

# Landslides and Its Remedial Measures in Mussoorie Hilly Sections

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**Abstract**— Mussoorie Landslides constitute one of the major natural disasters. The fragile terrain often faces significant problems of geo-environmental imbalance due to landslides. The term landslide includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. Mussoorie steep terrains also face problem of Landslides. After the terrain evaluation and Landslide hazard assessment, the mitigation measures have to be taken up. These are to stabilize the various soil and rock slope, which are prone to Landslides. The method or model is used are: stability of natural slope which depends upon the terrain and material parameters. Remedial Measures are apply after the proper analysis of soil parameters, slope stability and Geomorphologic condition of study area and select the cost effective remedial measures.

**Key words:** Landslide hazard assessment, Geomorphologic condition of study area, terrain evaluation

## I. INTRODUCTION

The problem of the landslide and stability of slopes, both natural and excavated, has to be faced in many fields of human activity, particularly in civil engineering. When slope stability is disturbed, a great variety of sliding movement takes place. Landslides are playing a role of two factors, extrinsic factors as well as intrinsic and common in the terrains. Extrinsic factors role is to change in slope geometry and land use pattern by human interface, whereas the intrinsic factors are primarily the geological conditions like unfavourable jointing, shears disturbances, weak rock types etc. Rainfall and seismic activity are mainly the triggers. Landslide analyzed from different point of view. First geologist, they are considered as natural processes which destroy land surface and comparison with geological studies. Geologist studies cause of origin of landslides with respect of sliding phenomena, among the significant exogenic denudation processes. Other aspects are developed from engineers, they investigate the slope stability, factor of safety, structure of strata. Therefore they Endeavour to identify those slopes that are susceptible to sliding where the equilibrium conditions might be disturbed by interference, and to determine the maximum permissible inclination of excavated slopes.

## II. REVIEW OF LITERATURE

**R.K. Bhandari et al., (1980)** carried out an analysis correction and efficacy of protective measures which belongs to major landslides in Sikkim (A.P.) (India). They presented the case history of a major landslide in Sikkim which had proved to be a source of continual trouble for many years. The landslide was successfully treated as a result of the planned implementation of remedial measures

borne of careful studies. An attempt is made to pin –point the reasons for the success of the control measures already implemented and to draw broad- based lessons for future guidance in tackling similar situations in the Himalayan region. The principle of synergism in landslide correction practice is adumbrated. Experience in the Himalayas taught us that a carefully designed drainage system (surface and subsurface) invariably proved to be the single most effective measure in preventing or correcting a landslide, irrespective of the type or the magnitude of the landslide involved.

**K.R.Datye, (1980)** studied about landslides control measures and their efficacy. All the remedial measures which belongs to control measures and study of local geology and experience of past landslides in the region or under similar conditions would help to identify the slide producing processes. The preventive or corrective measures can be designed to counteract the forces or factors responsible for slope failure. Control measures commonly used for landslide prevention or correction can be divided into the following categories which are grouped according to factors responsible for slope failure and their modes of action.

- Measures for reduction of pore water pressure comprising.
- Modification of the gravity force system by reducing slopes or placing stabilizing berms combined with provisions for prevention of toe erosion, scour or sub-surface erosion.
- Installation of a structural system consisting of piles and anchors for transfer of the load to apportion of the soil mass unaffected by slide producing mechanism and construction of artificial barriers such as retaining wall.
- Improvement of soil properties by compaction or by special processes such as electro-osmosis, lime columns, stone columns and strengthening of the rock by cement or chemical grouting.
- Another category of control measures relates to avalanche control. These are special categories since they do not involve land slide directly but help to prevent avalanches which may trigger a landslide.

**K.D. Dhakharia, (1980)** studied and carried out value of photogrammetric for landslides studies. Photogrammetric techniques provide detailed analysis of site to ascertain any active or potential landslide areas, and other information's for design of slope, etc. Which otherwise is not possible by conventional methods. The classification, causes diagnostic features in Aerial photographs (AP), Land sat Imagery, Terrain groups, and other sensors, scale, gauging of control, Himalayan problem and future capabilities have been dealt to impress upon the ability of techniques in landslide studies.

**K.S. Valdiya, (1980)** studied out the accelerated erosion and landslides prone zone in the control Himalaya region. They

describe all the causes like seismic flood overgrazing, deforestation and constructs with control and mitigation properties of landslides. They describes about the major cause of accelerated erosion is the loss of protective vegetal cover which is now only 35% against the optimum of 60% and causes of deforestation include overgrazing , harvest for timber and industries , and lopping of trees for fuel and fodder. The incidence of grazing is 2.5 to 4.5 times the supporting capacity of forest and the stripped of the protective vegetal cover; the Himalayan soils are fast losing their capacity of absorbing rain water, which largely runs off on the surface, bringing about recurrent damaging floods on the plains. Since little water percolates into the ground, the hill springs are drying up.

**R.K. Bhandari and Chanchal Gupta, (1980)** highlighted the problem of landslides in the Himalaya and future directions and brings out the nexus between the landslides and the rainfall, particularly for the regions witnessing cloud bursts. Also describes the fact of flash floods, deforestation, human activities and drainage are discussed and classification of the problems of mass wasting with some

examples of major landslides dams of Himalaya and studied out some of the common methods of landslides control.

