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SNOW SUPPORTING STRUCTURES FOR AVALANCHE HAZARD REDUCTION, 151 AVALANCHE, HIGHWAY US 89/191, JACKSON, WYOMING

By:
InterAlpine Associates
83 El Camino Tesoros
Sedona, Arizona 86336

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Notice

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Abstract: The 151 Avalanche, near Jackson, Wyoming has, historically, avalanched to the road below 1.5 to 2 times a year. The road, US 89/191 is four lanes and carries an estimated 8,000 vehicles per day in the winter months.

The starting zone of the 151 Avalanche is 1,140 vertical feet above the roadway. With the adjacent development of the South Park areas of the Jackson Hole Valley, using explosives for avalanche control is unacceptable. As a consequence, this project has led to the design and configuration of a deployment of snow supporting structures, that if implemented, would provide a more effective avalanche defense system. This has resulted in a unit structural and foundation design for seventy (70) snow supporting structures.

The unit design will support a maximum 6.6' snowpack. The 70 structures, deployed with a separation of 50' longitudinally, will cover the dominant portions of the 151 Avalanche starting zone. Moreover, novel deployment configuration has been developed to also retain the visual characteristics of the starting zone as seen from the Jackson Hole valley floor. This factors critically into the National Environment Policy Act (NEPA) rule-making responsibilities of the USDA Bridger-Teton National Forest and their resulting favorable Decision Memo.

The resulting design of a snow supporting structure is 12' long and 5.5' high, installed nearly perpendicular to the slope which is inclined at 35 degrees. A single structure weights 1,400 pounds, and the cost is estimated at $16,600 per structure; fabricated, transported and installed.

Key Words Wyoming, Snow Supporting Structures, Snow Bridge, Avalanche, 151 Avalanche, Jackson, Fabrication, NEPA, Visual Retention		Distribution Statement Unlimited	
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SI* (Modern Metric) Conversion Factors

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
Volume				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
Temperature (exact)				
°C	Centigrade temperature	1.8 C + 32	Fahrenheit temperature	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m
mi	Miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	ml
gal	Gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz	Ounces	28.35	grams	g
lb	Pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)				
°F	Fahrenheit Temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
Force and Pressure or Stress				
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

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Further, InterAlpine acknowledges the efforts of Stefan Margreth, Head of the (Avalanche) Warning and Prevention Unit of the Swiss Federal Institute for Snow and Avalanche Research, as well as the Institute's leadership, for authorizing and providing an advanced copy of the 2007 English language Swiss Guideline; Defense structures in avalanche starting zones Technical guideline as an aid to enforcement.

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Executive Summary

The 151 Avalanche is located above US 89/191 at milepost 151 in Jackson, Wyoming. It is a well known hazard and avalanches have struck vehicles, resulting in crashes, traffic delays, and attendant avalanche debris clean-up by WYDOT maintenance crews. The 151 Avalanche has, historically, avalanched to the road 1.5 to 2 times a year. There have been no loss-of-life incidents to date. US 89/191 is four lanes and carries an estimated 8000 vehicles per day in the winter months.

The starting zone of the 151 Avalanche is 1140 vertical feet above the roadway. It is managed by the USDA Bridger-Teton National Forest as critical big game habitat. This, along with the adjacent development of the South Park areas of the Jackson Hole valley makes the use of explosives for avalanche control unacceptable. Moreover, the time it takes WYDOT winter maintenance personnel to address the 151 Avalanche with traditional avalanche hazard forecasting and explosives initiation of the avalanche while the road is closed takes them away from other duties, typically during winter storm periods when these personnel resources are at a premium.

There are three forms of constructed, passive avalanche defense that are applicable to the 151 Avalanche; snow sails in the starting zone, snow supporting structures in the starting zone, and an avalanche shed or gallery at the roadway. The latter passes the avalanche safely over the road, but then in the case of the 151 Avalanche, onto adjacent private land. Hence, a snow shed at the road is not a feasible solution for avalanche hazard management at the 151 site. Moreover, a snow shed is the least cost effective option of the three passive systems. Snow sails are the most cost effective option for addressing the 151 Avalanche in its starting zone with a constructed, passive system. Passive avalanche defense systems do not require personnel to be effective or perform their duty of avalanche hazard reduction during winter storm periods. Snow sails have subsequently been assessed and installed in the 151 Avalanche starting zone. Though they were cost effective, by a factor of 10, and have reduced the frequency of avalanching, they have not been sufficiently effective in this vein nor do they appear to be effective against the larger and more severe avalanches. These caveats become even more pronounced in the face of growing traffic volumes on this roadway. Moreover, this traffic demand is, more often than not,

expected by motorists to be “all weather.” The snow sail project did bring WYDOT into a risk management status of reasonable and prudent, for its attempt to address a known avalanche hazard pro-actively.

As a consequence, the project being reported here has led to the design and configuration of a deployment of snow supporting structures in the 151 Avalanche that would, if implemented, serve as a more effective avalanche defense system. This has resulted in a unit structural and foundation design for seventy (70) snow supporting structures for the 151 Avalanche. The design process utilized the 2007 Swiss Guideline for these facilities. The Swiss Guideline is an evolutionary document resulting from over 50 years of experience in the design and implementation of snow supporting structures for avalanche defense. Snow supporting structures are a commonly found technology in the European Alps, and more recently in Asia. Consider that in some alpine states of Europe, their use is the single largest public works expenditure, ahead of the likes of transportation, energy or water infrastructure. The use of snow supporting structures on the 151 Avalanche, designed and configured for that specific site utilizing the latest 2007 Swiss Guideline, are at best practices for avalanche hazard management.

This project resulted in a unit design for a snow supporting structure in the 151 Avalanche starting zone that will support a maximum 6.6’ snowpack. 70 of these structures, deployed with a separation of 50’ longitudinally (up/down slope) will cover the dominant portions of the 151 Avalanche starting zone. Moreover, a novel deployment configuration has been developed, utilizing a collaborative work process, that has the potential to both meet the technical need of supporting the 151 Avalanche snowpack, as well as retain the visual characteristic of the 151 Avalanche starting zone, as seen from the Jackson Hole valley floor. Those factor critically into the National Environmental Policy Act (NEPA) decision making responsibilities of the USDA Bridger-Teton National Forest. It is their role to manage this project from their public lands perspective and mandate. A collaborative work-process was initiated with the Forest Service and resulted in a Decision Memo favorable to the eventual installation of snow supporting structures in the 151 Avalanche starting zone.

The resulting unit designed 151 Avalanche snow supporting structure is 12 feet long and 5.5’ height. It is to be installed nearly perpendicular to the slope, which in the 151 Avalanche starting zone is inclined at 35 degrees. A single structure weighs 1400 lb. Their costs is estimated at $16,600 per structure; fabricated, transported and installed in the 151 Avalanche starting zone. This results in a net estimated (2008) project cost to install snow supporting structures in the 151 Avalanche starting zone of $1.162M.

CHAPTER 1: Problem Description

As a consequence of the rapid urbanization of the greater Jackson, Wyoming area, the hazard to motorists and WYDOT personnel from an active avalanche path at milepost 151 on US 89/191 has also increased dramatically.

In addition to being the primary regional trunk road into and out of Jackson from the south, US 89/191 is the principal route for north-south commercial traffic in western Wyoming. Measurements of average daily traffic (AADT) on this route is11000 vehicles per day. This figure includes significant summer peak traffic, so winter use should be considerable less, though still significant at an estimated 8000 vehicles per day.

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 US 89/191 highway, which is located at the valley floor 1140 vertical feet below. The 151 site avalanches, on average, 1.5 to 2.0 times per year. These incidents cause significant traffic delay. In the past, a fraction of these avalanches have impacted motorists' vehicles on the roadway. To date, there have been no loss-of-life incidents.

The avalanche hazard at the 151 Avalanche has been addressed with limited success by the deployment of snowpack disrupting snow sails. However, the 151 Avalanche continues to consume significant WYDOT winter maintenance resources during storm fighting periods. This is because WYDOT winter maintenance crews have found it necessary to temporarily close the highway and attempt to bring down the 151 Avalanche with explosive control measures during these storm fighting periods. This, at a time when these WYDOT resources are at a premium and the regional surface transportation system is already taxed.

A nearly optimal solution for avalanche hazard management at the 151 Avalanche site would be a more effective passive (constructed) system that performs "stand alone" and does not require WYDOT winter maintenance personnel consideration during storm fighting periods (and attendant high avalanche hazard).

There are four existing avalanche hazard reduction technologies applicable to the 151 Avalanche in Jackson, Wyoming, specifically:

1. Avalanche hazard forecasting and active (explosive) control.
2. Wind/snow disrupters (snow sails) in the avalanche starting zone.
3. Snow supporting structures (snow bridges and rakes) in the avalanche starting zone.
4. Snow (avalanche) shed or gallery at the road.

Forecasting and explosives initiation of the 151 avalanche is presently practiced by WYDOT winter maintenance crews. It is less than optimal because it draws their attention away from other pressing winter maintenance activities during storm fighting periods. Furthermore, the 151 Avalanche starting zone is managed by the USDA Forest Service as critical big game winter habitat and the adjacent South Park area of the Jackson Hole valley is now developed and heavily populated. Hence, regular use of explosives is not compatible with either of these other uses of the surrounding area.

Moreover, at the time of Final Reporting of the Snow Sail project, the following cost estimates, amongst other decision making criteria, had been established for each of these four possible technologies applicable for the 151 Avalanche site. Detailed cost estimates for the fabrication and implementation of snow supporting structures are provided later in this report. Note that of the passive defense methods – snow sails were a logical first choice from a cost effectiveness stand-point, but only if they proved sufficiently effective in reducing the avalanche hazard.

Table 1. Cost/Criteria/Performance comparison of avalanche hazard reduction technology applicable at the 151 site, Jackson, Wyoming (adapted from: [1]).

	Forecasting and Active Control	Snow Sails in the avalanche starting zone	Snow Bridges or Rakes in the starting zone	Avalanche Shed or Gallery at the roadway
Avalanche Potential	Yes – optimally to a closed Road	Reduced	No	Yes – over the roadway
Costs	$50K/annually	$135K + $10K/annual	$1.4M	$14.0M
Traffic Delays	Moderate	Low to Moderate	None	None
Construction Impact	None	Low	High	High at roadway
Visual Impact	None	High - seasonally	Moderate	Moderate at roadway
Wildlife Impact	High	Low	Low	None
Noise Impact	High	None	None	None

The snow sail deployment at the 151 Avalanche was an attempt to address the avalanche hazard with a cost effective constructed solution. It has been of limit success in reducing avalanche occurrence, especially during period of intense snow and wind.

A snow shed or gallery (an artificial tunnel) at and over the highway is not a cost effective solution, exacerbated by the expansion of US 89/191 from two to four lanes at the point were the 151 Avalanche crosses the roadway. Additionally, the act of passing the avalanche over the roadway and onto adjacent private land poses an entirely new suite of issues.

Hence, the next logical escalation in efforts to reduce the avalanche hazard on the roadway at the 151 Avalanche was to explore the design, costs and USDA Forest Service National Environmental Policy Act (NEPA) requirements for a deployment of snow supporting structures in the 151 Avalanche starting zone.

Snow supporting structures are a form of constructed defense in the avalanche starting zone that holds the snow statically in place and precludes the onset of avalanching. They operate independently and do not require winter maintenance personnel resources to perform their function during storm fighting periods.

They are not novel. Dating from the late 1950's and early 1960's, they are used extensively in Europe and Asia for avalanche hazard reduction. Their use is also widespread. For example, their implementation constitutes the single largest public works expenditure in the Austrian Tyrol, to date. The standard-of-practice for the site specific design of snow supporting structures is the European (Swiss) guidelines.

CHAPTER 2: Project Objectives and Task Narrative

The 2007 edition of the evolutionary European (Swiss) standard-of-practice guideline, Defense structures in avalanche starting zones technical guideline as an aid to enforcement (in English), Federal Office for the Environment FOENWSL Swiss Federal Institute for Snow and Avalanche Research SLF, Bern, 2007 [2] for a site specific deployment of snow supporting structures in the 151 Avalanche starting zone was used to develop a "65%" preliminary design. The earliest Swiss guidelines for snow supporting structural design date from the early 1960's. Utilizing the resulting design and the site specific deployment configuration; cost estimates, including installation, were then prepared for the 151 Avalanche.

Developing an "on-the-ground," site specific configuration for a deployment of snow supporting structures in the 151 Avalanche starting zone carries challenges that are uniquely domestic in nature and not found in the implementation of this technology in Europe and Asia. The National Environmental Policy Act (NEPA) recognizes "visual attributes" of a given site as one of the primary environmental assets that must be addressed and protected with respect to projects on Federal lands. The 151 Avalanche starting zone is on Federal land, administered USDA Forest Service's Bridger-Teton National Forest.

A prior NEPA initiated Environmental Assessment (EA) was conducted for the resulting deployment of snow sails in the 151 Avalanche starting zone [3]; the same site that will be occupied by any future deployment of snow supporting structures. The results of this EA indicated that visual attributes were the only environmental asset at this site that might, potentially, be impacted. The net EA finding was one of no significant impact (FONSI).

Nevertheless, the NEPA requirement that the 151 avalanche starting zone "retain" its present level of visual quality, even after the deployment of snow supporting structures, is the principal criteria governing Forest Service permitting for their eventual use in avalanche hazard reduction at this site. A collaborative work process was initiated with technical personnel in landscape architecture and avalanche hazard management from the Bridger-Teton National Forest, and personnel skilled in avalanche hazard management from the Jackson WYDOT maintenance facility. These collective efforts lead to a snow supporting structure deployment configuration for the 151 Avalanche starting zone that has the potential to both reduce avalanching and, in conjunction with (re)forestation, retain the visual quality of the site.

The primary benefits of this project are the resulting preliminary design, cost estimate, and NEPA review and USDA Forest Service rule making that will allow WYDOT planners to determine if the subsequent fabrication and installation of snow supporting structures for avalanche hazard defense at the 151 Avalanche site is cost effective and warranted.

Furthermore, at the present time, WYDOT has and is demonstrating "reasonable and prudent" risk management of the avalanche hazard at the 151 Avalanche site through the use of both snow sails, and avalanche forecasting and explosives control; though explosives control is not a favorable long-term solution. It is estimated that the service life of the present fleet of snow sails is 4 to 6 years remaining years. To remain at a defensible level of reasonable and prudent risk management of the 151 Avalanche hazard, WYDOT must either maintain present activities and facilities, or move towards the use of snow supporting structures. This research gives WYDOT planners the tools to make that decision in an informed way. Moreover, the implementation of snow supporting structures in the 151 Avalanche starting zone, designed under the advice of the 2007 Swiss Guideline, would bring the risk management level at this site from its present reasonable and prudent to internationally recognized "best practices."

The location of 151 Avalanche with respect to the community of Jackson, Wyoming and US 89/191 is shown in Figure 1 and 2.

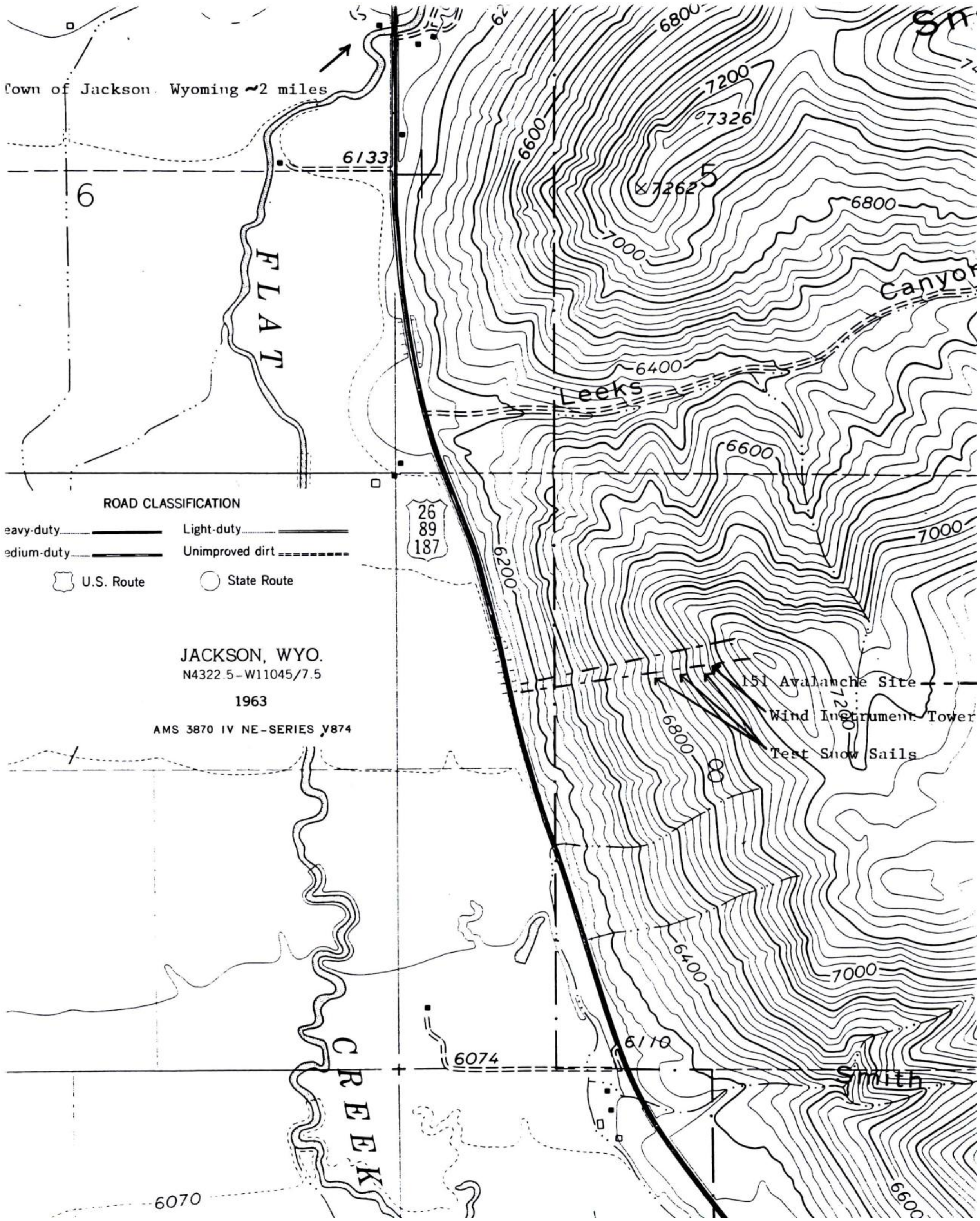


Figure 1. Location of the Milespost 151 avalanche with respect to the community of Jackson, Wyoming.

Figure 2. The 151 Avalanche on US 89/191 south of the community of Jackson, Wyoming (from: WYDOT Jackson maintenance facility Avalanche Atlas).

CHAPTER 3: Project Background

3.1 Avalanche Hazard Reduction at Jackson's 151 Avalanche

The existence of an active avalanche, capable of reaching the Jackson Hole valley floor, at the site of what has come to be known as (the US 89/191 Milepost) 151 Avalanche has been recognized for many decades and well before the more recent development of the South Park area of the Jackson Hole valley [4].

The 151 Avalanche is estimated to avalanche to the roadway, 1.5 times per year. This hazard has been addressed with operational consideration by WYDOT for the last several decades, at least. This has lead to incidents of avalanching unto the roadway during periods when the road was closed due to the risk, but also avalanching unto the road while it was open to traffic. These events usually require heavy equipment, typically front-end loaders and/or rotary snow-blowers, to clean-up and then re-opening of the road. Several of these incidents included avalanches impacting vehicles on the roadway and carrying them out of the right-of-way and into the avalanche's run-out on the adjacent valley floor meadow. Figures 3 and 4 depict just this, including the resulting rotary cut avalanche debris at the roadway shoulder; which is about as deep as the vehicle is high. Such incidents have resulted in attendant property damage, trauma, and the need for extrication and rescue. There have not been any fatal incidents associated with the 151 Avalanche, to date. Nevertheless, the potential for loss-of-life interactions between avalanches and vehicles are possible. Figure 4 is a vehicle that was struck by an avalanche in Alta, Utah. It was abandon at the time, as the occupants had, only minutes earlier, taken shelter in an adjacent lodge during a period of high avalanche hazard.

Figure 3. A vehicle struck by the 151 Avalanche on US 89/191 in Jackson, Wyoming.

Figure 4. Rotary snow-blower cut debris from the 151 Avalanche adjacent the US 89/191 roadway in Jackson, Wyoming.

Figure 5. An abandon vehicle struck by an avalanche in Alta, Utah.

3.1.1 Avalanche Hazard Forecasting and Artificial Release

WYDOT Jackson maintenance facility staff began to use temporary road closures during periods of forecast high avalanche potential as a hazard management technique in the late 1970's. This was augmented with the trial use of military weapons to initiate avalanches during these same periods, while the road was temporarily closed. Starting in the late 1980's these efforts were supplemented with explosives delivered to the 151 Avalanche starting zone with helicopters (heli-bombing) [5], and most recently, with explosives delivered into the starting zone by WYDOT winter maintenance staff climbing there on skies [6].

3.1.2 Snow Sails

In the 1990's, in the face of mounting concern associated with the hazard from the 151 Avalanche, coupled with three other dominant factors; increasing traffic volumes leading to roadway expansion from two to four lanes, critical big game habitat management in the 151 Avalanche starting zone, and increasing residential development in the South Park area; WYDOT initiated efforts to reduce the hazard from the 151 Avalanche with a passive, constructed defense system.

This resulted in implementation research and the trial deployment of the present snow sails in the 151 Avalanche starting zone [1,7,8].

Snow sails are designed to use the inherent energy of the wind to generate a highly turbulent eddy immediately under and downwind of the sail. This wind flow disrupts and modifies the snow deposition pattern from what would otherwise be a continuous and homogeneous "wind-slab." As a result of the disturbed depositional pattern, the snowpack is less likely to support clean, coherent fracture propagation. As a consequence, the occurrence of wind-slab avalanching, typical of the 151 Avalanche, is reduced. 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). These are both characteristics of the 151 Avalanche.

Dating from the 1940's, snow sails (Kolktalfen) have been successfully deployed for avalanche hazard reduction in Europe. Beginning in the late 1960's and early 1970's, the use of snow sails in Europe and Asia was superseded by the use of more effective (and more expensive) snow supporting structures, often in concert with re-forestation.

In the autumn of 2002, at an operational cost of $90K (and $85K in one time research and development costs), sixty (60) snow sails were fabricated and 50 were installed in the 151 Avalanche starting zone. Subsequent to the deployment of the snow sails, the average annual recurrence of avalanches from the 151 Avalanche had been reduced to 1.0 times per year, or less.

The full snow sail deployment, as seen from the Jackson Hole valley floor is shown in Figure 6. They can also be seen to the right (southern) boundary of the 151 Avalanche starting zone and track (in grey tone) of Figure 2.

Figure 6. A view from the Jackson Hole valley floor of the full 50 sail deployment of snow sails on the 151 Avalanche.

During the 2002/03 winter season there was no avalanches from the 151 Avalanche that ran to the valley floor and the US 89/191 roadway. However, and despite their cost effectiveness at nearly $1/10^{th}$ the estimated cost for snow supporting structures on the same site, a wind-slab avalanche on January 1, 2004 released naturally (without explosive initiation) and avalanched to the roadway. The roadway was inundated with ~10 feet of avalanche debris. The highway was open at the time of the avalanche. There was no reported property damage, or personal injuries or fatalities. The January 1, 2004 avalanche *did* fracture through the zone of disrupted snowpack created by the snow sails in the upper reaches of the 151 Avalanche starting zone. There were no further avalanches on the 151 site during the 2003/04 winter season that ran to the valley floor and the roadway. This included subsequent efforts during the remainder of the winter of 2003/2004 to release additional avalanches on the 151 site with explosive control.

As a consequence, the snow sail final report [1] recommended; "it also remains reasonable and prudent for WYDOT to continue *investigating* both novel and traditional avalanche hazard reduction technologies for implementation at this site. These to include both novel avalanche deflection structures at the road (and within the WYDOT right-of-way) and traditional snow supporting structures in the 151 avalanche starting zone."

