Avalanche contributory factors
&
Avalanche Mitigation Techniques

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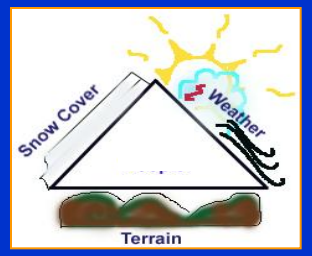
Avalanche Mitigation Techniques

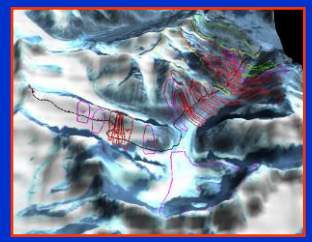
1. TEMPORARY METHODS

(i) AVALANCHE FORECASTING

(ii) AWARENESS & RESCUE TRAINING

(iii) CONTROLLED RELEASE (ARTIFICIAL TRIGGERING)





2. PERMANENT METHODS

(I) STRUCTURAL CONTROL MEASURES

(ii) HAZARD MAPS

(iii) AFFORESTATION

Data requirement

Class I:
Field Data/Stability Tests

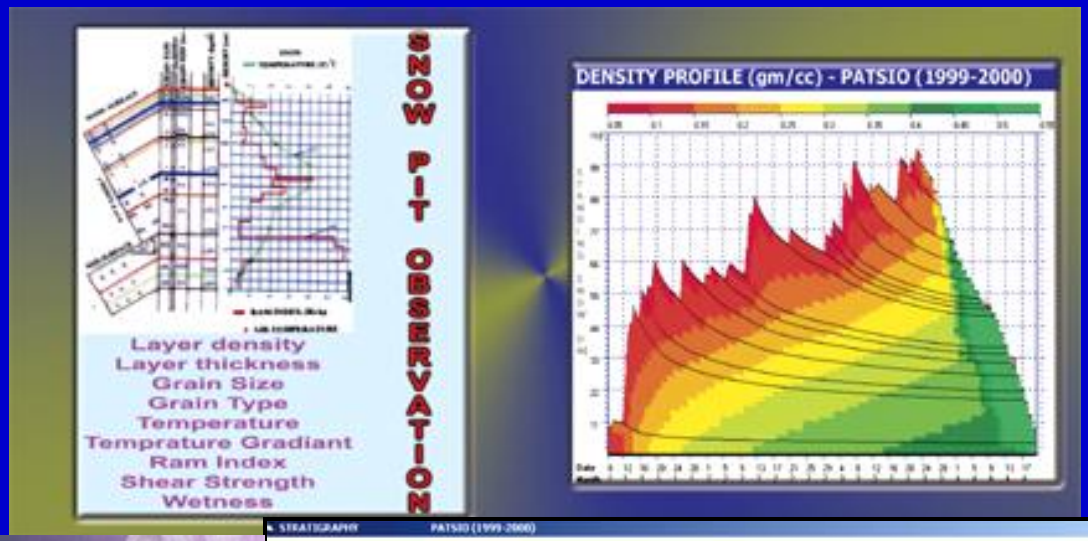
* Shovel Shear
* Rutschblock
* Collapse
* Shear Frame
* QSLBT

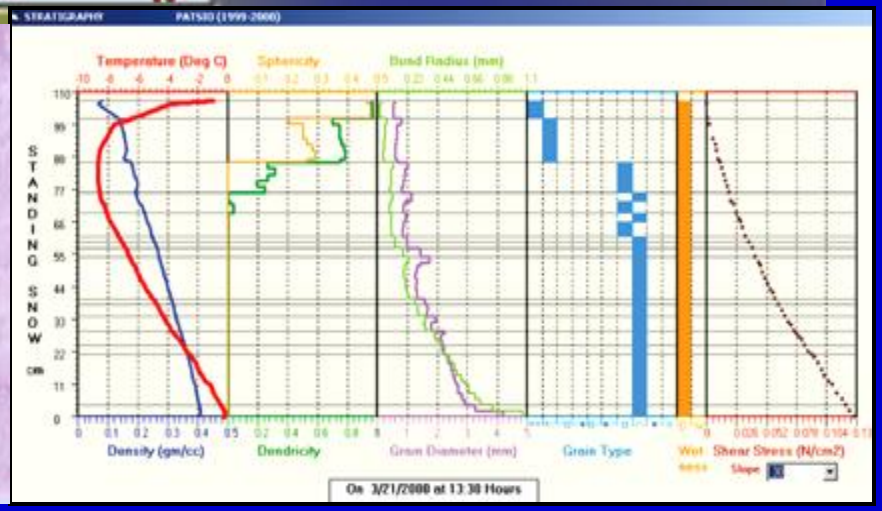





Data requirement

Class II: Stratigraphy Data



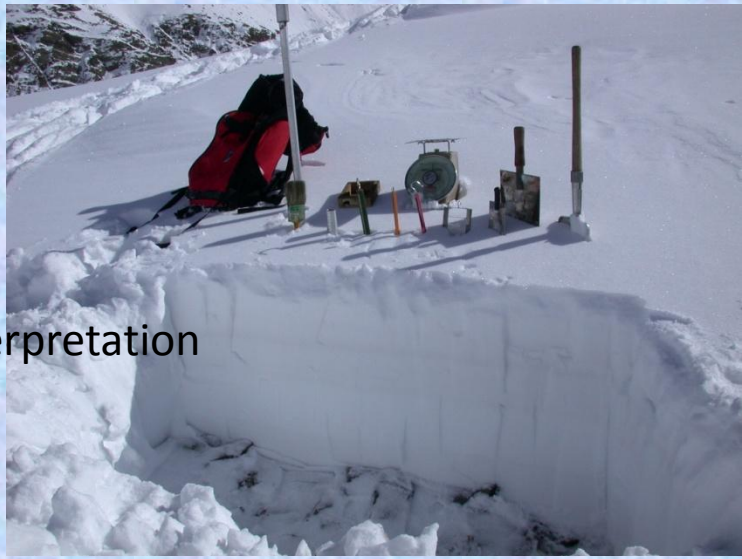


Data requirement

Class III: Meteorological Data

Stability evaluation of the mountain snow pack

- Factors used to interpret snow stability roughly stratified into three classes based on there relevance for assessing snow stability



- The higher the class number, the more uncertain the interpretation

- Class III : Met Factors
- Class II : Snowpack Factors
- Class I : Stability Factors

Uncertain

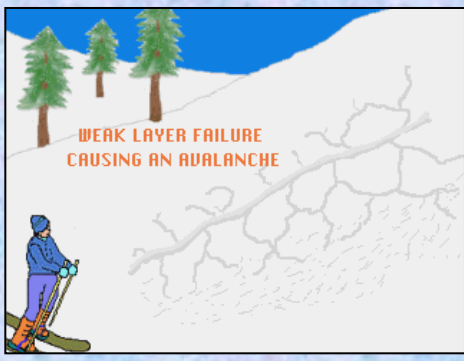
Relevant

Certain

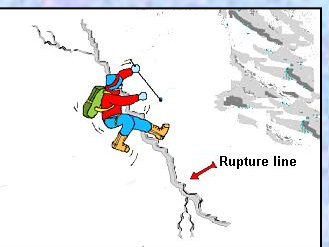
Stability evaluation of the mountain snow pack

Class I (Stability)

Deals with direct relationship between
loads on weak layers, relevant to current stability



- Stability tests
  - #Used to apply stresses to the snow cover and to observe whether or not it fails
  - # Best if carried out in formation zone



Stability evaluation of the mountain snow pack

Test Skiing

- Skier adds stress to the snow
- Limited to short slopes
- Avoided when weakness is suspected deep

Explosives

- Apply greater stresses at a more rapid rate
- Long slopes with unsafe access, deep weak layers, and hard snow

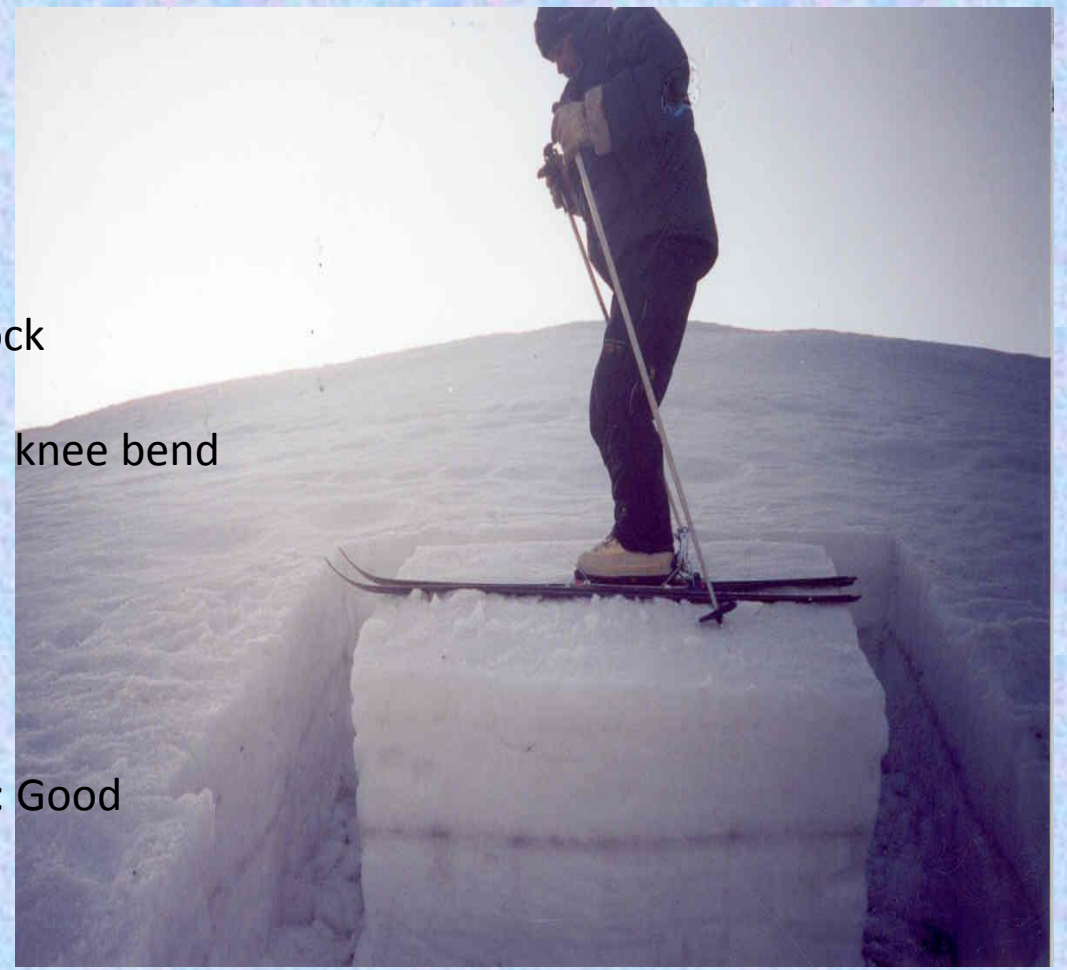
Stability evaluation of the mountain snow pack

Rutschblock Test

- Involves loading a block of snow by a person in several stages

1 : failure under the weight of the block
2 : One person on skis steps carefully
3 : Weights the skis by making a rapid knee bend
4 : The person on skis jumps
5 : Person on skis jump second time
6 : A person jumps without skis
7 : No failure Observed

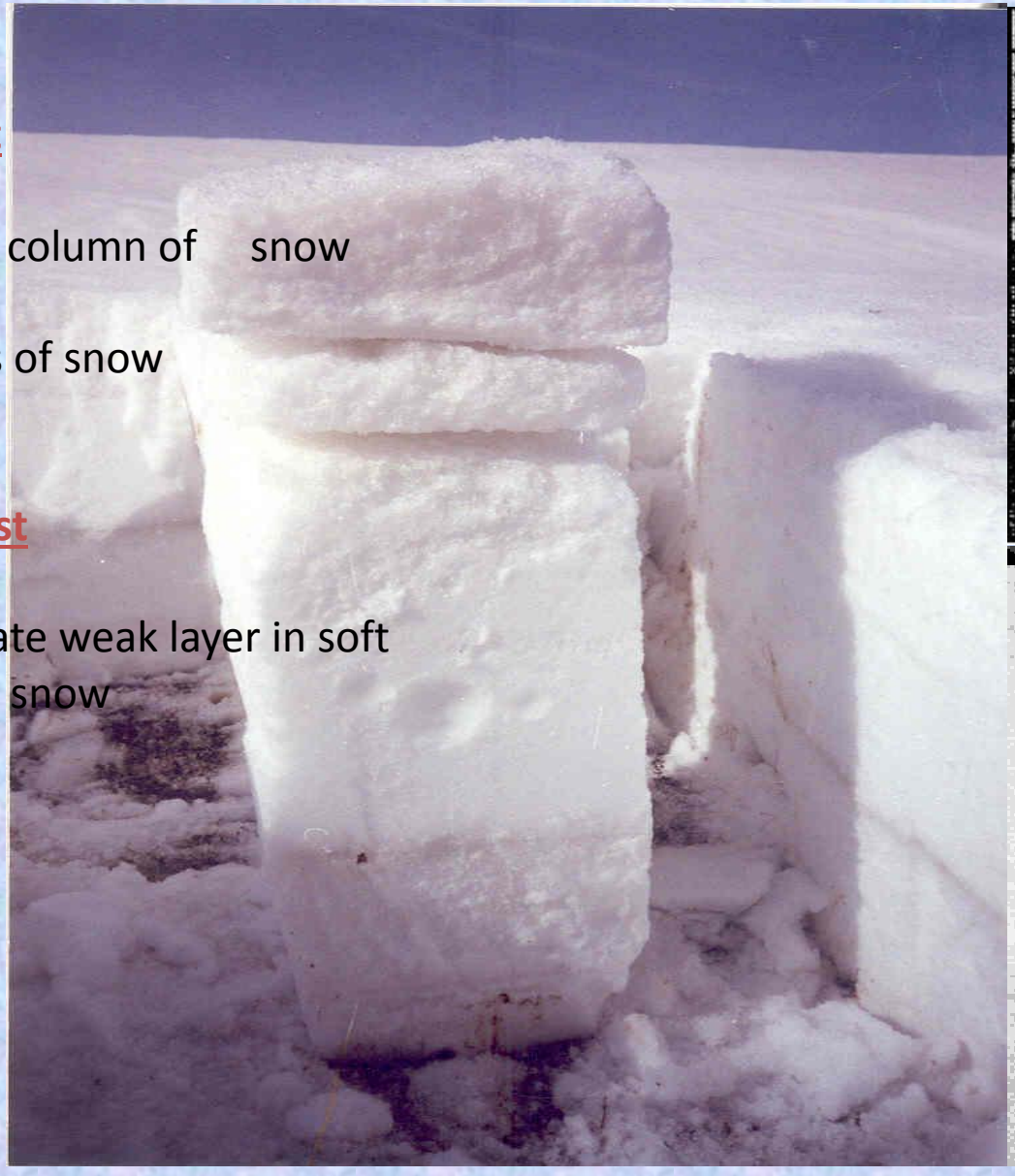
1,2,3 : Poor, 4,5: Fair, 6 or no Failure : Good

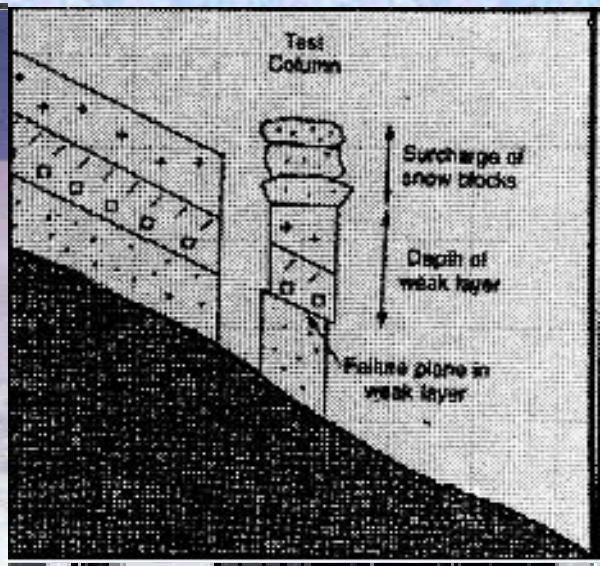


Stability evaluation of the mountain snow pack

Collapse Test

•Cutting of a column of snow and loading it with blocks of snow





Tilt Board Test

•Used to locate weak layer in soft and very soft snow

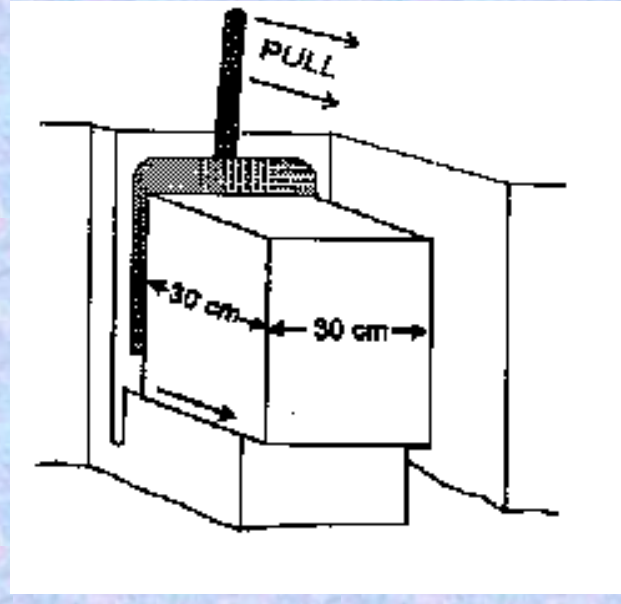
Stability evaluation of the mountain snow pack

Shear Frame Test

- Used to measure the shear strength of snow layers
- Shear frame and pull gauge
- Shear frame index = Force at failure/ Area(cross- sectional)

Shovel Shear Test

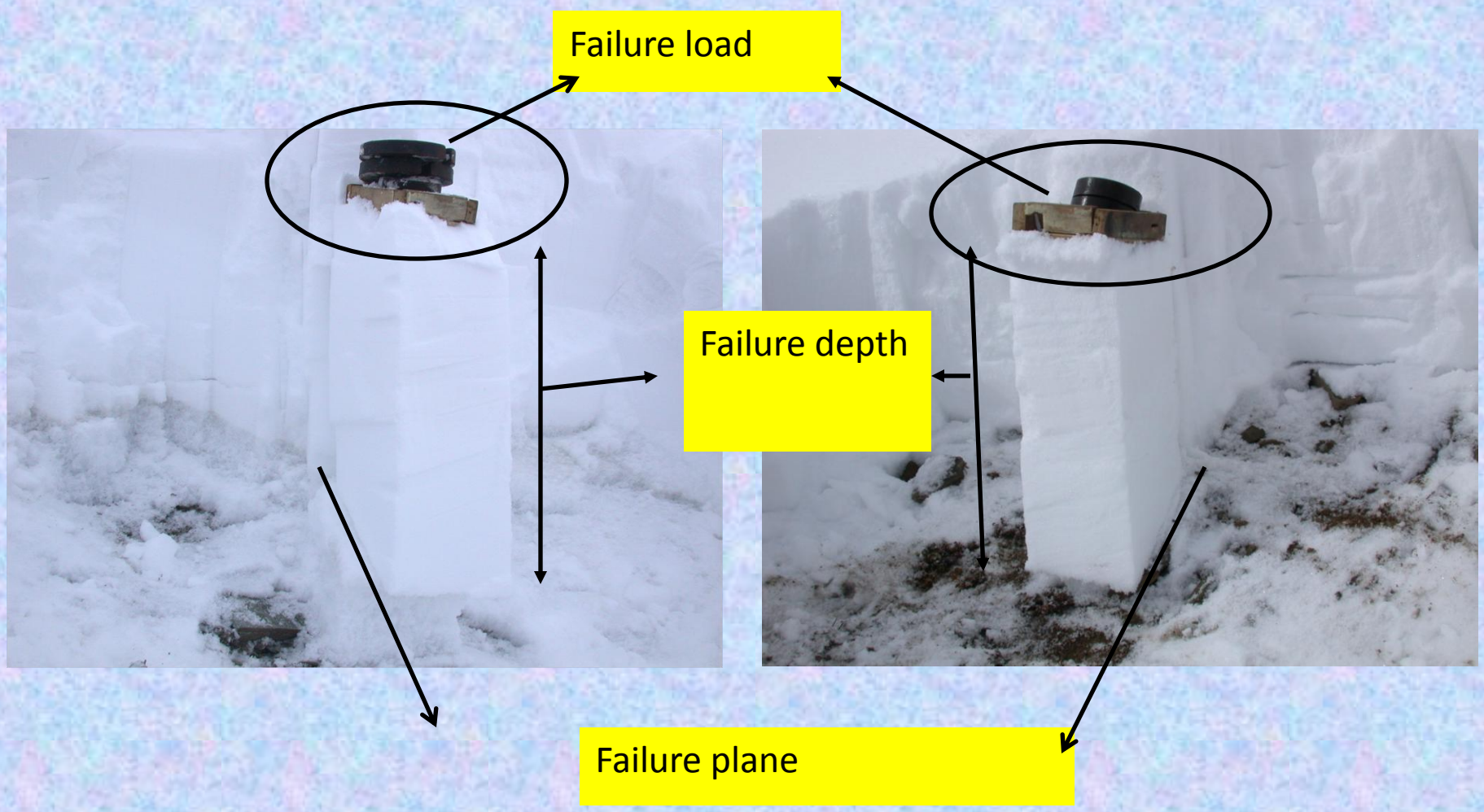
- Principal objective is to locate weak layers and interfaces



