Formation zone avalanche control scheme at D-10 avalanche site on National Highway, Jammu-Srinagar (India): A case study

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Abstract: The Pir Panjal range in the Indian Himalaya in Jammu and Kashmir state lies in the lower Himalayan region between latitude 33°10' and 34°40'N. This region experiences short winters (2-3 months) and moderately high snow precipitation having high moisture content, high temperatures and direct action avalanche activity. The area also experiences very high drift activity.

Due to the above conditions which are typical to the lower Himalaya region, the conventional structures for control of avalanches in formation zone are relatively very expensive. Keeping this in view it is desirable to follow a composite scheme having combination of wind control structures, supporting structures, terrain modification and controlled release of avalanches using explosives. The above has been done at an experimental site located on a mountain ridge in Pir Panjal range of Himalayas under which 2.6 km long tunnel joins the National Highway from south to north. Among 15 avalanche sites on this highway, D-10 is one of the most important sites with very high frequency of avalanche triggering. The mouth of the tunnel gets blocked frequently due to D-10 avalanche.

Since the catchment is very large and the snow accumulation pattern is quite different in various gullies, a composite scheme to use various types of formation zone control measures was worked out, both from the point of controlling the avalanches as well as understanding the efficacy of this scheme evolved for D-10 experimental site. This paper describes the composite avalanche control scheme, modification made in the design of Snow nets and the effectiveness of structures observed during last four winters from 1998-2002.

Keywords: Avalanche defence, snow drifting, snow fence, snow load on structures, controlled release of avalanches

1. Introduction

Indian Himalayan ranges, experience a wide diversity in climatic and precipitation patterns so that the snow properties and related avalanche activity assume a wide variation. The avalanche affected area in Indian Himalaya lies in Western Himalaya, Central Himalaya and North Eastern Himalaya. From climate and avalanche activity point of view, Sharma and Ganju (1999) have classified the Western Himalaya in three zones as, Lower Himalayan zone (LHZ) or subtropical zone, Middle Himalayan zone (MHZ) or Mid Latitudinal zone and Upper Himalayan zone (UHZ) or High latitudinal zone.

D-10 experimental site situated in Pir Panjal range in Jammu & Kashmir falls in the Lower Himalayan zone. Geological and climatic conditions of Pir Panjal range are entirely different from Alpine ranges.

The LHZ could be classified as the zone of warm temperature, high precipitation and short winter period. The precipitation is generally concentrated between December and March with the periods before and after experiencing wet snow precipitation or rains. Due to prevalence of warmer temperatures, the snow cover very soon changes into isothermal snow pack at 0°C.

The avalanche activity is quite high, with most of the avalanches triggering during snowfall as direct action avalanches due to excessive overburden or within 24 hours after a major snowfall on a clear sunny day. The peak winter avalanches are generally moist slab avalanches and late winter avalanches are melt avalanches (thaw avalanches) containing snow, mud and stones.

The terrain and meteorological factors characterizing LHZ are shown in Table 1.

The salient deductions regarding the avalanche occurrence in LHZ are as follows: (Sharma and Ganju : 1999).

Major avalanches occur :

- During snowstorms when overburden exceeds 200 Kg/m^2 after terrain irregularities get filled up with 150 cm of standing snow;
- within 24 h of storm on a clear sunny/windy day;
- radiation may cause loose snow surface avalanches;
- in spring, after snow-pack becomes isothermal, full-depth or even surface avalanches trigger;
- few delayed action avalanches on northern slopes trigger.

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Table 1: showing the terrain and meteorological factors characterizing Lower Himalayan zone

Factors : Terrain	
Altitude	3200-4100 m (76 %)
Slope	30-38° (64%) , 38-42° (13%)
Aspect	South East-South West (63%),North East-South East (28%), North (9%)
Ground	Tall grassy cover up to 3000 m, forested, bushes, boulders
Meteorology (9 years average)	
Snow fall in major storms	20-80 cm (56%), 80-200 cm (30%)
Average P.I (mm/h)	0.5-3.5 (90%) , 3.5-5.5 (10%)
Temperature in winter (°C)	
Highest max. 20.2	Mean max. 6.8
Mean min. -1.6	Lowest min. –12.0

This paper describes about the composite avalanche control scheme planned, designed and implemented for the above conditions as per the snow accumulation pattern and unique characteristics of each gulley and also the effectiveness of each structures observed during last four winters.