3.1.3 Trial (Re) forestation

The presence of large, spare stands of Douglas Fir conifer in adjacent areas, and at the same aspect and elevation (see Figure 6) indicates that the 151 Avalanche starting zone may also support similar forest growth. This is further supported by the presence of a very few large, old deadfall trunks on the ridge crown, adjacent the upper reaches of the 151 Avalanche starting zone. These trunks were not transported there – they rest where they fell. Conversely – similar deadfall in the 151 Avalanche starting zone proper would have been carried away by decades (if not centuries) of avalanching. The supposition is that the 151 Avalanche starting zone may have burned off in pre-history and then the resulting absence of seed sources, coupled with wind, avalanching and little or no vegetation to hold moisture has precluded the natural reforestation of this site.

As an auxiliary project, carried on concurrently with the development and installation of the 151 Avalanche snow sails, by USDA Forest Service's Bridger-Teton National Forest in collaboration with the regional District of the Natural Resource Conservation Service (NRCS), a trial planting of native conifer species in the starting zone was implemented [6]. This project was implemented at the recommendation of the USDA Bridger-Teton National Forest, with the support of the WYDOT snow sail project, in an attempt to determine if reforestation of the 151 Avalanche starting zone would be feasible and viable. Soil depth and composition was analyzed, subsequent to the excavation of five lateral benches, secured with log retaining structures, and planted with ~160 locally harvested conifer whips (12" to 18" in height and 3/8 " to 1/2" in diameter). These whips were harvested and then nurtured off-site for one year before being returned and replant, along with a modest amount of amended soil with each whip. Amending of the soil included both fertilizers and water retention agents. These trail efforts at reforestation of the 151 Avalanche starting zone have been successful through the establishment of whips. The survival rate is very high; on the order of 75% of the whips have survived through the summer of 2007 indicating that the 151 Avalanche site will support the establishment of local conifer species.

The cautionary attribute with respect to this effort is that for these and other conifer whips to become caliper trees – they must survive that period in their growth where they have to resist snowpack glide motion at the ground surface without being broken. Glide, as well as intra-snowpack creep, are the slow, but powerful, viscous flow motions of the snowpack under its own weight. They are on the order of 10^{ths} of inches per day, and are largest on steep slopes in "warm" snowpacks (those that are close to the freezing temperature). Whips will "lay-over" against the ground during snowpack gliding. Caliper trees (trunk diameters of ~6" +) will rigidly resist theses glide motions without breaking. Avalanches are capable of breaking tree of almost any size – hence the absence of timber in most active avalanche paths and run-outs, even where there is an abundance of timber on similar aspects and elevations adjacent to the avalanche's track. However, trees intermediate in size between whips and caliper are at risk and need to be protected from snowpack glide motions at the ground surface, as well as avalanche. Snow supporting structures provide both these protections for nascent reforestation efforts.

Conversely and by design, constructed snow nets, another form of snow supporting structure for passive avalanche hazard defense do not resist snowpack glide at the ground and intra-snowpack creep. The snowpack glides and creeps through their porous netting. This results in a structural system that, like typical or classical snow supporting structures, does resist the static snow load or weight, but does not have to support the attendant loads produced by snowpack glide and creep against the structure itself.

In the European and Asian experience – classical snow supporting structures are found in practice most commonly, and especially, where and when reforestation is warranted and sought [9]. Snow nets, more recently, are finding favor on sites that are above tree-line or where rock, soil and moisture conditions preclude any attempt at reforestation.

The majority of reforestation efforts, particularly in Europe, are designed to re-establish forests stand that once existed and which successfully reduce the onset and hence risk of avalanching from that site. Conversely, and as a consequence of the semi-arid climate of the Jackson Hole area, the conifer stands supported in the areas adjacent to the 151 Avalanche are not of sufficient density, in tree per acre or similar, to successful resist the onset of avalanches.

Hence, any future effort to reestablish conifer stands to the 151 Avalanche starting zone must be done with this caveat in mind.

3.2 Structural Systems for Passive Avalanche Defense

Beyond snow sails, there are two other primary passive, constructed systems for the reduction of avalanche hazard. These are systems that either support the accumulated snowpack in the avalanche starting zone, precluding elastic fracture of that snowpack and the subsequent onset of avalanching; or avalanche sheds or galleries, basically a constructed “tunnel,” that passes the avalanche over an affected and important portion of the avalanche’s track or run-out.

As a rule-of-thumb, an avalanche shed or gallery is approximately 10X more costly to implement for any given site than snow supporting structures in the starting zone; keeping in mind that snow supporting structures are typically an order of magnitude more costly, again, than snow sails. However, when the areal extent of the starting zone becomes sufficiently large that coverage with snow supporting structures becomes as costly as a shed or gallery; then the latter becomes a viable option from, at least, a cost standpoint.

Modern passive, constructed avalanche hazard reduction and defense systems have evolved over a period of nearly sixty (60) years, starting in the European Alps in the 1950’s. These systems now enjoy widespread application in most every developed country where avalanche hazard management is an issue, including Asia. In Europe, as well as other sites where constructed systems have been deployed, the Swiss guidelines for their implementation have been the rule. This includes the most recent guideline, used for the purpose of the efforts being reported here [2]. This 2007 document has several related precursors volumes, including those of 1961 [10], 1972 [11] and 1990 [12].

The exception is North America. Constructed, passive avalanche hazard management is rare in Canada and almost non-existent in the US. For many years the only exceptions were the avalanche sheds on the Canadian Pacific railroad through the Canadian Rockies and a similar deployment in California’s Sierra mountains along the Southern Pacific rail line alignment. These applications of passive avalanche defense date from the trans-continental rail building era of the mid and late 1800’s, and even then barrowed heavily from the European experience of the time.

Domestic deployments for passive avalanche hazard management for roadway application has been limited almost exclusively to a US Public Roads project dating from the early 1970's, where snow supporting structures, along with snow sheds on adjacent avalanche paths, was implemented on route US160 in Wolf Creek Pass, Colorado. There is also a US Public Roads passive avalanche defense system of unknown date, utilizing earthen mounds and deflection barriers, in the Hoback River canyon on US 191, east of Hoback Junction, Wyoming. Only very recently have domestic deployments of snow supporting structures, commonly snow nets, begun to see limited, modest application for, typically, private landowners and businesses.

The reasons behind this domestic scenario are two fold. Unlike the European Alps, where there have been year-round mountain populations and critical trans-alpine transportation corridors for many centuries, if not millennia, the mountains and roadways in the Western US have served small ranching and mining communities for little more than a 100 years. In the early days, these communities were prepared to sustain periods of isolation during winter storms with attendant avalanching. The major transportation corridors of the day, typical railroads, avoided the mountain as a matter of course and wherever possible. When winter recreation, in the form of ski resorts, came to the mountains of the Western US as early as the 1930's, and much more so in the post WWII period, avalanche hazard was dealt with through area closures, and later the application of avalanche hazard forecasting and active avalanche initiation with explosives after the avalanche's extent has been cleared of people and property.

These techniques were formalized and standardized by the USDA Forest Service's Snow Rangers in the 1961 Publication; "Snow Avalanches" [13]. This publication and the techniques it described barrowed heavily from the rigorous consideration given to the avalanche hazard at the ski venues of the Squaw Valley Olympics of 1960, as well as the pioneering experiences of the USDA Forest Service's Snow Rangers at Alta, Utah and Berthoud Pass, Colorado ski areas [14].

Monty Atwater is credited with first utilizing military weapons for delivering avalanche initiating explosives to avalanche starting zones in the Alta ski area, as well as above the town of Alta and along Utah SR 210; the roadway leading to Alta from the Salt Lake Valley. The use of military weapons to deliver an explosive charge and initiate an avalanche had been well known since, at least, WWI, where avalanches were initiated in this fashion for tactical purposes, alternately and against each other by Austrian and Italian troops in the European Alps of the South and East Tyrol. That avalanches posed a viable tactical "weapon" in mountain warfare became well recognized and its history was well documented by our own military [15]. It is not merely a coincidence that early Alta Snow Ranger Monty Atwater was a recently discharge military veteran with light artillery experience.

To this day, the vast number of domestic roadway winter maintenance specialists tasked with avalanche hazard management have ski area backgrounds with experience in avalanche hazard forecasting and active control. As a consequence, the avalanche hazard forecasting and control communities of the US and Canada are the world leaders in the use of this technique, including their application to transportation facilities and corridors [16]; even as we lag in our efforts to implement European style avalanche hazard defense with constructed, passive systems.

3.2.1 Avalanche Sheds or Galleries at the Roadway

In the case of snow sheds or galleries; these systems are often found near or at the valley floor where activities such as transportation corridors pass transversely across the avalanches track or run-out.

There is nothing "passive" about an avalanche. However, avalanche sheds are passive in the sense that they do not, unlike avalanche forecasting and active/explosives control, require human intervention to operate or perform their task during the period of avalanching. They suffer from the fact that once the avalanche has passed over the shed, it will still continue along the remainder of its track and out to the full extent of it run-out. Unlike the result with snow supporting structures, the full extent of the avalanche's starting zone, track and run-out are still affected during an avalanche.

Figure 7 and 8 are depictions, respectively, of a typical European avalanche shed and a novel application of the concept that includes a provision for bridging the gully that forms the avalanche's track at that location. In the former, note that the modern snow shed is being installed and will supersede an aging deployment of snow supporting structures, that in turn had replaced an even older deployment of snow sails that can be seen on the ridge line.

Figure 7. A typical European snow shed for avalanche hazard reduction.

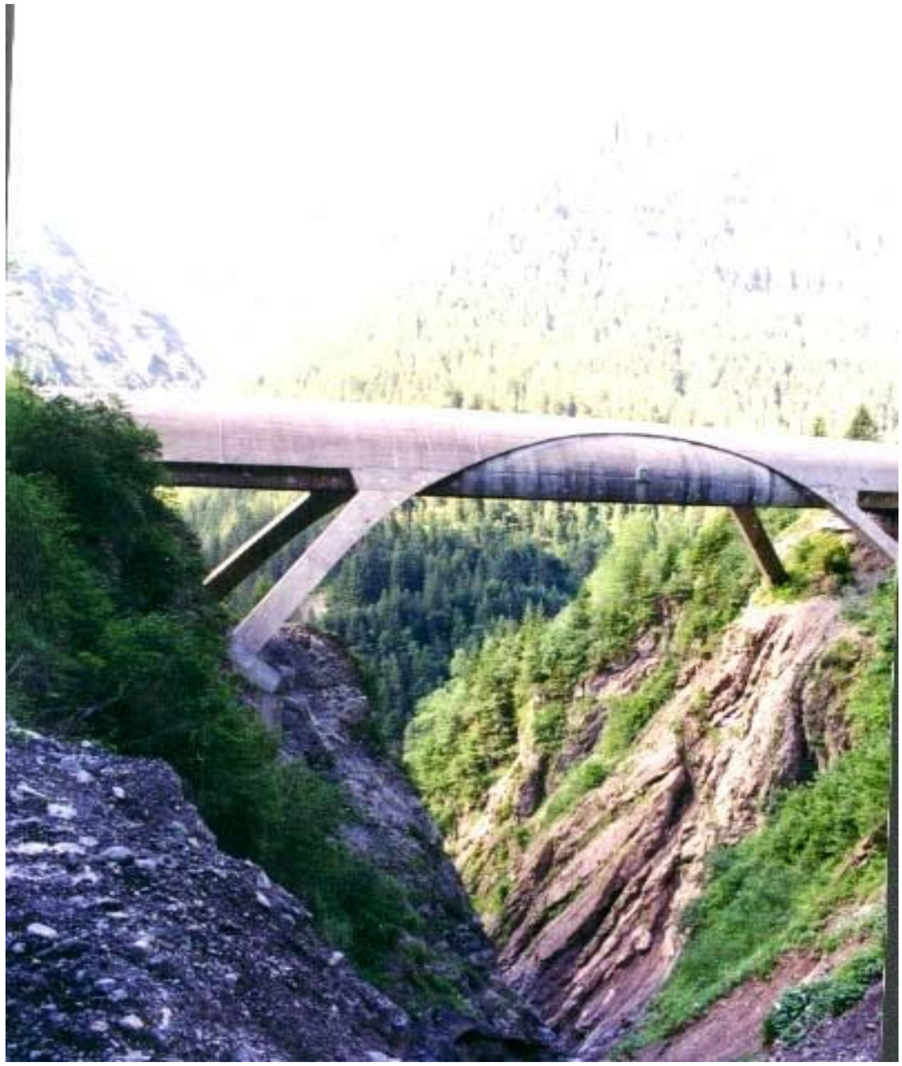


Figure 8. A novel European bridge/snow shed combination for avalanche hazard management.

3.2.2 Avalanche Starting Zone Systems

In the case of snow supporting structures; these systems are invariably in the avalanches starting zone where the snowpack or avalanche slab fails in elastic fracture and accelerates down slope as an avalanche. They are designed and deployed in such a way as to hold the avalanche starting zone snowpack in place statically and preclude the fracture that is the precursor to an avalanche. There are several important site specific attributes to their design, including the maximum anticipated snow depth, slope angle, aspect and ground cover at any given site.

Figures 9 and 10 depict typical European deployments of snow supporting structures for avalanche hazard management. Note that in Figure 10 there are at least three separate generations of snow supporting structures and an on-going effort to reforest the site. Moreover, one may note the small wooden tripods located between adjacent snow supporting structures. These are for the purpose of snowpack glide protection for tree whips in transition to caliper trees.

Figure 9. A typical snow supporting structure, deployed for avalanche hazard reduction in the avalanche starting zone.

Figure 10. Three generations of snow supporting structures for avalanche hazard reduction that include efforts at reforestation of the site.

Chapter 4: Unit Design for Snow Supporting Structures in the 151 Starting Zone

4.1 Implementation of the 2007 Swiss Guideline for Snow Supporting Structures

An explicit goal of the project being report here was to develop a generic process for snow supporting structural design and deployment that was intrinsically "American" in approach and would be valuable to domestic DOT's in general, and WYDOT specifically, in their attempts to implement this technology on their transportation corridors effected by avalanche hazard. In as much as this effort would establish a baseline for all subsequent modern, domestic efforts in this same vein, nothing short of "best practices" in snow supporting structural design was acceptable. The international standard for the design and site specific implementation of snow supporting structures for avalanche defense is the 2007 Swiss Guideline [2]. As noted previously, this Guideline has evolved over a period of nearly fifty years; having enjoyed updates, on average, every fifteen to sixteen years [10,11,12].

At the onset of 151 Avalanche snow supporting structure project, only the 1990 German language Guideline was available. However, in 2006 the Swiss Federal Institute for Snow and Avalanche Research provided an advanced copy of their soon-to-be-released 2007 English language Swiss Guideline to the 151 Avalanche project investigators. The 2007 Swiss Guideline is referred to extensively in the subsequent sections of this report. It is available from the Swiss Federal Institute for Snow and Avalanche Research.

As a consequence of over forty years of experience designing and deploying avalanche defense structures in Europe, the broad generic steps and order-of-events in such a process are now implicit in the Swiss Guideline. The Tables of Contents of the Swiss Guideline and this report reflect these generic steps and process for designing and deploying a configuration of snow supporting structures. Nevertheless, in an attempt to make this explicit, found in Appendix A is a "punch-list" or "recipe" of these steps, and the order in which one would implement them in the course of designing and deploying snow supporting structures for avalanche hazard management in a domestic application, including as was done here for the 151 Avalanche in Jackson, Wyoming.

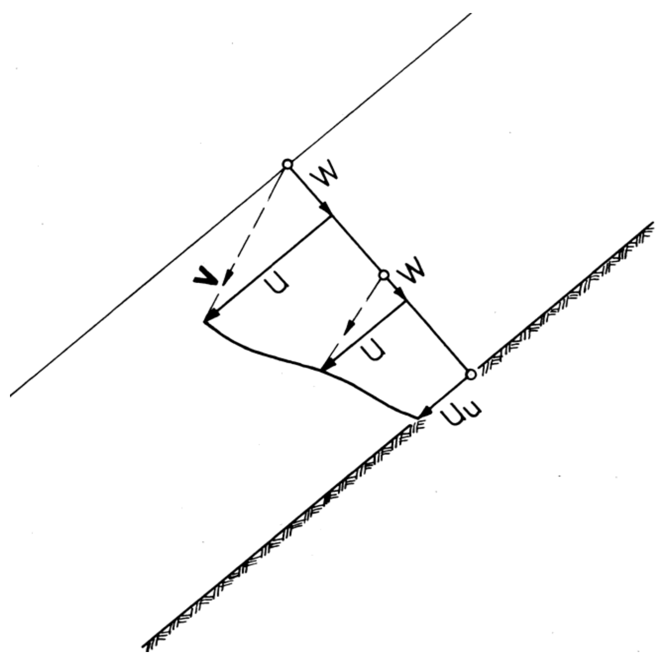
There is a suite of site specific attributes and characteristics that are common to nearly all efforts to design and implement snow supporting structures for avalanche hazard management. In the 151 Avalanche starting zone these include the following:

- Average Slope angle – 35 degrees.
- Elevation – 7200 feet ASL.
- Ground surface descriptor – "Smooth" - glide factor of 3.0.
- Density Factor – "Heavy" wind transported and compacted - .27 (27%).
- Maximum Snow Depth to be Support – 6.6 feet (vertically) – and a design snow depth of 5.6 feet perpendicular to the slope surface (slope normal), and a snow support structure height of 5.4 feet (installed or "laid-back" 15 degrees downslope from slope normal).

The 2007 Swiss Guideline advises that the maximum snowpack depth that any site specific deployment of snow supporting structures should be expected to support is that typical of a 100 year recurrence interval (the "100 year" snowpack). This assumes or implies that a significant record of annual maximum snowpack depth be available for the site in question. This record, and hence the statistical determination of the magnitude of the maximum snowpack depth in the 151 Avalanche starting zone that would recur on a100 year interval, is not available. Nevertheless, an estimate of the maximum design snow depth in the 151 Avalanche starting zone is a requisite element of the site specific design of snow supporting structures for avalanche defense purposes.

Based on empirical and anecdotal considerations, a maximum anticipated snow depth in the 151 Avalanche starting zone that would require support from snow structures has been set at 6.6 feet, measured vertically [5]. This is an important point. The implication being that snowpack depths in excess of 6.6 feet will *not* be supported by a deployment of snow supporting structures in the 151 Avalanche starting zone, with the attendant possibility that avalanches could occur from that portion of the 151 Avalanche starting zone, in the event that the maximum snowpack depth exceeds 6.6 feet.

Generically speaking, the unit design of a snow supporting structure, including those for the 151 Avalanche, is dominated by two sources of load or forces that they must resist; the down slope component of the snowpack's weight and the dynamic loads that result as a consequence of the snowpack's slow, viscous deformation under its own weight. These latter loads include the motion between the snowpack as a whole and the ground surface (glide) and the internal deformation of the snowpack (creep). These motions are depicted in Figure 11. These deformations are very slow; on the order of inches per days, and increase as the snowpack warms in the spring. Nevertheless, they produce large loads on any structure which resists these motions. The largest loads occur on the ends of the snow supporting structure, where these motions are both the most pronounced and have had to change direction as the snowpack deforms around the end of the structure. These glide and creep loads are, on average, three times those produced by the weight of the snowpack alone. For design purposes, these glide and creep loads are assigned a statically equivalent value that is applied as a uniform distributed load to a portion of the outboards ends of the snow supporting structure. See Figure 12 graphically depicts this scenario.



Where: **Creep and glide velocities in the snow cover.**
v (u,v,w) resultant velocity vector
u Velocity component in the line of slope
uu Glide velocity
u-uu Glide velocity in the line of slope
w Creep velocity normal to the slope

Figure 11. Viscous deformations (velocities) in a snowpack (section view). From [2].

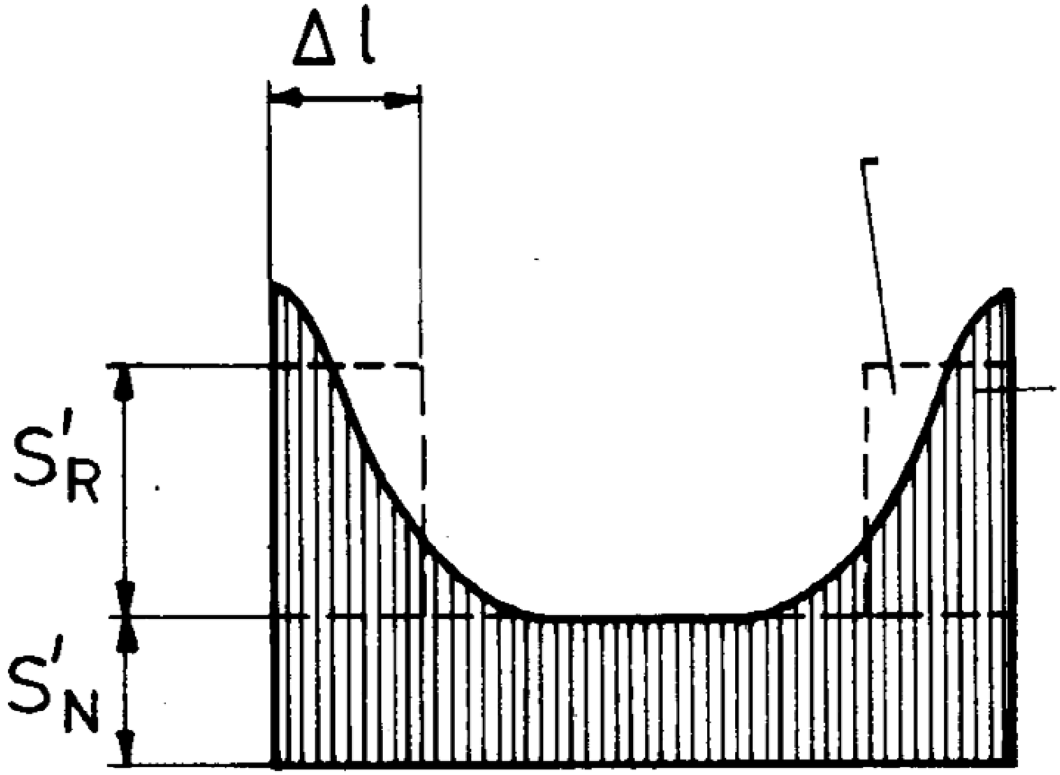


Figure 12. Forces on a snow supporting structure due to viscous deformations (velocities) in a snowpack (plan view). S(R), added end effect loads, as the snow deforms around the snow supporting structure and S(N), nominal loads due to the down-slope component of the weight of the snowpack. From [2].

Cumulatively, the down slope component of the snowpack's weight, in combination with the snowpack's glide and creep deformation, result in a snow load prism depicted graphically in Figure 13 which shows the loads on a snow supporting structure resulting from both the viscous deformations (velocities) in a snowpack and the down-slope component of the weight of the snowpack. D(K), maximum slope normal snow depth that is supported by the structure, R, resultant force on the structure h, the snowpack depth producing force R. From [2]. This structural loading becomes the basis for subsequent design considerations.