Stability evaluation of the mountain snow pack

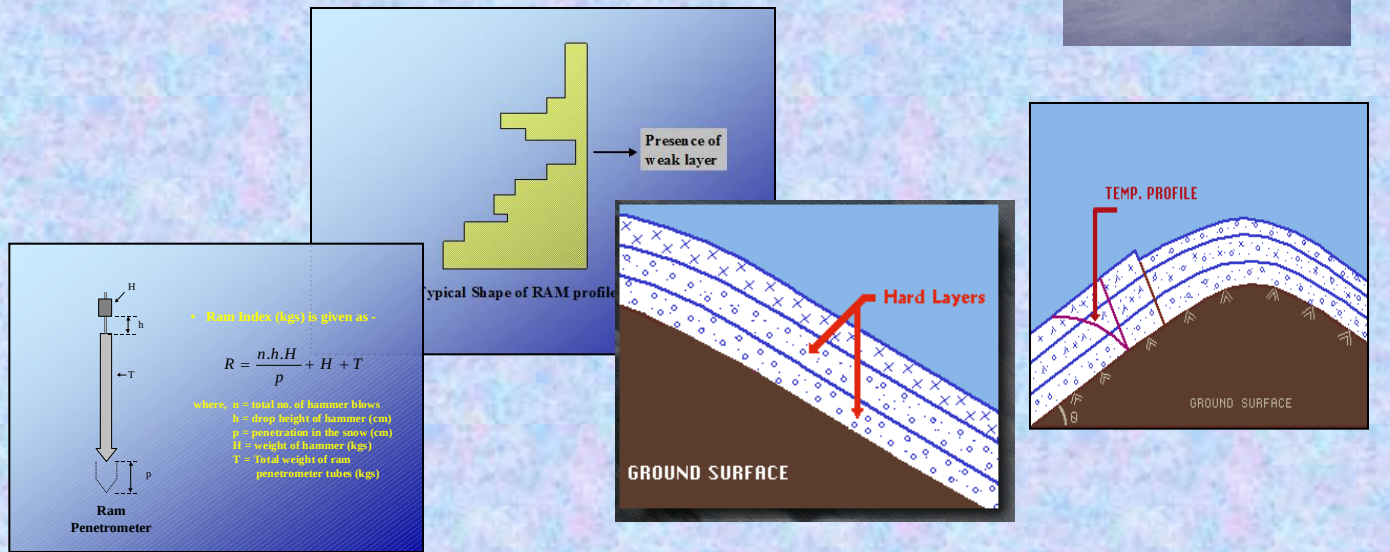
Quantitative Step Loading Block Test

- Determine failure load, failure plane and failure depth with good accuracy



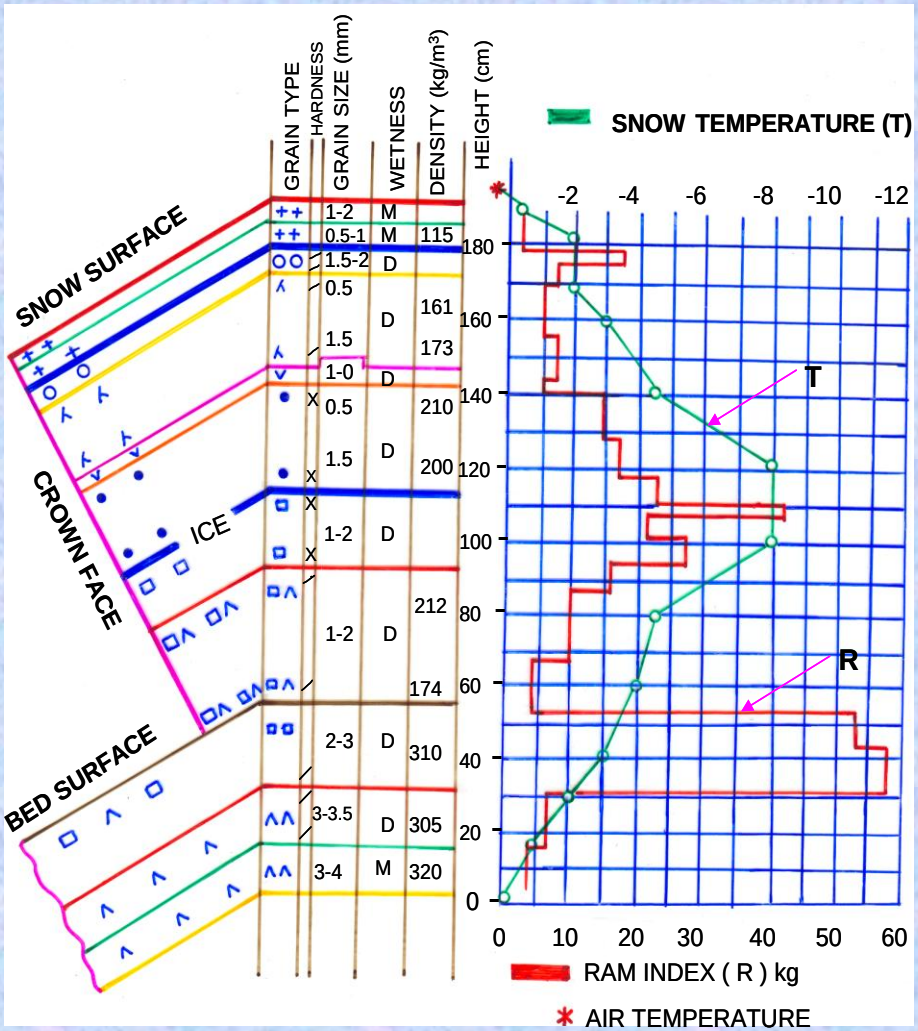
Class II (Snowpack) : Relevant, less directly related

- Past avalanches
- Snowpack Depth : Anchor, Surface penetrability
- Snowpack Structure
- Depth & Hardness of Snow above weak layer
- Snow temperature
- Ram profile
- Acoustic Signals
- Glide Speed



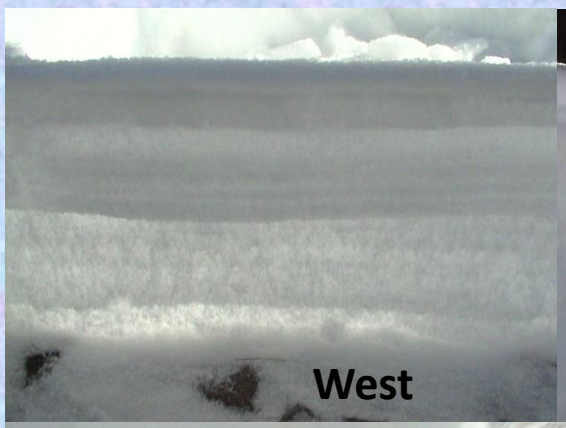
SNOW PIT OBSERVATION-Direct method

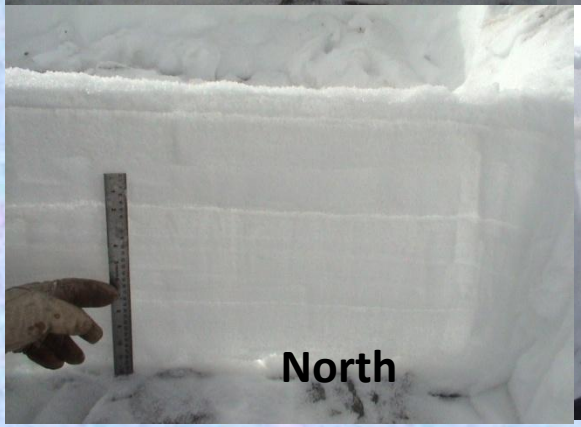
- Layer density
- Layer thickness
- Grain Size and type
- Temperature
- Temperature Gradient
- Ram Index, Shear Strength and Wetness

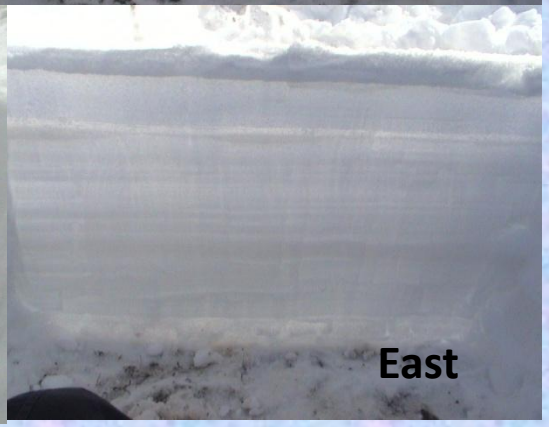


Frequent observations are not possible at a short interval for large area

LAYER IDENTIFICATION





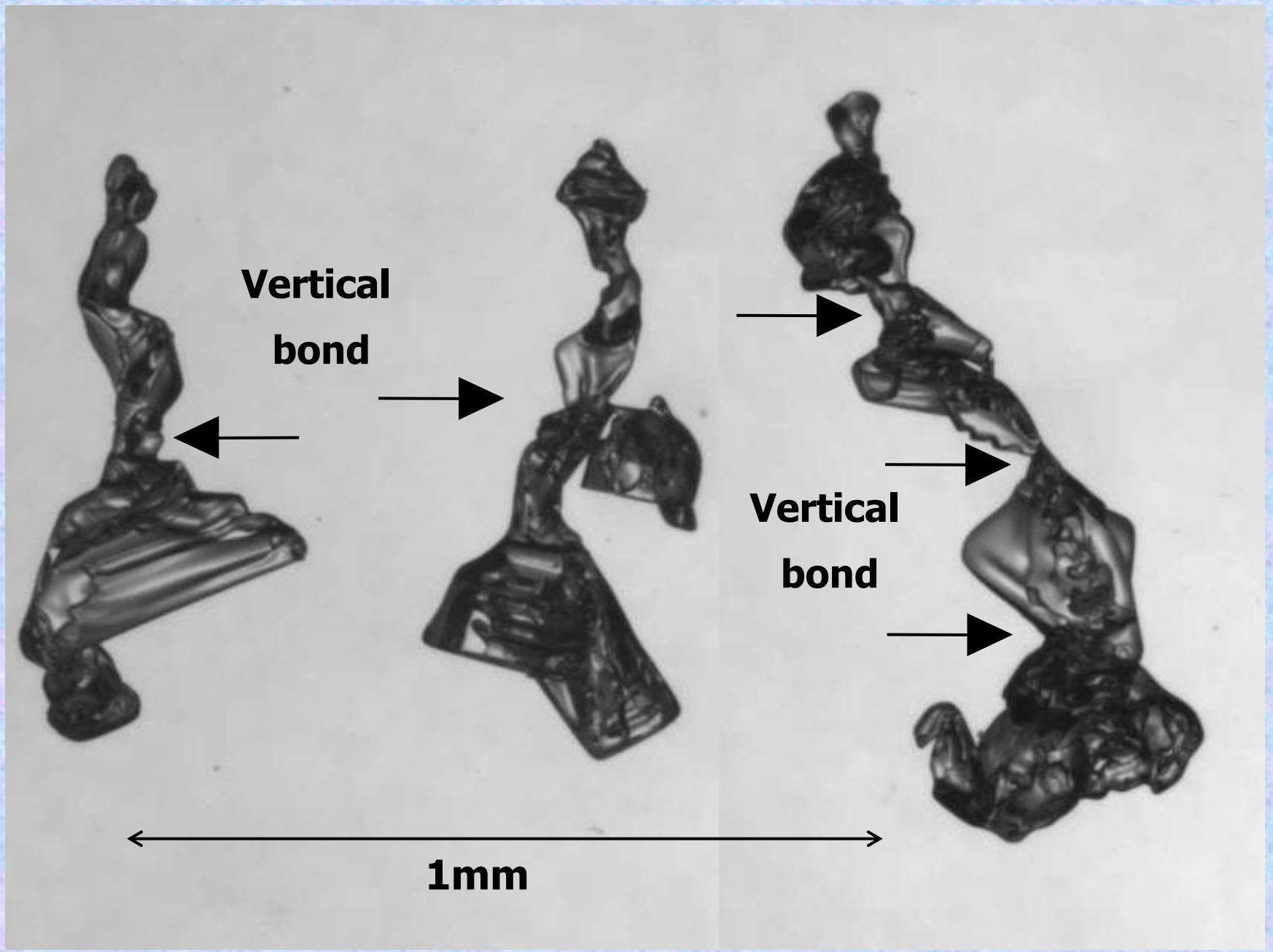


Failure load

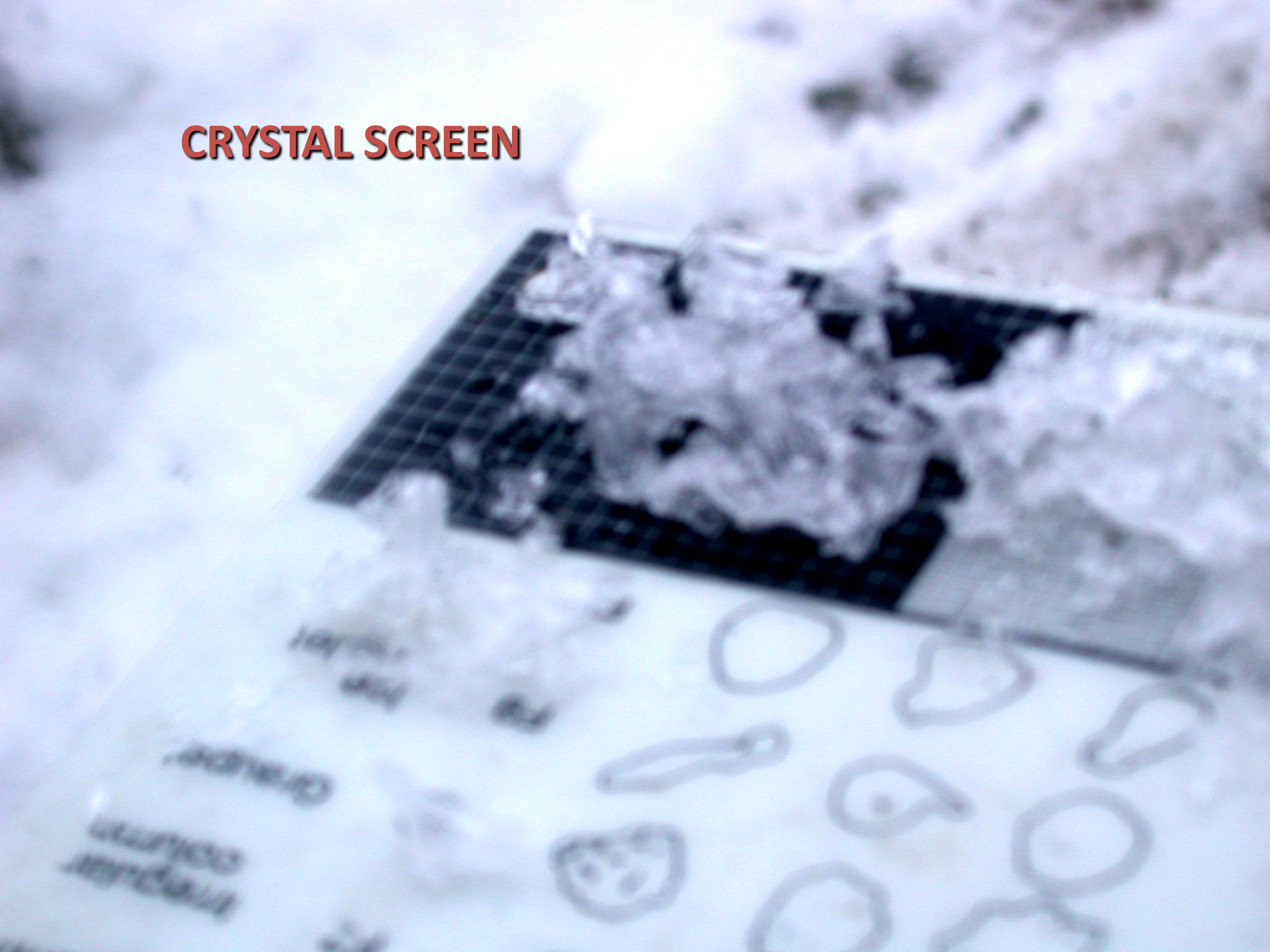
Avalanches


DEPTH HOAR GRAINS
SIZE 6-8mm

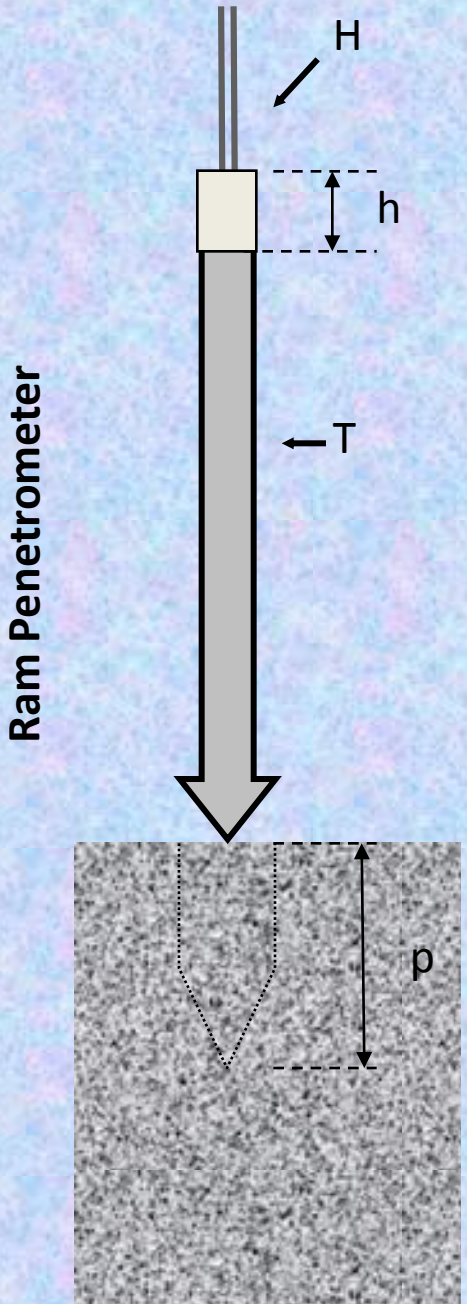
COLUMNS OF SNOW DURING TEMPERATURE GRADIENT



CRYSTAL SCREEN

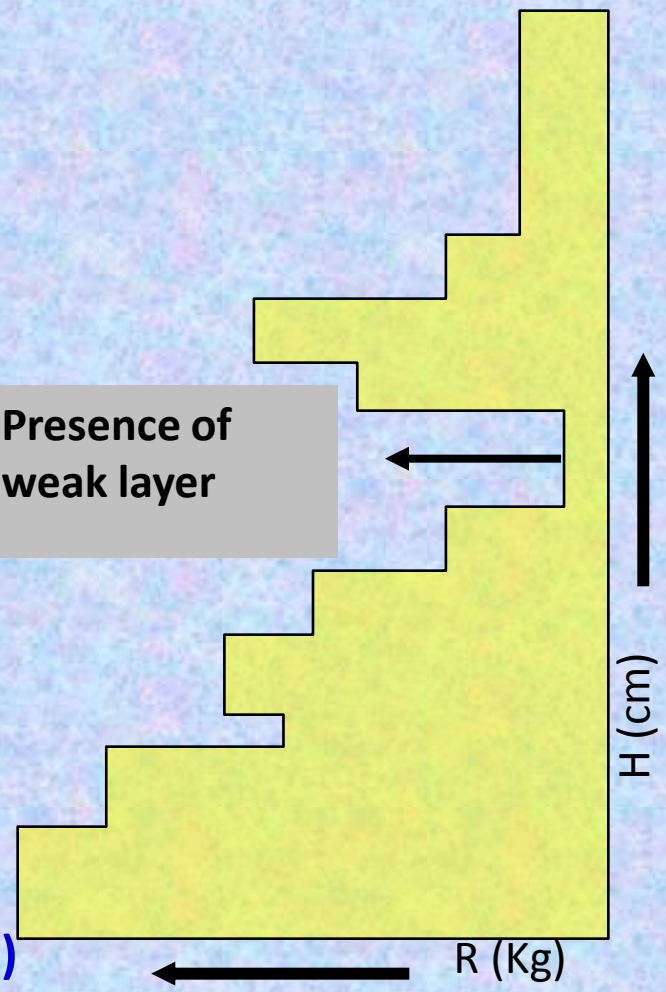


Hardness “ Resistance to the penetration by a rigid object”



