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GEOENVIRONMENTAL PROBLEMS DUE TO HARMONY LANDSLIDE IN GARHWAL HIMALAYA, UTTARAKHAND, INDIA

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ABSTRACT

Landslides constitute one of the major natural disasters in the Himalayan ecosystem. The fragile Himalayan terrain often faces significant problems of geoenvironmental imbalance due to landslides. A major landslide occurred in 1986 near Harmony village on left bank of Pinder River, along Karnaprayag - Gwaldam road in Chamoli district of Uttarakhand state. The Harmony landslide caused traffic blockade and consequent economic and environmental losses. Moreover, this slide was reactivated almost every year causing disruption of traffic along this important hill route, which is the only hill route, connecting Garhwal and Kumaun physiographic divisions of the state in upper hills. In view of importance of this landslide, detailed Engineering Geological investigations were carried out incorporating relevant Geotechnical parameters. The entire landslide area had been mapped on 1:1000 scale and three Geological sections were prepared. The shear strength parameters were obtained with the help of in-situ samples collected from the site. The slope stability analysis to calculate Factor of Safety (F) was carried out using Circular failure charts. Based on the analysis, the status of stability of the slide could be understood and accordingly suitable control measures for stabilizing the hill slopes have been suggested.

Keywords: Himalayan Ecosystem, Harmony Landslide, Factor of safety, Circular Failure Charts, Control Measures.

1. INTRODUCTION

Harmony Landslide is situated near Harmony village along Karnaprayag – Gwaldam road in Chamoli district of Uttarakhand State. The district was in news because of the devastating Chamoli earthquake. Harmony landslide is the biggest landslide along this road stretch that occurred in 1986. The slide has been activated in recent past and gets re-activated particularly during monsoon season, disrupting the traffic flow along this important road stretch. The debris are cleared off time to time, mainly during monsoon season. Detailed geological mapping and stability analysis have been carried out for this landslide and remedial measures have been designed.

2. LOCATION AND ACCESSIBILITY OF THE STUDY AREA

The Harmony landslide is situated on Karnaprayag - Gwaldam road, at about 30km from Karnaprayag, in Chamoli district of Uttarakhand.

It is the biggest landslide along this important hill route connecting Garhwal and Kumaun physiographic divisions of Uttarakhand state. The study area falls in Survey of India Toposheet No. 53 J/8. The location of the Harmony landslide is shown in the Fig. (1). The religious town of Karnaprayag is about 255 km from Roorkee on the Rishikesh - Badrinath route.

3. PHYSIOGRAPHY OF THE SLIDE AREA

The slide area is represented by rugged and undulatory topography of Lesser Himalaya. This slide is located on a fairly steep slope adjoining Pinder river on its left bank. The village Malla Harmony (EL ± 1638m) is located close to slide zone. The Pinder river after originating from Pinderi glacier, flows from N-S up to Dhaura and then takes a sharp turn towards WNW and joins Alaknanda river at Karnaprayag. The Pinder river generally flows through a deep V-shaped valley in its entire course except at certain locations where the valley is wider due to presence of older river terraces.

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This perennial river with high run-off, steep river bed gradient and tight V-shaped valley (between 50^0 - 60^0) indicates a young stage of regional geomorphologic development. In the landslide area, the Pinder river flows in a roughly WNW direction close to toe of the slide on left bank. Near slide area, the river has a wide course of more than 50m, within which the water course keep shifting from one end of the bank to the other. Close to the toe of landslide, the river takes an arcuate turn leading to toe erosion. The Harmony landslide is confined to an arcuate depression between two minor spurs running roughly in E-W direction. The slide extends over a distance of about 450m along road level. The general slope is of the order of about 35^0-40^0 while it becomes comparatively steeper (55^0-60^0) just above the road. However the slope below the road level is of the order of 40^0-45^0. The slope again becomes steeper (55^0-60^0) close to ridge top. The slide scarps are visible as barren patches close to the crown area of the slide. Two streamlets flowing eastwards border the slide area on its flanks. The one flowing on the upstream side has a clear course of flow with water flowing down up to Pinder river. But the other one shows breach on its course with part of water flowing into slide zone [1].

