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INSTRUMENTATION, MONITORING AND ANALYSIS OF A LANDSLIDE - A CASE STUDY

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ABSTRACT

Powari Landslide which is situated at Km.367 on National Highway-22, on the right bank of river Sutlej in Kinnaur District of Himachal region of North-Western Himalaya has been active since 1987 and recurring every year in the months of July-Sept and March-May. The traffic interruption due to this slide was estimated in one year as 25 full days, 60 half days and 55 less than half days. Money spent each year only to clean the slided debris was estimated approximately from 70,000 to 2,00,000 in Indian rupees. Geological and geotechnical investigations followed by instrumentation and monitoring of this typical landslide was carried out to notice the nature, magnitude, rate and direction of movement on its surface and subsurface part from 1992 to 1995. Remedial measures recommended on the basis of such studies are also described.

KEY WORDS

Landslide, Instrumentation, Monitoring, Slope movement, Remedial measures

INTRODUCTION

Landslides are among the most frequently occurring hazards in the hilly terrain of Himalaya. In rainy seasons, from July to September and March to middle of May there is almost no day left without occurrence of either a new landslide or reactivation of old in some or other parts of Himalaya. This vary reason pressurise the Engineering Geologists, engineers and planners to make it essential to have quick investigations and to recommend suitable remedial measures at a minimum possible time. Therefore the scope of long term instrumented monitoring of slope is limited in India. However, a systematic study having an integrated approach covering geological and geotechnical investigations with special emphasis on instrumentation and monitoring of slope movements and analysis have been attempted by Central Road Research Institute (CRRI), New Delhi from 1992 to 1995, under a project Investigation, Instrumentation and Monitoring of Landslides, sponsored by Department of Science and Technology, Ministry of Science and Technology, New Delhi.

The valley made by Sutlej river from its entrance into Himachal down to Rampur region is particularly sensitive to landslide and other mass movements, because of its

complex geostructural set-up, steep slopes and climatic conditions. It is noticed that on an average there are at least two landslides in every kilometre of road. A few of the landslides like Powari, Nathpa and Maling are about three to four decades old and recurring almost every year. Various type of remedial measures recommended by different organisations, although implemented partially did not prevent the slide movements. Most of the landslides in Sutlej valley are along National and State Highways. This is the case in other parts of Himalaya also. Since the hill roads need to be communicative throughout the year the immediate remedial measures are required to be implemented, the scope of long term instrumented monitoring is therefore becomes secondary and limited. Never the less, at the first time in India such a study was attempted.

GEOLOGICAL INFORMATION

Kinnaur earthquake of 7.0 on Richter scale in 1975 which rocked some parts of Kinnaur and surrounding areas of Himachal state has evoked interest in the geology of this area (Sharma, 1976). Being fragile and rocked by earthquake tremors the topographical as well as the

geostratigraphic setup of the region was changed. During 1975 earthquake number of landslides were developed and Powari area was also badly affected.

Rocks present in the slide area belong to mainly Vaikrita Group. This Group of rocks are separated from Jutogh Formation by Vaikrita thrust which is located about a few kilometers away from the slide area. Slope of Powari landslide comprises of gneisses and schists of precambrian age and debris of glacial and periglacial origin (Rao et al 1995). Rocks exposed at some locations of slide area are moderately to highly weathered. Strike of rock varies from NNW-SSE to NW-SE and dip varies from 25° to 60° in NE direction. Schistose rocks area are less jointed whereas gneissic are highly jointed.