- **Ram Index (kgs) is given as -**

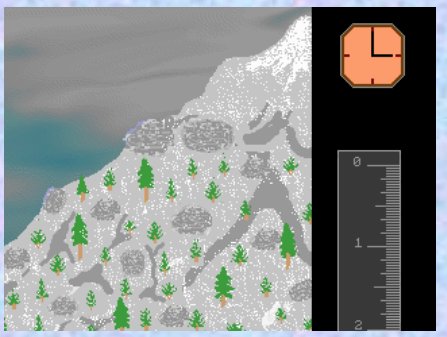
$$R = \frac{n.h.H}{p} + H + T$$



n = total no. of hammer blows
h = drop height of hammer (cm)
p = penetration in the snow (cm)
H = weight of hammer (kgs)
T = Total weight of ram penetrometer tubes (kgs)

Class III : Meteorological Factors : Indirect Evidence

- **Technique: Relate Met data to stability through empirical relationship**
  - Amount of new snow
  - Wind speed & Direction
  - Air temp
  - Solar radiation
  - Humidity
  - Snow surface characteristics
  - Weather Forecast
  - Blowing snow activity
  - PI
  - Settlement of new snow

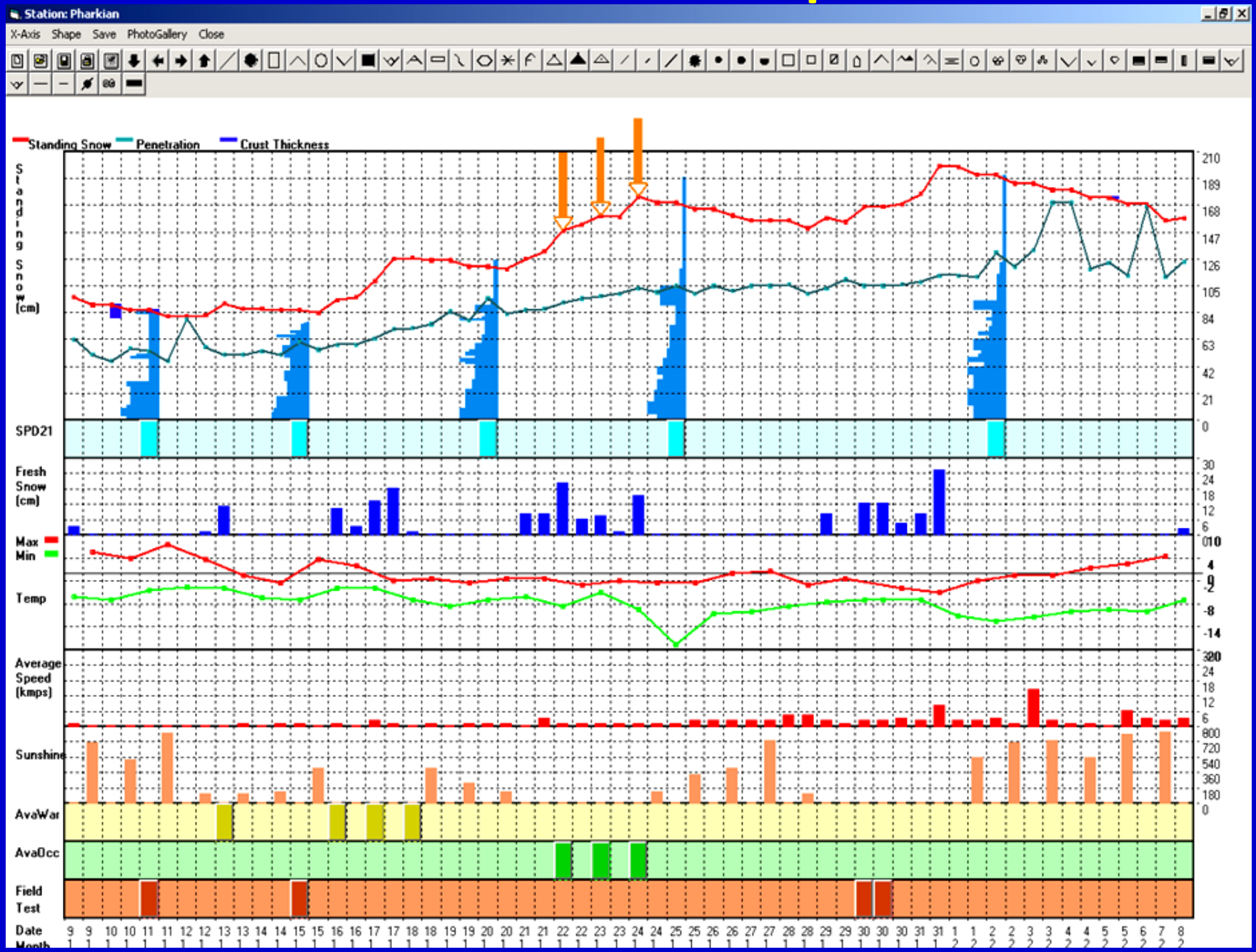


Avalanche Forecasting Techniques

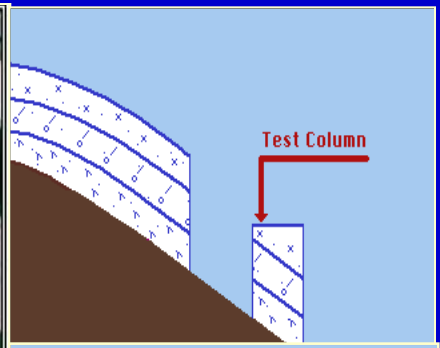
Forecasting Techniques at SASE

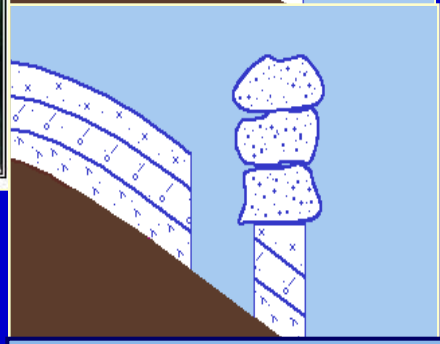
1. Contributory factors approach
2. Snow cover build-up
3. Field studies
4. Stratigraphy data
5. Statistical & AI Models
6. Snow cover simulation model
7. Remote sensing & GIS based model
8. Experienced judgment: Dominant

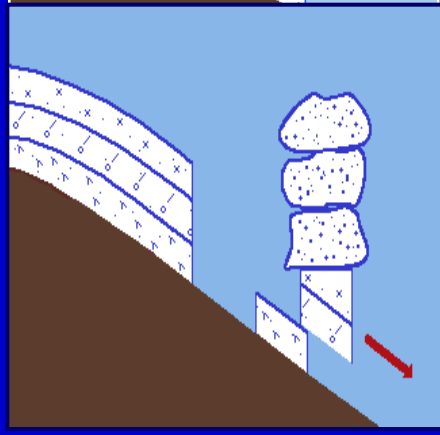
Snow Cover Build Up

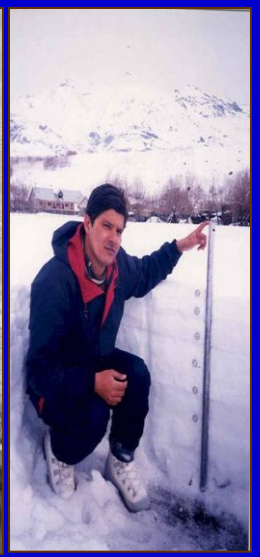


Field Tests Based Forecasting



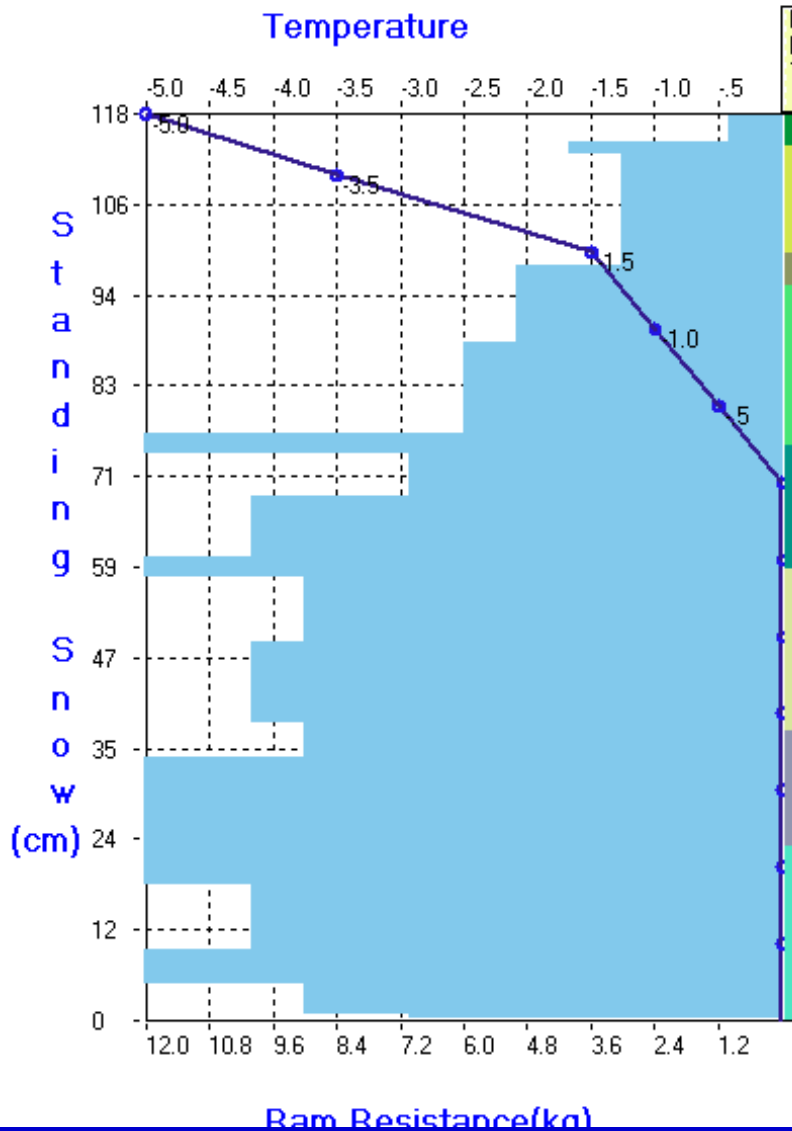






Station: 0402 Aspect: ZERO Date: 17-Mar-06 Weather: 0000

Time Of Start:0650 Hrs Wind Direction & Speed:0000 Temp at Start:-3 Temp at End:-2



Layer From..... To.....	Layer No	Layer Thickness	Wetness	Grain Type	Grain Size	Hardness	Density (gm/ cubic m)	Shear Strength (gm/ sqr cm)
114 - 118	8	04	Dry	(F S)	<1mm	V Soft	0.11	0.1
100 - 114	7	14	Moist	(F L)	1-2 mm	V Soft	0.16	0.3
96 - 100	6	04	Wet	(M G)	1-2 mm	M Hard	0.31	2.6
75 - 96	5	21	Wet	(M G)	1-2 mm	M Hard	0.41	2.5
59 - 75	4	16	Wet	(M G)	2-3 mm	M Hard	0.44	3.1
38 - 59	3	21	Wet	(M G)	3-4 mm	M Hard	0.46	3.4
23 - 38	2	15	Wet	(M G)	2-3 mm	M Hard	0.49	2.9
0 - 23	1	23	Wet	(M G)	2-3 mm	M Hard	0.46	1.9

Avalanche Forecasting Models

- **Numerical Avalanche Prediction:**
  - **# Nearest Neighbors**
  - **# Discriminant Analysis**

- **Expert Systems**
  - **# Neural Network Technique**
  - **# Fuzzy logic technique**

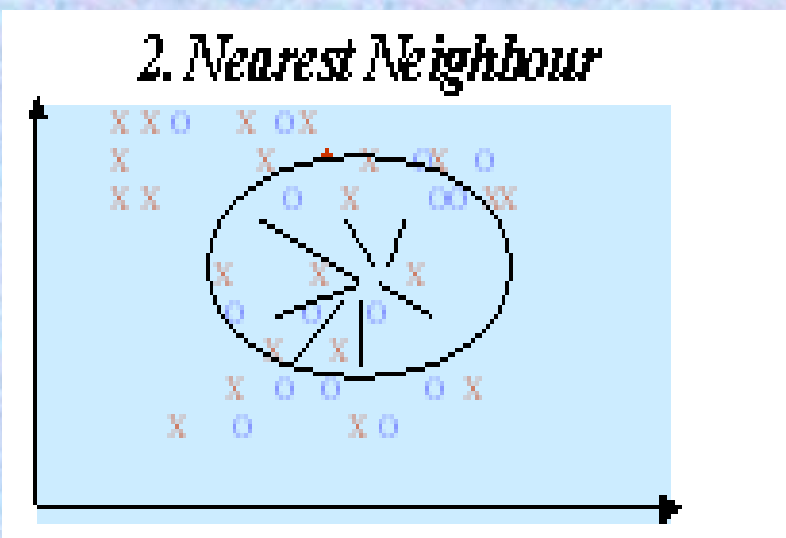
Techniques of Avalanche Forecasting

Nearest Neighbor Technique:

Past data set		Present data set
Max T	--d1----	Max T
Min T	--d2----	Min T
Amb T	---d3----	Amb T
RH	----d4----	RH
TSD	----d5----	TSD
FSD	----d6----	FSD

Total distance = D=d1+d2+d3+d4+d5+d6

$$d = \{ (X_2-X_1)^2\}^{1/2}$$



Techniques of Avalanche Forecasting

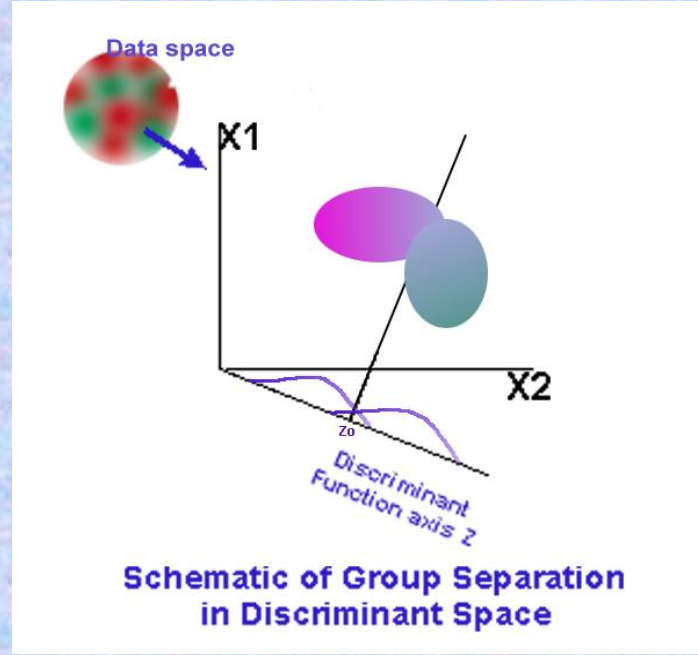
Discriminant Analysis:

Avalanche occurrence data are stratified into distinct groups

dry avalanches, wet or moist avalanches, Days without avalanches

#In which group do today's data fall?

Works best when the groups used to classify cases do not overlap much



Schematic of Group Separation in Discriminant Space

Techniques of Avalanche Forecasting

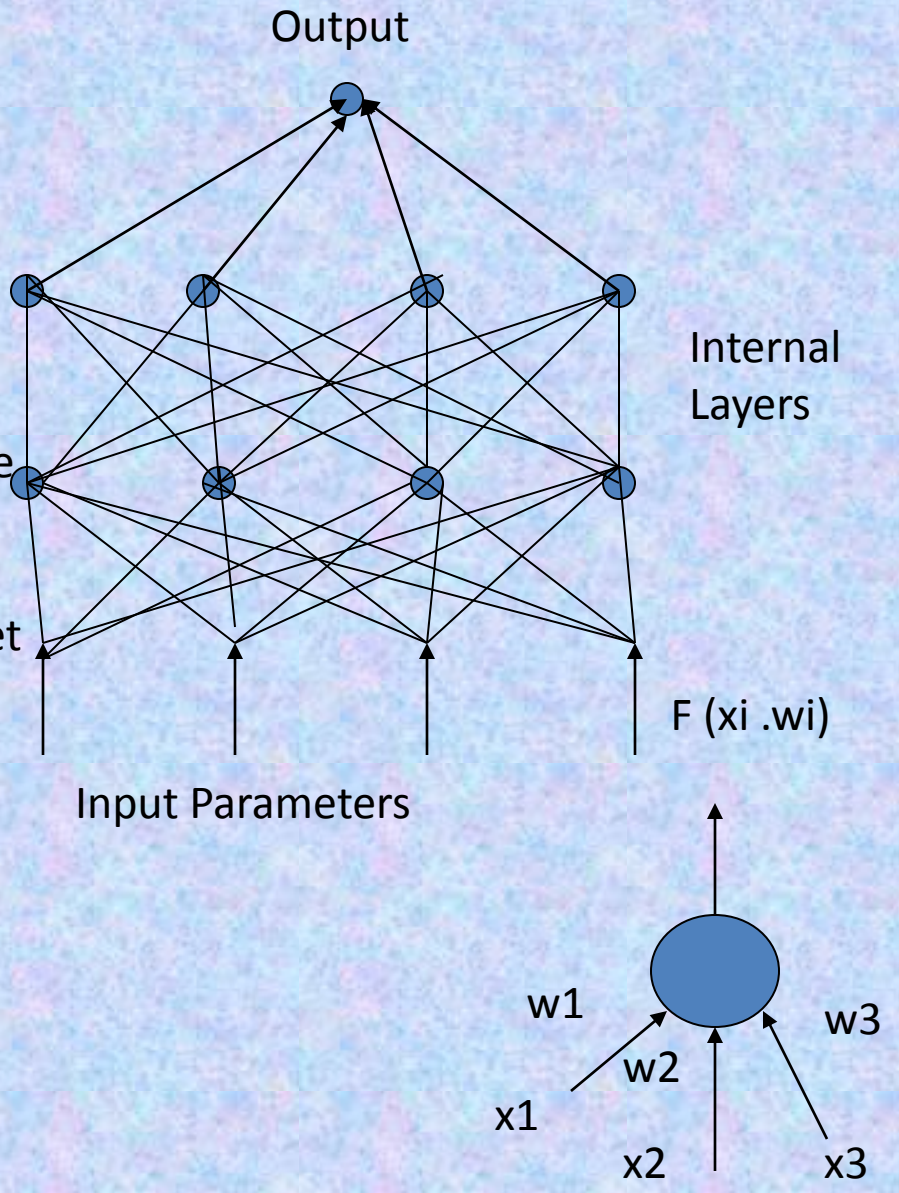
Neural Network Technique:

Network consists of layers of nodes

Between adjacent layers, nodes can be fully interconnected

within same layer they are considered as separate individual units

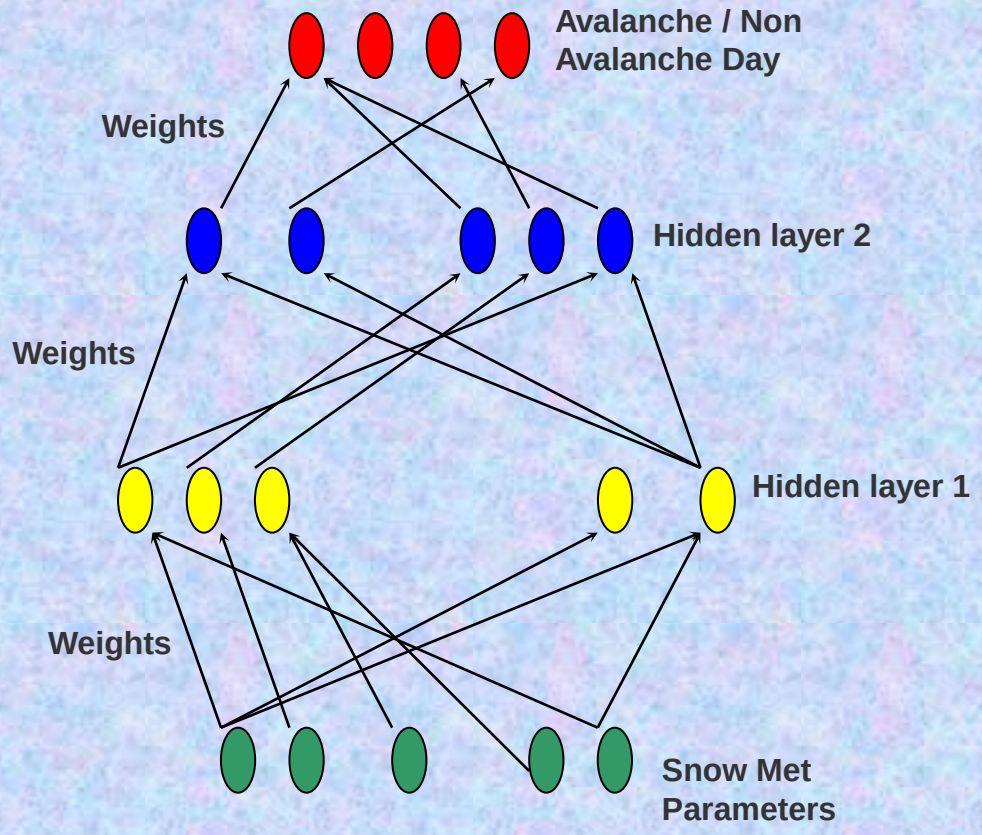
Output of a node is a non-linear function of its net inputs



