Snow Clearance — West Himalayan Road — Some Problems

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Highway construction and maintenance at high altitudes in the snow-bound regions of the Himalayas is now not only necessary but essential in the overall development of India. This paper indicates the present position in this regard and highlights some of the special problems faced in snow-clearance work. A few suggestions for future improvements have also been made.

Highways and roads have long been regarded as the physical symbol by which a country's progress may be measured. The Indian road network is one of the largest in the world. The Border Roads Development Organisation was set up in 1960 to build communication links to the inaccessible and neglected regions of the North and North-Eastern border States for economic development. This organisation has constructed, among other routes, some of the very high altitude roads; one such is the road from Srinagar to Leh. This route is now open for traffic for only about six months in a year and remains closed for the rest of the period. The sparse population of these outlying isolated regions in Ladakh, who have for long been living under the rigours of severe cold for most of the year, lead precarious lives, subsisting on the meagre produce of lands which support just bare vegetation. This population is now linked with the mainstream of life of the country in economic development.

The above high altitude roads are highways with a difference. The road under discussion stretches from Srinagar to Leh which passes through an average altitude of 3,000 metres above MSL and is completely snowbound from November to May every year. The snowfall in peak winter is very heavy and with the difficult terrain traversed by treacherous avalanches, it is well nigh impossible to clear the snow so as to keep the communication open throughout the year. The road, therefore, remains closed completely for six months in a year, due to a critical stretch about 80 km (Fig. 1). The second reach of over 250 km, although practically open for the best part of the year, has to be closed down during short spells of very heavy snowfall and intense activity of avalanches. This paper attempts to bring into focus the problems faced in the crucial sector.

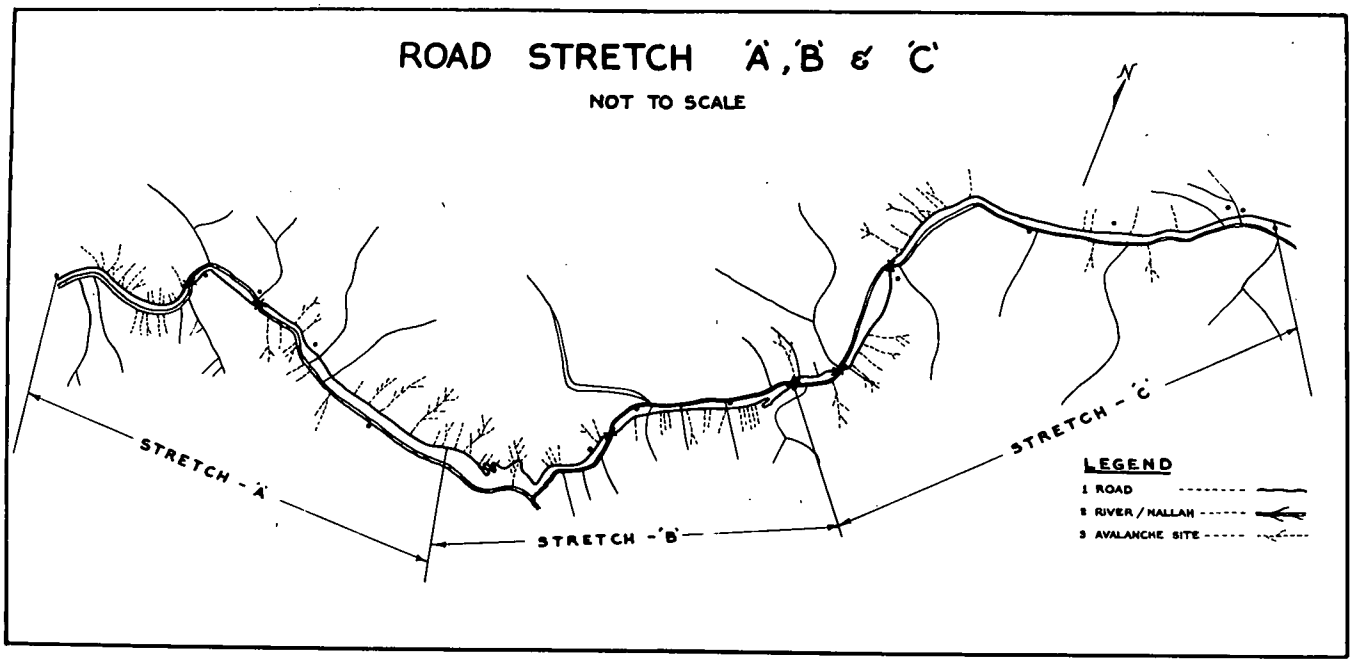
The methods adopted in snow clearance by men and machinery have been dealt with separately, detailing advantages and limitations of various kinds of operating machinery. Some suggestions have been made for improving the machinery to meet the special needs and difficulties observed during execution. The present technique, while aiming at keeping the road open for a short period of six months in a year, will require considerable improvements in methodology apart from additional resources to meet the increasing demand of keeping the road open throughout the winter. It is needless to emphasise that a greater element of risk is also inherent in this. The present limitations have also resulted in lack of mobility in the movement of men and materials. There is, therefore, an urgent need for evolving long-term solutions, and with this in view, some studies are already in progress. These would cover detailed ground and snow surveys, and installation of high-altitude snow laboratories equipped with advanced methods of remote measurement of all relevant snow data in collaboration with experts drawn from all related disciplines. There is presently scope for developing a system of prognosis of avalanche movement, on which considerable research has been done in India and outside. Research work also exists on methods to precipitate avalanche movement under certain conditions and for design of structures to arrest avalanche movement where such contingencies arise.