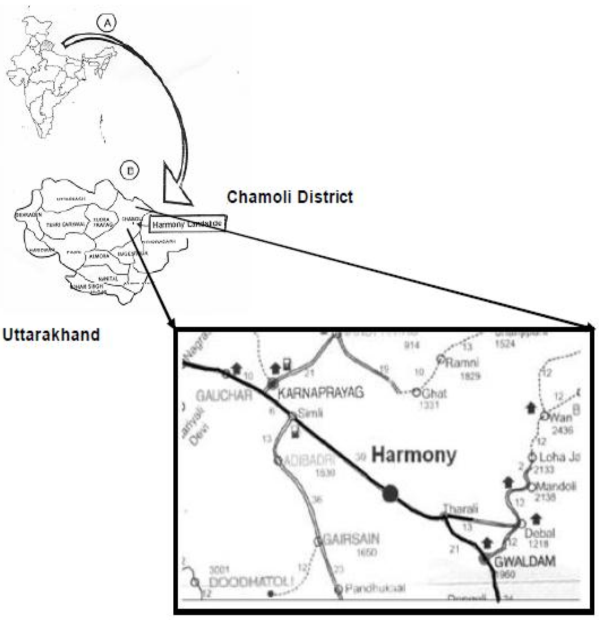

Fig.1. Location map of the study area

4. GEOLOGICAL SETTING OF THE SLIDE AREA

The Harmony landslide falls in Garhwal Lesser Himalaya. Regional geology around Harmony was studied by various workers in the past like [2], [3], [4], [5]. Garhwal Lesser Himalaya is comprised of medium to low grade metamorphic rocks, which occur as nappes/klippen over metamorphosed to unmetamorphosed sedimentary sequence. The slide area is comprised of phyllites, quartzitic phyllites, phyllitic quartzites and massive quartzites of Proterozoic age.

There are no rock exposures present within the Harmony landslide area. The entire area is blanketed by debris material derived from an ancient landslide. As such it consists of assorted materials ranging from clay to big boulders, which have been obtained from the adjoining rock exposures (Fig. 2).

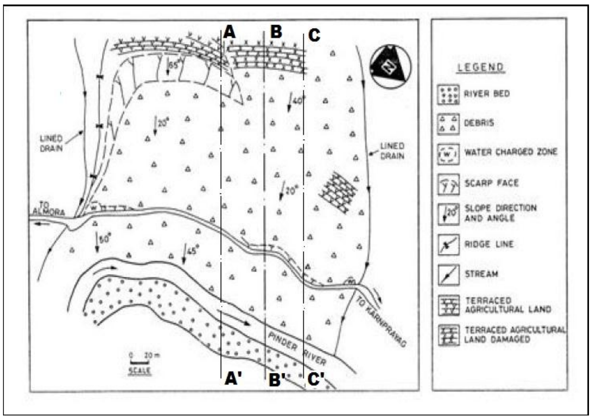

Fig.2. Geological map of the slide area

On surface, loose materials consisting of rock blocks embedded within a matrix of fine soil (clay to silt size fraction), are observed. The in-situ rock exposures are expected to be present at deeper levels. Large scale slope movements are reported every year during rainy seasons.

Because of repeated displacements, the Karnaprayag - Gwaldam road passing through the slide material got displaced down to lower levels in the past. One can see three of such roads at lower levels than the present level of the road. Water seepage can be seen at a number of locations within the slide. However no perennial stream flows through the slide area. On both the ends of the slide, two streams are seen flowing towards NE direction. A number of tension cracks are seen above the present slide area. Though they are mostly filled by the soil around, the traces are still identifiable. The slide materials do not have uniform slope gradients from the crown to road level.

5. GEOENVIRONMENTAL PROBLEMS

Himalayan terrain is highly prone to landslide hazards as compared to other physiographic divisions of India. Unstable geological conditions, heavy rainfall, cloudbursts, anthropogenic activities (excessive construction, deforestation etc.) etc. have been mainly responsible for several landslides resulting into loss of life and property or both. Due to these natural hazards, the Himalayan region is facing major problems of environmental degradation. Because of the geographic location of Himalaya in the path of moisture laden South-West Monsoon winds, this region receives heavy annual precipitation as orographic rainfall in its windward side. It is the source region for all the perennial North Indian rivers. Because of its regional elevation, all the major and minor rivers originating from this region, are in their youth stage.

