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SHORT COMMUNICATION

Flexible Retaining Barriers for Prevention of Avalanches on National Highway NH-1A

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ABSTRACT

An avalanche hazard can be reduced by active and passive methods. In an active method, which is a very effective, avalanche control structures are used to mitigate the avalanche danger. These structures can be installed in any of the three zones of an avalanche, viz., formation zone, middle zone and run-out zone. In the formation zone, avalanche can be controlled by supporting structures/retaining barriers, which are installed in the formation zone with a view to prevent formation of an avalanche. Their placement in the formation zone with proper arrangement and layout helps in preventing fracture in the snow mass. The basic concept lies in converting the shear and tensile stresses in snow into compressive stresses which can be conveniently sustained by the snowcover. Such supporting structures/retaining barriers can be categorised into rigid and flexible types of structures. Snow rakes and snow bridges are categorised as rigid structures, whereas wire rope nets are categorised as flexible structures.

The Snow & Avalanche Study Establishment, Chandigarh, had developed snow nets in 1988-89, which were installed at D-10 avalanche site on north portal of Jawahar tunnel, Jammu-Srinagar Highway (NH-1A). These nets were designed considering the snow forces acting in the direction parallel to the slope only. Hence, the movement of the swivel post was restricted in one direction only. However, detailed scientific studies carried out for retaining barriers over the last seven years have revealed that two types of failures occur in these nets. First, a major failure was noticed in hinge joint of swivel post, and second, a failure was noticed in the foundation of the uphill anchor. To overcome these failures, the swivel post joint has been redesigned as articulated ball and socket joint to cater for omnidirectional movement to the swivel post, and the uphill anchor foundation has been strengthened by providing the reinforcement. This paper deals with the concept of flexible retaining barriers, including criteria for height of structures, their layout, terrain investigation required and also considers the snow pressure for designing various components of snow nets.

Keywords: Avalanche danger, snowcover, avalanche hazard, avalanche control structures, flexible retaining barriers, avalanche prevention, snow rakes, snow bridges, snow nets, swivel posts, terrain investigation

NOMENCLATURE

H_k	Vertical height of the structure
D_s	Depth of snowcover
ψ	Average slope angle of formation zone
B_k	Height of swivel post
L	Slope distance
f_L	Distance factor
ϕ	Coefficient of friction between snow and ground
S_N	Component of snow pressure parallel to the slope per unit length
N	Glide factor
f_c	Altitude factor
f_s	Reduction factor
G'	Weight of the snow prism
A	Area of snow prism
l'	spacing between swivel posts
ρ	Average density of snow

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R	Resultant force
ε_R	Angle between resultant force and snow pressure parallel to slope
l	Length of row(s)
T_s	Length of side of the net segments
n_b	Number of bays
n	Number of net segments
H_{max}	Maximum snow depth
H_{ext}	Extreme snow depth
T_2	Tension at point D
T_1	Tension at point C
S	Tension in downhill anchor at point A
P	Axial force in the swivel post.

1. INTRODUCTION

A large mass of snow moving rapidly down the mountain slope at high speed is generally termed as an avalanche. Avalanche occurs due to structural failure of snowcover, resting on steep slope. Failure may occur as a consequence of external stresses caused by intense snowfall, movement of human beings and metamorphic activities, forming a weak layer which can fracture due to external or internal loads. Excessive melting of upper layer (when melt water percolates underneath and lubricates snow or soil surface) also helps to trigger off a slab avalanche.

An avalanche hazard can be mitigated by retaining barriers in the formation zone. These barriers are installed in the formation zone having slope between 30° and 50°. Supporting structures intend to support, sustain or retain the snow mass on uphill side. These structures are designed basically for the forces produced due to creep, glide and settling of snowpack. Supporting structures cannot withstand the large dynamic forces of an avalanche as these are designed for static forces only. However, these are so designed that they can withstand slides and sluffs, which occur between two rows of the structures. Two types of loading, viz., dynamic and static do not act simultaneously. Static snow pressure forms the basis for the design, while the dynamic forces determine the layout and arrangement of the retaining barriers[1]. The long axis of the structures is placed as near as possible, at right angle to the assumed direction of the snow pressure. As far as possible, the row of continuous structures is installed in such a manner that it follows the contour of the terrain.