Terrain

The Srinagar-Leh road traverses a series of mountain ranges tapering into the Leh Valley. The road crosses the Great Himalayan Range and Zanskar Range which are the two main mountain complexes. The tangled mountain ranges extend over several kilometres on either side of the ridge. Of these two, it is the Great Himalayan Range which is subject to heavy precipitation of snow and intense avalanche activity during winter. The "critical stretch" lies wholly in this complex.

The critical sector can broadly be sub-divided into three distinctive sectors designated for convenience as "A", "B" and "C." Each sector has its

Figure 1.



own special characteristics in respect of terrain, climatic conditions, snowfall and avalanche activity. A general description of the reach as a whole is given in succeeding paragraphs and followed by each sector's features.

The hills along which the road runs in the above stretch have generally steep slopes ranging from 30° to 60°, rising to bare, rocky cliffs and ridges. The valleys are very narrow and meandering. At places, there are deep gorges flanked by rising mountains on either side.

The vegetation is limited to south of Zozila Pass. Only scanty vegetation consisting of small bushes, shrubs and grass can be found in the north of the pass - a distinctive characteristic of Ladakh. Trees, which are mainly of the Pine and Birch species, grow only up to altitudes of 3000 m.

The region along the "critical stretch" is very sparsely populated, there being only five villages. Population of each village varies from 100 to 200.

Sector 'A' (14 km)

In this sector, the road ascends from 2310 m to 2720 m, generally passing through flat ground in Sindh Nullah Valley. It enters a short 2.5 km long, 'V' shaped gorge. This gorge is flanked by precipitous cliffs on both sides having slopes 30° to 70° with heights up to 3812 m on the north and 4855 m on the south. At places, there are vertical cliffs for a stretch of a kilometre or more. This stretch gets very limited amounts of sunlight and is subject to avalanche activity from the flanking hills. These avalanches wedge into each other to form a continuous avalanche belt of 3 km length. Snow deposit varies from 2 m up to 10 m. The road cuts through the terminal zone of avalanches and, therefore, receives huge deposits of snow. The soil is sandy clay and gets easily eroded by the thawing water and the river. The river, which is almost at the same level as the road, cuts into it easily at various sections.

Sector 'B' (27 km)

This sector of road traverses the southern side, starts ascending from 2720 m to 3529 m and then descends gradually to 3360 m. After crossing the watershed the road moves in the northerly direction.

The soil in the entire sector is sandy clay. The valleys all along are flanked with rugged mountains of towering height ranging from 4000 m to 5500 m and consisting of mostly granitic rocks. The road also passes through hairpin turns gaining quickly in height. Being one above the other, the turns pose a problem for snow clearance. The worst stretch of the road is at about 16 km, which offers the greatest problems in snow clearance work. High altitude, extremely low temperatures, heavy snow precipitation, fierce winds, incessant drift snow deposition and treacherous avalanche activity characterise this stretch of 16 km, making it virtually impassable and inaccessible during peak winter months. The snow deposit varies from 4 m to 30 m. It may be said without any exaggeration that every bit of this stretch is a potential avalanche site with its attendant hazards. In fact, any plan in this reach aimed at reducing the closure period or to keep the road opened throughout the winter must envisage construction of continuous RCC snow sheds or possibly a tunnel or similar structure for this stretch.

Sector 'C' (23 km)

This sector of the road traverses a comparatively wide valley except for a stretch of 7 km. The road alignment runs along the eastern aspect.

In this stretch the hill slopes are completely devoid of vegetation. The valley is flanked by high mountains having slopes of 25° to 60° with heights rising to as much as 6000 m. In this stretch, the road is crossed by numerous avalanches in their terminal zones. Some of these have long travel and deposit large quantities of snow on the road. Generally, this stretch is less problematic. The average depth of snow deposit varies from 3 m to 20 m.

Climatology

Climatically, the problem stretch experiences extremely low temperatures, heavy snow precipitation and fierce winds during winter months. Diurnal variations are quite high and vary from 10°C to 30°C. Typical observations at a location of the road stretch are recorded at Figure 2.

Temperature

The mercury starts dropping rapidly in the whole sector from October until the middle of February and then gradually increases. Generally December, January and February are the coldest months of the winter. The minimum temperature in the worst portion would probably be in the neighbourhood of minus 50°C. Due to the low ambient temperature and due to lack of direct sunlight, ice formation takes place during early winter and thawed water is solidified into ice slabs during night in late winter months. The mean temperature during 24 hours remains sub-zero during the winter months. It is unnecessary to over-emphasise the need for maintaining regular temperature data. No meaningful analysis can be made of avalanche activity and related matters in the absence of authentic records.

