FORMATION ZONE CONTROL STRUCTURES USED IN LOWER HIMALAYA ZONE - AN OVERVIEW

Vinay Chaudhary[1], Praveen Mathur[1] and Gursharan Singh[1]

ABSTRACT

D-10 avalanche site on NH-IA in Indian Himalayas takes a heavy toll of life and property, besides bringing the busiest highway to stand still for days together, year after year. The avalanche snow released by this site blocks the mouth of Jawahar tunnel, which needs massive effort in terms of manpower, machinery and time. The general area lies in the lower Himalayan region which experiences high temperatures, wet snow precipitation and high wind activity. Formation zone control structures based on conventional guidelines were first erected during 1987-88 at this site for studying their efficacy and evaluating their performance. These structures, though served their purpose of controlling the avalanche gullies where they were erected, they suffered heavy recurring damages due to additional load by accumulation of drifting snow, semi wet & wet snow and higher moisture content of the snow. This necessitated a systematic study for their future use on large scale in the warm climatic zone. The paper discusses the observations and modifications carried out over the years to minimize damages in the members and foundations of Snow nets and Snow rakes.

Key words : Lower Himalayan zone, Snow rakes, Snow nets

INTRODUCTION

Measures to prevent avalanches from starting are generally a more effective solution than to stop, retard or divert them (Bruno Haller 1995). Supporting structures, like Snow nets, Snow bridges, Snow rakes, etc are same measures to control a avalanche in its formation zone. Effectiveness of these structures is well proven and widely accepted.

In first attempt, supporting structures were made of wooden, prestressed concrete, aluminium and steel. European countries had tested supporting structures of the said material during 1951-1957 (Frutiger 1966 and Bruno Haller 1995). Failures in trial stage and observations made by skiers proved fruitful for establishing the guidelines for Alpine snow conditions and helped to standardize their designs. In 1961, a set of guide lines (A manual for planning structural control of avalanches) were published to cope complexities of design, layout and arrangement of the new structures.

In India, the formation zone control structures were erected at D-10 experimental site in Jammu & Kashmir state during 1987-88, using a limited numbers of Snow nets and Snow

1 SASE-RDC, Hirnparisar, Sector 37 A, Chandigarh 160036, India;
Tel: +91-172-699804-06; Fax: +91-172- 699802; E-mail: vinay_sase@rediffmail.com

rakes for their efficacy and performance evaluation. These structures, though served their purpose well, they suffered recurring damages. The observation and scientific studies carried out on failures of structures have helped in successfully improving/ modifying the design.

This paper discusses the failures of the members and foundations of previously designed rigid/flexible retaining barriers and remedial measures there of in subsequent designs.

SITE CONDITIONS

Jammu-Srinagar highway, a lifeline for Kashmir valley, runs through two major mountain ranges, namely Shivalik, 2000-3000 m and Pir Panjal ranges, 3200-4500 m. The highway ascends two passes on these ranges at Patni-top and Banibal-top, respectively. A stretch of 15 Kilometer of this highway in Pir Panjal range is marred by 15 avalanche sites, namely D-1 to D-15, among these sites D-10 is the most frequently occurring avalanche. This site is located in the Lower Himalayan zone which can be classified as the zone of warm temperature, intense precipitation with higher moisture content, short winter period and high wind activity. The snow, being wet in warm climatic zone, exerts more pressure over the structures and drifting snow causes unsymmetrical loading on supporting structures.

The formation zone of this avalanche site starts at an altitude of 3250 m and covers an area of 22 hectare. The site has twelve numbers of gullies having North to North East aspect. The average deposition of snow on the slopes of the formation zone is around 3 m. Considerable snow drift activity takes place due to high wind speed (100 km/h), culminating into formation of cornice as well as undesired additional loading in the formation zone.