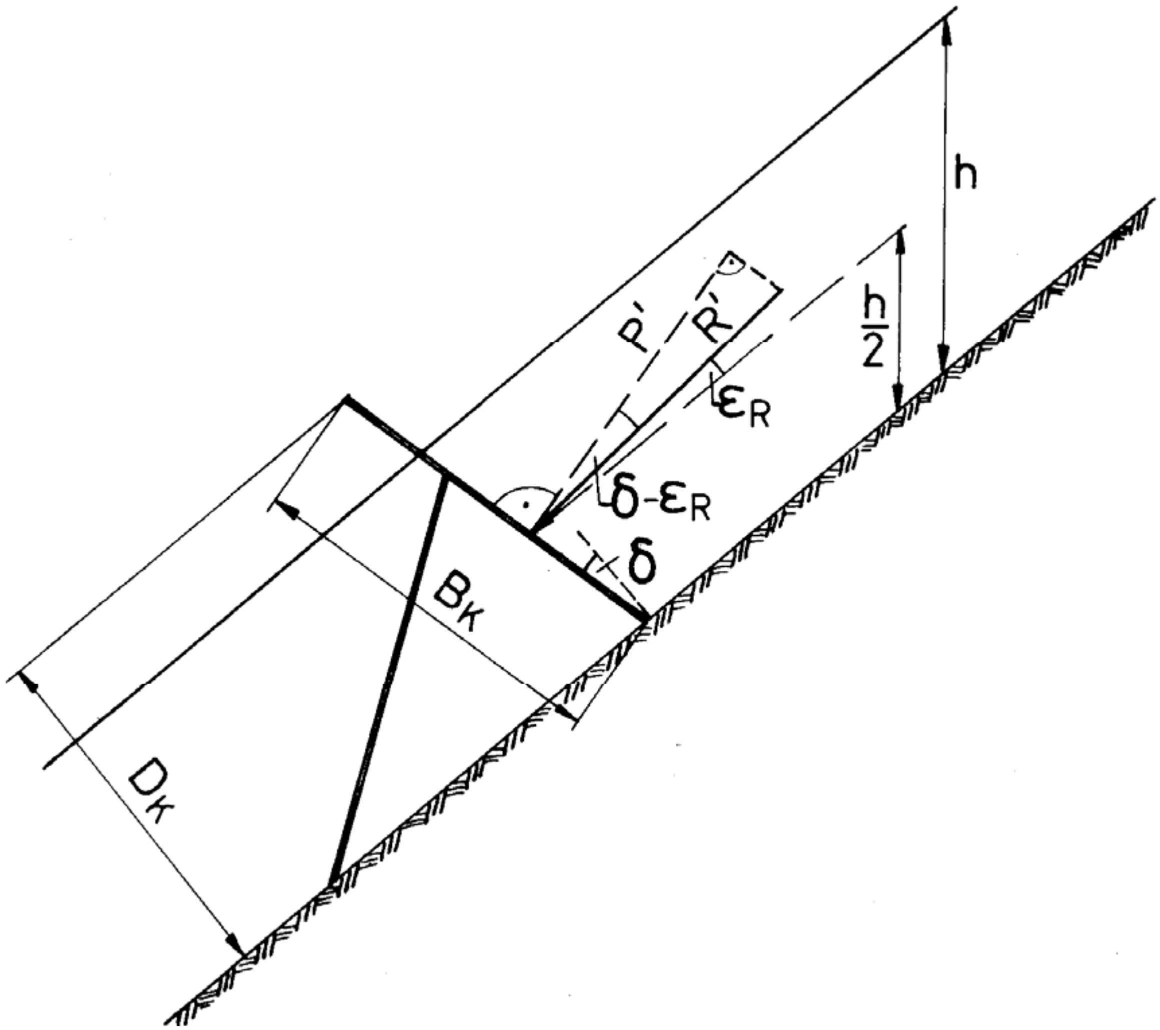


Figure 13. Loads on a snow supporting structure resulting from both the viscous deformations (velocities) in a snowpack and the down-slope component of the weight of the snowpack (section view). D(K), maximum slope normal snow depth that is supported by the structure, R, resultant force on the structure. h, the snowpack depth producing force R. From [2].

4.2 Unit Design of Snow Supporting Structures for the 151 Avalanche

Design of snow supporting structures for passive, constructed avalanche defense must hold paramount the importance of the public safety. Although the 2007 Swiss Guideline provides significant direction for the selection of design criteria, design loads, structural systems, and materials, engineering judgment along with appropriate conservatism is required for the successful implementation of any site-specific design. Because of the variability of snow loads with slope angle, unit end boundary conditions, and surface roughness conditions, and because of a desire to produce a solution that minimizes opportunities for errors during construction, a single unit design, that can be used for all potential conditions at the 151 Avalanche starting zone, was pursued. Also critical to the unit design is the ability to adapt to varying terrain while maintaining constructability and construction efficiency.

The design of the snow supporting structures for the 151 avalanche followed accepted domestic (USA) structural engineering practice, based on the American Institute of Steel Construction, (AISC) Steel Construction Manual, 13th Edition [17] and on the American Concrete Institute (ACI) Building code [18]. The unit 151 Avalanche snow supporting structure was designed for the strength limit state using the Load and Resistance Factor Design (LRFD) method. The 2007 Swiss Guideline suggests a snow load safety factors of $\gamma = 1.5$, and resistance factors of $\phi = 1/1.05 = 0.952$ and $1/1.25 = 0.80$ for member and connection strength verification, respectively. These values are similar to domestic structural design practice, but are slightly less conservative. In place of the 2007 Swiss Guideline load and resistance factors, a snow load factor of $\gamma = 1.6$ and resistance factors from the AISC Design Specification and ACI 318 were used.

4.2.1 Snow Loads and Structural Design

The slope angle at the 151 site over the region of deployment is 35 degrees. However, because of the potential for localized less steep or steeper slopes, analysis of snow loads and resulting structure internal forces and footing reactions was performed for inclines between 30 degrees and 40 degrees. The unit design also considered cases of units with and without end effect loads. Those loading scenarios with the maximum effect on individual member forces and foundation reactions was used in the final design of the unit. The loads applied to a unit also included provision for the case where snow creep and glide are not normal to the snow supporting structure's grate members, and this was done via application of a lateral load of 10% of the slope parallel snow load, including end effects. Table 2 shows the resultant snow load, per foot of 151 Avalanche snow supporting structure), below lists values of the resultant snow load per foot of SSS unit, ***R'*** (measured laterally or transverse to the slope).

Table 2. Resultant snow load, per foot of 151 Avalanche snow supporting structure.

Load case	R' (lbs/ft)	ε_R (deg) see [Sws Gdln]
No end effects	1144	14.6
With end effects	6280	2.6

4.2.2 Geometry, Structural Analysis and Unit Design

The 2007 Swiss Guideline provides for the selection of overall unit geometry and member arrangement, but also states that, "The present technical guideline allows considerable leeway in laying out and dimensioning the structures." The angle between the girder and strut axes is free to be chosen for the site specific design. Additionally, the 2007 Swiss Guideline stipulates that the girder axis be laid back (down slope) an amount of 15 degrees with respect to slope normal. With the girder orientation to the slope thus fixed, selection of the angle between the girder and strut is done with consideration of minimizing foundation reactions while also minimizing strut length (unbraced length for buckling and material quantity considerations). Figure 14 depicts the geometry selected for the unit design of a snow supporting structure at the 151Avalanche.

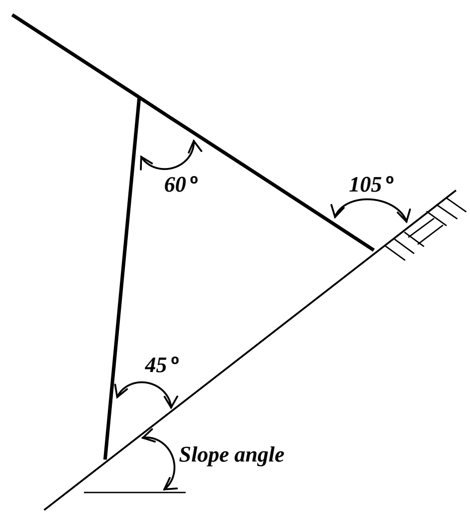


Figure 14. Geometry selected for the unit design of a snow supporting structure at the 151 Avalanche.

Unit dimensions including the distance between the top of the girder and the connection point to the strut, and the transverse distance (across slope and along contour) between girders were selected based on balancing negative and positive moments under the snow pressure distribution normal to the grate. In the girder, the negative moment at the strut connection location is balanced approximately with the maximum positive moment between the strut connection point and the base of the girder. In the crossbeams, maximum moment demand in the span between girders is approximately equal to the maximum negative moment at the girder and due to end effects acting on the overhang portion of crossbeam. Crossbeam spacing along the girder length was selected based on the 2007 Swiss Guideline, which provides a range of permissible opening widths between crossbeams.

Depending on the foundation boundary conditions applied, the snow supporting structure unit may or may not be statically determinate. Preliminary design of the unit assumed pin conditions at the bottom of struts and girders, and hand calculations were used to determine member and foundation reactions. Once initial sizing and unit geometry was selected, a three-dimensional finite element model of the unit was developed a finite element analysis approach. Figure 15 shows the frame element model developed. In Figure 15, the *x-axis* corresponds to the slope, the *z-axis* is normal to the slope, and the *y-axis* is across or transverse to the slope. Eight different load cases based on the Swiss Guideline were developed to bound and envelope member and foundation forces. These include cases with end effect loads and without end effect loads. Because the degree of restraint at the structure foundation varies between true pinned and partially fixed against rotation, models with both pinned and fixed foundation boundary conditions were analyzed to bound both unit structural and foundation demands. Elastic analysis and small deformations were assumed in these analyses. Table 3 lists the foundation reaction forces for both pinned and fixed analyses. Figure 16 depicts the orientation of these foundation reactions in the *x-z* plane.

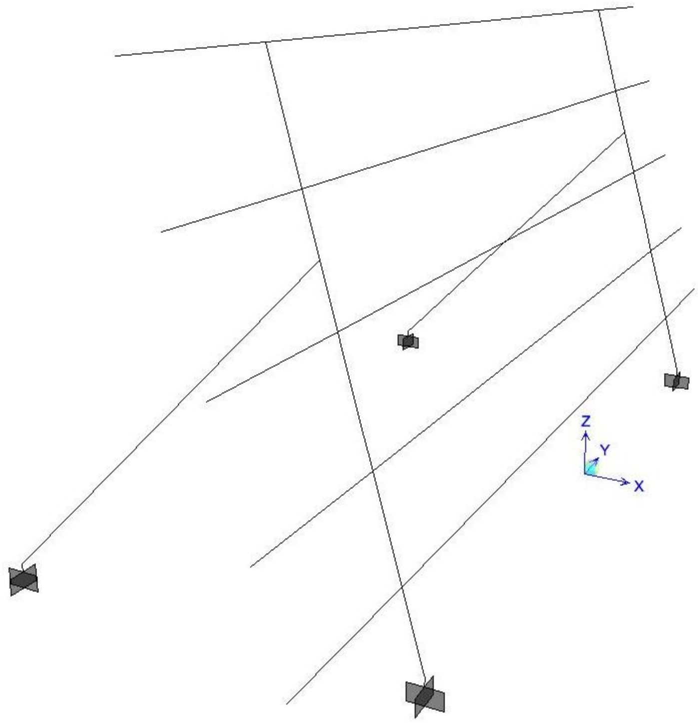


Figure 15. Finite element model of the unit design 151 Avalanche snow supporting structure.

Table 3. Foundation reaction forces for both pinned and fixed analyses, 151 Avalanche snow supporting structure.

Location & B.C.	F_x (lbs)	F_y (lbs)	F_z (lbs)	M_x (lb-ft)	M_y (lb-ft)
Strut, pinned base	11,200	100	11,000	0	0
Girder, pinned base	5,300	3,700	-8,200	0	0
Strut, fixed base	9,800	100	9,500	225	300
Girder, fixed base	6,800	3,600	-7,100	2,200	6,000

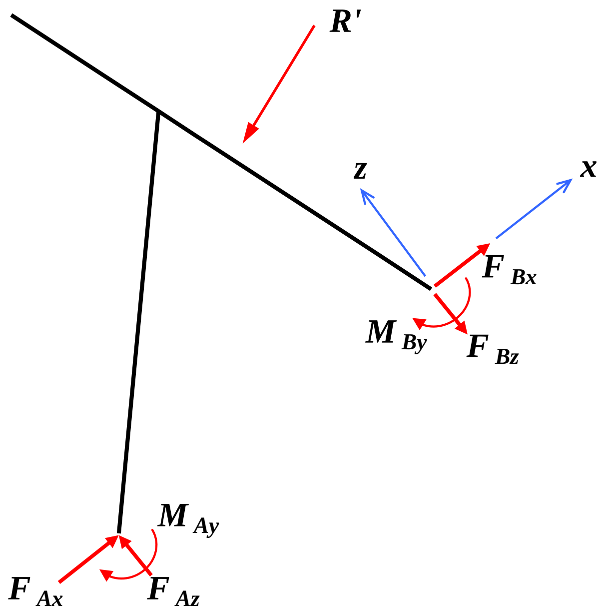


Figure 16. Foundation reactions for the *x-z* plane of the 151 Avalanche unit snow supporting structure reactions for x-z plane.

Shown below in Figures 17 and 18 are renderings of the resulting unit designed 151 Avalanche snow supporting structure shown for a unit on cast-in-place (CIP) concrete foundations. A scaled side elevation view of the snow supporting structure is shown in Figure 19. It is for the anchoring configuration case for foundations where the depth of soil over rock is several feet and cast-in-place concrete footings can be used. Total height of the snow supporting structure was selected so that vertical height from ground to the top of girder at its centerline is approximately equal to a design snow depth of 6.6 ft in the vertical or 5.6 feet of snow depth measured perpendicular or normal to the slope (at the nominal 35 degree slope inclination). The height to top of girder measured along the girder centerline to the ground surface is 5'- 7½". This design utilizes a W6x12 girder connected by a pin connection to an HSS5"x5"x¼" strut for the support system, and the two supports, spaced 8'- 4½" apart, are connected by five MC6x12 crossbeams. The distance from the top of girder to the center of the one-inch diameter pin is 2'- 2". Figure 20 depicts a view of the 151 Avalanche unit snow supporting structure normal to the grate and looking downhill. The overall width (transverse to slope) of the unit is 12'- 0".

Crossbeam spacing is a constant 8 inches. High strength bolts are recommended to connect the crossbeams to the girders in order to avoid welds at those connections.

A variation of the snow supporting structure unit design for the 151 avalanche was developed in order to accommodate locations on the slope with little or no soil cover. Areas with rock at the surface would require significant excavation if a CIP concrete footing was to be used. Hence, an alternative foundation system, using ground anchors without CIP concrete was developed. A side elevation view of the snow supporting structure for this alternative foundation system is shown in Figure 21. The dimensions of the girders and struts are only slightly different than the structure on CIP concrete footings and the basic unit geometry (angles, spacing between girders across slope, etc.) remains unchanged. See Figure 22.

This alternative rock and rock outcrop foundation design does contain one significant, additional element that is not present in the unit design with CIP concrete footings. That is the "pressure bar" connecting the lower and upper foundations. Due to the small section size of the ground anchor bar (on the order of an inch in diameter) and because perfect alignment of the strut and ground anchor axes is unrealistic in field installations, an additional structural element is required at the strut foundation. Any misalignment of the strut and ground anchor will result in forces transverse to the ground anchor bar axis, which in turn create large bending moments in the ground anchor. To avoid this, the pressure bar is used to transfer any off-axis (i.e. non-axial forces) to the upper foundation, thereby eliminating bending in the ground anchor bar. Note that the forces causes excessive bending in the strut ground anchor bar are acceptable at the upper (girder) ground anchors because of the presence of the two ground anchors, each with different orientation. This creates a very "stiff" point, which prevents the significant transverse deformation associated with bending. The pressure bar is designed with an adjustable connection near its mid-length in order to provide tolerance for misalignment of anchor locations.

Where snow supporting structures are to be installed in the 151 Avalanche starting zone in side-by-side configurations, to form double and triple arrangements, they will be spaced one foot apart (from the ends of adjacent crossbeams), and thus total width of snow supporting structures as deployed will be 12 feet for single isolated units, 25 feet for doubles, and 38 feet for three units arranged in line. When 151 Avalanche snow supporting structures are configured in this manner they are still considered, from a snow load standpoint, as independent structures and the unit design presented here is applicable. This is a conservative treatment from a structural design standpoint.

The total weight of each unit, not including foundations, is approximately 1400 lbs.

A complete set of fabrication drawings of the 151 Avalanche unit snow supporting structure, including connection details, may be found in Appendix B of this report.

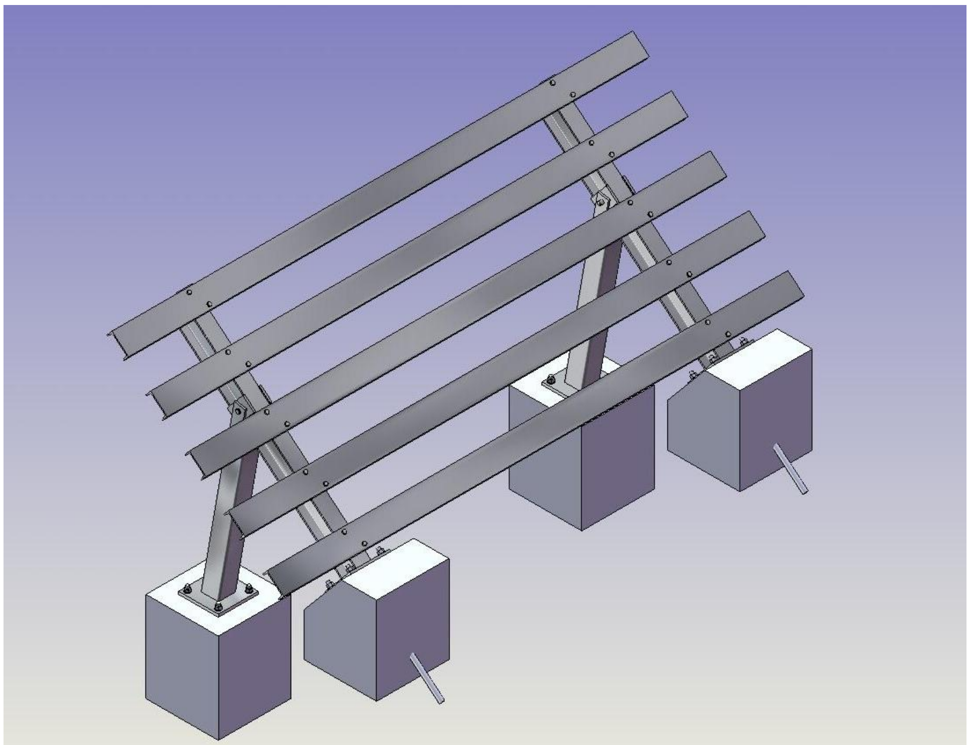


Figure 17**.** 3D rendered view of the snow supporting structure on CIP concrete footings.

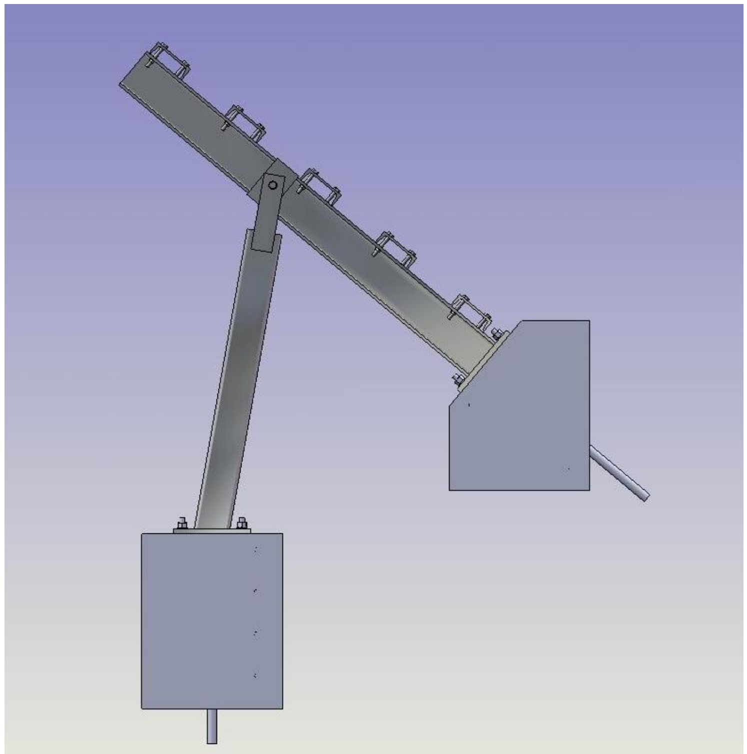


Figure 18. Rendered sideview of the snow supporting structure on CIP concrete footings.

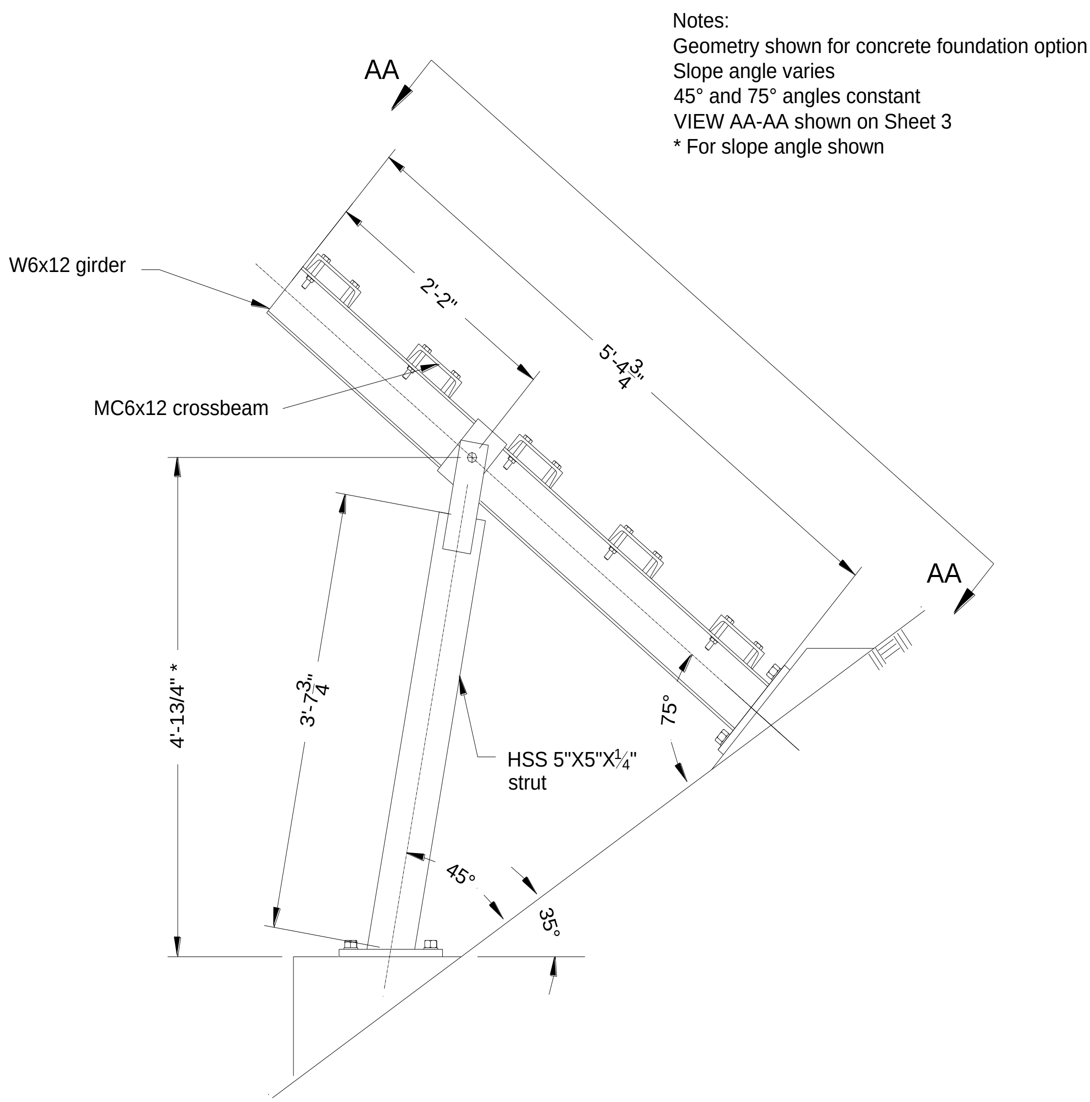


Figure 19. Side elevation view of snow supporting structure on CIP concrete footings

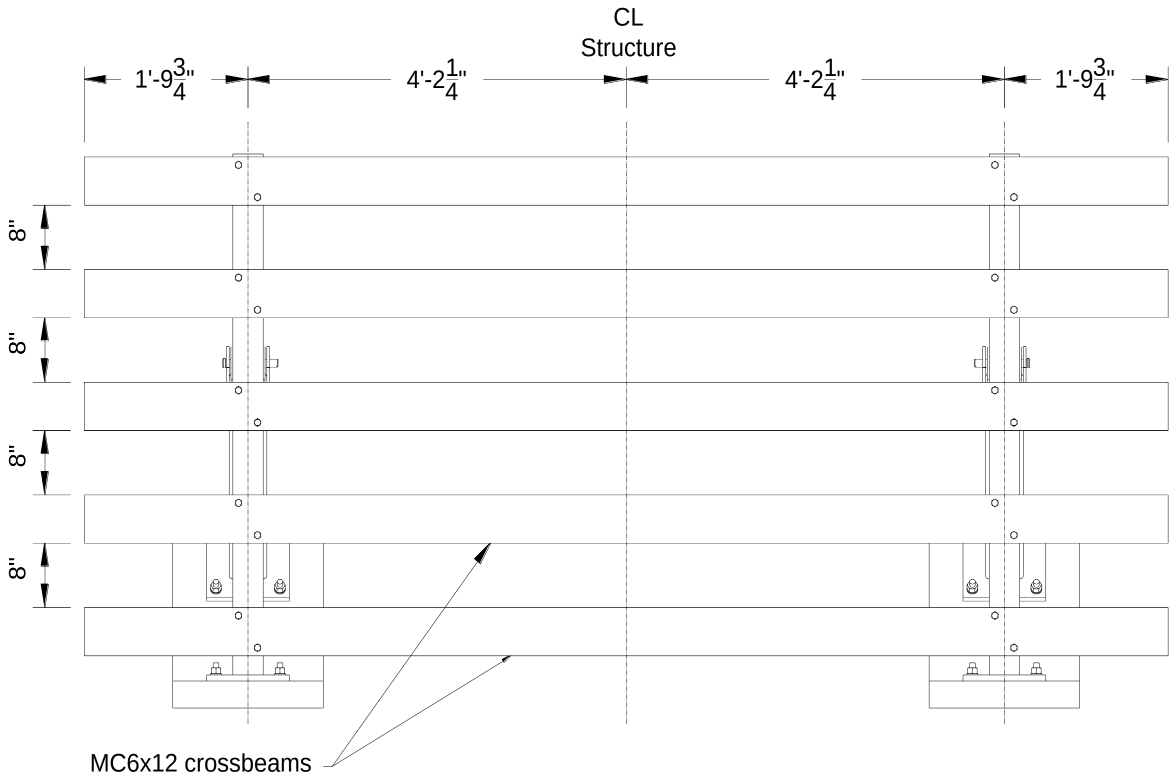


Figure 20. Snow supporting structure viewed downhill and normal to grate for the case of CIP concrete footings.

