SNOW AND ICE MANAGEMENT IN HIMALAYAS

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1. Abstract

Snow and ice management in Himalayas is one of the most challenging tasks of its kind. It is a risky, hazardous and tedious work prone to severest hazard a human being can face, due to terrain, geology and climatic conditions. The Himalayan chain is youngest, highest, and geologically active mountain range in the world, and the climate of Himalayas varies from sub-tropical to polar conditions. These, areas receive intense rain to high precipitation of snow (one of the highest in the world) i.e. plus of 10 mtrs. Due to very high and intense snowfall in short duration (approx 3 months) in the Himalayas, the same slopes may trigger avalanches 4 to 5 times, which is exceptionally high, considering activities in Alps and Rockies. In the Himalayas, innumerable avalanches (approximately one million avalanches occur every year) strike. In fact, Himalayan Mountains are considered to experience the most devastating avalanches in the world. All round developments of hill areas leading to increased habitation, expansion, use of hill roads and extension of settlements in mountains of the Himalayas necessitated the proper snow and ice management. The aspirations of local population have gone up due to technological advances and more interactions with other parts of world. The aim of this paper is to emphasise on the present practice of snow and ice management in Indian Himalayas, the present specifications followed for road pavement, permanent structure, problems faced in snow clearances and road construction and maintenance. To overcome present shortcomings, there is an urgent requirement for development of an integrated technology suitable for this terrain, within limited means available and also to exchange experiences with other experts in this field, for mutual benefits and further improvements in snow and ice management in Himalayas.

In the construction and maintenance of snow bound roads, the ground engineers at present face variety of problems, which need immediate attention. Therefore an integrated snow and ice management is of paramount importance for ground engineers. Practical problems faced and their related aspects are mainly discussed in this paper.

Neither much of research has been done in this field, nor the past experiences are well documented. At present ground engineers responsible for construction, snow clearance and maintenance of road apply their skills judiciously based on their observations and experience.

2. Terrain, Geology and Climate

Himalayas is the youngest, highest and geologically active chain of mountains in the world. The mighty Himalayan chain, longest in the world is more than 2500 Kms from West to East and 400 kms wide, starting from Pamir knot in Europe to border between India and Myanmar. The terrain of Himalayas is one of the most difficult in the world, as far as construction and maintenance of hill roads is concerned. It is one of the biggest challenges before the highway construction engineers, that too, when it is done, within limited resources. There is some magic in the mountains of Himalayas that stirs deep feelings in the hearts of all people living in this region. Among Indians, these feelings have come down, through generations, across millennia, as though spliced to the genes of our spiritual being and we consider these mountains as the Abode of Gods. Most of northern India would have faced acute water shortage, in the absence of mighty Himalayas.

Hill roads in Western and Eastern Himalayas traverse at an altitude ranging from 2500 mtrs to plus of 5000 mtrs. The highest hill road pass *Khardungla* in the world, is also situated at an altitude of 5640 mtrs in Western Himalayas. Snow bound roads are above tree lines and in very sparsely populated area. The soils in this area is mostly of the glacial origin and consist of metamorphosed, stratified and schistose rock formation which disintegrate under extreme weather condition. The portions, which are covered with fluvio-glacial materials, are very unstable and prone to land slides.

Though latitude wise, these areas are near to equator, but due to altitude they are nearer to polar conditions, due to which winter temperatures, depending upon the altitudes and places, could be as low as (-) 35^0 to (-) 50^0 C. In the summer, day temperatures may be as high as 30^0C, velocities of winds exceeding 80Km/H are common, especially in narrow valleys and near high passes. The chilling effect of wind in winters could be devastating thus making snow clearance operations very difficult. The average temperatures of a few accessible locations of middle Himalayan climatic zone for last five years are tabulated below:

Average Min/Max Temperatures in Degree Centigrade of Middle Himalayan Climatic Zone

Month	Min Max	95-96	96-97	97-98	98-99	99-00	Average
November	Min (-)	-21	-20	-23	-20	-18	-20.4
	Max	3	2	3	3	3	2.8
December	Min (-)	-25	-22	-30	-26	-23	-26.6
	Max	4	2	2	4	3	3.0
January	Min (-)	-30	-32	-28	-29	-33	-30.4
	Max	2	2	0	2	0	1.2
February	Min (-)	-27	-28	-27	-27	-37	-29.2
	Max	5	8	4	4	4	5.8
March	Min (-)	-24	-23	-25	-25	-37	-26.8
	Max	14	13	13	13	17	14.0
April	Min (-)	-18	-19	-24	-19	-29	-21.8
	Max	16	22	17	17	25	19.4

