EVOLUTION OF AN AVALANCHE PROGRAM: FROM ARTILLERY TO INFRASTRUCTURE

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ABSTRACT: The Wyoming Department of Transportation (WYDOT) has used artillery for avalanche reduction on State and Federal highways near Jackson, WY since 1972. As demands on the transportation system have changed, new technology and strategies have been implemented to improve the efficiency of avalanche reduction operations. This case study examines the effects of implementing active and passive avalanche mitigation measures on avalanche paths through three separate highway corridors. On State Route 22 over Teton Pass, WYDOT operates Gazex® and Avalanche Guard® active avalanche control systems and Infrasonic avalanche detection in the Glory Bowl and Twin Slides avalanche paths. On US 89/191/189/26 snow supporting structures are used for passive avalanche defense in the milepost 151 avalanche path. On US 191/189, through the Hoback River Canyon, two Obellx® gas exploders are used for active avalanche control at the Cow and Calf of the Woods avalanche paths. In each application terrain, avalanche conditions, environmental impacts, and highway concerns are considered with the implementation of infrastructure. With continued capital improvements and the realization of a long term strategy of implementing avalanche forecasting and mitigation technology, WYDOT is moving towards the end of artillery while reducing highway avalanche closures and their durations.

Keywords: Avalanche, Infrastructure, Gazex, Obellx, Howitzer, Snow Structures, Transportation

1. INTRODUCTION

1.1 Setting

Jackson, WY is located in Western Wyoming near Grand Teton and Yellowstone National Parks. The Wyoming Department of Transportation (WYDOT) avalanche safety office monitors avalanche conditions for four highway corridors. Wyoming route 22 over Teton Pass, US 191/189 through the Hoback River Canyon, US 89/26 through the Snake River Canyon, and US 89/191/189/26 through the town of Jackson. Each corridor has unique terrain, weather pattern, and snowpack characteristics that will be described in detail.

Jackson has a very high cost of living with a majority of the workforce commuting from nearby communities. Traffic volumes have doubled in the last 15 years, increasing the Avalanche Hazard Index (AHI) in all of the highway avalanche corridors near Jackson. This has led to increased pressure on WYDOT to operate a reliable and efficient transportation system.

1.2 Motivation

Artillery has been a very cost effective and reliable method for avalanche reduction on Teton Pass and in the Hoback River Canyon. However, with increasing demands on the transportation system, avalanche reduction methods that are deployed more efficiently have had a dramatic impact on road closure duration, manpower requirements, and environmental concerns.

2. HISTORY

2.1 History of Artillery

The Wyoming Department of Transportation has a long history of using military surplus artillery

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for avalanche reduction on State and Federal Highways near Jackson, WY. Avalanche reduction began with the realignment of Wyoming State Route 22 over Teton Pass in 1968. Plans called for the construction of a large bridge at the Glory Bowl avalanche path with the idea that avalanche debris would pass harmlessly under the bridge span. In January of 1970, before the bridge was completed (The concrete deck had not been poured), a large climax avalanche released from the Glory Bowl and destroyed the nearly completed bridge (Fig 1).

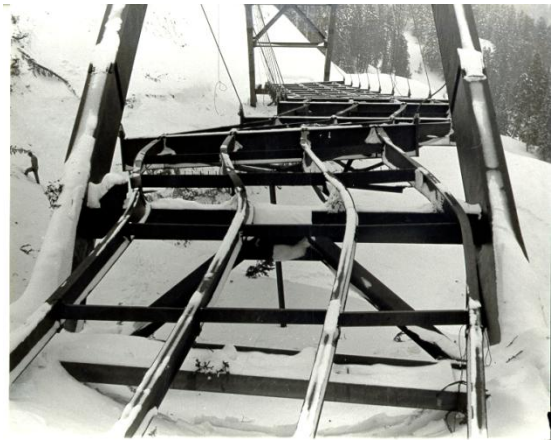

Fig. 1: The Destroyed Crater Lake Bridge.