2. Aim and area description

National Highway 1A is one of the important roads linking between Kashmir valley with the rest of India. It is affected by fifteen avalanche sites named as D-1 to D-15. It crosses the mighty Pir Panjal range through Jawahar tunnel at Banihal. Among these, D-10 is the most frequently/occurring avalanche site (about 3 to 4 times in a winter) which directly affects the highway and the mouth of Jawahar tunnel and extracts heavy toll of lives, properties and agricultural land. Closure of this highway disrupts the communication and is a major inconvenience to the civil as well as Army traffic on the road. In order to reduce the closure period of the highway and casualties, composite avalanche scheme has been prepared.

D-10 avalanche is located 207.2 Km away from Jammu on Jammu-Srinagar National highway (NH-1A). The formation zone of this site is at an altitude of 3250 m and covers an area of 22 hectare. It has large bowl shaped, rugged catchment area comprising of twelve gullies having predominantly North and North-East aspect. The average deposition of snow on the slopes of the formation zone is 3 m. During storm wind blows from South-West and North-East in normal condition. Due to high wind speed of upto 100 km/h, considerable snowdrift activity takes place, culminating into formation of cornice as well as further loading of the formation zone. Cornices upto the height 3-4 meter with overhang of 2-3 m are formed on the most of the ridge. Snowdrift also causes uneven accumulation pattern in different gullies. The track of this avalanche, confined near the highway, is full of scree material in upper reaches and tall bushes and small trees along the track in the lower part. First four gullies have a straight run upto the highway. Gulley Nos 5 to 10 and Gulley Nos 11 to 12 take curvilinear path in the track. The run-out zone, lies between 2180-2060 m, extends beyond the highway in the valley. Table 2 shows the characteristics and snow accumulation pattern of each gulley.

3. Avalanche control scheme for D-10 avalanche site on National Highway-1A

Ten of the twelve gullies of D-10 avalanche site were taken up for execution of the composite scheme. These gullies have got the following unique features:

- Part of the formation zone lies below & part above the tree-line,
- variation in aspect, snow accumulation pattern, cornice formation , snow pack conditions, prevailing wind direction , frequency of avalanche, ridgeline and slope angle of formation zone.

Considering the snow drift factors and unique characteristics of each gulley, a control scheme comprising combination of supporting structures in conjunction with wind control structures, terrain modification and controlled release of avalanches was worked out, both from the point of view of controlling the avalanches as well as for experimental purposes. The detailed description of the avalanche control scheme for various gullies and its effectiveness for mitigating the avalanche hazard are discussed in the succeeding paragraphs.

4. Results and discussion

4.1 Composite avalanche control scheme

The composite scheme comprises of supporting structures, wind control structures, terrain modification and controlled release of avalanches using explosives as adopted in various gullies of same avalanche site for making techno-economical solution. Table 3 shows the avalanche control scheme

Table 2 : representing the characteristics and snow accumulation pattern of each gulley

Gulley No	Catchment area (ha)	Characteristics of Formation zone	Snow accumulation pattern	Control measure prior to 1998	Remarks
1 to 3	Gulley No1 : 1.2 Gulley No2 : 2.1 Gulley No3 : 2.6	Gulley 1 : *Av. Slope : 33^0 Gulley 2 : Av. Slope : 34^0 Gulley 3 : Av. Slope : 34^0 Aspect : North Gulley : Confined Ridge line : knife edge Frequency : high	Snow conditions: Dec : semi wet , Jan : dry , Feb : semi wet , Mar : wet Snow accumulation 3 m Cornice height 3 m	Snow nets in Gulley No 1 17 Nos. (60 running m) erected in isolated arrangement	* Av.: average Erected in1988-89 & damaged 40 % Snow nets
4	Gulley No 4 : 3.1	Av. Slope : 34^0 Aspect : North-East Gulley : Confined Ridge line : wide flat of 40m Frequency : high	Snow conditions: Same as in Gulley No 1 Snow accumulation 3 m Cornice height 3.5 m	Snow Rakes 157 Nos. (630 running m) erected in isolated arrangement	Erected in 1988-89; Prevents the fracture initiation on 31000 m^2 area but small slides released between structures
5 to 6	Gulley No 5 : 3.2 Gulley No 6 : 2.6	Av. Slope : 37^0 Aspect : North-East Gulley : Open Ridge line : Sloping ridge Frequency : Very high	Snow conditions: Same as in Gulley No 1 Snow accumulation upto 2.5 m	-	
7 to 8	Gulley No 7 : 1.3 Gulley No 8 : 0.7	Gulley 7 : Av. Slope : 30^0 Gulley 8 : Av. Slope : 32^0 Aspect : North-East Gulley : Open Ridge line : wide flat of 30m Frequency : high	Snow conditions: Same as in Gulley No 1 Snow accumulation 2.0 Cornice height 3.0 m	-	
9 to 10	Gulley No9 : 1.8 Gulley No10 : 1.5	Av. Slope : 36^0 Aspect : North-East Gulley 9 : open Gulley 10 : Confined Ridge line : Sloping ridge Frequency : Very high	Snow conditions: Same as in Gulley No 1 Snow accumulation 2.5 m	-	
11 to 12	Gulley No11 : 0.8 Gulley No12 : 1.1	Gulley 11 : Av. Slope : 33^0 Gulley 12 : Av. Slope : 35^0 Aspect : North-East Gulley : Open Ridge line : Sloping ridge Frequency : Rare	Snow conditions: Same as in Gulley No 1 Snow accumulation 1.5 m	-	

