16 Landslide Monitoring: A Case Study of the km 19 Landslide along the Kathmandu-Trishuli Road, Central Nepal

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A landslide at Okharpauwa on the Kathmandu-Trishuli Road was taken as a case study by the Water Induced Disaster Prevention Technical Centre (DPTC) in collaboration with the Department of Roads to study investigation methods and landslide countermeasures. This is one of the first studies from Nepal that has attempted to understand the mechanisms involved in an individual landslide. The main purpose of this exercise was to recommend appropriate countermeasures.

Background

The case study landslide has been observed by the Water Induced Disaster Prevention Technical Centre (DPTC) since July 1993. It is situated at Okharpauwa village in Nuwakot district, 19 km from Kathmandu, along the Kathmandu-Trishuli Road (Figure 16.1). It lies directly adjacent to the main road. The average altitude of the landslide area is 1665m. The study was designed to identify and propose appropriate countermeasures against the landslide to protect the road. It also aimed to acquire data on the nature and movement of the landslide to prepare guidelines for the investigation and prevention of landslides using appropriate low cost methods.

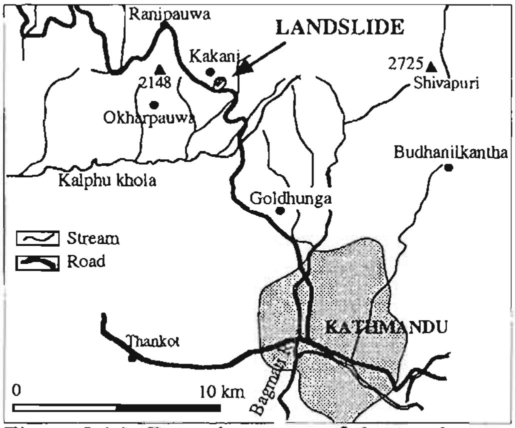

Figure 16.1: Location map of the study area

According to local residents, this landslide was triggered for the first time in 1942 after a long period of intensive rainfall. The landslide was reactivated in 1979 and again by an earthquake in 1989.

The landslide has damaged a section more than 100m long of the Kathmandu-Trishuli road. This road is a 3.5m wide degraded blacktopped road, constructed in 1950 as an access road to the Trishuli Hydropower Project. It is the main link road to the tourist areas of Kakani and the Langtang National Park. This landslide often hinders the smooth flow of traffic, especially during the monsoon season. It affects more than 1.5 ha of land above the road. The landslide area above the road is barren whilst the area below the road is covered by a sparse forest of *Alnus* trees and bushes. Perennial streams bound the landslide on both sides. Gradually more land and hence more people are being threatened as the landslide extends uphill. The landslide directly influences twenty households.

Many tension cracks are apparent on the landslide surface and their number and extent is increasing. Many springs have also developed within the landslide zone. The presence of leaning trees and electric poles indicates the ongoing movement of the landslide. Prominent landslide scars are visible near the crown and sides. The underlying cause of the landslide is the geology of the slope, whilst it is the strong monsoon rains that trigger it. The influence of the heavy rains is exacerbated by a number of man-made factors including

- seepage of water from farmland and streams into the landslide area, particularly from unlined irrigation canals;
- quarrying of stone at the downstream side of the road at the toe of the landslide;
- choked roadside drains; and
- leakage of a water supply pipeline in the landslide area.

Aerial photos of the area together with geological studies suggest that a fault passes along the landslide area. The landslide is on a colluvial mass resting on a steep slope. Soil samples from boreholes indicate that the sliding mass of the landslide developed in colluvial soil. This soil is a heterogeneous mixture of fine materials and gneissic boulders of various sizes. The extent of displacement of the landslide is gradually increasing and the road level has dropped considerably. At the points where the landslide crosses the road, the drainage channels, retaining walls and road pavement have been almost completely destroyed.

