# *Slope Failure and Remediation in Hill Stations of Himalayan Region - A Case Study*

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**ABSTRACT**

The present investigations for slope failure have been carried out in the area around the Shimla Hills (H.P.). The main causes of persistent reoccurrence of failure of slope in the region have been identified and remedies suggested. It has been observed that slope failures in the region under study have taken place due to various factors such as permafrost, excessive and arbitrary destruction of the vegetative cover, heavy rainfall, toe-cutting of the valley side slope, sheet, rill and gully erosion, instability of the geological formations and stone quarrying for road making. The slope failure that has occurred along the northern slope of Shimla Ridge appears to have been restricted to the overburden, and underlying rock is not involved. The slips and subsidence that occur in the area are mainly attributable to saturation during rains of overburden material due to the poor existing drainage system. It is, therefore, suggested to construct cross and radial drains in the affected area to facilitate the flow of water into the nearby drain.

*Key words:* Stratigraphy, Himalayas, slope stability, Shimla hills, saturation, drainage system, erosion.

## 1. INTRODUCTION

India is a sub-continent with great diversity in topography, climate, soil and vegetation. The Mighty Himalayan mountain is northern part of this sub-continent with a low lying plain in the south known as Indo-Gangetic plain. The northern portion of this mountain is called Tibetan plateau. The highest ground of the world called roof of the world or Pamir Plateau is a locality in the north of the Himalayan mountain chain. This mountain chain is a combination of various landforms, and slope is the main function of landforms. The initial orogenic movement began probably seventy million years ago during the cretaceous period when the Russian continent (Angaraland) moved southward against the Tethyan sediments. To the south of the Tethyan Geosynclines lies Indian sub-continent (Gondwanaland), which resisted and pushed back the Tethyan sediments toward north. Due to the movement of Russian land and Indian continent towards each other, the sediment of Tethyan got compressed and finally folded in syncline and anticline with simultaneously numerous parallel and quasi-parallel ridges formed. There was a tendency for the development of major joints, faults or even fractures at every significant bend in the trend of the ridges and steeper gradients at angular junction of two syncline folds.

During the same process, the northern margin of Indian sub-continent had slipped below the Russian continent and a fracture developed below marginal portion of the Russian continent and magma pushed the Russian continental margin upward. Due to this, the Tibetan and Himalayan region is having greater height than the Indian sub-continent and the steep slope of this region is facing the south.

## 2. STRATIGRAPHY AND STRUCTURE OF THE STUDY AREA

The geology of the affected area around Shimla Hills is highly complicated and complex, as the area has suffered several tectonic movements culminating in the oldest Jutogh formation resting on younger Chail and Shimla series of rocks. The stratigraphic sequence of the rock units and their lithological composition are as given below:

| **Age** | **Formation** |
|---|---|
| Recent | Soil cover and rock debris |
| Purana | Blaini boulder beds, |
| | Carbonaceous shale and sand stone |
| | Shimla slates and |
| | Carbonaceous shale |
| Archean | Jutogh, Carbonaceous phyllite, |
| | Chlorite phyllite, |
| | limestone and quartzite |

In the area under study the rock exposure is very rare. The area is mostly covered with thick mantles of unconsolidated debris and clay. The soil cover consists of matrix of non-cohesive material with broken and weathered fragments of phyllite, carbonaceous phyllite, slate, quartzite and quartz schist. This material appears to have been accumulated on the northern slope of the ridge at the time of construction on this ridge, ridge road, water tank and various other structures on this slope.

Blaini slates are exposed in Shankhli area. The slates are greenish grey in colour and are thinly bedded. The oxidation of ferrous into hematite has imported red and brownish colouration to the rock. The slates are inter-stratified with thick bands of hard, compact micaceous sandstone. At places, grey slates are thinly jointed and puckered.

The boulder beds of Blaini formation comprise of sub-angular to sub-rounded boulders, cobbles and pebbles of quartzite, shale, grey wacke and silt stone entombed in a matrix of argillaceous and arcanaceous composition.

Upper Sanjauli in the area comprising shale, siltstone, quartzite and carbonaceous shale represents the Shimla formation. Phyllite formations exposed on the side of road cutting suffer failure due to the toe cutting of slope as shown in Fig. 1.


Fig. 1 - Exposure of phyllites after a landslide on the way to Shimla from Chandigarh

Jutogh formation of the Shimla area lying at a highest tectonic level and surrounded structurally by younger Shimla, Chail and Blaini series is part of a Klippe brought into its present position by thrust sheet. This erosion remnant of Jutogh thrust sheet has been left isolated as restless mass capping the Shimla Hills. Members of Jutogh formation comprising carbonaceous phyllite, chlorite phyllite with interbedded carbonaceous limestone and quartzite is exposed in the area.