adopted for different gullies.

4.1.1 Supporting structures

Supporting structures in the form of Snow nets (17 Nos.) and Snow rakes (157 Nos.) were first installed in the year 1988-1989 in Gulley No 1 and 4 respectively. The effectiveness of the structures was studied for last 10 years. Some observations made are discussed below.

Snow nets

Snow nets were first installed in gulley No 1 during 1988-1989. These structures had been designed based on the Swiss guidelines (1962), revised subsequently in 1990. Snow conditions prevailing in India like semi wet & wet snow, higher density and drifting snow increase the design forces. The design force for snow pack of depth 3.0 to 4.0 m varies between 60 KN/m to 100 KN/m as per the measurement of snow pressure on supporting structures which is comparatively higher than the values obtained from the Swiss guidelines. The structures served their purpose well. However, the following shortcomings were observed.

(a) Failure of hinged support of Swivel

(i) Damage in the hinge section of the support (ref. Photo 1) has been to the extent of 40 per cent which is mainly due to limited manoeuvrability being in one direction only.

(ii) Snow nets were erected as isolated structures, leaving no scope for the prevention of the end effect forces and transfer of uneven loading onto the adjoining net/support.

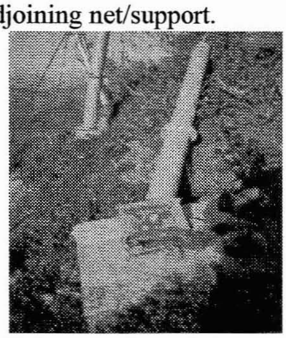

Photo 1: Damaged hinge section of Snow nets

Table 3: showing the avalanche control scheme adopted for different gullies after 1998

