REDUCING AVALANCHE HAZARD TO US ROUTE 89/91 IN JACKSON WYOMING USING SNOW SAILS

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ABSTRACT: Snow sails are a form of passive avalanche starting zone defense. A deployment of snow sails work to disrupt the formation of continuous, coherent wind-slabs in avalanche starting zones. Snow sails are only effective on avalanche paths were the dominant avalanche mechanism is through the formation wind-slabs. The objectives of using snow sail defense structures at the 151-avalanche path in Jackson Wyoming are to *cost effectively* reduce the avalanche hazard to motorists and highway maintainers on US 89/91 and minimize the visual and terrain impacts. The 151-avalanche path is managed as critical big game habitat and is located adjacent to the residential areas of Jackson Hole. Heavy snows and consistent S-SW winds with a ~1 mile fetch recurrently produce high hazard conditions, with snow slides frequently reaching the highway (~1.0/year). US 89/91 is the primary route for commuter traffic in the Jackson area and has recently been classified as the busiest primary highway in the state of Wyoming. In the autumn of 2002 a deployment of ~50 snow sails were fabricated, transported, and installed on the 151 avalanche path. The snow sails are removed annually in the spring and re-installed in the fall. This was required as a consequence of the National Environmental Policy Act (NEPA) Environmental Assessment (EA) to minimize year-round visual impact. After two seasons of operational use and continued evaluation, the project has proven effective in disrupting the formation of a coherent wind-slab in the 151 staring zone. However, widespread avalanche activity on January 1, 2004 produced an event at 151 depositing 10' of debris across five lanes of highway. Continued evaluation will be required to determine the success of the snow sail deployment in reducing the avalanche hazard, and those conditions and configuration where the deployment is most effective.

Keywords: passive avalanche mitigation, avalanche engineering, transportation

1. INTRODUCTION

Snow sails are a form of *passive avalanche starting zone defense,* designed to use the inherent energy of the wind to disrupt and modify snow deposition patterns, resulting in a reduced occurrence of wind-slab avalanching. A deployment of snow sails will disrupt the snowpack in an avalanche starting zone and inhibit the formation of coherent, continuous avalanche "wind-slabs".

To be effective in scouring and disrupting the snow depositional pattern, a given snow sail is deployed so that the wind must flow perpendicular, against, and under the broad face of the sail. A single snow sail is installed on a 14 foot mast. It has a broad trapezoidal fabric "sail" panel, 10 feet tall, mounted on two booms – 10 feet at the top, 8 feet at the bottom – with a 4 foot gap between the ground surface the lower edge of the sail. A given unit has an appearance similar to the sail of a Viking ship – hence the name: snow sails. The resulting complex, highly turbulent airflow erodes and disturbs the snow depositional pattern on the ground. The zone of disrupted snowpack is typically an ellipse 30 to 40 feet in diameter, with the shallowest snowpack being near or immediately under the snow sail itself.

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2. BACKGROUND

Snow sails where first constructed from on-hand materials and deployed in the European Alps in the late 1940's through the 1950's when military garrisons (and hence – labor) were plentiful in the international passes. They were known in German as kolktalfen – which translates literally as (airflow) eddy (generating) tables. Figure 1 shows suggested configurations for these original kolktalfen [1].

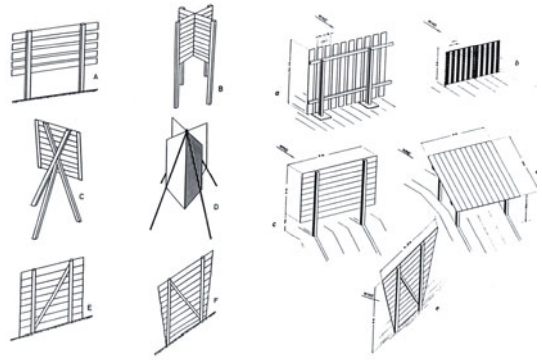

Figure 1

Based on European guidelines, for snow sails to be effective in reducing wind-slab avalanches, the sails must be deployed so that the distance between any two adjacent sails is 1.0 to 1.5 the sail top width (10 feet). Snow sails are only applicable to certain specific avalanche environments, including; sites where the dominant avalanche mechanism is through the formation of wind slabs and the total snowpack depth does not become large (> 6 feet). For these reasons, snow sail use in Europe was superseded by the use of more effective (and more costly) snow supporting structures in the avalanche starting zone and/or avalanche sheds (tunnels) at the roadway.

However, for reasons of cost effectiveness – European avalanche hazard specialist are once again experimenting with kolktalfen. Figure 2 shows a modern trial deployment of omni (wind) directional kolktalfen in the Austrian Alps.

Figure 2

2.1 Objectives of the 151 snow sail project

The objective the milepost 151 avalanche project was to assess, test, and install an operational deployment of ~50 snow sail in the avalanche starting zone as a means of *cost effectively* reducing the avalanche hazard, due primarily to wind-slab avalanching, for motorists and WYDOT maintainers on USR 89/191. This site is ~3 mile south of the community of Jackson, Wyoming. USR 89/191 is the primary route in and out of this valley from the south. The location of this site is shown in Figure 3.

