EVOLUTION OF AIR BLASTING TECHNIQUES FOR AVALANCHE CONTROL AT BRIDGER BOWL SKI AREA, BOZEMAN, MONTANA

ABSTRACT

Aerial detonation of explosives was not practiced at Bridger Bowl Ski Area ten years ago. Today twelve manually operated "bomb wires" are operational and are used routinely during daily avalanche control work. Ten of these twelve incorporate a "counterweight-belay" mechanism which enables the user to gently lower an explosive into a pre-determined position above the snow in an avalanche starting zone. Bridger Bowl's first bomb tram was built from bone yard lift parts in 1981. Its use indicated larger, higher volume avalanches could be released per amount of explosive used with aerial detonation. To take advantage of this increased explosive efficiency, other "bomb wires" were installed. Each consists of a permanent length of cable spanning a steep avalanche starting zone on which some type of retrievable bomb carrier rides downhill on pulleys. On early installations the bomb was simply thrown into place and would hang from the pulley. Later different mechanical and electromechanical carriers were built to transport bombs along the cable. In 1988 a mechanical "counterweight-belay" type of carrier began to replace all other types of carriers. This resulted in a standardization of bomb wire procedures. Routine use of bomb wires has become an important part of the avalanche control program at Bridger Bowl.

The Bridger Bowl Ski Area avalanche control program's goal is to reduce all avalanche hazard in the ski area to acceptable levels as early in the day as practical. Studies have determined (Gubler, 1977) (Brown, 1980) that explosive shock waves travel farther and impart more energy to a larger area when they travel through air than through snow. An air blast is ten to one hundred times more effective for delivering an explosive's energy to the snow than a sub-snow surface blast. Bridger Bowl's bomb wires now provide an efficient method of air blasting a large number of avalanche starting zones on any given morning.


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Air blasting did not start out as the efficient routine that is practiced today. Years of trial and error have taken it from curiosity to standard operating procedure. Air blasting was introduced to the Bridger Bowl Ski Patrol by Rand Decker, a graduate student at Montana State University at the time. While visiting France in 1981, Rand observed French bomb trams in action. Through the Snow and Avalanche Research Group at Montana State University, he suggested that Bridger Bowl Ski Area install a bomb tram to be operated by the ski patrol. The Civil Engineering and Engineering Mechanics Department built a hand operated bomb tram in August of 1981 above Bridger Bowl's south bowl with technical assistance from Eduardo Garreaud, snow safety director at La Plagne Ski Area in France, who was on a cooperative scientific exchange at Montana State University. This tram was designed to carry a bomb uphill and suspend it about two meters above the snow over one of two avalanche starting zones. Explosive preparation consisted of tying the bomb off a few inches below a carrier with a short static line to which a blasting cap was taped. When this static line was blown apart the bomb which was also connected to a spooled up bomb supporting "dropline" would drop into place and be detonated by a blasting cap with a longer fuse than the fuse used on the static line. The carrier which was connected to a movable cable was hand cranked into position after the two fuses were ignited.

The approach to the operating platform was a difficult climb in deep snow. Also, explosive preparation was time consuming and the cranking of the bomb and carrier into position was somewhat physically exhausting but the tram was used many times throughout the 1980's, often releasing significant snow slides and demonstrating the superiority of aerial blasting.

Bridger Bowl's rough terrain features provide many locations to suspend lengths of wire across avalanche starting zones from natural supports such as trees and rock outcroppings. One obvious easily accessible such place is Madmens Couloir. Its location off of the ridge close to the top of the Bridger chairlift was perfect for experimentation. A quarter inch polypropylene rope was hung across Madmens, spanning a large tree and a rock wall. Bombs were tied to a drop line which hung from a retrievable pulley which could roll down the rope when the bomb was tossed. Bombs had to be prepared ahead of time by securely tying and taping a two foot tail of rope to them. This tail of rope was secured to a permanent loop in the end of the drop line thus preventing the drop line from being shortened with each blast. Often larger, higher volume avalanches were released from Madmens Couloir with air blasts than from blasts within the snow on similar slopes on the same day. The Madmens bomb wire has been in use since the winter of 1982. The polypropylene rope has been replaced by a metal cable but the operation remains unchanged to this day.