The study shows that this landslide, which has a circular failure surface, is presently active within the ancient debris zone in the slope. Though the first occurrence of the landslide is thought to have been mainly due to geological and meteorological factors, the 1979 reactivation was due to disturbance of the stabilised mass by heavy rainfall and the 1989 event was due to disturbance by an earthquake. Monitoring shows that the rate of movement is increasing. Thus immediate application of countermeasures is vital, otherwise further development of the landslide upslope is inevitable. There is a two metre diameter sinkhole above the topmost crown which has developed as a result of piping seepage. The average slope of the upper zone is about 12^0, whereas the average gradient of the landslide area is 27^0. A number of springs that have developed above the landslide area have increased the amount of water in the landslide zone.

Investigations and Monitoring

In 1992 a 1:500 scale topographic map with 1m contour intervals was prepared for the landslide area (Figure 16.2). Streams, surface cracks, existing infrastructure, and other permanent objects were marked on this map. A cross section of the landslide is shown in Figure 16.3.

Geological survey

As there were no exposed rock outcrops in the landslide area, a 30m deep hole was drilled adjacent to the road to observe the geology of the sliding surface. The core samples gave a good indication of the sub-surface conditions of the landslide. Layers of clay 2.75 and 1m thick were recorded at depths of 3 and 17m. This indicated that the maximum depth of the sliding surface below road level at the boring point is 17m. A soft bedrock of gneiss was encountered 22.05m below the surface, and fresh hard bedrock of gneiss at 23m (Figure 16.4). Experiences from other landslides show that the cohesive strength of clay at landslide slip surfaces is about 1.7 t/m^2. The study was limited to a single drill hole. Other investigations such as geophysical explorations were not conducted.

Monitoring

The landslide was monitored using a range of equipment. The technical aspects are described in detail in the appendix to this paper.

Rain gauge – A manual rain gauge was installed in the area above the road in May 1993. Daily rainfall records have been recorded continuously since then.

