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SYNOPSIS

For over six decades Kaliasaur landslide (Lat. 30° 14' 30" N, Long. 78° 55' 50" E)is a nightmare on the Hardwar-Badrinath road in the Garhwal Himalaya. Located on a sharp bend on the left bank of river Alaknanda, it has emerged as a multi-tier repetitive major landslide, retrogressive in nature. Both surficial and deep seated movements have been monitored. The sliding in the upper layers have been predominantly in the colluvium but where interfaces of quartzite and shale participates, the sliding surfaces have been better defined and discrete.

In the present paper, the authors have highlighted the geological, geomorphological and morphometric parameters to diagnose the factors responsible for instability of slope and the magnitude of the problems involved. A scheme of remedial measures which include modification of existing drainage pattern, timber piling for stitching of debris cover on to the slope, construction of retaining walls and putting back the vegetation on the slope are recommended for control of the landslide.

INTRODUCTION

The Kaliasaur landslide located at km 147 in the Garhwal Himalaya has been a major problem to the communication and safety of road users for over six decades (Fig.1).

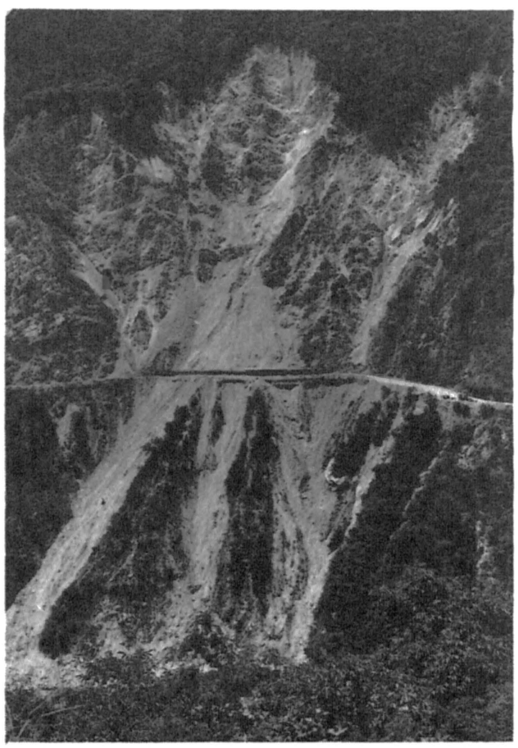

FIG.1 - KALIASAUR LANDSLIDE ON HARDWAR-BADRINATH ROAD

The slope forming material consists of weathered, loose, crushed and pulverised rockmass mainly of quartzites and shales. The slide is constantly on the move particularly during the monsoon season (June-September) when the debris flow and rock fall are quite severe. These mass-movements are caused mainly by heavy precipitation and consequent development of hydrostatic pressure build up in the colluvium in highly fractured and jointed rock mass. In addition, extensive toe erosion by meandering Alaknanda river also cause progressive failure of the overlying materials (Fig. 2).