Generally avalanches in Lower Himalayan Zone occur during snowstorms when load of snow exceeds 200 Kg/m² after irregularities get filled up with 150 Cm of standing snow and/or within 24 h of storm on a clear sunny/ windy day (Sharma & Ganju 1999). Triggering of avalanches from D-10 site takes place four to six times in a winter. A couple of avalanches of large dimensions block the mouth of the Tunnel and bring the traffic on the highway to a halt.

OBSERVATIONS

1. SNOW RAKES

151 Nos. of Snow rakes were installed for field trials in discontinuous staggered arrangement. Five rows of Snow rakes have covered Gulley No 4 from top of formation zone upto 35^o slope. Beyond that, approach road is crossing the end of formation zone which acted as Terrace. The limited numbers of Snow rakes have a gap of 2 m between two structures and 15-20 m slope distance between two rows. Ever since the erection of these structures, the behaviour and efficacy was monitored during and after every winter. Following major failures were observed in these structures: -

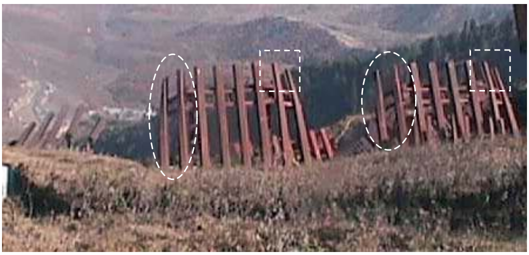


Photo 1: Damaged Snow rakes; square block showing bending of rafter forming cantilever part and circle showing twisting of end rafters

- Bending of rafter forming cantilever part (ref Photo 1)
- Twisting of the end rafters (ref Photo 1)

Summary of the damaged Snow rakes are tabulated below in **Table 1** :-

Sr. No	Row Number	Nos. of damaged Snow rakes	Type of failures
1.	I^{st}	6	Bending of rafters
2.	I^{st}	2	Buckling of Back support
3.	I^{st}	4	Twisting of rafters
4.	II^{nd}	7	Bending of rafters
5.	II^{nd}	5	Twisting of rafters
6.	III, IV and V	Nil	No damage occurred

Damage analysis

a. Bending of rafter forming cantilever part

Drifting snow persistence over this zone disturbs planning of control structures and produces exceptional accumulation of snow in formation zone. It reduces the retaining and catching capabilities of supporting structures, as a consequence of which risk of damage to structures increases (Stefan Margreth 1995). Snow depth on structures was observed to the extent of 1 m above the height of the structures. The higher snow depth in the formation zone (ref. Fig 1) is observed primarily on account of drifting snow which causes increased stresses on the cantilever part of the rafters, hence, as a consequence of which the rafters bent down.

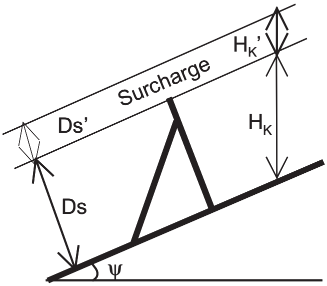


Fig 1: Showing height of snow over the structure (surcharge)

Where

D_s : Depth of snow cover
H_s : Height of snow cover
φ : Average slope of formation zone
D'_s : Depth of overhang snow mass (surcharge)
H'_s : Height of overhang snow mass

b. Twisting of end rafters/ members

Swiss Guidelines do not account for unsymmetrical loading on the members of the retaining plane. The design load assumptions thus remain underestimated for the exterior members as these members are subjected to more torsional effect due to end effect forces than the inner members. This causes torsional forces on end members as indicated at the D-10 site on some structures (ref. Fig 2).

