ANALYSIS OF PROCESS ORIENTED AVALANCHE FORECASTING TECHNIQUE FOLLOWED AT SASE, MANALI, INDIA

A.Ganju, D.K. Prashar, Naresh Thakur*

Abstract: Avalanche forecasting technique followed at SASE has evolved with experience, knowledge and science. Starting with the simplistic approach of snowfall related avalanche events; the scientists at SASE experimented with contributory factor approach and statistical approach of forecasting avalanches. Gradually with the experience and knowledge, an integrated process oriented approach was adopted. Avalanche forecasting using expert system is yet to be evolved at SASE. The paper describes the semi-quantitative process oriented approach experimented on a road axis in Kashmir and discusses its strength and weakness.

1. INTRODUCTION

The avalanche forecasting technique world over is practiced by a handful of experts. In spite of the development of many tools in this field, the reliance of the experienced forecaster has not lessened. The reason, why none of these tools are exclusively used for avalanche prediction, is very simple. The factors, which influence the formation and release of avalanches, are not fully known. And worst so, the known few factors can not be determined accurately. Since the information is incomplete, the models so developed are also incomplete. Statistical method, based on the past data of a region does not find universal application. In India, statistical approach could not progress due to the insufficient record of avalanche occurrence from different regions. Obviously, an integrated approach based on processes, reasoning field knowledge and the science found wider applications, not only in India, but in other countries too. The approach however, suffers from subjectivity, and relies heavily on the ability of a forecaster in a particular region. SASE adopted a snowcover build up approach with an aim to train its practitioners in understanding the basic processes, apply local knowledge and experience to predict avalanches. Combining this approach with the contributory factors and other statistical tools, the technique has yielded better results.

2. FORECASTING TECHNIQUES

Conventionally avalanche forecasting has been attempted by assessing the current stability using contributory factor approach Perla (1970. These factors were later on classified into three categories viz. terrain, snowfall and weather LaChapelle (1980). Terrain factor being somewhat fixed; it is the snow and the weather factors, which have been investigated in detail. The snowpack factors which have been considered, are the old snow depth, nature of old snow surface, existence of weakness within the snow pack, bond between old and new snow pack, quantity, density and crystal type of new snow. Similarly the current and future weather elements like wind speed and direction, precipitation intensity, temperature trends and snowfall amount have been considered important future weather elements.

The other technique where considerable efforts have been made to predict avalanches is statistical approach. Here the avalanche occurrence is predicted as an event. The various methods that are in practice are 'Deterministic Method', 'Nearest Neighborhood Method' and other 'Statistical Method'. All these methods require sufficient information of previous avalanche occurrence to stabilize the model.

The major drawback in statistical approach is that an event predicted does not give any indication of the type of avalanche. This predicted probability of an avalanche needs further interpretation by an experienced forecaster to use the statistical information efficiently. Hence various statistical methods have been used only to supplement the information, otherwise obtained through conventional contributory factor approach. Besides that, statistical methods in isolation have not been found suiting the operational requirement. Contributory factors approach, though still widely practiced, is qualitative and suffers from the lack of objectivity. This

Ashwagosha Ganju, Scientists D, Snow and Avalanche Study Establishment Manali, Himachal Pradesh India; tel.: 0091-1733-53508; fax: 0091-1733-53510; email: agg@sasehq.ernet.in

method can not explicitly bring out the complex mechanical and thermodynamic processes, which snow pack undergoes. In consideration of the above difficulties, efforts have been made to develop a process oriented snow cover and avalanche-forecasting model. Here the snow cover is built up layer-by-layer using snow and meteorological data of an observatory and based on the evolving snow pack structure, avalanches in the area where observatory is located, are predicted.