## 3. CAUSES OF SLOPE FAILURE

The most common driving force tending to destroy a slope is gravity; generally the weight of the slope material and that of superimposed loads, and an increase in this weight may decrease the stability of the slope. The most common resisting force, the shearing strength of the material, decreases due to excess moisture. Excess of free water may even convert the material into a suspension totally or almost deprive it of shearing strength. Most slides occur during or soon after rainstorms or rainy spells. Dry slides have been reported as a very rare exception. It should be noted, however, that the shearing strength of a rock or soil material may decrease by chemical changes also.

Increase in gravity and decrease in shearing strength, acting together or separately, generally constitute the cause of the slide. Besides these two common components of the cause of a slide, there may be one or several events or combination of events that facilitate the occurrence of a slide.

The weight of the slope may increase by saturation during rainy spells. This increase is relatively small in comparison to heavy loads that are sometimes applied at the upper edge of the slope by storing heavy materials or by parking heavy vehicles.

Excavations close to the toe of a slope cause the same effect as the loading of the slope. The removal of the lateral support, particularly the removal of the toe of the slope for emplacement of a building or a highway, is one of the very common causes of a slide.

## 4. PROBABLE CAUSES OF SLOPE FAILURE IN SHIMLA REGION

Most of the land surface along the hill slope of Shimla area is covered with unconsolidated permeable overburdened soil. This overburden material is made up of silty and clayey soil mixed with rock debris derived from the underlying bedrocks of phyllite and slate. The average hill-slope along the northern side of hills is 360 and gradient is 1:1.67, and the average hill slope along the southern side of hills is 39° to 40° and the gradient is 1:1.56. The soil cover along the slope shows signs of slow creep as indicated by the slight tilt in the tree trunks grown on this soil (Fig. 2), and also from the presence of numerous tension cracks developed along the hill slope. This sliding tendency of the soil blanket increases under saturated condition during heavy rains resulting in failure of hill slope.

Fig. 2 - Angular relation of tree trunk and vertical object

For want of adequate natural and artificial drainage system in this area, water enters into the unconsolidated and permeable soil, which becomes saturated. The clayey matrix present in the soil obstructs the free movement of ground water. This results into building up of pore water pressure within the body of the soil mass, which subsequently starts moving downwards along the hill slope. This produces cracks in the soil body along the upper slope where cohesion between the soil particles is less and also at places where there is sudden change in the slope angle.

Saturation of the soil mass reduces the frictional resistance between the particles by decreasing the apparent cohesion which holds the soil particle together in dry state.

Because of piping action of ground water during rainy season the finer particles in the soil are washed away, thereby increasing the number and size of already existing voids in the soil mass, which adds to the instability of the hill slope.

During winter, freezing of the water held in the voids and brought up by capillary action in over-burden soil and in the joints of underlying parent rock exerts pressure and opens up the existing voids and joints. This renders the slope material loose and prone to sliding.  Failures of hill slopes located in affected area are shown in Figs. 3 and 4. Figure 3 shows breaching of road on the way to railway colony at Shimla due to failure of top of slope. Figure 4 shows slope failure as a result of widening of road on the way to Shimla.

Figure 5 shows a case of uneven settlement of foundation of railway building due to slope failure in Shimla town. The inspection of the area has revealed the existence of local slip particularly in the down hill zones. The retaining walls below the building have suffered to varying degrees due to slope movement. Slope movement and subsidence seem to be restricted to the superficial overburden.

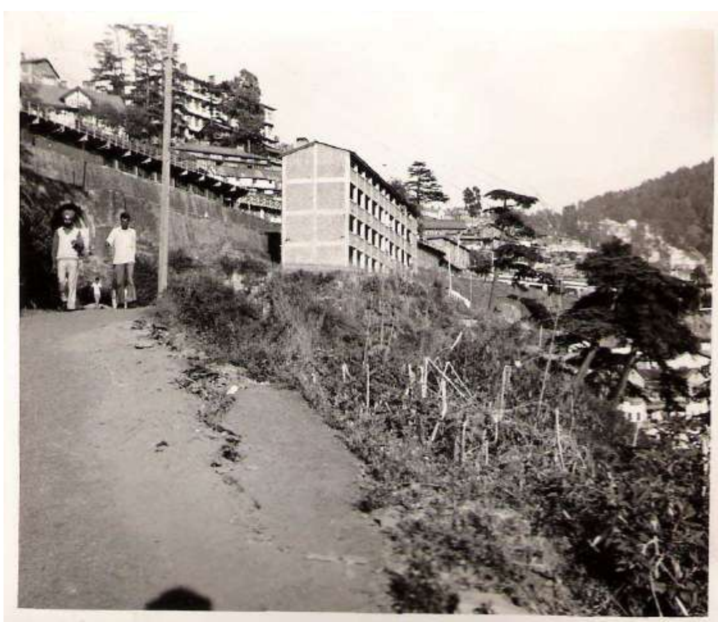

Fig. 3 - Road breaching on the way of railway colony

Fig. 4 - Slope failure due to widening of road

Fig. 5- Uneven settlement of boundary wall of railway building

It is apparent that the failure of hill slope, which has brought about numerous cracks and damage to roads and buildings in the Shimla area, is due to the instability of soil cover and topography of the area.