Wind

The entire sector is subjected to fierce winds during the winter months, particularly in the pass areas. Direction and velocities of wind recorded at the observation station do not bear any noticeable relation to those blowing at higher reaches. This is mainly because the winds are channelized along the valley by the flanking ridges. Winds are generally gusty and accompany the snow falls quite frequently. During November to February, snow deposition occurs by wind drift resulting in the formation of avalanches. The wind velocity in some of the worst reaches would probably be 100 km/hour or even higher. In some stretches, there is no set pattern of the wind direction. Maximum wind velocities are recorded during the months of February and March, which are also the maximum snowfall months. During early winters, the powdery snow is blown around in the form of snow clouds, reducing the visibility to near zero. It is almost impossible to face the wind and the feeling by men during this condition is that "some one is cutting your face with a sharp knife." The deadly cold is a menace for men carrying out the snow clearance by manual methods and in open types of machines.

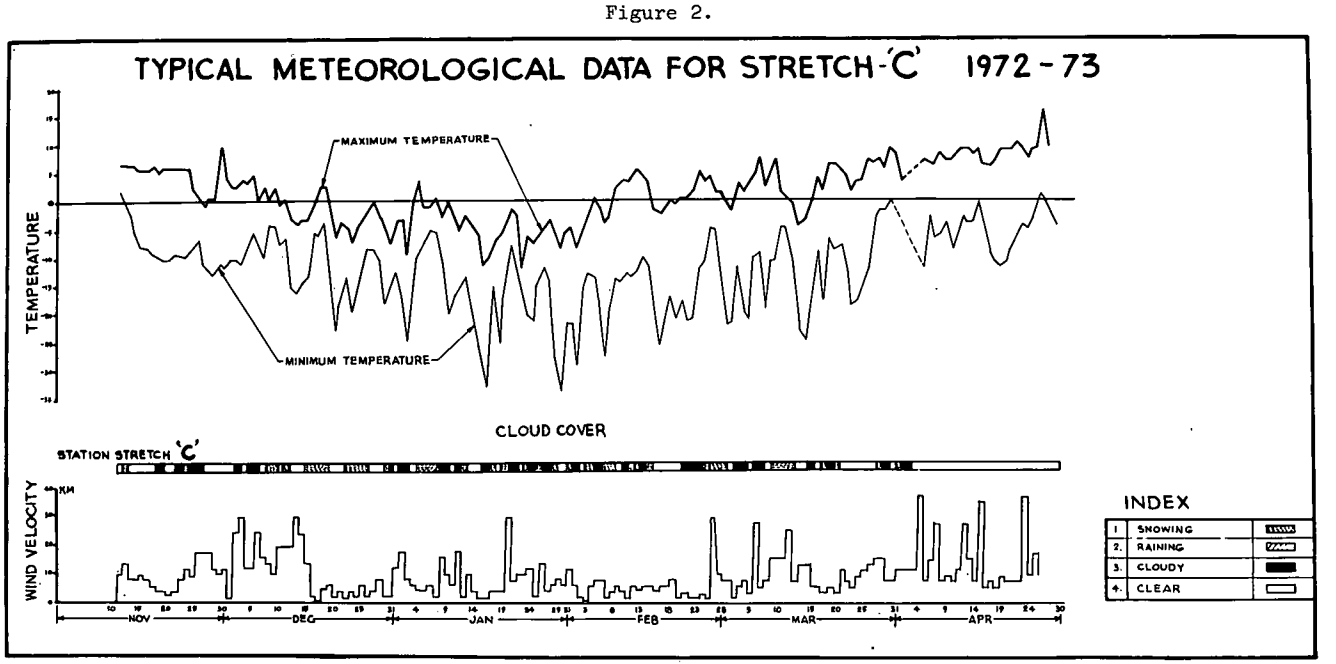
The number of clear days observed during June to April varied from 10 days to 20 days with hardly any possibility of carrying out continuous snow clearance operation. During non-clear days even driving of vehicles is hazardous in snow cleared roads.

Snow Observations

Snowfall data

Regular snowfall observations and data are essential for planning and designing any work related to snow clearance. Although long-term patterns of snow precipitation can be observed, there are years of lean and heavy snowfall like rainfall. There are areal variations and cycles too. The intensity of precipitation and daily totals are also very important. The "problem stretch" of over 70 km, being within "snow belt" receives heavy snow precipitation during winter. Generally, the entire section is subjected to heavy snow precipitation from November to April. At upper heights, snowfalls are experienced even

Figure 2.



during October and May. Precipitation is heaviest at the pass area and gradually decreases towards north or south of the pass.