Where $\mathscr{L}$: Length of structure (ref. Fig 2)

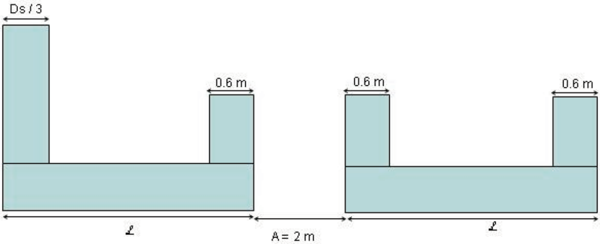


Fig 2: Unsymmetrical/ uneven loading along the length of the structures

Remedial measures

Following remedial measures were taken after the analysis :-

a. Bending of rafter forming cantilever part

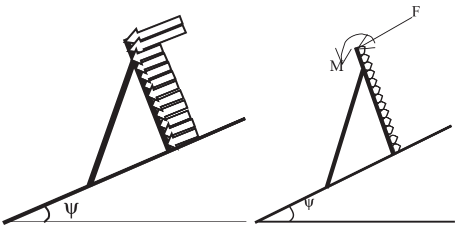


Fig 3 (a) & (b) : Loading due to surcharge of snow and transfer of forces and moments

Additional loading due to surcharge of snow has been accounted for in the design loads (ref. Fig 3(a)). This loading is transferred on top of the structures as an equivalent force and equivalent moment (ref. Fig 3(b)).

Where M : Equivalent bending moment
F : Equivalent shear force

The moments thus obtained are tabulated below in **Table 2** (Ganju and Kalra: 1994)

Sr No	Nomenclature	Maximum B.M on the structure	
		Using Swiss guidelines	Using modified method
1	Design moment for end rafter	41.79 kN m	51.41 kN m
2	Design moment for middle rafters	10.25 kN m	15.34 kN m
3	Design moment for channel beam assembly	27.0 kN m	34.68 kN m
4	Design force for back support	214.84 kN	276.47 kN

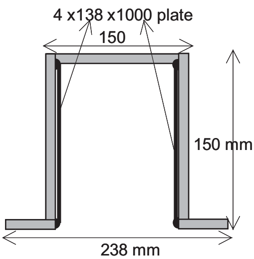


Fig 4: Cross section of the modified rafters-additional strengthening

In view of higher moments obtained using the modified method, the rafters were accordingly strengthened using stiffeners of size 4x138x1000 mm in cantilever portion of the rafters for preventing bending (ref. Fig 4).

b. Twisting of end members

In order to redistribute the loading on the retaining plane and to reduce moments due to end effect, an additional member (steel angle of size 75x75x6x1000) on either side was provided at the top. Each additional member connected four exterior members to take care of torsion and even-distribution of the forces acting on the retaining plane (ref. Photo 2).

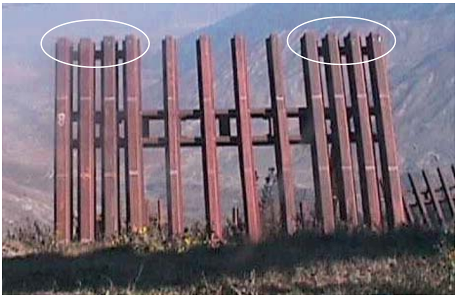


Photo 2: End members strengthened by structural steel angle

2. SNOW NETS

The Snow nets were designed for uniform sloping terrain considering the forces of snow acting in the direction parallel to the slope. The lower part of the swivel post had been designed as hinged joint which restricts the movement of the swivel post in one direction only, in, x-y plane. This hinge joint was designed for axial compressive force 'P' which gets transferred to pin in 'x' distance through hinge plate (ref Fig 5 & 6). The required diameter of pin 'd' to resist maximum bending moment taking place over its span 'L' is calculated from the Eq^n :-

$$d = \left\{ \frac{P}{1295} (2 * L - x) \right\}^{1/3}$$

Where x : Distance in which load from swivel

d : Diameter of pin

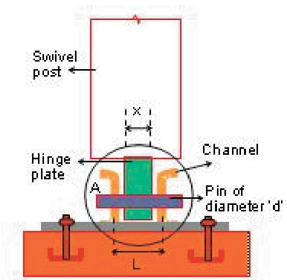
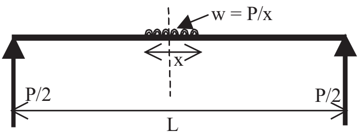


Fig 5 : Hinge joint at the base of swivel post in previously designed Snow nets



Where P : Axial compressive force
w : Uniformly distributed load
L : Distance between two channels

Fig 6 : Details of A: Load transferred through hinge plate to pin

Terrain conditions and snow movements resulted in multi-directional forces on the structures which caused uneven loading of the structures, resulting in failure of swivel post and uphill anchor foundations.