## 5. PREVENTION OF SLOPE FAILURE

Side-hill sections are often used in valleys when a railroad or highway or a part thereof is conveyed from a lower to a higher elevation to take advantage of the valley gradient. In general, it is difficult to forecast a slide, unless there is a definite evidence of a horizontal motion of sloping ground, such as cracking or relative motion of some points with respect to others. In each particular case, when the possibility of a failure is suspected, it should be investigated to determine whether or not the two most important failure-producing agencies, gravity and surface water, are acting detrimentally, and in what form. In addition to above causes, some local factors also cause failure of the slopes. Soil erosion is a major cause of the failure of the slopes.

The rains and winds, with the formation of streams and river deltas, leading to the gradual transformation of landscapes, are always moving soil. Under a cover of thick-growing vegetation of grass and trees, the rate of soil removal is, however, exceedingly slow. The favourable natural soil balance is, however, disturbed due to tilling of the earth for food, burning of the wild growth of vegetation, cultivation on steep slopes and overgrazing by herds of cattle, sheep and goats. Fields have been planted for the same crop year after year without any soil conservation measures.

Formation of gullies, which start as small rills, is the most spectacular symptom of this destruction. Growing gullies, unless promptly checked, get out of hand, and fields, farms and whole townships have to be abandoned.

Improper land use causes accelerated soil erosion and leads to the formation of gullies and ultimately ravines. Where both soil and sub-soil are commonly friable and easily cut by flowing water, we have gullies with vertical walls. Where the sub-soil is resistant to rapid cutting because of its heavy texture and toughness, gullies develop on sloping banks.  If cause of the slide is high pore pressure, a good sub-surface drainage should lower the water table to such a level as to overcome this danger.

The principle of drainage by intercepting the ground-water flow may be used in the form of deep galleries or toe trenches perpendicular to the direction of the flow and filled with pervious material. In all cases of interception of the water flow (both surface and subsurface), water should be conveyed to a lower elevation.

In arable agriculture, crops vary widely in their effect on erosion losses. Thus crops like maize, cotton, tobacco and potato that are cultivated can be classed as erosion inducing; while grass, forage crops and many legumines are erosion resisting. Small grain crops like wheat, barley, oats, and rice stand between these two extremes. Rotation and alteration of erosion-inducive crops with erosion preventing crops to minimize erosion is known on strip cropping. This, however, is inadequate unless it is combined with mechanical measures of conservation of soils of which terracing is probably the oldest.

The use of earthen structures includes the construction of banks and earthworks approximately along the contours or level lines across moderately sloping lands with the object of breaking long slopes into numerous short slopes, which incidentally checks the flow and promotes absorption of water by the soil.

For stability of side-hill section following measures could be taken.

(i) Covered galleries for badly fissured and coarsely fractured rocks of all kinds.

(ii) Retaining walls for sedimentary and metamorphic rocks as shown in Fig. 6.

(iii) Tie bars, underpinning and roof bolts for horizontal sedimentary rocks and compact igneous rocks.

(iv) Trees, bushes and stumps left on the slope give effective protection against rock falls.

Fig. 6 - Retaining wall to support a road at Shimla (H.P.)

## 6. CONCLUSION

The slope failure along the northern slope of Shimla Ridge appears to be restricted to the overburden and the underlying rock is not involved. The slips and subsidence that have occurred in the area are mainly attributable to the saturation of overburden material due to poor existing drainage system. From the case study, it is observed that slope failure generally occur only during heavy rains in Shimla Town, therefore, the preventive and corrective measures should mainly be directed towards providing a good drainage system and adopting a suitable method to avoid the percolation of water into the soil cover. It is, therefore, suggested to construct cross and radial drains in the affected area to facilitate flow of water into nearby drains. These drains should be constructed with stone masonry and cement mortar. The existing drains should be properly repaired. In order to bleed the ground water, sub-surface drainage holes or sub-surface drainage ditches should be provided. Proper lining of the drains in the concerned areas should be taken up. To prevent soil erosion it is advisable to construct retaining and breast walls of low heights at vulnerable points in the area. In addition to this, counterfort retaining wall may be constructed along the damaged roads. In order to check the percolation of rainwater into the soil, it is suggested to undertake spreading of the impermeable material, such as asphalt. In addition, quick growing deep-rooted plants may be planted to reinforce the soil cover. Heavy structures as far as possible should be avoided in the affected area. If such a structure, under very special circumstances, is to be constructed, foundation should be extended deep inside the rock. No structure should be allowed with foundation restricted to the soil cover.

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