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SYNOPSIS The Himalayan ranges experience intense mass movements, culminating in a large number of landslides every year. The road system in Himalayas is especially vulnerable to the landslide hazard. A number of techniques have been used in practice to manage and control landslides in these areas. The present paper deals with experiences gained in this regard. A few case histories are presented in the paper, wherein landslides have been successfully managed by appropriate techniques. These concern mainly (i) the use of hazard zonation techniques for solving chronic landslide problems by rationally identifying a stable alternate route and (ii) effective and economical techniques to control landslides induced by surficial erosion.

INTRODUCTION

A stretch of highway in North Sikkim was experiencing recurring and persistent landslide activity at a few locations. Conventional efforts to control these slide areas did not prove satisfactory. It was hence decided to investigate the feasibility of adopting alternate alignment at these locations. For this purpose, it was necessary to evaluate the possible alternate alignments from considerations of landslide susceptibility and provide a forecast of the stability rating of the slope areas. Hazard zonation techniques were adopted for this purpose. Based on the results of the study, the alignments were divided into stretches of different stability ratings. The management technique adopted was based on the overall stability rating of the alignment considered. Three sites were studied. At two locations better alignment was identified and road byepassing the slide area was constructed on this alignment. During the past five years, the alignment was found to have given trouble free service and the slopes remained free of problematic landslide incidence. In the third case, it was concluded that the existing alingment is better from long term stability considerations than other possible alignments. Hence the needed control measures were adopted to improve the slope stability.

METHOLDOLOGY OF HAZARD ZONATION STUDY

To evaluate the potential stability of the hillslopes along a stretch of road, detailed field surveys are carried out. Both quantative and qualitative data are collected for demarcating zones having different degrees of risk of failure. Several factors and subfactors usually taken into consideration for this purpose (Rao,1989) are shown in Table I. The uphill as well as downhill slopes were surveyed thoroughly from geotechnical, geological, hydrological and environmental aspects. Properties of the constituent materials of the hillslope were obtained. Each of the factors and associated subfactors interact in a complex way to keep the slope stable or render it prone to instability. The influence of these factors and their into ractions were integrated to obtained "Instability risk Rating", of the hillslope and delegrated the various zones according to risk of sliding. In order to evaluate instability risk rating value, each factor or subfactor was given a numerical rating. Appropriate weightages are accorded to various factors. These values for a particular stretch were summed up to get the total instability risk rating. The instability risk ratings were divided into four groups ranging from very high to low (Table II). Finally the model developed was compared or calibrated with the help of actual field observations or failures and finalised taking the same into consideration.

SITE I

The landslide at Site I on North Sikkim highway had been active for over two dicades. Several attempts were made to improve the stability of slide area but the efforts were not successful due to various reasons. The lowest limb has been experincing maximum instability. During 1986 a diversion was made to bypass this unstable limb. The bypass road had to be abandoned during 1984 due to creep and mudflow problem. The uphill bypass road was made at above 100m uphill of the old road alignment which also did not prove satisfactory. At this stage, it was considered that taking the road along an alternate alignment would be a better approach for managing the landslide problem at this spot.

Accordingly the slopes in the nearby stretch were studied and potential instability / stability ratings were evaluated using the concepts of hazard zonation technique. An alternate alignment was identified which had high potential stability rating. The road was constructed on this alignment which completely byepass the slide

TABLE I Factors Considered for Evaluation of Potential Stability or Risk Rating

A. Formation Materials

a. Rock

Type, Weathering, Nature of Bedding, Nature of Joints, Nature of fissures, Boulders, Fault planes, Presence of weak planes and Gouge material.

b. Soil

Type, Thickness of layers, Shear strength properties: cohesion and friction parameters.