### III. STUDY AREA

Mussoorie, popularly known as the Queen of the hills, is situated on the first range of hills running east-west parallel to the Dehradun valley and the Siwalik and on the lateral spurs there from having North-South direction. Mussoorie is allocated on coordinates 30.45°N-78.08°E and an average altitude of 1,880 meters (6,170ft.). Mussoorie has average elevation of about 2005.5metres (6,580 ft.) and located in Lesser Himalaya in close proximity of Main Boundary Thrust (MBT) that is a North-East dipping tectonic discontinuity bringing Lesser Himalayan rocks in juxtaposition with the rocks of Siwaliks. This discontinuity can be observed at the foot of the Mussoorie hills near Shahanshahi Ashram in Rajpur. The township of Mussoorie falls in Zone IV of the Seismic Zonation Maps of India (IS 1893, 2002). Description of area is described below with the help of map in fig-1.

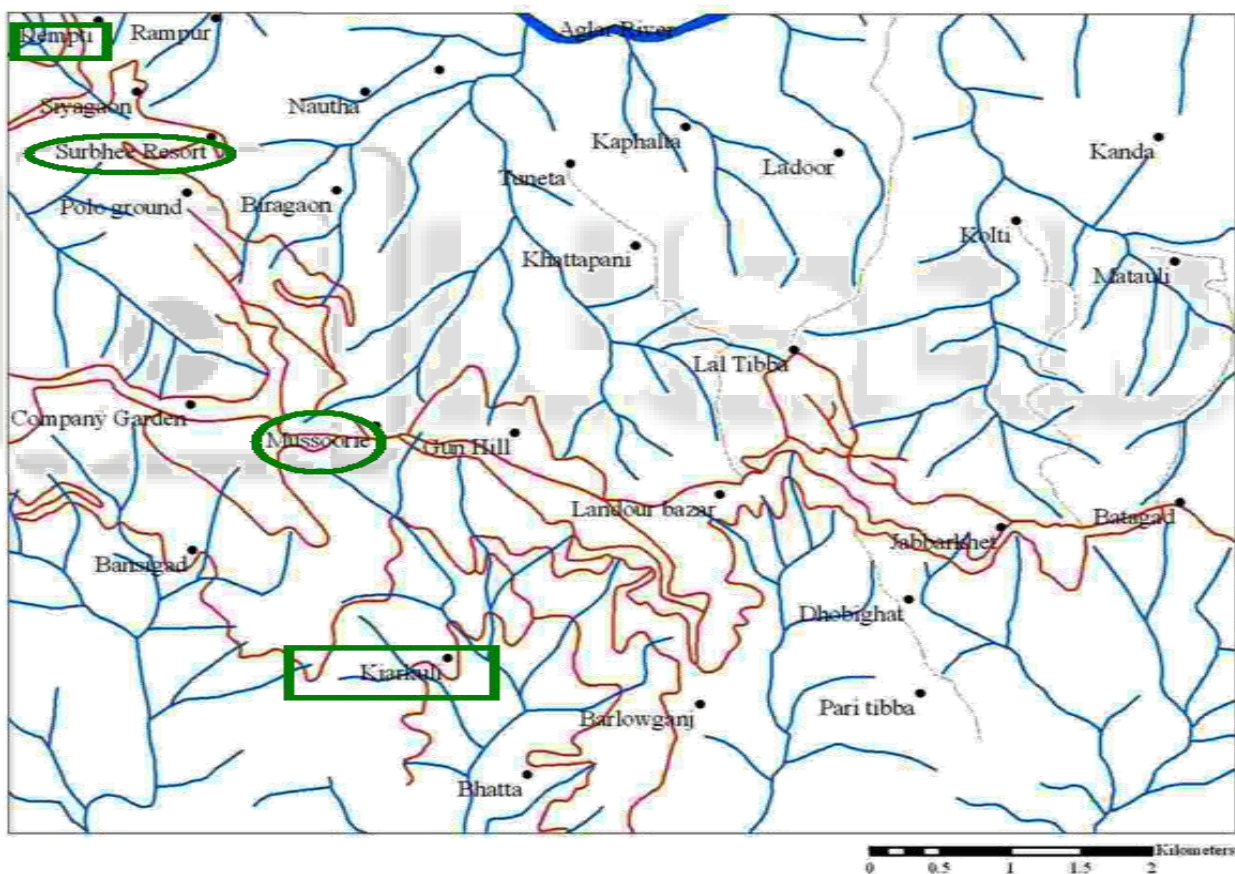


Fig. 1: Map of the study area over the Mussoorie divisions (Source-DMMC Uttarakhand)

### IV. GEOMORPHOLOGY OF MUSSOORIE DIVISIONS

A number of active and potential landslides of small to large dimension are observed around Mussoorie in different litho-units with rocks type, surface slope, bedding or foliation dip, slope type and landslide status according to active and potential. Rocks and soils comes under the active landslide

status and potential of landslide are divided into three parts; High, medium and low. Slope type are also classified in four parts; Cataclinal, Orthoclinal, Anaclinal and Ortoanclinal. These are summarized according to litho-unit and map in fig.2.

