AVALANCHE CONTROL IN THE BROOKS RANGE OF ALASKA AN ENVIRONMENT OF EXTREMES

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ABSTRACT: In 1974 the Dalton Highway was built north of Fairbanks to Prudhoe Bay, AK. along the route of the Trans-Alaska Pipeline being constructed at the time. It passes through the north-central Brooks Range and crests on the continental divide at Atigun Pass, where more than forty avalanche paths and half a dozen slushflow gullies threaten the transportation corridor. At 68 degrees north latitude at an elevation of 1500 meters in the Brooks Range, the climate of the area could be described as Arctic Continental. In winter a relatively shallow snowpack composed of large faceted grains overlain by hard windslabs predominates. Very low-density new snow is transported across barren ground through the pass by frequent hurricane force winds causing climax hard slab avalanches to occur at temperatures of -30 to -40 degrees C. In contrast, the rapid onset of spring (in May) with more than twenty hours of possible sun causes wet avalanches and highly destructive slushflows as temperatures can reach nearly 25 degrees C in the starting zones. After a slide in January 1993 buried more than 600 meters of road and involved several vehicles, the Alaska Department of Transportation decided to institute a pro-active avalanche forecasting and control program. The extremes of climate in conjunction with working in the Arctic at a remote maintenance camp 600 km from the nearest community contribute to unique challenges for the development and maintenance of an effective avalanche hazard forecasting and control program.

KEYWORDS: avalanche triggering, slushflows, snow melt and run-off

1. BACKGROUND

The gravel-surfaced Dalton Highway was built to facilitate construction and maintenance activities of the Trans-Alaska pipeline system and serve as the single surface transportation route to the North Slope oil fields of Alaska. It passes through the central Brooks Range and crests on the continental divide at Atigun Pass, where for 8.5 km the roadway climbs over and descends the pass at an average grade of nine percent, exceeding thirteen percent in places. In its course over the pass the road traverses through the lower tracks of more than forty avalanche paths and half a dozen slushflow gullies before entering the Atigun River valley to the north.

Highway maintenance on the northern Dalton was contracted to private firms by the pipeline consortium for the first few years after construction with no provisions for avalanche control. In 1980 the state took over the road; the Alaska Department of Transportation and Public Facilities being responsible for all maintenance of the 800-km long road.

Even though it is a state highway, traffic was restricted by permit to industrial vehicles servicing the pipeline, the pump stations and the North Slope oil fields. Average daily traffic volumes, although quite low (100 to 200 vehicles per day), consisted primarily of "18-wheelers" hauling essential items to help keep the fifteen to twenty percent of the nation's domestic oil supply flowing through the pipeline. Permit restrictions were lifted in 1995 so that now the Dalton Highway is open to all travelers, though few motorists drive the road for pleasure in winter.

Throughout the 1980's and early 1990's many of the big trucks travelling the road either ran into or were hit by avalanches and became trapped on the pass. If they were caught at night they would often have to wait until the next day to be plowed free by D.O.T. personnel from the Chandalar maintenance camp several km to the south. Usually the vehicles hit by slides were fully loaded trucks travelling less than 25 km/hr trying to pull the steep grade of the pass. Those that ran into slides, the more common encounter, were moving downhill unable to stop on the steep snow–packed surface before plowing into debris. During these years almost all of the D.O.T. equipment operators working out of Chandalar were hit or buried in their equipment by slides while clearing snow on the pass. Avalanche

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rescue training was sporadically given to the D.O.T. personnel and in a few instances reactive avalanche control took place after major events trapped vehicles and caused lengthy road closures of more than three days. After a slide in January 1993 buried more than 600 meters of road and involved several vehicles, carrying one big truck about 200m downslope below the road, the Alaska Department of Transportation instituted a pro-active avalanche forecasting and control program. A forecaster was hired and a 105-mm recoilless rifle was based at Chandalar.

2. THE CLIMATE

More than 230 km by road north of the Arctic Circle at 68° 08' north latitude 149°30' west longitude at an elevation of 1500 meters in the Brooks Range, the climate in the area of Atigun Pass would best be described as Arctic Continental. Summers are cool and short. Afternoon convective activity can produce snowfalls in mid-summer and below freezing conditions persist from early September through May, often into June. Average winter temperatures are below zero Fahrenheit (-17° C) from October through late March, normally staying in the -20° to -40° C range for several weeks around winter solstice when the sun remains below the horizon. (see figure 1) Conversely long hours of nearly perpendicular solar radiation on steep south facing slopes in late spring can turn starting zone basins into "mountain ovens" with evening temperatures greater than 20° C. In summer as the tundra bares and the coastal ice pack recedes under 24 hours of possible sun, onshore flow and thermally induced low pressure dominate, keeping conditions generally cool and cloudy.