3. METHODOLOGY

The first step in the avalanche forecasting using process-oriented approach is to evolve a snowpack using easily measurable snow-meteorological parameters. The evolution of snowpack at any place requires the calculation of standing snow in the first place. This involves densification of snow using simple settling law. While a settling law for all types of snow has yet to be found out, the assumption of Newtonian deformation with certain empirical constants does fairly represent a wide density range of seasonal snow in predicting its deformation (Ganju et al 1994). The structure of evolving snowpack is determined qualitatively using the field results of Armstrong (1985). The presence or absence of weak layers is estimated by following the snowcover evolution using energy exchange process and interaction of meteorological parameters with evolving snowpack. The estimated snowpack structure thus evolved semi-quantitatively is compared with the actual snow pit observation made once every week at the observatory site. The discrepancies, if any, are corrected and the evolution is once again followed till next stratigraphy day. Over a period of time, an avalanche forecaster gains enough confidence in building up a snowcover at observatory using easily measurable snow-meteorological parameters. Having achieved that, an attempt is made to build up a snow cover at formation zone of avalanche sites. This snowpack and ground information of erosion and loading zones, forest cover, avalanche occurrence etc. helps in assessing the potential avalanche zones in an area.

The main drawback with this scheme is that it cannot be followed at all avalanche sites and the evolution of snowpack at formation zone becomes erroneous when feedback on its occurrence/non-occurrence does not reach the forecaster in time. Alternatively, grouping of similarly behaving avalanche sites, based on past avalanche occurrence records, is resorted to facilitate evolution of snow-cover at selected places only.

The evolution of snow cover at Stg-II (Jammu and Kashmir) during peak, lean and normal winter vis-à-vis, process oriented approach of avalanche forecasting is given in the succeeding paragraphs.

4. CASE STUDY

Station: Stg-II (CC1 Axis). CC1 road axis, on outer Himalayan Range, (52 km long) with an east-west alignment winds its way across a mountain range Fig-1.

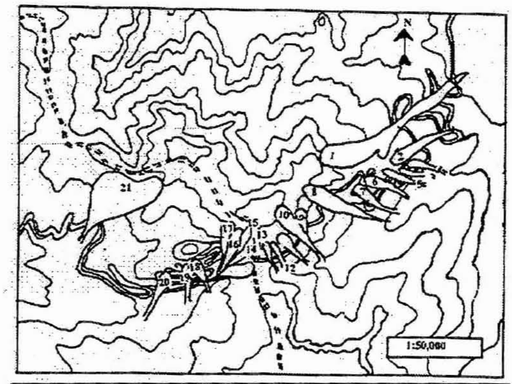

Fig 1. Avalanches affecting CC1 Rd-axis

26 avalanches, out of which 12 are in eastern side of the Pass and 14 in western side of the Pass affect this road axis. The altitude variation of the road across the range is given in Fig-2. This figure also depicts the average altitude variation of different avalanche sites.

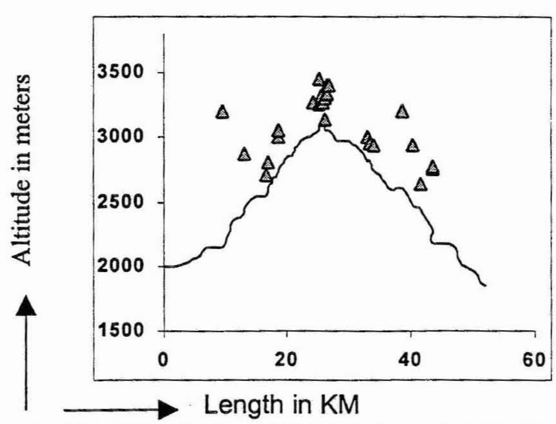

Fig 2. Altitude variation of road and F.Z of avalanches

The area from eastern end of the road at the foothills of the range, to the Pass is characterized by heavy snowfall whereas the area from the Pass to western end of the road is characterized by least snowfall. 14

avalanches have road passing through formation zone. The average build-up of the snowcover on the road from east to west, based on the data collected by SASE reconnaissance party is given in Fig-3.