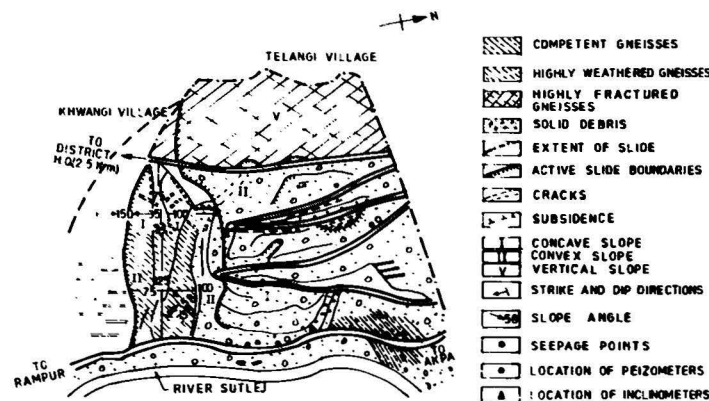


Fig.1. Geological sketch of Powari Landslide

Morphology of Slope

The Powari landslide is part of an old landslide which has occurred a few hundred years back. The slided material was deposited and afterwards the road as well as other settlements came into existence. The present unstable stretch of the slope extends for about 350m along NH-22 on right bank of river Sutlej and the apex of the slide is about 425m forming an area of about 1.5 sq.km. The crown part of the slide is composed of fractured gneissic rocks, forms a near vertical head scrap of about 100m height. The central part of the slide represented by generally a concave surface composed of debris material. The convex left and right flank of the slide is composed of competent to highly weathered gneissic rocks, strike of which varies from NNW-SSE to NE-SE and dip from 25 to 60 in North-Eastern direction. The inclination of the slope surface varies from 35° -60°.

As indicated in Fig.1 tension cracks of varying sizes developed are running parallel to the active slide boundary. The length of the cracks has increased by 0.2m to 1.0m in just three years similarly width from 0.01m to 0.5m and depth 0.1m to 0.6m. During rainy and snow melting season, infiltration gets enhanced in the presence of existing cracks. The affected area has also subsided in different parts of slope with different magnitudes. 2m to 6m subsidence has been observed at the top of the active slide boundary and 2m to 3m all along the boundary. The subsidence has increased from 0.5m to 1.0m in various parts of the slide in just one year. Due to this there are many landslide scars developed with in the landslide body. Natural drainage system is totally disrupted and only a few rills and gullies are formed due to runoff and subsidence. Seepage points are observed at a number of locations in the slide area. The outflow quantity of the seepage water was of the order of 2-5 lit./min. in the month of May.

GEOTECHNICAL INVESTIGATIONS

Geotechnical investigation includes advancing of bore holes at selected locations for knowing the subsurface stratification, water label, installation of instruments like peizometers and inclinometer casings. The selection of suitable locations for drilling bore holes was done based on the relief features and geological details. All the locations were selected in the central middle and lower part of the slide as seen from Fig.1. Six bore holes were advanced to a depth varying from 6 to 23m using volderill drilling machine. The bottom of each bore hole ends with the hard strata. Three locations for installation of Digitilt inclinometer were marked but the casings could be installed only in two locations. The third location was left because of the inaccessibility to carry drilling machine. Representative undisturbed and disturbed soil samples were collected. Soil properties were determined. Inclinometers were installed at two locations, one at the toe of the slope and another at the middle portion. The bore hole locations are shown in Fig.1. Geological profiles on basis of bore hole data is drawn and given in Fig.2.

Rock

In this region, rock types are high grade metamorphic schists and gneisses. Competent rocks exposed on the right and the left flank of the slide are not weathered while fractured at top. In the middle part rocks are covered with debris material. Four sets of joints are recognised in the area (Table 1). The main foliation plane along the dip of which the slide movement has been anticipated dips at 36° due North direction with the strike N334°. Orientation of the four sets of joints and the slope face are plotted on a stereonet. The Stereographic projection diagram shows that a wedge is formed by the intersection of two joint planes J1 and J4 with slope face. The plunge of the inter-section of J1 and J4 is less than the dip of the slope face, measured in the line of intersection (Fig.2). Hence the plunge of the line of

inter-section of two joint planes is in the direction of sliding (Hoek and Bray, 1982).