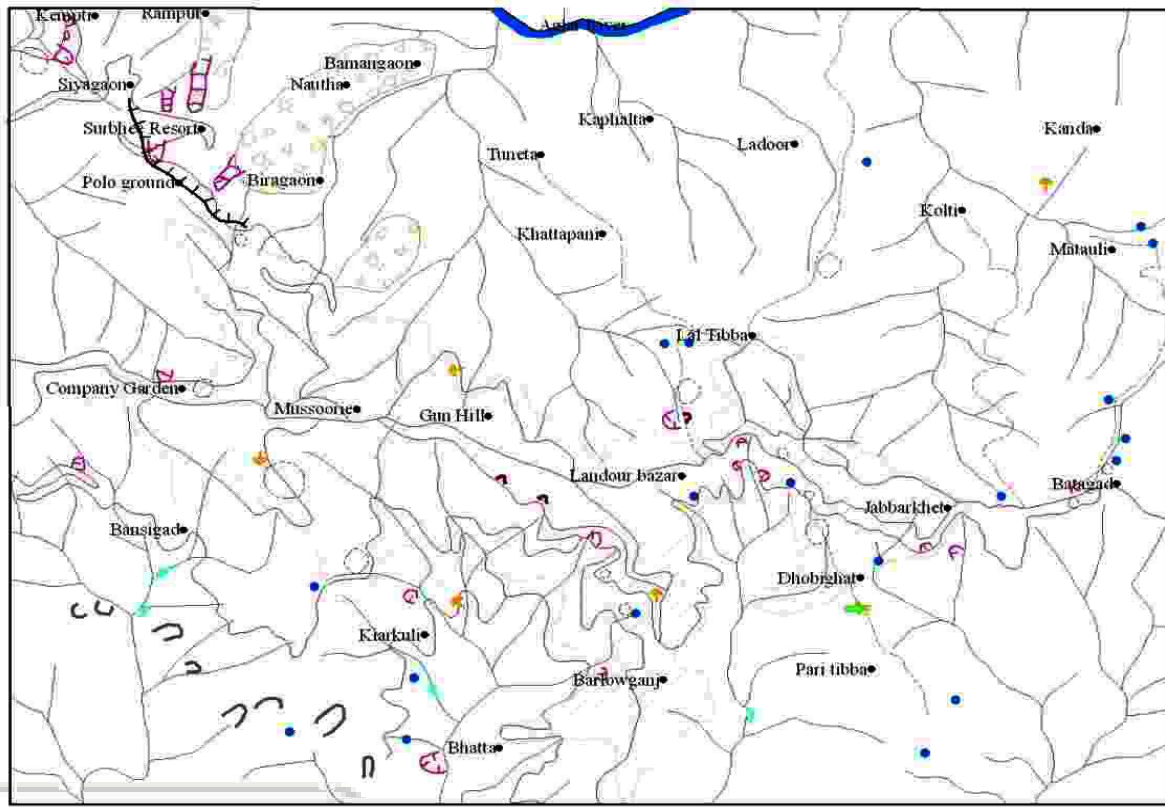


Fig. 2: Geomorphologic features observed over the area around Mussoorie divisions  
(Source-DMMC Uttarakhand)

#### V. TOPOGRAPHY OF MUSSOORIE DIVISIONS

Topography is an important bearing upon the geomorphic evolution of any area, particularly so in the hills of Mussoorie. The area around Mussoorie is observed to be dissected by several ridges and the ground elevations vary between 900 and 2,290 meters above mean sea level (msl). Lal Tibba with high top 2,290 meter above msl is highest point of the area while second highest point, gun hill and Dhanaulti have an altitude of 2,024 meter above msl. Company Garden and Mussoorie Lake respectively have elevations of 1,370 and 1,880 meters above msl. The intensity of soil erosion and mass wastage in this region is observed to be controlled by various processes, activities and features that include geological structure, precipitation, slope pattern, land use/land cover and infrastructure development. Even small change in slope amount can strongly influence the rate and intensity of soil erosion and land slide because of relatively thin soil cover over steep in-situ rocks in the area.

#### VI. IDENTIFICATION OF LANDSLIDE ZONES IN HILLY AREAS

Landslide prone zone identification is primary work for the analyzer and first step in a programmed for landslide hazard- mitigation is the identification of zones prone to mass- movements. This is done on the basis of geomorphic

features revealing history and indicating existing Stresses , and recognition of the establishing effects that some development work commonly have or are likely to produce. A hazard –zoning map involves comprehensive investigation in given table.

Information Needed	Uses
Geological Maps	For understanding causes of landslides for predicting density, severity and frequency of landslides in large areas. Aerial photographs enable recognition and mapping of landslides in larger area.
Topographic Maps	Provide a base for plotting landslide information. Geomorphologic (topographic) forms are used to identify landslides. Top maps provide basic data for slope analysis.
Slope Maps	Slope –stability maps combine steepness, land sliding and physical characteristics of different materials.
Climatic Data	Climatic data based on specific events and annual climate are needed for

	assessments of influence for case histories and probabilistic predictions.
Subsurface Water	Build up of pore water pressure in subsurface materials and changes in water –levels needed for predicting initiation of specific landslides and predicting probability of failure.
Seismic Data	Enable preparation of maps of susceptibility to land sliding by earthquakes.
Vegetation Maps	Vegetation tending to support and stabilize slopes need to be depicted in terms of types, density and canopy cover.
Weathering of Rocks	Information on thickness and kinds of weathered rocks products is used for estimating hill slopes strength and landslide susceptibility.
Land use Maps & Socioeconomic Data	Learning present and planned development for assessment of risks

Table 1: Information Needed for Landslide-Hazard Mapping and Risk Evaluation

#### VII. FACTORS INFLUENCING THE LANDSLIDES IN HILLY REGIONS AN ENGINEERING ASPECTS

Factor which influencing landslides or mass movement is primary importance to recognize the conditions that cause slopes to become unstable and the factors that trigger the movement. The susceptibility of sliding is determined by the geological structure of the slope, the litho- logy of the rocks, hydro geological conditions and the stage of morphological development of the area. Only an accurate engineering treatment makes it possible to appreciate the extent of the danger and to propose and develop effective remedial measures. There are great types of slope which reflects the diversity of factors that may disturb slope stability. The most important of these are as follows:

##### A. Slope Gradient:

Change in slope gradient may be caused by natural or artificial influence. (e.g. by the undermining of the foot of a slope by stream erosion. Or by excavations).An variation or increase in slope gradient creates a slight change in the internal stress of the rock mass and equilibrium conditions are disturbed by the increase of shear stress.