As a result there is tremendous down cutting of the river valleys for which we get many gorges and V-shaped valleys in this region. This leads to toe erosion of the hill slopes especially along the river bends. Hence, any improperly planned construction and associated excavations, in the name of development, which lacks proper geological and geotechnical investigations, is a cause of concern for stability for that hill slope in the Himalayan region. Now, for a long time back in the Geological Time Scale, any natural body having some significant relief is always being affected by the agents of weathering and erosion, leading to the reduction of its height and modification to a peneplain. So, the hill slopes are also not exceptional to this rule. In fact, this is a very important part of the rock cycle where we get formation of the sedimentary rocks. Apart from the relief there are other controlling factors like lithology, orientation of the discontinuity planes with respect to the slope, ground water condition in the slope, etc. which can be considered as controlling parameters in this process of modification of the hill slopes. Such slopes become highly unstable if it is located in a seismically active terrain or zones of high annual precipitation and they may act as a triggering factor for a landslide. In this circumstances if there is human interaction by means of unplanned constructional activities like excavations, then it causes instability of slopes. So, the ultimate and cumulative effect of all of these factors is the sudden movement of slope forming materials, down the slope, mostly along a plane of discontinuity. This is called a landslide or in a broad sense, may be called as mass wasting.

Since the formation of the hill state of Uttarakhand state, there is a rapid surge of road construction, all over the state. This is being done because the economy of this newly formed state by many ways is tourism based. But the fast rate of road construction does not often incorporate the essential geological parameters which are a necessity for stability of existing slopes. As a consequence, unplanned excavations may cause the cut slopes more vulnerable to failure. Hence a fast appraisal of the existing roads, particularly in the vulnerable sections will help to identify the landslide hazard prone slopes.

6. IDENTIFICATION OF FAILURE

In case of soil, a strongly defined structural pattern does not exist; hence the failure surface is free to find the line of least resistance through the slope. Deep seated shear failures in homogeneous soils, those are relatively unaffected by bedding and other structural anomalies, tend to slip in a rotational manner resembling circular slip surfaces. Such term is termed as ‘rotational’. The conditions for such type of failure are unconsolidated individual particles which are very small in comparison to the slope and the particles are not interlocked. Hence highly weathered and crushed rock will behave as soil on slopes and tend to fail in circular mode.

However there is a possibility for planar failure in soils, too. It will be observed in those cases where the thickness of soil is less, i.e. a thin veneer of soil and there is hard rock column just lying underneath it.

From the three sections viz. Sec – 1 (A-A’), Sec – 2 (B-B’) and Sec – 3 (C-C’) (Fig. 2) drawn across the slide area, the slide has been identified as rotational type of failure. The slide is observed as still active on the basis of observations and discussion with local people. The loose slope debris, mixed with fine soil (clay to sand size fraction), derived from the in-situ rock exposures of Phyllites and Phyllitic Quartzites are mixed with fine soil (clay to sand size fraction). In-situ bed rock may be present at the deeper levels. It is an active slide, which gets activated almost every year during rains. The slope materials of the slide area are mostly debris having low strength, derived from the in-situ rock exposures of Phyllites and Phyllitic Quartzites. Loose material consisting of rock blocks is mixed with fine soil (clay to sand size fraction) and in-situ bed rock may be present at the deeper levels.

7. ENGINEERING PROPERTIES OF SLOPE MATERIALS

It is the resistance offered by the material to shear stress, which tends to move one part of the material against the other part, by virtue of its cohesion (C) and angle of internal friction (Φ). Cohesion (C) is the tendency of the constituent particles present along the surface of separation to stick together by virtue of their electrostatic and molecular forces. Angle of internal friction or friction angle (Φ) refers to innate resistance offered as a result of interaction between particles constituting the plane of separation. Determination of reliable shear strength values is a significant part of the investigations. The shear strength can be measured in the laboratory by testing the sample in a portable shear strength testing apparatus by using Direct Shear Test. It is also possible to carry out simple tilt tests on site with portable apparatus which can give a first approximation of the angle of friction across discontinuities.

For the detailed stability analysis of the slide, three representative sections were chosen viz. Section 1 (AA’), Section 2 (BB’) and Section 3 (CC’) (Fig. 2). From these representative sections, soil samples have been collected for carrying out the laboratory testing (Direct Shear Test) for determining the shear strength. Three samples – one each from scrap face, main body and just above road level of this slide, have been collected.