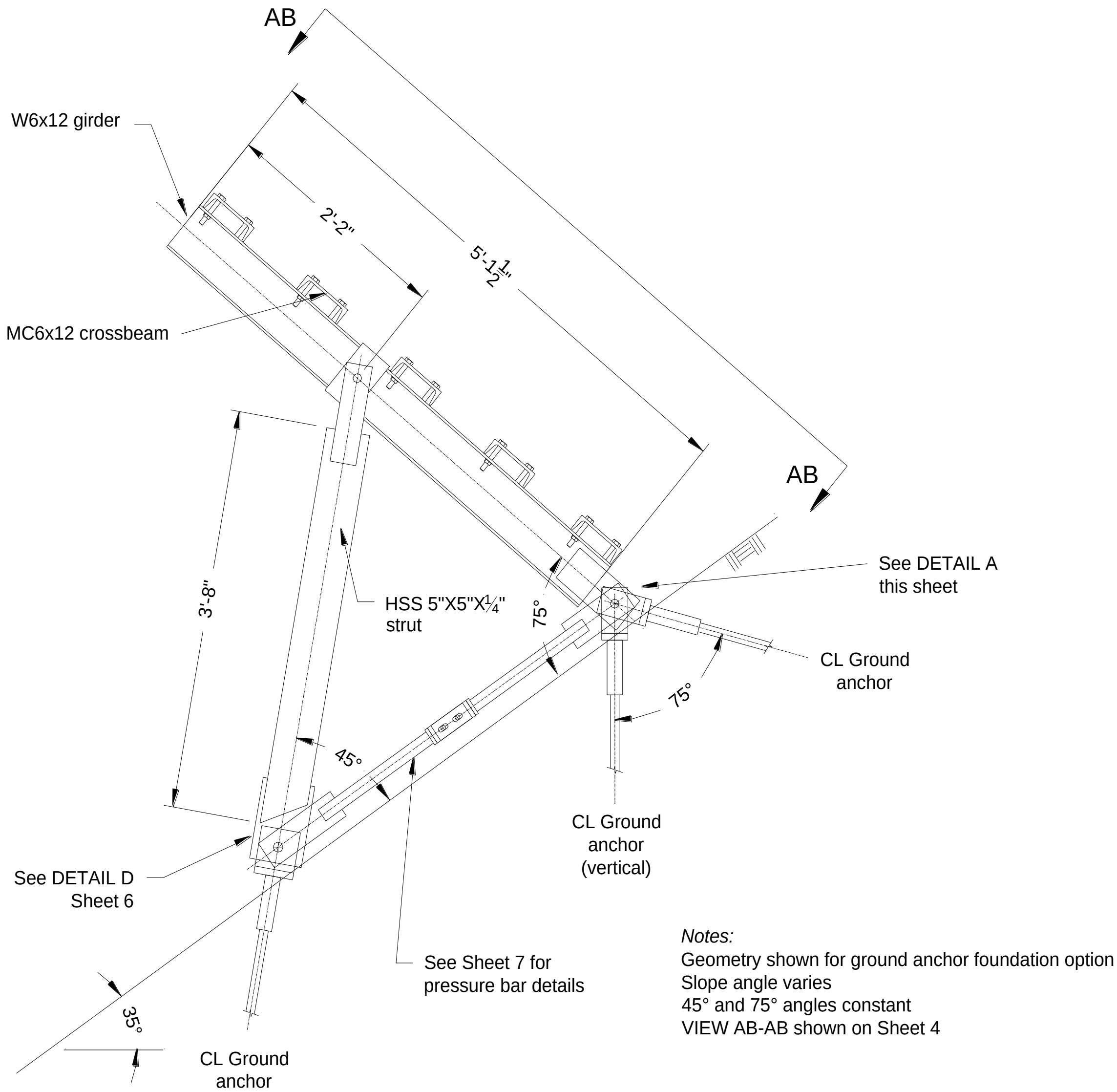


Figure 21. Side elevation view of snow supporting structure on ground anchor foundations.

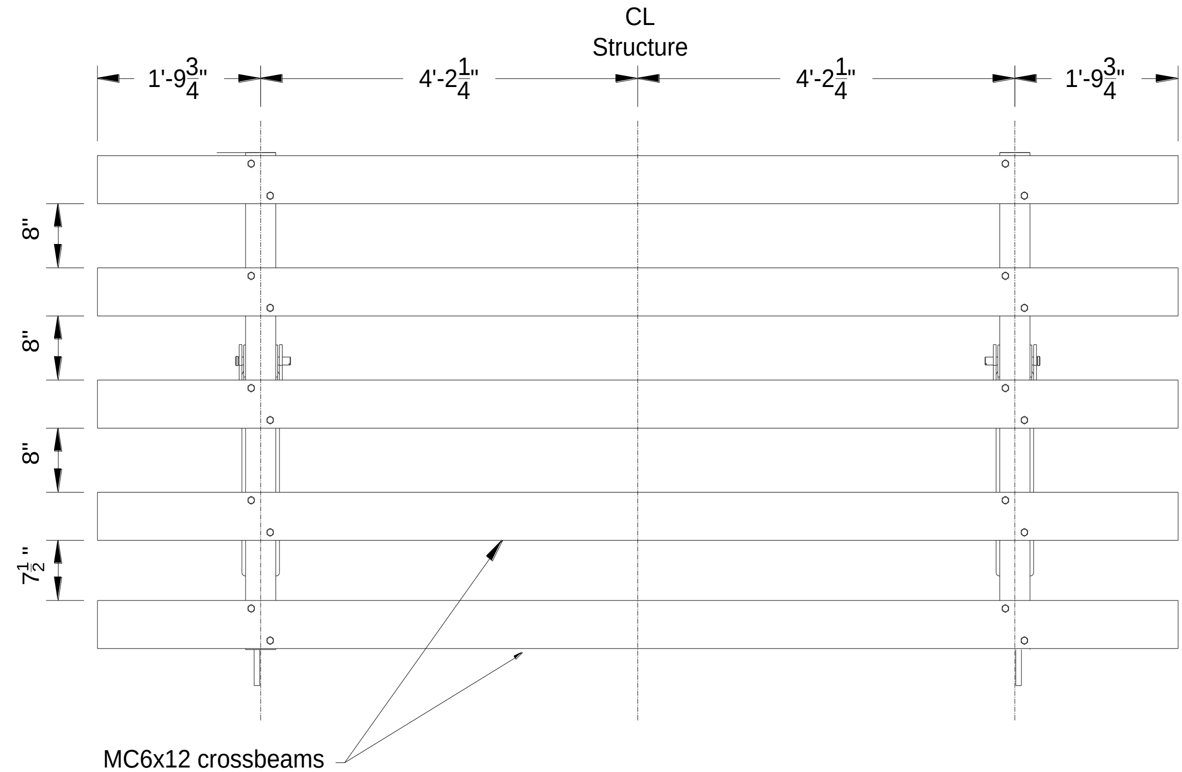


Figure 22. Snow supporting structure viewed downhill and normal to grate for the case of ground anchor foundations.

4.3 Structural Anchoring

Structural anchoring of the 151 Avalanche snow supporting structures to the steep hillside terrain has several challenges, including: the installation site is steep and relatively remote, which will prevent the delivery of machinery, supplies and the snow supporting structures without the use of helicopter support; and the subsurface conditions vary significantly across the 151 Avalanche starting zone. The thickness of cover soils varies from outcropping rock on the southern margin to several feet of soil to the north and into the “swale” or long, shallow and narrow trough of the 151 Avalanche starting zone.

These challenges require the system used for structural anchoring of the 151 Avalanche snow supporting structures be easily adaptable to varying subsurface conditions, yet sufficiently robust so that it can support the expected loads. One foundation system that has been identified is the use of ground anchors. The term “ground anchors” is used here as a general structural element that is set in a bored hole with grout, without reference to the loads subjected to it, whether tensile or compressive. The term is intended to include both micropiles and soil nails. Due to their predictable load bearing capacities, adaptable installation methods, and reasonable cost, ground anchors have enjoyed a growing popularity and is also a recommended practice for structural anchoring in the 2007 Swiss Guideline.

Figure 23 depicts a typical ground anchor drilling machine, working in steep terrain in the Austrian Alps [19].

Figure 23. A ground anchor drilling machine working steep terrain during installation of snow supporting structures for an avalanche starting zone in the Austrian Alps. From [19].

4.3.1 Structural Capacity of Ground Anchors

The Federal Highway Administration's (FHWA) Manual for Design and Construction Monitoring of Soil Nail Walls [20] provides recommendations for the allowable long-term tension in ground anchor elements as 55% of their yield strength. However, no consideration for shear across the element is provided. The American Railway Engineering and Maintenance-of-Way

Association (AREMA) guidelines [21] for the use of ground anchors also limit the long-term tension of structural elements to 55% of the yield strength, but in addition allows up to 35% of the yield strength to be taken in shear load.

Figure 24 depicts the controlling loads that are applied to the foundations by the snow supporting structure. These controlling loads include the highest individual loads from each boundary condition case and hence, are conservative. At the base of the girder (Point G), the ground anchor must support a tension load of 8.2 kips and shear loads in the X and Y planes of 6.8 kips and 3.7 kips, respectively. In a plane normal to the ground anchor axis, the resultant shear load is about 6 kips. At the base of the strut (Point S), the ground anchor must support a compressive load of 11.0 kips normal to slope and a shear load of about 11.2 kips parallel to the slope

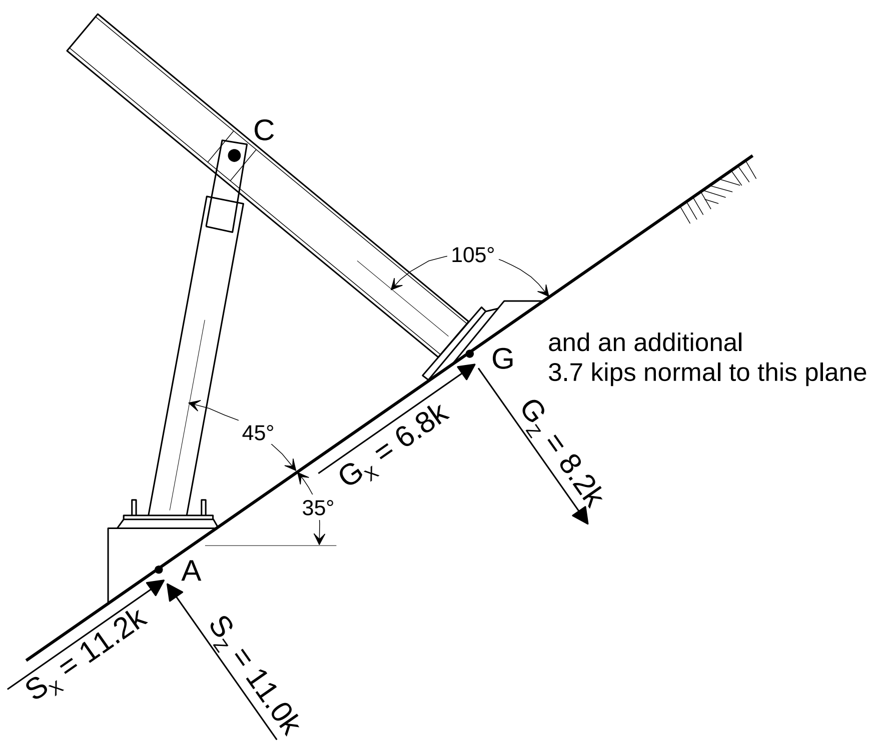


Figure 24. Snow supporting structural loads in the foundation system.

Assuming a ground anchor aligned with the girder axis at the upper foundation, and using the AREMA guidelines [21], the ground anchor supporting the girder shall have a yield strength of at least 6.0 kips/0.35 = 17.2 kips (based on shear) and a yield strength of at least 9.7 kips/0.55 = 17.6 kips (based on tension). Thus the tensile load controls the structural capacity of the ground anchor at the girder. Assuming a vertical ground anchor at the lower foundation, the ground anchor supporting the strut shall have a yield strength of at least 3.8/0.35=10.9 kips (based on shear) and a yield strength of at least 15.2/0.55=27.6 kips (based on axial compression). Thus axial compression controls the ground anchor requirements at the strut ground anchor. Since the strength requirements for the ground anchors at both the girder and strut are reasonably similar, and for simplicity in construction, a single sized ground anchor is recommended. This ground anchor should have a minimum yield strength of at least 28.0 kips. Analysis of ground anchor yield strength requirements for the ground anchors only foundation alternative are similar to but slightly less demanding than those detailed above.

Typical hollow-core ground anchor bars have a left-hand, rope-like threading on the outside that can receive a threaded nut or coupler for either adding extensions or for the placement of structural connections (see Figure 25). Hollow-core bars for use as ground anchors are available from a variety of sources and come in high strength (75 ksi) steel. Anchor bars having lower yield stresses may be available, and if the potential cost savings over high strength steel is warranted, they could be specified. Conversely, it is anticipated that the ground anchor material costs for the 151 Avalanche will be a small fraction of their net costs, installed on site. Using a yield stress of 75 ksi, the ground anchor should have a minimum net area of 28.0 kips/75 ksi, or 0.37 in^2. Table 4 presents data on available hollow-core bars that meet these requirements. It is further noted that these bars are the smallest available from each of these manufacturers and that, if required, hollow core bars having a higher strength can also be procured. To provide long-term protection against corrosion, all bars should be epoxy coated, prior to installation on the 151 Avalanche.

Figure 25. A typical hollow-core ground anchor showing left-hand threading.

Table 4. Available ground anchors, by vendor, that meet the required capacity at the 151 Avalanche (other sources may also exist from manufacturers not shown).

Item:	**Outer/Inner Diameter (mm)**	**Net Area (in^2)**	**Rated Yield Strength (kips)**
Contech Systems	30/16	0.54	40.5
AGL Manufacturing	25/12	0.45	34.0
DSI	25/12	0.45	34.0

4.3.2 Installation of Ground Anchors

The placement of the snow supporting structures on the ground anchor foundations will have minimal allowance for error. Hence, a ground anchor drilling template for the snow supporting structures of the 151 Avalanche is recommended so as to minimize the range of potential geometric tolerances. This to include a series of three templates that may be used in a sequential fashion so as to accurately locate each ground anchor bore hole This system is designed to operate in the following manner: Either one of two uphill ground anchors that will be used to support the tensile loads of the snow supporting structure shall be installed at the proper angle and to the required depth. An installation template will then be placed over this first anchor and positioned so that the snow supporting structure will, subsequently, have the proper orientation with respect to the slope at the specific location on the 151 Avalanche starting zone site. This template has one hole that fits reasonably snugly around the already-installed ground anchor and provides a steel cylinder through which the second ground anchor is to be installed. This process repeats itself sequentially and in a manner that each already-installed ground anchors help position the next and minimizes geometric tolerances between the ground anchor and the snow supporting structural connection.

Ground anchors use various types of sacrificial drill tips to penetrate the rock and soil conditions at the 151 Avalanche starting zone site. Typical drill tips are shown in Figure 26. From left to right, a conical bit used for heavy clays, a tri-cone button bit used for hard-rock drilling, and carbide-tipped bits used for alluvial soils through fractured rock. These bits are side-discharging, which allows for grout to be deposited under pressure to the sidewalls of the hole during installation. For the 151 Avalanche site, it is believed that 2-in diameter carbide drill tips will be sufficient for both deep and shallow soil profiles.

Figure 26. Typical sacrificial drill tips used for installing earth anchors.

4.3.3 Structure-to-Anchor Connections for the 151 Avalanche

Although the methods for anchor installation described previously should allow for precise control of installed anchor location, it is prudent to allow for some degree of misalignment of the structure and anchors. Furthermore, owing to the irregularity of the topography and the need to maintain the geometry of snow supporting structural unit design, a connection that is adaptable to terrain conditions and anchor locations is desirable. With this in mind, connection systems were developed that can accommodate drift of anchors from specified location, can adapt to varying terrain, and that allows for efficient structure installation.

For example, Figure 27 illustrates the strut foundation for locations with adequate soil cover, which for purposes of the 151 Avalanche starting zone site is rock overlain by at least two feet of soil and fractured rock. The strut is attached to a base plate, which in turn is connected to an anchor plate by four high strength rods. The anchor plate has a 5¾" diameter hole centered on the plate through which the ground anchor protrudes. Bearing plates and spherical nut washers secure the anchor plate and structure to the ground anchor once the correct elevation of the structure is obtained. The hole in the anchor plate is significantly larger than the anchor bar diameter and thus the system will accept bars that are out of alignment (both in plan and also with angular misalignment). Height of the base of strut can be adjusted both through the ¾" rods connecting the base and anchor plates and the threaded ground anchor bar. This system can also adapt to variations in slope. The rods, anchor plate, bearing plates, and portion of the ground anchor are encased in cast-in-place concrete. As shown in Figure 28, a similar foundation system is recommended for the upper (girder) snow supporting structure where sufficient soil exists to accommodate a CIP concrete footing. Full details of the foundation system using cast-in-place concrete footings in conjunction with ground anchors can be found in Appendix B of this report.

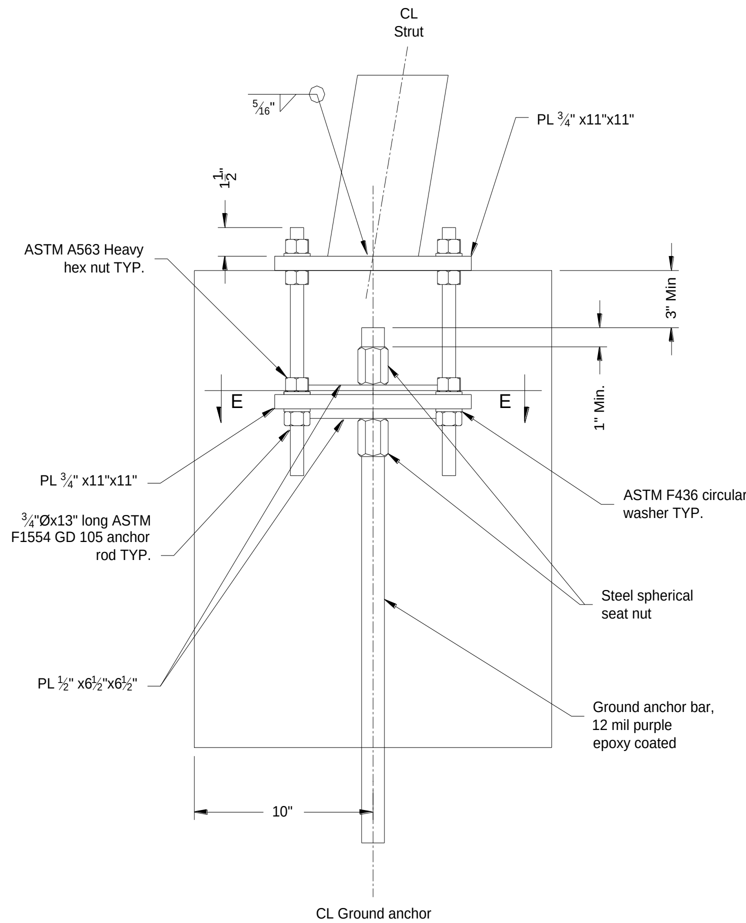


Figure 27. Snow supporting structure lower strut foundation and connection to ground anchor for case of CIP footings.

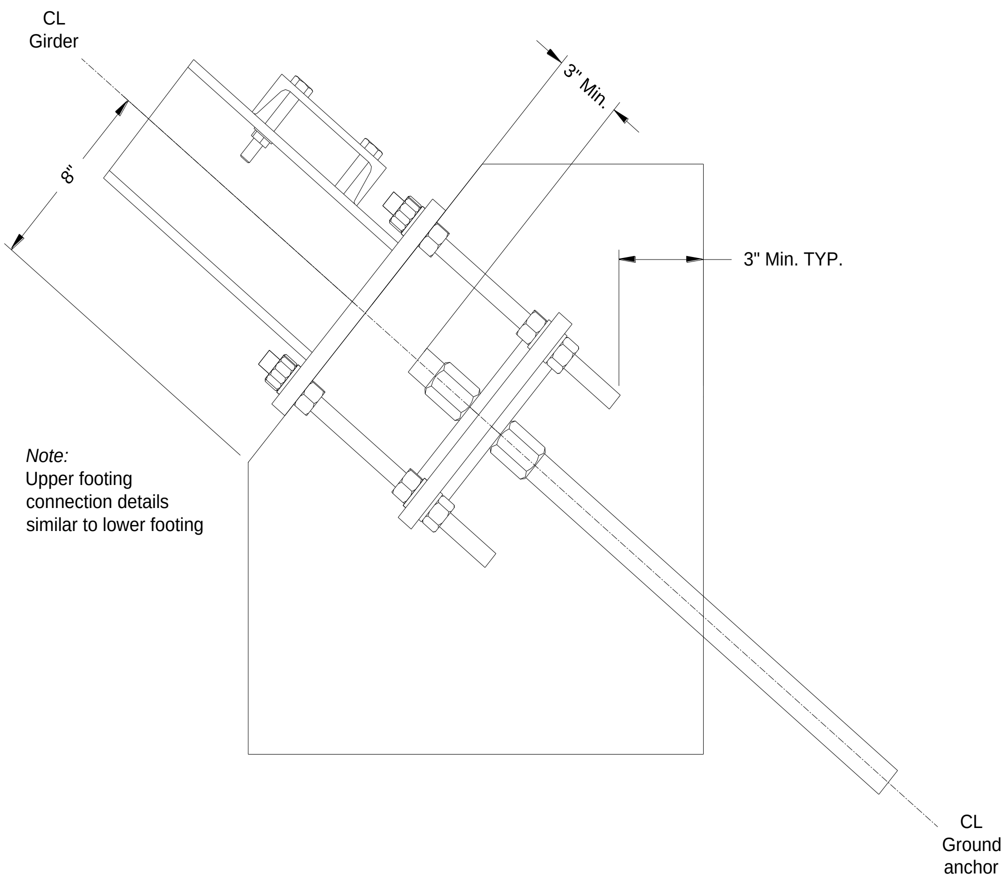


Figure 28. Snow supporting structure upper girder foundation and connection to ground anchor for case of CIP footings.