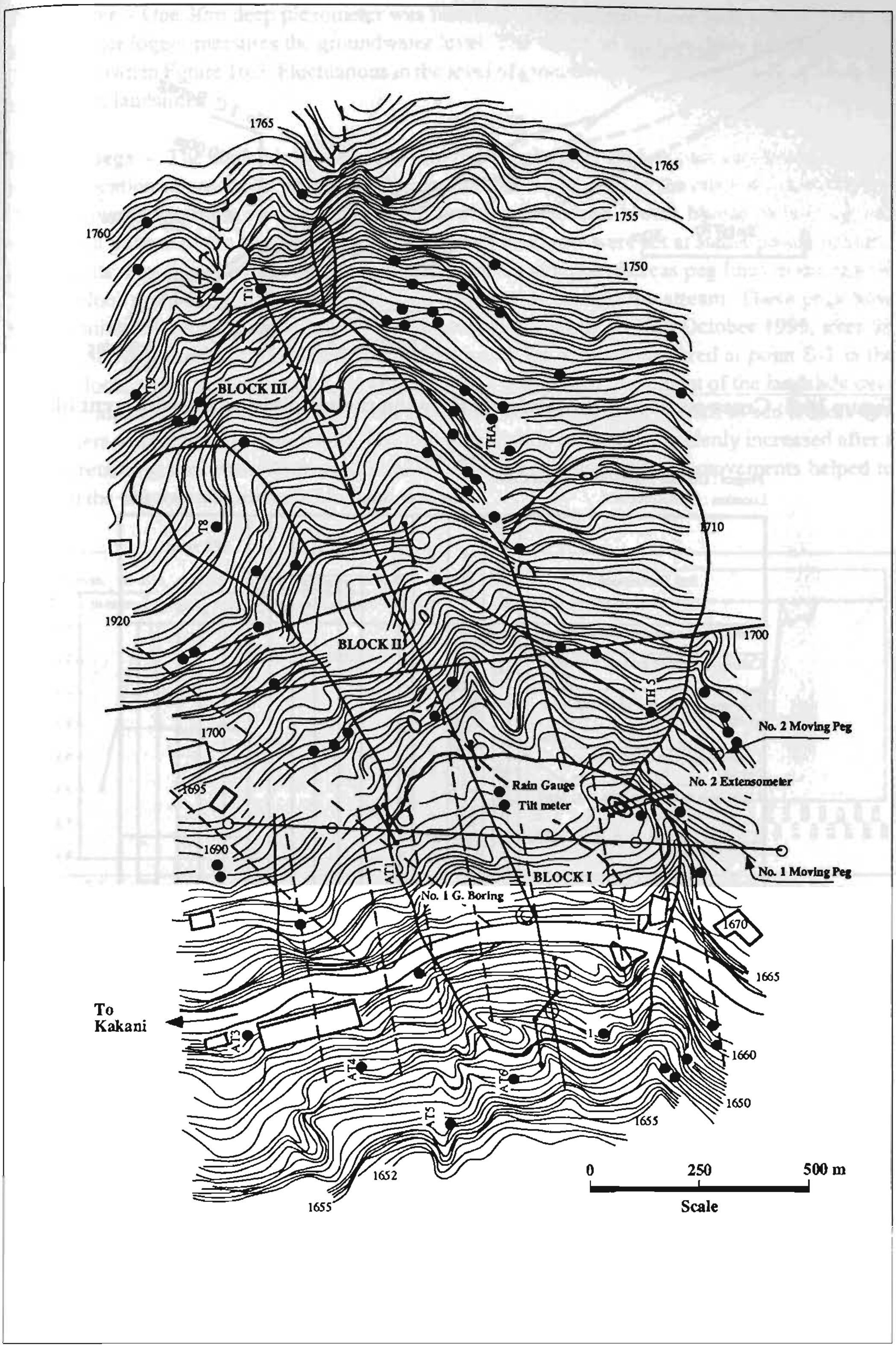

Figure 16.2: Topographic map of the landslide area and location of monitoring equipment

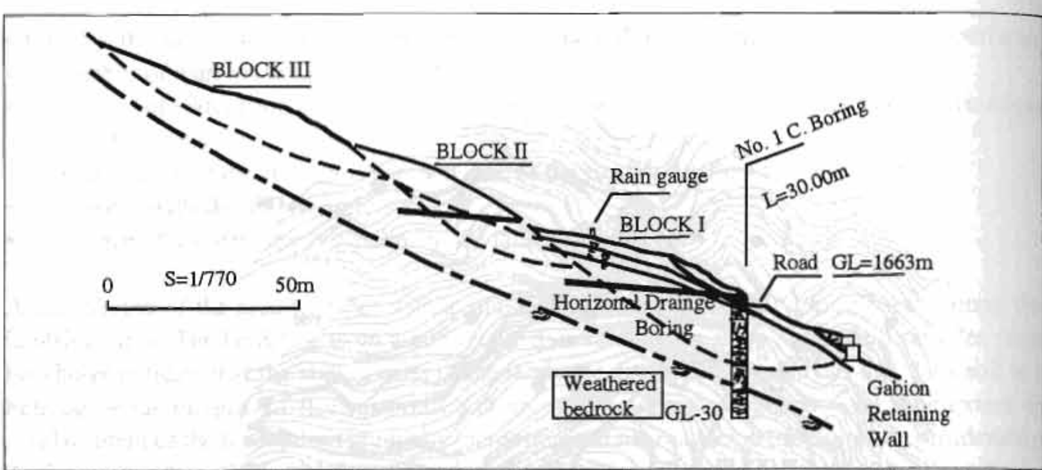

Figure 16.3: Cross-section of the landslide showing the subdivision into different blocks