Direct shear test has been carried out in the laboratory on the samples collected from the field to obtain shear strength parameters (C and Φ). Direct shear test machine consists of shear box, soil container, loading unit, proving ring, dial gauge to measure shear deformation and volume changes. A two piece square shear box is one type of soil container used. A proving ring is used to indicate the shear load taken by the soil initiated in the shearing plane.

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Soil sample is put into the shear box, after proper compaction. After etermining the shear displacement (in dial gauge) and stress applied (in proven ring), we plot these two parameters in a graph, where shear displacement is plotted in abscissa while shear stress in ordinate. The peak shear stress value in the graph is noted for a particular normal load and the procedure is repeated for higher normal load values. The peak shear stress values increase accordingly as we increase the normal load. Another plot is made between peak shear stresses (ordinate) verses normal load applied (abscissa), on a graph and successive points are plotted. A minimum five points are required to draw the best-fit line. The intercept of the best-fit line with the ordinate gives cohesion (C) and the acute angle of the line represents the friction angle (Φ) for the corresponding sample.

Shear strength of slope materials has also been carried out by carrying back analysis. The values obtained from laboratory analysis are less than the value obtained from back analysis. A judicial value of shear strength has to be adopted for slope stability analysis. The stability analysis will indicate present status of stability of the hill slopes. Accordingly different slope stability measures will be designed.

Three representative samples, one each from scrap face, main body and just above road level of slide, have been collected along the three section lines (Fig. 2). To estimate shear strength parameters of the samples, direct shear test was carried out on individual samples and result is shown in Table 1. The detailed stability analysis of this slide along all three sections has been carried out.

Table 1: Shear strength parameters obtained from Direct Shear Test

Sample No.	**Peak shear stress at normal load = 1 kg/cm^2**	**Peak shear stress at normal load = 1.5 kg/cm^2**	**Peak shear stress at normal load = 2kg/cm^2**	**Peak shear stress at normal load = 2.5 kg/cm^2**	**Cohesion (C) in kg/cm^2**	**Angle of Internal Friction (Φ) ^{0}**	**Moisture content (%)**
Sec 1/a	1.03	1.33	1.66	2.32	.115	40.23	1.55
Sec 1/b	.36	.59	1.47	1.91	.055	35.72	1.8
Sec 1/c	.80	.99	1.23	1.58	.247	27.02	.84
Sec 2/a	.87	1.33	1.65	2.04	.16	37	3.7
Sec 2/b	.80	1.32	1.57	1.97	.099	36.94	3.01
Sec 2/c	.74	.85	-	1.88	.14	29.68	3.89
Sec 3/a	.80	1.40	1.62	1.97	.142	36.5	9.58
Sec 3/b	1.12	1.51	1.99	2.61	.075	44.7	1.41
Sec 3/c	.72	1.28	1.28	1.89	.154	28.36	.64

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8. STABILITY ANALYSIS OF HARMONY LANDSLIDE

In the present study, the stability analysis of Harmony landslide has been done for rotational failure. For this purpose geological mapping was carried out covering the entire slide area on 1:1,000 scale and the geological map of the slide area has been prepared on the said scale. Besides, the geological cross sections have been prepared along all three selected section lines.

The Circular Failure Charts method, proposed by Hoek and Bray is used in the analysis of slip circle failure [6]. These include. Detailed stability analysis of the Harmony landslide has been carried out by using Circular Failure Charts method.

9. CALCULATION OF FACTOR OF SAFETY USING CIRCULAR FAILURE CHARTS

The calculation of Factor of Safety (F) has been done for the overall slope of the slide along different sections. All three sections have been taken for calculation of 'F' by Circular Failure Charts method. 'F' has been calculated for three selected sections as indicated in Fig. 2. The input data used in analysis are presented in Table 1.

9.1 FACTOR OF SAFETY OF THE SLOPE ALONG SECTION 1 (A-A')

Details of the parameters considered in analysis:
Slided material, clayey in nature
Slope angle : 40^0
Height of the slope (H) : 183m = 18300 cm
Density of soil (γ) = 1.65 gm/cc
Cohesion of soil (C) = 139 gm/cm^2
Angle of internal friction $(\Phi)^0$ = 29
Dimensionless ration (C/γHtanΦ) = .01

Based on the given observation the factor of safety as calculated for several ground water conditions are enlisted below. For dry condition circular failure chart No.1 is used. For 25% and 50% saturation, chart No. 2 and 3 are respectively referred.