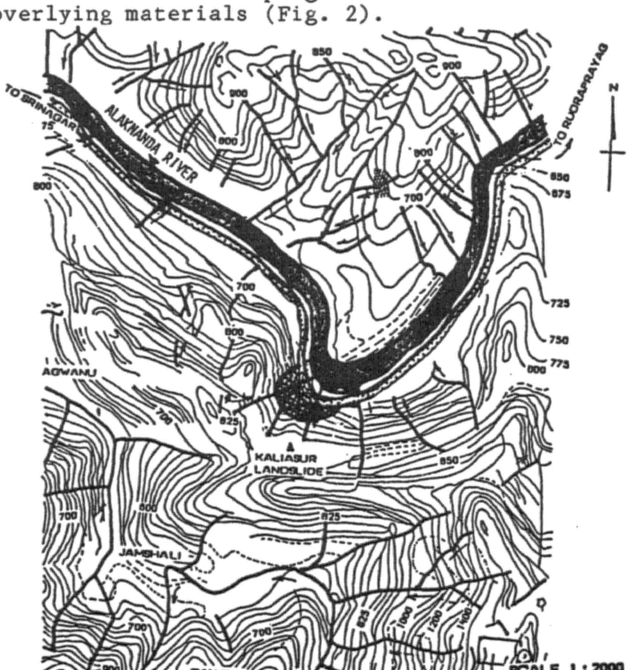

FIG. 2 - CONTOUR MAP SHOWING THE LOCATION OF KALIASAUR LANDSLIDE

The uphill slope of the slide area is steep being around 45° to 70°. The slide has advanced over 165m above the road and it is still advancing during the period of monsoon each year. The paper highlights the mechanism responsible for occurrence of multi-tier slides and a scheme for control measures based on the findings of investigation. It also reports on the experiences with timber piling and low cost retaining wall construction.

HISTORY OF THE LANDSLIDE

The Geological Survey of India records declare location km 147 on Hardwar-Badrinath road as the landslide area since 1920. Further occurrences of moderate to heavy landslides in 1952, 1963, 1964 and 1965 are reported. A major landslide at this location, however, occurred on 19th September, 1969 blocking nearly three fourth of the river about 100 m below the road level. A 300 m stretch of the road was badly damaged and got dislocated both vertically and laterally by about 2.5 - 3.0 m. The slide is reported to have remained active till 23rd September, 1969. During 1970, 1971 and 1972 repeat of moderate to heavy landslides occurred disrupting the communication system and each time, a new formation width had to be cut. During September, 1984, following heavy rainfall, a major landslide occurred and damaged the road considerbly, extending the rear scar of the slide retrogressively. The most recent slide was in August, 1986. The total area of the slide above and below the road level together measure 86000 m^2. Nearly one lac cu.m of landslide produced rock debris have gone into the river since the origin of the landslide.

GEOLOGY OF THE AREA

The rock formation in the landslide area belongs to the Garhwal Group of rocks namely white and light green quartzites interbedded with maroon shales.

Geological mapping of the area was carried out on a 1:2500 scale and the area included the surroundings of the landslide zone. Three traverses were taken i.e. along the main road, along the river and along the Khankra-Chhantikhal road (Fig. 3).

Observations along the road and along the river suggest the presence of two types of quartzites. One is of light green colour with thin beds of maroon shales, and the other is massive and well jointed yellowish white quartzite. On the western side of the slide zone the quartzite are light green with shale bands having a general southward dip with amounts ranging from 25° to 60°. These quartzites end up abruptly along a scree zone beyond which massive yellowish quartzites dipping southeast with amounts 30° to 40°, are exposed. It appears that the scree zone conceals a fault zone trending NE-SW and extending across the river. The massive quartzites continue upto the western flank of the slide zone where they end up against the slide debris. On the eastern side of the slide zone the quartzites exposed have maroon shales with a south eastern dip and amounts varying from 30° to 60°. These quartzites continue along the river bed. It appears that another fault zone trending NW-SE may be present somewhere within the slide zone.

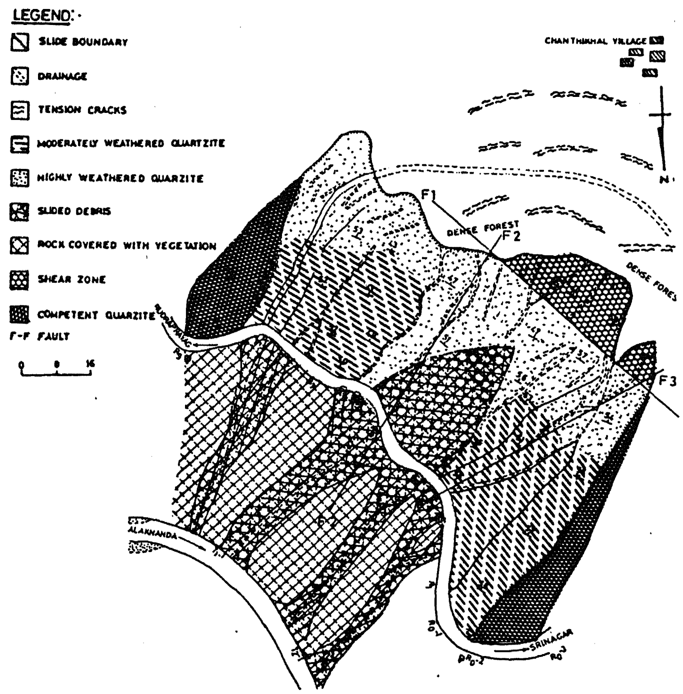

FIG. 3 - GEOLOGICAL MAP OF KALIASAUR LANDSLIDE ON HARDWAR-BADRINATH ROAD

The geological succession in this area appears to be as follows :