In one of the stations south of the pass, the results of observation for five years is given at Table 1. From this, it will be seen that two or three consecutive heavy snowfall years were preceded by similar years of light snowfall. The total snowfall varied from as low as five metres to as high as twenty metres. The monthwise pattern which influences occurrence of avalanches also varies.

A typical snowfall record with its characteristics from November to April is shown in Figure 3. The snowfall over the pass would be much higher than this.

Intensity of fall

Generally January, February and March are heavy snowfall months. During these months two to three major snowfalls occur, the average intensity being 4 to 5 cm/hour, totalling a high figure of 200 cm in a period of two to four days. It is significant to note that quite often the intensity of snowfall rises to as much as 10 to 15 cm per hour extending over 4 to 5 hours, followed by intense snow avalanche activity in the vulnerable sites. The intervals of time between major snowfalls is of considerable importance as it is directly related to avalanche activity. Successive snowfalls at small intervals pose serious problems for planning timely snow clearance and to permit passage of vehicles. There is also the added hazard of heavy avalanche movement.

Snow characteristics

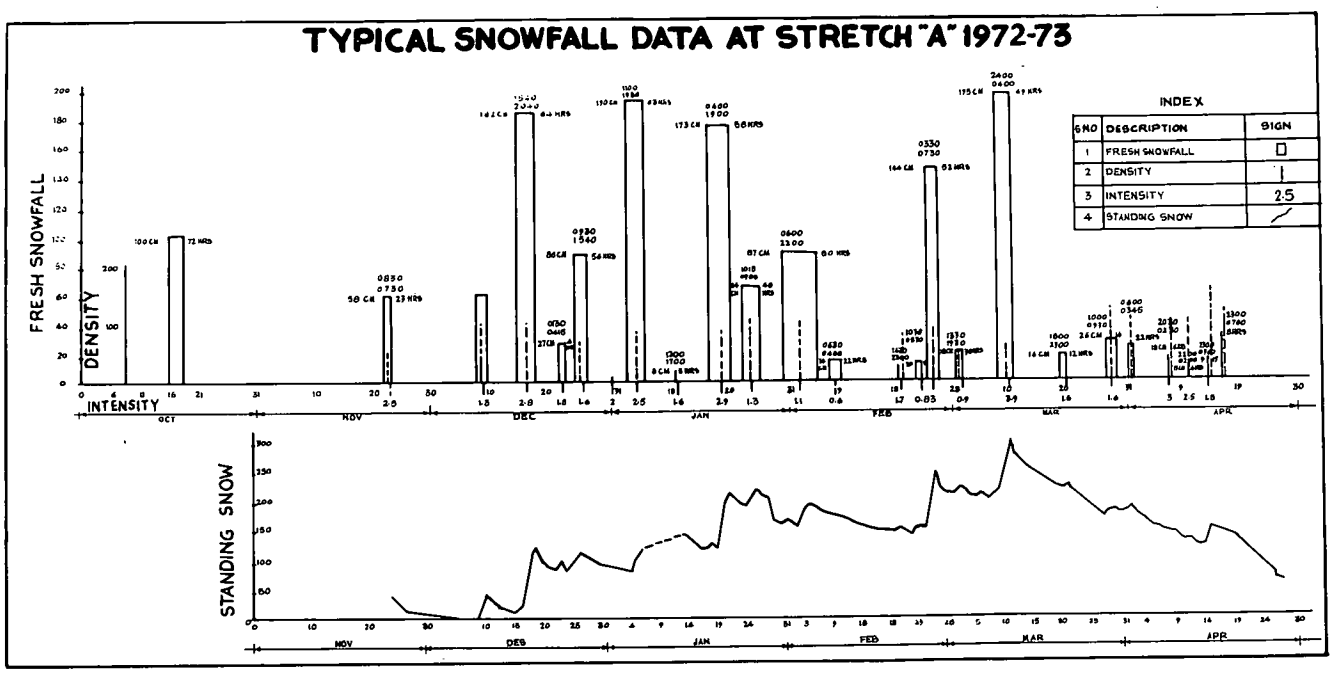
The density of the precipitated snow varies from as low as 0.05 g/cm^3 in November/December to 0.15 g/cm^3 in the late winter snowfalls. Low density snow during November, December and January is a major factor contributing to airborne avalanche activity and deposition of snow by drift. There is a gradual increase in the density of snow as accumulation takes place over a period of time. The rate of settlement of snow during the snowfall varies from time to time of the year. The rate of settlement observed varied from 0.2 cm per hour to 1.5 cm/hour in different months. This change is due to a variety of reasons, the more important of which are changed conditions of temperatures, humidity, irradiations of the sun and heat exchange through the ground. The density of standing, undisturbed snow has been found to be as much as 0.61 g/cm^3 which approaches the density of snow found in avalanches.

Structure of snow flakes varies from needles, platey crystals during early winter months and large-sized compound flakes of star, dendritic and stellar crystals during the later part. Snowstorms during March contain large quantities of soft hail which runs down quickly onto the road surface causing blockage.

