THE USE OF LARGE EXPLOSIVE CHARGES FOR AVALAHCHE HAZARD REDUCTION

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ABSTRACT

Mountain seismic exploration for oil-bearing strata involves the detonation of 34-50 kg of explosives every 200-300 m in areas chosen for interesting sub-strata with no regard for surface terrain. In order to mitigate post-control release problems in avalanche terrain, hazard reduction techniques had to be developed giving consideration to 34+ kg explosions at any point in an avalanche path. The traditional ski-area approach using 1-2 kg charges did not provide adequate protection under these working conditions, so avalanche personnel began experimenting with charges exceeding 23 kg. Since then, big bombs have become routine for seismic snow safety. In two seasons and over 500 km of line, there were no post-control releases in seismic work after using this technique.

The success of this technique in the backcountry led forecasters in 1985-86 to suggest using large explosive charges in certain hazard reduction situations within the Jackson Hole Ski Area. Thus far, success similar to the seismic results has been documented. Since this technique was introduced, 80 charges of 12+ kg have been recorded. 43 avalanches were induced with crowns of 30-600 cm in depth. The other shots produced settling and cracking over wide areas in the paths. In some instances, 1 kg charges were exploded for worker protection before bigger bombs were detonated. So far, no post-control releases have been observed. In addition to the empirical evidence, snowpit evaluation at two of the sites suggests that charges in excess of 23 kg are effective in stabilizing the snowpack in difficult hazard reduction scenarios.

SEISMIC APPLICATION

During the “Oil Crisis” in the late 1970s, petroleum exploration companies began intensive seismic evaluation of the sub-strata in the Overthrust Belt of Wyoming, Montana, Utah, and Idaho. This structure, part of the Laramide Uplift of 50 million years ago, is characterized by repeated layers of sedimentary and pre-Cambrian strata forming mountains 2,500 to 3,500 meters high. These mountains are capped with the sedimentary layers, which, with erosion, have formed steep narrow gullies, large alpine bowls, and dramatic dolomite cliff bands. The only method through which the desired information about hydrocarbon potential could be gathered was by using portable seismic crews. The personnel and equipment on such crews are delivered into the high mountain terrain by helicopter. Originally, the work was only done in during the summer and fall. However, as the “oil boom” progressed, work was done in the winter as well.

While summer work was not particularly simple, winter logistics and safety presented unique complications. Seismic lines are planned according to sub-strata which geologists find interesting. It is only after crews are ready to take the field that surface quads are consulted. After the lines are ordered, little or no variation is allowed form the straight line, point to point shooting. Difficult terrain features are to be conquered, not avoided. Avalanche hazard must be addressed by control and not by the prudence of route finding. Furthermore, the slopes must be made safe for workers who are detonating 30+ kilos of explosives every 200-300 meters, depending on the shooting configuration. The shots are elevated 1 meter above the snowpack, in a straight line or diamond, with 2.3-4.6 kilo shots posted approximately 10 meters apart. The shots, when detonated, resonate through the sub-strata and back. They are recorded by geo-phones, called “jugs” in the industry. Information from the “jugs” is received in a portable recording booth placed equidistant from shooting points spaced 2-4 km apart. The information is recorded on hard copies, then sent to a computer center for analysis. Recent technological innovation has made it possible for some companies to send the information to the computer center via satellite directly from the recorder.

All of this means that moving a seismic crew through the mountains is more than a one day operation. Crew members, called “juggies’, are assigned different responsibilities on the line. First are surveyors and chainers who set the line; then, front crew follows which lays out the strings of geo-phones. A powder crew is next, setting up the shots for the shooters who then cap and detonate. Back crew packs up the geophones to be delivered to the front of the line by helicopter and then polices the line for trash. Avalanche personnel must control for each crew component from the surveyors through the back crew. Under these conditions, had to devise a system to secure up to 10 kilometers of line while still spotting the shooting crew, who are particularly at risk.

When winter seismic first began, hazard control was run with 1-2 kg hand charges using strategies borrowed from the ski industry. If snow conditions were judged too hazardous, juggies were withdrawn from the field or were given the day off. This shut-down option became unacceptable to crew supervisors due to cost and the increasing emphasis on production. After a time, terrain became more hazardous as all the “easy” lines in the area where complete. Post-control releases, especially during detonation, compromised safety. Snow safety recommendations to leave the field were sometimes not followed. After some close calls, more effective control procedures were requested by the exploration companies.