Soil

Soil of the area is silty sand admixed with fragments of rock and considerable amount of mica content which plays an additive role to make the soil more susceptible to slide

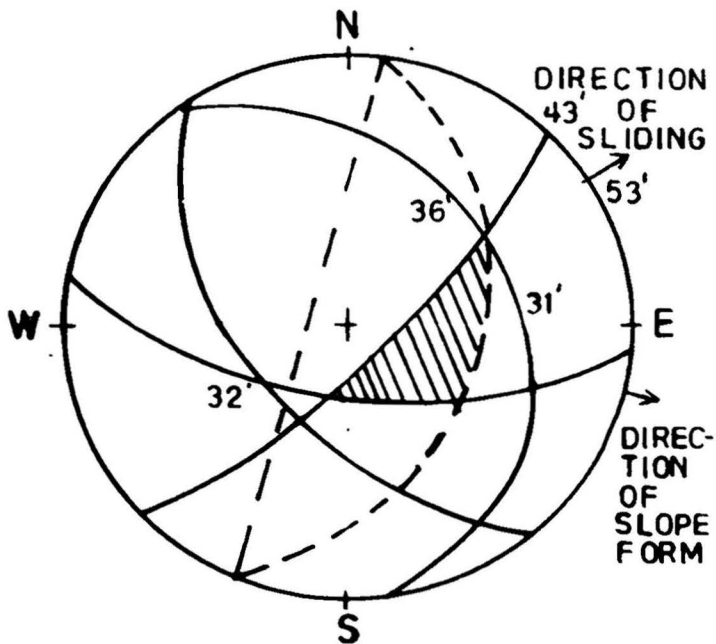


Fig.2. Stereographic Projection of Joint Planes and Slope Showing the directions of sliding

down the slope upon saturation. Index tests such as liquid limit, plastic limit, grain size distribution and engineering properties such as shear strength and coefficient of permeability were determined. Shear parameters were determined from direct shear test and coefficient of permeability was determined from variable head permeability test following relevant IS codes of practice. All the soil samples are in general non-plastic with sand content varying from 48-60%. Liquid limit values range from 20 to 33 percent. Shear parameters determined from direct shear tests have friction angle varying from 30° to 47° and cohesion varying from 0 to 50 Kpa. All shear tests and permeability tests were conducted at a dry density of 1.6 gm/cc and water content close to 18 percent.

INSTRUMENTATION OF THE SLIDE AREA

Three type of instruments such as Peizometers, Inclinerometers and Pedestals were installed in the slide area. The pedestals were used for monitoring the surface movement of slope material while subsurface movement studies with the help of inclinometers indicate the magnitude, direction and the rate of movement of slope.

Surface Movement

Instruments involving wooden pegs, theodolite, plane table, clinometer compass and steel etc. were used for the surface movement study. To facilitate measurements of relative displacements between two points, the wooden pegs were installed in the potential slide zone. Initial positions of wooden pegs were plotted on the contour map with the help of Theodolite and Plane table survey. The position of lateral shift of the pedestals determined by theodolite and for change in the direction of shift of the pedestals inclinometer was used. The difference between current reading and the initial reading was considered as the extent of the surficial movement. It was noticed that the pedestals moved laterally from 0.05m to 0.60m and vertical movement noted was from 0.10m to 0.40m (CRR I report, 1995)

Subsurface Movement

Before selecting the location for installation of inclinometer casings on the slope an idea of potential sliding zone or anticipated sliding surface was required so that the inclinometer results could represent the actual position of sliding (P.J.Rao et.al., 1995) The anticipated sliding surface was therefore marked before installing the inclinometer casings. The surface was marked on the basis of borehole details as indicated from the profile shown in Fig.3, surface morphology and topography, dip and strike of the rock beds and their discontinuities. The bore hole on upper end was drilled upto 15m depth, till the bed rock while the lower bore hole was drilled up to the depth of 12m.

Subsurface Monitoring by Inclinometer

Inclinometer enables quantitative measurement of lateral movement of slope as well as direction of movement and rate of lateral movement. The inclinometer has four essential parts such as Sensor, digital indicator, casings and electrical cable. The sensor contains two servo-accelerometers mounted with sensitive axis 90° apart. The sensor is supported laterally in the casings by means of guiding wheels and is suspended vertically by means of interconnected cable. The wheels are guided by four longitudinal grooves spaced equally around the inner circumference of the casing to control the directional orientation of the measurements. The length of the aluminium casing is 3m and they are attached one by one as per requirement of desired length. Prior to insertion of the sensor into the casing, the initial direction of the casing grooves are marked as A and B (CRR I report 1995). The sensor is lowered down in to the boreholes with both of its wheels are travelling securely in opposite grooves. The connected display device also record the reading in A and B directions. The readings are recorded at the interval of 0.5m. After removing the sensor from casing, in A

direction sensor is rotated at the angle of 90° and readings are recorded in B direction.