##### B. Slope Height:

Change in the slope height is a parameter or result of vertical erosion or excavation work. The deepness condition of valley relieves lateral stress and this leads to the loosening of rocks in the slope and the making of fissures parallel to the slope surface.

##### C. Overloading:

Overloading by embankments, fills and spoil heaps this produces an increase in shear stress and an increase in the pore- water pressure in clayey soils, which gives drastic results in decreased shear strength. The more quickly the loading, the more dangerous it is.

##### D. Shocks And Vibrations:

Large –scale explosions, machine vibration and tremors produced by earthquakes affect the equilibrium of slopes on account of the temporary changes of stress that are caused by oscillations of different frequencies. Vibration and shocks may disturb intergranular bonds and thus decrease cohesion.

##### E. Water Content:

Change in water content is most serious cause to triggers landslides. Rainfall and melt water penetrates joints and produce hydrostatic pressure. In soils the pore-water pressure increases and consequently the shear resistance decreases. Measurements of rainfall have confirmed that recurrent slope movements occur in periods of exceptionally high rainfall. Electro-osmotic effect between two beds which contact along a sliding plane there is a difference of electric potential which increase in the water content leading to slope movement. In clayey rocks, the deleterious effect of atmospheric water is greater when the rain comes after a long dry period: clayey soils are desiccated and shrunken so that water readily percolates deep into the fissures.

##### F. Ground-Water Effect:

Ground- water effect on landslides process in many ways like flowing ground water produces a pressure on soil particles which impairs the stability of slopes. Ground-water can wash out soluble cementing substances and thus weaken he intergranular bonds and reduce the mechanical strength of the ground. In fine sand and silt flowing ground –water flushes out fine particles and the strength of the slope is weekend by the cavities that are formed.

##### G. Frost Effects:

Water frost freezing in rocks fissures increases in volume and thus tends to widen them and rock penetrated by fissures consequently shows reduced cohesion. In clays and clayey –sandy soils ice laminae are formed, which on melting enlarge the water content in the thawing surface layer. The freezing of water on the surface impede drainage from the slope, so that the ground water table rises and equilibrium is eventually disturbed.

##### H. Weathering:

From the weathering point of view both mechanical and chemical, gradually disturbs the cohesion of rocks. In many landslides events, chemical alterations such as hydration and ion exchange in clay are thought to have contributed to the triggering of landslides.

##### I. Vegetation Effects:

The roots of trees maintain the stability of slopes by their mechanical effects and contribute to the drying of slopes by absorbing a part of the ground-water. Deforestation of slopes adversely affects the water regime in the subsurface layers.

#### VIII. ROLE OF SHEAR STRENGTH IN LANDSLIDES

At a point inside a soil mass subjected to non-isotropic stress system one can find shear stress along with normal stress induced on all planes passing through that point, except on principal planes. On the potential failure plane shear stress induced will tend to exceed the shear strength of

soil causing excessive shear deformation leading to shear failure. The shear strength is the maximum shearing resistance that is mobilized on the potential failure plane and is equal to the ultimate shear stress in the limiting equilibrium condition. The development of shear strength is attributed to one or more of the following:

- The frictional resistance between the particles at their points of contacts (combination of sliding friction and rolling friction).
- Cohesion or force of attraction between particles.
- The structural resistance to displacement because of interlocking of particles and cementation or adhesion between particles.

**IX. FACTORS INVOLVED IN INCREASING AND DECREASING OF SHEAR STRESS**

Landsliding is one of the most effective and widespread mechanism by which landscape is developed and role of shear stress is more effective in this type of faults. There is table that summarized the leading factors to an increase and decrease of shear stress given below:

Sl. No.	Types	Major Mechanism
1.	Removal of lateral support	Under cutting by water.
		Weathering of weaker strata at the toe of slope.
		Washing out of granular material by seepage erosion.
2.	Overloading by	Natural accumulation of water, snow, talus, material etc.
		Man-made processes i.e. building tip heaps, subbesh dumps etc.
3.	Transitory earth stress	Earthquake
		Man-made vibration
		Continued passing of heavy traffic
4.	Removal of underlying support	Undercutting by ringing water.
		Sub-aerial weathering and erosion.
		Sub-terrain erosion, solution etc.
		Mining activities.
5.	Lateral pressure	Building of pore water pressure.
		Freezing of water.
		Swelling by hydration of clay.

Table 2: Factors Leading to an Increase in Shear Stress

Sl.No.	Types	Major Mechanism
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1.	Composition and texture	Weak material such as sedimentary clay
		Loosely packed material
		Smooth grain surface
		Uniform grain size
2.	Physio-chemical relation	Low interval cohesion
		Cation(base) exchange
		Hydration of clay
3.	The effect of pore water	Drying of clay
		Buoyancy effect
		Reduction of capillary tension
4.	Change in structure	Viscous moving water on soil
		Spontaneous liquefaction
5.	Vegetation	Fault, fold, joints etc.
		Removal of tree
		Reducing normal loads
		Removal of tree roots

Table 3: Factors Leading to a Decrease in Shear Stress

**X. MODEL FOR THE STABILITY OF NATURAL SLOPE**

The cover of earth crust on the slope has a natural tendency to slide under the influence of gravitation and other forces. The stability of this cover on the slope is generally analyzed. Simons et al. (1978) proposed an infinite slope stability model for the stability of natural slope.