Where soil over rock in the 151 Avalanche starting zone is thin, making installation of the concrete footing difficult, different snow structure-to-ground anchor connections are required. Figure 29 shows the upper foundation system which utilizes two ground anchors to secure each girder. The girder has a ¾" plate welded to its web and a 1" diameter high strength bolt connects the plate to the ground anchors. This arrangement provides for a true pin-type connection and does not require cast-in-place concrete, but has the disadvantage of requiring extremely tight control of installation of ground anchors. The connection of the lower strut to the ground anchor where there is little or no soil overlying rock is shown in Figure 30. A single ground anchor is used and it is connected to the strut via a 1" diameter high strength bolt and plate welded to the strut.

The following installation procedure is envisioned for units founded on the ground anchors only foundation system. First, the ground anchors for one girder are installed in succession and quickly enough that the grout is still fluid enough to allow for movement of the anchor within the borehole. Then a 1” diameter steel rod of length sufficient to span across the slope to the opposite girder anchor location is inserted through the ground anchor connection plates. The installation rig is moved into position to install the other girder ground anchors, and markings on the steel rod guide the lateral (across slope) positioning of the anchors. Once the anchors are installed at the second girder, the rod is inserted through the anchor connection plates and the grout is allowed to set with the anchors held in the correct position. A similar procedure is used for the lower (strut) foundations.

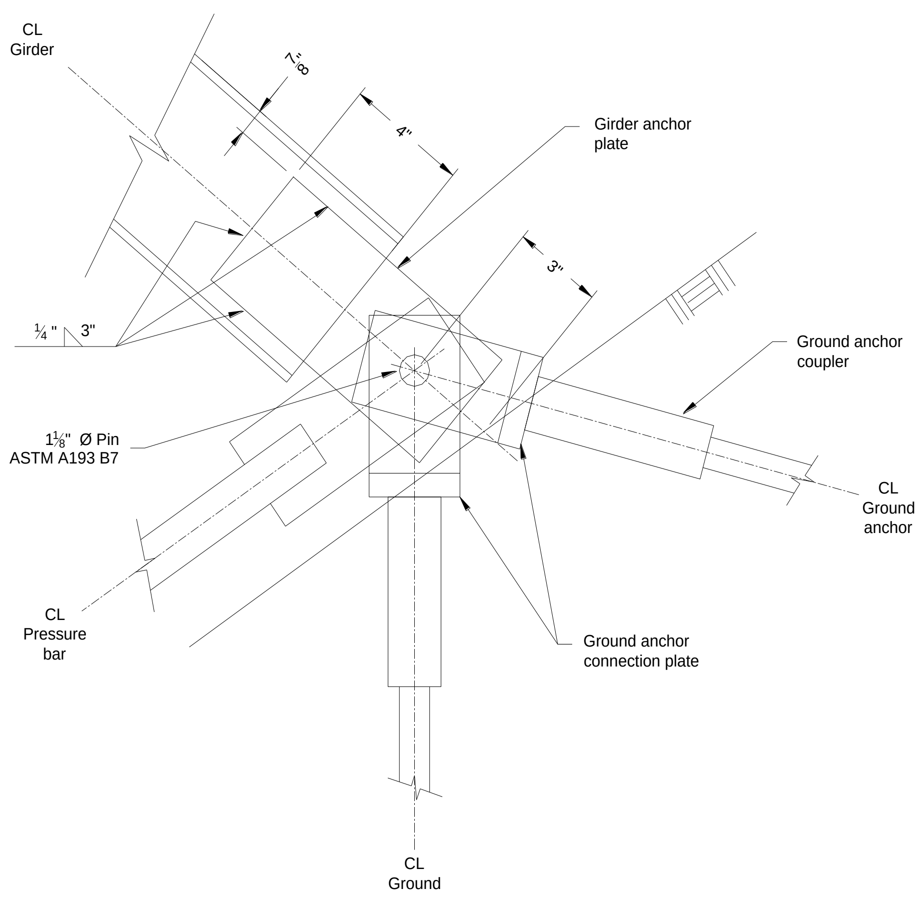


Figure 29. Snow supporting structure upper girder foundation and connection to ground anchor for case of ground anchor foundations.

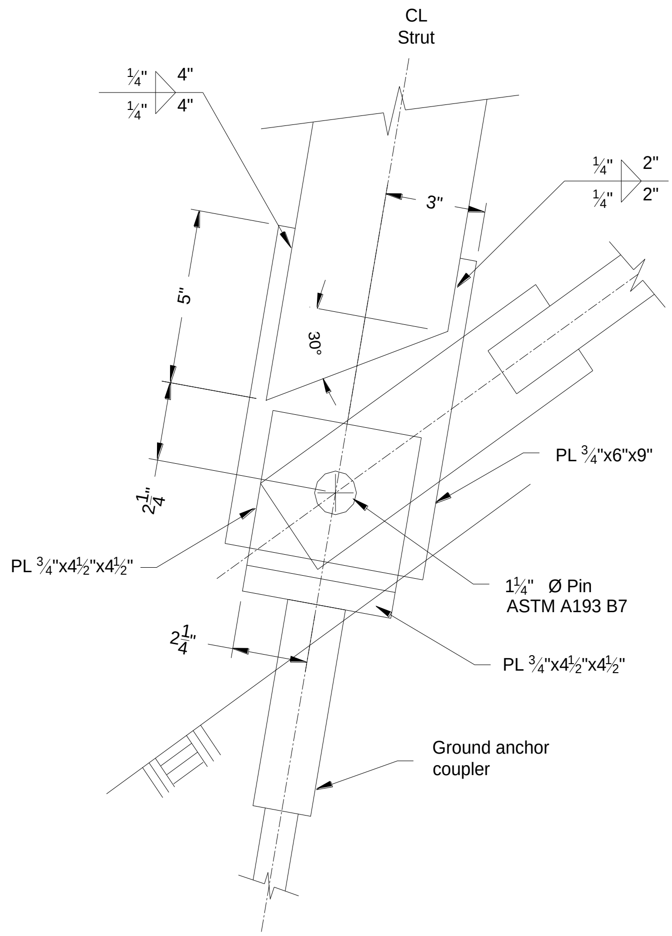


Figure 30. Snow supporting structure lower strut foundation and connection to ground anchor for case of ground anchor foundations.

The ground anchor to snow supporting structure connection systems also provide a means for rapid capture and securing of the snow supporting structure when it arrives on-site in the 151 Avalanche starting zone as a helicopter transported “sling load.” The following construction sequence is envisioned: The four snow supporting structure base connections must lie in the same plane, and non-uniform slope and cross-slope conditions can lead to a need to either raise or lower the height of any given ground anchor connection. Hence, the ground anchors must be positioned or cut to the correct height. Then the snow supporting structure can be lowered into position, as a sling load under the helicopter, while a ground crew secures the structure via its connection plates and attendant bolt and nut sets. The assembly being lowered into position includes the snow supporting structure unit and its connection plates, which are attached to the struts or girders prior to helicopter transport from the valley floor staging area. In the case of cast-in-place concrete footing foundations, concrete is poured in place to secure the connection system.

4.3.4 Snow Supporting Structural Foundation Capacity in Soil and Rock

The structural capacity of a ground anchor is only a partial step in the analysis of the foundation system for the 151 snow supporting structures. The balance of the required analyses for the design use partial factors of safety applied to the input parameters, including soil strength, tendon strength, pullout strength, and nail head strength. In this manner, the resisting forces are reduced and thus, the computed factor of safety is comparable to an acceptable factor of safety of 1.0. Table 5 presents partial factors of safety taken from those recommended in Table 4.5 of the FHWA Manual for Design and Construction Monitoring of Soil Nail Walls for critical structures [20]; Group I load combination, which includes only dead load plus live load. As a comment, it is noted that it is common to report partial factors of safety in values that are numerically greater than 1. Conversely, FHWA Manual uses partial factors of safety that are presented as numerically less than 1. These values are simply the inverse of the partial factors of safety normally presented as greater than 1. For example, from the FHWA Manual, the allowable tensile load for a ground anchor is 55 percent of the yield strength, which is equivalent to a factor of 0.55. The partial factor of safety for tensile capacity is shown to be 1.82, which is about equal to the inverse of 0.55.

Table 5. Partial safety factors recommended for permanent applications on critical structures. From [20].

Item:	Factor
Soil or Rock Shear Strength	1.50
Nail-Soil/Rock Adhesion	2.00
Nail Tension Capacity (with respect to yield)	1.82

One of the primary parameters in the design of ground anchors is the identification of the nail-soil/rock adhesion strength, which is commonly referred to as the pullout strength. For an initial design, such as this investigation being reported here, the pullout strength is generally estimated based on either experience or from information included in Tables 3.2 through 3.4 of the FHWA Manual [20]. These tables are included herein as Table 6 (Table 3-2 through 3-4 from [Federal Highway Administration (FHWA) Manual for Design and Construction Monitoring of Soil Nail Walls (FHWA-SA-96-069R)]), for estimating the ultimate pullout strength of ground anchors in differing soil conditions).

Table 6. Table 3-2 through 3-4 for estimating the ultimate pullout strength of ground anchors in differing soil conditions. From [20].

ULTIMATE BOND STRESS - COHESIONLESS SOILS

Construction Method	Soil Type	Unit Ultimate Bond Stress kN/m^2 (psi)
Open Hole	Non-plastic silt	20 -30 (3.0-4.5)
	Medium dense sand and silty sand/sandy silt	50 - 75 (7.0-11.0)
	Dense silty sand and gravel	80 - 100 (11.5-14.5)
	Very dense silty sand and gravel	120 - 240 (17.5-34.5)
	Loess	25 – 75 (3.5 – 11.0)

ULTIMATE BOND STRESS - COHESIVE SOILS

Construction Method	Soil Type	Unit Ultimate Bond Stress kN/m^2 (psi)
Open Hole	Stiff Clay	40 - 60 (6.0-8.5)
	Stiff Clayey Silt	40 - 100 (6.0-14.5)
	Stiff Sandy Clay	100 - 200 (16.5-29.0)

ULTIMATE BOND STRESS -ROCK

Construction Method	Rock Type	Unit Ultimate Bond Stress kN/m^2 (psi)
Rotary Drilled	Marl/Limestone	300 - 400 (43.5-58.0)
	Phillite	100 - 300 (14.5-43.5)
	Chalk	500 - 600 (72.0-86.5)
	Soft Dolomite	400 - 600 (58.0-86.5)
	Fissured Dolomite	600 - 1000 (86.5-144.5)
	Weathered Sandstone	200 - 300 (29.0-43.5)
	Weathered Shale	100 - 150 (14.5-21.5)
	Weathered Schist	100 - 175 (14.5-25.5)
	Basalt	500 - 600 (72.0-86.5)

These values were not provided from ground anchors installed with side-discharge grouting, but from open hole boring and followed by tremie pipe grouting. Side-discharge grouting injects the grout into the hole cavity under pressure and thereby provides a higher bond strength than tremie pipe grouting. Hence, the values shown in Table 6 are generally considered to be the lower bound. The design tensile load must be developed along the area of bond, which is the perimeter of the grout-soil/rock interface. This is idealized as a cylinder having a width of the drill bit and a length equal to the embedment length of the ground anchor. Hence, force equilibrium provides the following equation:

$$\text{Design Tensile Load} = \frac{\left(\text{Bond Stress}_{\text{ULTIMATE}}\right)\left(\pi\ d_{\text{HOLE}}\ L_{\text{minimum}}\right)}{\left(FS_{\text{ADHESION}}\right)} \tag{4-1}$$

Solving for the minimum length of embedment, $L_{minimum}$, provides:

$$L_{\text{minimum}} = \frac{\left(\text{Design Tensile Load}\right)\left(FS_{\text{ADHESION}}\right)}{\left(\text{Bond Stress}_{\text{ULTIMATE}}\right)\left(\pi\ d_{\text{HOLE}}\right)} \tag{4-2}$$

Using the design tensile load of 8.2 kips from Table 6, a partial factor of safety for adhesion of 2.0, and a 2-inch diameter carbide drill bit, this equation reduces to only a function of the ultimate bond stress as:

$$L_{minimum}\ (ft) = \frac{(9700\ \text{lb})(2)}{Bond\ Stress_{ULTIMATE}\ (\pi)(2inch)} = \frac{257\ (lb\text{-}ft/in^2)}{Bond\ Stress_{ULTIMATE}\ (psi)} \tag{4-3}$$

In locations where the depth of soil is sufficiently deep such that the installed ground anchor may not reach the underlying fractured limestone bedrock, values from the upper two tables of Table 6 may be appropriate. A review of the values in these two tables indicates that except for a non plastic silt or loess, a lower bound value of about 6 psi should be conservative. While the 151 Avalanche starting zone soils are not known, they are not likely to be a non plastic silt or loess, as these soils are not typically found in mountainous regions. From Eq. 4-3 with an ultimate bond stress of 6 psi, a minimum embedment ground anchor length of 42.9 ft is found. The 151 Avalanche starting zone site does not have soils of this thickness. Hence, it will likely be more appropriate to ignore any bonding in the soil cover and let the embedment depth be controlled by penetration into the underlying fractured rock.

A significant number of the 151 Avalanche snow supporting structures will be placed at locations where there is limited soil covering. Moreover, based on the preceding discussion, none of the sites are expected to provide sufficient soil covering so as to anchor the structures independent of the underlying limestone bedrock. From Table 6, values from the lowest table may be appropriate. Using a lower bound value for limestone (i.e., 43.5 psi) in Eq. 4-3, a minimum embedment length of 6 ft is required.

The embedment lengths herein have been computed based on tensile forces. However, the ground anchors supporting the lower struts will be subjected to compressive forces. Hence, the bearing capacity of the underlying soil/rock must be considered. A cursory review of the literature suggests that the bearing capacity of a 2 inch diameter grouted column in fractured limestone is a trivial situation, but which should be, nevertheless, checked prior to final design and installation with an on-site inspection of the soil and rock conditions.

Hence, independent of the surficial conditions in the 151 Avalanche starting zone, the ground anchors should have a minimum specified penetration into the underlying bedrock. Based on the computations included herein, the minimum penetration should be 6 ft. However, this embedment length is based on estimated values and may not be appropriate; hence, site-specific pullout tests must be completed prior to the placement of ground anchors that will bear the load of the subsequently installed snow supporting structures.

4.3.5 Pre-installation Testing, Construction Monitoring and Inspection

Prior to commencing any pullout tests of the 151 Avalanche ground anchor system, the ground anchor contractor shall submit detailed methods to be followed for this verification testing. Additionally, calibration reports and data for each test jack, pressure gauge, and master pressure gauge to be used should be included. The calibration reports shall not be older than 60 days. The verification testing and review of all results shall be complete and approved prior to beginning the installation of any production ground anchors expected to carry the foundation loads of snow supporting structures in the 151 Avalanche starting zone.

Verification pullout tests should be completed on not less than 1 percent of the number of production ground anchors. These pullout tests generally move the ground anchor sufficiently such that they should not be used for production anchors. However, for this project, performing pullout tests on the ground anchors supporting the lower struts may be an option, as the loads in this anchor are predominantly compressive. Pullout movements should not affect their long-term performance, especially after grouting. Verification test ground anchors shall be installed using same geometry, techniques and equipment as the production ground anchors.

It is recommended that the test ground anchor shall be incrementally loaded to twice the design test load (DTL) followed by unloading in accordance with the following schedule. The ground anchor's movements at each load and unload increment shall be recorded. The DTL shall be the bonded length, L_b multiplied by the ultimate bond adhesion, A_d divided by the partial factor of safety for adhesion as shown in the design report.

Although the ground anchor installation contractor is to provide a submittal outlining the verification test methods to be used, the following steps are recommended to be included.

- A time-loading sequence is to be established. For cases where the ultimate bond strength is not well known, more steps having a longer hold time is advantageous. This will likely be the case for the first couple of verification test nails. Conversely, once the ultimate bond strength is reasonably known, the ultimate load can be approached more rapidly. In either case, the ultimate load (i.e., twice the DTL) should be held for a minimum of 60 minutes. An example time-loading sequence is presented in following Table 7.

Table 7. Ground anchor verification testing time-load sequencing.

LOADING		UNLOADING	
Load	**Hold Time**	**Load**	**Hold Time**
AL (0.05 DTL max)	1 minute	2.00 DTL	Until Stable
	10 minutes	1.75 DTL	Until Stable
0.25 DTL	10 minutes	1.50 DTL	Until Stable
0.50 DTL	10 minutes	1.25 DTL	Until Stable
0.75 DTL	10 minutes	1.00 DTL	Until Stable
1.00 DTL	60 minutes	0.75 DTL	Until Stable
1.25 DTL	15 minutes	0.50 DTL	Until Stable
1.50 DTL	15 minutes	0.25 DTL	Until Stable
1.70 DTL	15 minutes	AL	Test complete
1.90 DTL	15 minutes		
2.00 DTL	60 minutes		

- During each hold time, the load shall be maintained within 2 percent of the intended load as shown on the load cell. The ground anchor shall be unloaded in increments of the DTL with movements recorded as each unload increment. Each unload increment shall be held only for a time sufficient to allow stabilization of the movement reading.
- The bonded length. L_b, shall be 10 ft but should not create a situation where the ultimate test load is greater than the yield strength of the ground anchor.
- The alignment load, AL should be the minimum load required to align the testing apparatus and should not exceed 5 percent of the DTL. Dial gauges should be set at 'zero' after the alignment load has been applied.

Services for work inspection, material testing, surveying, and monitoring of ground anchor soil installations during and subsequent to installation is required. To better facilitate this, it should be understood that the ground anchor installation contractor must cooperate with the inspecting and testing agencies selected. An independent construction and materials testing firm should document the installation process of each of the snow supporting structure ground anchors with photographs and as-built drawings, and daily field reports. Variances to the “as design” configurations should be noted. All documentation should be reviewed by a licensed professional engineer and all parties notified of any variances or deficiencies. Deficiencies should be rectified prior to installation of the snow supporting structure on any suspect ground anchor system.

At a minimum, and as part of the daily field reports, the construction and materials testing firm shall prepare and submit to WYDOT and the Engineer a full-length installation record for each ground anchor installed. The record should contain the following information: ground anchor rod head evaluation, drilling start and end time, actual embedment length, installation orientation angle, deviation from “as designed” plan location, grout quantity, and relative drilling difficulty.

Chapter 5: Snow Supporting Structure Deployment in the 151 Avalanche Starting Zone

The factors which determine the distribution and configuration of snow support structures in an avalanche starting zone are dominated by the size of the avalanche starting zone and the longitudinal (up/down slope) and laterally or transverse (across slope) separation between individual snow supporting structures [2].

As a noted previously [1], the dominant factor leading to avalanching on the 151 is the capacity for strong southwesterly winds, during and immediately after heavy snowfall, to transport snow from the large meadow to the south of the 151 Avalanche across that expanse, over the southerly crest of the 151 swale and into the 151 Avalanche starting zone, where it is deposited. Hence, the 151 Avalanche starting zone is not the typical headwall of a high mountain basin or cirque, rather it is a “ribbon” drift (narrow and long) and that forms along the south side of a modest valley in the ridge directly above and flanking US 89/191. Physiographically, the 151 Avalanche starting zone is much less pronounced than a deeply incised “gulch.” The ribbon drift structure of the 151 Avalanche starting zone can be seen in the following Figure 30.

The 151 Avalanche starting zone is approximately 900 feet long (up/down slope) and has an average width of 60 feet laterally for a net area of 54,000 feet^2 or about 1.24 acres.

The 2007 Swiss Guideline provides advice on the both the longitudinal and lateral separation of snow supporting structures based on the same parameters that are used to determine the snow-loads on each structure, specifically; the maximum anticipated snow depth that will require support, the slope angle, a snowpack density factor and the a ground condition factor as that effects snowpack glide and creep. Utilizing the same values for this suite of parameters laid out in section 4.1 of this report, Implementation of the 2007 Swiss Guideline for Snow Supporting Structures; the average longitudinal separation of the 151 snow supporting structures is 50 feet.

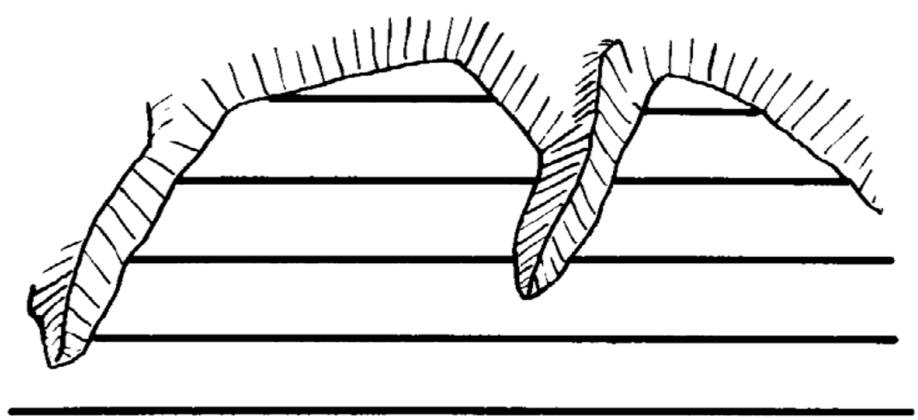
Moreover, the 2007 Swiss Guideline allows for modest lateral separation of adjacent snow supporting structures without compromising the effective or net area of supported snowpack. As noted in section 4.2.2 of this report, Geometry, Structural Analysis and Unit Design; snow supporting structures in the 151 Avalanche starting zone are to be implemented as single units that are 12 feet long laterally and hence support a “tile” of snowpack 12 feet wide and 50 feet long, or as double units separated by a 1 foot gap for a net lateral effective length of 25 feet, or as triple units with a resulting effective lateral length of 38 feet. Though supporting a slightly wider tile of the snowpack; double and triple units are limited, in the same fashion as single units, to a longitudinally effective length of 50 feet.

Based on this geometry and the areal extent of the 151 Avalanche, it will take approximately 70 unit snow supporting structures, in various combinations of singles, doubles and triples to adequate tile, and hence support the 151 Avalanche snowpack in place.

5.1 Typical Configurations for Snow Supporting Structural Deployments

Despite being valuable information, the resulting number of 70 snow supporting structures in the 151 Avalanche starting zone says little about their cumulative appearance once they are installed there. Conversely, the appearance of a deployment of snow supporting structures in the 151 Avalanche starting zone is not a trivial matter. Moreover, and beyond just their total numbers, the appearance of 70 snow supporting structures in the 151 Avalanche starting zone can be dramatically different, depending on the configuration chosen for their deployment.

The 2007 Swiss Guideline provides the following four different snow supporting structure deployment configurations, all applicable to the same site.