Gulley No	Control measure in 1998-2002	Total structures	Cost of structures	Effectiveness	Cost of scheme	Remarks
1	a. Jet roof b. Modified Snow nets	a. 02 sets; 30 m length b. 264 running m	a. *$ 2551 per set for 15 running m	a. Prevents cornice formation for 63 m of ridge length		*1 $ = Rs. 49.0
2	a. Modified Snow nets b. Snow bridges c. Jet roof	a. 150 running m b. 100 running m c. 03 sets ; 45 m length	a. $ 38775 per 100 running m b. $ 32653 per 100 running m	a./b. Prevents avalanche initiation on 21000 m^2 area c. Prevents cornice formation for 96 m of ridge length	Supporting structures, wind control structures, terrain modification $ 734210	a. Erected in 1999-2000 c. Erected in 1999
3	a. Modified Snow nets b. Snow bridges c. Jet roof d. Terrain modification	a. 376 running m b. 170 running m c. 03 sets ; 45 m length d. 1500 m^2 area	d. $ 11602 per 1000 m^2 area	a./b. Prevents avalanche initiation on 26000 m^2 area c. Prevents cornice formation for 90 m of ridge length d. Area free from snow by creating fracture in early stage of the slab formation		Erected in 1999-2000
4	a. Snow fence b. Jet roof	a. 80 running m b. 04 sets; 60 m length	a. $ 1921 per 100 m	a. Prevents drifting snow & cornice formation for 80 m of ridge length b. Prevents cornice formation for 167 m of ridge length		a. Erected in 1998
5	a. Avdhav Visphotak Vahan (Bomb Tram) b. Improvised method using explosives	01 set ; span 150 m	a. $ 4082 per one set	a./b. Prevents catastrophic avalanche by releasing premature snow mass in the form of small sluffs	Controlled release of avalanche $ 12245	a. Erected in 1999
6	a. Avdhav Visphotak Vahan (Bomb Tram) b. Improvised method using explosives	a. 01 set ; span 100 m	b. Nil	a./b. Prevents catastrophic avalanche by releasing premature snow mass in the form of small sluffs		a. Erected in 1999
7	a. Snow fence	a. 55 running m		a. Prevents drifting snow & cornice formation for 55 m of ridge length		
8	a. Baffle wall	a. 05 sets ; 20 m length	a. $ 2449 per set for 4 width	a. Prevents cornice formation for 46 m of ridge length		a. Erected in 2000
9	a. Improvised method using explosives			a. Prevents catastrophic avalanche by releasing premature snow mass in the form of small sluffs		
10	a. Avdhav Visphotak Vahan (Bomb Tram) b. Improvised method using explosives	a. 01 set ; span 75 m		a./b. Prevents catastrophic avalanche by releasing premature snow mass in the form of small sluffs		Erected in 1999
11	-					No structures erected
12	-					No structures

(b) *Failure in uphill anchor foundation*

Open-cast foundation of uphill anchor failed due to typical ground conditions. The foundation could not counter balance the tensile forces acting on it. Cracks developed through the top surface of the foundation which led to stress concentration and finally resulted in foundation failure.

In order to overcome the above said shortcomings, the following modifications were made in the recent work :-

(i) Continuous arrangement

Modified Snow nets were erected in continuous arrangement as shown in Photo 2. This has helped in proper and uniform distribution of snow loads on adjoining nets as well as prevents the damages to the structures due to the end effect forces.

(ii) Modified Snow nets with multidirectional articulated Swivel post

The new design of Swivel post takes care of the failures observed in the previously designed Snow Net. Being most important component of the structure due to its function as all forces get transferred through it, Swivel post has been designed afresh with *Ball & Socket joint* arrangement (ref. Figure 1), which gives free movement to Swivel post in all directions resulting in better functioning. Swivel post is designed for axial force in compression as well as lateral forces (Chaudhary, Vinay, et. al.: 2002). Various sections have been tried and circular hollow section 175 mm nominal bore of 4.85 mm thick @ 22.6 Kg/m, St 40 grade steel is selected (IS: 1161-1979).

The Swivel post supported on a pivot has omni-directional movement at the upper end, i.e., about 20° with respect to vertical (z) axis in the X-Y plane. This is a versatile arrangement having ability to react in the direction of uneven forces and in preventing the bending moment. Design of the pivot neck has been checked for axial force in compression.

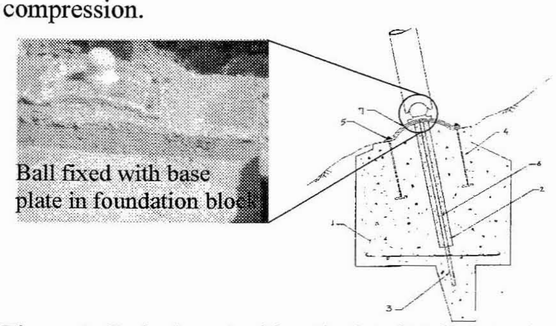

Figure 1: Swivel post with articulated Ball & Socket joint arrangement showing (1) concrete M-20, (2) sleeve MS, (3) anchor bolt, (4) foundation - bolt, (5) nut & washer (6) resin, and (7) base plate.

(iii) Design of uphill anchor and foundation

The uphill anchor is designed to withstand the tension while the foundation counter balances the tensile force exerted by the structure. Uphill foundation block has been designed and checked against pull. Following additions have been made: -

- A steel sleeve has been provided over the exposed SWR loop and filled with molten lead for better distribution of forces.
- Two Nos. cross bars of 800 mm length have been tied at the lower end of the uphill anchor embedded in the open cast foundation block to increase the resistance against pull.
- Steel chicken wire mesh of size 25mmx25mmx14G has been provided as reinforcement in the uphill open cast foundation for distribution of tensile forces and to prevent cracks observed in the previous foundation.
- Eight Nos. of Tor steel dowels of ϕ20 x 500 mm long have been provided in the open cast foundation base, driven half of the length into the ground, for better anchorage against sliding pressure acting parallel to the slope.