$$SF = \frac{C_s + C_r + A \cdot \cos^2 \beta \cdot \tan \phi}{B \cdot \sin \beta \cdot \cos \beta}$$

$$A = q_0 + (\gamma_{sat} - \gamma_w) \cdot (h - z) + \gamma_b \cdot (H - h)$$

$$B = q_0 + \gamma_{sat} \cdot (h - z) + \gamma_b \cdot (H - h)$$

Where,

- SF = Factor of safety,
- $c_s$  = soil cohesion ( $T/m^2$ ),
- $c_r$  = effective root cohesion ( $T/m^2$ )
- $q_0$  = tree surcharge ( $T/m^2$ ),
- $\gamma_b$  = bulk unit weight of soil ( $T/m^3$ ),
- $\gamma_w$  = unit weight of water ( $T/m^3$ ),
- $\gamma_{sat}$  = saturated unit weight of soil ( $T/m^3$ ),
- $\phi$  = internal angle of friction of soil (degrees),
- $\beta$  = slope inclination (degrees),  $H$  = thickness of soil cover above the bedrock (m),  $h$  = height of groundwater above the bedrock (m)
- $z$  = height of slip surface above the bedrock (m)

If the complete earth crust above the bedrock slides then  $z = 0$ . If the soil is fully saturated and groundwater table rises to surface then  $h = H$ ; from this equation we understand the data which is required to be collected in the analysis for slope stability and mitigation measures. The soil properties as density, cohesion, angle of internal friction can be evaluated from the laboratory tests on the undisturbed samples collected from the study area. The depth of ground water table can be measured by piezometer. The tree cover

and root area measurements for estimating the effective cohesive force due to roots and the tree surcharge is difficult and in the absence of correct data it is neglected as finally it may add to safety factor.

## XI. REMEDIAL MEASURES USED IN MUSSOORIE DIVISIONS

### A. Drainage Control And Dewatering Measures:

The first step in a programmed of slope stabilization is to get rid of water-the agent of provocation –by dewatering the affected mass and directing the water away from the landslide area. This is accomplished by constructing an elaborate drainage network. All streams and watercourses must be diverted around the crown of the slide or the potentially hazardous area through properly lined drains and ditches that have adequate gradient. The springs within the area are entrapped and likewise diverted through pipes into the drains. The drains within the affected area can be filled with gravel from sediment- charged runoff. In special cases perforated pipes placed at the base serve as outlets. The ditches may be lined with polypropylene sheet to prevent seepage of water. Construction of a drainage network is accompanied by leveling the ground surface to eliminate all depression where water can accumulate and cause difficulties .The cracks and openings are filled or plugged or grouted with cement, hydrated lime-slurry, sodium silicate solution or bitumen emulsions. On critical spots the surface must be covered with impermeable layers of asphalt or clays to prevent infiltration of rainwater.

### B. Vegetating Damaged Slopes Measures:

An effective method of arresting erosion and protecting damaged or exposed subsurface material is to cover it with a net of coir jute or synthetic yarn of about 2.5 to 1.5 cm opening, which will allow quick growth of vegetation. The area is fenced before the seed bed is prepared. The netting prevents the soil from breaking due to impacts of rain and wind, and allows unhindered vegetation growth. The soil is first seeded with quick –growing local grass, the root slips being dibbled 15-20 cm apart –root to root, row to row taking care that no turfs or clumps are dibbled (Natarajan and Gupta, 1980).The netting is firmly secured by overlapping 5-8cm fringes and pegged down with staples of 10 gauge steel wire 30-60cm apart-the top and bottom of the net being fixed in slots 30cm deep. This netting eventually disintegrates to contribute to the store of manure. The seeded soil can also be covered with fibrous material such as chopped straw, shredded bark and wood pulp.A number of grasses has been found useful for protecting slopes, such as ‘nara’(*Arundo donax*), lemongrass, napier (*Pennisetum purpureum*), ‘gorda’(*Chrysopogon fulvus*), *C.nepalensis*, etc.-the choice depending on local conditions including climate and soil composition. The legume *Pueraria hirsta*(*P.thunbergiana*) with deep roots have been found very promising. It is planted in January and February.

### C. Slope Modification Measures:

The stability of the slope can be increased by grading it-by constructing benches which not only reduce the slope but also serve as traps for falling, sliding, and creeping material so that down slope damage is prevented . But the reshaping of a slope involves appropriate disposal of debris generated. Another method of stabilizing a slope is to reduce the load at

the head of the landslide and/or strengthen the base by enlarging the toe. If only 4% of the slipping mass can be removed from the head and placed at the toe , the stability will increase by 10% (Zaruba and Mencl,1969).This also implies removal of heavy structures (including buildings and big trees) and dumps from the top of the unstable area.

### D. Piles, Bolts And Shear Keys:

Rows of steel or concrete piles are driven deep into the ground, securing anchorage for the unstable or slipping but non-plastic mass, particularly if the movement is taking place at shallow depths. Commonly, the piles are linked together by horizontal bars .This measure is supplemented by sealing of joints, cleavages and cracks. In mines and tunnels and on roadsides, steel bolts are used to prevent blocks or sheets of rocks from falling or slipping. Holes are drilled through potentially unstable jointed or cleaved rock slabs, and bolts fixed in them. Stabilization of the slipping rocks can also be achieved by making prism-shaped holes compactly filled with clays called shear keys as done in the case of dams.