Data obtained from both the locations were analysed and processed. The lateral displacement, rate of movement, magnitude and direction of movement were separately calculated as follows:

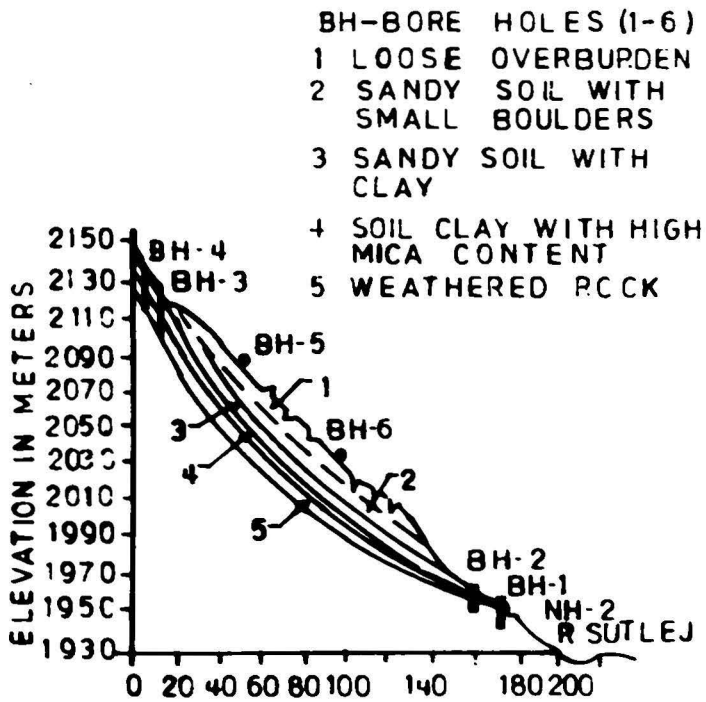


Fig.3. Anticipated Sliding Surface and Borhole Locations of Inclinometers in the Slide Area

Analysis and Interpretation of Data

The recording of data were repeated with the sensor rotation of 180° in order to cancel minimum error caused by casing irregularities and instrument drift and to verify the reading at each depth were recorded accurately.

- Readings were taken at depth intervals of 0.5m in each location
- The digital indicator displays the reading in terms of $2.5 \sin \theta$ with four decimal digits and reduces the time in recording session.
- The validity of data were checked in the field by adding the opposite reading at each depth.
- The reading was converted to lateral displacement (Lateral deviation) using the formula $L \sin \theta$ with 0.5 interval.
- The displacement of the casing was calculated from change in inclination readings. Readings from each set was compared to readings from initial set (current reading - Initial reading = change)
- The change was converted to lateral displacement by using the formula $L \sin \theta$, θ is the change in inclination.

Cumulative deflection in respect of the depth for both the locations was determined as indicated in Fig.4. The graph shows two distinct breaks one at 0.5m and another at 5.3m. The first break reflects surface deflection while the second break indicate the subsurface movement. In all ten sets of readings recorded from 02.06.93 to 02.10.94 the trend and the place of deflection was noticed unchanged.