Successful air blasting in Madmens promoted the spanning of more starting zones with simple bomb wires. All of the simple wires are built so that the cable slopes downhill. They are operated from above. This configuration takes advantage of gravity for shot placement and generally places the operator in a safe position above the avalanche path. However, the tie and toss method of operation which worked successfully on the Madmens wire proved to be very unreliable in other places where the bomb could not be easily tossed far enough beyond terrain obstacles to hang free below the cable. An early solution was a mechanical carrier built to transport the bomb along the cable and drop it into position. This "drop-release" type carrier was designed so that a firm jerk on a trigger lever would allow another lever holding the bomb to fall and release the bomb. In operation the "cocked" drop release carrier and explosive would be released and allowed to accelerate down the cable. A retrieve line tied off at the operating area was stored in a five-gallon bucket. This line played out of the bucket as the carrier accelerated down the cable and provided the jerk on the trigger lever when it was completely played out. Drop release carriers were utilized in 1984 and 1985 in two bomb wire locations: Stupor Couloir and Bombs Away. A common problem with drop
release carriers occurred when the bomb supporting dropline would break from the tension of the falling bomb jerking to a stop. Experimentation was done with flexible bunjie drop lines. These were unsatisfactory because they deteriorated in sunlight, and stretched to different lengths for different weight bombs.

In 1987 two experimental electromechanical carriers which could gently lower the bomb into place were built to replace the drop release carriers on the Stuper Couloir and Bombs Away wires. This carrier called the "banjo" carrier because of its shape contains an internal six inch spool containing the dropline. The spool is mounted on the output shaft of a twelve volt D.C. gear motor which provides dynamic breaking during the lowering of the bomb. Upon explosion of the bomb a spring operated switch applies current from two six volt lantern batteries contained in the carrier allowing the motor to reel the dropline neatly back onto the internal reel. In operation the bomb prepared with a rope tail is hung from a dog leash type clip on the end of the drop line. The carrier and "hot" bomb are then hand reeled down the cable until the carrier bumps into a permanently mounted stopper on the cable. This stopper releases a brake on the gear motor input allowing the weight of the bomb to completely unwind the drop line spool.

In 1987 two new bomb wires were built in the Three Bears area. A treated pole was installed as an upper support for the cables. One cable spanned Papa Bear and the other spanned Momma Bear. A small crow's nest type platform was built on the pole to provide a place to stand while operating the bomb wires. A new type of experimental electromechanical carrier was built for the Bears' bomb wires which could provide more versatility of shot placement. Instead of releasing the bomb for lowering upon bumping into a permanently mounted stopper, an internal electronic timer provided a time delay between the lighting of the fuse and the lowering of the bomb during which the carrier could be hand reeled to any position along the cable. The number of feet of dropline reeled out below the carrier at which the bomb would stop lowering was electronically adjustable by means of a thumb wheel switch on the carrier. The operator was thus able to place the bomb anywhere above the snow in the vertical plane containing the cable. This carrier was built around a six volt Volkswagen worm gear type windshield wiper motor. The motor was disassembled, thoroughly cleaned, and re-lubricated with a teflon based synthetic grease rated for temperatures down to -65 F. Also, the internal wiring of the motor was modified to enable it to turn in both directions. The worm gear transmission of the wiper motor provides a natural brake to hold the bomb in place when the motor is not under power. Electronic circuitry in the carrier provides a time delay between the time a START button is pushed until power is applied to the motor causing the bomb to lower. This circuitry also monitors the amount of droline lowered and cuts power to the motor at the distance dialed in on a DROP thumbwheel switch. Power is provided by a twelve-volt six-amphour gel-cell type battery. The carrier weighs twenty one pounds and is equipped with quick release clips so it can be moved between the Papa and Momma Bear wires while standing on the operating platform.

The Bears have always presented a serious avalanche problem at Bridger Bowl due to their propensity to quickly build up hard wind slabs on a steep breakover above beginner terrain. A number of patrollers have been caught in slides over the years doing control work here. The bomb wires provided a much safer and more effective means of bombing these hard slabs. The new electromechanical carrier was used during the 1987 and 1988 ski seasons on the Bears bomb wires. However, different air shot placement along the wires in the Bears did not make any significant difference in performance. The whole starting zone would usually release whether the bomb was placed under the north end of the wire or the south end -- and often a two pound air shot in Papa Bear would release a slide in nearby Momma Bear and vice-versa.
In the fall of 1988 another double bomb wire was installed over the large starting zone of the Coulter Crawl avalanche path. These wires are operated from another crows nest type platform on a pole set in the rock on top of the ridge. An experimental two piece mechanical carrier was used on these wires. Rather than being stored on a spool, the drop line on this carrier is held stretched out down the length of the cable by a counterweight riding on pulleys. See Figure 1. The drop line runs up from the counterweight to a simple mechanical belay device, where it is threaded through a guide hole, around an eye bolt, back through a guide pulley, and tied to a bomb hanging hook. Friction provided by the dropline bending tightly around the eyebolt allows the counterweight to hold the bomb in place under the belay carrier. Additional friction can be provided by rotating the eyebolt so that the dropline twists around itself as it travels through the belay. As with the banjo carrier a permanently mounted stopper on the cable determines the spot at which the bomb is lowered. In operation the counterweight-belay carrier with bomb is hand reeled down the cable. The counterweight bumps the stopper first and releases tension on the dropline as the belay continues down the cable. The weight of the bomb then pulls the dropline through the belay and the bomb lowers itself into position as the belay travels the rest of the way down the cable to the stopper. Explosion of the bomb removes the bomb's weight from the dropline. As the belay is hand reeled back up the cable the light-weight dropline is pulled all the way back through the belay until the bomb hanging hook is back in position under the belay at which point the belay pulls the counterweight back up the cable.