With the destruction of the Crater Lake Bridge, active avalanche control began with surplus military artillery. During the winter of 1972 a 75mm pack howitzer was used to shoot targets in Glory Bowl and an early generation avalauncher was used for targets in Twin Slides. By 1974 a 105mm recoilless rifle was mounted on a snowcat and used to shoot all targets on Teton Pass. This weapon system was in use until 1998 when WYDOT acquired a M102 105mm Howitzer. The howitzer is a lightweight towed weapon that uses modern day ammunition and is more readily supported by the US Army. In 2011 WYDOT acquired a M101-A1 105mm Howitzer which is the standard weapon system for artillery avalanche control among the 16 members of the Avalanche Artillery Users of North America (AAUNAC). The M101-A1 howitzer is currently in use on Teton Pass and in Hoback Canyon with plans to phase out of artillery by 2018.

2.2 History of Infrastructure

In 1989 Rod Newcomb and Art Mears prepared an avalanche hazard and control analysis for Teton Pass. One of the recommendations was for a 85 m snow shed at the Glory Bowl Slide path. Preliminary design was done with an estimated cost of $2 million dollars. Teton Pass is considered a secondary highway making it hard to justify the expense of a snow shed when road closures do not have the economic impact of primary roads or interstates. Cost effective alternatives to the shed were explored and in 1992 WYDOT made an investment in 2 early generation Gazex® exploders for the Twin and Glory avalanche paths on Teton Pass. In 1993 2 additional exploders were built in Glory Bowl and WYDOT's relationship with constructed avalanche defense began.

3. STUDY AREAS

3.1 Mt. Glory, WY 22 Teton Pass

WY 22 over Teton Pass is a 27 km highway corridor that connects the communities of Jackson, WY and Victor, ID. Average daily winter traffic is 5,500 cars per day with no trailer traffic allowed November 1 to April 1. The highway crosses the Teton Mountain range at an elevation of 2,570 m. Average annual snowfall is 890 cm with January as the typical highest snowfall month.

The highway traverses Mt. Glory crossing the Glory Bowl and Twin Slides avalanche paths mid track (Fig 2). The Glory Bowl starting zone is a large 0.2 km^2 northeast through southeast facing bowl at an elevation of 3,058 m. The path has a very high return interval of events to the highway and is capable of producing dangerous and deadly slab avalanches. Twin Slides is a small but steep south facing avalanche path that is easily loaded from the prevailing westerly winds.

Fig. 2: Mt. Glory and the Glory Bowl.

Mt. Glory is also a very popular backcountry skiing area with skiers and snowboarders descending avalanche paths that impact the highway. Artificially triggered avalanches from skiers and snowboarders have occurred onto an open highway.

Today, four Gazex® exploders with one central control shelter are used on Mt Glory. Three exploders are in the large Glory Bowl avalanche path and one exploder is in the Twin Slides path. The early system was plagued with problems and took several years of maintenance and upgrades before it began to operate reliably. Diligent off season maintenance of each exploder was the key to success in winter. The other key to the successful operation was detailed leak detection of all pressurized oxygen and propane gas lines, the installation of check valves to isolate potential leaks, and pre season test firing (Fig. 3).

Fig. 3: Pre Season Gazex Test Fire .

The following chronology documents the problems, upgrades, and associated cost of the Glory and Twin Slides Gazex® system.

1992 - Two 2.6 m^3 exploders installed (Glory and Twin)

1993 - Two 2.8 m^3 exploders installed (Glory) using the existing shelter. Double action design, more durable than 1992 exploders.

1993-2002 - Mechanical problems plague the system. Gas leaks, weld failures, broken manifolds, and multiple problems with the exploder ignition system.

2003 - $100k system upgrade. New shelter from TAS of France. All exploders serviced by High Angle Construction (Welding, Ignition system check).

2003-2015 - With diligent maintenance the system operates reliably but with several mid winter repairs to the 1992 exploders. Maintenance requirements also include annual welding to the 1992 exploders.

2015 - $150K upgrade. Two exploders from 1992 replaced with 1.5 m^3 inertia exploders. New dosage tanks and valves at the shelter. Construction done in house by WYDOT Avalanche Office, $100k in capital cost, $50k construction costs.

3.2 Mount Glory Avalanche Guard

In 2003, an Avalanche Guard® (Fig. 4) project was funded through the WYDOT Research Advisory Committee (RAC). One Avalanche Guard® was constructed on the northern edge of the Glory Bowl and one Avalanche Guard® was constructed for targets in Twin Slides. The goal of the project was to test new avalanche mitigation infrastructure against existing technology (Gazex®, Howitzer). The units have been very reliable but with a high cost per shot.