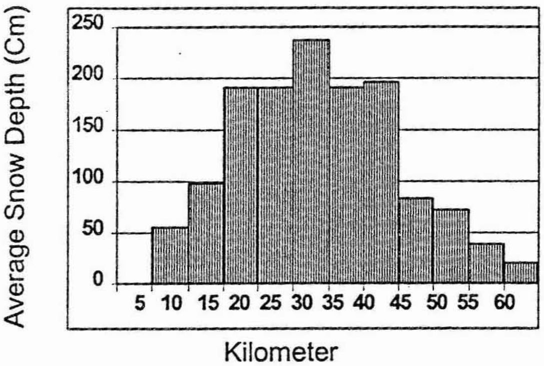

Fig 3. Average snowcover build-up.

The meteograph depicting average meteorological conditions and average frequency of the release of different avalanches in a season is given in Fig-4.

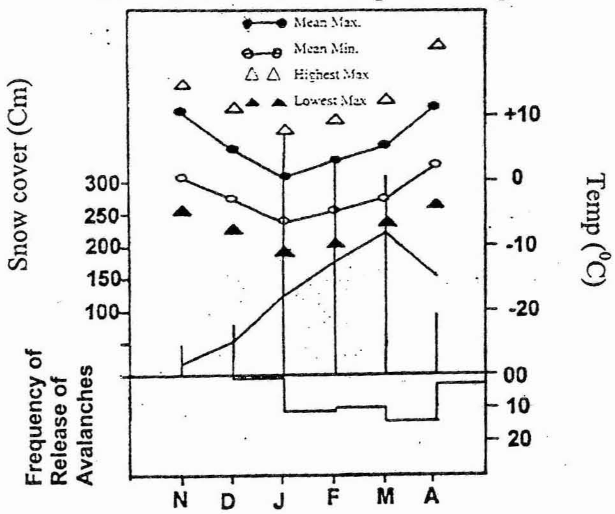

Fig 4.Meteogram of StgII (2650m)

The ground information pertaining to snow drift loading pattern and the release zones of various avalanche sites on this axis has been compiled and is used for predicting wind slab avalanches (Agrawal et al 1994). Armed with the terrain details, local knowledge and data of Stg-II of three winters, the snow cover build up at an observatory is followed.

The snow cover build up of three diverse winters is shown in Fig-5,8 and 9.

The general deductions of three different types of winters are given in subsequent paragraphs.

4.1 *Normal winter (1993-94)*

A good snowfall in the early winter, followed by frequent minor spells develops generally into a stable snowpack on a level ground. The lowermost layers with every addition of fresh snowfall gains strength. The weaknesses are introduced subsequently due to formation of weak layer (surface hoar, for example) on a cold thin crust or over a cold snow layer etc. The ram values of the snowpack at different time intervals Fig 5

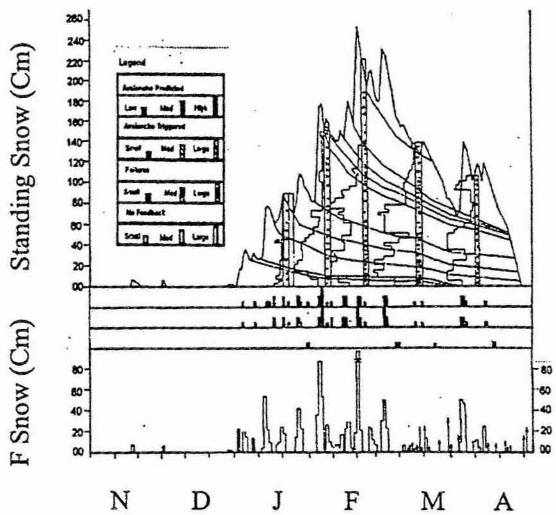

Fig 5. Snowcover build-up and avalanche activity

follow a definite pattern with wide base, a constriction in the middle and staircase structure above it. However, there are numerous variations possible within the same framework as can be seen from the ram value record of last few years of the same station Fig-6.

The ram values of the pit profiles taken at the formation zone along with the ram values at the level ground of the same year are given in Fig 7.