Wyoming Avalanche Services (WYAV), started by Richard Francis, a former Jackson Hole ski patrol, contracted to provide all day, every-day protection for the crews. Avalanche control began in the morning ahead of the crew deployment, and continued after juggies left the field. Logistics were devised that assured each crew component would guided and spotted by avalanche personnel while in critical parts of the line. The job quickly changed from helicopter skiing to mountaineering. Most important, small charges were abandoned and experimentation with large explosive charges began.

No doubt, the use of 23-48 kg charges on seismic lines originated with an unkown juggie and his supervisor early on in winter mountain exploration. Rumer has it that crews would do sporadic control operations before the days of paid avalanche consultants. That these efforts were effective is generally agreed upon by field workers. WYAV consultants began with elevated, 23 kg shots strung together with primer cord. Seismic charges are packaged in 2.3 kg bags, 10 to a rectangular box. These boxes are easy to transport by skiers and can be balanced on sticks above the snow. We found that a primer line of 125 kg or so was impressively effective in zippering long, ridgeline starting zones. With this knowledge and unlimited availability of explosives, and era of "industrial strength" avalanche control began.

The primer lines were for clearing large areas at once, especially when starting out in uncontrolled terrain. The lines were typically cleared in front of the surveyors. Before the rest of the crew passed through, boxes were detonated in the smaller pockets, likely to be dislodged by the shooters. As time went on, 23 kg boxes in these pockets were replaced by the so-called "T-100", one box on end in the pack and another, width-wise across. Easy to set up, this shot was effective in propagating sympathetic releases up to a kilometer away in some cases.

CONCLUSION

Francis remembers resisting the introduction of big bombs, reasoning that otherwise stable snow could be induced into instability by such a large shock. This theory was empirically tested through procedures in the field. Before setting up the shots, workers threw 1 kg hand charges to protect themselves. When the big bombs were detonated, they either induced a slide or propagated a web of settlement cracks over a wide area. Then the shooters would further test the slope with their shots, which could be anywhere in the path. Using 23 kg charges, there was one post-control release involving snow safety workers ski-checking a path which had slabbed out to 75 cm at the crown. As they skied on to the debris, about 200 m below the crown, the slab underneath broke and the debris slid. Had the shooters been working below that point, they would have been at risk. After the T-100 was introduced, there were no incidents of workers on the line being caught.

The conclusions WYAV personnel drew from this experience were as follows. It is more likely that explosive charges in excess of 23 kg stabilized rather than de-stabilize avalanche paths. Most often, the danger is removed through slope failure rather than settlement. However, both are effects of high-poundage control. This stability lasts until changes in weather and snow conditions alter snowpack structure. In late springtime percolation scenarios, this could be as short as the afternoon through the morning following control. In dry conditions, with stable, cooler temperatures, control induced stability lasts longer. In two years, this method was thoroughly tested in backcountry, previously uncontrolled terrain. Shot-by shot data is not available; however, some explosive totals are. In one day, for example, workers detonated 1000 kg in 30 shots in a line up Coburn Creek in the Snake River Range. That line, only 25 km long, took over three weeks to complete due to weather. 12,000 kg were used for that one expedition. In two seasons, over 50,000 kg were used over an estimated 500 km of work, perhaps 2/3s of which was avalanche terrain. We found that the radius of influence of the large explosive charges is substantial, rendering them effective for clearing large areas of mountainous terrain at once. Also, given the intensive field testing of the procedures, we believe the conclusion that “big bombs” mitigate the problems of post-control release by inducing stability is justified.

SKI AREA APPLICATION

The Jackson Hole Ski Patrol began using large explosive charges in certain hazard reduction situations during the winter of ’85-’86. That season, 337 kg of HTP explosives were detonated in 20 shots, initiating 5 releases. By far the most impressive was a pre-opening day slide in Rendezvous Bowl. After being shot with 21 kg, the avalanche stepped to the ground and ran nearly 400 m vertical, a historic distance. Ski Patrol snow safety leaders have been integrating big bombs into the Avalanche Hazard Reduction Program ever since. Over the next four seasons, charges from 11-124 kg were used in 60 shots resulting in 38 avalanches with crowns 30-600 cm.