Analysis resulted in the following observations :-

Nature of failure:

(a) Failure of hinged support of swivel post (ref. Photo 3)

- Damage in the hinged section of the support has been to the extent of 40 per cent which is mainly due to limited manoeuvrability.

- 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 3: Damaged hinge section of Snow nets

(b) Failure in uphill anchor foundation

Open-cast foundation of uphill anchor failed due to typical ground conditions and soil shrinkage. The foundation could not counter the pull-out forces which developed heavy tensile forces. This resulted into the development of cracks in foundation blocks which led to stress concentration and finally foundation failure.

Remedial measures in recent work :

In order to overcome the above said failures, the following modifications were carried out after due analysis :-

(i) Modified Snow nets with multidirectional articulated Swivel post

The new design of the Swivel post takes care of the structural failures of hinge joint by replacing with the *Ball & Socket joint* arrangement (ref. Fig 7). The arrangement helps in the omni-directional moments, resulting in even distribution of loads. The Swivel post supported on a socket has omni - directional movement at the upper end, i.e., about 20^{o} 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.

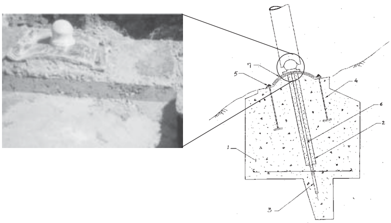


Fig 7: Swivel post with articulated Ball & Socket joint arrangement showing (1) concrete, (2) sleeve MS, (3) anchor bolt, (4) foundation - bolt, (5) nut & washer (6) resin, and (7) base plate.

Having observed failure in pin hinge joint, the ball and socket joint was designed with ball fastened with the base plate and socket inserted in inverted position fixed at the bottom of the post. Later (ref Photo 4), positions of the two components were interchanged with a view to introduce locking arrangement. Pivot neck (smallest section in a ball portion) has been designed and checked for critical shear conditions. 15 mm diameter of pivot neck meets the requirement, however, it is kept as 50 mm. Gap of 30 mm in between pivot neck and socket facilitates 20^{o} movement in all directions. This ideal dimension of ball and socket avoids fastening problems with its accessaries and reduce wastage of material during turning process.

Photo 4: showing ball and socket portion in field

Provision of locking system

To overcome apprehension of uplifting or dislocation of the swivel post, a locking arrangement (ref. Photo 4) has been introduced in the modified version of the Snow nets. Locking segment of 12 mm thickness has been introduced on the top collar of the socket to prevent uplifting or dislocation of the ball, out of the socket, in extreme / critical loading conditions.

Provision of drainage system

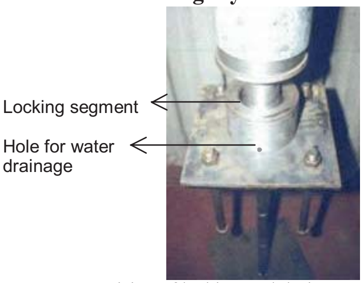


Photo 5: Provision of locking and drainage system

Two angular holes of ϕ 8 mm (ref Photo 5) have been provided in socket to allow drainage of water from socket, due to rainfall and melt water from snow & ice. This arrangement is made to reduce corrosion and other problems due to icing.