The sudden rise in temperature from mid February warms the whole region and snowfall is often accompanied by drizzle from mid March onwards during normal winter conditions.

The avalanche activity generally commences from steep slopes in the beginning followed by some of the massive releases from moderate slopes during February. The avalanche activity after February is generally observed on bright sunny day following a moderate snowfall. The snow accumulated as tree intercepts during the storm often releases on bright sunny day following a storm and

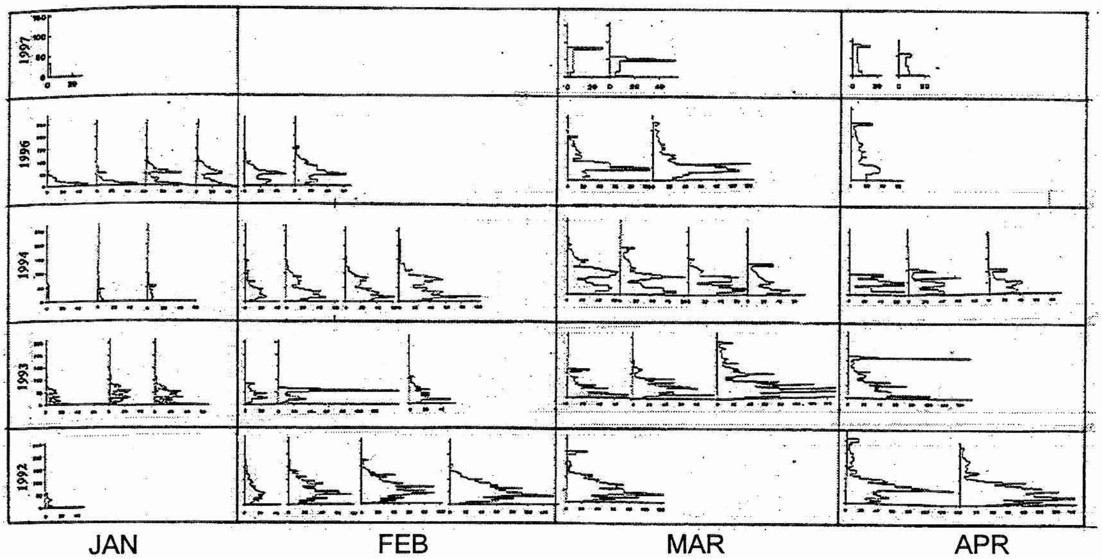

Fig 6. Variation of Ram Profile in different months recorded at StgII

initiates at times massive avalanches from some slopes. A few slopes oriented in southeasterly direction accumulate drift snow, thereby, release frequent slab avalanches. Similarly western flanks of a few avalanches trigger frequently with every snowfall of 30-40 cm of fresh snow. All of the above is observed during normal winter conditions. Deviations in peak and lean winter are described in the subsequent paragraphs.

4.2 Peak winter (1995-96)

Generally same conditions as observed in normal winter are found in peak winter. A wide base ram values tapering to the top during early period followed by weak middle and stable top and bottom are the characteristic profiles that are observed during the early period of peak winter.

The bottom layers transforms to melt freeze grains with marginally higher water content thus producing weak bottom during March (Fig 8). The snowpack at the observatory site (2650 m) becomes isothermal at zero by March end. The avalanches trigger both as a result of excessive overburden on slopes and failure of weak layers (5-6 times) during winter and each major storm releases 2-3 waves of avalanches from some slopes. The snow pack at the formation zones generally evolves with less ram values than at observatory site. Often surface hoar layer has been found developing during mid winter period and it is assumed that massive releases following its burial by fresh snowfall could be attributed to the weak layer failure related avalanches.