Since the ’86-’87 ski season, boxes of HTP have been replaced by “bag bombs” of inexpensive Ammonium Nitrate in weights of 11-22 kg. Two, 400 g HTP primers capped by #6 caps with 5 minutes of safety fuse are used for detonation. The bags are then usually tied to a children’s plastic snow toboggans and lowered into the starting zones from safe vantages above. Occasionally, bombs are dangled over cliff bands or suspended from dead trees or stumps. Since the upper mountain geology is sedimentary, carved into glacial cirques and hanging snowfields over dolomitic cliff bands, starting zones tend to be 10-50 m below the ridecrests. The “sled bomb”, a patroller’s idea, has addressed the problems of shot placement perfectly, so far.

Jackson Hole lies in the belt of the continental snowpack and is typified by early season shallow snows and cold temperatures with later season warming conditions and possible heavy snows. Early season conditions produce deep and mid-pack temperature gradient layers which form weak points in the snowpack. With predominately south and east facing aspects, hard, slick sliding surfaces are also formed during clear weather, only to be buried by subsequent snows. Consequently, we are concerned about how much loading these sub-surface layers can hold before a deep slab release is likely.

In the past four years, large explosive charges have been used during pre-season hazard reduction to evaluate stability. Early season reduction is particularly complicated because it has been snowing for a month or more on the upper mountain by the time snow safety personnel come to work. In this situation “big bombs” are used to give snow workers some indication of snowpack strength. One season, circumstances were such that “before and after” pit profiles were done during early season hazard reduction. Three 23 kg sled bombs were detonated in Rendezvous Bowl, which is approximately

800 m wide. A pit was dug after detonation in a historic pit site. Midway into the profile, the slope settled dramatically – not a good sign after 69 kg of explosives. The workers tiptoed away from the scene and took a safe route to the bottom. Next day, 115 kg was lowered into the center of the bowl and detonated. The resulting avalanche had a 3.5 m crown and the fracture line was 30 m wide. Settlement cracks reached out another 40 m on both sides. Pits on either side of the path, outside the disturbed snow showed 3-5 cm of settlement. Shear tests revealed some strengthening of the pack as well.

We have also used "big bombs" later in the season in big loading situations. On three occasions in the past five years, prolonged storms with heavy winds have interrupted daily hazard reduction for two days or more. At the end of the period, 13 cm or more of moisture has loaded the slopes. Mega-charges have proven effective in "regaining the mountain" safely and efficiently. As in seismic exploration, large areas of terrain can be cleared quickly because of the wide radius of influence inherent in the shots.

There are a few other uses as well. Once or twice in a season, when some worrisome weakness is uncovered in the snow pits, 23 kg will be detonated on test slope identified as a good indicator. Since we inventory the pit and crownface profiles in our database, we can compare the results over the years. This might help us in understanding how weakness in the pits can be projected into general slope stability. Then there are also the "janitorial uses". In a few places on the ski mountain, there are snowfields which build above dolomitic cliff bands which loom over heavily skied terrain. Before build up becomes critical, workers will sweep-off the snowfields using one or two 23 kg sled bombs. In one site, Laramie Bowl, this procedure is used three or four times a year.

CONCLUSION

In the early days of seismic work, there was some question as to whether there was any application for "big bomb" techniques in ski area scenarios. At Jackson Hole, the large explosive charges have proved to be a useful tool. In areas where they have been used, no post-control releases have been observed. While the total number of shots is less than one week's seismic totals, there has been a better chance, in the ski area, to monitor effects using snow pit studies and experimental shots to build a database. So far, the empirical conclusions of seismic workers seem to be supported. Basically, "big bombs" set off avalanches in places even when small charges don't. If the slope doesn't fail, settlement is deep enough so that the slope has been stabilized until weather and snow conditions change. Esoteric, but persistent avalanche problems at the Jackson Hole Ski Area are better addressed by having large explosive charges available as a hazard reduction tool.

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