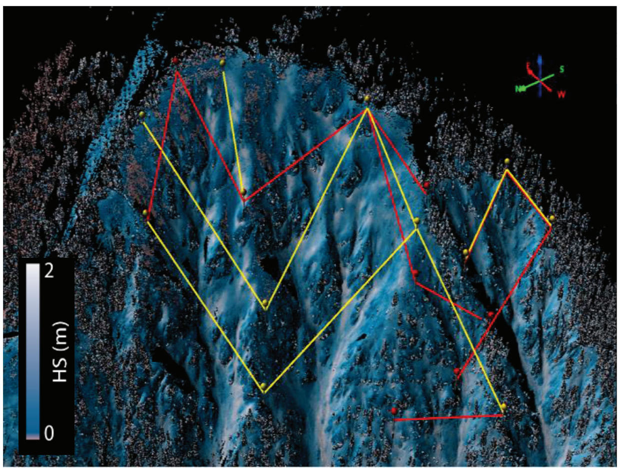

Figure 2: Planned Steep Gullies EDS network. Initial layout (red) was revised (yellow) using LIDAR snow depth imaging.

We were also able to utilize several LIDAR images of the Steep Gullies which afforded us the ability to see and better understand snow deposition based on the terrain with respect to aspect and wind (Deems, et. al., 2016) (Fig. 2). These LIDAR images provided a roadmap for terminal and fixed wire locations.

The Steep Gully zone (Fig. 1) is made of 10 distinct avalanche paths varying in size, terrain, trees and vertical gradients. Slope angle varies between 30 to 39 degrees and the macro aspect is northwest, with micro aspects ranging from west thru north thru east. Steep Gullies 1, 2 and 4 are the largest ranging in 372 to 422m of vertical. These larger paths are extremely rocky throughout their entirety with smaller trees, large rocks and runnels at the run outs. The remaining paths get progressively smaller in vertical size but maintain similar aspects and slope angles throughout the Steep Gully zone.

3. AVALAUNCHER USE

The use of avalaunchers at the ski area has always been an effective tool at reducing the avalanche hazard, especially on the East Wall, which is a 5.2km west thru north facing ridge with 62 avalanche start zones (Borgeson and Hartman, 2008). Since 2007/2008 (Zuma Bowl expansion) the ski area has averaged approximately 1000 ordinances annually, 18% of which are projectiles. The ski area currently has a fleet of avalaunchers available for use that include an Avacaster, X2000M Tray Loader, and a B2000M McCracken.

After numerous site visits it was decided that an avalauncher in the Steep Gullies would be impractical for numerous reasons. First, overshooting would be possible and even more pronounced with a deflecting projectile. There would be unintended consequences of hitting infrastructure which lies directly opposite this terrain. Furthermore, there was not a good place to locate a gun tower. U.S. Highway 6 would be extremely close considering the Table of Distances and regulations set forth by the BATFE. Also, there was not a gun/tower location that would allow us to shoot a majority of critical targets either because of oblique angles or tall tree canopy. The potential gun/tower would also need to be located in a roadless area that is only accessible in the winter making maintenance and access difficult. Access would be further complicated on an avalanche mitigation morning.

4. EDS (EXPLOSIVE DELIVERY SYSTEM)

4.1 Bomb trams

Bomb trams are also a common mitigation method at many ski areas in the west and Arapahoe Basin installed one rudimentary fixed line years ago on the north end of the East Wall. We utilized left over steel, lift parts and some cable from a local hardware store. Like many existing bomb trams, we wanted to dictate where in the path a shot could be placed and to also raise and lower the shot (air blast) to an effective height off the snow surface (Ueland, 1992). Not only would this be a requirement for our new design in the Steep Gullies but we would also need multiple fixed lines to cover dynamic shot placements.

4.2 EDS Design

The final design plan called for the installation of 8 fixed wires through a series of 11 terminals. The major paths (Steep Gullies 1,2, 3 and 4) would see the installation of this network and we contracted with Unique Fabrication and Mark Bosse out of Norwood, CO to design and build the Explosive Delivery System (EDS). This EDS (fka bomb tram) would use tension, compression and anchors rather than concrete footers or foundations. Tension of the fixed line and guy wires, combined with compression of the terminal towers would create the structure of the EDS. Similar to a suspension bridge, all the forces are applied to the anchors and these anchors must be secure. The tension of the system is determined by the amount of deflection and length of the fixed line. When calculating tensions, allowances must be made for thermal expansion, wind speed, altitude, and slope angle. Due to the light weight nature of the trolley and its typical explosive cargo (2lb cast primer), it plays a small role in tension. The EDS at Arapahoe Basin is unique because there are multiple fixed lines attached to the terminal towers using two guy wires. This becomes more complicated since the fixed lines each have different tension values. Tension values for the EDS vary from 181 to 498 kg (400 to 1098 lbs). A short and steep tram will have less tension, whereas a long and flat tram will use higher tension (M. Bosse[2]).