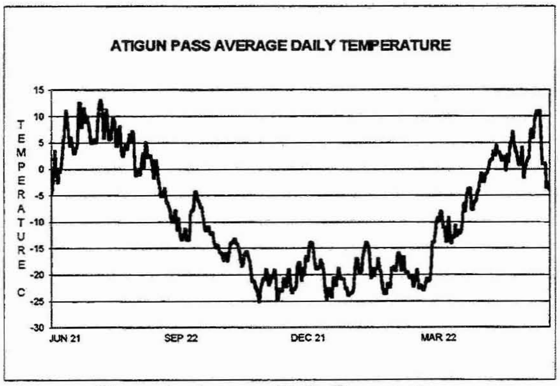

Figure 1. Average Daily Temperature

Precipitation averages 635 mm (25 in) a year at the pass, 380 mm (15 in) on the south side at Chandalar D.O.T. camp and 300 mm (12 in) on the north side. Data has been taken for only 10 to 20 years in the area primarily for streamflow prediction. Limited snowfall data (less than ten years) from the D.O.T. camp at 1000m elevation average 380cm (150 in) per winter with 170 mm (6.75 in) water equivalent. The pass receives substantially more snow, around 500 to 750 cm (200 to 300 in). Typical winter snowfall events occur with little wind at low temperatures resulting in many "wild snow" events with densities below 020 kg/m^3. The density of all snowfalls from August to June averages 048 kg/m^3.

Due to its orientation and surrounding topography, Atigun Pass is one of the conduits in the Brooks Range for the flow of air masses between the interior region of Alaska and the North Slope/Arctic Coastal region. The Dietrich River valley approaches the pass from the south for more than 55 km and the broad Atigun River valley runs for about 40 km north from the pass, opening onto the North Slope. The roadway crests the pass at 1450 meters (4,750 feet) and the surrounding peaks are 1850 to 2300 m (6,000 to 7,500 feet). This situation makes the pass the "mouth of the balloon" for air flowing from the interior to "the slope" and vice versa. During mid-winter anticyclones cold air that pools on the North Slope side of the pass can cool to -50° C before spilling over the pass. When advected into low pressure approaching from the south, torrents of cold air reach hurricane velocity on the south side of the pass creating triple digit wind chills (°F) while calm conditions prevail on the north side and elsewhere. The opposite situation occurs when powerful highs often greater than 1050 Mb build in the Alaskan interior and low pressure systems traverse the Arctic Coast: winds achieving storm force blow from the south only on the north side. These wind events, locally known as "Blows" can last up to several days completely obscuring visibility with blowing snow, drifting the road closed and creating high avalanche potential at severely low temperatures.

3. THE SNOW

A relatively shallow snowpack composed of large faceted grains at the bottom overlain by hard wind deposited slabs separated by faceted layers predominates. An average mid-winter snowpack in the pass at a representative study plot site is approximately 1.5m in depth. Some winters the site may be scoured of snow while gullies in the area can accumulate 5 to 8 meters of snowpack. Little settling or creep of the snowpack occurs during the winter until air temperatures begin to moderate in May. The major agent for change in depth is wind deposition and scouring. The major agent for change in crystal type is temperature gradient through the pack.

This is a region of continuous permafrost where at the height of summer the tundra usually thaws about a meter deep. In winter the ground temperatures at the interface of a one to two meter deep snowpack average -6° C on south exposures and -12° C on north exposures in the pass. Extended cold periods can subject the snow to gradients of more than 35° C per meter in winter and a reverse gradient of 15° C per meter has been observed on north aspects in the spring. The facets sometimes don't know which way to grow. The very cold temperatures of mid-winter tend to keep crystal growth slow but over the course of several months fully developed cups and scrolls can grow two to three centimeters in length and join to form long columns. Porous fist-hard depth hoar with densities averaging 220 to 280 kg/m^3 is the result deep in the pack.

Mid-winter snow events typically consist of 10 to 25 cm of 015 to 040 kg/m^3 density snow falling from nearly windless skies. The low-density new snow is later transported readily across the tundra and barren ground through the pass by high winds as the atmospheric pressure patterns change. There is no ground cover to reduce wind velocities so exposed areas are stripped clean and lee gullies and depressions are filled in with deep wind slabs. The wind deposited snow that survives a couple of trips back and forth through the pass consistently measures 480 to 500 kg/m^3 and rests on thin layers of low density snow. The disparate snow layers that compose the pack contribute to the destructive capability of both the dry and wet avalanches that affect the road.

