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Optimum Configuration of Rigid Barriers to Mitigate Avalanche Hazard

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Abstract: Measures to prevent avalanches from starting zone are generally a more effective solution than to stop, retard or divert them. Supporting structures are used to prevent the avalanche formation in starting zone and are categorized as rigid and flexible type of structures. Snow rakes and snow bridges fall in the category of rigid structure, whereas Snow net, Ombrello etc fall in the category of flexible structures. Snow bridges are made of standard steel sections and hence, it is difficult to shift the structure’s components to higher reaches of mountains because of heavy weight. There is a need to optimize the external length (overhang component) and internal length of component of Snow bridges in order to reduce the weight by balancing the moments. Limited numbers of Snow bridges with new dimension were erected at Creep & Glide site near Dhundhi (Himachal Pradesh) and it is proving its worth in an exemplary way for the last 04 years. The paper deals with design criteria for selection of overhang length of crossbeam and girder of snow bridges, and internal angle of support with inclined sloping terrain.

Keywords: *Snow bridges, Optimum overhang length of crossbeam and girder, Avalanches, Static force*

1. Introduction

The snow particles lying on inclined slope are moving continuously downward because of gravity and visco-elastic properties of snow. The downward movement, composed of a gliding motion parallel to the ground and a creep motion, is exerting the force on the structure. According to Newton’s third law, every action has equal and opposite reaction. Action causes the pressure on the structures and reaction on opposite direction helps in stabilizing the snowpack. The extent of stabilizing zone is termed as back pressure effect, wherein creep and glide velocities are continuously reduced in the upstream side of obstruction (supporting structure). Within the back pressure zone, which practically covers a slope-parallel distance of at least three times the vertical snow depth, additional slope parallel compressive stresses are created which absorb the shear and tensile stresses developed within snow cover and converts it into compressive stresses which can be conveniently sustained by the slope.

The predominant action on obstruction in the form of snow supporting structures is the static snow pressure, which appears because of a local braking of the creep and glide movement in the snowpack on a steep slope. Through a suitable placement of the snow supporting structures, it is possible to ensure that the dynamic loads from avalanche actions do not become greater than the static snow pressure. There is a strong increase of snow pressure on either side of structure because of end effects forces. Since dead load of a snow supporting structures is much smaller as compared to the snow pressure, it is generally neglected in the design. Supporting structure can also be affected by lifting forces. In India, design of supporting structures in the form of rigid barrier is based on the Swiss Guideline for Defence structures in avalanche starting zones [1].

Rigid retaining barriers (snow bridges) are common devices for stabilizing the snow cover in the avalanche starting zone (Figure 1). Snow bridges are made of horizontal a crossbeam (structural steel section) that is supported by vertical girders connecting to the foundation. A major advantage of snow supporting structures is that it can prevent powder snow avalanches [2]. In India, Rigid barriers have been used at limited places for mitigation of avalanche hazard in order to provide the safety to road traffic.

Swiss guidelines [1] is a very comprehensive, mature and widely accepted design guidelines for supporting structures, which is the results of last 50 years of research experience and include revised layout, type of approval test and use of anchor grout in supporting structures. It is being implemented all over the world. The traditional European design of snow bridges is based on linear and continuous rows of structures separated by a fixed distance in the line of slope and distributed over the avalanche starting zone. Although it is the most effective deployment configuration for retaining the snow pack [3]. Most of the time, continuous line is not practical in Indian conditions due to typical geology of Indian Himalayas, rugged terrain, deep depression, rocky outcrop, etc. Therefore, a single unit design of snow bridges is developed for these avalanche sites so that bridge can be extended in continuous fashion depending upon the terrain conditions.

Previously a great deal of work has been carried out on erection of rigid barriers. An excavator has been used in hilly region of Austria for their erection and its practical experiences were highlighted [4]. In India, snow bridges were erected at D-10 Banihal top (J&K) for controlling the avalanches [5] and testing of their efficacy was highlighted [6]. Design parameters for supporting structures were investigated [7] under Icelandic conditions through measurement of snow pressure on the steel bridges. Comprehensive mitigation concept and life cycle management of protection measures were suggested in Austria [8]. An overview of the effects of snow pressure, requirement for supporting structures and brief of foundation forces on Snow bridges were given by Margreth, S. 2008 [9].