Several terminals would also share fixed wires thus creating a connected network to help us deliver explosives lower within these paths and give us the ability to position air blasts in precise locations.

4.3 Installation of the EDS

Tools, anchor materials and compressor were flown in above SG 1 on 6/27/17 and the entire month of July was spent drilling holes varying in depth to accommodate permanent anchors, temporary anchors, and dowels for the terminals to sit. The towers were pre-assembled in our parking lot and flown in on 9/1/17. Tension was pulled on the entire network from 9/4 to 9/8.

Terminals would require a minimum of four holes (averaging 3.8cm diameter) 2.5 – 3m deep. These would be the holes that would receive the 2.5cm x 300cm (1 inch) all-thread steel rods. The all-thread rods were poured with concrete grout to solidify the holes. These would provide the anchors for the guy wires that attach to the top of each terminal (Fig. 3). Each terminal sits on a 3.8cm x 1.5m steel dowel that was also drilled into the rock. Out of 11 terminals, nine are fabricated at 6m (20 ft) tall whereas the remaining two are 9m (30 ft).

Terminals 1 to 2 had the shortest fixed wire distance at roughly 92 meters, where as terminals 10 to 11 had a distance of approximately 186 meters.

The largest challenge was drilling holes in steep rocky terrain with poor footing and loose granite. The terminal sites also varied in distance from the

Figure 3: all-thread rods drilled and grouted into rock with guy wire

location of the compressor. Distances from the compressor to terminal locations ranged from 30m up to 427m (terminal 11). We utilized a two inch (5cm) lay flat hose with air fittings to cover large distances and avoid power loss on the rock drill. The lay flat hose was ordered in 15m (50ft) sections to facilitate transport, setup and tear down at each terminal location.

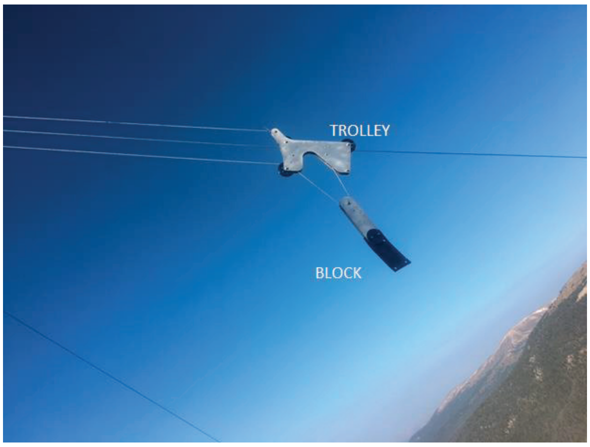

Figure 4: block and trolley

4.4 <u>EDS anatomy</u>

Each top terminal, has at least one trolley and one block that rides on the fixed wire (Fig. 4). Terminal 8 would be integral to one system alone, as it receives shots from terminal 7 as well as delivers shots to terminal 9 and terminal 6. Terminal 6 receives from terminal 5 and terminal 7 also delivers to terminal 4. Terminal 4 also receives from terminal 3. In summary, terminals 5, 6, 8, 9, 7, 4 and 3 are all under tension together thru fixed wires and guy wires in one stand-alone system (Fig. 6).

Each top terminal has one spool to lower or raise the trolley on the fixed wire, and another spool to control the height of the block (which has the explosive attached) from the snow surface (Fig. 5).

Terminals 7 and 8, each have two trolleys and two blocks, thus 4 spools.

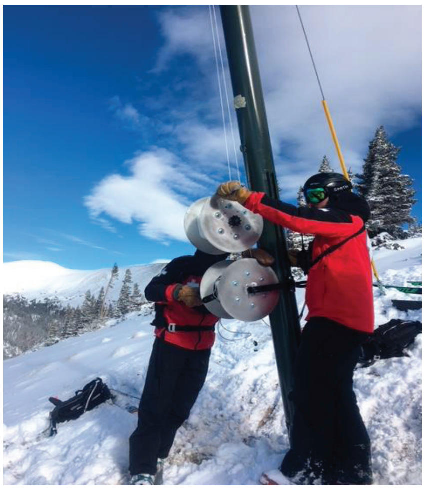

Figure 5: terminal 1

Maximum shot weight capacity is approximately 25 lbs. The most common form of explosive used on the EDS was a 2lb cast primer with two, 2m pre-made fuse assemblies.