Snow cover

The snow cover on the road is due to the combined effect of direct precipitation, snow slides, avalanches, bank slides and snow drift. Direct precipitation accounts only for depths varying from 1.0 m to 4.5 m at different stretches. Large deposits of snow on the leeward side of spurs are caused by winds carrying snow. The snow which is generally blown and carried from the adjoining peaks and high ridges is deposited to create what are designated as wind-borne avalanches. Formation of snow mounds up to a height of 1 m has also been observed. Even after the road is cleared, quick deposition of snow by wind drift blocks the road and holds up movement of vehicles; instances of long convoys stranded due to drift snow deposits are innumerable. With the available knowledge, it is not possible to predict the rate, place and time of buildup of snow due to wind drift even approximately, resulting in certain areas near the pass

Figure 3.



virtually becoming death traps during the months of November, December and January.

Ice formation

The phenomenon of ice formation on the road surface exists on practically the complete stretch of the road. Thin layers up to 0.5 m thick of ice formation on the road surface due to melting of snow during positive daytime temperatures and subsequent freezing during nights present a serious problem to vehicular traffic and clearance. The removal of these ice layers by rotary machines is impossible. The machines themselves skid and the blades get damaged. Even for a dozer, it is very difficult to cut these layers. The formation of ice also results in blocking the mouths of culverts and drains, resulting in spillage of water on the road surface and freezing into ice. At places, even subsoil water seeps onto the road surface and solidifies into ice slabs. The ice formation poses big problems in the proper maintenance of roads for which satisfactory solutions have still to be found. Added to this are the problems due to the snow left on the road sides and boxcuts during snow clearance by the machines.

Avalanches

The problem posed by avalanches in snow clearance is one of the single largest factors. In the preceding paragraphs, passing reference to the threat of avalanches has been made at relevant places. This problem is now dealt with exclusively in greater detail in view of its severity. Although direct snow precipitation is a cause of closure of the road, the duration of holdup is only for a limited period and is, therefore, capable of being tackled with well deployed snow clearance teams. The problems caused by avalanche activity are enormous in magnitude and complexity particularly as they are treacherous in character. This problem is acute in the pass area and one or two more stretches lying to the south and north of it totalling to 25 km. The suddenness of the attack is primarily due to the airborne avalanches which are very destructive and widespread, originating as they do and even from the opposite hills. Deaths and severe damage to property by such avalanches are now regarded as routine. Some of the recorded major avalanche sites are shown in Figure 1. Figures 4 and 5 show a typical avalanche site during and after snow clearance, respectively. Table 2 indicates the magnitude of snow clearance in quantitative terms which vary monthwise. Approximate estimates indicate that a quantity of 2 to 6 million m^3 would be required for clearing in the month of April alone. These figures give a fair idea of the work involved if the road is to be kept on throughout the year, as this operation would have to be repeated a number of times during the year.

Present avalanche data

The R&D Organisation team has collected substantial data on some of the avalanche sites which have been identified. An attempt has also been made to suggest remedial measures. The recorded data covers only a few years. Every year some new avalanche sites are identified. The data collected covers certain salient factors, viz the nature of the originating zones, catchment areas, vegetation, steepness of slopes, soil condition along the

Figure 4.

Figure 5.

avalanche path and their longitudinal section and other important features of these sites. It is seen that in a number of cases the avalanche paths are confined only up to short distances after which they become unconfined and spread out in the form of detritus fans. The lengths of avalanche paths vary from 1000 m to 1500 m. The starting zones are located at altitudes varying from 3800 m to 4400 m. The road crosses some of the avalanche paths in their middle zones and in some cases at the terminal zones. In the critical stretch of road of over 70 km, the identified number of major avalanches (which extends at least 50 m along the road) is about 90, the medium and minor avalanches are about 50 with numerous slides. In certain stretches on either side of the Zozila Pass, the conditions of snow precipitation, drift snow activity, extremely low temperatures, steep side slopes and high velocity winds render the entire sector highly prone to avalanches, particularly of the airborne type. In fact, this sector is truly the crucial problem sector where every bit of it can be regarded as a potential avalanche site. A number of fatal accidents have occurred in this area.

Forecasting avalanches

Much research work is known to have been done outside India on making reasonable forecasts of the onset of avalanches. Attempts are being made in this direction by the Snow and Avalanche Study Establishment of the R&D set-up. The studies referred to above are already related to observation of snowfall, terrain and climatic conditions which vary from year to year as any system of prognosis has to take due account of all these variables. As more and more vital data become available and analysis of these are made, it will be possible to draw up reasonable guidelines for prognosis of avalanches.

Snow Clearance Equipment

In any mechanised work, the efficiency of execution depends on the suitability of the operational machinery, the skill of operation, maintenance and other factors. As snow clearance work in this country is comparatively new, reliance has to be placed on machinery used outside the country, until improvisations become possible. Most of this equipment though not ideally suited to prevalent conditions in this sector, have to be accepted for want of another suitable indigenous alternative. The various types of equipment presently used for the snow clearance operations are:

1. Crawler tractors
2. Rotary snow cutters
3. Motor graders
4. Wheeled tractors

Out of the above equipment, rotary cutters are specially meant for snow-clearance. Special features, their merits and limitations as per our ground experience are discussed below.