The snowfall season begins with the onset of winter and as such the first snowfall in the higher altitude of the Himalayas may occur some time towards end September and continue till mid April. Advancing winter season results in accumulation of snow as well as extending it towards the greater Himalayas and even on its lower ranges, during which accumulation and extent both increase rapidly. Snow melt at least in the lower Himalayan ranges and the latitude belt 30^0 to 40^0 North may begin from April and continue till June. Snowfall pattern detail of frequency and distribution and snowfall intensity of a particular area in western Himalayas are given below:

Average Frequency Distribution of Snowfall and Storms

Month	Average frequency distribution of snow fall amount in 24 hours			Average number of storms	Average number of storms in a day	Average number of intensity in cm/hrs	Average intensity between storms in days
	20-40	41-60	60		2	--	--
Oct	--	1	--	1	5	1.80	7 to 10
Nov	1	--	1	2	8	2.60	2 to 10
Dec	1	1	1	3	9	2.60	2 to 6
Jan	1	1	2	4	10	2.50	3 to 5
Feb	1	2	2	5	12	2.50	3 to 5
Mar	1	2	--	5	5	2.50	2 to 10
Apr	1	1	--	2	2	1.50	--

Following deduction can be drawn:

- Although the majority of snowfalls remain concentrated during December to March, yet early and late snowfall even during October/November and April/May cannot be ruled out.
- Each major storm is expected to deposit as much as 190 cms of snow whereas other storms may deposit anything up to 40 cms.
- While major storms during December to March may generally last as long as three to four days the storms during other months are likely to last for maximum of two to three days. However snow- storms extending beyond one week are not uncommon.

3. Types of Problems Faced by Road Engineers

In Indian part of Himalayas, approximately 30,000 kms of roads exist, out of which approximately 5,000 km falls in snow bound areas, and about 90% roads are of single lane specifications. Following problems are generally encountered by Engineers during maintenance and snow clearance:

- Deciding date/time of commencement of snow clearance operation.
- Data-base suitable for planning, construction, maintenance and snow clearance of roads in snow bound areas is not adequate.
- Proper guidelines for construction/maintenance and snow clearances in snow bound area, yet to be formulated.
- It has been experienced that about 25% of road stretches are badly damaged due to frost heaving. After every snow clearance operation, extensive and expensive repairs are required to these

stretches. Well-documented theory on thawing indexes for Himalayan region is yet to be developed.

- Road pavement experiences heavy damages due to movement of tracked vehicle, during snow clearance and land-slide clearance operations. The maximum damages have been noticed on zigs and sharp curves.
- Loss of ductility of bitumen due to sub-zero temperature conditions results in reduced life of bituminous wearing surfaces. The normal laid down life cycle is 5 years, but substantial damages are observed after 2 to 3 years.
- Severe damages are caused to road pavement and other permanent structures like retaining wall, breast wall, cross drainage works, due to large diurnal variation temperatures, frost heave, and heavy water seepages. This problem is more severe on few Kms of either side of high passes and stretches with clay and silt as base.
- Snow clearance operations and road maintenance are well known challenging tasks due to hazardous terrain and absolute hostile climatic conditions. In the absence of upgraded technology and equipment, snow clearance operations are very risky.
- In the absence of non-existence of similar terrain conditions and working conditions in other parts of the world, fruitful exchange of ideas has not taken place so far.

Avalanches. Avalanches are the most risky and hazardous, during snow clearance operations. As already stated above, we have more than hundred thousands active avalanches in this region. The extent of problem can be gauged from the fact that the most of roads pass through active avalanches that also in formation/middle zones and data of 75 km stretch of a road portion from Western Himalayas are enumerated as under:

Avalanches Details of a Road Stretch of 75 Kms

Sl. No	Sector/stretch of road	Length of road stretch	No. of avalanches	Total length covered in avalanches in meter	% of length in the sector
1	A	25.50	55	10200	40
2	B	18.50	33	14600	80
3	C	31.00	21	5000	25
	TOTAL	75.00	109	29300	39

Quantitative and qualitative results from above details can be summed up as under:

- Road experiences 109 avalanches in 75 kms of stretch.
- Total length of road portion covered by avalanches is approximately 29.80 km, which works out to be about 39% of the total stretch of 75 km considered.
- Frequency of avalanches observed during winter is 4 to 6 times.