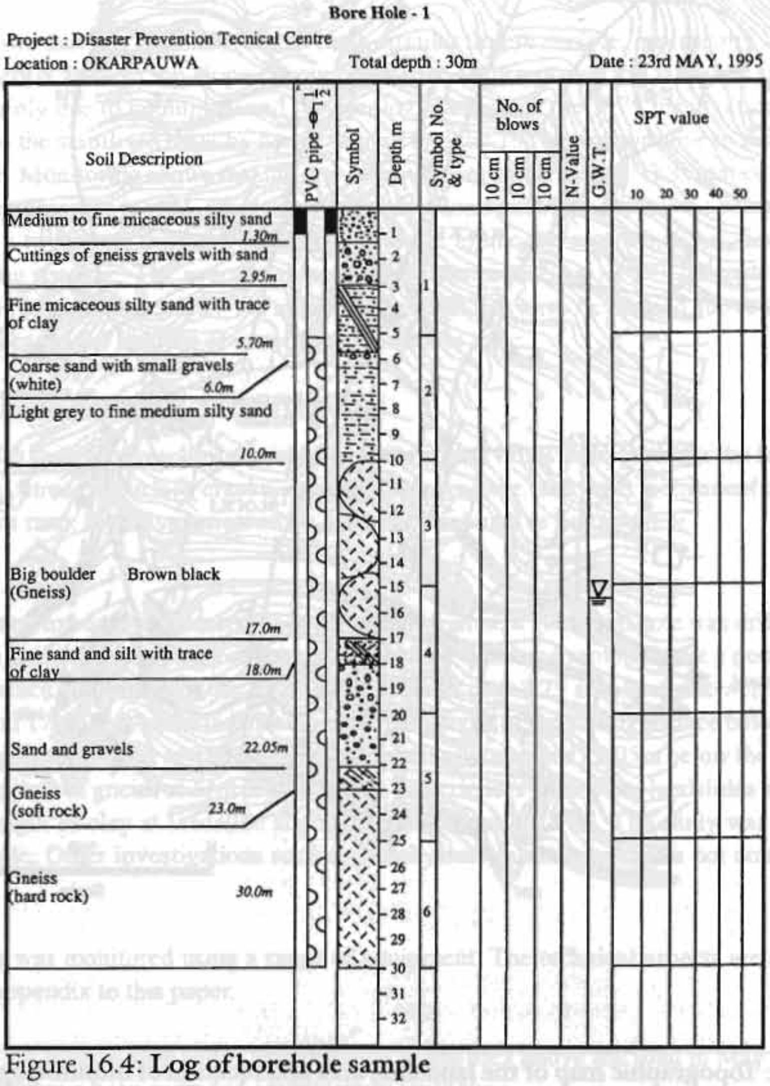

Figure 16.4: Log of borehole sample

Piezometer – One 30m deep piezometer was installed in the roadside bore hole in May 1993. A groundwater logger measures the groundwater level. The variation between May and September, 1995 is shown in Figure 16.5. Fluctuations in the level of groundwater are useful to help analyse the stability of landslides.

Moving pegs — The landslide was divided into five blocks after studying the topographical map and the location of cracks on the surface, three of these can be seen in the cross-section (Figures 2, 3). Rows of pegs were positioned on the lowest and second-lowest blocks to indicate the movement pattern of the landslide. The end points of each row were set at stable points as reference points. Peg lines in the lower-most blocks were set straight whereas peg lines in the second lowest block were set at an oblique direction downwards beyond the stream. These pegs have been monitored regularly since July 1993. Measurements taken on 30th October 1995, after 28 months, showed that the maximum displacement was 5.7m and had occurred at point B-2 in the lowest block, with a settlement of 2.7m (Figure 16.6). The rate of movement of the landslide over time was also calculated (Figure 16.7) and compared with cumulative rainfall to see if these two parameters were related (Figure 16.8). The rate of landslide movement suddenly increased after a gabion retaining wall was constructed in May 1994. The pattern of these movements helped to confirm the existence of separate blocks.