Crawler tractors

The relative advantages and limitations of crawler tractors which are essentially used for dozing work are as follows:

Advantages

1. They can be utilized in other than snow clearance operations reducing the idle depreciation.

2. As they are on tracks, they do not slip on snow and can transmit considerable tractive effort.

3. They have good maneuverability and turning radius especially for restricted locations.

4. The presence of boulders and rock pieces in snow and glaciers does not affect their performance.

5. They can conveniently tackle the hardest snow except frozen ice.

6. Output of tractors varies from 1000 to 1200 tonnes per hour.

Limitations

1. Since it is a tracked vehicle, it damages the road considerably if sufficient precautions are not taken during snow clearance. Normally 15 to 30 cm depth of snow could be left in the initial clearance to reduce the damage. However, in subsequent moves for clearing stone-infested avalanches the road surface gets damaged badly.

2. No closed cabin is provided as a result of which the efficiency of operator gets reduced due to weather conditions. But this disadvantage sometimes proves a blessing in disguise as it facilitates operators' visibility and in times of avalanches falls, the driver can jump and escape to a place of safety.

3. Difficult to transport.

Rotary Snow Cutters

This organisation has had the benefit of using rotary snow cutters of different manufacture. While each particular piece of equipment has its own special advantages, certain limitations are also inevitable to meet the special locational requirements. The more important aspects of the above are discussed below.

Advantages

1. They can attack snow up to 3 m high.

2. They are generally highly maneuverable.

3. They have builtin cabins which keep the operator quite comfortable during snow clearance in severe winter conditions.

4. Their output varies from 500 to 800 tonnes per hour on soft snow.

5. Being mounted on wheels, they do not damage the asphalted road surface.

6. The cutter height can be adjusted so that not more than 7 mm snow on the surface is left.

7. Unlike a tractor, these discharge the cleared snow into the air through a chute which is adjustable on either side of the road and can cut a nice box out.

8. They generally require only the operator.

9. During idle season, some of them can be converted into payloaders and can be used as cranes, reducing the idle depreciation.

Limitations

1. As they are mounted on pneumatic wheels, they tend to be slippery on ice and hence non-skid chains will be required.

2. They cannot be used singly on glacier sites and have to be used in conjunction with a dozer.

3. In the rotary cutters fitted with shear-pins this often gets sheared off when stone fragments are not within the snow mass. Hence, frequent stoppage and replacement of shear-pins will be necessary in such machines.

4. These are not ideally suited for snow mixed with stone fragments.

5. In machines which are water cooled, sufficient care is necessary to prevent engine bursts due to a solidification of water.

6. In some machines width of road cut is not adequate to take heavy vehicles. Perforce machines have to do two cuts involving additional movements, or alternate use of two machines is required.

7. If the snow is hardened and very dense their cutters get damaged and they cannot cut.

8. If the snow deposit is wet their chutes get choked very frequently resulting in loss of time.

Other equipment

Many other kinds of equipment made by other countries, such as wheeled dozers and motor graders are also used but with limited success. Hence, they are not elaborated upon in this paper.

Snow Clearance

As emphasised earlier, the problem is to study and find solutions to keep the Srinagar-Leh road open throughout the year instead of six months, as at present. No piecemeal solutions will answer the requirements; the problem has to be tackled in its totality to arrive at the most economical and feasible solutions. As already stated, steps have been undertaken towards finding long-term remedial measures.

A brief description of the present snow-clearance technique adopted, the organisation, the type of machines with their characteristics, and the problems encountered are given below.

Operation

The snow clearance teams commence the clearance work during first week of April and open the road to traffic by the end of May every year. It is clear from the earlier chapters that snow clearance operation on this road is a major task full of hazards and, therefore, needs advance planning and coordination for execution. In order to ensure smooth and orderly progress during snow clearance, considerable preparatory work has to be readied from middle-October onwards. Some of the more important steps that are taken in the preparatory works are summarised below.

1. Checking up serviceability of snow clearance equipment, snow blasts, rotary cutters, crawler tractors, vehicles and availability of manpower, etc., and their placement before the onset of snow, especially for the north sector.

2. Advance procurement of spares for imported and local equipment, vehicles, etc.

3. Procurement and storing at suitable places of winter grade fuel, lubricants, starting aid capsules, etc. It is pointed out that the approximate quantity of diesel sub-zero that has to be stored every year for tackling this single stretch is about 0.2 million litres.

4. Procurement of winter clothing and heating stoves to men, as well as to machines and equipment, which also need to be warmed up.

5. Procurement and storing of ration items.

6. Procuring and fixing of road marking pillars at intervals and in difficult stretches of road to help with the identification of road alignment.