The snow nets are categorised as flexible retaining barriers/supporting structures because they have the ability to follow the movement of snowcover due to creep and glide of the retained snow mass. The snow nets can be installed on all types of grounds encountered, however, their use can be optimised by fixing them on rocky surfaces or load-bearing surfaces created artificially. The snow nets are preferred to snow rakes and snow bridges (rigid type retaining structures) mainly because of the following:

- Strong capability of working as rock fall protection
- Low cost
- Easy installation on difficult terrain
- Relocatable foundation being independent of super structure
- Reduced optimum period of fabrication and installation
- Easy transportation due to their lightweight parts
- Low damage due to flexibility and adaptability of uneven forces
- Better blending with the landscape.

The snow nets serve as retaining barriers by adjusting their supporting plane with the increasing depth of snow to control the snow forces. The snow nets as flexible retaining barriers have additional advantages due to their flexibility, adaptability to terrain configuration and also adjustment with the amount of the snowcover on the slope from time to time.

D-10 is one of the most important avalanche site on Jammu-Srinagar National Highway (NH-1A) having very high frequency of avalanche triggering. During winter, the mouth of the Jawahar tunnel gets blocked towards its north portal frequently by avalanche debris. The formation zone of this avalanche site lies at 2800 m. The area of formation zone is approximately 1,50,000 m^2. It has large, bowlshaped, rugged catchment area comprising 12 gullies and lies predominantly in north and north-east aspect. The average snow deposition on the slopes of formation zone is 3 m, besides cornice formation on the ridge. Considerable snowdrift activity takes place due to high wind, up to 120 km/hr. The formation zone has smooth grassy surface and some gullies have shrubs, small trees and rocky outcrops. The track of this avalanche confined near the highway has rocks and grassy surface. Its area of run-out zone extends beyond the highway.

Three of the 12 gullies of this avalanche site have been taken up for control with the snow nets having multidirectional articulated ball and socket joint arrangement. Most of the formation zone area of these gullies lies between 38 ° and 50 ° having 55,000 m^2 and 292 m, 337 m and 362 m length in formation zone.

The paper highlights the advantages of flexible retaining barriers over the rigid barriers, whose performance has been improved considerably by introducing an articulated ball and socket joint arrangement at the base of swivel post. Also, the improved design of foundations has enhanced the performance of these structures.

2. CONCEPTS & DESIGN PRINCIPLES

Avalanche formation can be prevented by converting shear and tensile stresses into compressive stresses. Thus, the erected structure acts as a dam against these stresses. A backpressure zone, approximately equal to three times the vertically measured snow height, extends uphill from the structure. It is seen that the compression zone is created upslope the structure, while tension zone is created downslope, and a neutral zone is created between the tension and the compression zones (Fig. 1), where distance between two rows is longer. No failure in snowpack occurs in the compression zone but shear failure is possible in the neutral zone while tension failure in the tension zone. Thus, the possibility of shear failure can be eliminated by shortening the distance between the rows.

2.1 Criterion for Determining Height of Flexible Retaining Barriers

The main criterion for designing the flexible barriers is snow height (H_k) measured vertically in the snowpack. Height of structures depends upon the extreme snow depth (H_{ext}) encountered on the avalanche defence site. For this, long time observations of the site under control are required . The vertical height of the structure should be more than the expected H_{ext} at the location of the structure.