Snow nets with modified design having continuous arrangement were placed at the top of formation zone in Gulley No 1,2 & 3. Layout and arrangement of these Snow nets and Snow bridges have been done as per Swiss guidelines (1990).

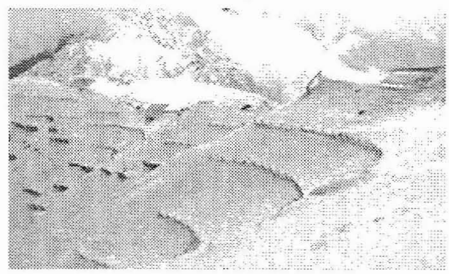

Photo 2 : Continuous arrangement of Supporting structures

4.1.3 Wind control structure

(i) Jet roof

Jet roofs are used to accelerate and deflect the strong wind underneath, thereby, deposition takes place away from the ridgeline. It has been placed on two types of terrain conditions for preventing the cornice formation. Six sets have been erected in Gulley No 2 and Gulley No 3 on the ridge crest of the mountain (ref. Figure 3) and another six sets, erected little bit towards the leeward slope in Gulley No 1 and Gulley No 4.

It has been observed (ref. Photo 3 and Figure 2) that drifting snow particles suspended in the air stream hit the roof and get deposited below the inlet point of the Jet roof. This reduces the effective flow cross-sectional area and snow transportation capacity of the wind. Because of this, deposition starts 14 m onwards from the ridgeline towards the leeward slope. Snow profile of varying height from 1.8 to 0.4 m is also observed on windward slope due to rotation of wind from leeward side.

From two types of trial, it was concluded that position of the Jet roof must be at the top of the ridge crest as well as the roof should preferably be parallel to the terrain towards the leeward side.

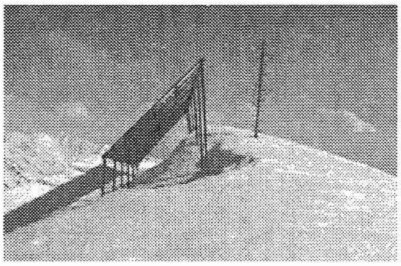

Photo 3 : Jet roof placed towards leeward side

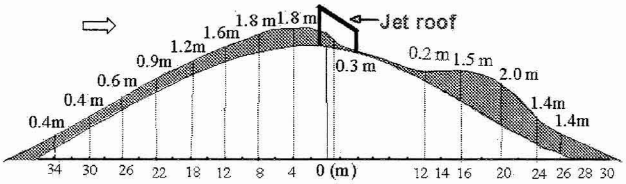

Figure2 : Placing of Jet roof at the top of knife edge : snow deposition starts 14 m onwards from ridge

Four meter length on both side of the Jet roof along ridgeline is free from cornice. To economise the cost, it is advisable to place the Jet roof with a gap of 20 to 30 m along the ridgeline. Small size conical shape cornice is formed between two Jet roofs which may not contribute to any avalanche formation.

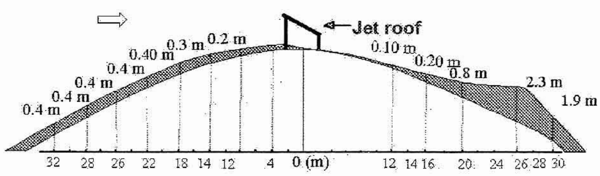

Figure 3 : Placing of Jet roof at the top of knife edge : snow deposition starts 20 m onwards from ridge

Total 12 numbers of Jet roofs were placed from Gulley Nos 1 to 4. Jet roofs, covering 416 m effective span along the ridgeline, have prevented the avalanches. It stabilised the slope through the jet effect as well as densified the snow cover below the structure. Hence, placement of first row of the modified Snow nets from the ridgeline was increased to the extent of 25 m in place of 2-3x H_K (H_K: vertical height of the structure) ,i.e., 10 m from guidelines.