B. Slope Angles & Surface Conditions

C. Nature of Erosion

- Possibility and extent of toe erosion
- Channel erosion in rock formation
- Surface erosion

D. Hydrological Conditions

- Presence of streams on the hill slope
- Catchment area and pattern
- Run-off characteristics

TABLE II Instability Risk Rating Adopted for Hazard Zonation

Very high insta-instability risk rating (greater than 50%).	Zones where failures have already occured for further failures are likely to occur
High instability risk rating (45% to 50%)	Zones where severe distress or sign of moderate surface erosion, creep etc. are noticed.
Medium instability risk rating (40% to 45%)	Zones where minor distress or signs of moderate surface erosion, creep etc. are noticed.
Low instability risk rating (35% to 40%)	No apparent sign of instability.
Very low instability risk rating (less than 30%)	Nearly stable slope conditions and governing parameters are favourable for its stability.

area.

The road has been functional for past six years and no landslides occured during this period. Fig.1 shows the alternate alignment currently in use as well as the landslide affected area. Thus zonation technique has been used here successfully at this site.

Fig.1. Stable Alternate Alignment Adopted Shown With The Landslide Affected Area Juxtaposed.

SITE II

A bridge having a span of 18m exists at the site under consideration. The uphill slope at the site of the bridge was unstable. As such the bridge site was susceptible to erosion and landslides. Field investigations were carried out with the objectives (i) to byepass the present unstable site by a suitable realignment of road and construct a new bridge at an upstream location where the bridge span is relatively smaller OR (ii) to improve upon the existing road alignment by adopting suitable remedial measures to ensure stability of unstable slopes at the existing site.

Landslide hazard zonation studies were carried out . The whole area was surveyed to assess the pessibility of various options. The study indicated that it would be most appropriate to provide additional remedial measures to improve the stability of adjoining hillslopes at the existing bridge site. Landslide hazard zonation studies were thus used to rationally arrive at a cost effective solution for improving a landslide effected stretch of slope.

SITE III

At this location the hillslope has been experiencing instability for past many years, requiring back-cutting of the hilside for providing the roadway. To avoid the trouble spots, two new alignments, designated the Eastern Byepass and the Western Byepass, were considered. Studies were carried out on both the alignments with the view to evaluate their comparative merits with regard to landslide susceptibility.

Eastern Byepass Alignment

The total length of the road is 3.8km. The elevation difference between the two points is about 180m. The road alignment broadly traverses over a set of spurs with valley slopes varying from 25 to 60 degree. The rock formation on the hillside of fair to medium strength, except at a few locations where weathering of rock is more. The top mantle on the slope generally consists of micaceous sandy silt/ clayey silt with varying percentage of boulders. The thickness of the mantle varies from 0.5 to 10m. The area has a fairly good vegetation cover.

For assessing the feasibility of the proposed alignment, the entire stretch was divided into four zones. The zonation rating pattern for each zone was evaluated with respect to stability.

These studies indicated that the area lies in zones with high potential for instability. Thus the proposed Eastern byepass alignment was not considered as a suitable one to serve as byepass.

Western Byepass Alignment

The length of Western Byepass was about 1.02 km. The stretch was divided into three zones and various factors contributing to instability were considered for each zone. Based on the cumulative assessment of these factors and their probable effect on the stability of the hillside, the zones were rated with regard to slope stability.

The study indicated that the proposed Western byepass alignment is suitable as the potential instability was low on this alignment. Based on hazard zonation studies remedial measures were suggested at a few locations to maintain or improve stability and avoid the problem of slope instability due to cutting of formation. The performance of the alignment was observed to be satisfactory.

SITE IV

The 32km length of the stretch Kathgodam-Nainital Highway was affected by periodic incidence of mass movements of different types, viz., rockfall, planar slide, subsidence, debris flow and debris slides at different locations. The stretch of highway caters to tourist traffic. Thus, an urgent need was felt to keep the highway free from landslide incidence. Detailed investigation were carried out over the entire stretch and landslide hazard zonation maps were prepared covering the hillslopes adjoing the entire highway.