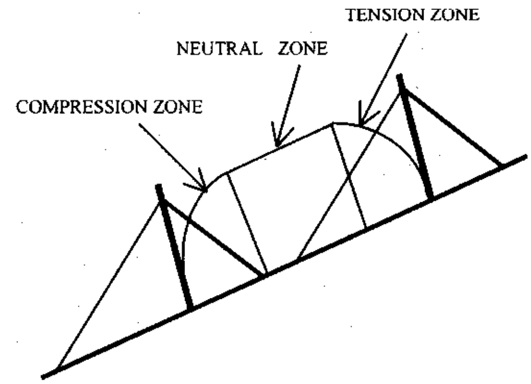

Figure 1. Creation of a neutral zone between the tension zone and the compression zone.

Snow depth measured perpendicular to the slope is called depth of snowcover (D_s) which is expressed as

$$D_s = H_k \times \cos \psi \qquad (1)$$

2.2 Layout & Arrangement

Generally, the catchment area of an avalanche site is determined along the ridgeline and the spur, where cornices build up towards leewardside due to wind activity. The problems of cornice formation and excessive loading onto the first/top row of the structures can be mitigated by placing drift-control structures on the ridge. The supporting structures in the top row should be placed as near to the foot of the cornice as possible, ensuring that these are prevented from getting buried in the developing cornice. Flexible retaining barriers can be used effectively in the top rows and are preferred for the avalanche sites having undulations and rockfall in the formation zone.

Swiss guidelines[2] suggest two types of arrangements for supporting structures as continuous arrangement and discontinuous arrangement.

2.2.1 *Continuous Arrangement*

This arrangement as shown in Fig. 2(a) and photograph at Fig. 3 gives higher degree of protection at a very high cost, hence adopted for uniform terrain.

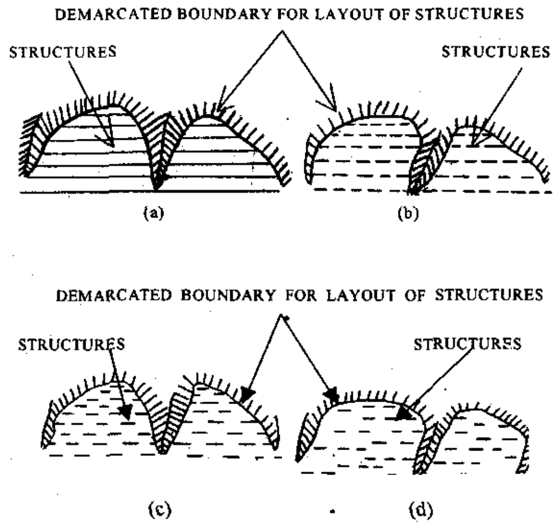

Figure 2. Plan showing (a) continuous arrangement of structures, (b) interrupted arrangement of structures, (c) staggered discontinuous arrangement of structures, and (d) combination of discontinuous arrangement of structures.

2.2.2 *Discontinuous Arrangement*

This arrangement gives slightly low protection at a much lower cost, hence used where ground has higher degree of undulation and obstruction by large boulders. It is further subdivided into interrupted, staggered and combined arrangements as shown in Figs 2(b) to 2(d) and photograph at Fig. 4. Optimum effectiveness with minimum cost is often achieved with a combination of different arrangements. In an area where the terrain and the depths of the snowcover vary greatly, the staggered arrangement would be the best[3].

2.3 Terrain Investigation

The following steps for designing, layout and arrangement of the structures are required to be carried out:

(a) Terrain characteristics

(b) Altitude

(c) Snow deposition data for arriving at extreme snow depth[4]. [Maximum snow depth H_{max} can be considered as extreme snow depth H_{ext} where data of adequate period of previous years (minimum 30 yr) is not available].