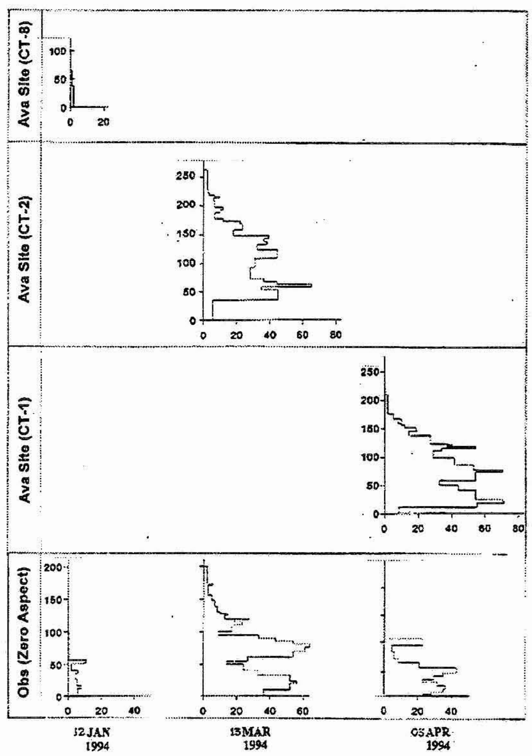

Fig 7.Comparison of Ram profile at F.Z Vs Ram Profile at Observatory.

4.3 Lean winter (1996-97)

Two minor snowfall events during December melted completely from southern slopes. In shady areas, shallow snowpack was found in patches that had developed sugar grains. Late winter build up from 18 Jan under cold condition evolved in to a weak structure Fig-9. With every minor snowfall (<30 cm), minor

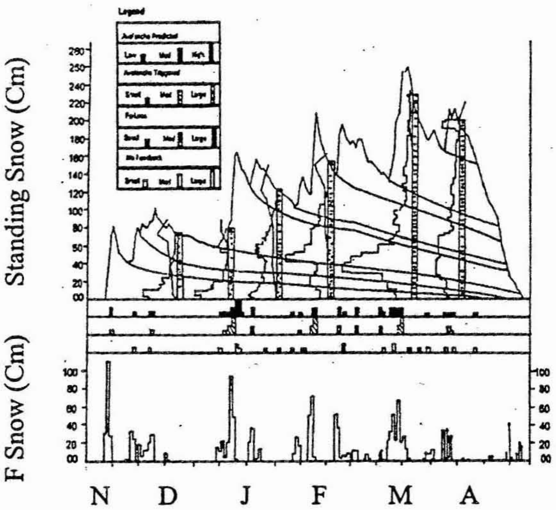

Fig 8. Snowcover build-up and avalanche activity

avalanches triggered from all possible slopes. The late winter period terminated abruptly in April with increased amount of rain. The lean winter, as can be deduced from above, does not imply less avalanche activity. The situation often results in more casualties than normal winter conditions as an individual is tempted to venture in all directions quite ignorant of the frequent development of depth hoar layer within the snowpack.

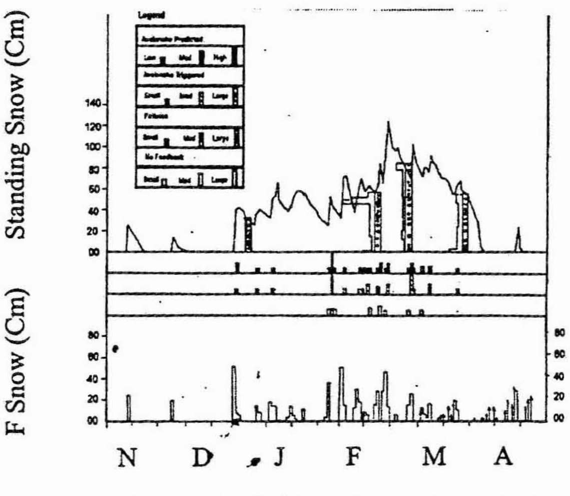

Fig 9. Snowcover build-up and avalanche activity

5. COMPARISON OF SIMULATED VERSES ACTUAL SNOWPACK

Following the methodology described above the simulated snowpack of three different types of winters was evolved and compared with the actual observations made in the field.