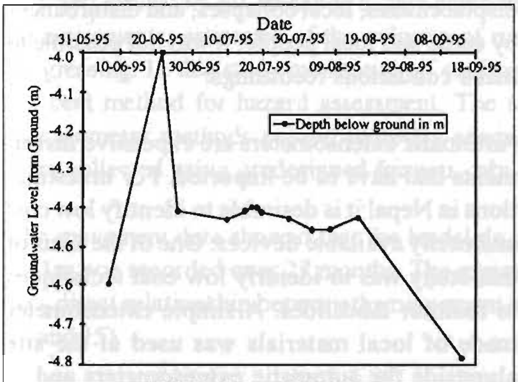

Figure 16.5: **Variation of groundwater level in the landslide area as shown by piezometer readings**

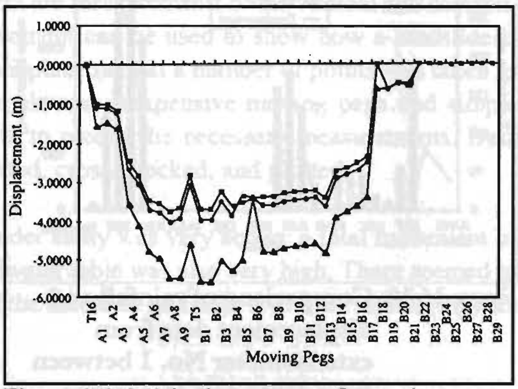

Figure 16.6: **Displacement of pegs in a northerly direction in the lowermost block after 28 months**

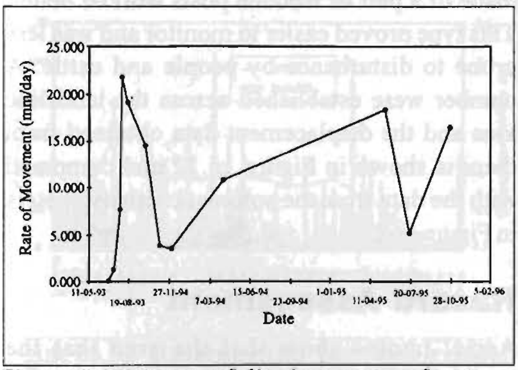

Figure 16.7: **Rate of displacement of pegs over time**

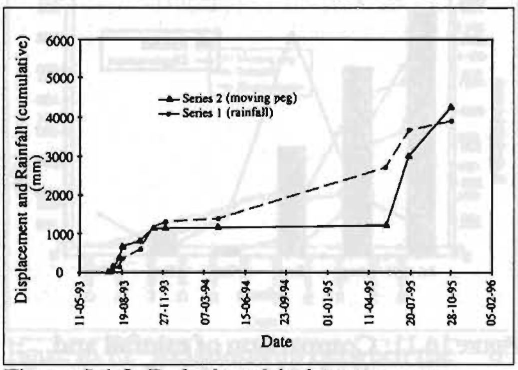

Figure 16.8: **Relationship between peg displacement and cumulative rainfall data**

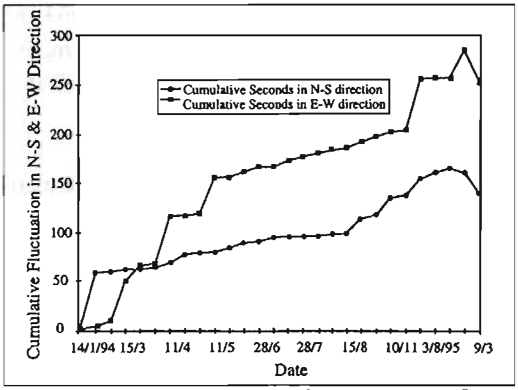

Figure 16.9: **Cumulative fluctuation of ground (in N-S and E-W directions) measured by tiltmeters over time**