(ii) Continuous arrangement

Photo 6 : Continuous arrangement of supporting structures

Modified Snow nets were erected in continuous arrangement as shown in Photo 6. This has helped in uniform distribution of forces in a better way to adjoining nets. This also prevents damages to the structures due to the end effect forces. Layout and arrangement of these Snow nets and Snow bridges have been done as per Swiss guidelines (1990).

(iii) Design of uphill anchor and foundation

The uphill anchor was designed (Chaudhary, Vinay, et. al. 2002) to withstand the tensile forces while the foundation weight counter balances the pull out forces. Following additions have also been made in modified design :-

Photo 7: Uphill anchor foundations (stepped shaped) of modified Snow nets

- Provision of steel sleeve over the exposed SWR loop of uphill anchor and filled with molten lead for better distribution of forces.
- Provision of chicken wire mesh as reinforcement in the uphill foundation for distribution of tensile forces and to prevent minor cracks observed in the previous foundation.
- Provision of tor steel dowels of size (ϕ20 x 500 mm long) have been provided in the foundation base, driven half of the length into the ground, for better anchorage against sliding pressure acting parallel to the slope.

In subsequent design (as per photo 7), foundation has been redesigned as stepped shaped foundation (concrete volume 1.5 m^3) with a view to economise the huge dead weight of foundation block as in previous design ($2.1m^3$). The space above the step used for soil filling which holds the foundation in position and resist over turning and pull out forces.

For evolving guidelines for avalanche control in the lower latitudes in Himalayas, research studies specific to the Indian snow and climatic conditions were taken up in the subsequent years and modified formation zone control structures, in conjunction with other control measures, were erected in the years 1997-2000. To reduce the excessive loading on these structures, wind drift control structures, viz, Snow fence, Jet roof, and Wind baffle were erected on ridge-line.

CONCLUSIONS

Variable wind speed and terrain conditions were responsible for cornice formation and excessive loading of formation zone. This resulted in excessive loading on structures which was not anticipated in earlier design loads, thus, causing structural failures. After due observations and analysis, corrective measures were incorporated in the subsequent design. Higher moisture content of snow in Lower Himalayan Zone also contributes considerably towards design loads. All the above factors were taken care in the subsequent design. Also it was also observed that better results could be achieved by continuous arrangement.

Height of the supporting structure must be designed by taking into account the extreme snow depth expected at the site. It should be decided based on the long-term observations. Damages in rafters due to over surcharge and end effect forces were taken care by providing suitable stiffeners of plate and angle.

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 or activity has been noticed. Combinations of remedial measures on supporting structures and wind drift control structures have a telling effect on the entire successful efforts in keeping the highway open. Cost-effective solutions to the control of avalanche in formation zone have been demonstrated in a mighty D-10 avalanche site.

REFERENCES

Chaudhary, Vinay, et al (2002): "Flexible retaining barriers for prevention of avalanches on National Highway NH-1 A", Defence Science Journal, Vol. 52, No 2, pp. 197-198.

Frutiger, Hans and Martinelli, Jr. (1966): "A manual for planning structural control of avalanches", Rocky Mountain Forest and range Experiment Station, Fort Collins, Colorando, P9.

Ganju, V.K., and Kalra, M, (1994): "Modified design of formation zone control structures", proceedings of snow symposium, Manali, India, pp. 521-522.

Haller, Bruno (1995): "Wire rope safety net systems for the prevention of snow avalanches and rockfall", International co-operation in disasters, Hilton Hotel, Ankara, Turkey.

Margreth, Stefan (1995): "Long-term avalanche control structures" , Université Européenne d'Eté sur les Risques Naturals, Session: Neige et Avalanche, Sion (Valais, Suisse).

Sharma, S. S. and A. Ganju (1999): "Complexities of avalanche forecasting in Western Himalaya- an overview", Cold regions science and technology, 31(2000) 95-102, pp. 96-97.

Swiss guidelines for avalanche control in the fracture region, Original title: Richtlinien für den Lawinenverbauung im Anbruchgebiet, BUWAL/WSL, 1990, pp. 49-50.