These maps clearly indicate the probable failure zones, the type of failure and the degree of risk failure. These maps can be used to proiritise the slope stretches where stabilising measures are required, as well as specify the type of such measures. This has resulted in optimising the resources required for maintaining the highway in a state of minimum exposure to landslide hazard. Fig-2 shows the map indicating probable failure types and the extent of mass movement. The zones of different instability risk rating are shown in Fig-3.

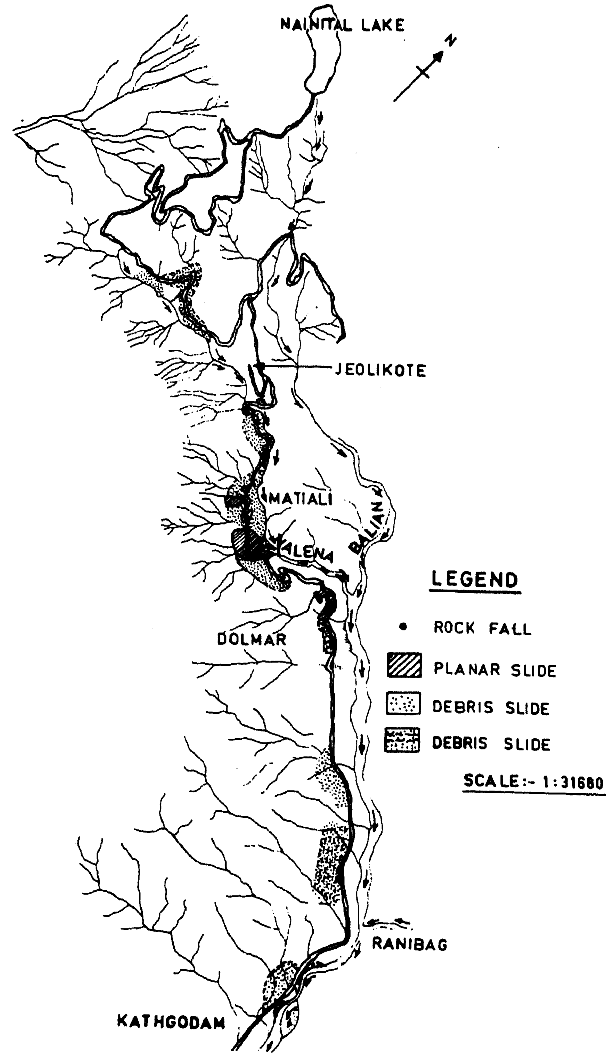

Fig.2. Maps Showing Probable Failure Types

CONTROL OF LANDSLIDES INDUCED BY SURFACE EROSION

Shallow surficial landslides induced by surface erosion form a significant part of landslides in the western Himilayas. It has been observed that a small surficial slope erosion problem transform into a major slope failure or a landslide if the initial damages sustained by the slope are not rectified. Such escalations would necessitate costlier restoration works. Erosion of slopes is therefore being increasingly recognised as a problem needing effective and economical solutions. Different kinds of geofabrics, natural as well as synthetic are being currently in use to protect erosion prone slopes. While in many countries geo-grids and nets made of geosynthetics have been in use for erosion control, it has been found in the Indian context that the use of netting from natural fibres is highly effective and significantly economical to control surficial erosion. Field experiments were carried out in Kumaon area and near Mussorie, to develop economic techniques to control such landslides. The viability of promotion of a vegetation cover, in conjuction