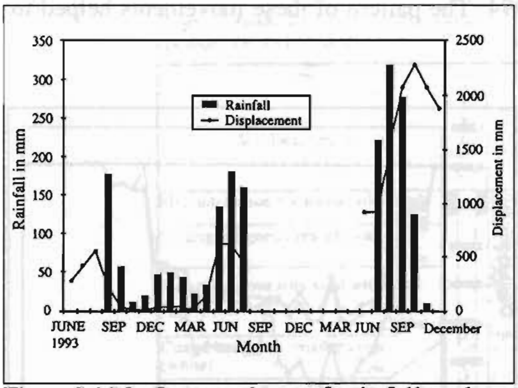

Figure 16.10: **Comparison of rainfall and displacement data from extensometer No. 1 between June 1993 and December 1995**

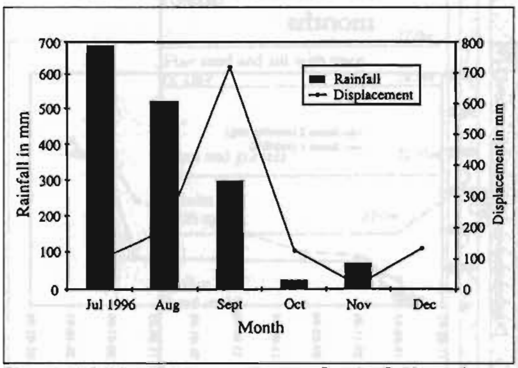

Figure 16.11: **Comparison of rainfall and displacement data from extensometer No.2 between July and December 1996**

Tiltmeter – A tiltmeter observation platform was constructed in June 1993 to study the ground fluctuation over time. Since then the ground fluctuation has been measured at regular intervals in north-south and east-west directions. The results are shown in Figure 16.9. The ground fluctuation in an E-W direction was more than that in a N-S direction.

Extensometers – Two types of extensometers were located to check the surface displacement of the landslide at specific points. One automatic extensometer was positioned in the western part of the lowermost moving peg line in September 1993 and another in the lowest landslide block in the easternmost part. Measurements were recorded regularly. The correlation between rainfall and displacement is shown in Figures 16.10 and 16.11. As a result of the occurrence of large displacements, local collapses, and disturbances by cattle and local people, it was not possible to make continuous recordings.

Automatic extensometers are expensive instruments that have to be imported. For investigations in Nepal it is desirable to identify low cost and easily available devices. One of the aims of this study was to identify low cost techniques to monitor landslides. A simple extensometer made of local materials was used at the site alongside the automatic extensometers and in other areas to monitor crack and block movements. The initial design using wooden posts and planks did not work well. A second design made of a pair of wooden posts worked better. This type proved easier to monitor and was less prone to disturbance by people and cattle. A number were established across the landslide area and the displacement data obtained from them is shown in Figure 16.12 and compared with the data from the automatic extensometers in Figure 16.13.

Hazard Assessment

Aerial photos show that the area that the Kathmandu-Trishuli Road passes through has a moderate distribution of landslides. A comparison of 1978 aerial photographs with ones taken

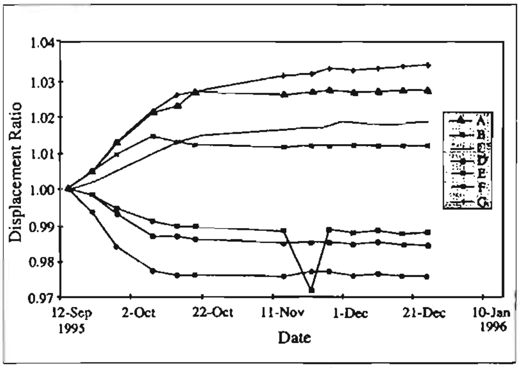

Figure 16.12: **Displacement data obtained by the simple extensometers**

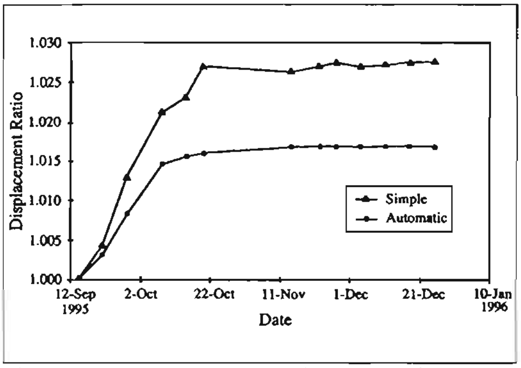

Figure 16.13: **Comparison between the displacements shown by simple and automatic extensometers**

in 1993 showed that a considerable number of landslides had happened in this period along the Kathmandu-Trishuli road.