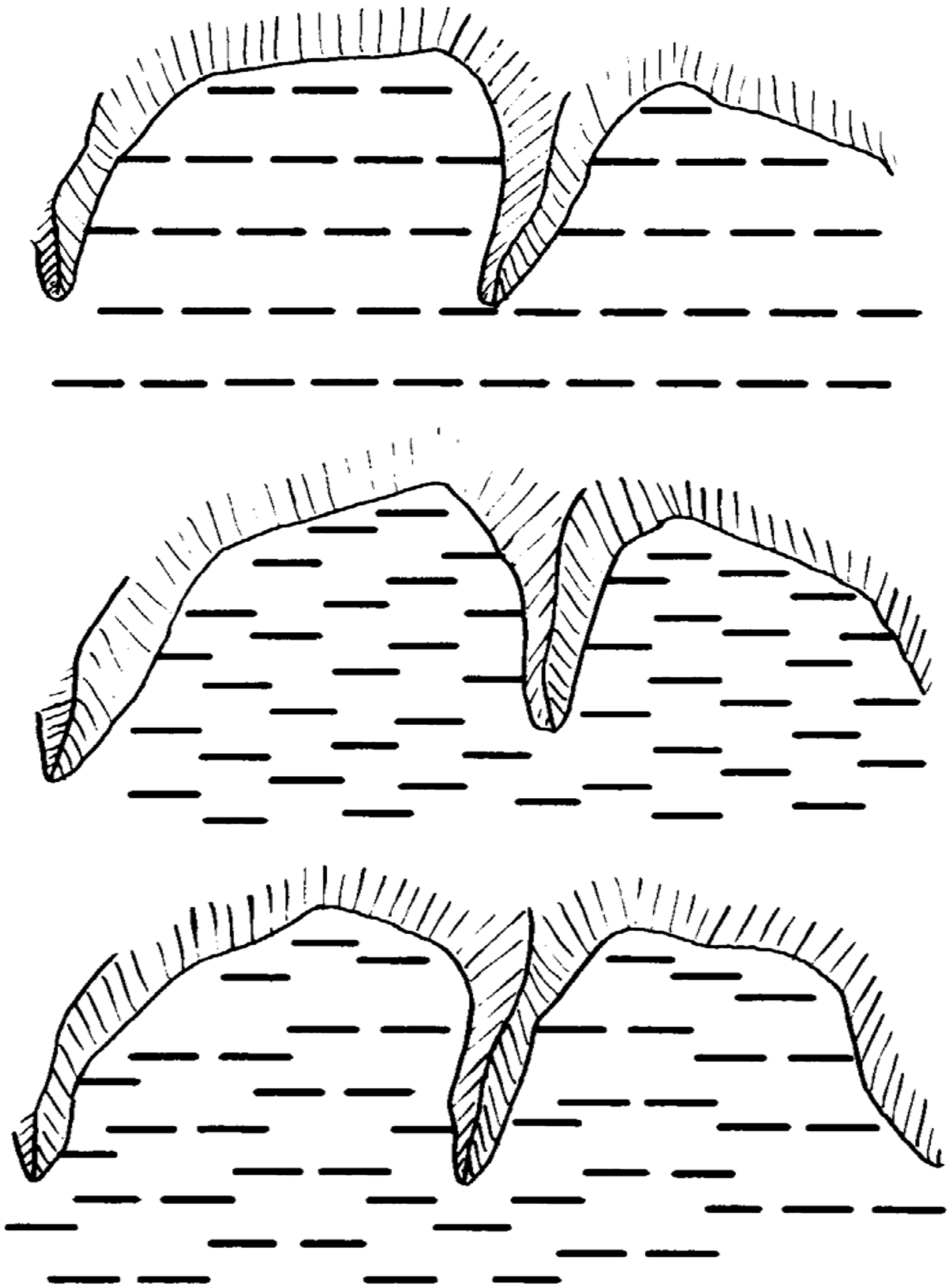


Figure 31. Suggested deployment configurations for snow supporting structures. From top to bottom: Continuous, Separated, Separated-Staggered, and Separated-Combined configurations. From [2].

If we were to deploy snow supporting structures in the 151 Avalanche starting zone typical of the “Continuous” configuration, the resulting appearance would be very similar to Figure 32. This configuration would probably be acceptable in both European and Asian deployments and examples of this are common in practice there. However, for reasons to be introduced in the following section 5.2 of this report, NEPA Requirements and the 151 Avalanche Deployment Configuration; this orderly and otherwise highly visible configuration for snow supporting structures in the 151 Avalanche starting zone is not acceptable in a domestic deployment.

Fortunately though, the only requisite necessity for snow supporting structures is that they effectively cover or tile and hence support the starting zone snowpack area. This is alluded to in the other suggested deployment configuration shown in Figure 31. This leaves considerable choice in the final placement, and hence appearance of the resulting deployment of snow supporting structures slated for the 151 Avalanche starting zone.

Figure 32. A virtual rendering of snow supporting structures in the 151 Avalanche starting zone deployed in a typical orderly, continuous fashion.

5.2 NEPA Requirements and the 151 Avalanche Deployment Configuration

As with the existing snow sails in the 151 Avalanche starting zone, future implementation of snow supporting structures on this site requires consideration of the National Environmental Policy Act (NEPA) process. With respect to the NEPA requirements for projects on public lands, the USDA Bridger-Teton National Forest is the review and rule-making entity for activities, including those that are focused on public safety such as the efforts being reported here for the 151 Avalanche starting zone.

In a NEPA required Environmental Assessment (EA) for the existing deployment of snow sails in the 151 Avalanche starting zone "visual attributes" was the only identified environmental asset identified as one that could, potentially, be impacted by the installation of the snow sails [3]. The finding of that EA with respect to the impact of snow sails on the visual attributes of the site was one of no significant impact (FONSI). The 151 Avalanche snow supporting structures will occupy the same site and visual foot-print as the snow sails.

To meet NEPA requirements with respect to the visual attributes of a site, the project must “retain” the visual characteristics of the site that are present before the project’s inception. This is known in the parlance as “visual retention.” [22]. A collaborative decision making and work-process was put in place for the purpose of assuring that a deployment of snow supporting structures in the 151 Avalanche starting zone could both retain the visual characteristics of the site and perform their technical task of avalanche defense.

Critical to configuring a deployment of snow supporting structures in the 151 Avalanche starting zone that would support the snowpack, even while retaining the visual character of the site, was the capacity of rendering virtually through digital photo manipulation, the appearance of the deployment from the Jackson Hole valley floor. This technique was used successfully during the EA process of the existing snow sails. In the following Figure 33 we see the anticipated appearance, in a virtual rendering, of snow sails prior to their installation. An examination of Figure 6 indicates that there is a high degree of confidence between the anticipated appearance and the subsequent result.

Figure 33. A virtual rendering of the snow sail deployment at the 151 Avalanche, Jackson, Wyoming.

Based on this technique of virtually rendering the appearance of avalanche defense facilities in the 151 Avalanche starting zone, Figure 34 depicts, as virtual rendering, the configuration of a deployment 70 snow supporting structures in the 151 Avalanche starting zone. This deployment is rendered with both the existing snow sails in place and the (re)planting of native conifer adjacent below (and in the glide and creep protected zone) of the snow supporting structures. Figure 35 depicts the snow supporting structures in the 151 starting zone without reforestation, but continues to include the existing snow sails. It may be typical of the appearance of the snow support structures just after their installation, while the snow sails are still in place and prior to significant growth of (re)planted conifers. It should be noted that the existing snow sails will help in the establishment of (re)planted native conifers, in that they also serve as wind breaks for these stands. Figure 36 depicts the 151 Avalanche snow supporting structures without the snow sail deployment or significant growth in any (re)planted conifer stand. The snow supporting structures are visually "porous." That is; they are not solid structures but are near vertical girders with cross-members that have significant (~50%) gap or open areas between them.

Figure 37 depicts the "organic" and an otherwise less than continuous configuration for the 151 Avalanche snow supporting structures. It is shown without any base photo. It should be noted that there is a very significant pattern to this deployment configuration. It emulates clusters of visual elements that are typical of the 151 Avalanche starting zone; specifically pairs and triplets of small conifers that are found in and adjacent to the site. By configuring the 151 Avalanche snow supporting structures in a fashion that replicates visual elements that are native to and commonly found in the local landscape allows the snow supporting structures to blend in visually. In this fashion, the visual character of the 151 Avalanche starting zone is retain, even with the presence of the snow supporting structures that are to be installed for the purpose of avalanche hazard defense.

The complete set of the 151 Avalanche snow supporting structure deployment configurations, with and without (re)planting, with and without the existing snow sails, and without any base photos can be found in Appendix C of this report.

Figure 34. A virtual rendering of snow supporting structures with reforestation in the 151 Avalanche starting zone in a configuration that retains the visual character of the site.

Figure 35. A virtual rendering of snow supporting structures without reforestation in the 151 Avalanche starting zone.

Figure 36. A virtual rendering of snow supporting structures without reforestation or the existing snow sails in the 151 Avalanche starting zone.

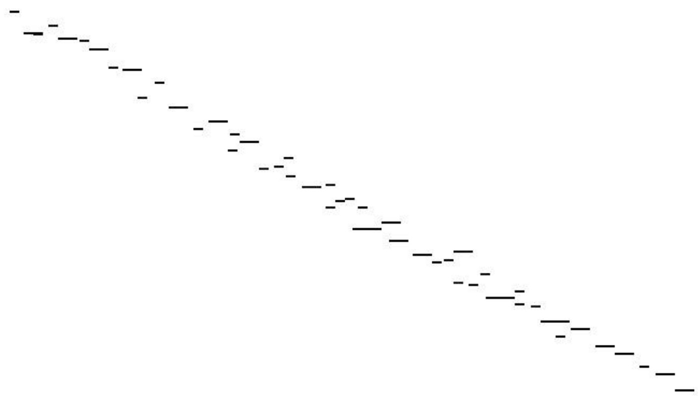


Figure 37. A virtual rendering of (darkened) snow supporting structures without base photo in the 151 Avalanche starting zone.

Chapter 6: 151 Avalanche Snow Supporting Structural Defense Cost Estimates

Table 8 presents cost estimates for snow supporting structures to be fabricated, coated, shipped and installed in the 151 Avalanche starting zone. The one-time and fixed costs are amortized for an installation of 70 structures. The net unit cost per snow supporting structure installed in the 151 Avalanche starting zone is $16,600.00. This results in an estimated, near future, project cost for snow supporting structures in the 151 Avalanche starting zone of $1.162M. This detailed cost estimate is approximately $240,000 less than previous “ballpark” estimates of cost.

These costs are scalable to the extent that additional units will only modestly decrease the cost per unit resulting from the fixed and one-time costs of the project. Moreover, with some caution, the cost estimate of $16,600 per structure is exportable to other avalanche sites where the primary factors governing the costs may be similar. Note that these cost estimates do include the provision of engineering support to prepare bid and contacting documents, as well as work on-site during installation. Conversely, these cost estimates do not amortize the one-time research and development costs of this project being report here.

Table 8. Cost estimates for materials, fabrication, transport and installation of snow supporting structures for the 151 Avalanche, Jackson, Wyoming.

	Lump & One Time Costs	Costs: Net and or Amortized	Unit Cost	Number of Item/Activity	
Engineering (Bid Docs)	Bid Docs and Contracting	and On-site	$180.00/hour	400 hours	$72,000
Structural Materials			$3700.00	70	$259,000
Structural Coating			$600.00	70	$42,000
Structure Shipping	12 loads @ $6.50/mile	@350 miles (Provo, UT)		n/a	$27,3000
Staging and Prep	Crew of two, $200/hour	10 hour day		20 days	$40,000
Heli-tac: Structures	0.33 Heli Hours/unit	$2500/hour	$825.00	70	$57,750
Structure Installation	Crew of four, $400/hour	4 units per 10 hour day	$1140.00	70	$79,800
Ground Anchors	Drill and Crew	Includes Mobilization	$860.00	40*4 + 30*6 = 340	$292,400
Anchor Concrete	$240/yrd, with rebar	40 yards total, 4 flights/yard	$1307.00	40	$52,280
Heli-tac: Crew Trans	0.67 hour/day	$1600.00/hour	$1072.00	20 days	$21,440.00
Heli-tac: Mobilized			$2500.00/hour $1600.00/hour	6 hours 6 hours	$15,000.00 $9,600.00
Totals	Net: $968,570	Profit/Contingency: Margins @ 20%:		$193,714	$1,162,284 **$1.16M**

These 151 Avalanche snow supporting structure cost estimates reflect an installation of 40 of the 70 structures where there is adequate soil cover to utilize the single ground anchor to girder connection at the uphill connection and concrete footers around both the upper and lower connections. The remaining 30 units utilize double ground anchors at the girder to anchor uphill connection and no concrete in either upper or lower connections. The unit costs of either

configuration are comparable. The former utilizes only 4 ground anchors per structure, but has the addition of 0.9 yards of concrete per structure, while the latter does not utilize concrete in the footers but has a total of 6 ground anchors per structure.

The following data summarizes the sources and basis for these estimates. In some cases, these estimates result as a consequence of experience gained during helicopter supported installation of the existing snow sails in the 151 Avalanche starting zone. Figure 38 depicts this activity.

Structural Materials and Fabrication (Structure and Connections):

- From a regional steel fabricator: $3700 per structure, fabricated with connections, and galvanized or with high endurance/low maintenance coatings.
- Shipping costs from regional flat bed tractor-trailer schedules from Provo, Utah (the nearest center of heavy steel fabrication) to Jackson, Wyoming.
- The bulk of the valley floor preparation and staging labor costs are applicable here.
- 20 minutes (0.33 hours) of helicopter “collective” time per structure to lift it in place @ $2500.00/hour. This is a helicopter capable of lifting in excess of 2000 lb. The snow supporting structures are estimated to weight 1400lb+ and there are smaller helicopters that have maximum lifting capacities in the neighborhhod of 1400lb. However, at the 151 Avalanche starting zone elevation (7200’ ASL) and with the need to hold the structure steady in “hover” while it is slung onto its foundation, precludes using a smaller helicopter.
- A smaller helicopter in support, capable of lifting ~1400lb and/or carrying a pilot plus a crew of 4 safely to the 151 Avalanche starting zone. There is the need for some ferry time of this amount, daily.
- An on-slope crew in the 151 Avalanche starting zone of four at $400/hour net, 10 hours per day or $4000/day, 4 units per day installed.

Anchoring Materials, including On-site Preparation:

- Ground anchoring has been estimated by this project’s geotechnical engineer [23] and includes material, drill, crew and mobilization. The larger, heavy lift helicopter is also necessary for transporting the ground anchor drill to the 151 avalanche starting zone site. That cost is included in the per unit ground anchor estimate.

- 40 of the structures will utilize 0.9 yards of concrete (3000 lb per yard) per structure at a cost of $240. This includes concrete delivered to the Jackson Hole valley floor staging area, forming and rebar. There is also the cost associated with four lifts per structure @ 10 minutes of helicopter collective time per lift, utilizing the smaller helicopter (1400 lb capacity), or 40 minutes (0.667 hours) for transporting concrete to all 4 anchors connections. The smaller helicopter is appropriate for this chore, at a cost of $1600/hour.

Helicopter Mobilization:

- The industry average for bringing a helicopter to any given job site is 6 hours of helicopter time at its standard operating rate.

Figure 38. Helicopter supported transport and installation of snow sails at the 151 Avalanche, Jackson, Wyoming.

Chapter 7: USDA Forest Service Decision Making Process and Resulting Decision Memo

As noted in section 5.2 of this report, the existing snow sails in the 151 Avalanche starting zone, as well as any future implementation of snow supporting structures on this site requires consideration and decision making under the National Environmental Policy Act (NEPA). The USDA Bridger-Teton National Forest is the review and rule-making entity for these activities.

In a NEPA required Environmental Assessment (EA) for the existing deployment of snow sails in the 151 Avalanche starting zone "visual attributes" was the only identified environmental asset identified as one that could, potentially, be impacted by the installation of the snow sails [3]. The finding of that EA with respect to the impact of snow sails on the visual attributes of the site was one of no significant impact (FONSI). The 151 Avalanche snow supporting structures will occupy the same site and visual foot-print as the snow sails.

Certainly, the snow supporting structures must perform the task of holding the snowpack in place and hence preclude or greatly reduce the potential for avalanching from the 151 Avalanche starting zone unto US 89/191 below. Simultaneously, the deployment of snow supporting structures must meet NEPA requirements with respect to the visual attributes of the site. That is, the resulting deployment of snow supporting structures must be installed so as to "retain" the visual characteristics [22] of the site that are present there before the snow supporting structures are put in place in the 151 Avalanche starting zone. The resulting deployment configuration of the snow supporting structures was presented in Chapter 5 of this report. It has been determined by the USDA Bridger-Teton National Forest that this snow supporting structure deployment configuration will retain the visual character of the 151 Avalanche starting zone, and as a result they have authorized WYDOT to proceed with their installation. That authorization is in the form of a Decision Memo. This Decision Memo, along with supporting documentation, can be found in Appendix D of this report.

Presented here are the elements of the work process and decision making environment that was utilized for the purpose of assuring that a deployment of snow supporting structures in the 151 Avalanche starting zone would perform it's avalanche defense tasks as well as retain the visual characteristics of the site, leading to the requisite Forest Service Decision Memo authorizing their eventual deployment. The philosophy, critical steps and lessons learned from this work process are summarized here.

Predictably, a suite of working meetings between USDA Bridger-Teton National Forest administrative and technical staff, WYDOT administrative and technical staff and InterAlpine staff were conducted. Their chronology, those in attendance, and attendant decisions and or outcomes are as follows. The Meeting Summary documents for each of these can be found in Appendix D of this report.

- **June 8, 2006 – Getting Introduced and How-to-Proceed.** Attending for WYDOT: Jim Montouro, Ed Smith, Galen Richards, Jamie Yount; USDA Forest Service: Kniffy Hamilton, Rick Dustin, Elizabeth Brann, Dave Cunningham, Ray Spence; InterAlpine: Rand Decker

The critical element of this meeting was the decision *not to make a decision.* However, the technical needs and decision making criteria that governed each stakeholder was identified and shared. Then, before the administrative leadership of the agencies involved made any firm decisions, the technical staff of each agency and InterAlpine would attempt to address the competing technical elements of the criteria on the 151 Avalanche starting zone site. These elements being the previously noted need for the snow structures to support the snowpack and preclude avalanching, while also maintaining visual retention of the site. The specific NEPA decision mechanism that would eventually be implemented by the Forest Service was also left open, pending the technical working session.

- **December 1, 2006 – Collaborative Technical Working Session.** Attending for WYDOT: Ed Smith, Galen Richards, Jamie Yount; USDA Forest Service: Rick Dustin; InterAlpine: Rand Decker, Perry Wood

Working collaboratively, Forest Service Landscape Architect Rick Dustin instructed WYDOT Avalanche Technicians and InterAlpine technical staff on the presences of “doublets and triplets of small conifers” that make up the dominant visual elements in the 151 Avalanche starting zone, and the need to deploy the snow supporting structures in a fashion that replicated this pattern. Then, WYDOT and InterAlpine technical staff proceeded to “tile” the 151 Avalanche starting zone with snow supporting structures, based on their previously determined uphill zone of snowpack supporting influence. They deployed snow structures as single structures, doubles and as triples. As WYDOT and InterAlpine technicians sited individual snow structures with advice and input from the Forest Service Landscape Architect, their location was captured on digital photos of the 151 Avalanche starting zone. These digitally manipulated photo renderings of the deployment of snow supporting structures are those found in Chapter 5 and Appendix C of this report. These renderings became the basis for subsequent agency and public consideration of whether or not the visual characteristics of the site could, potentially, be retained after the installation of a sufficient number of snow supporting was implemented to keep the 151 Avalanche from avalanching. That visual retention could be maintained was further evidenced by the virtual placement of small conifers in and around (and predominantly downhill) the snow supporting structures. This critical working session closed with agreement that snow supporting structures could be deployed in the 151 Avalanche starting zone so as to preclude the onset of avalanches and retain the visual characteristics of the site. The technical working group provided this assessment to their respect administrative decision makers and also provided indication that a NEPA "Categorical Exclusion" would be the appropriate decision making mechanism a basis for "how-to-proceed."

- **September 7, 2007 – Agency Administrators Agree to a Decision Process.** Attending for WYDOT: Jim Montouro, Jamie Yount; USDA Forest Service: Mike Balboni, Rick Dustin, Kristi VonKrosigk, Ray Spence; InterAlpine: Rand Decker

The virtual renderings of the snow supporting structures in the 151 Avalanche starting zone, as developed at the December, 2006 working session were shared with the decision makers. It was noted by WYDOT and InterAlpine technical staff that these deployments were sufficient for the purposes of avalanche defense. Similarly, Forest Service technical staff also noted that these deployments, with their "organic" deployment configuration and attendant conifer replanting, were sufficient to retain the visual characteristics of the 151 Avalanche starting zone. Subject to changes that may arise from public comment on the potential use of snow supporting structures for avalanche hazard reduction on the 151 Avalanche, it appeared that a Categorical Exclusion would be the appropriate NEPA mechanism for this decision. To initiate this process, WYDOT filed the requisite "APPLICATION FOR TRANSPORTATION AND UTILITY SYSTEMS

AND FACILITIES ON FEDERAL LAND" on October 5, 2007. That Application and its transmittal memo may be found in Appendix D of this report.

- **March 12, 2008 – Design and Deployment Configuration De-briefed.** Attending for WYDOT: Jim Montouro, Michael Patritch, Bob Hammend, Ed Smith, Jamie Yount; InterAlpine: Rand Decker, Josh Hewes

The completed unit design for the 151 Avalanche snow supporting structures, along with their deployment configuration was presented to WYDOT Headquarters Research staff, District Three administrators and Jackson Maintenance Facility staff. At this time it was noted that the only outstanding element of the project was the completion of the NEPA process and USDA Forest Service Decision. A WYDOT Research Advisory Committee (RAC) presentation on the design and technical elements of the deployment configuration was scheduled and subsequently conducted in Cheyenne on July 9, 2008. In addition, it was noted that an International Snow Science Workshop (ISSW) presentation would be made at the up-coming October, 2008, Whistler, British Columbia ISSW. The resulting paper was jointly authored by InterAlpine, WYDOT and USDA Forest Service personnel [24]. Concurrently – USDA Forest Service personnel were provided background information, text and graphics for the purpose of developing the Request for Public Comment (NEPA Public Scoping) that would need to occur prior to any forthc-coming Forest Service Decision.

- **October 15, 2008 – NEPA Public Scoping Hits-the-Streets.** Attending for WYDOT: Jim Montouro, Jamie Yount; USDA Forest Service: Ray Spencer, Dale Deiter; InterAlpine: Rand Decker

The final language for the NEPA Public Scoping was finalized and subsequently approved at the Forest Supervisor's level. A significant element of the Scoping request was the virtual rendering of the potential appearance of a deployment of snow supporting structures in the 151 Avalanche starting zone, developed jointly with the USDA Forest Service earlier in the project process. A copy of this Request-for-Public Comment may be found in Appendix D of this report. It was released to the public on November 19, 2008 and open for one (1) month. Surprisingly, the only respondents to this critical element of the NEPA process was WYDOT and InterAlpine. Those responses may also be found in Appendix D of this report.

In the absence of significant public concern, in light of the Finding of No Significant Impact (FONSI) from the prior EA conducted on this site [3], and couple with the fact that there was significant confidence that the snow supporting structures could be deployed in such a way as to preserve or "retain" the visual character of the 151 Avalanche starting zone site; a USDA Forest Service Decision Memo was released in February, 2009. This Decision is favorable to the use of snow supporting structures in the 151 Avalanche starting zone for the purpose of reducing the risk of avalanche onto US 89/191. The Decision Memo may be found in Appendix D of this report.

There are at least two (2) critical and generic ***lessons learned*** that can be gleaned from this specific NEPA Decision process.

Extraordinary stretches of calendar time elapse between individual Forest Service actions on the NEPA Decision process steps, this despite the fact that the actions themselves did not take long at all, once initiated. For example, 8 months elapsed from completion of the technical snow supporting structure deployment configuration joint working session and a meeting with decision makers for the purpose of setting "how-to-proceed." Similarly, 14 months elapsed from the establishment of how-to-proceed to the release of the NEPA Scoping request. Can these delays be mitigated? Clearly – there are effective, high level WYDOT-USDA Forest Service liaison relationships in place. These relationships are in place primarily to usher WYDOT Constructions projects through the USDA Forest Service decision process, including and primarily NEPA. However, this specific project was not held and considered within the bevy of projects in this liaison environment until note-worthy delays were already being accrued. Once this project had the advantage of this liaison, it progressed much more rapidly and effectively. Hence, a ***valuable lesson is to get WYDOT Research Projects*** into the WYDOT-USDA Forest Service NEPA process liaison environment and queue earlier than later. The potential for this need can and should be identified at the time of the project proposal and/or when it is initially reviewed by the WYDOT Research Advisory Committee (RAC). This need, the liaison environment and the responsible parties should be communicated to the project Investigator at the earliest possible date in the project.

The other value, generic lesson is the need for maintaining NEPA process progress through an early, clear and two-way understanding of the process steps that the Forest Service will initiate and when, and what technical input and information they will need from WYDOT and its contractors in support of this process, and how long each process step should take. Something as simple as an agreed upon Gantt style Time-Task-Deliverables-Responsible Parties matrix would suffice and provide, at a minimum, a basis for culpability and rectification when delays become both extraordinary and unexplainable.