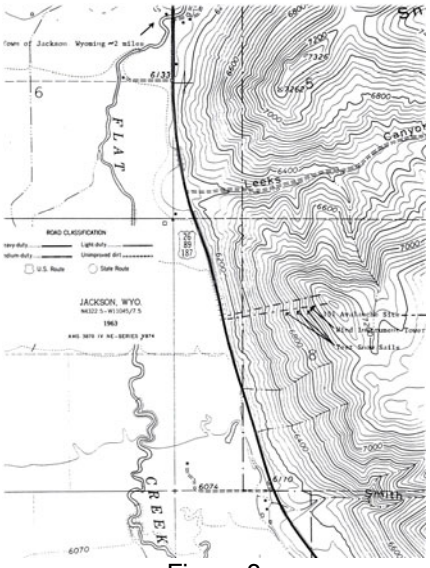

Figure 3

The 151 avalanche is pre-dominantly a "wind-slab" avalanche. During periods of heavy snow, coupled with strong southwesterly winds, snow is transported into the 151 avalanche starting zone. When the resulting wind-slabs become unstable, they may avalanche onto the

USR 89/191 roadway, which is located at the valley floor, approximately 1000 vertical feet below.

Potential alternative techniques for avalanche hazard reduction in at the 151 avalanche site include the use of avalanche hazard forecasting and explosive control or other forms of constructed, passive defense measures; such as snow supporting structures in the starting zone or a snow shed at the road. The 151 avalanche is located adjacent a populated residential area and is also critical, managed big game winter habitat. This precludes the regular use of explosives for avalanche control. Additionally, cost estimates for snow supporting structures in the 151 avalanche starting zone indicates that this form of passive avalanche defense at this site would cost ~$1.4 million, installed. A snow shed at the roadway has been previously estimated at ~$12.7 million for this site for a two lane roadway. USR 89/191 is now an upgraded four lanes highway.

3. SPECIFICATIONS – THE 151 SNOW SAIL DEPLOYMENT

The net cost to fabricate, transport and install the operational deployment of 50 snow sails on the 151 avalanche and leave 10 pre-assembled sails in reserve at the WYDOT Maintenance facility in Jackson was $~90K. This cost was originally estimated at $96.6K. In addition, there was one-time proto-type development and testing costs of $82K during the pilot phase testing during three winter season prior to 2002/03. The final snow sail design is fabricated from aircraft grade aluminum and uses a vinylized commercial truck tarpaulin material for the sail. It is cable stayed with earth anchoring pins, each driven ~3 feet deep. The static design wind load is 1200 lbf. lateral, which would be produced by a design wind of 90 mph. There is an on-going, automated wind study being conducted on-site.

Figure 4: Full 151 Snow Sail Deployment

During the summer and autumn of 2002 a compliment of 60 snow sails were fabricated and transported from Salt Lake City to the Jackson, Wyoming area. The final sail design was similar to the initial trial design – with little or no modification and the simplest (stitched) connection for the cloth sail panel to the aluminum frame. The original proto-type of this sail is still in service on the 151 site. It has now been in continuous service since the summer of 1999. Helicopter supported logistic were used to transport the pre-assembled snow sails, earth pin anchors and cabling from the Jackson valley floor to the 151 avalanche site.

3.1 National Environmental Policy Act (NEPA) Requirements

The 151 avalanche starting zone is managed by the USDA Forest Service as a "Critical Big Game" habitat. It also has high quality visual attributes. Hence, during the autumn and winter of 1999/00, Carter & Burgess, a Denver based contractor, and WYDOT headquarters personnel pursued and developed the requisite National Environmental Policy Act (NEPA*)* Environmental Assessment (EA) for the 151 Snow Sail project.

The findings of the draft EA supported continued progress towards the full, operational deployment of ~50 snow sails on the 151 as a preferred method of avalanche

hazard reduction at this site. The visual impact of the ~50 sails remained the most pressing public and USDA Forest Service concern. The primary mitigation technique for visual impact includes the provision to annually remove the sails in the spring and re-install them in the autumn. In addition, the winter 1999/2000 pilot project addressed the issue of sail cloth color and the visual impact of the sails when they are installed in the 151 avalanche starting zone. The prairie brown color blended well visually. The white sails blended well with the snow and sky, but stood out starkly when seen against the mountainside.

The 151 avalanche snow sail deployment National Environmental Policy Act (NEPA) Environmental Assessment resulted in a Finding of No Significant Impact (FONSI) [2]. This was due, in large part to the fact that, unlike other forms of constructed, passive avalanche starting zone defense, snow sails may be removed annually in the spring and re-installed in the autumn. This minimizes their year-round visual impact. Annual removal/re-deployment and maintenance costs for the 151 avalanche snow sail system has been estimated at $21K. Figure 5 shows personnel re-installing one of the final compliment of 50 snow sails in the full deployment at the beginning of the 2003/04 winter season.