The best indicators for landslide hazard assessment are measurements of the vertical and horizontal movements; estimates of the velocity of movement can be used to show how a landslide is progressing. In this study monitoring of surface displacement at a number of points was taken as the best method for hazard assessment. The simple and inexpensive moving pegs and simple extensometer methods proved perfectly adequate to record the necessary measurements. Data were collected using predesigned formats, tabulated, cross-checked, and plotted.

The movement data showed that the landslide under study was very active; a total movement of 5.61m was recorded over 27 months. The groundwater table was also very high. There seemed to be a direct relationship between the movement of the landslide and high levels of rainfall (Figures 14 and 15).

In the past nothing had been done to stabilise the landslide except for the construction of one retaining wall. This wall however had not been built at the proper location and had failed to contain

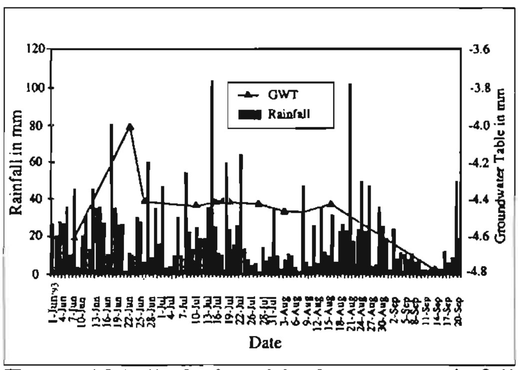

Figure 16.14: **Relationship between rainfall and the groundwater table**

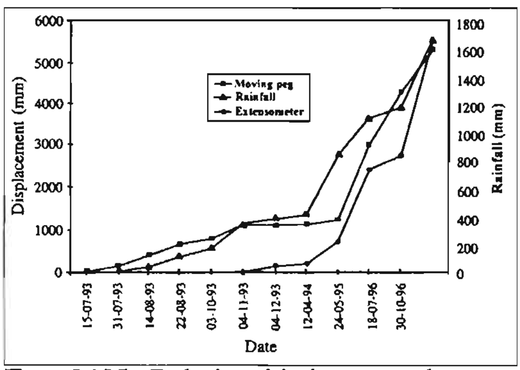

Figure 16.15: **Relationship between the displacement shown by pegs and extensometers and rainfall (cumulative)**

the landslide. Where a landslide is affecting a road, the cost of stabilisation should be compared with the cost of re-routing the road. In this case, although the landslide was very active, it was impractical to re-route the road because of the steep topography. Thus it was essential to stabilise the landslide

Proposed Stabilisation Measures

As mentioned above, the landslide was found to be very active during the investigation and monitoring period. The geological setting of the area is prone to landslides. However, the high groundwater level in the sliding mass and the weight of the sliding mass itself were considered to be the main causes of this particular landslide. The following stabilisation measures were recommended by the investigating team to control the landslide.

Protective measures

The movement data showed that the lowermost block was moving significantly downhill, thus control of this block was the first priority. The priority protective measure was to control water leaking from water supply pipes, irrigation channels, and the landslide surface itself by constructing surface drainage and diverting the stream that ran down the landslide area to outside. Non-structural measures such as planting appropriate species were also recommended. As the toe of the lowermost block was severely disturbed, the possibility of a landslide below the lowermost toe could not be ruled out. However, measures to counteract this were not so urgent

Planning long-term countermeasures

A road can be protected by either preventive or restraining work. Preventive works, which include surface drainage works and shallow sub-surface drainage works, aim to control landslide movement by ameliorating the natural condition. Restraining works such as retaining walls aim to control the landslide by decreasing its movement.