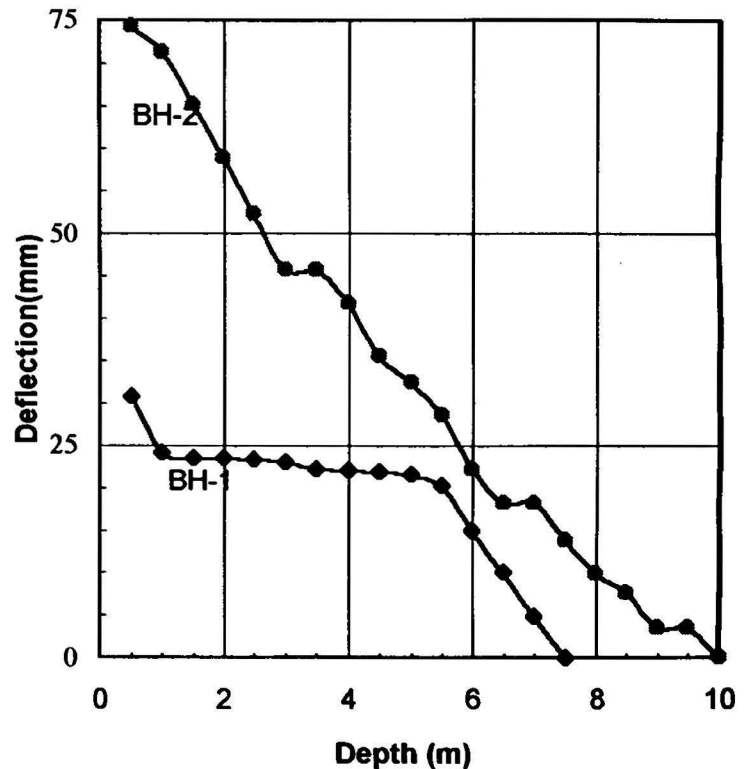


Fig.4. Figure showing Depth Vs Displacement of boreholes 4 and 5

Direction, Rate and Magnitude of Movement

The inclinometer casing at BH-4 and NH-5 were installed with a groove orientation in the general downhill slope direction as 2E and 19E respectively. After 480 days of monitoring the inclinometer, it was found that orientation of grooves of aluminium casing has not changed from its initial direction of North-Eastern, incremental rate of movement is determined for both the locations and the results are shown in the Fig.4. Figure indicates that the rate of movement is more in snow melting season and rainy season than in the other time of year (Fig 5 and 6). After 480 days of monitoring the magnitude of slope movement was found in the order of 30mm and 74mm in uphill and downhill slope respectively.

STABILITY ANALYSIS

The slope profile which was identified as potential failure surface from bore log details, stereographic projection of joint planes, surface movement and subsurface movement

studies considered for global stability analysis. The analysis shows that the likely movement is in North-Eastern direction. From the data available from bore logs, three distinct soil layers have been identified in the section of the slide area. The top layer is essentially a loose overburden followed by a sandy soil layer with small boulders. Second layer is sandy layer and third layer consists of sandy soil with clay and mica content. All the soil layers rest on weathered rock formation. The details of soil properties considered for different layers and details of analysis are presented in Table-2 (CRRRI 1995).

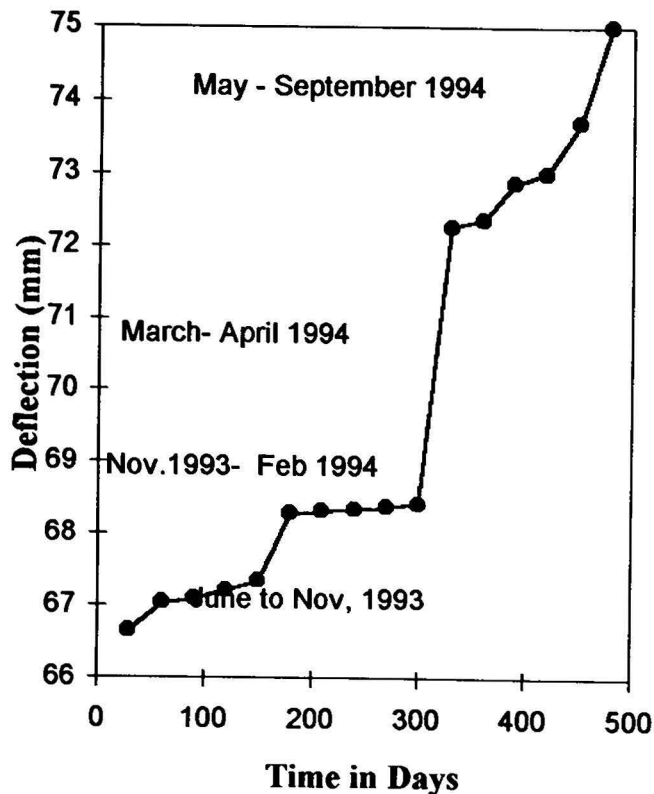


Fig. 5 Time vs Deflection curve for borehole 4.