In case of normal snowpack, the simulated snow profile matches fairly well with the actual observed snowpack. The simulated snowpack with the deduced structure and the actual weekly stratigraphy data of the station has been shown in Fig10.

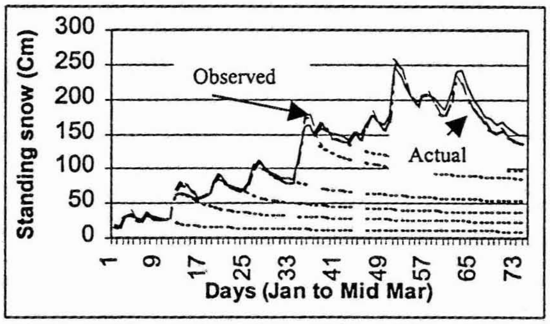

Fig 10. Simulated Vs actual snowpack (Normal Winter)

Except for minor variations in the layer positions and the appearance of some additional layers, the normal winter simulated snowpack matched well with the observed snowpack.

The simulation for formation zone conditions, however, posed many problems. An attempted simulated profile with an observed reading is shown in Fig11.

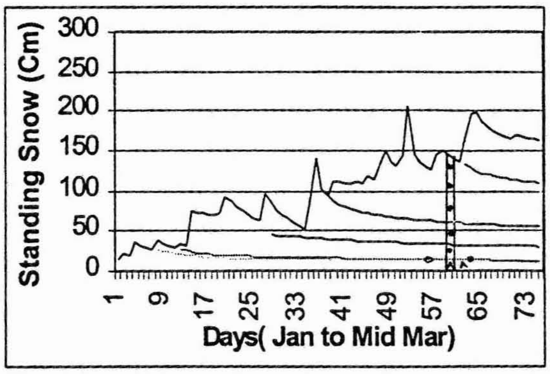

Fig 11. Simulated snow cover at Formation Zone of an avalanche site

Notwithstanding the difficulty of assessing the structure of snowcover at formation zone, an avalanche forecaster can draw useful deductions by keeping a close track of avalanches triggered during the winter.

Similarly an attempt was made to simulate snowpack structure of a lean as well as a peak winter. The result of peak winter with actual stratigraphy conducted at a field station has been shown in Fig 12. From these figures it can be clearly deduced that simulation of snowpack, if modeled correctly can provide very useful information in the prediction of avalanches.

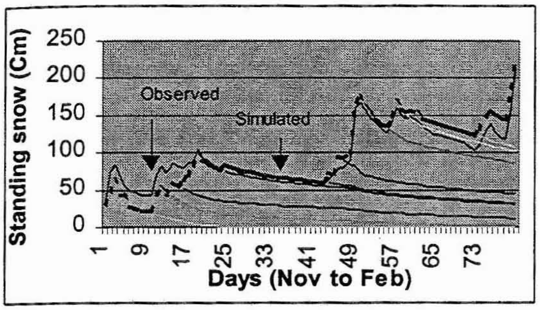

Fig 12.Simulated Vs actual snowcover (Peak Winter)

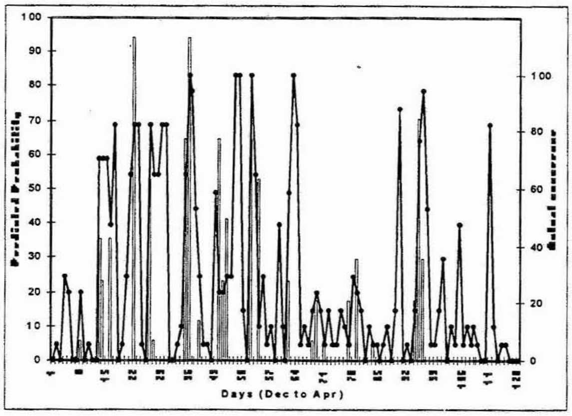

Fig 13. Results of NN Model (% probability) and actual magnitude of avalanche occurrence observed.