Figure 1 *Overhang of crossbeam 'c' & girder 'g' and internal angle of support 'φ'*

Snow bridges have been designed by Joshua et al (2008) [10] for 151-Avalanche on US route 89/191 in Wyoming. He highlighted concept in brief for selection of three aspects which are not covered in Swiss guidelines such as overhang length of girder where support attached with the girder ('g' in Figure 1); Inclination of support axis with terrain 'φ' in Figure 1 and overhang length ('c' in Figure 1) of cross beam from girder.

This paper highlights the detailed design criteria for optimize the structure's configuration in terms of selection of overhang length of crossbeam, length of girder of Snow bridges, and internal angle of support with slope.

2. Methodology

2.1 Optimum Length of Overhang Crossbeam

One crossbeam was considered for obtaining the optimum overhang length. A uniformly distributed snow load (8 kN/m) was applied over the crossbeam of length L (4m) which was supported at two points 'A' and 'B' and subsequently bending moment was drawn for same load (Figure 2). Load was calculated for own site conditions taking extreme snow depth 5.65 m, glide factor 2.4, altitude factor 1.3 m and angle of terrain 45^{o}. The value of snow load varies from 5 to 10 kN/m. The value depends on width of rafter and magnitude of snow pressure. For uniform pressure distribution, optimal crossbeam overhang length 'c' in Figure 2 could be determined. It was chosen so that the maximum positive crossbeam moment in the span (L-2c) between girders was equal to negative moment in the overhang portion of crossbeam.

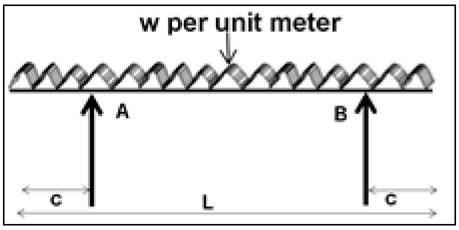

Figure 2 *Snow loading over a crossbeam with placement of support at optimum distance 'c'*

2.2 Inclination 'φ' of Support Axis with Terrain

Support angle to terrain plays very important role in making stable triangular geometry, consequently, transferring huge lateral snow load to ground and maintaining overall equilibrium in the structure. Axis of support is maintained in such a way that the most of the snow load gets transferred safely to the ground under compression and it should remain in its own position to avoid overturning from eccentric loading to the support.

2.3 Optimum Length of Overhang Girder

Support is attached to the girder at optimum distance 'g' (Figure 3) and a uniformly distributed snow load (115 kN/m) is acting over the girder. The snow load is computed for the conditions mentioned in 2.1. Overhand length is determined based on consideration of balancing the girder negative moment at the support attachment point with the positive girder moment in the span between the support attachment point and the foundation (Joshua, T.H, et al, 2008).

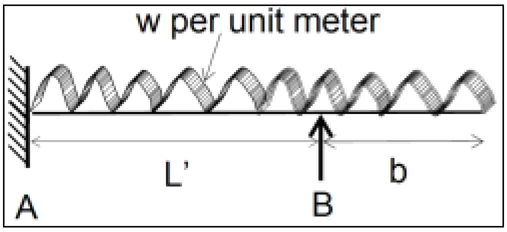

Figure 3 *Snow loading over a girder*

3. Results

3.1 Optimum Length of Overhang Crossbeam

Magnitude of negative moment increases with increasing length of overhang portion from X to Y and magnitude of positive moment reduces with the reduction in length between the supports X-X' to Y-Y'. Negative moment is further increasing at support and positive moment is decreasing at mid span while shifting the support position at Z-Z' (Figure 4). Table

1 shows the change of bending moment while shifting the support position. Negative moment (2.752 kN/m) and positive moment (2.752 kN/m) is balanced at an optimum position 'c' (0.828 m).