Table 2. Details of Soil Parameters and Analysis

Layer number	Cohesion kN/m ²	Angle of friction	Density t/m ³
1	0.0	39°	1.700
2	10.0	35°	1.800
3	50.0	38°	2.000

Bishop's modified method of slope stability analysis is used in the analysis (Bishop 1975). Local stability analysis of slopes at road intersections along National Highway and

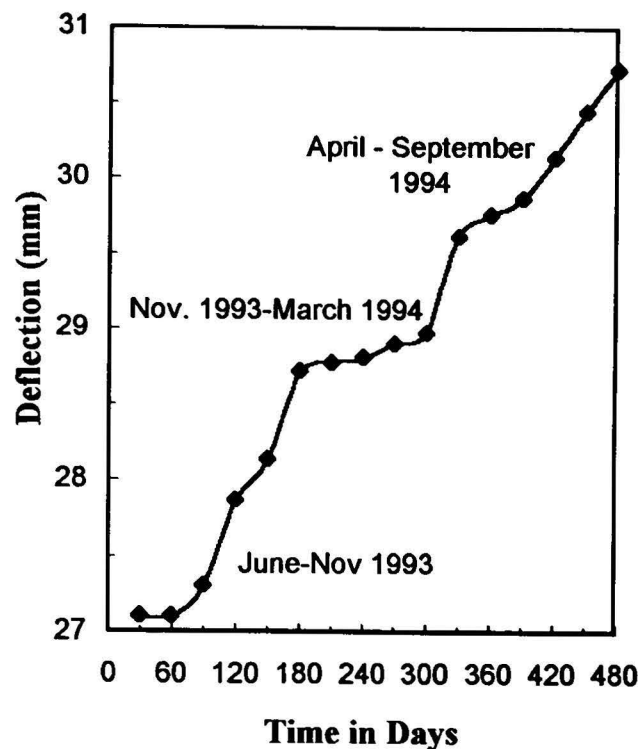


Fig. 6. Time vs deflection curve for borehole 5

State PWD link road was also performed. The factors of safety estimated assuming negligible cohesion and 39° and a bulk density of 1.7 t/m³ indicate that slopes in the slide area in general are unstable and prone to failure particularly upon saturation. Global stability analysis also indicates the possibility of failure under saturated conditions when the above shear parameters are adopted. The potential failure surface cuts across heterogeneous matrix of rockmass, fragmented rock and other material which could invariably impart cohesion and it may be possible that stable condition of slope may likely exist at global level. However, all along the State Highway and National Highway, where the slip circles pass through debris material which has negligible cohesion, it is likely that shallow slips occur. (It is evident from the observation that no. of small and shallow slips occur during and after snow melting and rainy season.

REMEDIAL MEASURES

On the basis of the above studies, innovative and cost effective remedial measures were suggested. A few of them are listed below:

- Drum Diaphragm Retaining Wall - A cost effective empty bitumen drum retaining wall filled with the local debris material (Bhandari 1987)
- Improvement of drainage system as per CRRRI report 1995

- Wire crate retaining structures only along the link road
- Sealing of tension cracks as per CRRI report 1995.
- Laying of coir-nettings for erosion control and vegetation growth. The analysis and detailed drawings of the above remedial measures are mentioned in CRRI State-of-the-art report on Landslide Correction 1995.

CONCLUDING REMARKS

The instrumented monitoring of slope, geological investigations and stability analysis have clearly indicated the possibilities of shallow sliding in snow melting and rainy season of the year. Essentially, water being an important inducing factor should not be allowed to flow into the slide area from its adjoining parts. Therefore, more emphasis is required to be given to the provision of adequate drainage in the slides area.

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