Massive yellowish white quartzites

Greenish quartzites interbedded with maroon shales and Metabasics

Greenish grey phyllites and shales
Dolomitic limestone

The rocks appear to have been folded into a plunging overturned anticline on the western side of the slide zone with a plunge towards north-east. Another anticline appears to be on the eastern side of the slide zone with plunge towards south. There appears to be a number of fault zones in this area. A major fault appears to be along roughly East-West trend. This fault zone passes through the crest of the slide zone and separate the metabasics from the quartzites. Two other faults with trends roughly NE-SW exist in this area. They all appear to be high angled and one of these passes through the main slide zone. All these faults merge into Chhantikhal fault.

GEOMORPHOLOGY

The geomorphological mapping was carried out on scale 1:3125. In this area Alaknanda occupies a deep sinuous gorge with the crest of sinousity located near the slide zone.

The slopes on the left side of the river are steep whereas they are rather gentle on the right side. Slide zone is located on the left side of the river, where the main road is passing through. This area contains a number of smaller scree zones, along with exposures of quartzites. There appears to be a significant escarpment running east-west below the Chhantikhal village. This escarpment continues upto the river bed. The lower part of this escarpment is occupied by colluvium resting nearly at its angle of repose. The middle part exposes quartzites and on the top there are cultivated fields. Above this escarpment, there is a dense forest.

There are a number of small streamlets flowing over the escarpment and meeting the river at high angles. Two such streamlets are reported to pass through the landslide zone.

The profile of first streamlet towards the eastern part of slide zone is very smooth and is concave upward characterising the profile of stabilised repose slope. The profile of second streamlet in the slide zone indicated the upper part of the slope to be gentle and slightly convex possibly due to the accumulation of talus. In the middle part, the slopes become highly convex with exposed free faces of quartzites. The tension cracks varying in length from 1 m to more than 50 m were present at several locations above the crown of the slide. The lower part of this profile is slightly concave having accumulation of talus material. It appears that the slopes are generally unstable above the road and are currently under the process of severe mass wasting.

MORPHMETRIC PARAMETERS

The morphometric parameters studied in this area can be classified (a) Drainage Basin Morphometry and (b) Landslip Morphometry Parameters.

Drainage Basin Morphometry :

Seventeen second order basins present in this area were analysed and studied in details. The mean values of various parameters studied are given in Table I.

TABLE I. Stream Morphometry Parameters (Mean Values)

Basins	Area (Sq. km)	Shape	Stream Frequency	Drainage Density	Relief	Drainage Texture
Eastern Part	2.58	0.41	2.45	0.42	1.95	1.10
Slide Zone	0.74	0.22	5.86	0.60	2.72	3.62
Western Part	1.62	0.38	2.46	0.36	1.91	1.05

The data clearly indicate that the longer and larger basins are located in the eastern part of the slide zone whereas shorter and smaller basins are present in the slide area. The parameters like stream frequency, drainage density, relief and drainage texture etc. have maximum values for slide zone. All these facts suggest that the slide zone is full of newly emergent streams and is highly dissected with an active process of erosion. Due to the presence of porous scree material in slide zone only few streams can be seen. This, however, shows that there must be many concealed underground streams active in the slide zone.

Landslip Morphometry Parameters :

The landslip parameters were analysed on the basis of stream profiles, classification index, and dilation index values.

The distribution of these parameters are given in Table II.