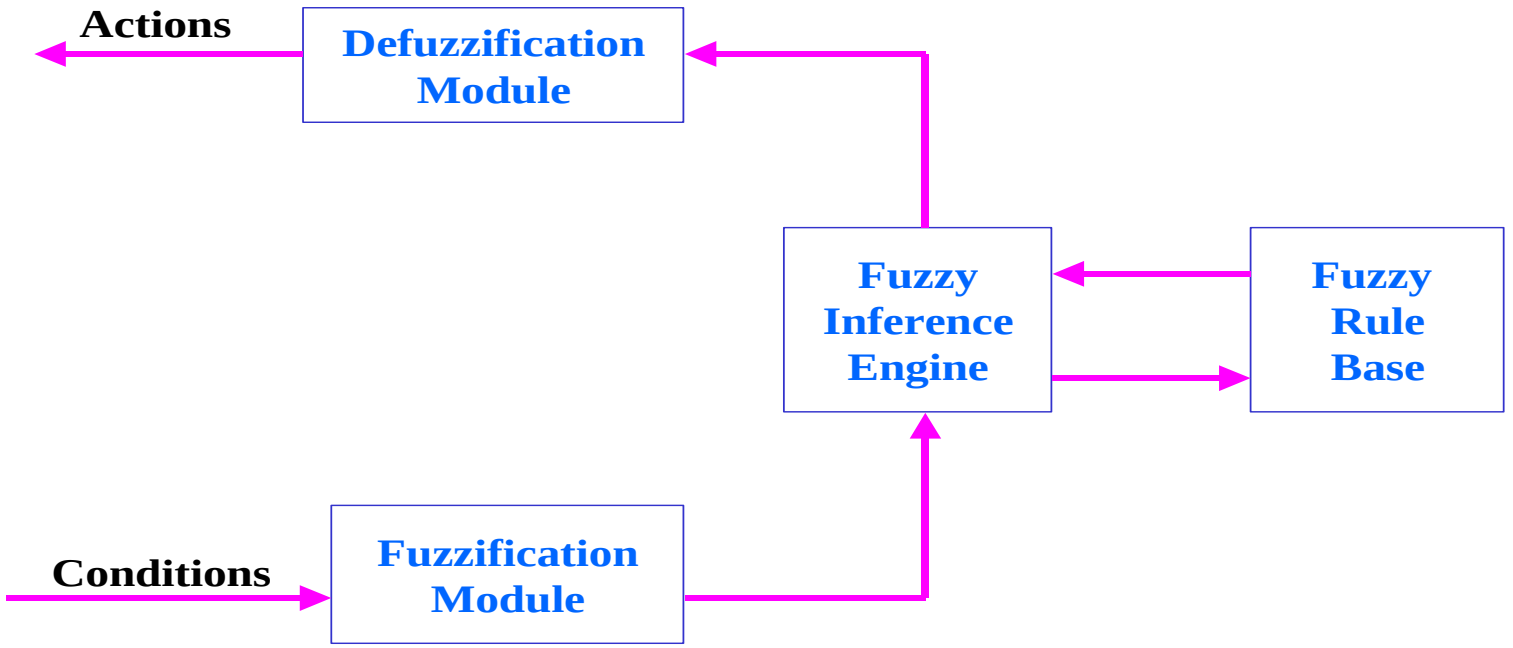
Neural Networks Approach

- Seven relevant parameters are taken for study viz.

1. Fresh snow amount
2. 24 h fresh snow amount
3. 72 h fresh snow amount,
4. Standing snow,
5. Maximum Temperature,
6. 24 h departure of ambient temperature,
7. 24 h departure of snow surface temperature



Fuzzy Rule-Based System



General Scheme of a Fuzzy System

Parameters

Parameters used:

1. Fresh Snow
2. 24hr Fresh Snow
3. 72 hr Fresh Snow
4. Snowfall Intensity
5. Standing Snow
6. Free Penetration
7. Wind speed
8. Ambient Temperature
9. Snow Surface Temperature
10. Sunshine Duration

AVALANCHE ASSESSEMENT (Contributory Factor Approach)

AVALANCHE SITUATION ASSESSMENT GULMARG SECTOR (09-FEB-2005)

Current Situation	Gulmarg	Himmat
Fresh snow (cm)	57	65
Storm snow (cm)	258	459
Standing snow (cm)	197	420
Settlement (cm)	17 (09%)	45 (11%)
Snow surface condition	01199	01199
Snow surface temp (^{0}C)	-3.0	-13.0
Av wind speed (kmph)	0.6	XXX
Current weather	7487	7487

Projected weather & Avalanche warning bulletin	MM5		Statistical Forecast
	Day 1	13	Light snowfall
	Day 2	08	Light snowfall
	Day 3	28	V light snowfall
	Day 4	14	

NN Model	33%
Expert Systems	Medium
Forecaster assessment	Medium
Forecast to be issued	Medium danger avalanche warning along steep avalanche slopes above an altitude of 3200 mtr.

S. No.	Parameters	Qualitative CS	Qualitative PS	Quantitative
1.	Fresh Snow	C	C	
2.	Standing Snow	C	C	
3.	Storm Snow	C	C	
4.	SI/PI	C	C	
5.	Settlement	C	C	
6.	Snow Temp	N	N	
7.	Wind Speed	T	T	
8.	Wind Direct	N	N	
9.	Radiation	N	N	
10.	Field Test	-	-	
11.	Stratigraphy	-	-	
LOW	25-40	Score C	55%	55%
MED	40-70	Score T	11%	11%
HIGH	70-90	BIAS		
ALL ROUND	>90	DECISION	MEDIUM	
Feed Back	NO feed back			

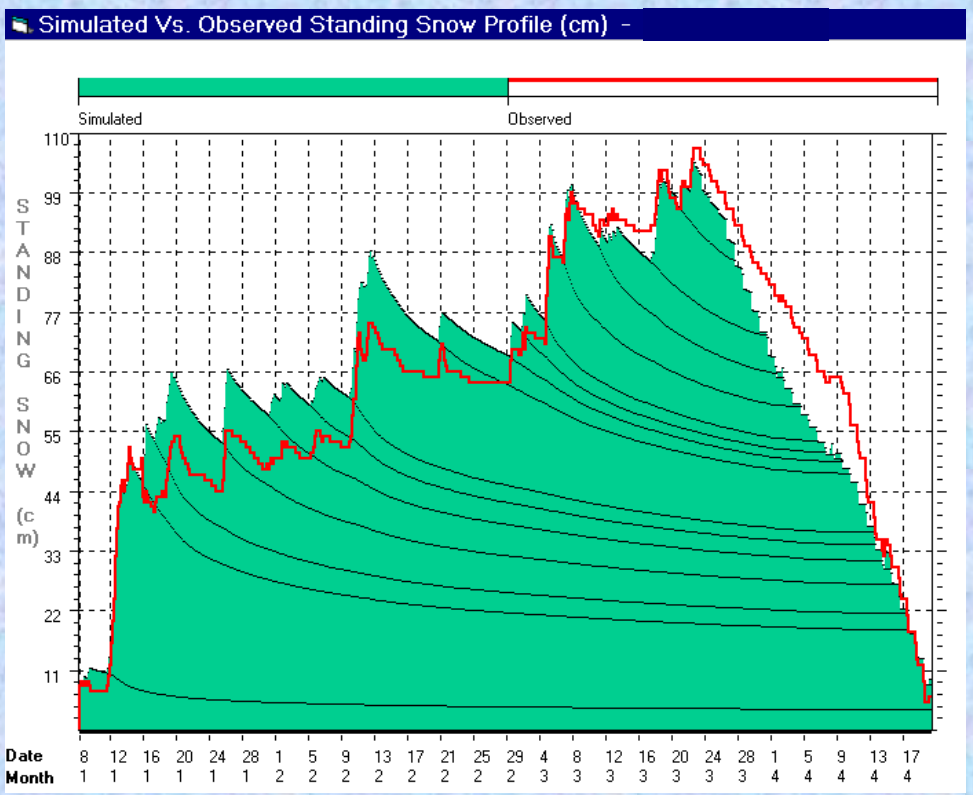
STRATIGRAPHY STABILITY ASSESSMENT

Profile	Crystal	Ram	Week Layer	RB Score	Stability	C/N/T	Danger	Applicable
	+ ʌ +	>10	NO	7	Abs Stable	NC	NO	
	□ □	>10						
			NO	6	Very Good	NC	NO	
		70	YES	6	Fairly Good	NC	NO	
	ʌ ʌ	>20 >10						
	X X X X X	>10	YES	6/5	Good	T	ADV	
	□ □							
		50 >10	YES	5	Fair	T	ADV	
	ʌ ʌ							
		4	YES	5/4	Fairly Poor	T/C	LOW	
	+ +	~ 4	YES	4/3	Poor	T/C	LOW	
	ʌ ʌ							
	v v + + v v	<4 30	YES	3/2	Very Poor	C	MED	
	ʌ ʌ	10	YES	2/1	Abs Poor	C	MED	
	v v X X X X X	<2	Definitely YES	1	Abs unstable	VC	HIGH	

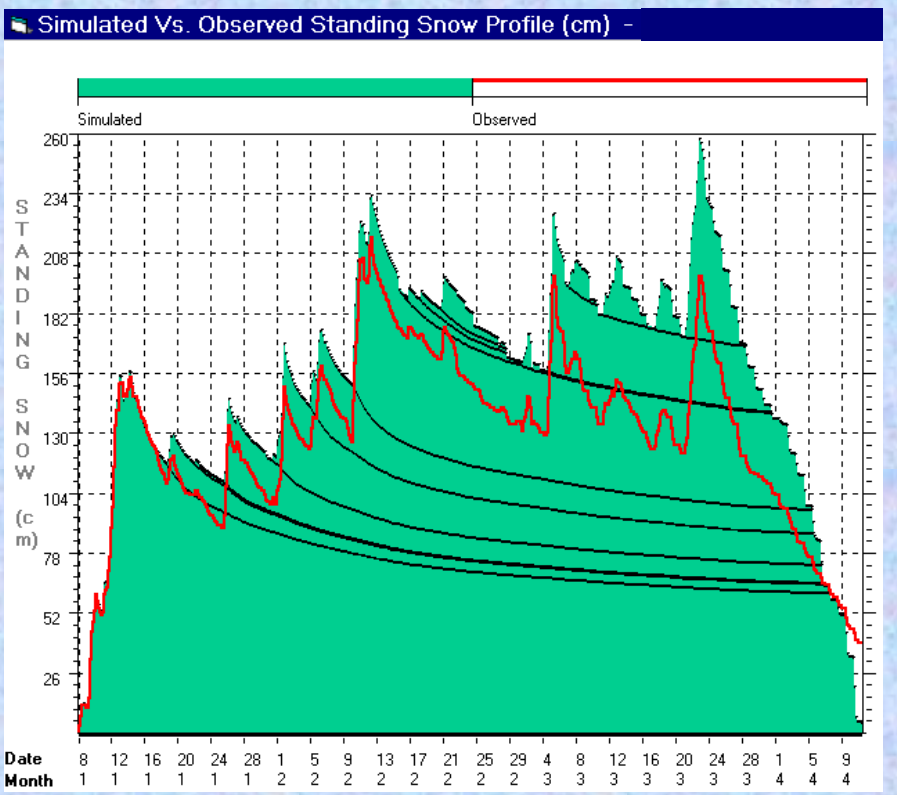
- Valid up to 3 days (Absolutely)
- Valid up to 6 days, if departure of mean snow surface temp is within +1^{0}C

Snow Cover Simulation Model

Station Patsio (02-03)



Station Dhundi (02-03)



In Greater Himalayan range

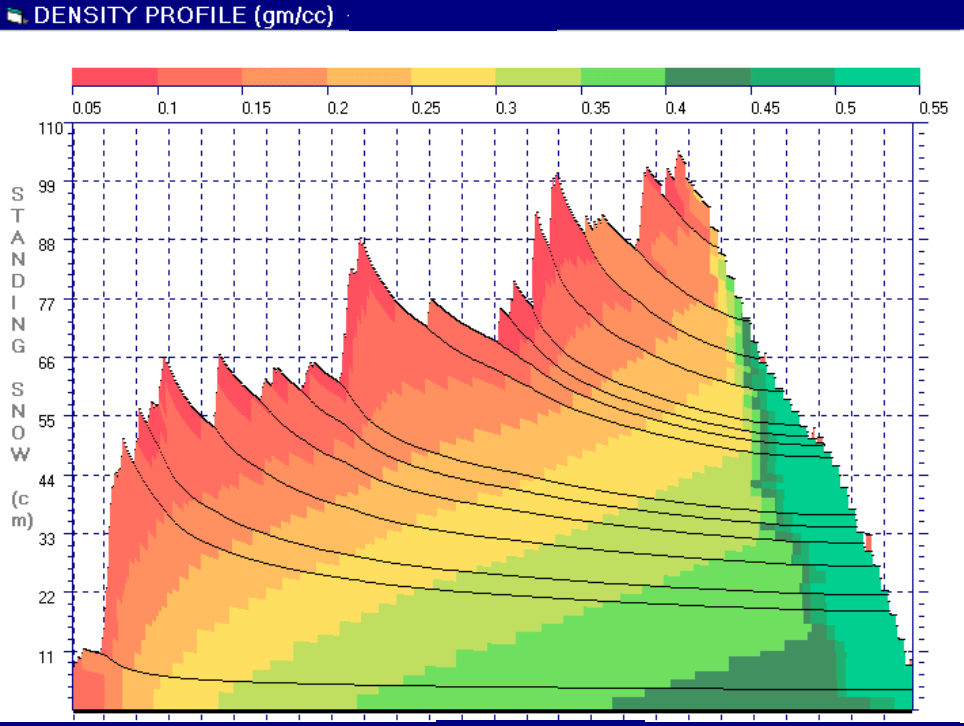
Low temperature

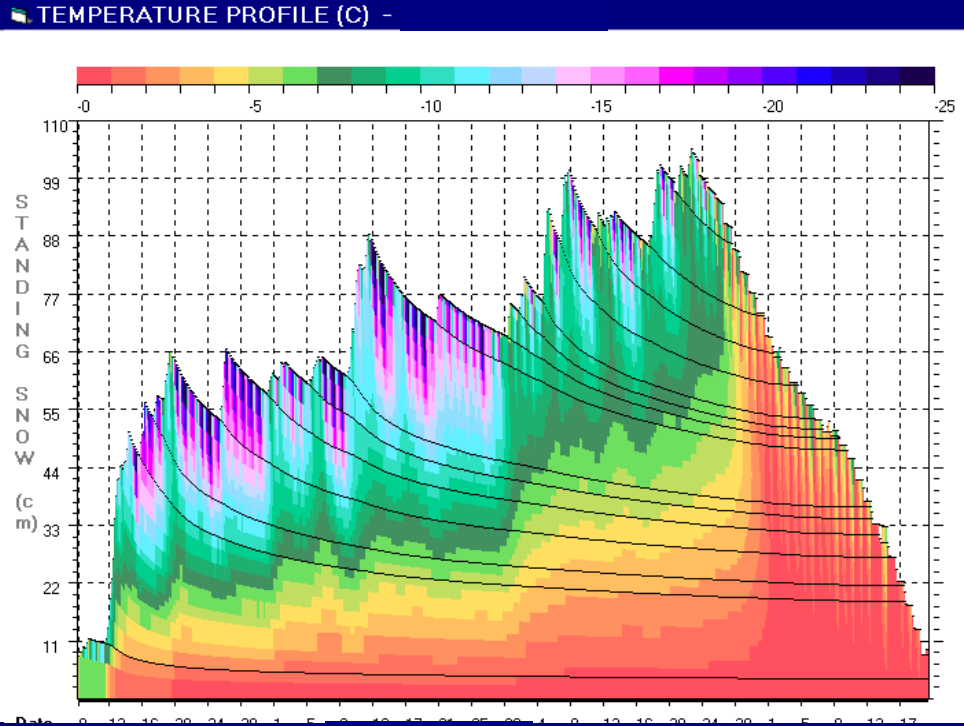
Low Precipitation (Dry Snow)

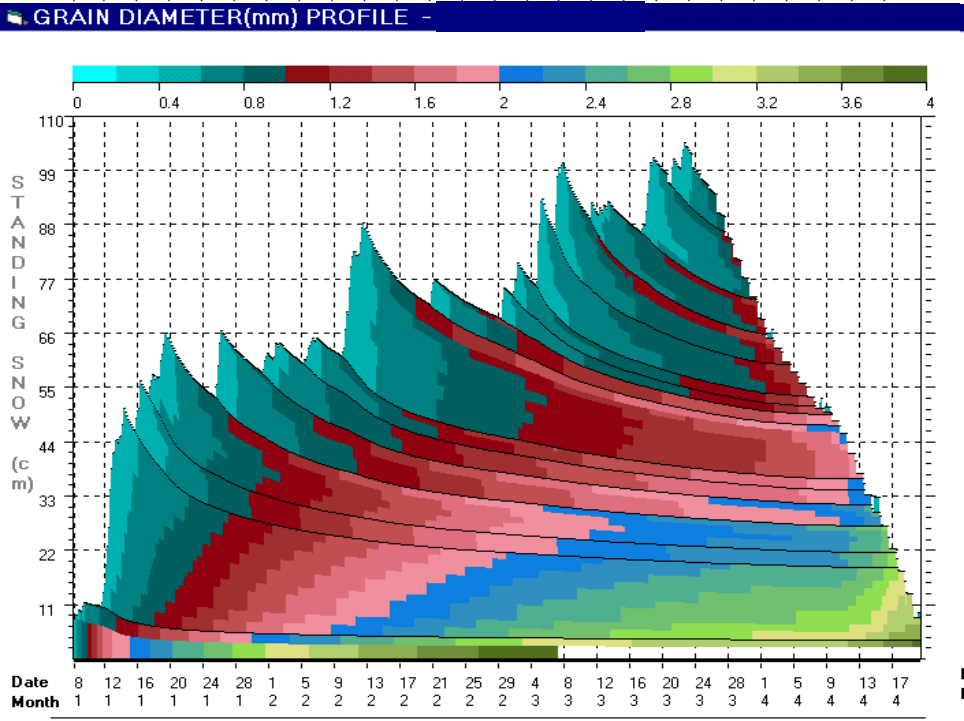
In Pir Panjal range

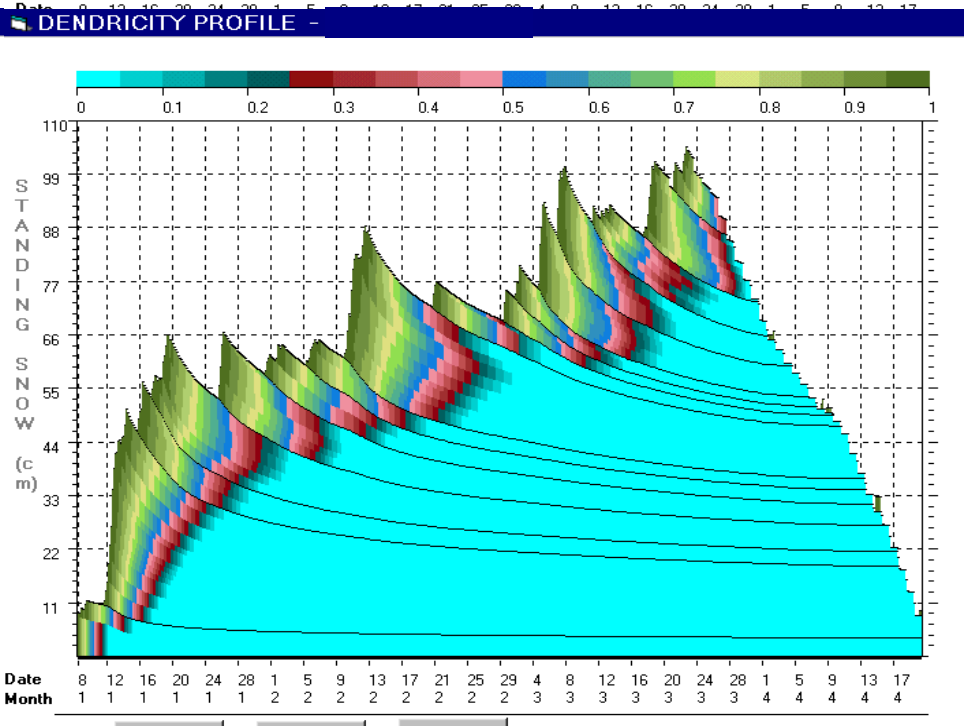
High precipitation

Temp High (Wet snow)