From the above, it can be well imagined that the severity and risk involved in snow clearance operations in Western Himalayas is partaking.

Icing. Icing is one of the major problems faced during road maintenance and snow removal/clearance. Due to vast diurnal temperature variations, more so during early and late winters the duration of sunshine is more during this period. The details of sunshine duration and insolation for year 1999 are as under: -

Sunshine Duration and Insolation

S.No	Month	Duration in Hours and Minutes From		to	
		Hrs	Min	Hrs	Min
1	Nov	3	00	9	00
2	Dec	3	00	8	00
3	Jan	1	37	4	27
4	Feb	2	23	7	20
5	Mar	3	16	6	52
6	Apr	5	18	9	02

Spring Thaw. During the frost-melting period, the excess water released by melting of snow/ice can not drain out through still frozen side-drains and flows with tremendous velocity, over the pavement, due to the steep gradient of hill roads, causing erosion and severe damages to the road surface. Generally most of hillroads are single lane and due to geologically unstable conditions, debris keep on falling, in the side drains continuously and it becomes practically difficult to maintain drainage system, resulting in, road itself acting as conduit of waters. It has been observed that frost susceptible soils in which ice segregation has occurred experience a loss of strength during frost melting periods, with corresponding reduction in load supporting capacity as the melting water releases excess of water within soil. The application of traffic during the period of weakness may cause remolding of the soil, with attendant further reduction in sub-grade strength. The degree of reduction in pavement-supporting capacity during a frost melting period and the length of the period during which the supporting capacity is reduced depend on the type of soil, temperature conditions during the freezing and thawing periods, the amount and type of traffic during the frost melting periods, the availability of water during the freezing and thawing periods, and drainage conditions.

Snow Drift. Heavy snowdrift activities are prevalent in most of Himalayan region. The high velocity of winds at a number of stretches of roads activates deposition of large quantity of snow in a small stretch of road from adjacent slopes. This adds to exceptionally high snow deposition due to snowdrift, thus resulting in densification of snow; this causes more strain on equipment and also extra efforts in snow removal.

4. Present Practice of Snow and Ice Management in India

Roads in higher reaches especially in western Himalayas, where, the intensity and periodicity of snowfall combined with avalanche activity and icing problems make it almost impossible to undertake any snow clearance operations continuously, snow perforce has to be allowed to accumulate during winter months (4 to 6 months) and in such cases the road sector has to be closed during this period. The compact snow on the road at some stretches may be of the order of 10 to 12 mtrs and at major-avalanched sites this may exceed 25 mtrs around **Zozila** and **Rohtang** passes. This is also known as summer snow clearance. The snow removal operation, in India is known as snow clearance operation. Some of important roads above up to 5000 mtrs are kept open by continuous snow clearance using appropriate equipment. This is known as winter snow clearance. In India, two types of snow clearance operations, winter snow clearance and summer snow clearance is undertaken.

Organization. Summer snow clearance operation is mostly based on machines, adequate manpower is essential for various allied task like deicing, launching of modular bridges, carriage of fuel/ration, repair and maintenance of equipment, blasting of boulders brought down by in avalanches and water. The location and number of snow clearance parties are decided, before hand, as snow clearance operation requires advance planning and preparation with utmost care. Careful and detailed planning for use of equipment and manpower during snowstorms and avalanche activity is necessary for successful operations. It is absolutely essential that appropriate type of equipment for snow clearance be positioned at the appropriate locations, based on past experience and their mechanical conditions.

Snow Clearance Methods. The snow clearance operation is most challenging and hazardous task, as it is being carried out in absolute inhospitable climatic conditions and with limited resources and a meagre funds. The personnel selected for this job are generally highly motivated, physically robust, mentally alert and preferably of lower age group (below 45 years). The courage of snow clearance teams can be described by famous saying of Jean Paul Richter " A timid person is frightened before danger, a coward during the time, and a courageous person afterwards". All administrative arrangements for their stay, safety, medical cover, communication, rescue etc. are planned in advance. Due to extreme climatic conditions and altitudes the efficiency of both man and machine is reduced as much as 30 to 40%. It has been observed that the most useful machine for clearing accumulated snow of winter is the bulldozer due to the high density. It is versatile equipment and clears all types of snow. Snow cutters, which are in use with other countries, are not found as much useful, due to boulders in avalanches, formation of hard ice at a number of stretches and non-availability of spare parts in time. The snow cutters are useful in box cuts portions and for snow accumulation up to 2 to 3 meters, without boulder/stones. Therefore generally one-snow clearance party consist of:

Composition of a Snow Clearance Team

S.No	Description	Numbers
1	Bull-Dozer	2
2	Snow-Cutter	1
3	Load Carrier 4x4	2
4	Light Vehicle 4x4	1
5	Equipment Repair Team	1
6	Medical & Rescue Team	1
7	Communication Team	1
8	Officer & Supervisors	4
9	Skilled manpower	10
10	Unskilled manpower	30

Most of snow avalanches contain boulders/stones and thus snow-cutter in isolation is not a complete piece of equipment in our context. The dozer cuts ramp through avalanched snow, reducing the height up to 3 mtrs, after which the snow-cutters take on the snow clearing responsibility.

Avalanches. Most of roads in higher reaches of western Himalayas pass through avalanche prone areas. To tackle the problem of avalanches, fairly accurate knowledge and data of the type of avalanches, frequency, location, its magnitude, intensity, extent of spread and return period, are necessary. A Research Institute is conducting research, for over 30 years in the field of snow and avalanches. Avalanche Atlases for some of roads have been prepared and for other roads, it is under preparation. Fruitful interaction between laboratory scientist and ground engineer is the need of hour. Though the techniques about various control structures like, Snow Gallery, Guide wall, Diversion dams, Avalanche ramps, and Avalanche wedge, are available, but the same could not be implemented due to lack of resources. The snow clearance operations are cheaper on day-to-day basis, however permanent control measures will be economical in the long run.

Avalanche triggering using explosive is being attempted at number of places before snow clearance operations, so as to reduce risk to operator as well as equipment. This also helps in reducing duplication of efforts, as it becomes difficult to clear debries afterwards. Some more experiments in this field are being conducted, to improve our knowledge in this field.

Some control structures have been designed and installed at one location on National Highway.

Snow net. Two types of snow net have been developed. The first type of snow net is based on hinged support and other is based on ball and socket joint. The snow net, with hinged support is suitable for open slopes (Unidirectional) formation and modified snow net with the ball and socket suitable for multidirectional slope terrain.

Snow Bridge. Snow bridge is a rigid supporting structure. Supporting plane of bridge structures consist of horizontal rafter being supported by the vertical column and back support. The front view of these structures has appearance of a bridge. .

Jet roof. Himalayas experiences very severe snow drift condition, which results in massive cornices. This in turn triggers avalanches, as and when it breaks. Jet roof is a cornice control structure; it works on the principle of ventury effect. The jet roof is used to boost the wind velocity and change the wind flow direction parallel to the slope in lee-ward side, due to increase in out going wind velocity and change in flow direction, the snow transportation capacity of wind is considerably increased at the exit point of jet roof. It prevents deposition of snow on the leeward side of ridge up to 20 to 50 mtrs, distributing snow mass on lower ridge slope. It has been observed that each jet roof has prevented cornice formation in about 25 to 50 mtrs across ridge length by its suction effect. The cornice of 4 to 5 mtrs formed in other locations where the jet roofs were not installed.

Controlled released of avalanche using Sprengbahn. Large amount of snow mass released from avalanche formation zone, causes severe losses to vehicles, lives and damages to vehicles other properties, year after year in winters. To mitigate the avalanche danger a research institute has developed a mechanical device, which has been suitably modified for conditions being encountered in the Indian Himalayas.

Earthen Mounds. These structures are intended to slow down, deflect or stop avalanches in the track of run out zone. These are massive in size, built on slope greater than 20 degree. Uphill side of these structures is generally pitched with concrete or masonry to prevent erosion. Earthen mounds have been constructed at number of places.

Snow Gallery. At a number of places, Snow Gallery has been constructed.

Afforestation. Tree trunks like supporting structure, modify the terrain, provide anchor to the snow and break the continuity of slab. Forest almost eliminates snow drifting and produce uniform stable snow pack. Afforestation is, therefore, found to be effective method of mitigating avalanche hazard.

Snowdrift. Heavy snowdrift activities are prevalent during Feb and Mar months, in most of areas, and in certain higher altitudes above 4500 mtrs and it may continue up to May. Generally this causes drift of snow from higher reaches/ridges to accumulate on roads, which are generally in the valley/ lower slopes. This adds to, exceptionally high deposition of snow, and in turn results into, densification of snow and causes additional strain on equipments as well as extra efforts during snow clearance operations. Snowdrift can be controlled with the help of Snow Fences, and it has been installed on experimental basis, to check its efficacy. Snowdrift activity is a major contributory factor for extra efforts and delay in snow clearance operations.