Table 2: F values of the slope for different groundwater flow condition (Section - 1)

Factor of safety (F) as per the 'X' and 'Y' intercept of the chart	Groundwater Flow Conditions		
	Completely Dry (Chart No. 1)	25% (Chart No. 2)	50% (Chart No.3)
Y intercept (F_1)	0.83	0.73	0.66
X intercept (F_2)	1.01	0.85	0.69
Average F value	0.92	0.79	0.67

Generally in geological conditions, material consists of both 'C' and 'Φ'. So average value of the (F_1 and F_2) is taken as final factor of safety and in present case the material is nearly equally proportioned (in C and Φ). So, as per the existing condition the Factor of Safety (F) of slope along section 1 is 0.92 for dry condition.

9.2 FACTOR OF SAFETY OF THE SLOPE ALONG SECTION 2 (B-B')

Details of the parameters considered in analysis:
Slope angle : 40^0
Height of the slope (H) : 176m = 17600 cm
Density of soil (γ) = 1.65 gm/cc
Cohesion of soil (C) = 133 gm/cm^2
Angle of internal friction $(\Phi)^0$ = 33.46 = 33
Dimensionless ration (C/γHtanΦ) = .01

Based on the given observation the factor of safety as calculated for several ground water conditions are enlisted below. For dry condition circular failure chart No.1 is used. For 25% and 50% saturation, chart No. 2 and 3 are referred respectively.

Table 3: F values of the slope for different groundwater flow condition (Section - 2)

Factor of safety (F) as per the 'X' and 'Y' intercept of the chart	Groundwater Flow Conditions		
	Completely Dry (Chart No. 1)	25% (Chart No. 2)	50% (Chart No.3)
Y intercept (F_1)	1.15	0.88	0.72
X intercept (F_2)	1.28	0.91	0.80
Average F value	0.21	0.90	0.76

Generally in geological conditions, material consistent of both 'C' and 'Φ'. So average value of the (F_1 and F_2) is taken as final 'F'. In present case the material is nearly equally proportioned (in C and Φ). So, as per the existing condition the Factor of safety (F) of slope along section 2 is 1.21 for dry condition.

9.3 FACTOR OF SAFETY OF THE SLOPE ALONG SECTION 3 (C-C')

Details of the parameters considered in analysis:
Slided material
Slope angle : 42^0
Height of the slope (H) : 210m = 21000 cm
Density of soil (γ) = 1.65 gm/cc
Cohesion of soil (C) = 124 gm/cm^2
Angle of internal friction $(\Phi)^0$ = 36.52 = 36
Dimensionless ration (C/γHtanΦ) = 0.008

Based on the given observation the factor of safety as calculated for several ground water conditions are enlisted below. For dry condition circular failure chart No.1 is used. For 25% and 50% saturation, chart No. 2 and 3 are referred respectively.

Table 4: F values of the slope for different groundwater flow condition (Section - 3)

Factor of safety (F) as per the 'X' and 'Y' intercept of the chart	**Groundwater Flow Conditions**		
	Completely Dry (Chart No. 1)	**25% (Chart No. 2)**	**50% (Chart No.3)**
Y intercept (F_1)	0.60	0.57	0.60
X intercept (F_2)	1.05	0.88	0.76
Average value of F	0.83	0.73	0.68

Generally in geological conditions, material consists of both 'C' and 'Φ'. So average value of the (F_1 and F_2) is taken as final factor of safety and in present case the material is nearly equally proportioned (in 'C' and 'Φ'). So, as per the existing condition the Factor of Safety (F) of slope along section 3 is 0.83 for dry condition.

10. DISCUSSIONS

After averaging the three factor of safety values along respective sections [1 (AA'), 2 (BB'), 3 (CC')], the overall factor of safety comes to 0.98 under dry condition. It can be seen from the Tables 2, 3 and 4 that the 'F' value decreases with increasing water saturation. Hence the slope is stable under dry condition. The slope becomes unstable on consistent water saturation. During rains, the slopes may get saturated to varying degrees and hence leading to instability.