6. CONCLUSION

Avalanche forecasting in any of the area cannot be attempted without the full knowledge of terrain and the process producing avalanches. All other tools can be taken as aids, which help in reinforcing your own judgement. Avalanche forecasting of a road axis in Jammu and Kashmir based on process oriented approach and field knowledge gained over a period of time has helped in accurate avalanche prediction in a region. While it is difficult to construct a snowpack structure at formation zone altitude based on snow-meteorological data of a base station, yet this approach has an edge over other techniques where often one is found groping in the dark. By process-oriented approach and the field knowledge, avalanches on a road axis in Jammu and Kashmir have been predicted accurately as shown in the table 1.

TABLE 1

S. No	Year	Avalanche Accuracy in Percentage
1.	1990-91	80
2.	1991-92	74
3.	1992-93	73.5
4.	1993-94	85
5.	1994-95	40
6.	1995-96	85
7.	1996-97	89

In combination with the results of NN Model Buser (1983), as shown in Fig 13, the prediction of avalanches using process oriented approach can be attempted with reasonable success.

No doubt, all avalanche sites behave differently and trigger during different hours on different days even when terrain conditions are alike, but predicting occurrences of each site separately is not what is being attempted through process - oriented approach. It builds up a snowpack structure at formation zone, which may not be entirely correct, and predict avalanches based on evolved snowpack structure, knowledge and other factors. Thus what has been assumed to have finally caused an avalanche, may not be exactly same but the potential of threat can be foreseen. Again forecasting based on the process - oriented approach is not for a single avalanche. It is the group of avalanches having similar terrain and behaviour, the forecast is issued for. The average frequency distribution of different avalanches on this road axis is given in Fig 14.

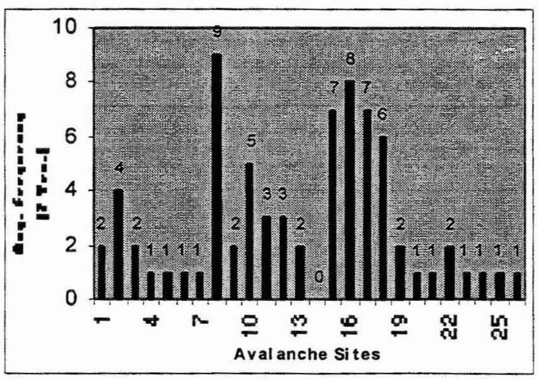

Fig 14. Frequency distribution of avalanche sites on CC1 axis

While most of the avalanches trigger less than four times in a year, only few avalanches have frequency as high as 6-7 time in a year. One avalanche site (CC1-8) triggers with almost every snowfall event.

7. RECOMMENDATIONS

Avalanche forecasting may be attempted through various tools in years to come, but a forecaster without assessing the various processes that could release avalanches would not find himself at ease with the prediction drawn exclusively using numerical techniques. In order to use this technique very efficiently, it is imperative to have a good snowcover simulation model with an in-built mechanism of diagnosing weak snowpack structures. The model that would assess the stability of the snowpack on different slopes would prove to be the most beneficial tool when integrated with other numerical tools and an expert system for the prediction of avalanches.

8. ACKNOWLEDGEMENT:

The authors wish to express sincere thanks to scientific assistants of Avalanche Forecasting Group for the help rendered in compiling the data. The authors are grateful to Director SASE for encouraging us in producing this paper.

9. REFERENCES:

Armstrong, RL (1985). Metamorphism in a subfreezing seasonal snowcover – The role of thermal and vapour pressure conditions, Thesis work

Agrawal, KC, Ganju. A.(1994). A semi-quantitative approach to avalanche forecasting. Proc. Snowsymp 94 India.

Avalanche Atlas (1992). Restricted publication of Snow & Avalanche Study Establishment, Manali (Himachal Pradesh) India.

Buser, O., (1983) Avalanche Forecast with the method of Nearest Neighbors: An interactive approach. Cold Region Sciences and Technology, 8 (1983)

Ganju, A., Agrawal, KC, Rao, DLS. (1994). Snowcover Model. Proc. Snowsymp 94 India.