TABLE II. Landslip Morphometry Parameters (Mean Values)

Area	Classification Index	Dilation Index	Type of Mass Wasting
Eastern Part	9.5	14.8	Debris Avalanche/ Rotational Slides
Slide Zone	7.5	9.8	Planar Slides
Western Part	4.5	4.7	Flow and Creep

The values of classification index for the slide zone and eastern parts of the area suggest failure mainly by planar slides by the process of debris avalanche whereas in the western side of slide zone the classification index values depict failure by erosion only. The values of dilation index show the possibility of rotational slides involving the movement of bed rocks alongwith planar slides in the eastern part of the slide zone. In slide zone only planar slides are possible through debris avalanche. All these data clearly indicate that the eastern part of the slide area may be potential slide zone and the present slide zone may get extended eastwards by future landslides and mass movements.

INSTRUMENTATION AND MONITORING

The landslide was monitored for its surface as well as crustal movement behaviour.

For measurements of slope movement a scheme was drawn for locating markers for tape extensometer and geodetic triangulation observations. Grid map of the slide area was used for locating the positions of monuments and pedestals (Fig. 4). To facilitate measurements of relative surface displacements between points, 65 pedestals (markers) were installed. Measurements were made through tape extensometer and clinometer. Additionally 50 RCC pillar/monuments (markers) anchored up to 2 - 3 m depth were monitored through triangulation and high precision methods.

Monitoring of surface movements were started before the onset of the monsoon in 1986. During rainy season fortnightly observations were taken. About 1000 observations have been taken so far. Some of the typical time displacement observations are shown in Fig. 5. The analysis of the data clearly indicated two directional movements - north eastern and north western - in the eastern and western sides of the slide zone (Fig. 6). The extent of the lateral movement of pedestals towards the eastern side varied from 0 - 117.8 cm whereas the pedestals on western side showed movement 0 - 76.1 cms indicating thereby that the eastern part of the slide area is more unstable.

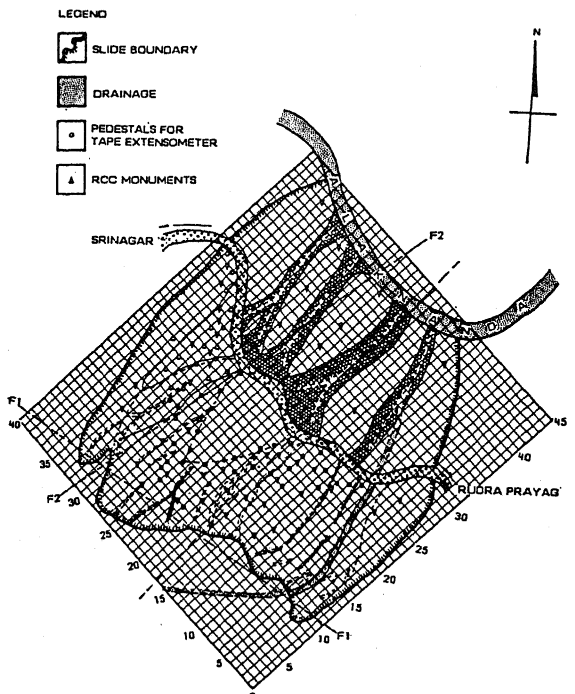

FIG. 4 - SCHEME FOR MONITORING OF SURFACE MOVEMENTS OF SLOPES AT KALIASAUR LANDSLIDE

The crustal movement studies pertaining to movement of the underlying slope material were carried out with the help of Electronic Distance Meter (EDM). The observations were taken before monsoon, during rainy season and thereafter till April 1987. The analysis of the data have shown significant lateral movement towards north east direction ranging from 0-22.5cm. The lateral movement towards north-west direction varied from 0-17.6 cm.(Fig. 7). The results further indicated movement in vertical direction ranging from 0-6.9 cm.

The study has thus clearly indicated that the eastern side of the slide area is a zone of intensive landslide movements involving both deep seated and surface movements. In the central and western sides of the slide area, the movement is confered predominantly to surface debris.