11. CONTROL MEASURES

From the stability analysis and field observations, it is clear that the slopes are unstable and are still in active state of instability. Even the newly constructed houses just above the crown show cracks on the walls. Several prominent open ground cracks are seen in the upper parts of slide area as well as on the slopes close to the road. The field investigations reveal that the toe erosion of slope by Pinder river is a significant factor in inducing instability. Taking into consideration the nature of instability, type of slope materials and slope geometry, a set of control measures as suggested below may help to improve the overall stability of the slopes.

1. Along the left bank of Pinder river, two rows of concrete cubes (size 1m×1m×1m) be placed one over the other at the toe of slide mainly to prevent river erosion. This will cover up to the high flood level (HFL) of the river.
2. Further above two rows of wire crated gabion walls of 1m height each, be constructed to provide effective toe support for slope materials below the road.
3. The Karnaprayag - Gwaldam road may be widened to about 8m to facilitate locating toe drains on the hill side of the slope.
4. On the hill side of the road, a 4m high retaining wall may be provided. The stability analysis of this wall indicates that the wall is adequately safe under static and dynamic conditions.
5. On the valley side, a 2-3m high retaining wall may be provided to support the valley side end. The stability analysis of this wall indicates that the wall is adequately safe under static and dynamic conditions.
6. Adequate attention may be given in the inclination of the drainage holes within the retaining wall.
7. The slope materials excavated from above the road be dumped below the road and compacted well to flatten the slope gradients behind the gabion wall located close to river bed.
8. A 50cm wide and 60cm deep lined drain may be constructed at the toe of hill side retaining wall with gradient of 25:1.
9. Lining of northern and southern streams located on fringe of the slide may be helpful to prevent subsurface seepage.
10. Grass turfing of barren slopes be done to prevent ingress of rain water into slope. Fast growing plants and tree species be planted to provide resistance to surface erosion.
11. The arcuate cracks be filled with silty clay or locally available fine grained matrix and compacted well.

12. LANDSLIDE MONITORING AND SUSTAINABLE DEVELOPMENT

It is vital for us to know the ecological state of the world, as well as to determine the dangers that might affect the environment, including the irrational exploitation of natural resources, demographical problems, unsustainable development and climate change. The probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area is known as hazard. New technologies such as GPS or laser scanning have significant potential use in the analysis of natural hazard such as landslide. Landslide monitoring is very important in ensuring sustainable development. Instruments like inclinometers, extensometers, piezometers, rain gauges, and other related equipments are used for landslide monitoring.

13. CONCLUSIONS

Construction of roads in Himalayan terrain is hazardous, if the existing instabilities are properly not accounted during excavations. The highly seismic and unpredicted concentrated rainfall pattern are also responsible for landslide in Himalaya.

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Hence, it is essential that systematic studies including inputs of Geology and Geotechnical parameters are taken up during planning stage of projects in order to minimize the environmental hazards in the form of landslides. However, most of the presently constructed roads were practically constructed with very less or no inputs of geology and geotechnical parameters during planning and hence have many unstable stretches

In the present study, the Karnaprayag-Gwaldam road falling in Higher Himalaya had been taken up for detailed evaluation. It is a strategically very important road, since it is the only connecting link between Garhwal and Kumaun Divisions of Uttarakhand. Geologically Nagthat-Berinag Formation of Jaunsar Group of rocks containing mainly Karnaprayag metavolcanics and interbedded quartzites are exposed between Karnaprayag and Begali. Higher Himalayan Almora Group of rocks are predominantly exposed in the eastern sector of the study area.

In the study area, Harmony landslide is the most important one as it affected the road traffic almost every year during rains. It is a rotational slide involving loose debris of old landslide, that took place in the area in geologic past. The slide was mapped on 1:1000 scale and observed three Nos. of geologic cross sections. Field samples were collected and tested in the laboratory for their shear strength. Stability analysis was carried out using circular failure chart method. The analysis indicated that the slopes are just stable under dry conditions and on water saturation the slopes become unstable. A set stability measures have been suggested including construction of retaining walls and other related measures. The designs of all these measures have also been provided for implementation on the ground.

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NOMENCLATURE

Symbol		
γ	Density of Soil	(gm/cc)
C	Cohesion	(gm/cm^2)
F	Factor of safety	
Φ	Angle of internal friction	(degrees)

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