7. Procuring and installing markers in avalanche-prone zones.

8. Building suitable fresh shelters for the snow clearance parties wherever required.

9. Laying out actual campsites with high markers to identify the same in the snow deposits.

10. Improving the drainage system before the closure of the road.

11. Dismantling any special structures, viz bridges, etc., in avalanche-prone areas and making suitable diversion.

Organisation

The snow clearance work of the problem stretch of 80 km of road is tackled from the south up to the pass and also from the north. Each sector is adequately provided with the required number of men, staff and machinery for the clearance work. All requirements mentioned in previous paragraphs are ensured to be in position by the 15th of every year. The deployment of men and machinery is shown in Table 3.

Methodology

Snow clearance operations adopted on this road consist of a judicious combination of men and machinery. Men are basically employed to help the machines at difficult spots of hazard, warning operators where necessary, and for machine maintenance and repair. Drainage improvements and pavement marking maintenance jobs such as deicing, etc. are also carried out. The main snow clearance is carried out by the machines.

The snow clearance work is commenced from both faces more or less in the same pattern. A crawler tractor or rotary cutters are used, depending on density of snow and the overburden of snow. If the standing snow height is less than 3 to 2 m then the ideal combination would be to lead with a crawler tractor with a road guide on it. After the initial alignment cut, the tractor is followed by combinations of one crawler tractor and two rotary cutters. The crawler tractor loosens the snow and feeds both the cutting machines. These latter can cut and as well as throw the snow fed by the tractor. This method was tried in the working season of 1975 and was found to be quite suitable in most of the stretch.

Where the depth of the deposit was less than 2 m and not interspersed with stones and boulders, use of two rotary cutters in tandem (to obtain full width of road for a 3 ton vehicle) proved better. In this method, the crawler tractor pushed up to the nearby avalanche sites (if any) or opened new faces at intervals of 200 to 300 metres for deployment of additional cutters. This combination helped in preserving the pavement structure from damage. Also, the quantity of snow removed from the road surface would be smaller, as compared with the

Table 1. Total snowfall at a typical location (cm)

Month	1965-'66	1966-'67	1968-'69	1971-'72	1972-'73	1973-'74	1974-'75	1975-'76
October	---------- Not recorded ----------				100			
November	32	Nil	not recorded	26	58			
December	36	40	88	72	358			
January	9	107	157	308	435			
February	185	296	269	349	269			
March	313	253	116	373	255			
April	45	not recorded	200	139	84			
TOTAL	520	696	830	1267	1559			

Table 2. Typical deposition of snow on road.

Stretch	Monthwise snow accumulation in cubic metres									
	December		January		February		March		April	
	Aval.	Direct	Aval.	Direct	Aval.	Direct	Aval.	Direct	Aval.	Direct
'X'	2895	34200	3840	5400	7742	76200	9600	66200	11000	63000
'Y'	12000	38000	30000	56000	30000	74000	35000	87000	47000	53000
'Z'	40000	28000	56000	30000	74000	35000	87000	46000	53000	-

Table 3. Organisation of snow clearance groups

Serial No.	Item	North Group	South Group
1.	Supervisory staff officers/subordinates	6	8
2.	Technicians (mechanics, electricians, etc.)	8	5
3.	Plant operators and drivers	30	25
4.	Medical officer and assistants	3	3
5.	Unskilled labour	200 - 500	200 - 500
6.	Plants:		
	(a) Tractor with angle dozers size I	5	6
	(b) Rotary snow cutters	5	5
7.	Vehicles:		
	(a) Jeeps, closed body including ambulance 4x4 with non-skid chains	3	3
	(b) 1 ton vehicle, 4x4 with non-skid chains	2	2
	(c) 3 ton vehicle, 4x4 with non-skid chains and heating arrangement	3	3
8.	Radio station	2	2
9.	Camping site kit with snow tents, heaters, cooking arrangements, etc.	2 sets	2 sets
10.	Fuel pumps with suitable filters for quick refuelling of plants directly from the vehicles	2 nos	2 nos
11.	Salts for use in icy area	1 ton	1 ton
12.	Winter heavy clothing including snow goggles, etc.	Full	Full
13.	POL and lubricants dumped various known locations	0.1 million litres	0.1 million litres

clearance by a tractor. This method ensures full utility of all the machines. A number of trial combinations were made to find out the most suitable alternative for a given situation.

In heavy avalanche sites, this combination of tractor and rotary cutter was found to be most suitable. Even in shallow valley stretches, where box cuts are required to be done, this combination proved to be most economical.

Where the standing depth of snow is more than 3 m, the rotary type of cutters by themselves are generally not capable of doing the task due to their limitations. In order to achieve linear progress, only one carriageway in the width of the road is cleared of snow except at a few passing places and the rest of the snow is allowed to be melted away by the natural heat.

One or two tractors accompanied by one or two rotary cutters have to be left in the portions already cleared to clear any fresh avalanches, slides and fresh snow deposits or drift snow. This is very essential to keep communication to the camp sites for evacuation of casualty - a fact which should be thoroughly borne in mind. Figures 6, 7, and 8 show some of the combinations of machines deployed in this region.