MECHANISM OF KALIASAUR LANDSLIDE

Kaliasaur landslide is essentially a multi-tier, retrogressive landslide in a complex rock formation with clear evidences of fault planes revealing intense tectonic activity in the geological past. Evidences of sliding at the interface of quartzites and maroon shales must presumably have been the starting point. Road construction activity in general and repeated back cutting required for restoring the road width, year after year, poor drainage, recurring debris slides in the colluvium cover on the slope robbing it of the vegetative cover and river action at the slope toe have all been responsible to develop the landslide to it's formidable size obtaining today. A typical slide cross-section is shown in Fig. 8.

A very large number of point load tests on quartzite specimens reveal uniaxial compressive strength of the order of 1800 kg/cm^2. The samples of maroon shale were however found to be so soft that even undisturbed sampling was difficult to achieve. During dry weather, samples were found to readily crumble into powder. Large displacements have, however, been inferred due to presence of polished surfaces. The characteristics of polished surfaces and genesis of their formation were therefore important factors. The condition of particle breakdown at

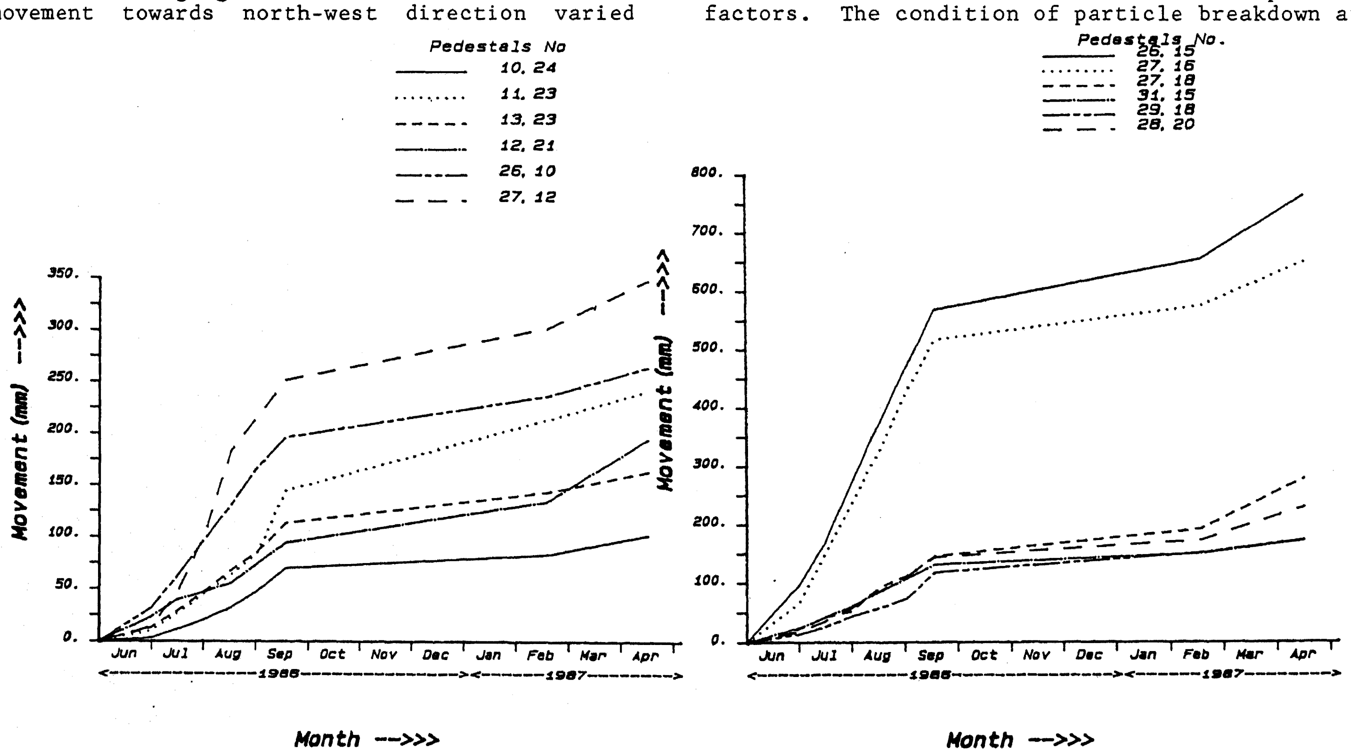

FIG. 5 - LATERAL MOVEMENT OF PEDESTALS BY TAPE EXTENSOMETER

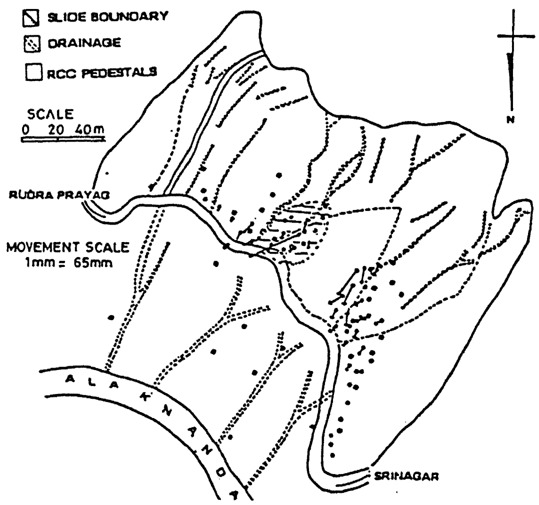

FIG. 6 - SURFACE MOVEMENT PATTERN OF KALIASAUR LAND SLIDE

the shale surface was simulated in the laboratory by subjecting the surface to artificially created abrasion effect for different intervals of time and determining particle size in laser particle Analyser. The results, clearly indicate that initially because of break