Table 1: *Variation in bending moment while changing support position at a-a, a'-a' & a''-a'' from free ends*

Position		Negative moment (kN-m)	Positive moment (kN-m)
a-a	0.6 m	1.44	6.4
a'-a'	0.9 m	3.24	1.6
a''-a''	1.3 m	6.76	- 4.8

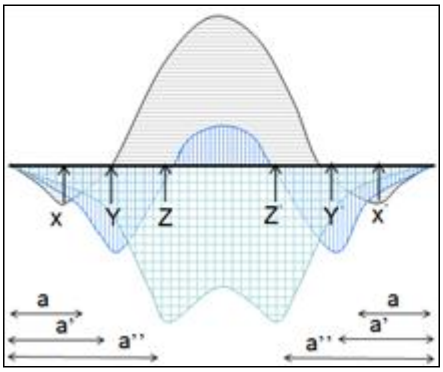

Figure 4 *Bending moment diagram for simply supported beam while changing support position at X - X', Y- Y' and Z - Z'*

3.2.1 Inclination of support axis with terrain 'φ'

Curve of negative bending moment and positive bending moment is drawn in Figure 5 which intersects at a distance of 0.828 m. The negative value on other side is discarded.

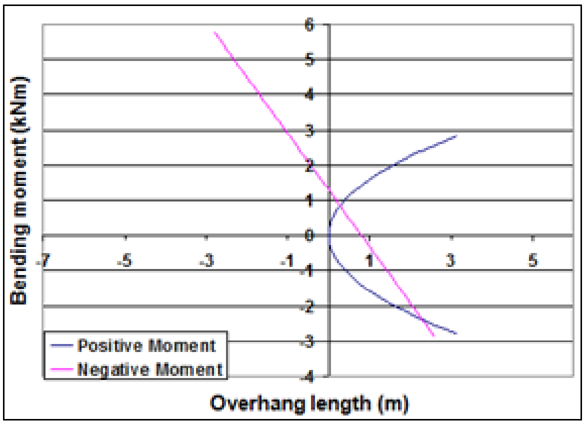

Figure 5 *Plot showing negative and positive moment curve intersection*

An analysis of change of support angle with terrain on both the foundations was carried out. Axial compressive force 'U' acting over back support foundation and tension force 'T' acting over front support foundation (as shown in Figure 8) is calculated by graphical method. Results of tension & compression force with change in support angle with terrain were plotted in Figures 6-7. Figure 6 indicates that foundation forces 'T' as tensile force in girder and 'U' as compressive force in back support are increasing with the increasing the support angle with terrain.

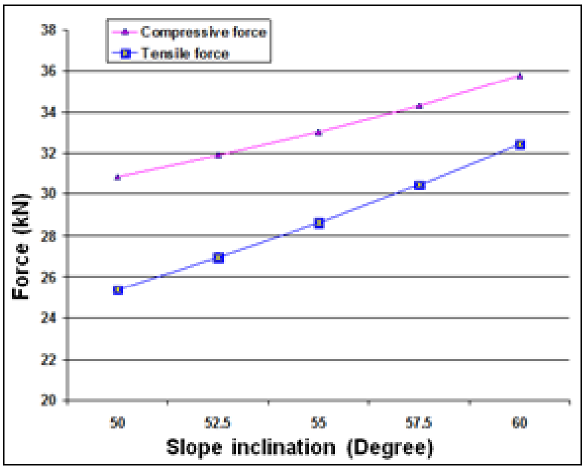

Figure 6 *Plot between Foundation force and support angle with terrain*

Figure 7 shows that foundation force 'T' as tensile force in girder and 'U' as compressive force in back support are decreasing with the decreasing the support angle with terrain.

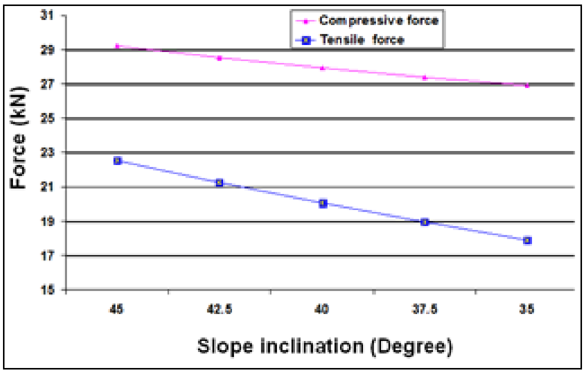

Figure 7 *Plot between Foundation force and support angle with terrain*

3.3 Optimum Length of Overhang Girder

Overhang length of girder 'g' is chosen considering balancing the positive and negative moment. Both the moment are at equilibrium position at 1.172 m (say b=1.2 m) where support meets the girder at B (Figure 3).