## XII. DESIGNING OF GROUND ANCHOR FOR SLOPE STABILIZATION

### A. Designing Of Ground Anchor:

#### 1) Ground Anchors:

Ground anchors mainly consisting of cables or rods connected to a bearing plate are often used for the stabilization of steep slopes or slopes consisting of soils, as well as the enhancement of embankment or foundation soil capacity, or to prevent huge erosion and landslides. The use of steel ground anchors is often constrained by overall durability in placement (due to weight), and the difficulty in maintaining tension levels in the anchor. Anchor systems fabricated from fiber reinforced composite materials show a number of benefits compared to conventional systems for the following factors:

- Enhanced durability including resistance to corrosion and resistance to alkalis and solutions in soils increase their life and greatly reduce the need for maintenance, thereby decreasing life-cycle costs.
- Lighter weight results in easier transportation of cables to site, and increases the efficiency of handling and placement.
- Enhanced tensile strength coupled with lighter weight and enhanced mechanical properties results in greater safety during installation in areas with limited clearance.

In most cases, it is possible to use conventional jacking systems and still realize greater flexibility in placement and tensioning in difficult ground formations.

### B. CFCC Anchor Used For Slope In Hilly Region:

#### 1) Properties Of CFCC (Carbon Fiber Composite Cables):

This type of anchor is made up of carbon fiber and epoxy cable diameter of 712.5mm.They is mainly used for steep slope to prevent landslide and erosion durability.

C. Composite Ground Anchors Generically Consist Of Three Parts:

- (1) The anchorage is generally a stainless steel sheath with an anchor nut/plate through which the composite cable is run. The anchorage is usually filled with a non-shrink expansive cement mortar that ensures fixity and no slippage. The anchorage also is used to fasten the system to the outside structure.
- (2) The cable can consist of multiple rods that are separate or braided together, or a single rod.
- (3) A sheath or sleeve made from polyethylene or PVC that is fitted around the free anchor length of the cables.

Nominal strand diameter(mm)	12.5
Nominal cross section(mm <sup>2</sup> )	76.0
Fiber volume fraction (%)	142.2
Tensile strength	1.8
Tensile modulus(Gpa)	137
Extension of failure (%)	1.6
Coefficient of thermal expansion (x10 <sup>-6</sup> /°c)	0.6
Specific gravity	1.5
Unit weight(g/m)	151

Table 4: Properties and Specification of CFCC

D. Designing Process Of CFCC Ground Anchor:

- Establish project requirements including all geometry, external loading conditions (temporary and/or permanent, seismic, etc.), performance criteria, and construction constraints.
- Evaluate site subsurface conditions and relevant properties of in situ soil and rock.
- Evaluate design properties, establish design factors of safety, and select level of corrosion protection.
- Select lateral earth pressure distribution acting on back of wall for final wall height. Add appropriate water, surcharge, and seismic pressures and evaluate total lateral pressure. A staged construction analysis may be required for walls constructed in marginal soils.
- Calculate horizontal ground anchor loads and wall bending moments. Adjust vertical anchor locations until an optimum wall bending moment distribution is achieved.
- Evaluate required anchor inclination based on right-of-way limitations, location of appropriate anchoring strata, and location of underground structures.
- Resolve each horizontal anchor load into a vertical force component and a force along the anchor.
- Evaluate horizontal spacing of anchors based on wall type. Calculate individual anchor loads.
- Select type of ground anchor.
- Evaluate vertical and lateral capacity of wall below excavation subgrade. Revise wall section if necessary.

- Evaluate internal and external stability of anchored system. Revise ground anchor geometry if necessary.
- Estimate maximum lateral wall movements and ground surface settlements. Revise design if necessary.
- Select lagging. Design walers, facing drainage systems, and connection devices.

E. Anchor Establishment For The Slope Modification In Mussoorie Divisions:

To stabilize the concrete panel over steep slope in hilly terrains of Mussoorie divisions/sections. Anchor bolt (CFCC) used for stabilization of concrete panel. A hole is drilled through the block of concrete perpendicularly to, and into, the slope anchor bolt cable is inserted. One end of the cable is secured by cement, when hardened. At the outer surface of the concrete, a cap and nut secure the other end of the cable. The nut is then tightened.

According to Newton third law, the anchor exert an equal and opposite force on the concrete panel. This force will also be parallel to a cross section of the anchor bolt and therefore is a shear force. The force acts to resist the sliding of the concrete panel. Description is given through figure below:

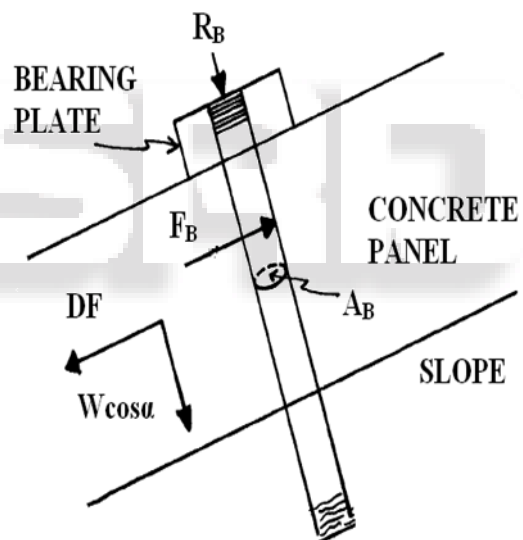


Fig. 3: General description of slope with concrete panel and anchor bolt (CFCC)