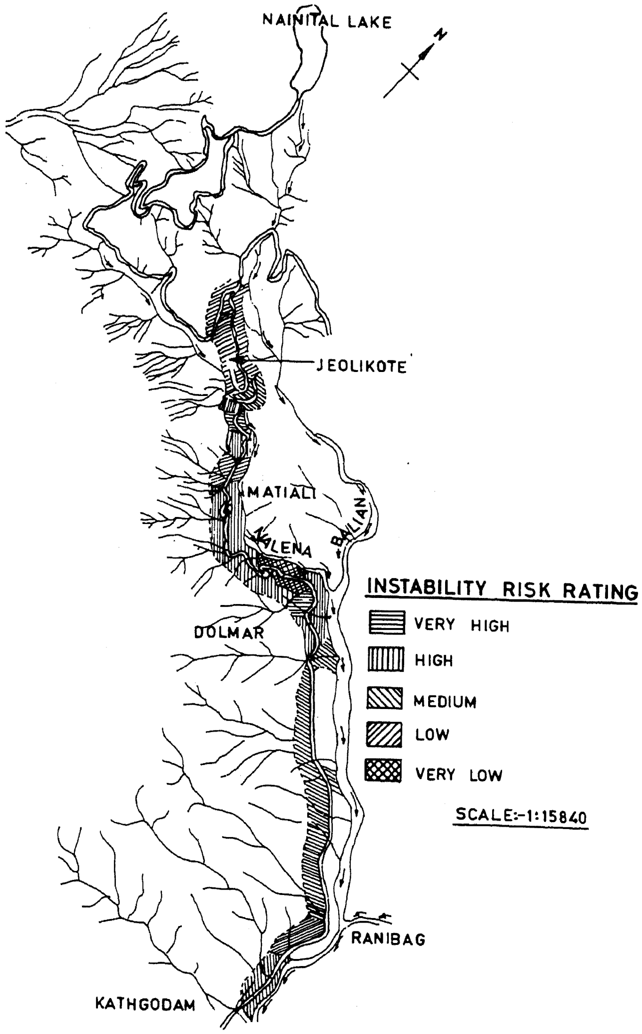

Fig.3. Zones Showing Instability Risk Rating

with the use of biodegradable and environmentally friendly nettings such as coir nets, was studied in these field trials. The experiments covered nearly 6,000 sq.m. of slope area in these hills and another 4,000 sq.m in Nilgiris, where also such phenomenon was observed. Field studies covering a period of four years have shown that the soil loss in treated slopes is reduced by 90% as compared with untreated slope. A clear increase in the stability of slope was observed. Details of the field experiments and the result of the same are given below.

PROPERTIES OF COIR GEO-GRIDS

The natural fibres that have found wide spread applications in surface erosion control are jute and coir. Strands of jute or coir are woven into an open mesh configuration, the size of the mesh ranging from 1.5 to 2.5cm. Normally, the fibric is supplied in rolls of 1 to 2m width and 50m length.

Coir fibre is a completely biodegradable organic fibre, resistant to rotting under alternate wetting and drying conditions. Its retention of tensile strength is also good. Single threads have a tensile strength of the order of 150 to 200N. In the field, coir retains its tensile strength for about 3-5 years. On the other hand, jute deteriorates within a span of 2-3 years.

METHODOLOGY

The procedure adopted for laying the coir netting on erosion prone slopes is as follows:

The slope is first levelled to remove any unevenness present, viz; deep irregular gullies or projecting stones etc. A suitable fertilizer is mixed into the soil at a rate of 0.5 kg per 10 sq.m. Seeds of selected varieties of deep rooted and quick growing grasses and bushes are then spread over the slope . Half of the quantity of seeds are spread prior to covering the slope with the netting and the other half subsequent to the laying of coir-netting. Coir-netting acts as a series of check dams and reduces the velocity of water flowing down the slope. Due to the check dam action, erosion of soil is prevented, seeds and nutrients are preserved on the slope and the vegetation takes root quickly.

CASE STUDIES

Full scale field experiments using coir-netting for surface erosion control of slopes were carried out at the following locations:

- Nagapattinam-Gudalore-Mysore Highway
- Coonoor-Kundah Road
- Kathgodam-Almora State Highway
- Lambidhar Mines Area
- Meerapur Davel Road.

About 6000 Sq.m. of coir-netting was used in the above five experiments. These sites were chosen since the slopes were found to be highly susceptible to erosion.