(ii) Snow fence

Snow fences are used to trap the drifting snow on flatter ridge, thereby, reducing the quantity of snow in the formation zone and onto the top rows of the supporting structures. It is erected on windward side down the ridgeline, at the distance of 15 times the height of the Snow fence.

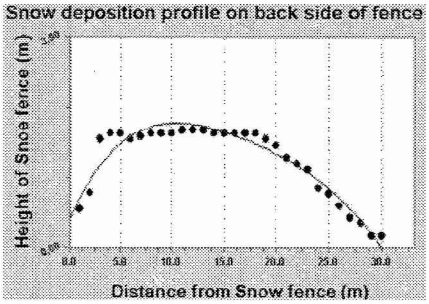

Figure 4 : Snow deposition profile on back side of fence on dated 17/02/2000 ; area under curve 42 m^2

The quantity of drifting snow that blows in the formation zone can be hundred times greater than the precipitation that falls directly on the road (Tabler,R.D. :1994). Snow fence acts as a snow collector. The additional quantity of snow collected (ref. Figure 4) towards leeward side after placing the fence was 30 m^3 per m length of the fence (excluding quantity of snow cover of 12m^3 per m length made adjacent to fence in undisturbed conditions). It means that drifting snow of snow quantity 30 m^3 per m length in formation zone got deposited on the ridge top which otherwise would have got accumulated in the formation zone slope or on the ridge top as cornice. This has also saved the first rows of the structures from excessive accumulation which earlier used to get overloaded with snow and, in some cases, resulted in damage to the structures. Snow fence also provides huge snow storage capacity which partially fulfils water requirement of D-10 observatory from March till mid May.

(iii) Baffle wall

Baffle walls are placed directly on the edge of the ridgeline to prevent the cornice formation. It creates obstruction in the wind flow pattern and causes the formation of snow scoop around the structure as well as strengthening of snow cover leeward side.

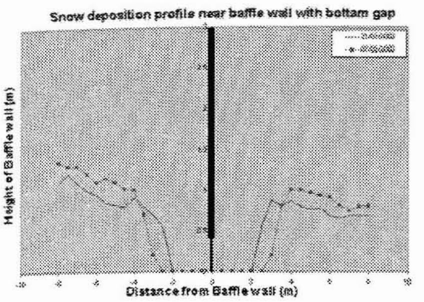

Figure 5: Side view of baffle wall- line represents snow deposition pattern

Baffle wall perpendicular to the prevailing wind direction resulted into formation of snow scoop of 6 m diameter (ref. Figure 5) for 3 m height of structure and 0.4 m ground clearance. This scoop produces discontinuity in the snow cover and break-up of the stress field. Tensile stresses developed in the snow cover towards leeward side are reduced by consolidation, thus, probability for occurrence of a slab snow avalanche is reduced. Leeward side of the structure is free from cornice.

4.1.3 Terrain Modification

The purpose of the terrain modification is to release small sluffs under its own weight with harmless magnitude. This is done by covering the avalanche prone slope with PGI (plain galvanise iron) sheets in the upper region, possibly in the vicinity of the expected fracture line. The PGI sheets, due to low friction and absorption of solar and geothermal energy, initiate micro level movements in the snow, thereby, causing fracture in the early stage of the slab formation. The snow accumulated remains in motion at gliding velocity, thereby, preventing a catastrophic failure which triggers massive avalanches. Under this method a platform covering 1500 m^2 area in Gulley No 3 to protect the forested area in middle zone was erected in the formation zone where area is devoid of vegetation. The upper edge of the platform starts from the ridgeline and extends along the gulley upto the place of the sudden terrain break or slope upto 30°. This platform keeps on breaking the overhang cornice and prevents the large avalanches in the general area of the slope. It is very economical in comparison to supporting structures. Only disadvantage is that metallic sheets cover the natural terrain and do not look aesthetic.

If overburden pressure exceeds 120 Kg/m^2, deposited snow mass over the platform starts gliding down. In normal cases like LHZ, avalanche triggers when load increases 200 Kg/m^2 after filling all irregularities with 150 cm of standing snow (Sharma and Ganju: 1999). Once sufficient snow of the order 0.4 to 0.6 m is deposited on the platform, a fracture develops at the starting edge of the metallic platform. The fractured snow-mass broken into small pieces (ref. Photo 4) while moving at particular velocity on smooth platform and got deposited below the platform. When standing snow increases beyond 0.6 m in a single spell, fracture formation was observed which propagated very slowly. At the same time snow mass in motion at gliding velocity takes the shape of folds due to large compressive forces and gets densified. This densified snow mass glides very slowly.