The largest possible value  $F_B$  of this force exerted by the anchor bolt on the concrete panel is given by:

$$F_B = T_B A_C \tag{Eq.no.01}$$

Where,

$T_B$  = Shear strength of the material of which the anchor bolt cable is made

$A_C$  = Cross- sectional area of the cable (anchor)

$F_B$  = Force exerted

The ratio of the maximum possible value of the total resisting force to the driving force is called the factor of safety against sliding.

$$FS = \frac{RF}{DF} \tag{Eq.no.02}$$

Where,

FS = Factor of safety

RF = Resisting force

DF = Driving force

And,

$$DF = W \sin \alpha + F_{ext} \quad (\text{Eq.no.03})$$

Where,

$F_{ext}$  = Extra driving force

By using coulomb's law:

$$f_{s, \max} = \mu_s R \quad (\text{Eq.no.04})$$

Where,

$f_{s, \max}$  = Frictional force (maximum)

$\mu_s$  = Co-efficient of static friction

R = Sum of the normal forces on the slopes

Replace,

$$\mu_s = \tan \Phi \quad (\text{Eq.no.05})$$

So,

$$f_{s, \max} = R \tan \Phi \quad (\text{Eq.no.06})$$

And,

$$f_{s, \max} = W \cos \alpha \tan \Phi \quad (\text{Eq.no.07})$$

If the base of the cable is fitted into the slope, than the anchor cable can be tightened. Since each anchor cable is installed perpendicular to the slope, the force exerted due to the tightening is also perpendicular or normal to the slope, call this force  $R_B$  and expressed as:

$$R_B = \sigma_C A_C \quad (\text{Eq.no.08})$$

Where,

$\sigma_C$  = Stress on the cable due to the tightening

$A_C$  = Cross-sectional area of the cable

The effect of  $R_B$  is to increase the normal force and therefore to increase the maximum friction force available by (Eq.no.04) the part of R due to gravity  $W \cos \alpha$  always present. If there is n no. of cable, all tightened to the same tension, then the total normal force becomes:

$$f_{s, \max} = W \cos \alpha + n R_B \quad (\text{Eq.no.09})$$

$$f_{s, \max} = \mu_s (W \cos \alpha + n R_B)$$

$$f_{s, \max} = (W \cos \alpha + n R_B) \tan \Phi \quad (\text{Eq.no.10})$$

Therefore by (Eq.no.01, 08 and10) the maximum resulting force available with anchor cable installed perpendicular to the slope.

$$RF = (W \cos \alpha + n \sigma_C A_C) \tan \Phi + cA \quad (\text{Eq.no.11})$$

It is assumed that the cable is identical and that all have been tightened to the same tension  $\sigma_C$ . The driving force (DF) on the concrete panel is unaffected by the anchor bolt cable. After combining (Eq.no.02, 03 & 11)

$$FS = \frac{(W \cos \alpha + n \sigma_C A_C) \tan \Phi + cA}{W \sin \alpha + F_{ext}} \quad (\text{Eq.no.12})$$

Above equations represented that how anchor bolt (CFCC) can be situated over in the concrete panel. It's all dependent upon the steepness of slope, if slope is less steep than it should be possible to establish the anchor panel over there. If the slope is very steep than it difficult to established a panel for prevention from landslide and debris flow, so at that condition only jute netting can be possible from the prevention of debris flow and landslide. In Mussoorie division's two types of slopes are finding, less steep and more steeper so; these two techniques are suitable for prevention from mass movement and debris flow. Mainly used these techniques along the road side of Mussoorie divisions for control of landslide. But it also used over the heavy infrastructure like Hotel, Institutions and many more. Fig 4 describes general overview of establishment of anchor panel and jute netting with effectiveness area like type of slope.

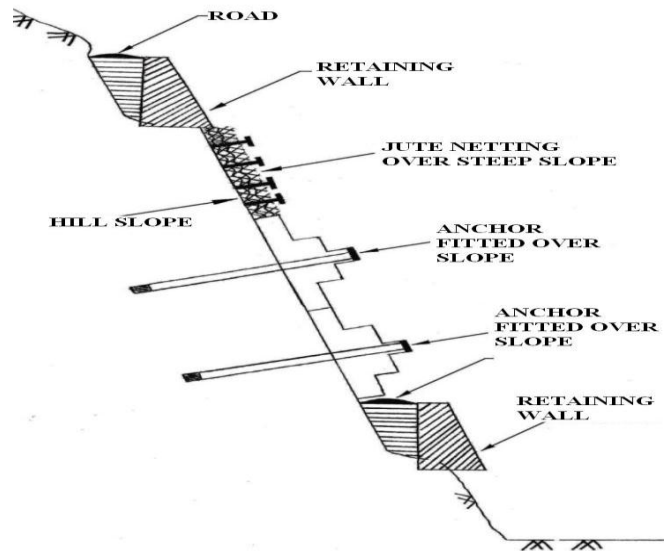


Fig. 4: Layout overview for establishment of anchor bolt (CFCC) and jute netting

### XIII. DISCUSSION

#### A. Anthropogenic Interventions:

Mussoorie is highly tectonised and area around it in naturally unstable state. The rapid pace of erosion and high instability of hill slopes in this area is highly attributed to anthropogenic interventions; indiscriminate construction of heavy infrastructure like buildings, disproportionate quarrying for construction raw materials and site development, disturbance and encroachment in natural water bodies, forest area and randomly disposal of excavated material.

#### B. Lithology:

Lithology of area around Mussoorie divisions are mostly erodible and the response of rocks to the processes of weathering and erosion is the main factor in awarding the ratings and the therefore a correction factor on the status of weathering rocks have been situated over there and for this rock exposure in this area have been observed. Various area around Mussoorie have thick vegetal cover. Thin soil cover is found in the areas to the north of Mussoorie –Dehradun road, east of Camel Back road, Barlowganj, south of kempty section, north of bataghat.