Icing. Icing is one of the major problems the faced during the snow clearance and maintenance of roads. The problem is more severe, as most of roads were constructed more than four decades back. During construction, due to paucity of time and funds, no proper planning could be done, which has resulted in major icing, in snowbound or waterlogged stretches. There is large diurnal temperature variation, more so, during the early and late winters. The road pavements are generally flexible in nature, which permits water to come on surface due to capillary action and also from surface. This is another major problem faced by road engineers during snow clearance and maintenance of road, as our most of roads are with flexible pavement, undulation on road surface. During above mentioned period, the thin layer of ice is formed in and above bituminous surface. It is not possible to break this ice film, by any equipment, other than manual breaking, which causes heavy damages to the road surfaces. As precautionary measure, when icing problem is very serious, all vehicles will have to use non-skid chains.

At present spreading of common salt, urea, medium sand, saw dust mixed with sand and manual breaking methods are being used with limited success.

5. Road Maintenance Subsequent to Snow Clearance

This is one of the most difficult tasks for road engineers in Himalayas. After snow clearance the road pavements and other structures show, enormous damages due to, frost heave, movement of dozers for snow clearance, high velocity flow of snow melting water in the center of road, land slides, sinking areas and failure of permanent structures. At present we do not have proper database and appropriate specifications for road pavement/permanent structures in snow bound areas. The specifications meant for other normal terrain are being followed. In the absence of inadequate specifications, it has been observed that, the damages are substantial, in the portion of few Kms of road stretch across high mountain passes, at times there is no trace of road pavement at all, and at places damages to surface is to the extent of 30 to 40% of pavement area. Failure of retaining wall and cross-drainage works is also very common, and more so in areas having cohesive soils. The restoration of damaged portion of roads is one of most difficult as well as costly affair. Therefore at present it is one of the biggest problems of snow bound area for road engineers. There is an urgent need for revision of specifications.

6. Development of an integrated Technology Suitable to Himalayan Terrain

There are a number of research institutes in India engaged on road research, snow and avalanche studies. Not much of research has been carried out so far so far, for snow bound roads by these Research institutes. Similarly, there is an urgent need to integrate snow and avalanche studies to the requirement of road engineers. Therefore, the close co-ordination among road research wings, snow and avalanche study groups and road engineers to develop an appropriate technology and specifications, suitable to Himalayan terrain is the need of an hour.

Knowledge available and experience gained in this field in other parts of world can also be exchanged for mutual benefits. At present the interaction in this regards has not reached the desired level due to various constraints. The International Winter Road Congress 2002 Sapporo, Japan will be most appropriate platform for this mutual exchange knowledge.

The main areas/fields, which need immediate attention to upgrade the methods and technologies, can be summarized below:

Planning and design:

- Development of new specifications for road pavement and other road structures
- Database suitable for planning, construction and maintenance of snow bound roads
- Suitable alignment of roads, so as to minimize problems, due to snow and ice

Construction, Maintenance and Snow Clearance:-

- Improvement, automation and efficient use of machinery, suitable for construction, maintenance and snow removal for Himalayan region
- Technology support on winter road management and mechanism for its exchange on latest knowledge/research
- Use on natural energy in Snow and Ice Management
- Improvement in de-icing methods

- Winter management and early opening of roads in Himalayan region using GPS
- Eco-friendly snow control measures

7. Conclusion

It is well known fact, that, the Himalayan chain of mountains is youngest, geologically most active ranges in the world and problems are enormous. An attempt is made to identify various types of problems, which need immediate attention and close co-operation with other countries and experts in this field. These problems broadly can be summarized under the headings of, Planning and design, construction, maintenance and snow removal/clearance.

In current paper, the problems related to Snow and Ice Management in Himalayan region are confined to roads only, and can be summarized as under: -

- Types of problems faced by road engineers in Himalayan region
- Present practice of Snow and Ice Management in India
- Need for development of appropriate road specifications and integrated technology suitable for Himalayan terrain.

In order to, improve living conditions, sustainable economic development and other activities in Indian part of Himalayas, there is an urgent need, to share/ exchange knowledge on innovative research and information's on outstanding technology available with other advance countries.

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