The location of the unit in Glory Bowl proved to be problematic. In above average snow years the unit would become buried in snow and was inoperable later in the season. The location was

also not ideal for avalanche initiation as the unit could only reach targets with east through southeast aspects. The majority of avalanche events occur on the northeast aspect of Glory Bowl. With these problems, a new site was selected that was more readily accessed and with lower snow depths. The new sight also provided the opportunity to impact targets low on the northeast face of Glory Bowl that could previously only be controlled with a howitzer or helicopter bombing. With the relocation, the Avalanche Guard® operates to its full potential providing redundancy to Gazex® and mitigating new terrain that eliminated several howitzer targets.

Fig. 4: Avalanche Guard unit on Mt. Glory.

3.3 Mile Post 151, US 89/191/189/26 Jackson Area

The Mile Post 151 (MP 151) avalanche path is located just south of the Jackson city limits on US 89/191/189/26 at the mile post 151 marker (Fig. 5). The path is critical big game habitat and is closed to human activity from December 1 to May 1. Average daily traffic on the highway is 15,000 vehicles per day making it one of the busiest sections of highway in the forecast area.

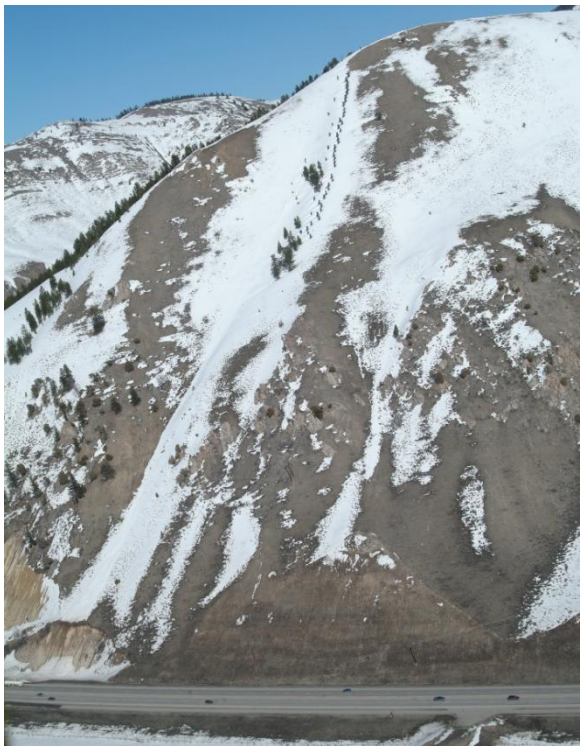

Fig. 5: Mile Post 151 Avalanche Path.

Avalanche mitigation has been conducted using helicopter bombing and hand charging. There are no road closure gates for this section of highway, traffic control is time consuming and requires significant manpower.

Passive avalanche defense at the MP 151 path has been a long term goal with an initial attempt funded by the WYDOT Research Advisory Committee in 2002 for the construction of 65 snow sails. The snow sails worked to disrupt the formation of a continuous slab in the starting zone. On January 1, 2004, during an impressive winter storm event, a large natural avalanche released from the MP 151 and deposited 3.5 m of debris onto an open highway. Later investigation revealed that even though the slab varied greatly in depth, the presence of well developed depth hoar contributed to the large size of the avalanche.

Fig. 6: Snow Supporting Structures at MP 151.

With the large volume of traffic, dangerous avalanche potential, difficulty of avalanche control, and wildlife concerns, a project was conceived to construct snow supporting structures in the MP 151 starting zone (Fig. 6). Using the 2007 Swiss Guidelines for Avalanche Starting Zones and guidance from the United States Forest Service through the NEPA process. A unique design was conceived by Inter Alpine Engineering that staggered the structures across the slope. Instead of straight linear lines, the structures are constructed in clusters that maintain the visual retention of the slope.

3.4 Cow and Calf of the Woods, US 191/189 Hoback River Canyon

The Cow and Calf of the Woods avalanche paths in Hoback River Canyon are very active slide paths that impact US 191/189 several times per season (Fig. 7). The starting zone is at 2378 m with a very steep track to the highway and river at 1875 m. The topography is rugged with steep loose talus, rock outcrops, thick brush, and mature conifer. The path faces due north and is one of the coldest and darkest locations in the forecast area. The starting zone is inaccessible in winter due to nonexistent helicopter landing zones. Avalanches consistently occur during storm events with occasional deep slabs and large wet snow avalanches in spring. Multiple releases can occur in the path increasing the risk for highway maintenance personnel performing cleanup operations.