Figure 3. Continuous arrangement of structures

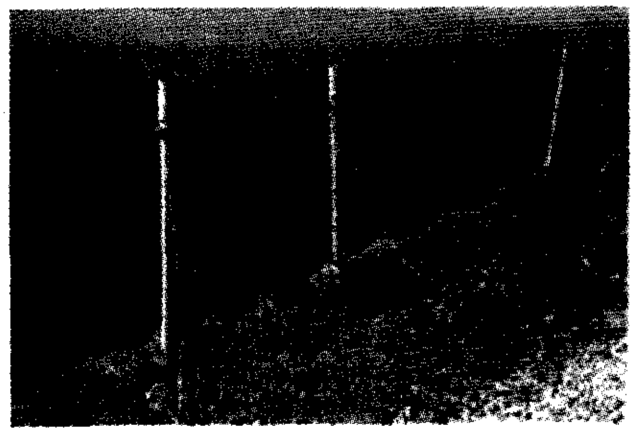

Figure 4. Interrupted arrangement of structures

2.4 Inclination of Supporting Plane

To increase the retaining capacity of the structures, the supporting plane is erected at an angle perpendicular to the slope. This angle varies from 15 ° to 30 ° depending upon the angle of repose. In case of steeper slope, it must be kept smaller[5]. The inclination of supporting plane wrt an imaginary plane perpendicular to the slope from the foot of the net is taken as 30 ° for flexible retaining barriers.

Swivel post, which supports the supporting plane, is inclined 10 ° uphill wrt plane perpendicular to the slope as shown in Fig. 5. This inclination is maintained to avoid accumulation of stresses in the foundation.

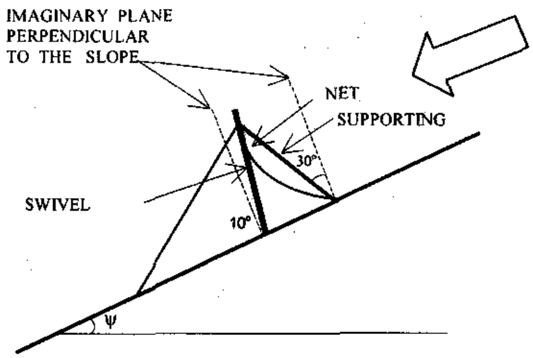

Figure 5. Swivel post inclined 10 ° uphill wrt plane perpendicular to the slope.

2.5 Slope Distance Between Two Rows of Structures

The slope distance[6] (L) between two rows of structures measured along the slope depends upon glide factor (N), depth of snowcover (D_s), slope angle and the vertical height of the structure (H_k). The height of swivel post B (Fig. 6) is expressed by

$$B_k = D_s/\cos 10^{\circ} \quad (2)$$

The slope distance (L) between two rows of structures shown in Fig. 6 is given as

$$L = f_L \times H_K \quad (3)$$

Distance factor (f_L)(upper limit being 13) is given by

$$f_L = 2 \times \tan \psi/(\tan \psi - \tan \phi) \quad (4)$$

2.6 Snow Pressure on Snow Net

The following formulae are used to calculate the snow pressure on the snow net .

(a) *Snow Pressure Parallel to the Slope*

The component of the creep and glide pressure parallel to the slope (S_N) (Fig.7) which exerts a force on a unit length of a supporting plane is expressed as

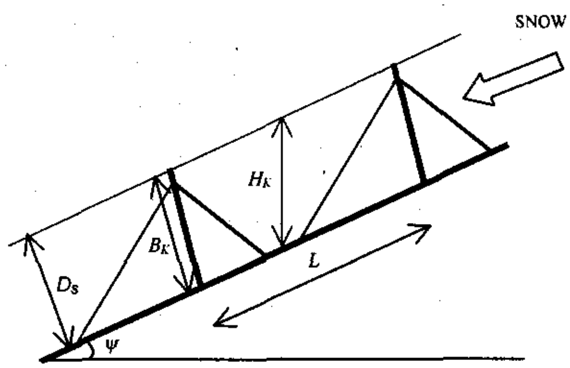

Figure 6. Slope distance between two rows of structures

$$S_N = f_c \times (H_K)^2 \times N \times f_s \text{ (kN/m)} \quad (5)$$

Altitude factor (f_c) expresses the general increase in snow density with altitude (1500 m: f_c = 1.0, 3000 m: f_c = 1.3). The reduction factor (f_s) is taken as 0.8 due to flexible supporting plane[7].