DENSITY PROFILE (gm/cc)
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55
STANDING SNOW (cm)
110 99 88 77 66 55 44 33 22 11

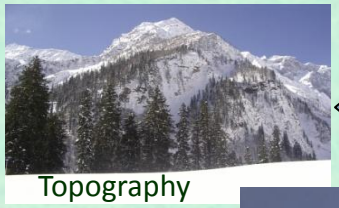

TEMPERATURE PROFILE (C)
-0 -5 -10 -15 -20 -25
STANDING SNOW (cm)
110 99 88 77 66 55 44 33 22 11


GRAIN DIAMETER(mm) PROFILE
0 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2 3.6 4
STANDING SNOW (cm)
110 99 88 77 66 55 44 33 22 11
Date 8 12 16 20 24 28 1 5 9 13 17 21 25 29 4 8 12 16 20 24 28 1 5 9 13 17
Month 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 4 4 4 4 4

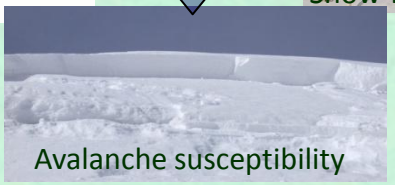

DENDRICITY PROFILE
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
STANDING SNOW (cm)
110 99 88 77 66 55 44 33 22 11
Date 8 12 16 20 24 28 1 5 9 13 17 21 25 29 4 8 12 16 20 24 28 1 5 9 13 17
Month 1 1 1 1 1 1 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 4 4 4 4 4

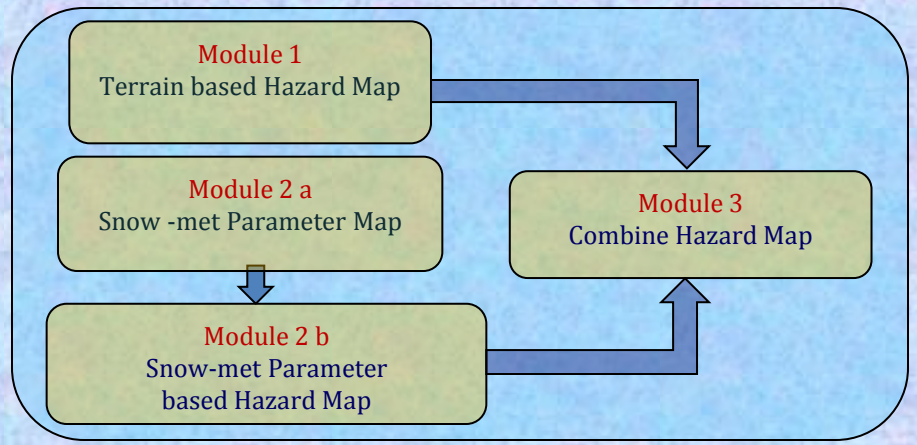
GIS-based dynamic avalanche hazard modeling

Integration of the topographical and meteorological parameters

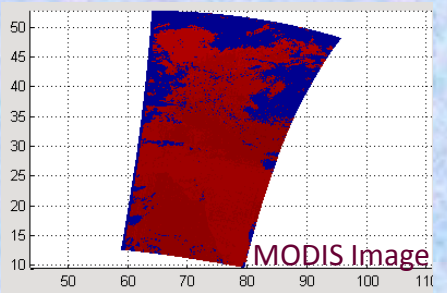

Topography

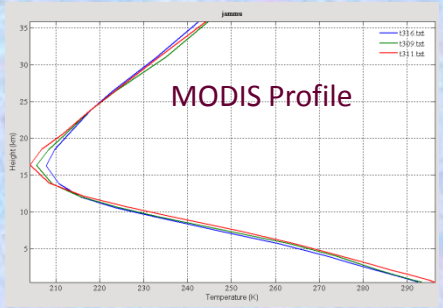

Snow-met Parameters

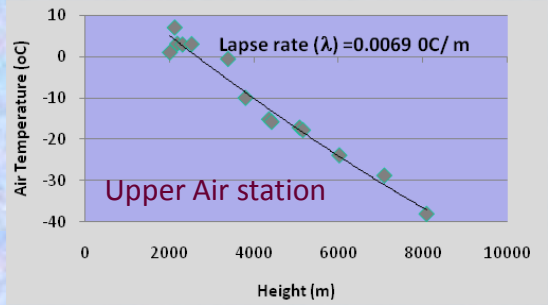

Avalanche susceptibility

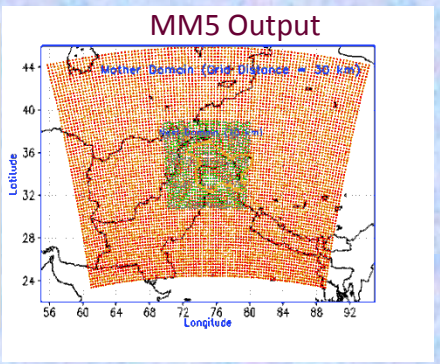


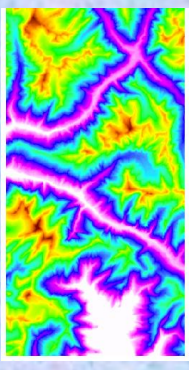
Data

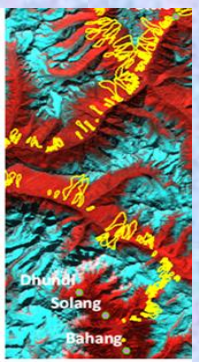

MODIS Image


MODIS Profile

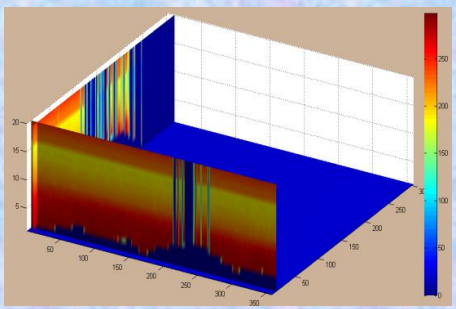


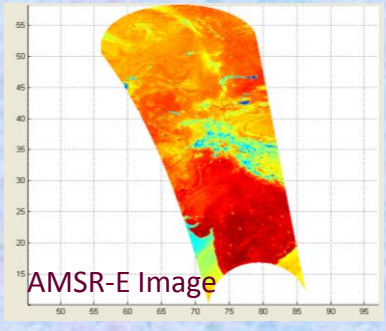


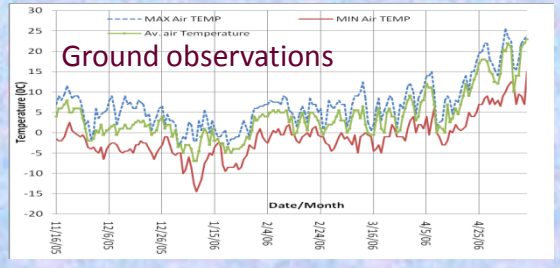

DEM



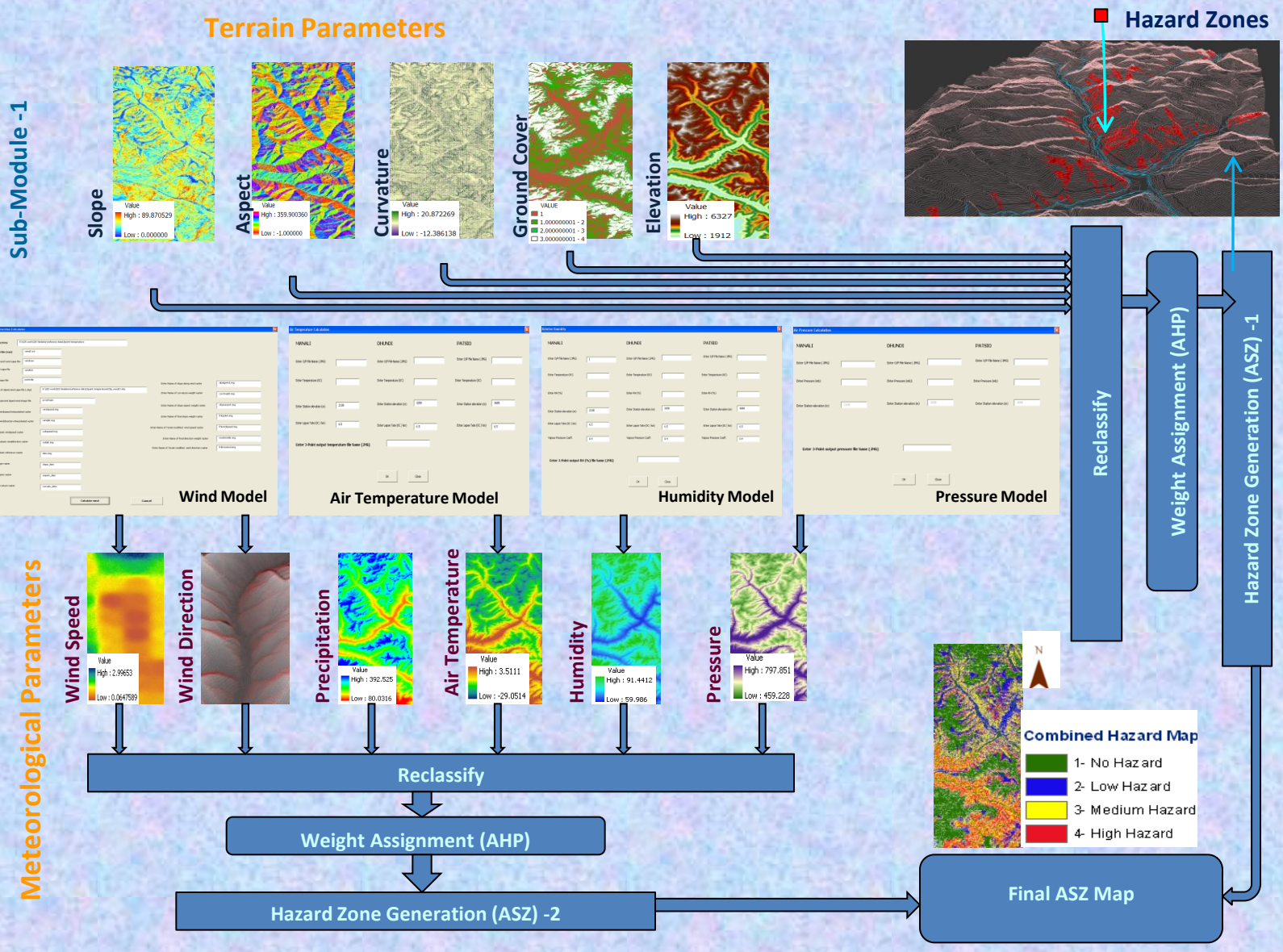
AWiFS Image and avalanche sites




AMSR-E Image



Methodology: avalanche hazard

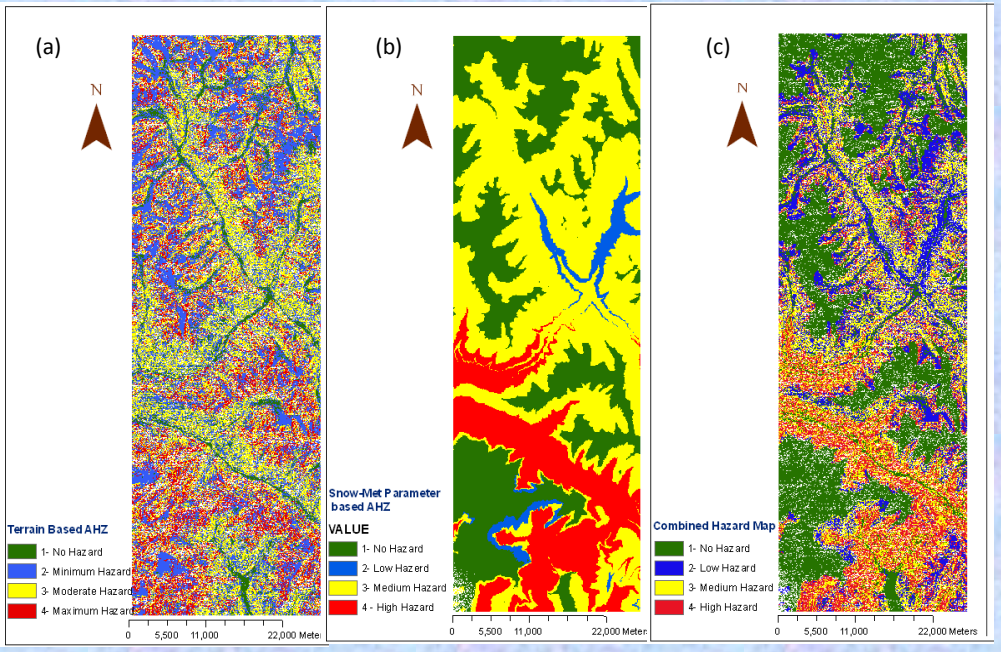


Results: dynamic avalanche hazard

Combined hazard matrix

Terrain parameter / Met parameters	High	Medium	Low	No Hazard
High	44	43	42	41
Medium	34	33	32	31
Low	24	23	22	21
No Hazard	14	13	12	11

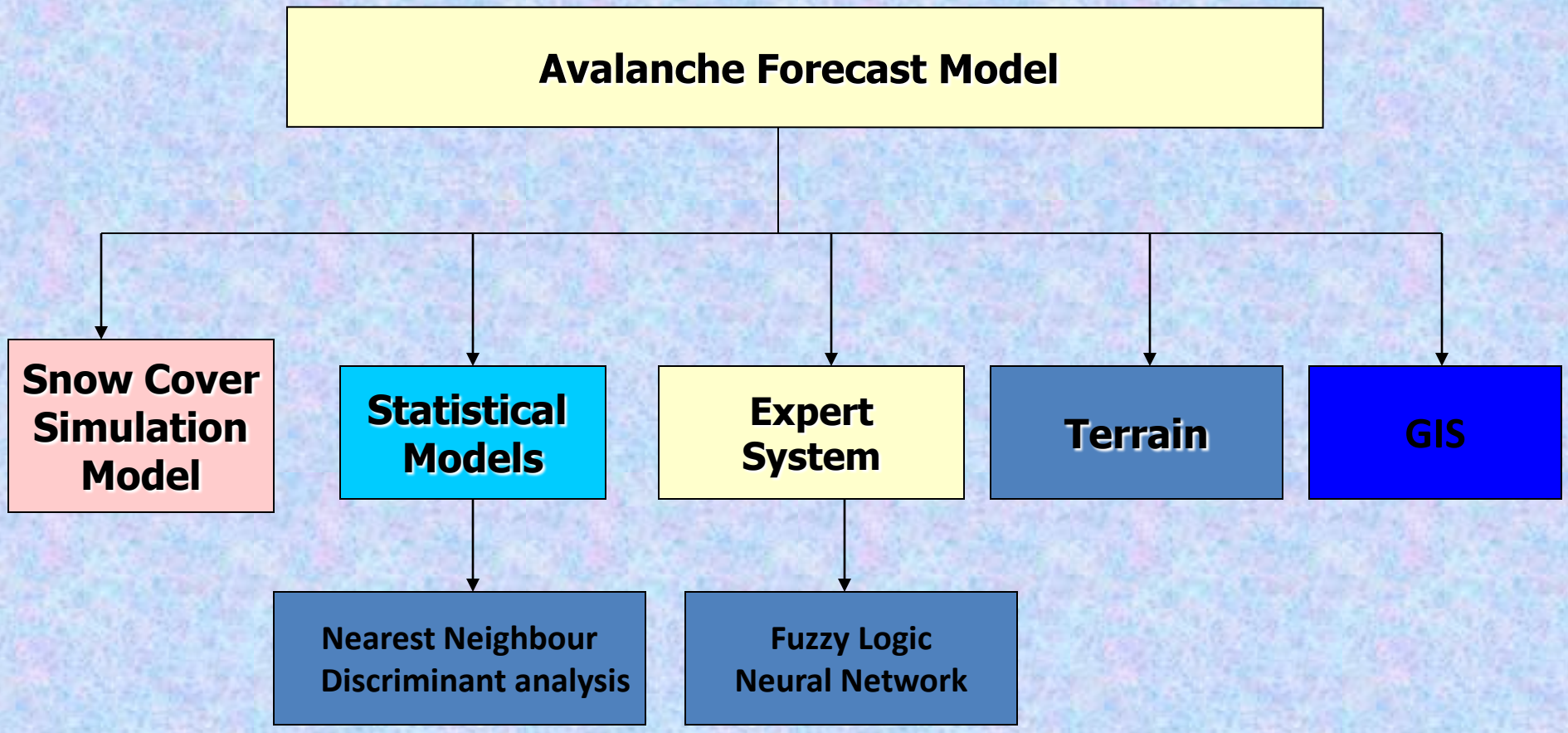
High Hazard
Medium Hazard
Low Hazard
No Hazard



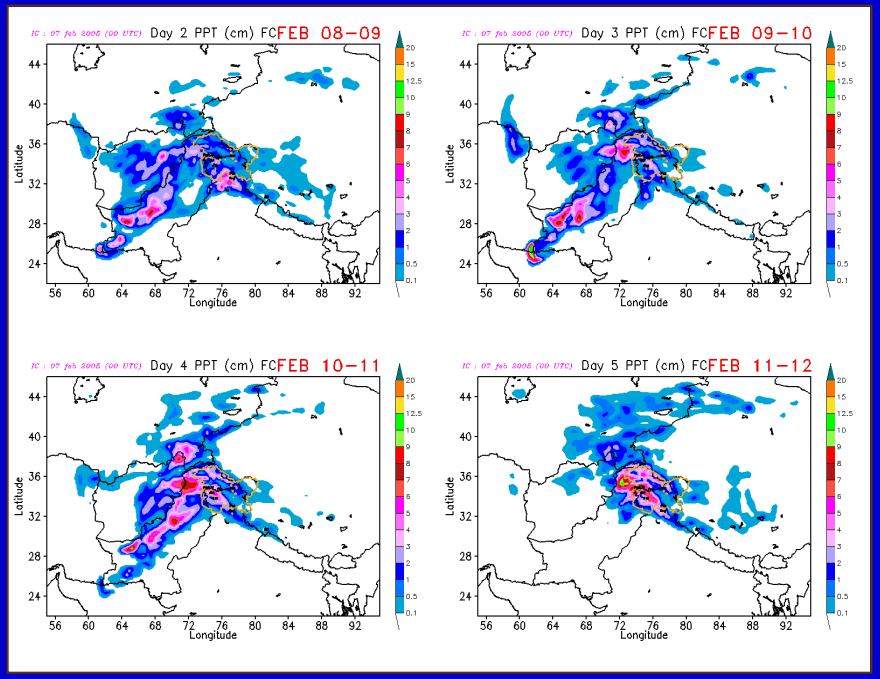
Terrain parameters Snow-met parameters Combined

Maps will help in assessing the eminent hazard.

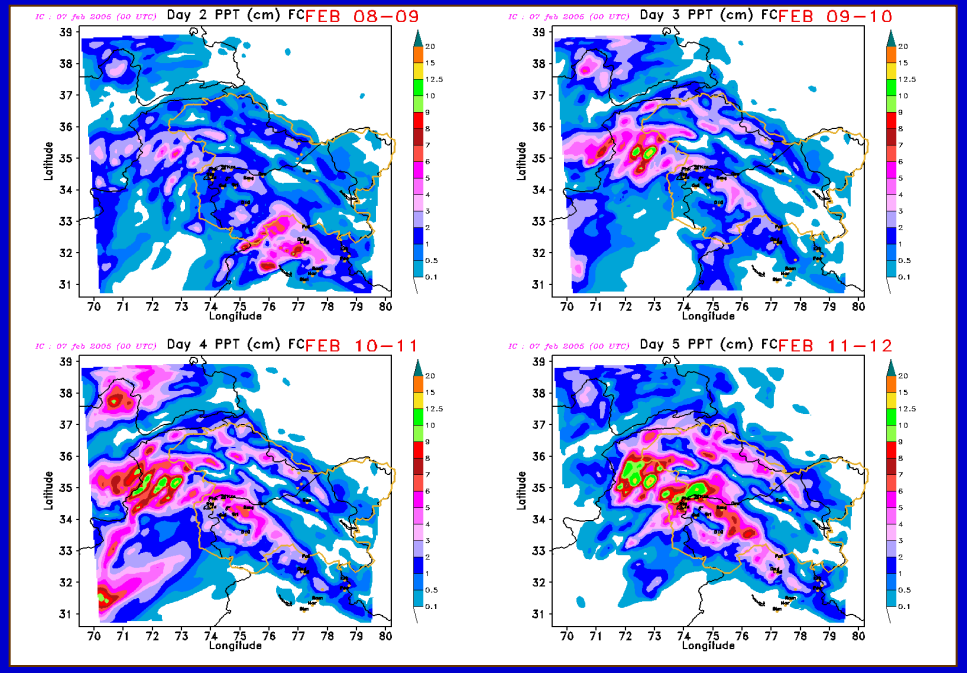
Hazard Zones	Terrain based		Snow - Met parameter based		Final Hazard	
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
High Hazard	45353	19.9	40456	17.8	38251	16.8
Medium hazard	71403	31.4	109007	47.9	52799	23.2
Low hazard	91670	40.3	7977	3.5	50817	22.3
No Hazard	19140	8.4	70126	30.8	85699	37.7


Avalanche Forecast Model
Snow Cover Simulation Model
Statistical Models
Expert System
Terrain
GIS
Nearest Neighbour
Discriminant analysis
Fuzzy Logic
Neural Network

Current & Six Day Advance Weather Prediction used for avalanche Forecasting



27 KM Resolution



9 KM Resolution

AVALANCHE DANGER SCALE

Degree of danger	Implications	Suggestion/ Precautions
Low	Generally favourable condition. Triggering is generally possible only with high additional loads and on very few extreme slopes. Only sluffs possible and reach valley in small sizes.	Valley movements are safe. Movement on slopes with care.
Medium	Partly unfavourable condition. Triggering possible from the most avalanche prone slopes with low additional loads and may reach the valley in medium size.	Avoid steep slopes. Route should be selected with care. Valley movement with caution. Movement on slopes with extreme care.
High	Unfavourable condition. Triggering possible from all avalanche prone slopes even with low additional loads and reach the valley in large size.	Suspend all movements. Airborne avalanche likely.
All round	Very Unfavourable condition. Numerous large avalanches are likely from all possible avalanche slopes even on moderately steep terrain.	Suspend all movements. Airborne avalanche likely.