#### C. Lineament:

Lineament is primary and linear characteristic in a landscape that is considered to be an expression of the underlying geological conditions and structures. Survey of Indian toposheet and satellite images is used for delineating the lineaments. It is important to analyze the lineament which show a trend both parallel and traverses to the alignment of the Mussoorie axis. Most lineaments showing WSW-ENE TO SW-NE trend is found in the east and north of Mussoorie town.

#### D. Slope Facet:

Slope facet is a factor of hill slope which have less or steep slope conditions and observed as consistent slope direction and inclination. Slope facets are mostly delaminated by

stream course, ridge line, gullies, spurs. According to SOI toposheet 350 slope facets divided in Mussoorie divisions.

#### E. Hydrogeological Conditions:

In Mussoorie hilly terrains groundwater is mostly flow along structural discontinuities of rocks and there is no any channelized flow only observed a disturbed flow pattern. After study observed that groundwater on hill slopes is not possible over large areas. Proper channel for indication of water such as damp, wet, dripping, and flowing are necessary over hill slopes.

#### F. Land Use /Land Cover:

In Mussoorie upper region of hills are mostly barren and sparsely vegetated areas which show rapid erosion and huge instability. The feature of the landcover is an indirect indication of the stability of hill slopes and forest cover respond the root system of vegetation by increasing the shearing resistance of slope materials like soil.

#### G. Slope Morphometry:

##### 1) Slope Morphometry Of Mussoorie Areas Are Divided Into Five Slope Type:

- Escarpment/cliff(>45°)
- Steep slope(36°-45°)
- Moderately steep slope(26°-35°)
- Genteslope(16°-25°)
- Very gentle slope(0°-15°)

#### XIV. CONCLUSION AND SCOPE FOR FURTHER STUDIES

##### A. Conclusions:

Among the factors that govern the stability of hill slopes, the structural conditions of rocks and soils, the gradient of the slope and the amount of water that finds access underground play very crucial roles in initiating and controlling landslides. Seismic shocks trigger and accelerate mass-movements on alarger scale but the principal agent is always water. It not only acts as a lubricant, especially if mixed with clays or other slimy materials, but also reduces their shear strength by building up pore pressure within soils or rocks. The mass-movements are manifest in the form of slow movements without breaking into discrete failure planes, comparatively speedy sliding on discrete planes of failures at deeper levels(slumps and slides), or very rapid , almost spasmodic descent or flow of non-cohesive masses of rubble (debris avalanches) or silt and mud (mudflow). The incidence of landslides is therefore very frequent and their magnitude greater during rainy spells.

Landslides are main factor for geological hazards for most of hilly terrains and these cause massive demolition with loss of life, infrastructure, environment and property. The hill steep slope in the area around Mussoorie sections has been experiencing serious slope stability problems for a long time. Unplanned anthropogenic interventions steep slopes are observed to accelerate this problem.

The strategy for controlling the occurrence of landslides is therefore to stop the entry of water or remove it from the threatened or affected area by a system of surface or subsurface drainage, and by resorting to pumping.

The second step is to place buttress wall or retaining wall at the toe of the slope or slide in order to check the movement of the dislocated or destabilized mass. Finally, the damaged

slope and its soil should be put under a protective cover of grasses, shrubs and deep-roots.

Instability is like to be induced in many hitherto stable slopes during strong seismic shaking. The falls in Zone of seismic zoning map of India (IS1893, 2002) and therefore due caution is required while undertaking slope modification, site development and infrastructure development. Heavy and multistoried infrastructure in the vicinity steep slopes should be avoided. Adequate attention is also required to be paid as safe disposal of excavated rock and soil and in no case these should be allowed to be roll down the hill slopes. In view of the vulnerability of the area around Mussoorie meso and micro scale (1:10000/5000) landslide hazard zonation mapping is recommended.

##### B. Scope For Further Studies:

In this work many measures for protecting the landslide by various methods and remedial measures like mostly protecting the active landslide around the hill side roads and most attractive tourist place. Drastic seasonal change in soil-water content causes serious effects on public and communication system of area which situated near the steep slope of hill in Mussoorie divisions. Remedial measures or two would not be effective in preventing mass-movements. It is always a package of measures that have to be taken like:

- Proper and lined drain needs to be provided along the road section to flush out the surface runoff. The water should be transported downhill by providing culverts where the bypass road intersects the channel.
- The drainage channels and the culverts are to be cleaned at regular intervals so that there is free flow of water and the fine sediments.
- In the lower valley slope, tipping of garbage is to be avoided at any cost to obviate the problem of overflow of water and sediment which results into numerous problems beyond easy solution.
- Strictly, there should not be any new construction along the path of the drainage descending either from the hill or coming up at the bottom of the hill.
- River borne materials (RBM) used in retaining walls need to be cut into square blocks to provide maximum contact between the blocks for the stability of the structure. Uncut RBM have been frequently used in the retaining structures along the Mussoorie –Tehri bypass and is often a site of failed structure mainly caused by least resistance against the free flowing water.
- At places, the cliff sections along the road in the area are acting as a natural retaining wall, however, due to the presence of unfavorable joints the rocks blocks are hanging loose on the slope which may fall down any time. It is thus advisable to do scaling of these cliff sections so as remove the hanging rock blocks.
- Wherever rocks are exposed critically along the road section, these should be strengthened by rocks bolting and wire meshes.

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