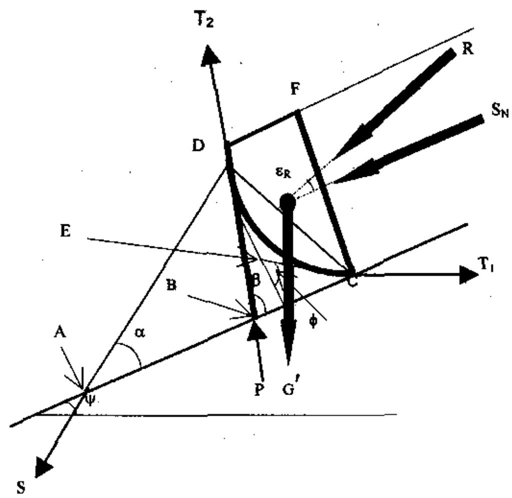

Figure 7. Component of creep and glide pressure parallel to the slope.

(b) *Additional Forces due to Snow Prism*

Weight of the snow prism (G') (CDF in Fig. 7), formed by the supporting plane of the net and imaginary plane perpendicular to the slope starting at the foot of the net is expressed by

$$G' = A \times l' \times \rho \quad (6)$$

where A is the area of snow prism, l' is the spacing between swivel post and ρ is the average density of snow.

Resultant force of S_N and G′ are expressed by .

$$R = [S_N^2 + G'^2 - 2\, S_N \times G' \times \cos(90 + \psi)]^{0.5} \quad (7)$$

The resultant force R is acting at the mid-point of the structure for first type of loading. In a typical winter condition when snow depths are great and density are low, it is based on maximum snow depth equal to the height of structure. The angle between resultant force and snow pressure parallel to slope (ε_R) is given as

$$\tan(\varepsilon_R) = (S_N / G') \quad (8)$$

2.7 Estimation of Nets Required

In a continuous row of structures, the number of bays (n_b) vary depending upon the length required to be covered along a contour. To work out the number of bays required for a particular row, it can be expressed as

$$n_b = (\, l \,/\, T_s)$$

where T_s is the length of side of net segments.

The estimated number of net segments (n) can be worked out for a particular row as

$$n = 2 \times (l \,/\, T_s) - 1$$

2.8 Construction of Flexible Retaining Barriers

Snow nets have three main components: (i) woven net, (ii) swivel post, and (iii) anchoring and foundation (Fig. 8).

2.8.1 *Woven Net*

A smallest unit of snow net, which can be erected independently, comprises three triangular woven nets, called two-bay net. This, when assembled, forms a trapezoidal shape, supported by two swivel posts.

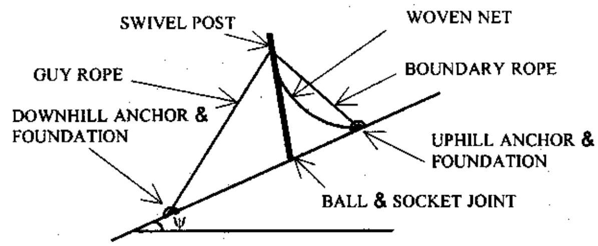

Figure 8. Main components of snow nets

Snow nets have a boundary rope of SWR and mesh is woven with a thinner SWR having polypropylene core for better flexibility. The net works as a supporting plane and the base of the net forms an angle of about 60 ° wrt the ground slope. This supporting plane is hung on swivel post, while the lower ends of the triangular net are held by uphill anchors.

2.8.2 *Swivel Post*

This is the most important component of the structure as the shear and tensile forces converted into compressive forces are transmitted through the swivel post. Upper end of the swivel post is provided with a pin where net is hung, while the bottom of the swivel post is supported on articulated ball and socket joint arrangement. Upper end of the swivel post is tied with a guy rope anchored at the rear.