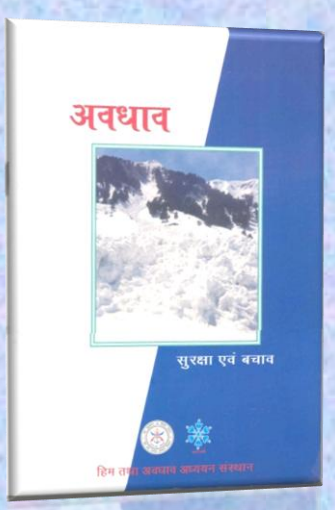
Movement with care - All safety measure shall be taken while crossing suspected avalanche paths.

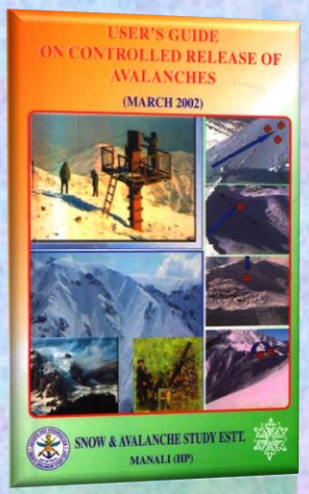
Movement with extreme care – Rescue party shall stand by.

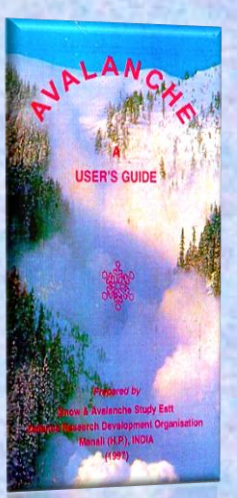
AVALANCHE AWARENESS COURSES

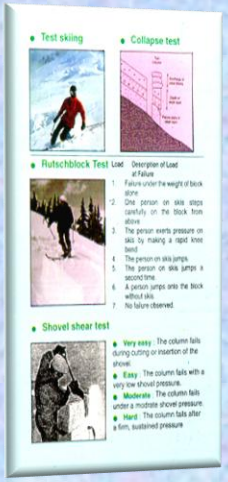
Year	No. of Persons Trained
2004-05	11149
2005-06	10876
2006-07	10360
2007-08	11130
2008-09	8628
2009-10	7287
2010-11	6012
2011-12	5573
2012-13	3756

AVALANCHE AWARENESS TRAINING MATERIAL

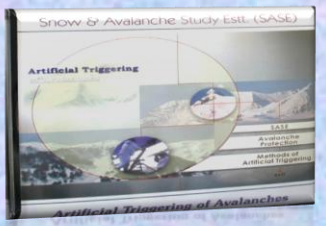


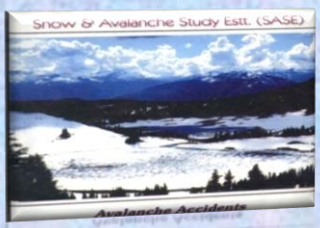




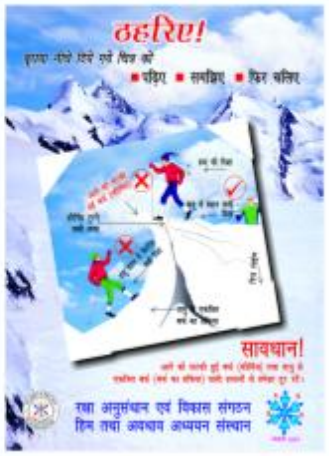


AVALANCHE AWARENESS MULTIMEDIA





AVALANCHE AWARENESS POSTERS



Artificial triggering : Controlled release of avalanches

Objective :

- To release avalanche under controlled conditions and
- To test the stability of the snow pack

Avdhav Visphotak Vahan

Hand placing of charge

ARTILLERY

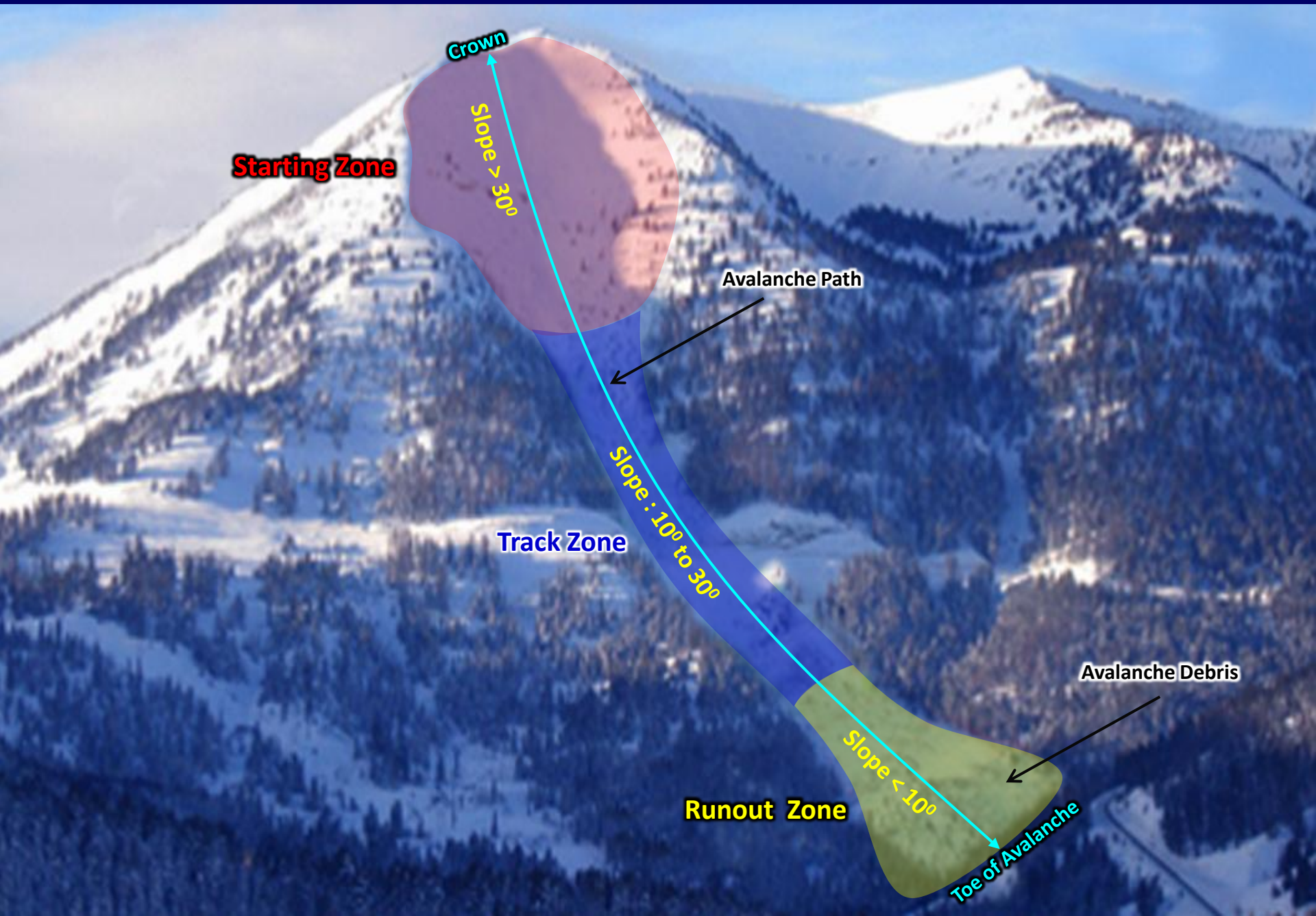
Results

- large avalanche formation prevented
- No avalanche reached national highway
- Improvised techniques developed , training to Army, BRO,ITBP

* Total no of triggering : 30-40 Every year
* Total explosive used : 50-60 Kg Every Year


Overview
of
Avalanche Control
Structures

Avalanche Path



Starting Zone Avalanche Control Structures

- **Formation Zone Structures**
- **Supporting Structures**
- **Snow Retaining Structures**
- **Avalanche Barriers**

Purpose

To arrest/retain the snow on slopes,
to avoid its sliding to **tolerable limits**

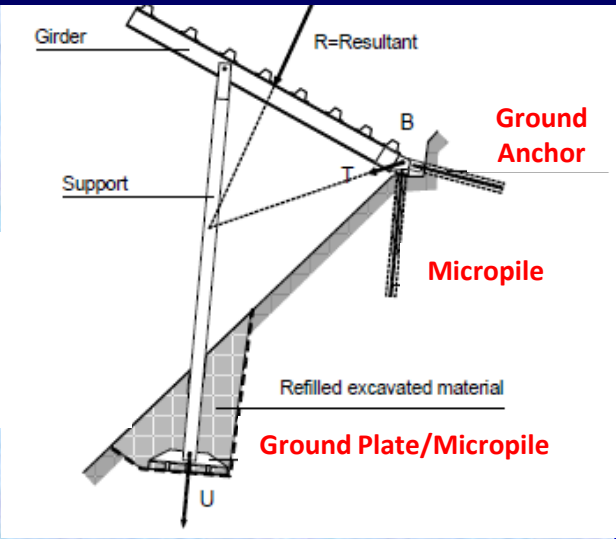
Good Choice

- Object to be protected lies in starting zone
- Slope is reasonably regular and even
- Technically feasible and economically viable
- Area is accessible for construction and erection

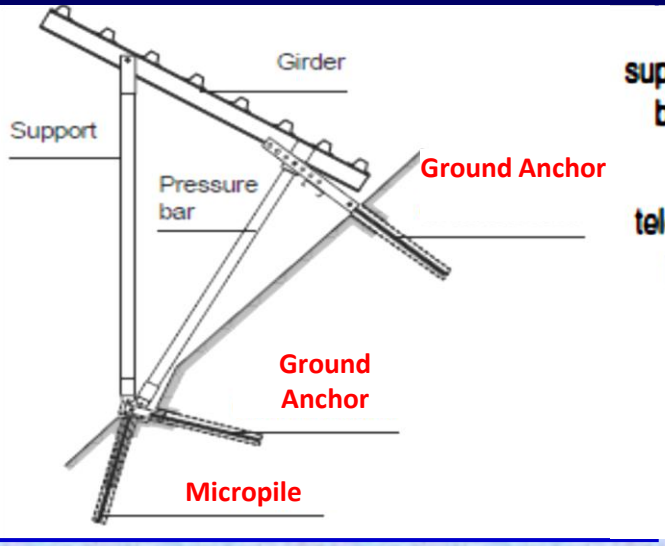
Motto : It is best to fight the root of evil

Starting Zone Rigid Avalanche Control Structures - Snow Bridges

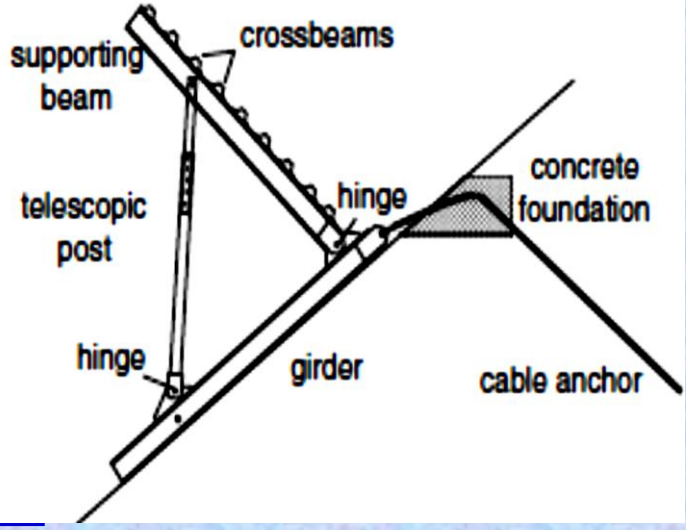
Type of Snow Bridges



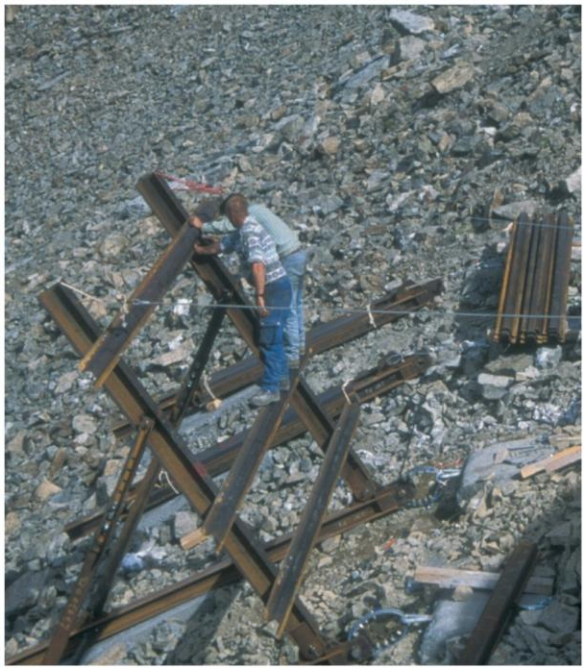
Single Support (Classic) Snow Bridge



Two Supports (Y Type) Snow Bridge



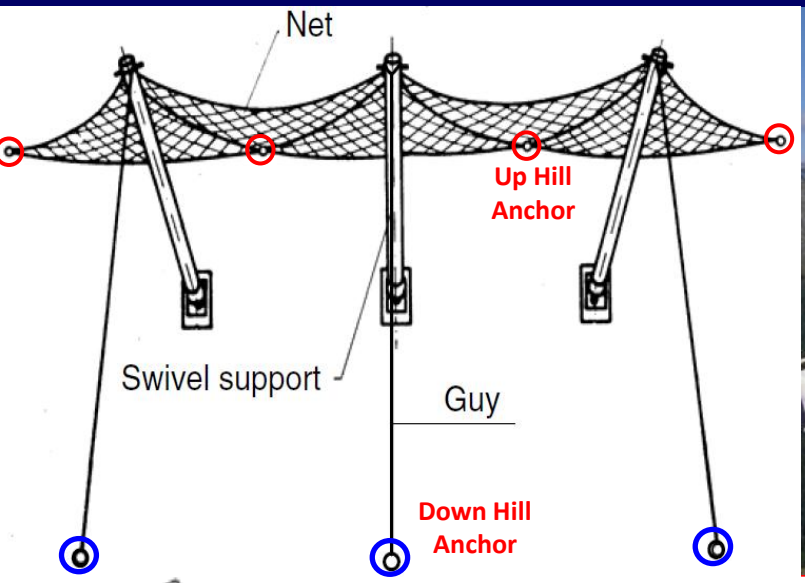
Suspended (Sledge) Type Snow Bridge

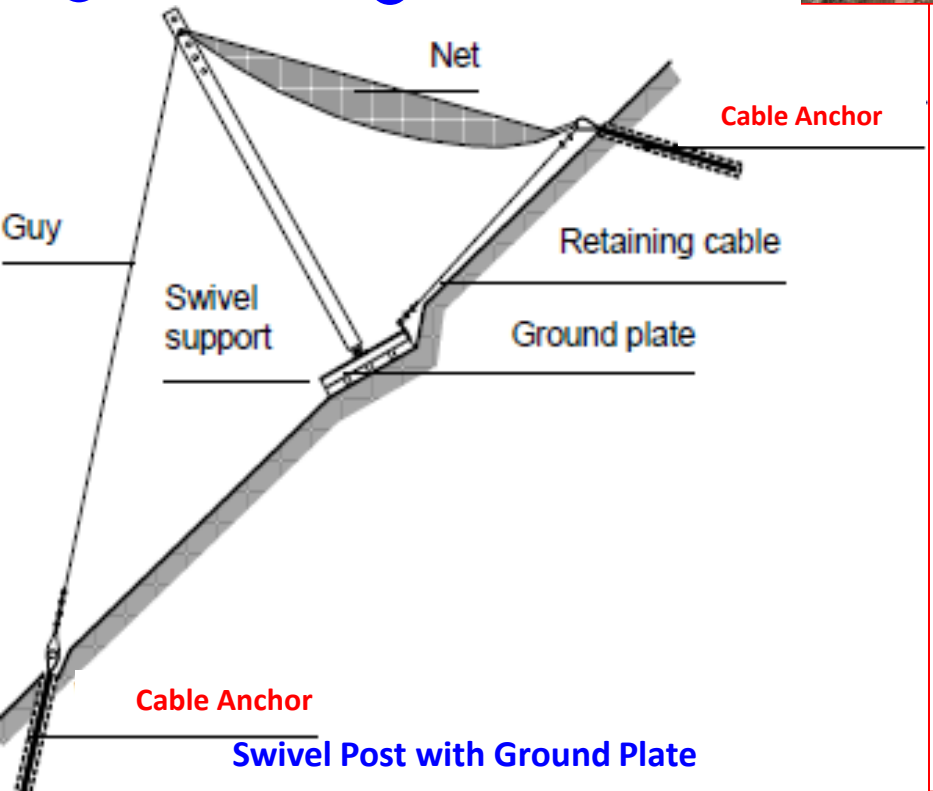


Starting Zone Rigid Avalanche Control Structure - Snow Rakes

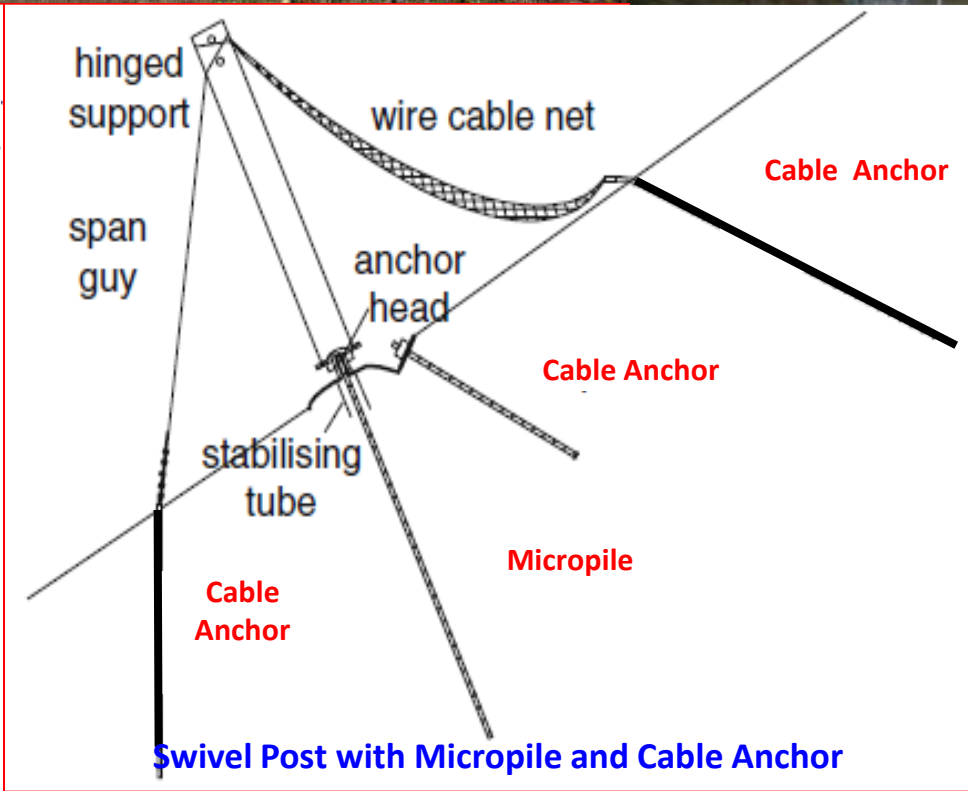
Starting Zone Flexible Avalanche Control Structure - Snow Nets