Figure 5

An additional element of the EA included a recommendation that forest species planting (or re-planting) be assessed and, if found feasible, conducted on the 151 avalanche starting zone. The premise is that mature conifer stands on the 151 avalanche starting zone, if in sufficient numbers and size, could serve the same purpose as the snow sails in disrupting snow depositional patterns and, hence, reducing avalanche hazard. There is some evidence (a few large, old downed timber trunks) in the upper reaches of the 151 avalanche starting zone to suggest that there was once a stand of timber on this site during pre-history. Perhaps it was burned. Subsequently, it's possible that the barren nature of the site, with its attendant high winds, avalanching, and snow creep and glide, would not allow the site to re-seed naturally.

4. EVALUATION

The operational snow sail deployment at the 151 avalanche path has undergone 2 seasons of evaluation.
Winter 2002-03 operational deployment
Spring removal and damage assessment
Winter 2003-04 operational deployment
Spring removal and damage assessment
Evaluation of the complete operational deployment for two winter seasons has yielded several conclusions of the feasibility, reliability, and, effectiveness of the snow sails deployment.

4.1 Reliability

The current snow sail design uses cable stays to secure the assembled sail to the slope. Experience of the winter 2003-04 show that during periods of heavy snow deposition in the starting zone, snow creep mechanisms increase the forces on these cable stays. The combination of increased loads on the stays and strong winds has led to sail damage in some cases. A majority of the observed failure has occurred in the connection between the boom and mast. This connection is accomplished with .5in high grade steel all-thread that is susceptible to the extreme stresses of wind and snow creep. The estimated failure rate for the current design is ~10% of the full deployment requiring minor repairs and ~2% needing major repair or replacement.

4.2 Effectiveness

During the winter of 2002-2003 there was no avalanche activity observed at the 151. Snowpack accumulations were near normal at the upper elevations and slightly below normal at the lower elevations. Observations of the snow distribution at the 151 showed a highly disrupt snowpack with variations depth exceeding 80cm. Minor avalanche activity was observed in some lower elevation starting zones, but no low elevation avalanches paths in the Jackson area impacted the highway during the 2002-03 winter.

While the snow sail deployment has proven effective in the disruption of the formation of a continuous/coherent wind slab, there has been one avalanche event at the 151.

On January 1, 2004 strong winds and heavy snows produced high avalanche conditions throughout the Jackson Hole area. At approximately 2100hrs a large natural avalanche released and impacted US 89/191 with ~10' deposition across five lanes of highway. There was no property damage or vehicle interaction with the slide. Numerous other avalanches also slide to the valley floor and the backcountry avalanche hazard was high. Conditions leading up to the event consisted of heavy snow at both upper and lower elevations with several low pressure systems moving through western Wyoming within a 7day period. This was the first true test of the deployment during a period of extended heavy snowfall and high winds. Two strong cold fronts associated with the low pressure systems worked to produced strong S-SW winds with maximum gust velocities of 75mph and average wind velocities of 30-45mph. The avalanche coincided with the passage of a very strong cold front seen in the peak wind velocities in figure 6. Cold frontal passages in Western Wyoming typically drive strong S-SW winds ahead and heavy snows of the front. Snowfall rates were estimated at ~2-3in/hr two hours prior to the avalanche event on January 1.

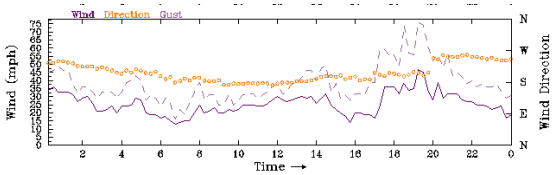

Figure 6: 24hr Wind Data; 12/31/2003 to 1/1/2004

Observations taken at the 151 starting zone several days after the event revealed a crown face traversing the slope and another crown fracturing down the southern flank and through the areas of disrupted snowpack created by the snow sails, see figure 7. The crown extended into the slope beyond the area of influence formed by the sails (~50ft). A profile of the crown face identified a layer of large facets/depth hoar near the ground produced the sliding surface.

Figure 7: Crown traversing slope and southern flank

Multiple days of heavy snows and strong S-SW winds decreased the effectiveness of the snow sail deployment's ability to disrupt the snowpack in the 151 starting zone. Effectively, the deployment was unable to decrease the avalanche hazard at the 151. While the depth hoar was a significant contribution to problem, a semi-continuous slab was able to form in the starting zone and eventually release to the highway.

5. CONCLUSIONS

The 151 snow sail deployment has proven effective in disrupting the formation of a continuous coherent wind slab. However, the deployment does not mitigate 100% of the avalanche hazard. While this is a cost effective alternative to snow supporting

structures, the effectiveness is limited to periods of snowfall and wind with moderate duration and intensity. Performance of operational effectiveness of the 151 deployment is ongoing. Continued evaluation will be required to identify conditions and configuration where the deployment is most effective.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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2. *Snow Sail (Draft) Environmental Assessment – Jackson South Avalanche Mitigation*, Carter & Burgess for the Federal Highway Administration (FHWA), WYDOT, and the USDA Forest Service