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Appendix A

Process and Steps in the Design and Deployment of Snow Supporting Structures for Avalanche Hazard Management

Step 1. ASSESS AVALANCHE HAZARD AND DETERMINE IF SNOW SUPPORTING STRUCTURES ARE THE BEST CHOICE

- ✓ Avalanche hazard index or anecdotal evidence indicates hazard management is warranted.
- ✓ Cost/Benefit/Consequence analysis of forecasting and explosive control vs passive defense.
- ✓ available weather and snowpack data.
- ✓ explosives use, logistics, delivery, and crew and public safety.
- ✓ on-site and adjacent land uses, including full extent of the potential run-out.
- ✓ estimated cost of starting zone structures vs cost of snow shed at the roadway.
- ✓ Starting zone access and constructability.
- ✓ Environmental considerations, including National Environmental Policy Act (NEPA) review on Federal lands.

Step 2. DETERMINE SITE SNOW LOAD ENVIRONMENT

- ✓ Determine or estimate maximum design snow depth, $H_{k.}$
- ✓ Establish slope characteristics: starting zone extent and area, elevation, exposure *(e.g. southwest, west, etc.), slope angle, ground surface roughness, vegetation.

Step 3. DETERMINE DESIGN SNOW LOADING FOR STRUCTURAL DESIGN

- ✓ Glide factor, N, from [2], Defense structures in avalanche starting zones Technical guideline as an aid to enforcement (in English), Federal Office for the Environment FOENWSL Swiss Federal Institute for Snow and Avalanche Research SLF, Bern, 2007, section 3.10.5 and Table 5.
- ✓ Altitude factor, f_c, [2], section 3.10.6.
- ✓ End-effect factor, f_r, [2], section 5.5.2.4.
- ✓ End-effect region, ΔL, [2], section 5.5.2.4.
- ✓ Strut support influence factor, η, [2], section 4.6.1 (consider $1 \leq \eta \leq 5$).
- ✓ Snow load perpendicular to slope factor, a, [2], section 4.3 (consider $0.2 \leq a \leq 0.5$).

Step 4. SELECT INITIAL STRUCTURAL GEOMETRY

- ✓ Set structural height to accommodate design snow depth.
- ✓ Width of any single structure across slope.
- ✓ Establish distance from tip of girder to pin connection at strut, a $\alpha_1 \approx 0.38$ balances girder moments.
- ✓ Crossbeam overhang length, α_2 based on balancing crossbeam moments.
- ✓ Strut axis to slope angle, α_S, first trial laid back 10 deg. & then iterated to reduce forces and limit total length.

- ✓ Number of crossbeams and spacing, based on [2], section 5.8.1.

Step 5. STRUCTURAL AND FOUNDATION DESIGN DETAILS

- ✓ Assume pin foundation conditions and analyze as a determinate structure.
- ✓ Determine controlling Load Cases I & II, [2], section 5.5.
- ✓ Consider range of values for factors "η" and "a".
- ✓ Apply loads at foundation connections and size foundation for both concrete footers in soil and earth pins in rock, [2], section 5.5.
- ✓ Apply loads along crossbeams to determine internal forces, [2], section 5.5.
- ✓ Consider end-effect loads (e.g. ends of structures not adjacent to other units).
- ✓ Select member sizes (girders, crossbeams, connections, etc.).
- ✓ If advisable and as needed - modify structural geometry and re-calculate foundation reactions and internal force.

Step 6. AVALANCHE STARTING ZONE DEPLOYMENT

- ✓ Establish uphill zone of support and for an individual structure and lateral separation between adjacent structures, if any, [2], section 3.7.2.
- ✓ Configure the full deployment of structures in the avalanche starting zone.
- ✓ Adjust the deployment to meet or reduce environmental impacts, if any.

Step 7. ESTIMATE COSTS

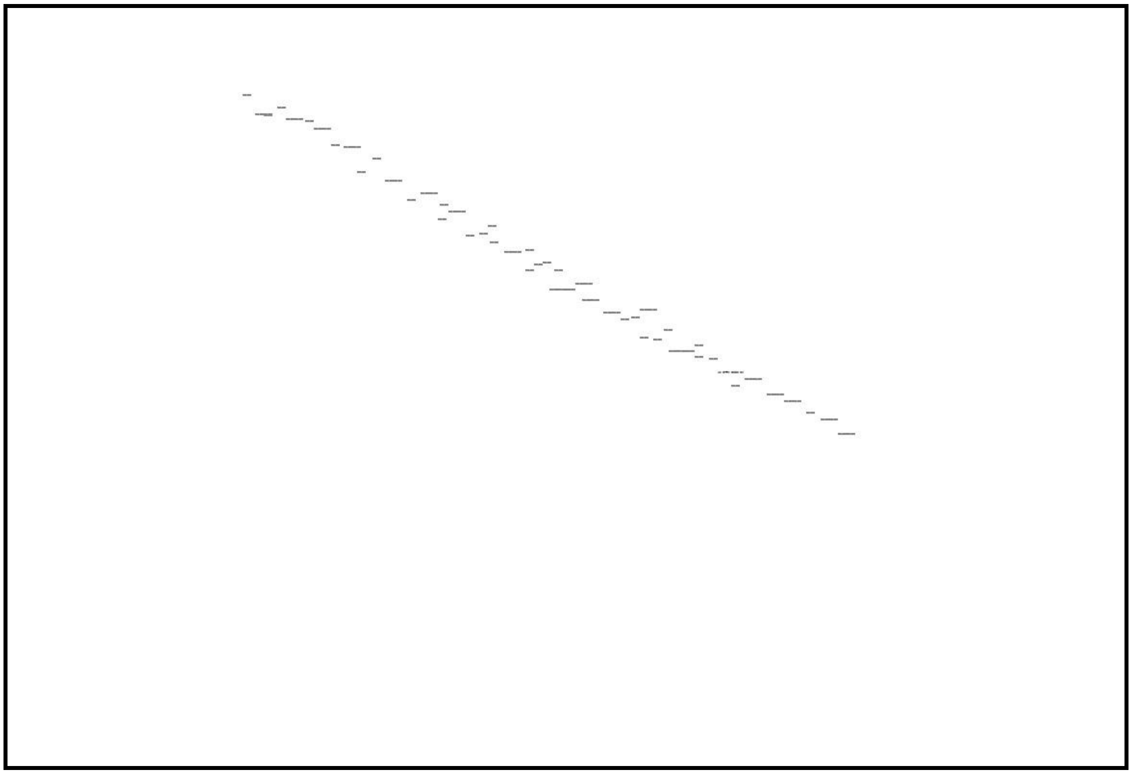
- ✓ Engineering, Design, Construction Oversight, Testing, Inspection and Maintenance.
- ✓ Materials and fabrication.
- ✓ Mobilization and transport.
- ✓ On-site foundation preparation.
- ✓ Installation.

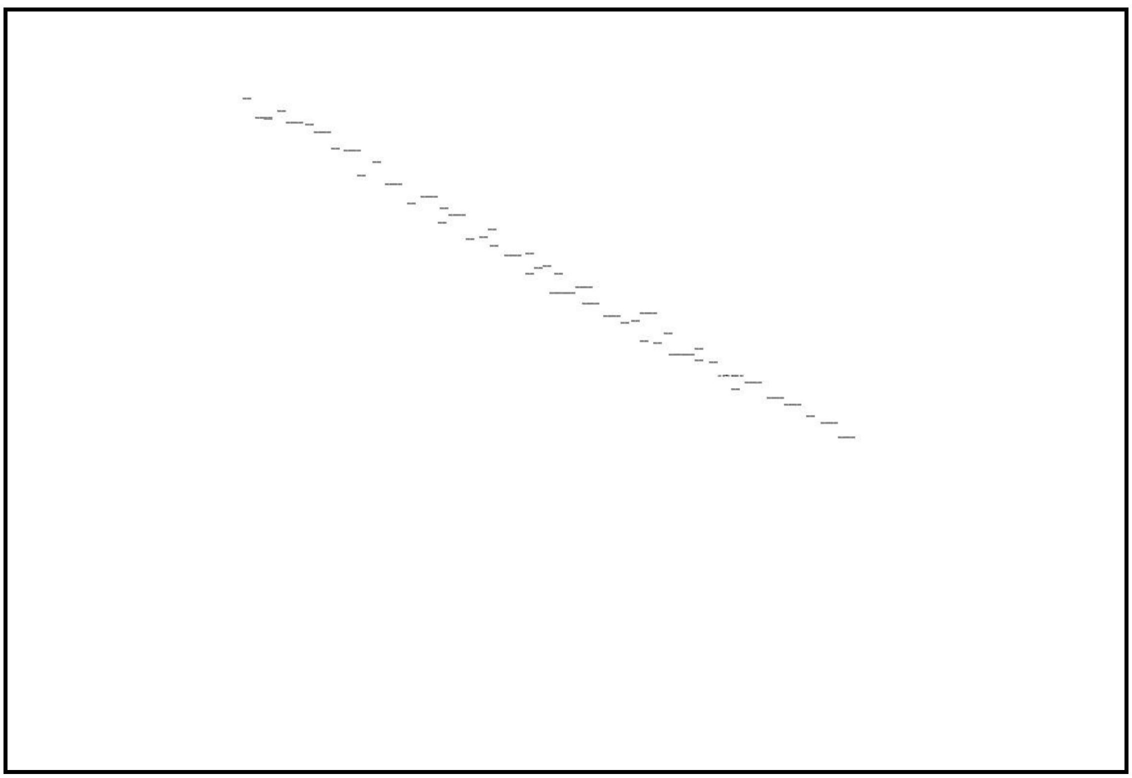
Site remediation and (re)forestation.

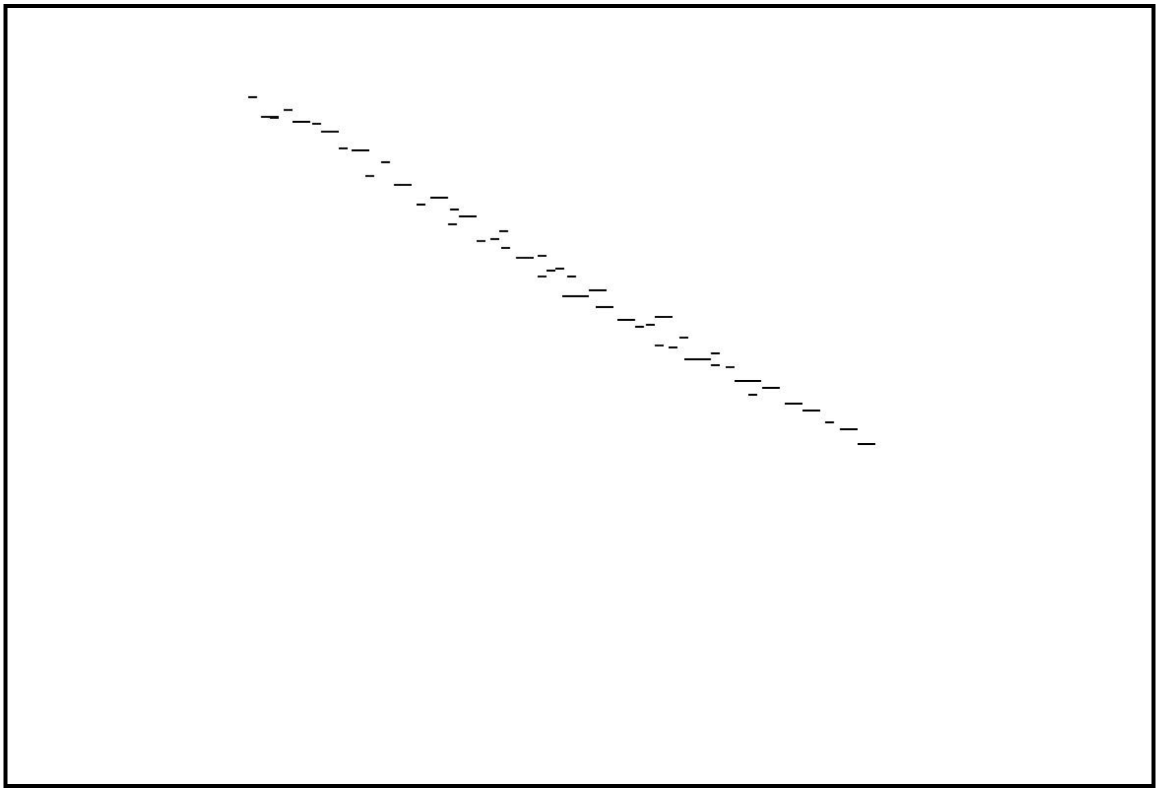
Appendix B

Plan Sheet Details – Unit Structural Design, Connections, and Ground Anchors

Appendix C
Virtual Renderings – Snow Supporting Structure Deployment Configurations







Appendix D

USDA Bridger-Teton National Forest 151 Avalanche Decision Memo and Work Process Meeting Summaries

Snow Supporting Structures for the 151 Avalanche, Jackson, Wyoming

An informational briefing for USDA Forest Service and WYDOT decision makers
WYDOT Jackson Maintenance Facility, Jackson, Wyoming
10:00am – Noon, June 8, 2006

Attending:

WYDOT:
Jim Montouro – District Three Maintenance & Operations Engineer, James.Montuoro@dot.state.wy.us
Ed Smith, WYDOT Jackson Area Maintenance Foreman, edward.smith@dot.state.wy.us
Galen Richards, WYDOT Jackson Facility, Galen.Richards@dot.state.wy.us
Jamie Yount, WYDOT Jackson Facility, Jamie.Yount@dot.state.wy.us

USDA Forest Service:
Kniffy Hamilton, Supervisor, Bridger-Teton National Forest, khamilton@fs.fed.us
Rick Dustin, B-T National Forest, rickdustin@fs.fed.us
Elizabeth Brann, Acting Jackson District Ranger, B-T National Forest, ebrann@fs.fed.us
Dave Cunningham, Jackson District, B-T National Forest, dcunningham01@fs.fed.us
Ray Spence, Jackson District, B-T National Forest, rspencer01@fs.fed.us

Contractor(s):
Rand Decker, InterAlpine, randdecker@aol.com

Meeting Synopsis:

This meeting was the second of two (2) meetings organized for the purpose of sharing information with USDA Forest Service stakeholders regarding WYDOT efforts to design and determine the feasibility of using Snow Supporting Structures for avalanche hazard management on the 151 avalanche, south of the community of Jackson, Wyoming.

The 151 avalanche starting zone is under Forest Service land management. It is managed seasonally as critical big game habitat. The avalanche that comes from the 151 impacts the highway and is a hazard to both motorists and WYDOT highway maintainers.

Using avalanche hazard forecasting, couple with temporary highway closures and explosive release of the 151 avalanche, though technically viable, is not an alternative for the 151 avalanche. The use of explosives is not acceptable with respect to both wintering big game and adjacent residential communities. Moreover – the use of avalanche forecasting and active (explosive) control further impacts WYDOT's winter maintenance personnel resource during storm fighting periods when this resource is at a premium.

There are three forms of constructed, passive (not requiring personnel) avalanche hazard management systems that are technically feasible on the 151; snow sails and snow supporting structures in the avalanche starting zone, and a snow shed (tunnel) at the roadway. These constructed, passive avalanche defense alternatives constitute a hierarchy in terms of both effectiveness and cost. Snow sails have been used, with limited success, for the previously four (4) winter seasons. Their relative effectiveness and continued growth in highway usage has motivated WYDOT to explore the other alternatives. A snow shed at the roadway is both cost prohibitive and is precluded by adjacent (private) land ownership. Snow supporting structures are the alternative under consideration at this juncture.

The use of snow sails as a means of avalanche hazard reduction in the 151 starting zone, to date, was submitted to a National Environmental Policy Act (NEPA) Environmental Assessment (EA). Identified concerns included both potential visual and wildlife impacts. The net result of the EA was a finding of no significant impact (FONSI) for use of snow sails in the 151 avalanche starting zone.

Snow supporting structures have evolved, primarily in the European Alps, over the last fifty (50) years. In Europe, snow supporting structures are often installed along with (re)forestation efforts. Their design follows state-of-practice guidelines. Using these guidelines and a design snowpack (vertical) depth of 6.6 feet – the unit structural design for a snow structure 11.5 wide and 5.5 feet high (~perpendicular to the slope) has been designed for the 151 avalanche starting zone. The 151 avalanche's starting zone will require a patchwork of ~175 structures to cover the starting zone and preclude, except in the most dire of conditions, the onset of avalanching.

There are choices as to whether or not these structures are installed in rows – in this case ten (10) continuous rows of structures, separated by ~ninety (90) feet or distributed in a more random appearing, but nonetheless, effective pattern in the 151 avalanche starting zone.

The ***resulting action items*** from the meeting of June 8, 2006 was that WYDOT contractor – Rand Decker would work collaboratively with USDA Forest Service Landscape Architect – Rick Dustin to identify potential configuration for snow supporting structural deployments in the 151 avalanche starting zone that have the highest probability of retaining ("retention") the visual attributed of the 151 starting zone landscape. This exercise will initially be conducted with virtual renders of the site. It will include considerations for (re)forestation efforts, and the visual appearances prior to tree growth above the height of the structures and subsequent to that. This exercise will be on-going, with an eye towards completion by ~October, 2006.

Once potential configurations are identified that have the highest probability of retaining the visual attributes of the site – a field trial will be conducted, whereby the "first choice" snow supporting structural configuration will be simulated on-site and in full scale for the purpose of verifying its visual impact and for the purpose of both agency and public consideration.

The sum of these follow-on exercises will form the basis for collaborative WYDOT - USDA Forest Service decision makers' determination of the appropriate "next steps" in the environmental review for implementation of snow supporting structures on the 151 avalanche. These steps to include some or some combination of the following: A Categorical Exclusion, based on the FONSI from the snow sail EA; an addendum to the snow sail EA, including additional public consideration and comments; and/or a stand alone snow supporting structure EA; and/or other process mechanisms that USDA Forest Service leadership might identify and suggest.

A concurrent engineering review of the snow support structure's snow load environment and resulting unit design will also be underway with contractor Rand Decker, WYDOT Engineering, and external reviewers, with an end goal of being able to utilizing the 151 snow support structure "65%" design and configuration in the preparation of procurement/bid documents for the same.

Meeting and Working Session Synopsis:
Snow Supporting Structures for the 151 Avalanche, Jackson, Wyoming

WYDOT Jackson WM/Aval. Techs, USDA FS BT Landscape Architect and InterAlpine
WYDOT Jackson Maintenance Facility, Jackson, Wyoming
8:30am ~ 2:00pm, Friday, December 1, 2006

Attending:

WYDOT:
Ed Smith, WYDOT Jackson Area Maintenance Foreman, edward.smith@dot.state.wy.us
Galen Richards, WYDOT Jackson Facility, Galen.Richards@dot.state.wy.us
Jamie Yount, WYDOT Jackson Facility, Jamie.Yount@dot.state.wy.us
USDA Forest Service:
Rick Dustin, Bridger-Teton National Forest Landscape Architect, rickdustin@fs.fed.us
InterAlpine Contractor(s):
Rand Decker, randdecker@aol.com
Perry Wood, perry.wood@nau.edu

Meeting Synopsis:

This meeting was a collaborative working session of WYDOT winter maintenance and avalanche technicians, the USDA Forest Service Landscape Architect from the Bridger-Teton Forest, and WYDOT Contractor personnel from InterAlpine. This meeting satisfied an action item that was identified and resulted from the June 6, 2006 meeting of WYDOT and USDA Forest decision makers on the topic of snow supporting structures for the 151 avalanche starting zone.

This meeting's goal was to develop a virtual rendering of a deployment of snow supporting structures in the 151 avalanche starting zone that, if installed, would reduce the avalanche hazard to the roadway below, while simultaneously preserving ("retaining") the visual attributes of the site.

The 151 avalanche starting zone is under Forest Service land management. It is managed seasonally as critical big game habitat. The avalanche that comes from the 151 impacts the highway and is a hazard to both motorists and WYDOT highway maintainers. There is presently a deployment of WYDOT snow sails along the southern boundary of the 151 avalanche starting zone. It was deployed in the hopes that they would reduce some of the hazard associated with this avalanche. Prior to their deployment, the snow sails were submitted to a requisite NEPA EA. The result of that EA was a finding of no significant impact (FONSI). The primary attribute identified in the EA as potentially impacted by the snow sail deployment was the visual assets of this scenic corridor. The snow sails are now an established visual element of the 151 avalanche starting zone site.

Working collaboratively – WYDOT and InterAlpine avalanche hazard reduction experts virtually positioned snow supporting structures within the 151 avalanche starting zone so that their cumulative "tiled" zones-of-influence would have the potential to hold the 151 avalanche "pillow" in place quasi-statically and preclude the onset of avalanching. This was done using single (11.5' * 5.5') snow supporting structures, "doubles" – side by side (~24' * 5.5') and "triples" (~36' * 5.5').

Simultaneously, the Bridger-Teton Forest landscape architect adjusted the spacing and choice of single, double and triple snow supporting structural elements to minimize any dominance of horizontal lines on this vertically lined landscape and other visual impacts of the virtual deployment of snow supporting structures and, hence "subordinate" the visual appearance of the deployment within that specific landscape as it would appear to a "casual observer."

This work process was managed digitally and in real time using digital photo manipulation under the direction of InterAlpine personnel (Perry Wood).

The net results of this effort was satisfactory, as an initial deployment and rendering, to both the technical avalanche hazard reduction needs of the WYDOT and its contractor, as well as the "visual retention" needs of the 151 avalanche starting zone site in the eyes of the Forest Service's landscape architect.

It was noted that the visual characteristics of the site now includes the snow sails and that from a "visual retention" stand-point the snow sails are not only part of the landscape but that their presence will also assist in visually subordinating the snow supporting structures on this site by defining the southerly boundary of the scene. The snow sail deployment is estimated to have an operational life of 5 to 7 years, depending on maintenance and replacement rates, as determined by WYDOT.

The outcomes of these efforts are attached as two separate JPEG files. One is the virtual deployment of the snow supporting structures against the background of the 151 avalanche starting zone. The background base photo of this rendering is a winter season photo that delineates the 151 avalanche pillow. It pre-dates the full deployment of the snow sails that are presently on this site. The second file is the tiled deployment of snow supporting structures without the photo background.

Subsequent activities and discussions in this vein that were identified include:

- Virtually darken and color (dark green) the snow supporting structural elements of the deployment.
- Transfer the virtual deployment to a rendering that includes the existing deployment of snow sails. The base photo for this is available and was considered during the 1December working session.
- Develop a similar set of renderings using a base photo of the 151 avalanche starting zone for the summer season. The requisite base photo for this has not yet been identified or digitized.
- For all renderings noted above – develop both the "just installed" and a "7 year out" rendering. The latter would include native trees growing in the immediate downhill (and creep protected) region of the snow supporting structures. Once the trees reach a height that exceeds the 5.5' height of the snow supporting structures, they will further subordinating the structures within this landscape.
- In addition, it was discussed and note here that the time needed for native species conifers to exceed the height of the snow structures could be greatly reduce, if native seeds where harvested now and their starts nurtured and maintained in the USDA Forest Service's nursery. The resulting caliber trees (3' to 5') would then be planted at the same time, if and when the snow supporting structures are installed. Planting these prepared trees at the same time as the snow structures are installed is not only possible – it is nearly optimal from a manpower/transport logistics and integration stand-point. The planting of these trees will be a necessary visual mitigation requirement of the Bridger-Teton Forest, if and when snow supporting structures are deployed in the 151 avalanche starting zone.

Those issues that remain outstanding with respect to the visual attributes of the deployment of snow supporting structures on the 151 avalanche's starting zone include the following. It is anticipated that the next go-around in this vein will be conducted in Jackson in February of 2007.

- Do USDA Forest Service decision makers, working with input from their counterparts from WYDOT, continue to see a need for an on-site, full scale simulation of the appearance of the deployment of the snow supporting structures in the configuration being identified by this process?
- Pending the consideration, above, can USDA Forest Service decision makers anticipate issuance of a "categorical exclusion" for an installation of snow supporting structures in the 151 starting zone, based on efforts to date (and planned); in light of the fact that the only site impact identified in the previously conducted snow sail EA, was visual assets?

Prepared on 6 December, 2006 by: Rand Decker, InterAlpine.

Reviewed by Rick Dustin, Bridger-Teton National Forest Landscape Architect on 8 December, 2006.