2.8.3 *Anchoring & Foundation*

Base of the snow net is anchored by uphill anchors, which are mainly under tension, hence, the uphill foundation forms a crucial part of the structure. The uphill anchor is made of SWR with a loop protruding out of the foundation. The loop is protected by metal sleeve filled with molten lead. The body of the anchor is embedded in adequately designed foundation. The downhill anchor is tied with upper end of the swivel post. The guy rope, which is used as backstay between downhill anchor and the upper end of the swivel post, is also under tension.

The construction of the downhill anchor is similar to uphill anchor. The swivel post resting on the articulated ball and socket joint arrangement is supported on adequately designed foundation (conventional open-cast foundation or micropile foundation). Foundation for the snow nets can be selected depending upon the terrain characteristics. It could be either conventional open-cast foundation or micropile foundation.

3. CASE STUDY

3.1 Design Calculations

As only 15 yr snow data for the area of interest is available, hence maximum snow depth (H_{max}) is considered as extreme snow depth (H_{ext}). For this site H_{max} is 4 m. In this specific case study, the values of different parameters have been taken as under

$H_k = 4.25$ m $\quad \psi = 45^0 \quad \phi = 0.55$

$f_c = 1.2 \quad f_s = 0.8 \quad N = 2.2$

$A = 3.06\ \text{m}^2 \quad \rho = 300\ \text{kg/m}^3$

Thus, reactions in the rope at D, C, B and A (Fig. 7) are as follows:

$T_2 = 178.31$ kN, $T_1 = 220.1$ kN, $\quad P = 211$ kN

$S = 60.25$ kN, $\quad \alpha = 25^\circ, \quad \beta = 80^\circ$

A combination of arrangements [Figs 2(a) and 2(b)] have been adopted as shown in photographs at Figs 3 and 4 for the gullies under control. A total of 690 running meters of snow nets have been installed in these gullies.

3.2 Improvements in Design

3.2.1 *Observations*

A limited numbers of snow nets designed and erected by the Snow & Avalanche Study Establishment earlier were subjected to field trials at D-10 avalanche site for performance evaluation. The results are satisfactory. However, the following shortcomings were observed:

(a) *Contributing Factors for Failure of Hinged Support of Swivel Post*

(i) Damage in the hinge section of the support has been to the extent of 70 per cent which is mainly due to limited maneuverability being in one direction only.

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

(b) *Failure in Uphill Anchor Foundation*

Open-cast foundation was not provided with reinforcement. The foundation could not counter-balance the tensile forces acting on it, hence, cracks developed through the top surface of the foundation led to stress concentration, and finally resulted in foundation failure.

The authors' opine that the shortcomings could be overcome by improving the design of the swivel post and uphill anchor and foundation.

3.2.2 *Design of 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 articulated ball and socket joint arrangement (Fig. 9), which gives

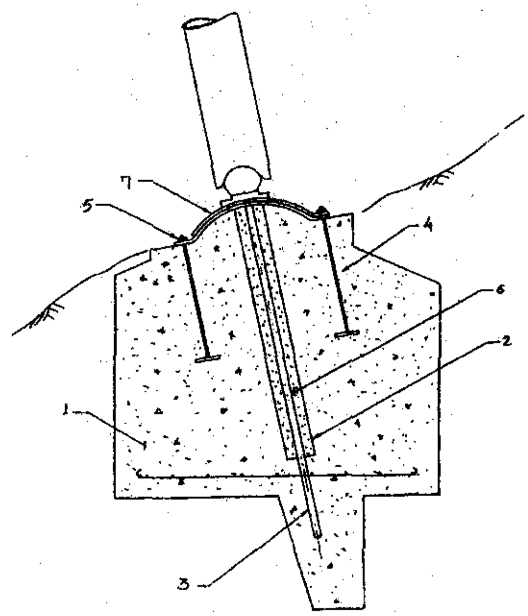

Figure 9. Swivel post with articulated ball and socket joint arrangement showing (1) concrete M-20, (2) sleeve MS, (3) anchor bolt, (4) foundation bolt, (5) nut and washer, (6) resin, and (7) base plate.

resulting in better functioning. Swivel post is designed for axial force in compression as well as lateral forces. 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)[8].