Figure 6

Figure 7

Figure 8

Special problems

Problems faced by the field staff to keep the road open have already been sufficiently detailed; however, certain special problems in addition to those described earlier are enumerated below.

1. Realignment of stretches of road to avoid shallow valleys is quite expensive but even so will not completely solve snowfall problems.

2. Afforestation will be useful, but it is a matter for experts in the field to say whether this is possible in the climatic conditions of the region.

3. Stabilisation of hill slopes, especially at stretches where the rock is fragmented and soil is loose, is quite expensive.

4. Extreme cold, gusty winds, blizzards, uninhabited snow mountains with hardly any sunshine for days on end produce adverse psychological effects. Further, the climatic conditions result in a number of physical disabilities like hyperthermia, exhaustion, frost bite, sun burns, snowblindness, etc., all of which are effects of high altitudes. This reduces the efficiency of men employed. Such handicaps have to be removed by suitable preventive measures.

Control Measures

There are no known methods by which natural calamities like floods, cyclones, avalanches, etc. can be completely eliminated. We have to admit that in problems like these ultimate and complete safety cannot be assured. As with flood control measures in India, which have improved as the country has developed, the control measures to mitigate snow hazards on the road in question are being gradually developed. There is, however, scope for the control measures to be intensified, so that most of the hazards can be checked to a large extent.

There are a number of control measures which are in vogue in various foreign countries. Some of these techniques have been tried with success on the road in question but only on an experimental scale.

The control measure generally include braking, containing, channelization and diversion of avalanches. Prevention of drifting snow by afforestation, baffles, snow fences, diversion barriers and channels has also been found to be useful. Activating avalanches by explosives and artillery fire, construction of snow avalanche sheds, and tunnelling are also well-known control measures.

A comparatively recent development is the prognosis of avalanche onset which has already been referred to. Methods have also been developed to identify avalanches which are likely to advance, after the lapse of an estimated interval of time. Such avalanches can be activated and put into motion to suit the programme of snow clearance operation. Construction of bunds at intervals along the avalanche path has also proved to be successful on the road in question.

Suggestions for Future Improvement

The foregoing paragraphs clearly indicate the magnitude and complexity involved in maintaining the high altitude roads which are of vital importance to the economy and related matters of the country. While the long-term solution should await adequate organisational and institutional arrangements to be completed, it would be advisable to undertake expeditiously the more important corrections for future improvement as given below.

1. The broad lines on which the existing organisation has to be strengthened have already been referred to. Immediate action should be taken by the above setup to collect further salient meteorological data and carry out such other ground surveys as may be found necessary.

2. As a first step, a high altitude laboratory should be set up to locate vital observation stations.

3. A thorough techno-economic study should be initiated to compare the present working costs versus maintenance of a year-round road with ancillary structures and the recurring maintenance costs.

4. A system for quick analysis and dessemination of the data collected should be developed to facilitate operations by snow clearance parties on field.

5. Much is required to be done in design of snow clearance equipment. Ideal snow clearance equipment for this region should be able to cut through soft to very hard snow (density 0.1 g/cm^3 to 0.6 g/cm^3 and break ice sheets. The equipment should be capable of cutting and throwing off snow of depths of 1 metre to 30 metres. They should be capable of removing snow interspersed with stones and boulders by the addition of an automatic angle blade or some digger attachment. This attachment should be capable of being activated by pressing a lever or a switch. It should also be capable of negotiating gradients of 45° on ice slabs and cut through snow. This may have to be a combination of a tractor with tracks and rotary cutters. The machine should be capable of changing from tracks to pneumatic wheels as the situation demands by operating suitable controls.

6. The tendency of snow throwing chutes to get choked while working with wet snow deposits should be reduced by a suitable design of impellers and chute system.

7. A very useful type of light snow vehicle would be one that can travel on soft snow, hard snow or ice slabs, move fast and be capable of negotiating steep gradients up to 45°. Such a vehicle would facilitate evacuation of casualties quickly and would carry out day-to-day reconnaissance of the road stretch.

8. Sufficiently high snow markers and electronic devices should be designed to locate the road stretches at avalanche sites and at locations where snow deposits exceed 6 m in depth.

Conclusion

The construction of highways at high altitudes and their maintenance in the snowbound regions is a comparatively new development in India. The foregoing paragraphs leave no doubt that the complexities and hazards it opens for traffic, even for a limited period of a few months in a year, are gigantic. The road in question is a typical example which bristles with all the challenging problems.

The challenge for the future is tremendous. The possibilities of meeting the challenge are unlimited, both for design by research engineers and manufacture of equipment by the construction industry. These have been dealt with at length in the body of this paper. Although rapid strides have been made in India in the efficient maintenance engineering of high altitude roads afflicted with snow problems, we cannot stop until we achieve an acceptable measure of efficiency but should continue our efforts in gradually improving on what we have already done. Suggestions have been made on what should be done to achieve the long-term objective of keeping such vital roads open for traffic year-round, although interruptions can occur due to circumstances beyond human control.