Avalanche mitigation for the Cow of the Woods has been performed with artillery (1998 to present), helicopter bombing, and the Obellx® gas exploder.

The Cow of the Woods avalanche path presented unique challenges for the implementation of avalanche control infrastructure. The complex terrain and poor access required a system that could be deployed and retrieved by helicopter. The introduction of the Obellx® gas exploder from TAS was a good fit for the rugged terrain of Hoback Canyon and in 2011 a research project was granted for funding the purchase and installation of the first unit in North America (Fig. 8).

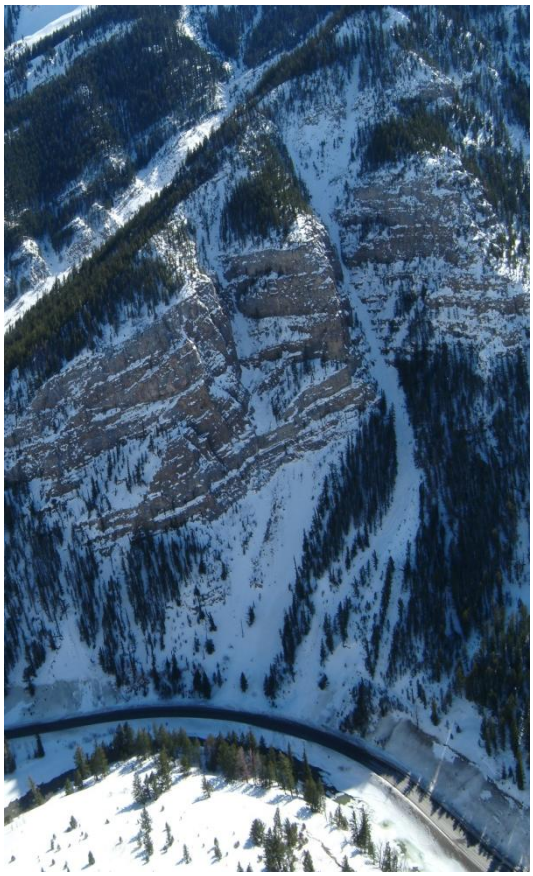

Fig. 7: Cow and Calf of the Woods .

The first season of Obellx® deployment in 2013/2014 was unsuccessful due to problems with inefficient solar panels and battery failure, providing few opportunities for avalanche

mitigation. With the unit still under warranty, TAS refitted the Obellx® with five 30 watt high efficiency solar panels, a new solar controller, a new 100 amp hour gel battery, new brackets for valves, and rubber bushings for mounting solar panels. The refitted Obellx® was flown in place for the 2014/2015 season and successfully used for avalanche mitigation operations with no technical issues.

Fig. 8: Obellx® in the Cow of the Woods.

After a successful season using the Obellx® gas exploder in the Cow of the Woods, a project was funded by the State of Wyoming for an additional Obellx® unit for the adjacent Calf of the Woods avalanche path. The install was completed in August of 2015 by WYDOT Avalanche Office with $142k in capital costs and $30k for installation.

The Calf of the Woods Obellx® project eliminated the last howitzer targets in Hoback Canyon.

4. RESULTS

4.1 Road Closure Duration

By implementing avalanche control infrastructure, WYDOT has seen dramatic reduction in road closure duration for avalanche mitigation. Cleanup operations of large avalanches create longer duration road closures, but time required for avalanche reduction efforts have been greatly reduced. The average time required to conduct avalanche reduction with the howitzer on Teton Pass is 144 minutes. Average time for avalanche reduction with Gazex® and Avalanche Guard® on Teton Pass is 52 minutes.

The most dramatic results in road closure duration have been in the Hoback Canyon. With the Howitzer, avalanche reduction missions and cleanup operations averaged 77 minutes. With the Obellx®, the average time required for avalanche reduction and debris removal is 26 minutes.

4.2 Manpower

During storm periods, manpower for road maintenance operations, road closures, avalanche mitigation work, and avalanche debris removal is in high demand. Reducing the number of personnel required for avalanche mitigation work provides substantial results in the level of service WYDOT provides to the public.