down of bigger particles proportion of the clay size fraction at the boundary tends to decrease but later on clay fraction records marked increase, as could be expected corresponding to large movements. Well graded character of material at slide boundary is seen to turn into very nearly a single size fraction. The angle of shearing resistance is of the order of 28^{o} but it's residual value corresponding to very large strains is yet to be studied in the light of the above observation though post peak values of shearing resistance may lie in the range 18^{o}-22^{o}, Bhandari (1987).

Debris accumulation on the slope is excessive. Plentiful supply of water during the monsoon season combines with it to cause debris flow. Rockfalls are also very frequent.

Field studies have also shown that outlet of some concealed flow channels below the existing road level are responsible for undercutting of road resulting into its subsidence.

CONTROL MEASURES

As a result of detailed investigation, the following measures were recommended and are under various stages of implementation :

1. Grading of the slope uphill of the road.
2. All tension cracks and fissures in the rocks to be sealed.
3. Timber piling for stitching of the slope.
4. Construction of anchored drum diaphragm retaining wall along the road to control the slide mass overlooking the road.
5. Construction of anchored stone masonry wall towards other side of road to check the under cutting of road due to palaeo channels.

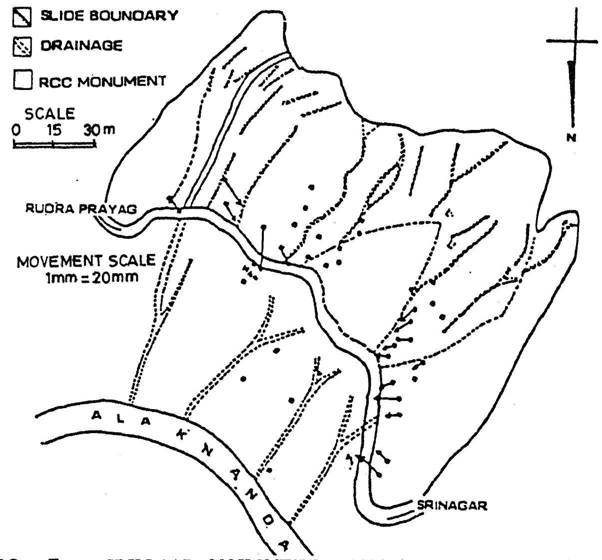

FIG. 7 - CRUSTAL MOVEMENT PATTERN OF KALIASAUR LAND SLIDE

6. Vegetating the slope.
7. A toe wall in masonry at the junction of the slope down hill of the road with the river. This wall is to be designed to withstand the scour of the river.