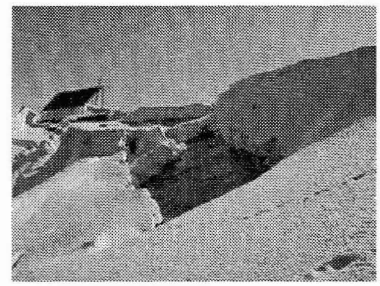

Photo 4: Gliding of snow mass on modified area having 35° slope

4.1.4 Controlled release of avalanches

This scheme is adopted in the gullies which have very high frequency of avalanches. For controlled release of avalanches, methods like Avdhav Visphotak Vahan and improvised method using explosive were used in gulley Nos 5-6 & 9-10. Avdhav Visphotak Vahan is developed on the pattern of Sprengbahn (Germany and Switzerland) or Bomb Tram (US and Canada). These methods are less expensive in comparison to avalanche control structures.

Avdhav Visphotak Vahan (AVV) : AVV is a system which transports explosive to the desired location in the formation zone. It consists of a cable and pulley supported on two towers/columns. This cable rope is meant for carrying explosive to the area of interest for maximising the effects.

Improvised method using explosive : This method is commonly used to release the cornice and snow deposition. This technique was commonly adopted where AVV could not be established. Improvised technique is user friendly, very easy to operate, economical and can be used after little training. In this method, explosive is tied to a bomboo stick or nylon rope and placed at a desired place. Following are the details of trials (ref. Table 4) conducted during last three winters.

Table 4 : details of trials conducted during last three winters

Year	Numbers of trials	Explosive used (Kg)	Success (%)	Failure (%)
1999-00	29	76	90	10
2000-01	15	25	92	8
2001-02	22	32	95	5

The released avalanches moved to distances of approximately 700-800 m and stopped well before reaching the mouth of the tunnel. The snow mass, by controlled release, accumulated in the middle zone of the avalanche path, which retarded the flow of the subsequent avalanches. No damage to the terrain, life and properties was caused due to the above-mentioned methods. Controlled release of avalanches not only ensured the safety of the traffic on the highway but also avoided the chances of any casualties as well as long closure periods.

5. Conclusions

Formation zone avalanche control structures have been developed in Switzerland and some European countries but they generally cater for dry snow having lesser density, thus exerting lesser pressure on the control structures. This paper discusses a composite avalanche control scheme designed and developed for typical lower Himalayan conditions having loose soil, higher snow density, semi wet and wet snow, heavy additional loads due to drifting snow and occasional alterations of the prevailing wind direction. The scheme was designed to understand the efficacy of composite scheme. For that, various factors like cornice formation, terrain conditions, avalanche frequency and catchment area are taken into account. This paper also summarises the modification made in the design of Snow nets and the effectiveness of structures observed during last four winters.

Supporting structures provide high degree of protection to the traffic and important installations. The Snow nets and Snow bridges when used in conjunction with each other judiciously reduce the overall cost of the control scheme. The placing of first row of the supporting structures from ridgeline is increased by using wind control structures at appropriate place which also reduces the size and number of structures required for a given slope.

Performance of modified Snow nets has been improved by introducing an articulated Ball & Socket joint arrangement at the base of the Swivel post and strengthening of the uphill foundation. This arrangement works satisfactorily, as no damage has been noticed.

Entire ridgeline of the D-10 experimental site is covered by wind control structures. This has considerably reduced the load on the formation zone control structures which enhances the life of the structures and reduce the cost of the supporting structures.

Terrain modification, a new technique, is developed to protect the forested area in the middle zone/run-out zone. It is likely to give handsome dividends once proper methodology is developed. This technique is found to be very effective for creating the fracture in early stage of the slab formation, thus, reducing chances of avalanches of catastrophic dimensions.

The controlled release of avalanches using explosives has been done in four gullies to reduce the overall cost. This scheme is very effective and does not require long-term planning/ construction. The AVV (Bomb Tram) covers only small area through cableway and is fixed over a particular area generally having high frequency of avalanches. Improvise methods using explosives being mobile, portable and flexible can be used at any location. This method does not require any elaborate arrangements and provides very good dividends.

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