Howitzer operations require a four man crew. With Gazex®, Avalanche Guard®, and Obellx® infrastructure, only one person is required to perform an avalanche mitigation mission.

4.3 Timing

Without permanent firing bases, artillery missions on Teton Pass and in Hoback Canyon are difficult to initiate in a timely manner. Clearing the firing base of snow and ice and positioning the weapon into place is time consuming and requires substantial effort and manpower. The additional challenges of inclement weather and darkness make an artillery mission a time consuming and arduous task.

With infrastructure, avalanche mitigation can be done with ease at any time of day or night.

4.4 Cost Benefit

The cost benefit ratio of implementing avalanche control infrastructure is difficult to quantify. Active and passive infrastructure requires a large initial investment and ongoing maintenance. Artillery remains one of the most cost effective avalanche reduction methods available.

While no good metrics currently exist, a cost per shot is a quantifiable comparison. Table 1 accounts for annual costs associated with each active avalanche reduction method. Gazex® and Obellx® cost per shot calculations use gas prices plus helicopter time required for annual resupply. Avalanche Guard® cost per shot calculations include the price for the 4 kg cast booster, propellant cup, pull wire igniters, and pre made cap fuse assemblies.

The WYDOT Avalanche Office has averaged 40 howitzer rounds per year over the last 10 years. Annual howitzer operating costs include membership dues to the AAUNAC ($2000), annual gun maintenance from the US Army ($1000), Army cost share for lease of the weapon ($1100), and travel and expenses for two attendees to the required annual AAUNAC meeting ($4000). These annual costs averaged over the 40 rounds equal $202 per round plus $98 for the actual round.

Tbl. 1: Active Control Methods Cost per Shot

Avalanche Control Method	*Cost per shot*
Howitzer	*$300*
Gazex®	*$60*
Obellx®	*$125*
Avalanche Guard®	*$215*

Table 2 summarizes the total initial capital investment spent on each project. It should be noted that no cost modifications for inflation have been made for the 1992 Gazex® project.

Tbl. 2: Total Initial Capital Investment

Avalanche Control Method	*Cost*
M101 Howitzer	*$35,000*
Gazex®	*$600,000*
Obellx®	*$314,000*
Avalanche Guard®	*$385,000*
Snow Supporting Structures	*$2,400,000*

4.6 Passive vs. Active Avalanche Control Infrastructure

The implementation of passive avalanche defense at the MP 151 path allowed WYDOT crews to focus their avalanche forecasting and mitigation efforts on other highway avalanche corridors.

Passive avalanche defense is the preferred method at the MP 151 for several factors. An avalanche corridor that contains multiple starting zones and avalanche paths would be too expensive to implement passive avalanche defense but the MP 151 is the only path in the corridor that consistently impacts the highway. Also, the critical game habitat closure and proximity to the Town of Jackson make active control less desirable. High traffic volumes and potential for wildlife triggered events also contributed to the decision for passive avalanche defense at the MP 151. While the cost is an order of magnitude greater than active avalanche control infrastructure, the benefits of eliminating a path from the forecasting and control program are substantial.

5. LESSONS LEARNED

With over 20 years of experience in constructed avalanche defense at the Wyoming Department of Transportation several lessons have been learned.

The most critical component of operating a successful array of avalanche control infrastructure is a well planned and executed troubleshooting and maintenance program. Maintenance should be a paramount consideration when planning for the construction

of infrastructure. When considering the options in Hoback Canyon, infrastructure maintenance was the primary concern that lead WYDOT to construct Obellx® exploders.

Mistakes have also been made with site selection. Max snow depth from deposition and drifting is of critical importance in sight selection. One Avalanche Guard® unit on Mt. Glory became inoperable during high snow winters as a result of snow depths exceeding 5 meters. Site selection is also of great importance for triggering avalanches. While the air blast of Gazex® makes this less critical, Avalanche Guard® targets need to be precisely located for optimal results.

6. CONCLUSION

The Wyoming Department of Transportation has made large investments in passive and active avalanche control infrastructure. By implementing methods that best address each avalanche paths unique terrain, access, and environmental challenges; road closure duration has decreased, manpower requirements have been reduced, and avalanche reduction can be conducted during optimal times. These factors all contribute to a safer more efficient transportation system.

6. ACKNOWLODGEMENTS

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