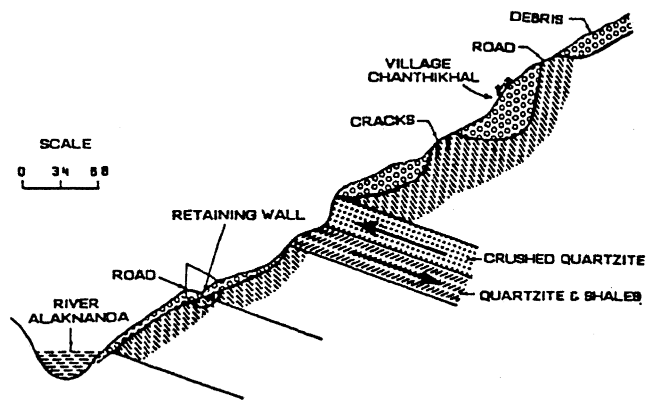

FIG. 8 - CROSS SECTION OF KALIASAUR LANDSLIDE

Of the above recommendations, the drum retaining wall as a concept is described by Bhandari (1987). The stitching of debris on slope and vegetative turfing are briefly described below.

Stitching of Debris on Slopes

Timber piling or bally cribbing is sometimes being used for arresting surficial movements in the slope cover so that vegetation and drainage facilities are not harmed and hazards due to debris flow could be minimised. Driving of timber piles result in densification of loose and shallow granular slide prone carpet on the slope and provide 'stitch action' that helps to hold the earth mass. Such piles are usually stiffened laterally by horizontal runners of timber. For example some 60,000 ballies of 12.5 - 15 cm diameter, 3 m long were driven to depths ranging from 1.5 to 2.0 m to stabilise Padamchen

FIG. 9 - STITCHING OF COLLUVIUM ON THE SLOPE AT KALIASAUR BY A SIMPLE PILING MACHINE

Slide in Sikkim. After stiffening the ballies laterally, the space (in between) was filled up and the vertical parts were tied with each other by 8 SWG binding wire. The bally cribbing and terracing were also used to stabilise a shallow landslip at the rear slopes of Idgah sub station building in Simla, Bhandari (1973). After intensive field trials, 20 cm diameter, 3 m long ballies were driven to a depth of about 2 m using a 30 kg hammer, about a metre apart. These ballies were braced on the uphill side by means of 15 cm diameter, 3 m long ballies in three tiers using dogs, nails and 8 SWG wire.

Difficulties of timber piling have now been largely overcome by a new, lowcost portable timber piling machine developed at the Central Building Research Institute, (Fig. 9). Timber piles 10 cm square from Deodar, Sheesham and Eucalyptus wood were driven in lengths of 1.5 m each suitably spliced, at six locations on the Kaliasaur slide using the portable machine requiring only one man to operate. The 30 kg hammer used earlier is now being replaced by 50 kg hammer to achieve higher orders of driving energy.

Vegetative Turfing on the Slope

The corrective measure appropriate for stabilising this slide after stiching the slope with timber piles comprise erosion control by establishing vegetation on the slopes. The resulting dense network of root system, penetrating about one metre into the slope anchors the soil adequately so as to render it resistant to erosional control. Slope treatment by vegetation is considered an important a maor corrective measure in surficial slides whereas in multitier slide like Kaliasaur the vegetation by itself will not be meaningful unless used in conjunction with other remedial measures.

CONCLUDING REMARKS

The slide at km 147 on Hardwar-Badrinath road has been a major problem to the road users. The past treatments given to this slide area have met with little success. The slide is constantly on the move during the monsoon each year. The present detailed investigation has led to better understanding of the nature and cause of the slide.

Based on the study corrective measures have been suggested with a view to stabilise the slide mass. The corrective measures include construction of retaining walls to check the under cutting of the road, a masonry toe wall to withstand the scour of the river, grading of slope, timber piling,, vegetation turfing and a system of surface and trench drains.

As a part of the landslide control programme, a drum diaphragm wall 100 m in length and 2.15 m high has already been constructed. Stabilisation of surface colluvium by timber piling has been partially accomplished. The total success could however be expected only after all other control measures are completed. The stage has already been set for the total completion of the programme in early 1988.

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