A comparative study of the following techniques of erosion control was carried out at the site of Meerapur Davel road.

- Use of coir-netting
- Use of stone pitching
- Pitching of shoulders with bricks
- Use of coir netting with pitching of shoulders
- Control section without any treatment

On the erosion prone slope of Meerapur Davel road, the loss of soil from the above stretches after a heavy monsoon was found to be as given in Table III. A significant growth of vegetation was observed on the slope protected with coir netting whearas no growth of vegetation could be seen on the control panel.

At Lambidhar mines area, coir netting was used for control of movement of lime stone scree resting on the steep denuded slopes. The area being subject to heavy rainfall in monsoon season

TABLE III Efficacy of Different Methods of Erosion Control

Technique Used	Amount of Soil lost per 100 sq.m. of embankment (cu.m.)
Coir netting	300
Stone pitching	125
Brick soling of berms	600
Control panel	900
Coir netting of slopes coupled with brick soling of berms.	NIL

and severe cold in winter. The slopes lacked any soil cover and were highly infertile. During the rains the scree was getting washed down the slopes resulting the blocking the hillside streams at the foot of the slopes. After the installation of coir netting the scree material was completly retained , the seed and roots present on the slope were afforded a chance to germinate and grow. Encouraged with the success of the experiment, the State Mining Development Corporation procured 16,000 sq.m. of coir netting for further use in slope protection in the mines area.

Experiments at other sites also were very encouraging.

In the laboratory a detailed study was carried out on the shear strength behaviour of a number of soils reinforced with natural root network. During the course of study it was observed that the root network imparts a significant increase in the apparent cohesion of soil and also in the failure strain. As a result, as shown in Fig.4 the overall stability of the slope is improved.

CONCLUSIONS

The paper demonstrates asuccessful applications of the use of hazard zonation technique to manage chronic landslide problems. Evaluation of stability / instability potential of nearby slopes has enabled identifying alignments which are far less susceptible to landslide hazard than existing ones. Performance experience of the realigned highway proved this to be valid since the realigned stretches did not suffer from landslide hazards over a period of six years.

Use of landslide hazard zonation technique for developing an optimum maintainance strategy for keeping the highway free from landslide hazard has been demonstrated.

By means of large scale field experiments it has been demonstrated that shallow landslides can be successfully controlled by using geogrids madeup of natural fibres like coir or jute in conjunction with promotion of growth of vegetation.

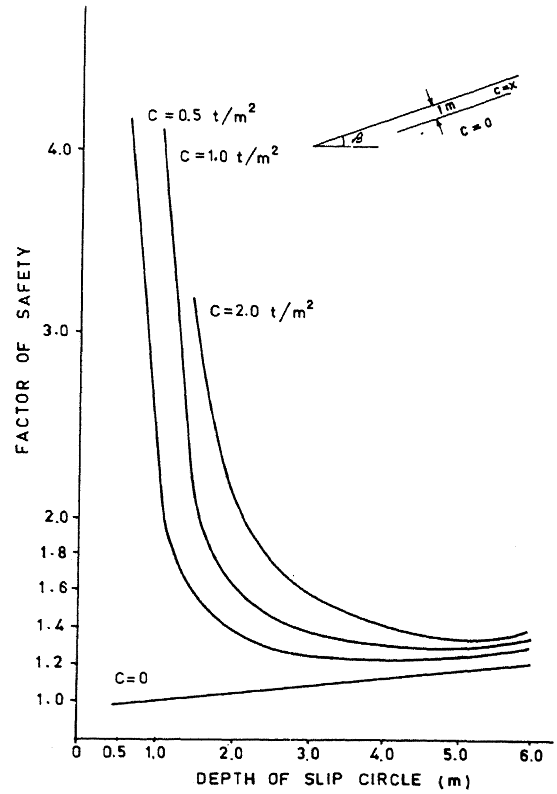

Fig.4. Effect of Root Network on Stability of Slope (= 15 Degree)

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