The swivel post supported on a pivot has omni-directional movement at the upper end, i.e., about 20 ° wrt 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.

3.2.3 *Design of Uphill Anchor & Foundation*

The uphill anchor is carrying all tensile stresses developed in the structure, the tensile force is

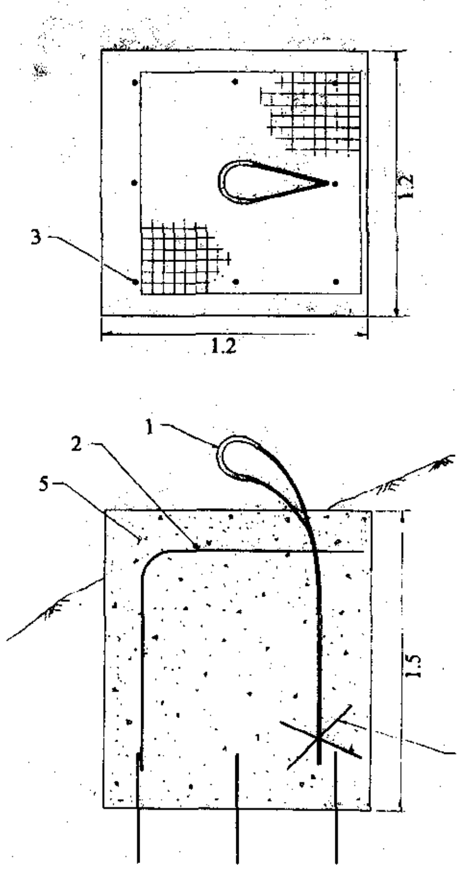

Figure 10. Uphill foundation block showing (1) anchor uphill, (2) chicken wire mesh, (3) dowel bars, (4) cross bars, and (5) concreate M20.

anchor is designed to withstand the tension while the foundation counterbalances the tensile force exerted by the structure. Uphill foundation block has been designed and checked against pull. The following additions have been carried out (Fig. 10):

- A steel sleeve has been provided over the exposed SWR loop and filled with molten lead for better distribution of forces and protection.
- Two cross bars of 800 mm length have been tied at the lower end of uphill anchor embedded in the open-cast foundation block to increase the resistance.
- Steel-chicken wire mesh 25 mm × 25 mm × 14G has been provided as reinforcement in the uphill open-cast foundation for distribution of tensile forces to prevent cracks observed in the previous foundation.
- Eight tor steel dowels of $\phi 20 \times 500$ mm length have been provided in the open-cast foundation base. These have been driven half of the length into the ground for better anchorage against sliding pressure acting parallel to the slope.

4. CONCLUSIONS

- After evaluating the performance of earlier snow nets installed at D-10 avalanche site for about seven years, it is concluded that the supporting plane of the structures should have enough movement to withstand and counterbalance the uneven forces of snow acting on it. Accordingly, snow nets with articulated main support at the base have been designed as a solution to the failure of base hinge of previous structures. Also, the foundations have been redesigned for better distribution of tensile forces within the foundations for sound anchorage in peculiar soil conditions.
- The limited trials at D-10 avalanche site covering three of the 12 gullies were carried out for performance evaluation of the snow nets having omni-directional articulated ball and socket joint arrangement. The results have been encouraging as no avalanche activity took place in the gullies

under protection and no damage to the structures has been observed.

- It is concluded that the snow nets can be used effectively to control avalanche at the sites with sound terrain or loose rock/soil terrain. These flexible retaining barriers have advantages over the rigid supporting structures.

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