Snow Nets Erection





Swivel Post with Ground Plate



Swivel Post with Micropile and Cable Anchor

Middle/Track/Accelerating Zone Control Structures

i) Direct Protection Structures

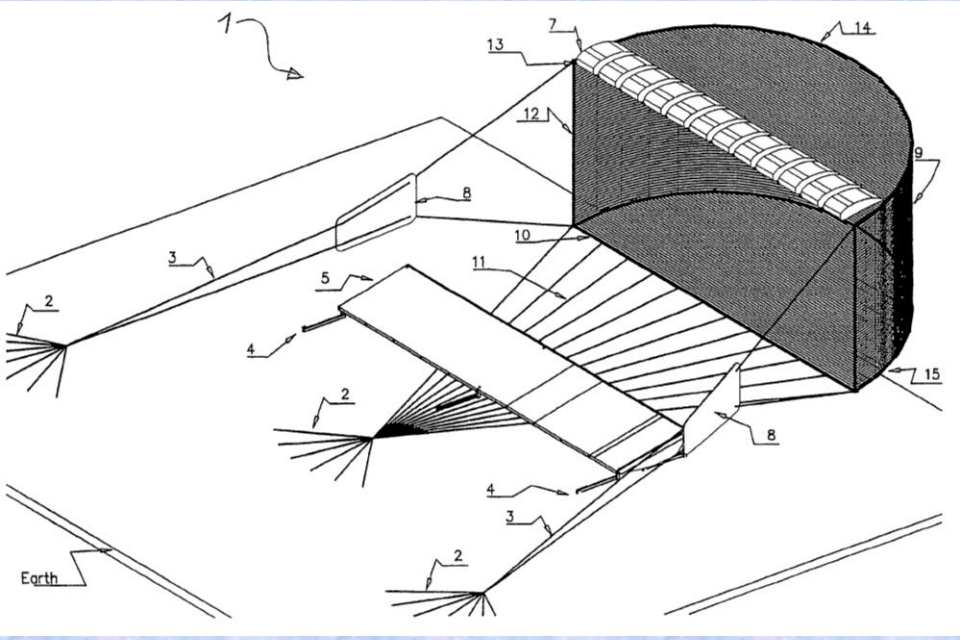
- Braking Dam/Splitter
- Wedges
- Avalanche Protection System (APS)

ii) Deflecting Structures

- Snow Shed/Snow Gallery (Artificial Tunnel)

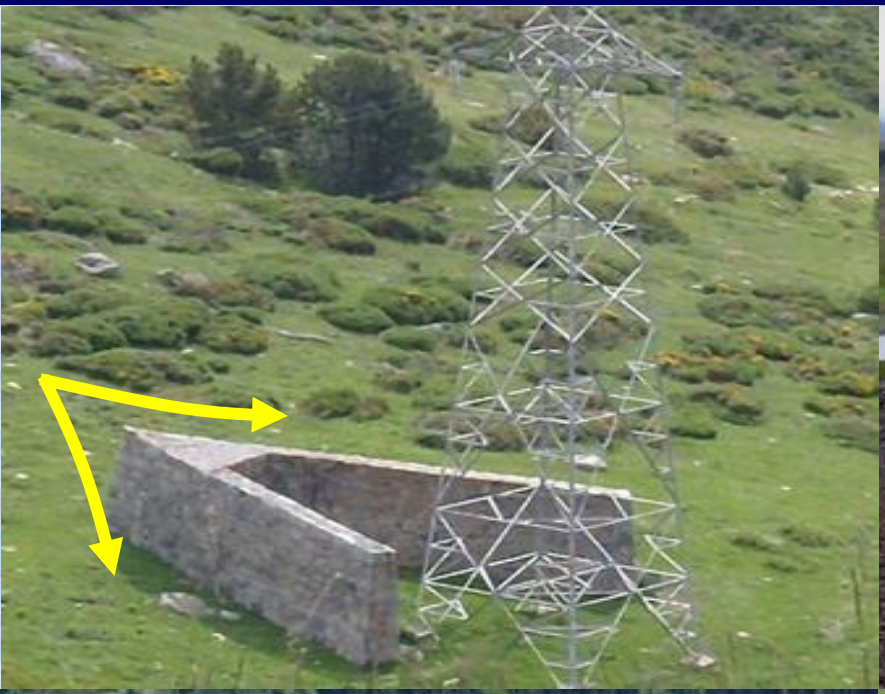
Middle Zone - Direct Protection Structures

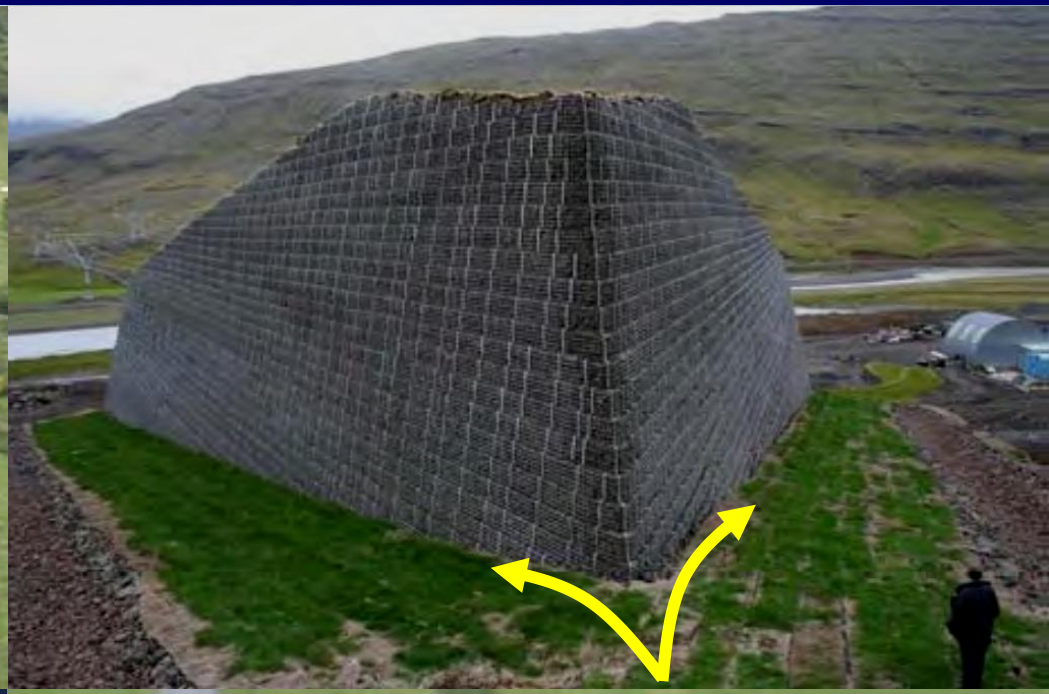
Splitter/Braking Dam



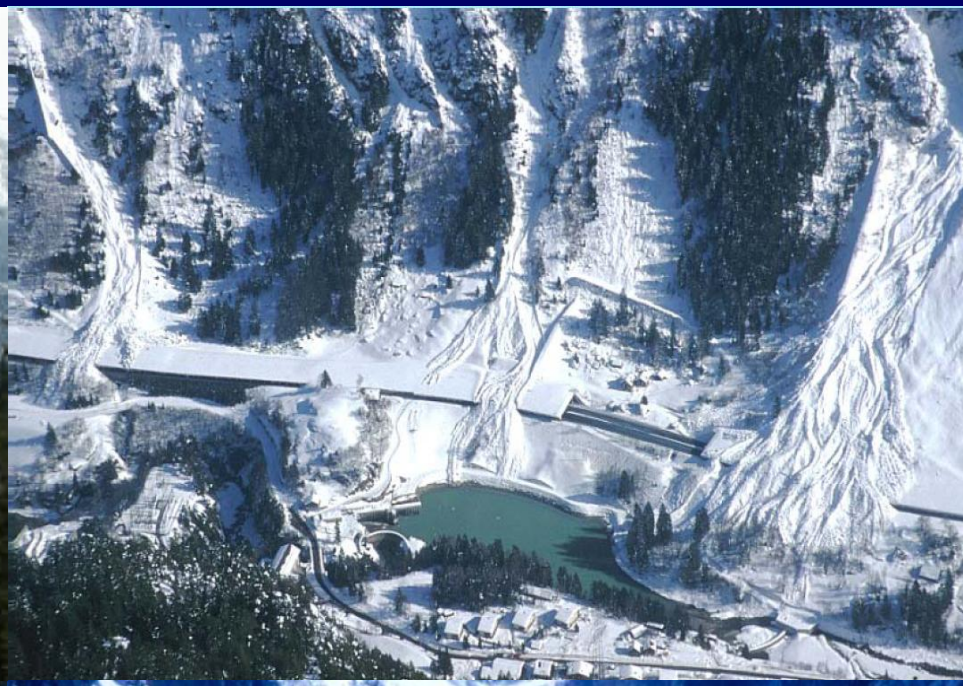
Avalanche Protection System

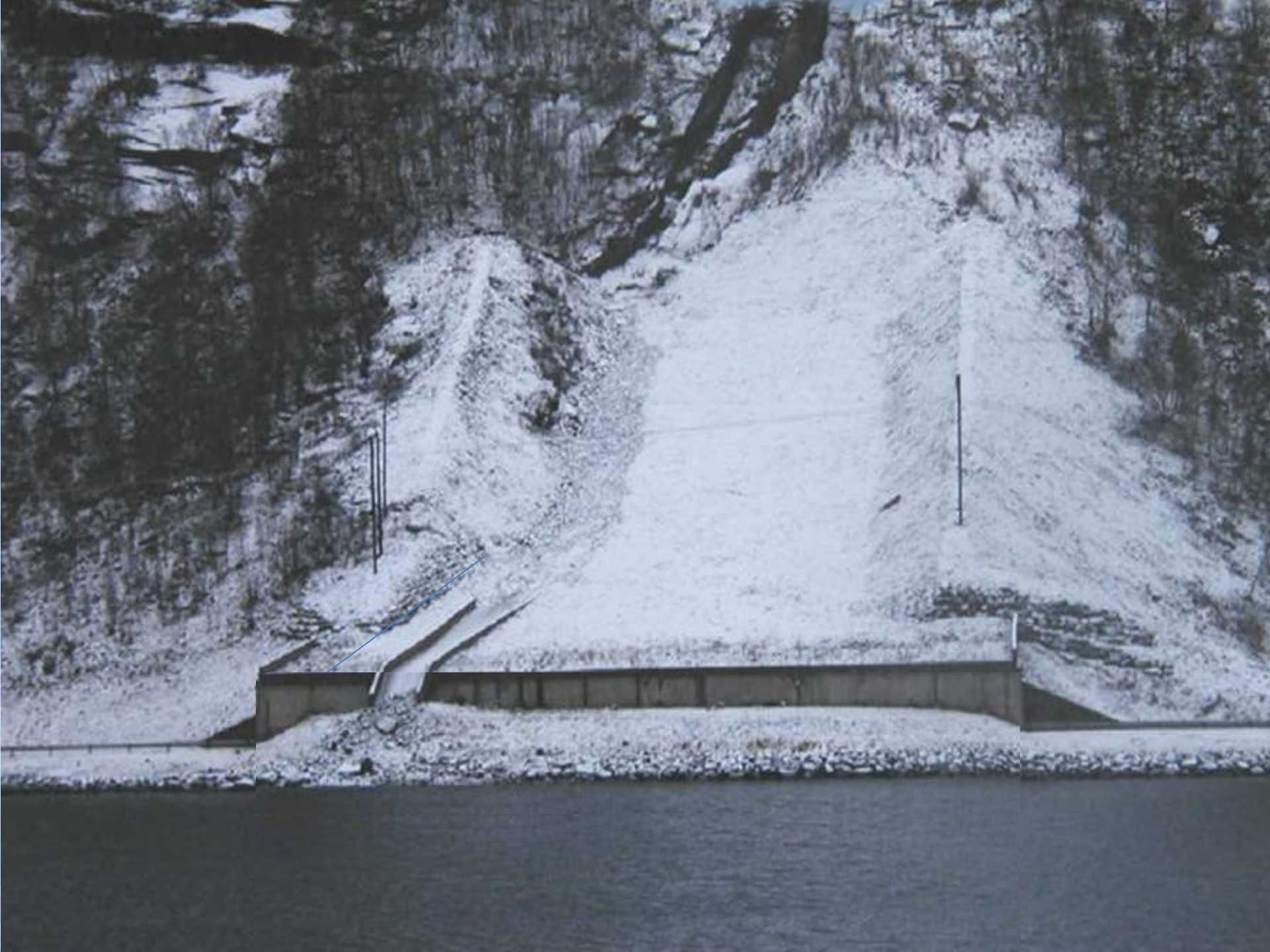
Wedges





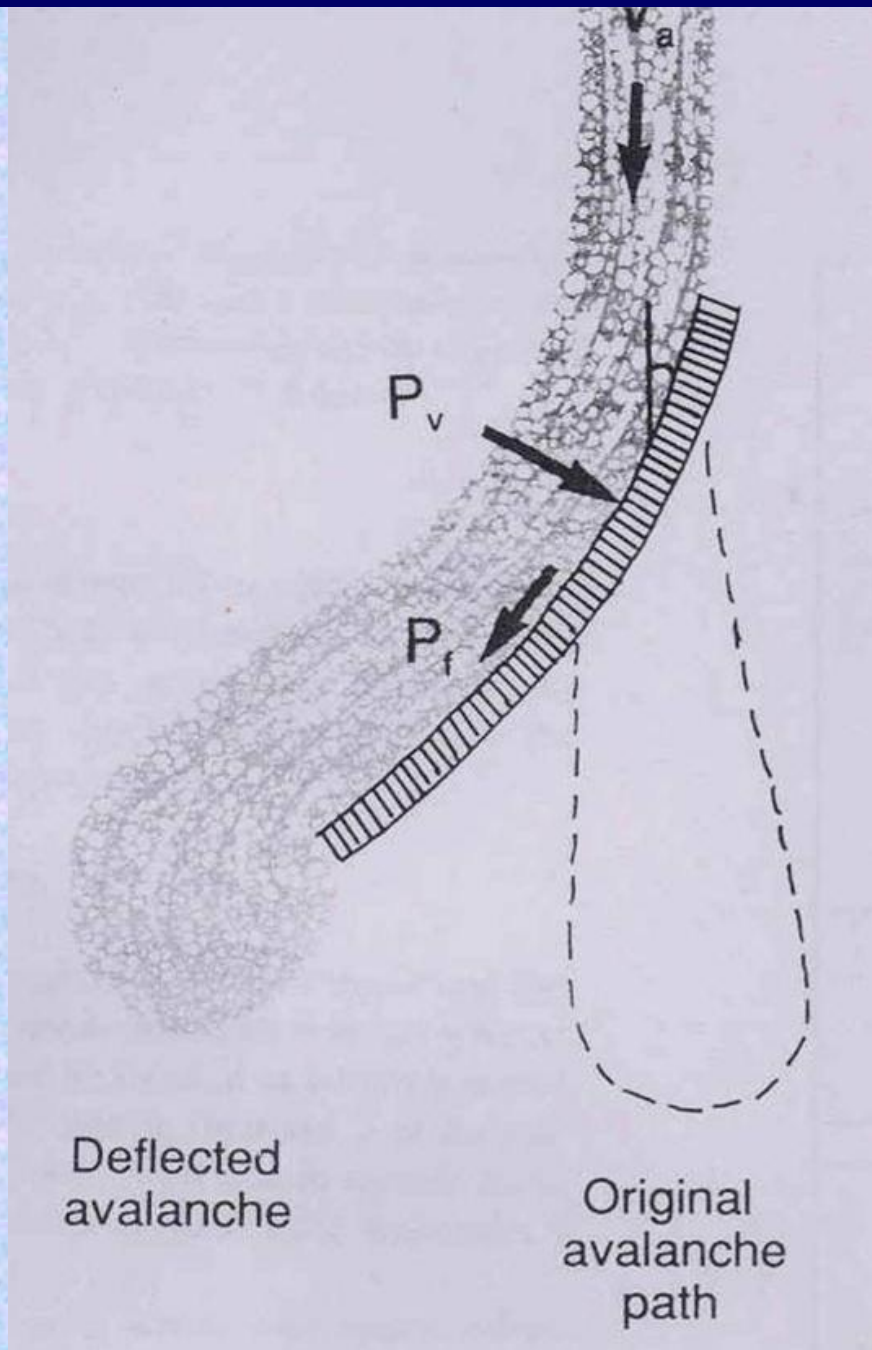
Middle Zone (Deflecting Structures) - Snow/Avalanche Shed





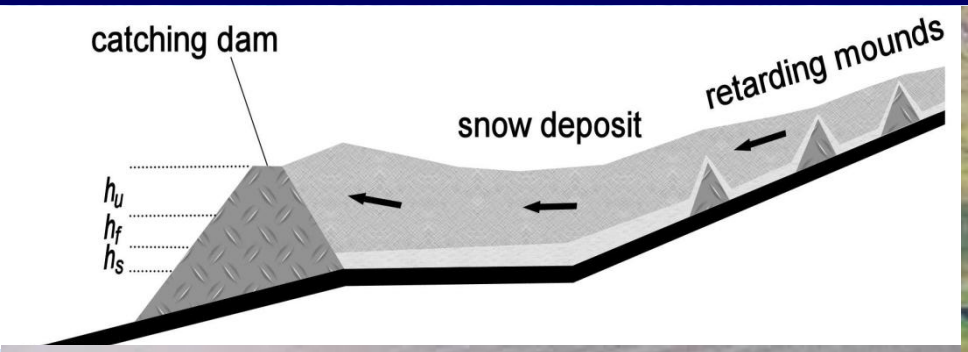
Run out Zone Avalanche Control Structures