4. Discussions

The design aspects described in the paper can be chosen as per Engineer's will and his own perspective. To achieve a uniform safety level for all components of the structure with varying slope inclination, the angle of the triangle formed by the girder, support and ground surface should be kept constant as per Swiss guideline 2007 (2).

Value of 'c' comes out to be 0.828 m for unit design of snow Bridge. This overhang is safe for uniformly distributed load (8 kN/m). Optimum overhang is kept on both sides in unit design of Snow Bridge for efficient use of crossbeam member. Negative value in Figure 5 is discarded because length cannot be negative.

Support angle with respect to terrain inclination is decided by considering forces transferred to the foundations. High magnitudes of compression and tension forces are produced when support angle to slope become large or distance between the front and back foundations becomes smaller (Figure 6). It requires robust foundation corresponding to large foundation force which is undesirable. The impact of reducing the support to slope angle is that distance between front and back support foundation becomes greater which leads to smaller foundation force (Figure 7). However, it may increase the length of support and has a tendency to buckling. The results obtained by the analysis confirm that the result of Joshua, T.H, et al, 2010.

In the present case, inclination of support angle with terrain is approximately 45^o which is sufficient to distribute the snow load safely to the ground. Overhang length of girder (g) is maintained 1.2 m from support attachment to avoid any deflection at free end and utilize the girder length efficiently.

4.1 Unit Design of Snow Bridges

Snow & Avalanche Study Establishment (SASE) has recommended permanent avalanche defence measures in the form of supporting structures (snow bridges) in nine avalanche sites near Rohtang. It was designed considering unit design concept. Axial compressive force ‘U’ and tension force ‘T’ (Figure 8) are calculated by graphical method. Detailed design reports have been submitted to Border Road Organization (BRO), India for their implementation. Limited number of Snow bridges have been erected (Figure 9) at Creep & Glide site near Dhundhi research station (Himachal Pradesh) with the aim to assess efficacy of these structures, which have withstood the test of time.

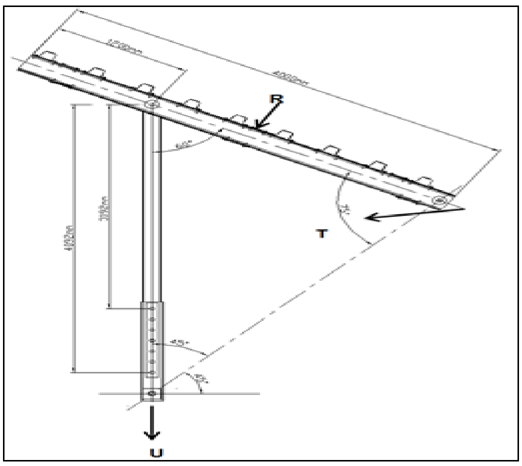

Figure 8 *Side elevation view of snow supporting structure unit design*

In the present work, Indian standard codes have been used to design the snow bridges which includes: General construction in steel (Code of practice IS:2007), Plain and Reinforced concrete - (Code of practice IS 456: 2000), and design and construction of pile foundations (Code of practice IS: 2911, Part I/Sec2).

Figure 9 *Winter view of snow bridges at experimental site*

5. Conclusions

In the present work, proper attachment of crossbeam with girder and attachment of girder with support at an optimum position leads to an efficient use of the both components. It was designed on the basis of past experience gained with supporting structures at D-10 Banihal top (Jammu & Kashmir).

In this case, support angle with terrain is selected 45^o to maintain balance between foundation force and the support length that forms the stable triangular geometry. Overhang length is observed to be important component to utilize the structure’s component efficiently in case of unit design concept of structure.

Their placement in the formation area with proper arrangement and layout helps in preventing fracture of snow mass which needs proper planning on paper, slope distance calculation and knowledge of expected fracture line of an avalanche. Limited number of Snow bridges with this configuration was erected at Creep & Glide site near Dhundhi (Himachal Pradesh) and it is proving its worth in an exemplary way for the last 04 years.

Acknowledgements

Author would like to express gratitude to Director SASE for encouragement.

Nomenclature

C: Overhang length of crossbeam
G: Overhang length of girder from junction of support
φ: Internal angle of support axis from terrain
U: Axial compressive load on lower foundation
T: Tension force in uphill foundation

L: Length of crossbeam
L': Length of girder upto support junction

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