Meeting Synopsis: Snow Supporting Structures for the 151 Avalanche, Jackson, Wyoming

Informational briefing and NEPA planning session for USDA Forest Service and WYDOT decision makers
USDA Forest Service, Bridger-Teton Forest Office, Jackson, Wyoming
1:00 ~ 2:30pm, Friday, 7Sept, 2007

Attending:

WYDOT:
Jim Montouro – District Three Maintenance, James.Montuoro@dot.state.wy.us
(307)352-3000
Jamie Yount, Avalanche Technician, Jackson Facility, Jamie.Yount@dot.state.wy.us, (307)733-5126

USDA Forest Service:
Mike Balboni, Deputy Supervisor, Bridger-Teton National Forest, mbalboni@fs.fed,us, (307)739-5509
Rick Dustin, Landscape Architect, Bridger-Teton National Forest, rickdustin@fs.fed.us, (307)739-5512
Kristi VonKrosigk, Permitting Specialist, Bridger-Teton National Forest, kvonkrosigk@fs.fed.us
(307)739-5597
Ray Spencer, Acting Jackson District Ranger, Bridger-Teton National Forest, rspencer01@fs.fed.us
(307)739-5414, (307)413-2046

Contractor(s):
Rand Decker, InterAlpine Associates, randdecker@aol.com, (928)202-8156

Synopsis:

This meeting was the third of a suite of on-going meetings, organized for the purpose of developing an action plan for meeting NEPA requirements for a proposed installation of snow supporting structures in the starting zone of the 151 avalanche, south of the town of Jackson, Wyoming.

The 151 avalanche can and has avalanched unto the USR 89/191 highway and is a significant risking to the public, as well as WYDOT winter maintenance personnel. WYDOT has the requirement to manage this risk with respect to the highway. The 151 avalanche starting zone is on USDA Forest Service managed lands and is also US Game and Fish identified critical winter big game habitat. There are seasonal access closures to this area. Enforcement of this seasonal closure is handled by the USDA Forest Service.

In a previous meeting, the scope of potential technology available to manage this hazard was presented to both USDA Forest Service and WYDOT decision makers (8June'06). Using advice and instructions from that meeting, a collaborative technical working session was conducted that included the USDA Forest Service Landscape Architect, WYDOT Avalanche Technicians from the Jackson facility and InterAlpine contractors (1Dec'06). These efforts resulted in the virtual renderings considered at this 7Sept, 2007 meeting. The synopses from both the 8June'06 meeting and 1Dec'07 collaborative working session are transmitted again, here.

At the 7Sept'07 meeting virtual renderings for an installation of snow supporting structures that have the potential to support the snowpack in place and preclude avalanche onset, as well as meet NEPA visual retention requirements on this site were reviewed by WYDOT and USDA Forest Service decision makers and technical personnel. Moreover – the NEPA process for the existing deployment of snow sails on the 151 avalanche starting zone site was recalled. An EA was conducted for the snow sail deployment. The potential impact on visual assets in the 151 avalanche starting zone site was identified during that EA's scoping. The EA resulted in a Finding of No Significant Impact (FONSI). Visual retention was identified then and remains the single most prominent NEPA attribute of concern on the 151 avalanche starting zone site. The existing snow sail deployment is a permitted use on the 151 avalanche starting zone through 2009.

It was also echo'ed at the 7Sept'07 meeting that, though the most cost-effective of the available technologies, the existing deployment of snow sail has not proven to be sufficiently effective from an avalanche hazard reduction stand-point. For this reason, snow supporting structures are now under consideration. Snow supporting structures are an established technology in both Europe and Asia. Moreover, snow support structures are finding more and more favor in domestic application, as winter travel on mountain highways becomes more prevalent, and less amenable to both avalanche risk and attendant delay. The 151 avalanche snow supporting structural design is following the state-of-the-art 2006 Swiss guideline.

Additionally – it was noted that from a risk management stand-point the presence of the snow sails places avalanche hazard management on this site at "reasonable and prudent." The use of snow supporting structures on the 151 avalanche would place risk management at "best practices," a higher order legal test. Failure to continue to address the avalanche risk on the 151 and retreating to a "do nothing" scenario would result in a risk management status on this site that is less than "reasonable and prudent."

Rick Dustin – USDA Forest Service Bridger-Teton Landscape Architect , participated in laying out the proposed installation of snow supporting structures at a previous (1Dec'06) collaborative technical working session. It is his opinion that if the proposed installation of snow structures is deployed as per the renderings considered and availed to the introduction of native confer species, that the visual attributes of the 151 avalanche starting zone site will be retained.

At the request of Mike Balboni – USDA Forest Service Bridger-Teton Deputy Forest Supervisor, Jim Montuoro – WYDOT District Three Maintenance and Operations Engineer, noted that any future installation of snow supporting structures in the 151 avalanche starting zone would need a minimum of two elements in place prior to being advanced in the WYDOT construction priorities; a completed engineering design and deployment plan for the facility, and a completed USDA Forest Service NEPA permitting process. The former is an on-going effort of this project's contractor and is on schedule to be completed by 31 December, 2007. Pending completion of USDA Forest Service NEPA permitting – the 151 snow supporting structures could be in the WYDOT construction queue as early as the summer of 2008.

WYDOT is strongly committed to addressing this hazard to winter motorists in a timely and effective manner. Jamie Yount – WYDOT Avalanche Technician from the Jackson facility noted that the 151 avalanche is "a really dangerous situation," given the kinds of users and volumes of traffic presently utilizing this highway. Traffic volumes are only expected to continue to grow.

The following ***action items*** and ***responsible parties*** were developed at the close of this meeting:

1.) Rand Decker will send a copy of the snow sail EA to the Jackson Ranger District, c/o Ray Spencer.
2.) Kristi VonKrosigk will send Jim Monturo the requisite "proposal form" upon which WYDOT will make formal request of the USDA Forest Service for the installation of the snow supporting structures in the starting zone of the 151 avalanche.
3.) Ray Spencer, in collaboration with the Forest Supervisor's office, would review the prior snow sail EA and other criteria relative to the USDA Forest Service's NEPA process responsibilities for the purpose of subsequently submitting the snow supporting structure deployment in the 151 avalanche starting zone to a Supplemental Information Request (SIR) or another NEPA mechanism as may be indentified. The latter to potentially include a (visual attributes) Categorical Exclusion.
4.) *Post note:* In the interim – Dale Deiter has been posted to the role of Jackson District Ranger. In anticipation of his active participation in these efforts, he is copied this meeting's agenda, Powerpoint presentation and synopsis, along with the synposes from the 8June'06 meeting and 1Dec07 working session.

This meeting synopsis was prepared and submitted for meeting participants' review and edits (if any) by Rand Decker on 12September, 2007.

Meeting Synopsis: *151 Avalanche Snow Supporting Structures – Project De-briefing*
Informational briefing and draft Final Report feed-back:
WYDOT and InterAlpine Associates, 1:00 ~ 3:00pm, Wednesday, 12March, 2008

Attending:

WYDOT: Jim Montuoro, District Three
Michael Patritch, Research Division, Cheyenne
Jackson Facility: Bob Hammond, Ed Smith, Wayne Tompkins, Jamie Yount
InterAlpine: Rand Decker, Josh Hewes

Synopsis:

The *goal of this meeting* was to review the design process and resulting details for both the unit and foundation design, and resulting suggested deployment configuration for snow supporting structures for the 151 Avalanche, south of the town of Jackson, Wyoming. Rand Decker and Josh Hewes of InterAlpine made a Powerpoint presentation on these topics. None of the comments associated with the material presented indicate or would suggest that major sections or sub-sections of either the design process or the result are missing or in need of extensive re-consideration.

InterAlpine collected edits of the draft Final Report that were provided by Jim Montuoro and Michael Patritch. These editorial comments will be implemented in the final draft of the Final Report, along with the following elements already identified by InterAlpine. The goal is to file the final draft of the project Final Report by mid April (2008).

- Complete ground anchor detailing:
  - Double check the 5 ft versus 6 ft of rock embedment for the single ground anchor to upper girder connection, and implement that change in the Final Report.
  - Double check requirements for the double ground anchors to girder (upper) foundation for use where there is an insufficient soil profile for a single ground anchor with a CIP concrete footer.
  - Prepare and implement in the CAD drawings of the Final Report the double ground anchor foundation and connection noted above; as well as the single ground anchor to lower strut micro-pile (compression) foundation and connection; the latter to be used without the CIP concrete footer in the absence of sufficient soil for that application.
- Prepare a "site investigation and design process" flow chart that makes explicit the snow supporting structure design and deployment process steps, including site review, and both site specific and non-site specific design elements.

The following activity is on-going. It is anticipated that this activity will be reported out as an Addendum to the project's Final Report.

- Bridger-Teton National Forest NEPA Rule-making (permitting) for snow supporting structures in the 151 Avalanche starting zone.
  - Visual retention is maintained with the (re)forested, organic deployment configuration.
  - The Supplemental Information Request (SIR) to the prior Snow Sail EA is in progress. The Problem Description, Project Objectives and Task Narrative, Project Background, and Snow Supporting Structure Deployment in the 151 Avalanche Starting Zone sections of the project's draft Final Report have been provided to Ray Spencer, the USDA Bridger-Teton National Forest individual tasked with preparing the SIR. InterAlpine will continue to maintain contact and offer support to Ray.
  - It has been re-iterated to Ray that for WYDOT to move ahead they must have both the technical design and the Forest Service's Rule (Permit) in place. Ray indicated that Rule-making should be completed by June (of 2008).
  - It was noted that the resulting Forest Service Rule may dictate terms, including provisions for (re)forestation.

The following additional activities are also identified for implementation:

- A WYDOT Research Advisory Committee (RAC) Presentation on the project – 9July, 2008.
- Planned and possible disseminations, amongst others – 2008 International Snow Science Workshop (ISSW), 2009 TRB Annual Meeting.
- A possible Workshop on Snow Supporting Structures for Avalanche Defense in Transportation Applications Workshop (see note, below).

At the time of this project presentation, a very valuable question was asked from the floor; "We can see the design, but has anyone ever done the before (domestically)?" This question is particularly germane with respect to practical issues associated with on-site installation practices. In response to this, InterAlpine recognizes that there is abundant European expertise in the area of on-site activities for snow supporting structures, and similar expertise and experience in alpine/mountain construction in specific domestic sectors – particularly ski lift and power line installation. Moreover – it can be anticipated that interest in snow supporting structure technology for avalanche defense of domestic transportation corridors may increase in the future. For these reasons – a Workshop is being explored, outside the mandate or budget of this project, to bring domestic DOT, engineering, and on-site constructors together, along with European counterparts, to explore the technical and practical issues in some depth. A request for modest support for this Workshop has been made of the NCHRP's Snow and Ice Cooperative (SICOP). As an element of that and future overtures in this vein – InterAlpine is prepared to disclose its contract efforts with WYDOT in this technical niche'.

InterAlpine also re-iterated their willingness to support, via additional project development, the following activities associated with any future implementation of the snow supporting structures on the 151 Avalanche:

- Assist in snow supporting structure deployment siting and geometric control.
- Support WYDOT bid document preparation and contracting.
- Provided fabrication and installation oversight, as well as post-installation facility inspection and performance assessment.

This project has enjoyed one no-cost time extension, from 31December, 2007 through 30June, 2008. It is anticipated that this project will be completed on-budget, including USDA Forest Service Rule-making, by that time. In the event that Forest Service Rule-making is still on-going at that time – a project extension for the purpose of maintaining InterAlpine's support and engagement in this specific element of the 151 Avalanche snow supporting structure project will be explored and pursued with WYDOT District Three and Research.

This meeting synopsis was prepared and submitted for meeting participants' review and edits (if any) by Rand Decker on 21March, 2008.

Meeting Synopsis: Snow Supporting Structures for the 151 Avalanche, Jackson, Wyoming

NEPA process progress meeting with USDA Forest Service, and WYDOT and their Contractor
USDA Forest Service, Jackson Ranger District Office, Jackson, Wyoming
9:00 ~ 10:30am, Wednesday, 15October, 2008

Attending:

WYDOT:
Jim Montouro – District Three Maintenance Engineer, James.Montuoro@dot.state.wy.us (307)352-3000
Jamie Yount, Avalanche Technician, Jackson Facility, Jamie.Yount@dot.state.wy.us, (307)733-5126

USDA Forest Service:
Dale Deiter, Jackson District Ranger, Bridger-Teton National Forest
Ray Spencer, Winter Sports Forester, Jackson District, B-T, rspencer01@fs.fed.us (307)739-5414, Cell: (307)413-2046

Contractor(s):
Rand Decker, InterAlpine Associates, randdecker@aol.com, Cell: (928)202-8156

Synopsis:

This meeting was one of a suite of on-going meetings, organized for the purpose of developing, implementing and reviewing progress on an action plan for meeting NEPA requirements for a proposed installation of snow supporting structures in the starting zone of the 151 Avalanche, south of the town of Jackson, Wyoming, by the Wyoming DOT (WYDOT).

The 151 Avalanche can and has avalanched unto the USR 89/191 highway and is a significant risk to the public, as well as WYDOT winter maintenance personnel. WYDOT has the requirement to manage this risk with respect to the highway. The 151 Avalanche starting zone is on USDA Forest Service managed lands and is also US Game and Fish identified critical winter big game habitat. There are seasonal access closures to this area. Enforcement of this seasonal closure is handled by the USDA Forest Service.

In previous meetings, the scope of potential technology available to manage this hazard was presented to both Forest Service and WYDOT decision makers (8June'06). Using advice and instructions from that meeting, a collaborative technical working session was conducted that included the Forest Service Landscape Architect, WYDOT Avalanche Technicians from the Jackson facility and InterAlpine contractors (1Dec'06). These efforts resulted in the virtual renderings considered at a 7Sept, 2007 meeting.

Following the 7Sept, 2007 meeting, on 5October, 2007 WYDOT submitted an Application for Transportation and Utility Systems and Facilities on Federal Land with the Jackson Ranger District of the Bridger-Teton National Forest.

Action items from the 7Sept, 2007 meeting included:

5.) Rand Decker will send a copy of the snow sail EA to the Jackson Ranger District, c/o Ray Spencer. This was accomplished.
6.) Kristi VonKrosigk will send Jim Monturo the requisite "proposal form" upon which WYDOT will make formal request of the USDA Forest Service for the installation of the snow supporting structures in the starting zone of the 151 avalanche. This was accomplished
7.) Ray Spencer, in collaboration with the Forest Supervisor's office, would review the prior snow sail EA and other criteria relative to the Forest Service's NEPA process responsibilities for the purpose of subsequently submitting the snow supporting structure deployment in the 151 avalanche starting zone to a

Supplemental Information Request (SIR) or another NEPA mechanism as may be indentified. The latter to potentially include a (visual attributes) Categorical Exclusion.

8.) *Post note:* In the interim – Dale Deiter has been posted to the role of Jackson District Ranger. In anticipation of his active participation in these efforts, Rand Decker has copied this meeting's agenda, Powerpoint presentation and synopsis, along with the synopses from the 8June'06 meeting and 1Dec'07 working session to him.

An internal meeting of WYDOT District Three Maintenance and InterAlpine personnel was held on 12March, 2008 to review progress on the 151 Avalanche Snow supporting Structure project in general, and progress on the Forest Service's NEPA decision, specifically. The elements of that meeting germane to the NEPA decision process were:

- Bridger-Teton National Forest NEPA Rule-making (permitting) for snow supporting structures in the 151 Avalanche starting zone.
  - Visual retention is maintained with the (re)forested, organic deployment configuration.
  - The Supplemental Information Request (SIR) to the prior Snow Sail EA is in progress. The Problem Description, Project Objectives and Task Narrative, Project Background, and Snow Supporting Structure Deployment in the 151 Avalanche Starting Zone sections of the project's draft Final Report have been provided to Ray Spencer, the USDA Bridger-Teton National Forest individual tasked with preparing the SIR. InterAlpine will continue to maintain contact and offer support to Ray.
  - It has been re-iterated to Ray that for WYDOT to move ahead they must have both the technical design and the Forest Service's Rule (Permit) in place. Ray indicated that Rule-making should be completed by June (of 2008).
  - It was noted that the resulting Forest Service Rule may dictate terms, including provisions for (re)forestation.

At the meeting being reported here (15Oct'08), the following was discussed:

Ray Spencer and Dale Deiter indicated that:

1. .. a "whole new Decision" – in particular a Categorical Exclusion for a site of less than five acres, leading to a Decision (signatory at District or Forest – TBD) was being pursued by the Forest Service for the snow support structures in the 151 Avalanche starting zone. This is a change from the Supplemental Information Request on the Snow Sail EA leading to Forest Decision, as per the 7Sept'07 meeting. The possibility that this could happen was alluded to at the 7Sep'07 meeting.
2. The solicitation for public comments (or scoping) for the Categorical Exclusion for the snow supporting structure project should be "on-the-streets by the end of month" (October, 2008). The Jackson District and the Bridger-Teton Forest maintains a mailing-list that will be the basis for who receives the solicitation. WYDOT (via Jim Montouro) and InterAlpine (via Rand Decker) will also receive the same solicitation. There will be a 30 day period to collect comments (leading to ~end-of-November). In the absence of "big" issues – a Forest Service Decision on the use of snow supporting structures in the 151 Avalanche starting zone should be forth-coming by the end of December, 2008.

Rand Decker to Ray Spencer: A (re)forestation commentary needs to be in the solicitation for public comment explicitly, but it should be noted that even a mature forest density at this site is not sufficient and hence will not replace snow supporting structures for the purpose of avalanche hazard defense. This is not always the case. i.e. in Europe, mature reforestation efforts can have a sufficient density to preclude the onset of avalanches.

Follow-on (~8:30am Thursday, 16Oct): Ray Spencer had the public comment solicitation reviewed by John Kuzloski, NEPA administrator for the Bridger-Teton National Forest and it's O.K. Hence, the solicitation should be finalized and "on-the-streets" for a 30 day comment period "soon" (i.e. about a week.. or ~Thursday or Friday, 23 or 24 October).

Rand Decker, Jim Montuoro and Jamie Yount agreed to coordinate the WYDOT and InterAlpine responses to the Forest Service's solicitation for public comment on the use of snow supporting structures for snow avalanche hazard management on the 151 Avalanche.

TO: Dale Deiter, Jackson District Ranger
Bridger-Teton National Forest
25 Rosencrans Lane, PO Box 1689
Jackson, Wyoming 83001

FROM: Rand Decker, Principle at InterAlpine Associates
83 El Camino Tesoros
Sedona, Arizona 86336
Phone (cell): 928-202-8156, email: randdecker@aol.com

Dated: 8 December, 2008

RE: ***On the use of snow supporting structures in the starting zone of the Milepost 151 Avalanche, Jackson, Wyoming***

Dear Mr. Deiter,

Thank you for the opportunity to respond to your request for public comments for the Wyoming Department of Transportation's (WYDOT) proposed use of snow supporting structures (snow bridges) for avalanche hazard reduction in the starting zone of the Milepost 151 Avalanche in Jackson, Wyoming.

As you are aware, I am WYDOT's contractor for the unit design for the structures; the deployment configuration in the 151 Avalanche starting zone; and assist in the National Environmental Policy Act (NEPA) review and Decision process for their installation, of which this public scoping is an element.

I have reviewed your November 19, 2008 request for public comments. It outlines the principal issues. I am also aware of the content of WYDOT's response to your request for public comment and I'm in full support of those. Please consider my comments on those issues I feel should dominate your consideration and subsequent Decision:

1. The 151 Avalanche is predominantly a safety issue to the Jackson area's surface transportation system. There are users in this corridor that include motorists, WYDOT and other public safety agency and emergency services vehicles, as well as bicyclists and pedestrian on their designated, highway marginal pathway. The 151 Avalanche has caused property damage and ambulatory injuries to motorists in the past. Traffic volumes on US Route 89/191 under the 151 Avalanche have and continue to increase. The number of travel lanes has recently been expanded from 2 to 4. Under these circumstances, the potential for property damage, injury and/or a loss-of-life avalanche remains real and significant.
2. The use of active (forecasting and explosive) control of the 151 Avalanche puts WYDOT maintenance personnel at risk. There are significant risks associated with traveling on foot or

skis to the 151 Avalanche starting zone for the purpose of delivering avalanche control explosive, especially when the avalanche forecast indicates the potential for an avalanche is high.

3. WYDOT's highway maintenance personnel resources during intense winter storms that lead to avalanching are at a premium during those storms. Active avalanche control takes those individuals away from other winter highway maintenance tasks, including snow plowing.
4. Managing the hazard from the 151 Avalanche with forecasting and explosives control is not compatible with the designated critical big game habitat uses of the 151 Avalanche starting zone. Also, the resulting noise pollution affects the residents of the adjacent valley floor area. Active control also requires the closure of the highway; interrupting traffic. This includes both the public, as well as public safety and emergency services vehicles. Moreover, active control may not produce the desired result – an avalanche while the road is closed. What then? Should the highway be re-opened to traffic?
5. Passive (constructed) alternatives for managing the avalanche hazard from the 151 Avalanche include the snow supporting structures being proposed. Passive avalanche defense systems do not require road closures during periods of high avalanche potential, nor do they require human (WYDOT) personnel to do their job during these winter storm periods. The existing snow sails in the avalanche starting zone and a snow shed (artificial tunnel) over the highway are also forms of passive avalanche hazard defense. Snow sails are the least costly, but also the least effective. Despite their installation in the starting zone, the 151 Avalanche continues to avalanche to the highway. They are not effective. At an estimated construction cost of $10 to 14 million, a snow shed to pass the avalanche over the highway is approximately ten times more expensive than snow supporting structures in the 151 Avalanche starting zone. With a shed, the avalanche would not impact the highway, but it would be passed onto the adjacent private lands of the South Park ranch.
6. WYDOT's proposed snow supporting structures have been designed using the internationally accepted Swiss Technical Guideline for these types of facilities, in conjunction with modern domestic structural and geotechnical design practices. The use of snow supporting structures for avalanche defense is found extensively in Euro and Asia, and has been for over 50 years. There use is not novel or untested. Snow supporting structures superseded snow sails (also pioneered in Europe), despite their increase in cost, due to their higher degree of effectiveness. In some instances in Europe (the Tyrolean State of Austria), snow supporting structures constitute the single largest public works expenditures, exceeding others such as water, energy and transportation.
7. For the existing snow sails in the 151 Avalanche starting zone, a NEPA Environmental Assessment (EA) was conducted. It was determined that the visual characteristics of the site were the only environmental asset which could, potentially, be impacted. That EA's overall Finding was one of No Significant Impact (FONSI). WYDOT avalanche technicians from the Jackson Maintenance facility, myself and Bridger-Teton National Forest Landscape Architect – Rick Dustin work collaborative to develop a novel snow supporting structure deployment configuration for the 151 Avalanche starting zone that has the potential to both defend from avalanches and retained the visual characteristics of the site. This non-traditional deployment configuration does not use the orderly rows for structures typically found in European practice, but mimics doublets and triplets of small conifer stands found in the existing

landscape. Coupled with helicopter supported construction practices, low reflectivity coatings, and (re)planting of native conifer in and around the structures, the visual characteristics of the site can be retained. However, it should be noted that even with (re)planting – conifer stands typical of those found in the 151 Avalanche starting zone area will not ever be sufficient to hold the snow in place to prevent avalanches, and hence, replace the snow structures for that purpose.

8. Analysis has borne out that snow supporting structures are the least costly effective avalanche defense system for reducing the 151 Avalanche hazard to highway users, WYDOT maintainers, other public safety and emergency services users of US Route 89/191; even while retaining the visual character of the site. They do not require WYDOT maintenance personnel to accomplish their purpose during periods of high avalanche hazard. There use does not typically require road closures.
9. From a risk management stand point, the use of snow supporting structures for avalanche hazard management at the 151 Avalanche would be at international "best practices."

Almost needless to say, I strongly support the use of snow supporting structures for reducing the risk from the 151 Avalanche to US Route 89/191 in Jackson, Wyoming and encourage you to favorably approve WYDOT's request for their installation and use.

If you have any questions or concerns that I might address or address further for the purposes of your consideration, please don't hesitate to contact me at your earliest convenience.

Yours, Rand Decker, Ph.D. and Principle at InterAlpine Associates, ________________________