In the spring, precipitation amounts and density increase with warmer temperatures stressing a very weak snowpack. With the rising temperatures, heat and moisture migrate through the dense upper slabs "softening them" and weakening the depth hoar beneath to the point of failure. As small portions of the tundra are exposed by continued melting, the snowpack recedes very rapidly creating a brief intense period of meltwater runoff. The water produced flows at the interface of the snowpack and the frozen ground causing a water table to develop in the snow in low angle gullies: a primary factor in the formation of slushflows in the area.

4. THE AVALANCHE TERRAIN

The paths threatening the road are of two distinct groups: normal avalanche paths, and slushflow paths. Shallow basin-like starting zones of 35 to 45 degrees that drop into incised gullies characterize the normal paths. The roadway crosses many of these paths in the track where the average path angle to the road is 30 to 36 degrees. Vertical relief from the starting zones to the road varies from 200 to 650 m (650 to 2100 ft). Gullies that produce slushflows affecting the road have starting zones of 3^{0} to 20^{0}, similar average path angles to the roadway and may run for more than 2 km before intersecting the road. The ground surface of the avalanche paths and slushflow gullies is composed chiefly of loose frost-split rock, is easily entrained in both dry and wet avalanches and comprises a substantial portion of the material involved in slushflows. The highway and pipeline right-of-way pass through numerous obvious drumlin-like mounds that have large boulders strewn on the surface at the mouths of the slushflow gullies. These flow deposits called "whalebacks" extend for several hundred feet beyond the road in many locations indicating the occurrence of slushflow events with magnitudes significantly greater than those seen during the last few decades.

5. THE AVALANCHES

Annually an average of more than 1200 meters of road is covered by avalanche debris 1.5 m in depth with a maximum of 7m measured. Fortunately most of the avalanche debris continues beyond the road into the runout zones. Cold dry hard slab avalanches caused by windloading predominate from September to April. Climax hard slab avalanches with crown faces of 1 to 3 meters are not uncommon at temperatures of -30° to -40° C during wind events induced by cold air advection. (see figure 2)

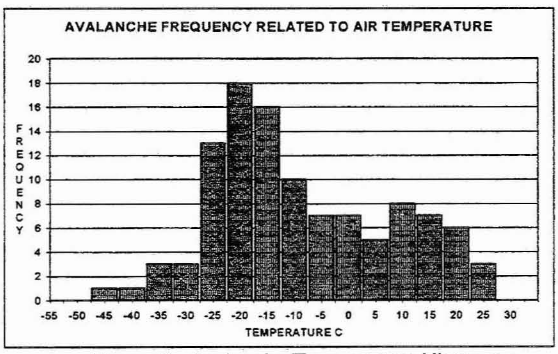

Figure 2. Avalanche/Temperature Histogram

Several paths produce slides that hit the road every few hours during a blow. Typical densities of the debris from cold dry avalanches vary from 650 to over 1000 kg/m^3. In most of the climax avalanche events observed, a significant percentage of the debris by volume is rock rubble. Boulders as large as 1.5 m across are often dislodged by the moving slabs and become entrained by the slides bounding across the highway after the main body of debris has passed. These errant missiles are quite destructive and can pose considerable hazard to avalanche control personnel.

A spring avalanche cycle occurs in mid to late May (sometimes June) when twenty-four hours of sun and rapidly rising temperatures create melt water that lubricates and weakens the porous depth hoar in the pack. Climax wet slabs with crown faces of 1.5 to 5 meters that entrain substantial amounts of rock result. Measured densities of typical debris from wet avalanches in the area span a wide range from less than 700 to over 1500 kg/m^3. Unique methods for measuring boulder-laden debris must often be used. The climax wet slide cycle normally precedes the occurrence of slushflows in the area.

6. THE SLUSHFLOWS

The slushflow season begins late in the spring avalanche cycle when temperatures continuously above freezing cause meltwater to accumulate in the nearly isothermal snowpack in low angle gullies. Meltwater retained in the base of the snowpack migrates toward the surface sometimes creating visible pools of slush that fail causing slab releases. Crown faces 2 to 5 meters in height are common with one gully consistently releasing almost 7 meters deep. These hybrid avalanche/debris torrents are often the most destructive of the avalanche events in the area as they carry a significant load of rock, soil and slush onto the roadway. As a consequence of their flow down active stream courses, the debris often blocks culverts and channels beneath bridges causing the streams to washout the road. Although rarely observed in motion, several slushflows have been initiated and observed during avalanche control activities in the Atigun Pass area.