- Guide Wall
- Diversion Wall
- Catch Dam
- Mounds

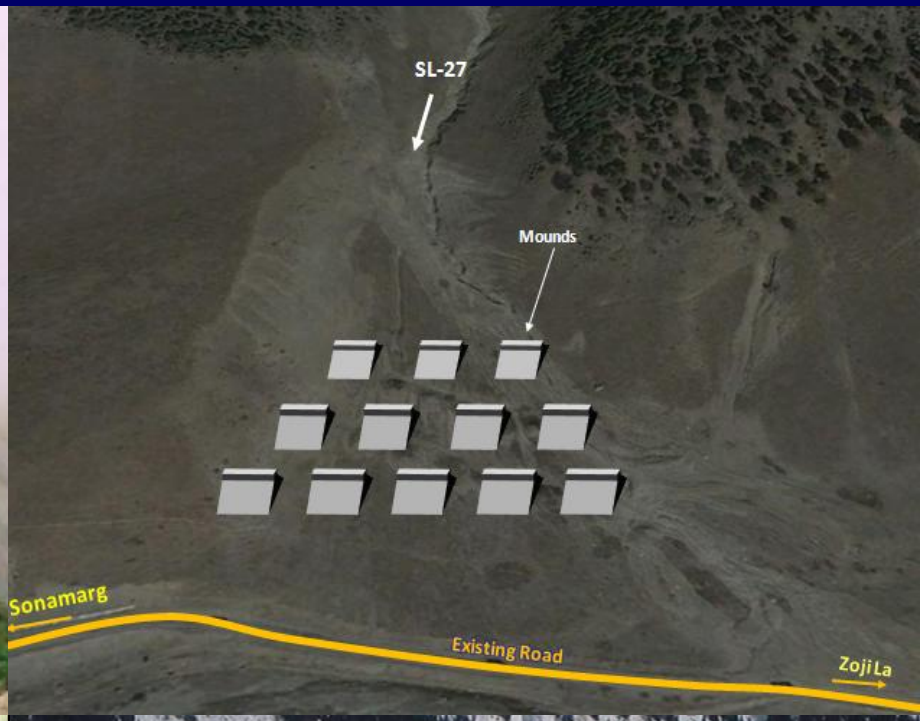


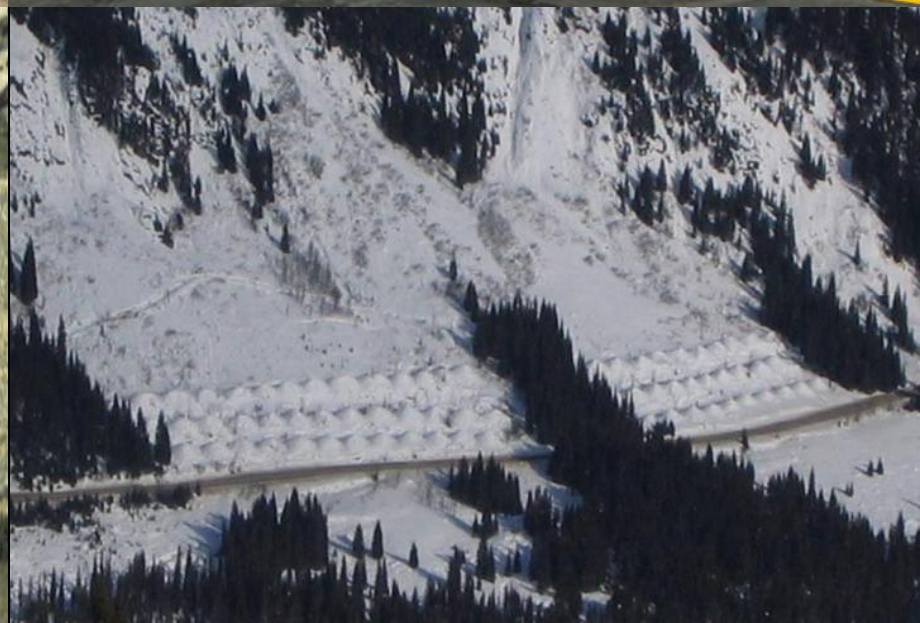
Diversion Walls & Guide Walls

Catch Dams

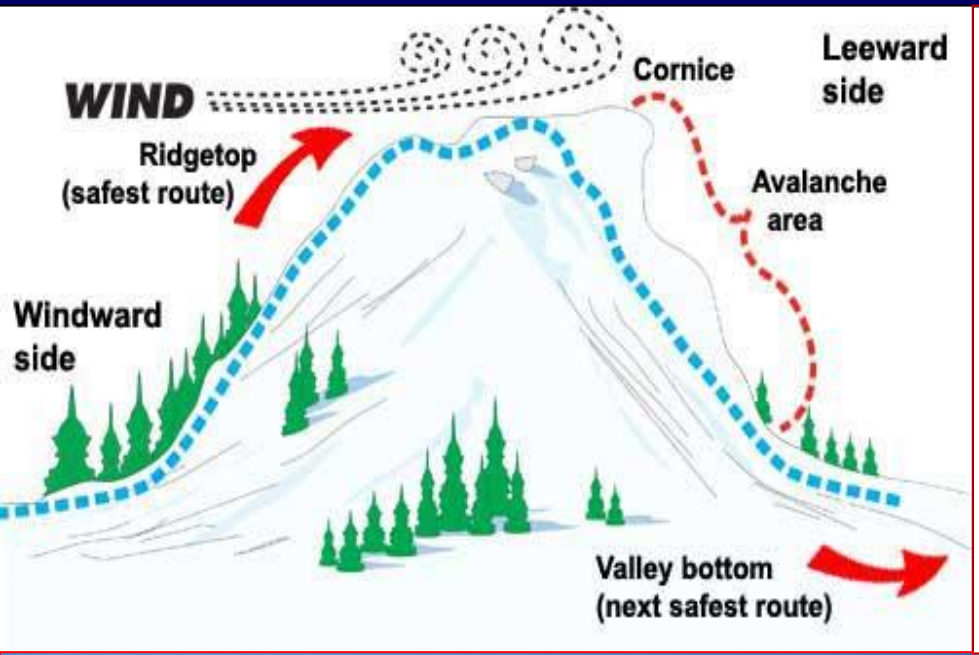


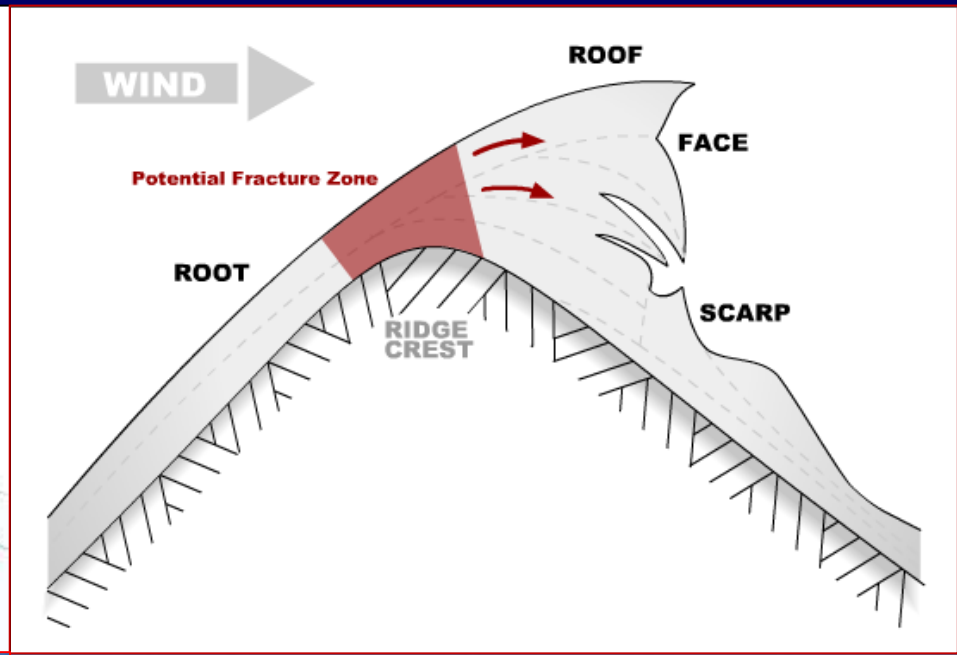
Mounds



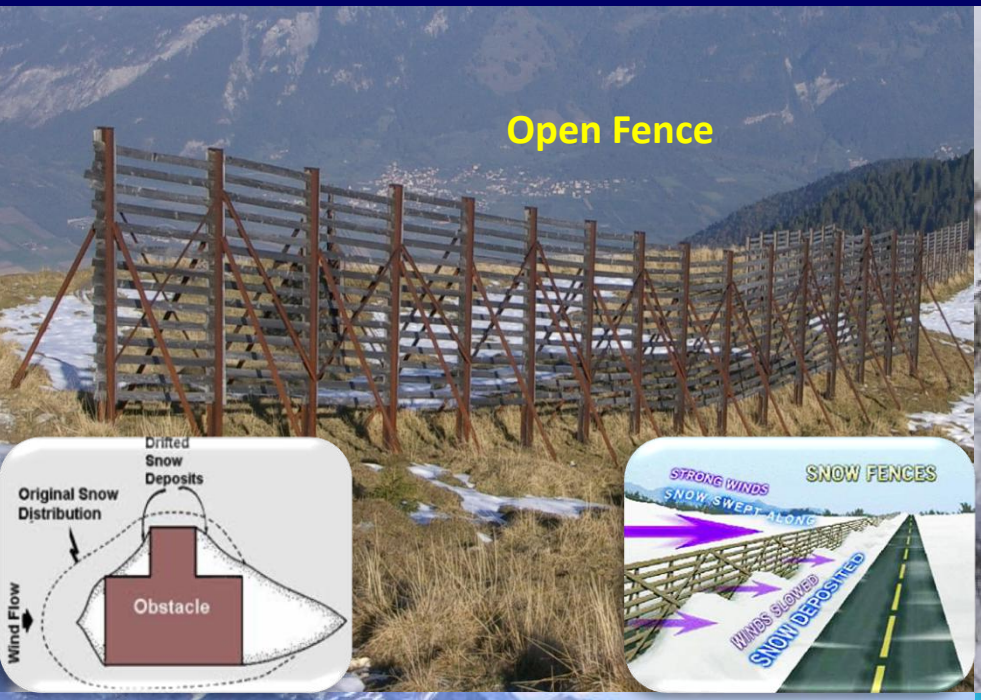


Wind Drift Control



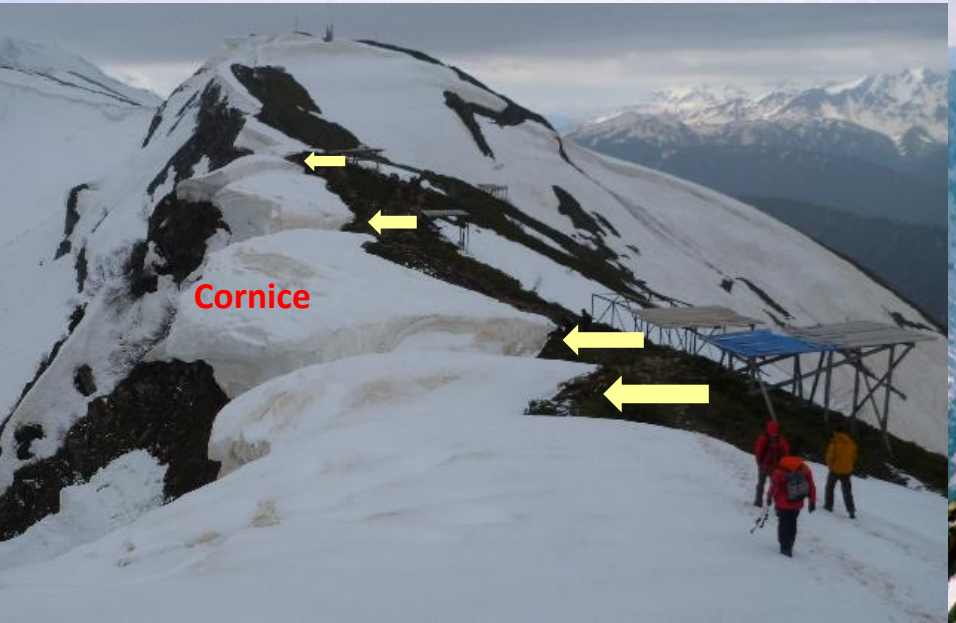


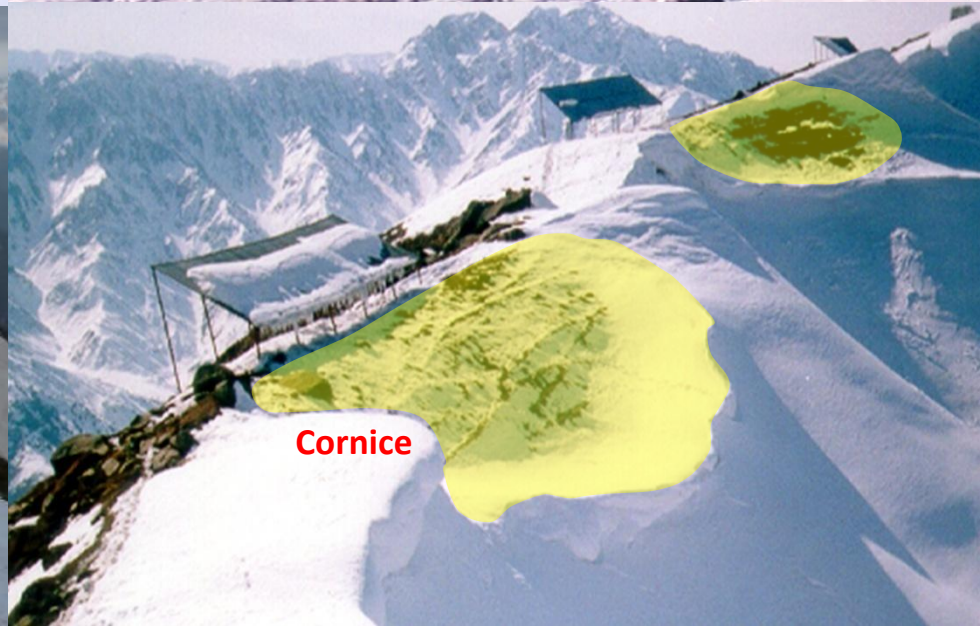
Wind Drift Control Structures - Snow Fences



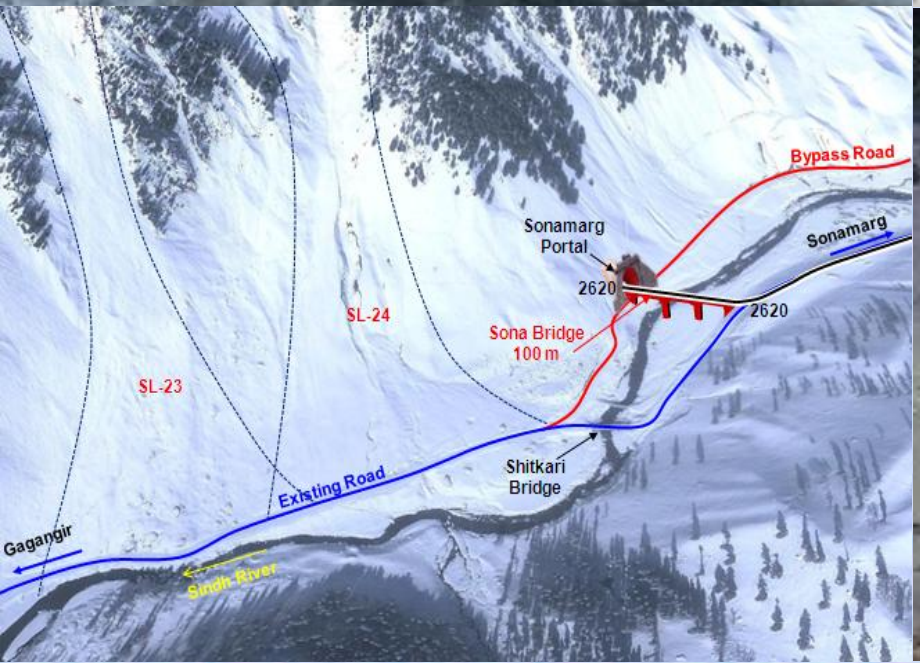
Wind Drift Control Structures – Wind Baffles

Wind Drift Control Structures - Jet Roofs

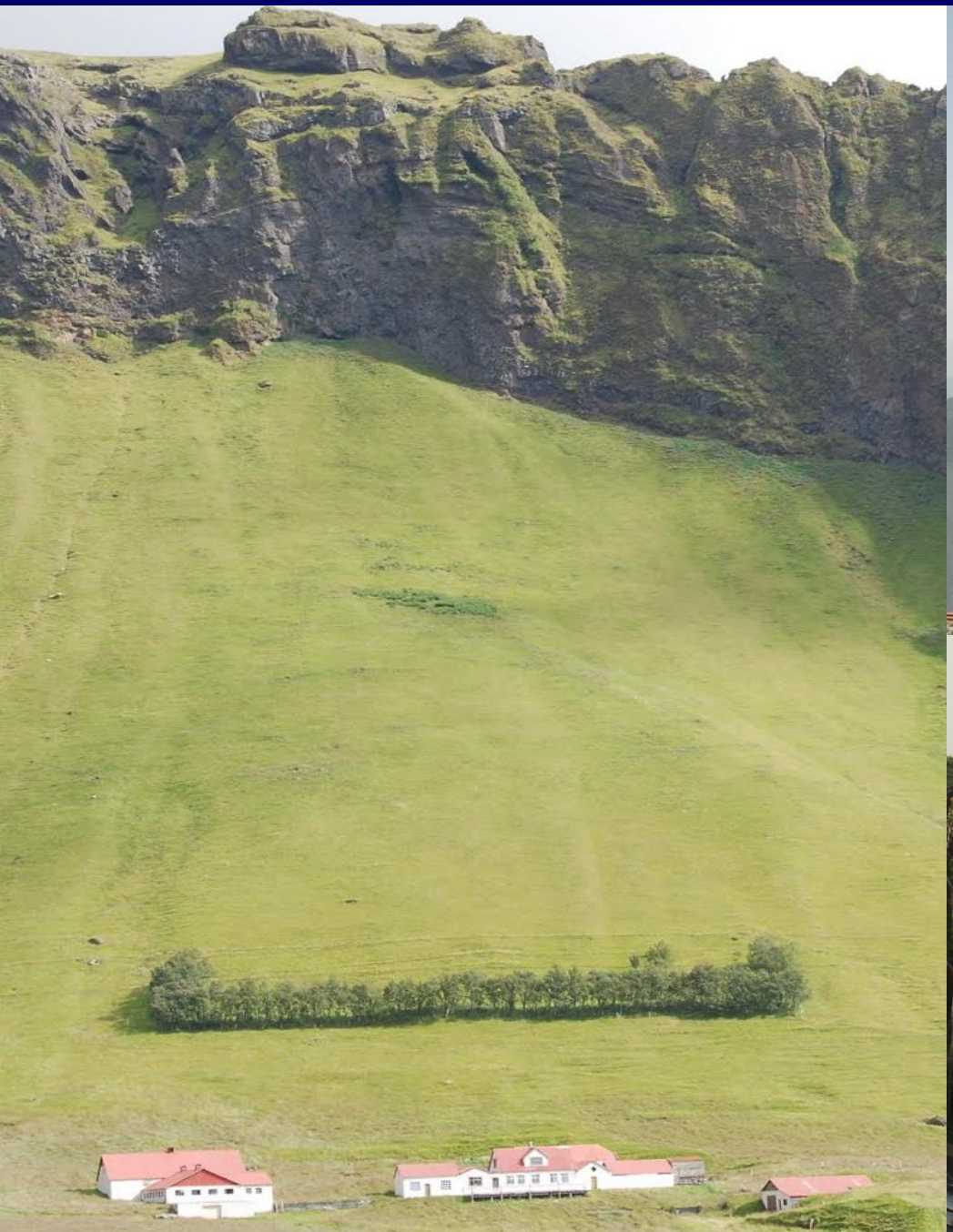




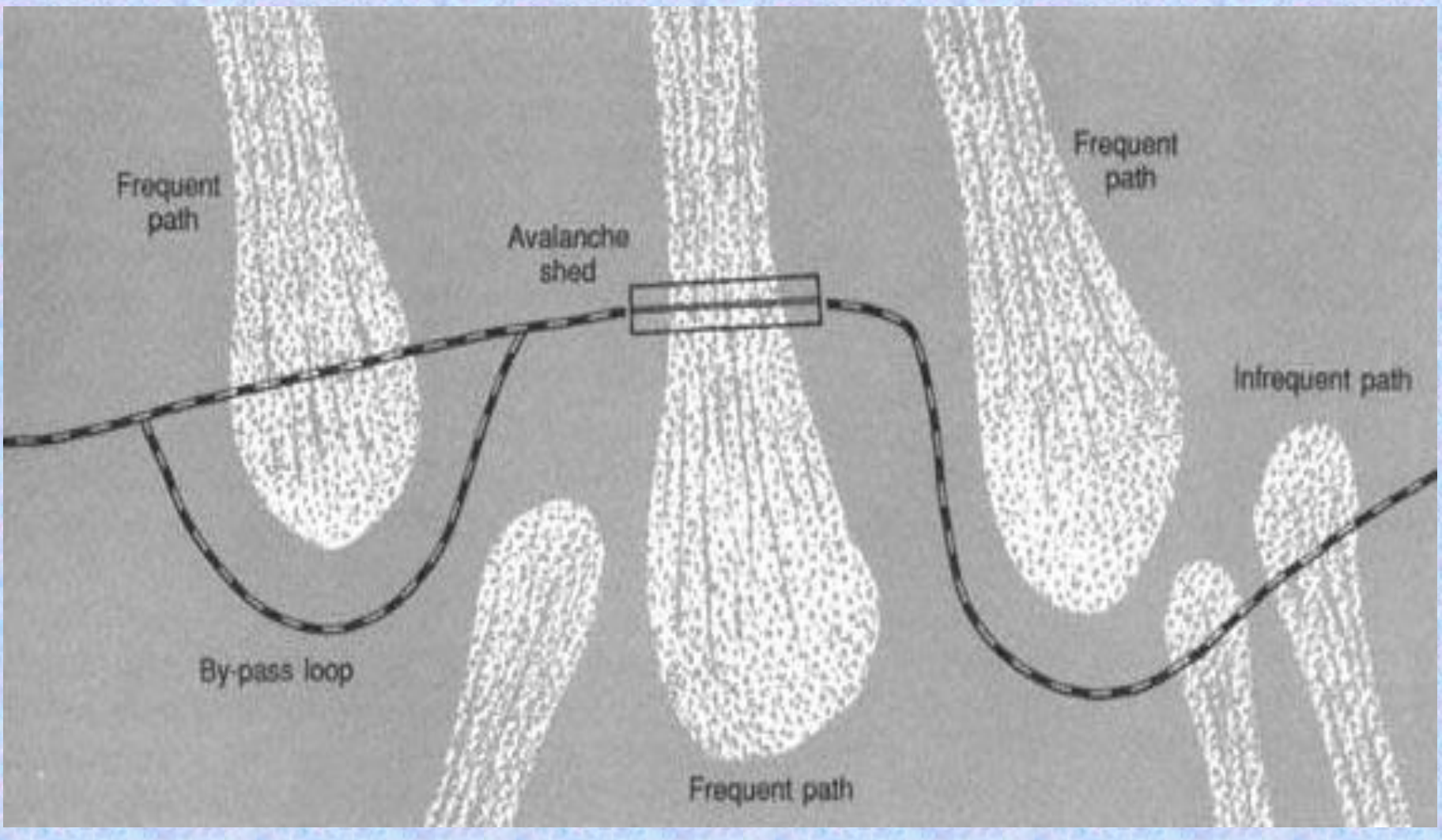
Tunnels


Bypass Road
Sonamarg
Portal
2620
Sonamarg
2620
SL-24
Sona Bridge
100 m
SL-23
Shitkari
Bridge
Existing Road
Gagangir
Sindh River

Biological Measures - Afforestation



Re-alignment of Highway



Thank You