Figure 1. The counterweight belay mechanism. The counterweight (left) holds tension on the dropline which is threaded through the belay (right) to the bomb hanger.
The counterweight-belay mechanism was very simple to construct and worked very reliably on the Coulter Crawl wires. During the 1988 ski season the electromechanical carrier in the Bears suffered a malfunction while being used for avalanche control. A mechanical problem caused a four pound bomb to lower only a few feet. The blast rendered the carrier inoperable and in need of repair.

Versatility of bomb placement was observed to not provide any great performance advantage on the Bears bomb wires. Installation of permanent stoppers on the cables and replacement of the damaged carrier with counterweight-belay mechanisms was the easiest way to get the Bears wires back into operation as quickly as possible. The aging experimental banjo carriers on Stupor Couloir and Bombs Away were also replaced with counterweight-belay mechanisms. By the 1990 ski season all but three of Bridger Bowl's bomb wires were utilizing the counterweight-belay mechanism. The other three are still simple tie and toss systems.

In 1987, experimentation was done with plastic grocery bags for holding bombs - both for use on bomb wires and for dangling over cornices. The handles on these bags provides a convenient place to tie a string even while wearing gloves. When a bomb explodes in a bag the bag is vaporized. Larger shots can be made up by simply putting more bombs in the bag, eliminating the need to tape bombs together. Stick bombs can be easily prepared on the spot by cow-hitching a plastic grocery bag to a stick of bamboo or a dead branch stuck in the snow. It was found that the plastic grocery bags hold up very well under this use, and using them can save a great deal of time with air shot bomb preparation. On the bomb wires special bag hangers are installed on the ends of the dropline. See Figure 2. These consist of eighteen inch flag stake wires bent on the end to clip around the handles of a plastic grocery bag. The eighteen inch wire hanger places the bag and bomb for enough below the end of the dropline to prevent the dropline from being burned upon explosion of the bomb. Damage to the wire hanger is minimal enough to allow one to be re-used a good number of times. Some wire hangers are in use which have held over fifty exploding bags and have not failed.

Figure 2. Wire bomb hanger used for holding a plastic grocery bag containing explosive.
Replacing these wire hangers about once a season is probably prudent though because they do tend to become somewhat bent and stressed after holding a number of exploding bags. The major advantage of the use of plastic grocery bags on bomb wires is that it provides the patroller freedom from the need to prepare bombs ahead of time with rope tails thereby simplifying bomb wire operation.

Use of simple trams for placing bombs requires additional explosive safety considerations over those needed for standard hand charge placement. It is obvious that a hand charge must always be thrown a good distance away as soon as it's fuse is ignited. Similarly, a bomb wire and carrier system must quickly transport a "hot" explosive away from the operator with absolute reliability. Use of a double cap and fuse is preferred to minimize the chance of a hanging dud. Before an igniter can be inserted on the fuse a thorough inspection is essential. The use of the counterweight-belay system on all of Bridger Bowl's hand cranked bomb wires allows a standardized procedure to be followed with all bomb wire operation to minimize the chance of an explosive accident which could cause bodily injury or equipment damage. The procedure is as follows:

1. The operator must make sure all rime is removed from the cable, dropline, retrieve line, and retrieve line spool.

2. The operator must make sure that neither the dropline nor retrieve line is wrapped around the cable, and that the retrieve line travels freely through all pulleys with no twists.

3. After the explosive is in position in the hanging bag, but before the igniter is inserted on the fuse, the bomb and carrier must be reeled a short distance down the cable and returned to assure flawless operation.

At this point "Fire in the Hole" is called over the radio, the igniter is inserted and lit, and the carrier and bomb are quickly hand reeled into position. To prevent the possibility of the plastic bag being burned from the spit of flame out of the end of the fuse the igniter is always left in place over the fuse and after ignition.

**CONCLUSION**

Over the years air blasting techniques at Bridger Bowl have evolved from the experimental trial and error stage to standard operating procedure. Use of plastic grocery bags for bomb containment as well as the standard installation of the counterweight-belay mechanism on twelve hand cranked bomb wires now allows the advantages of aerial blasting to be obtained at many locations on regular avalanche control routes with virtually the same ease and speed as throwing hand charges into the snow. The final advantage goes to skiers who are able to get out as soon as possible after a new snowfall and safely ski the "Steep and the Deep."
REFERENCES