5. RESULTS

As of June 3 (closing day) we finished the 2017/2018 season with a total of 732cm (85% of average) of snowfall. We opened the Steep Gullies on the 25th of January and closed them for the season on April 26th, totaling 92 days with intermittent closures for mitigation. Approximately 72 ordinances were suspended air blasts using the EDS and results were achieved from 61 of those shots (Tbl. 1)

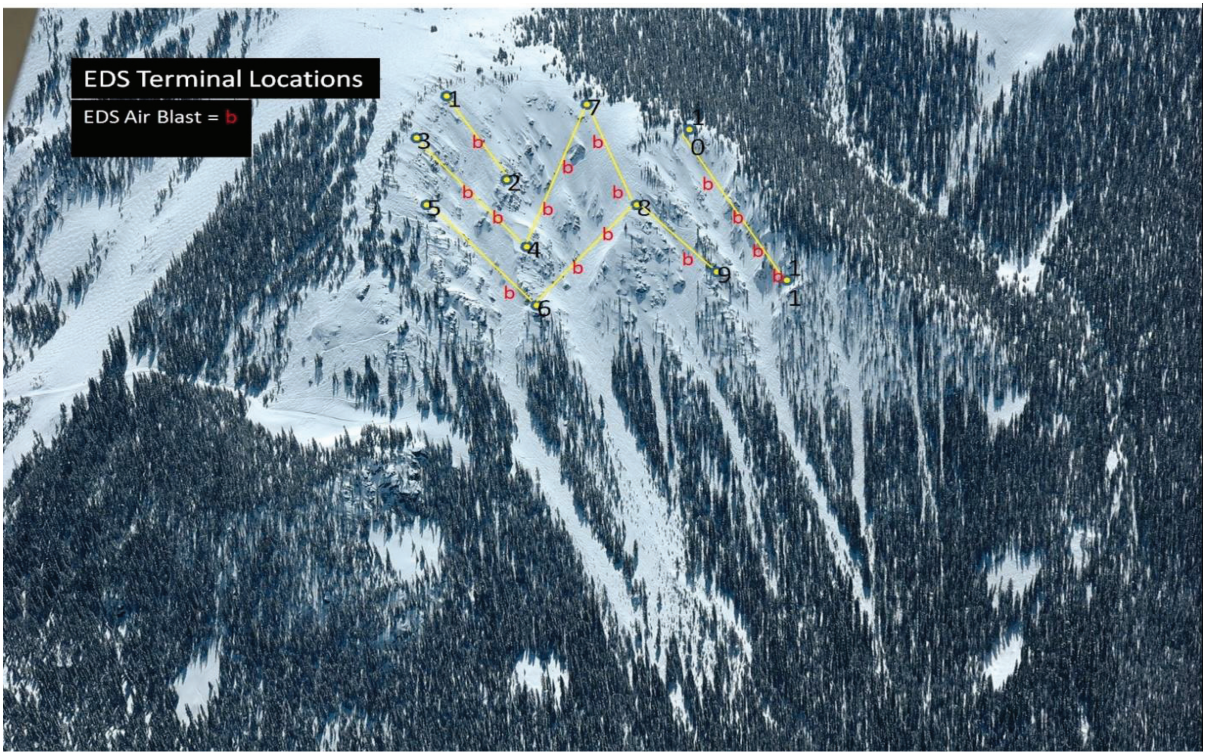

Figure 6: EDS terminal locations 1-11 with potential air blast locations. *Note the connection of terminals 5, 6, 8, 9, 7, 4 and 3*

Tbl. 1: Total of 61 EDS results

Relative Size-Destructive Size	*# Air blasts*
R1-(D.5-D2)	58
R2-(D1.5-D2)	3

5.1 Problems and work arounds

The most common problem was to arrive at a terminal and find the block on the ground from broken nylon rope. The only fix is to ascend the tower and re-attach the block which requires a two-person team with a climbing belay set up for safety. The blocks were being stored high up and tight to the trolley. The tight marriage of block and trolley caused abrasion of the nylon rope from winds.

We came up with three different solutions or a combination to help alleviate this problem:

- Utilize a metal cable in place of the nylon at point of abrasion
- Utilize industrial weather stripping on the edge of the aluminum trolley to prevent abrasion of nylon rope
- Store the blocks low on the towers limiting tension of the rope

6. CONCLUSION

After one season, the EDS is proving to be an effective tool in helping us mitigate the Steep Gullies efficiently and safely. Shots can now be deployed from many locations prior to patrollers entering high consequence terrain as a supplement to hand routes. Arapahoe Basin will continue to use, test and maintain the functions of the EDS in future seasons in order to maximize its benefits to worker safety, avalanche mitigation and open terrain.

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