Several factors contribute to the formation of these events in the Brooks Range. Rapid intense melting of snow late in the season by continuous (24-hour) solar insolation supplies the water necessary to raise a water table in snow-filled gullies. An impermeable ground surface of ice (permafrost) or bedrock in the area of initiation that prohibits free water in the snowpack from draining into the ground is prevalent. Porous depth hoar at the base of the snowpack accumulates significant amounts of water and the denser small-grained slabs above likely delay failure. Two or more days of continuous above-freezing temperatures (and occasionally rainwater) supply enough runoff to create a "high tide" that weakens the basal snow to the point of failure, probably by the reduction of bond strength and increase in hydrostatic pressure.

The slabs released are commonly many times longer than wide, as the width is controlled by the gully walls. A typical length to width ratio observed for slabs in the area is around 7 to 1. After failure the slab overrides an apparent stauchwall at its lower boundary riding on a wave of lubricating slush and then gouges into the gully bottom entraining snow, rocks, soil and anything else which isn't frozen down. The head of the debris torrent has been observed to retain a lobe-shaped form when the flow is confined in a gully and can travel at speeds of more than 20 m/sec. It is quite possible that low friction of a running surface composed of ice with water on top, the simultaneous release of such long slabs, and the lubricating slush contribute to the high velocity and lobate fronts of the flows that have been observed in the area.

Supercritical rates of descent are evidenced by significant super-elevation of the moving mass in the bends of the gullies where it caroms back and forth off the confining walls. These high speed flows have been observed to jump over hillocks thirty meters high upon exiting the gullies and resemble the stream of water from a high pressure fire hose in appearance, though are composed of slush and rock. Small flows disperse or are deflected upon reaching the gully mouth depositing thin layers of unsorted material and boulders when the upslope sides of the whaleback forms of previous events are encountered. The larger flows in stream channels of the area have been observed to travel nearly 4 km on grades of less than 2^0 before dissipating, though moving at slower speeds resembling flash floods. Several methods of artificial initiation of slushflows have been attempted with varying levels of success.

7. CONTROL METHODS

Conventional avalanche control methods with some modifications for Arctic conditions are effective for the artificial release of cold snow hard slabs in the area. Blind fire from permanent gunmounts with a 105-mm recoilless rifle allows control work to be accomplished during the several week period of low light conditions around winter solstice and when visibility is nil during blows. When temperatures fall below -25^0C the ammunition must be stored at room temperature for several hours before firing to insure reliable muzzle velocity. Below -35^0C weapon use is restricted to critical situations because of the propensity for metal parts to fail and the gelling of lubricating fluids. Additionally the hydraulic systems of equipment used to clear avalanche debris do not function well below -40^0C, so "natural preventive closures" are used until conditions moderate once slide debris is on the road or the road is blown shut from drifting snow at very low temperatures.

Initiation of wet slab avalanches can be accomplished using the rifle; however, stone-age methods have proven to be much more cost effective over the last few years. Climbing to the starting zones of paths above the road and using rocks or glissading to start small wet loose slides which then drop into the gullies and break out full depth (1.5 to 5 m crowns) is a proven technique with an unlimited supply of "ammunition" available at no cost.

Slushflow initiation presents a more complex problem because of the presence of free water in the snowpack. Explosive charges whether pre-placed in arrays at the base of the pack, placed on/above the surface, or dropped from aircraft tend to remove material locally without causing slab failure. The most effective method for release found thus far has been to create a minor disturbance in the area of slush accumulation to raise the water table. The saturated snow then fails removing support for the non-saturated slab above and upslope which releases full depth. Metasediment volume displacers half a meter across rolled about 50 m vertical down the steep side slopes of the gullies into the slush pools do the job quite nicely, and are fortuitously perched above in unlimited numbers. Refinements in these artificial release techniques are expected as more experience is gained in the springtime Arctic snowpack.

8. SUMMARY

Avalanche forecasting and snow management in an Arctic environment differ somewhat from that in more temperate climates. Snowfall events seldom supply enough weight to the snowpack to create slab avalanches. The transport and deposition of snow by high winds at very low temperatures is the primary cause for mid-winter avalanche releases. Darkness, severe cold and blizzard conditions complicate the job of avalanche mitigation during this period. Snow remains on the ground until late in the spring when intense solar radiation rapidly degrades the snowpack causing widespread failure. Slushflow occurrences in the area pose a significant hazard to the transportation corridor during this brief but intense period each spring and the artificial release of these unusual and complicated hybrid avalanches is in its infancy. Scarce monetary resources, dwindling ammunition supplies and environmental constraints on operations require the use of unsophisticated but effective avalanche forecasting and control methods. With a keen interest in resource extraction in the Arctic of Alaska, the Dalton Highway will continue to play an important role in transportation to the North Slope in winter requiring the maintenance of an effective avalanche safety program at Atigun Pass.

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