The landslide mass consisted of five major blocks of which the lowermost block was the most unstable and directly threatened the road. As it was the lowermost block that was unstable, it appeared to be crucial to prevent the other blocks from sliding and affecting it. Past experience shows that for a road the safety factor should be at least 1.1 to 1.2.

The protective measures suggested were a combination of drainage works and retaining walls. Groundwater should be drawn away from the landslide area by installing bored horizontal drainage. Improved surface drainage should control the percolation of surface water and divert it to outside the landslide area.

Stability analysis was done to find the safety factor of the lowermost block. As the landslide is very active, the factor of safety was taken to be 0.95. The value of the cohesive strength of the landslide clay was taken to be $1.7 t/m^2$ and the value for the bulk density of the soil $1.8 t/m^3$. Using these values, the estimated value for the angle of internal friction of the soil at the slip zone was 21.2^0. This value was taken as the basis for estimating the effects of various countermeasures proposed for stabilising the landslide in terms of the change in the estimated Factor of Safety. The results are shown in Tables 16.1 and 16.2.

The analysis showed that if the groundwater level in the landslide area could be reduced as expected as a result of the proposed drainage works, the stability of block I would be improved by 17% and that of Block I + Block II by 12%. If a retaining wall could be built at the toe of the

Table 16.1: **Factor of safety for various conditions of the landslide (Block 1)**		
Condition of landslide	Factor of safety	Remarks
Without any countermeasures, when the groundwater level is maximum and the ratio of the resisting force to the overturning force a minimum	0.950	angle of friction 21.2° from back analysis
With surface drainage and horizontal drainage works	1.108	1.0~2.0m reduction in the water level is assumed
With retaining wall with embankment at the toe of the landslide	1.145	
With combination of drainage works and retaining wall with embankment	1.303	

Table 16.2: **Factor of safety for various conditions of the landslide (block I + block II)**		
Condition of landslide	Factor of safety	Remarks
Without any countermeasures, when the groundwater level is maximum and the ratio of the resisting force to the overturning force a minimum	0.980	angle of friction 21.2° from back analysis
With surface drainage and horizontal drainage work	1.098	1.0~2.0m reduction in the water level is assumed
With retaining wall with embankment at the toe of the landslide	1.113	
With combination of surface drainage, horizontal drainage and retaining wall	1.234	

landslide, the stability of block I would be improved by 21% and that of Block I + Block II by 14%. If the combination of retaining wall and drainage works could be built to control the landslide, the stability of block I would be improved by 37% and that of Block I + Block II by 26%. Considering the importance of the road and the construction cost for the countermeasures, the results of the analysis seemed to show that the construction measures would be justified.

The proposed countermeasures are described in detail below and their location shown in Figure 16.16.

Gabion retaining/toe wall with embankment – The location of the toe of the lowermost landslide block was identified by core drilling and regular monitoring with a simple extensometer. The team proposed that a gabion retaining wall be built at the toe to contain landslide movement. A small portion above the toe of the landslide would need filling with soil to form an embankment to act as a counterweight against the landslide. The embankment should be planted with trees and shrubs.

Surface Drainage – Surface drainage should be installed to divert water from the springs, and seeping and leaking water away from the landslide area to reduce groundwater levels. Two types of surface drainage, one along the stream and the other along the landslide area were recommended.

Roadside-drain cum irrigation-channel – Water seeping through from the unlined roadside drain had contributed to movement of the landslide. This roadside drain should be lined.

Horizontal drainage boring – To control the groundwater level, the team proposed that a horizontal drain be bored at two places. This was expected to reduce the water table by about 3m.

Extensive **bioengineering works** were also proposed.

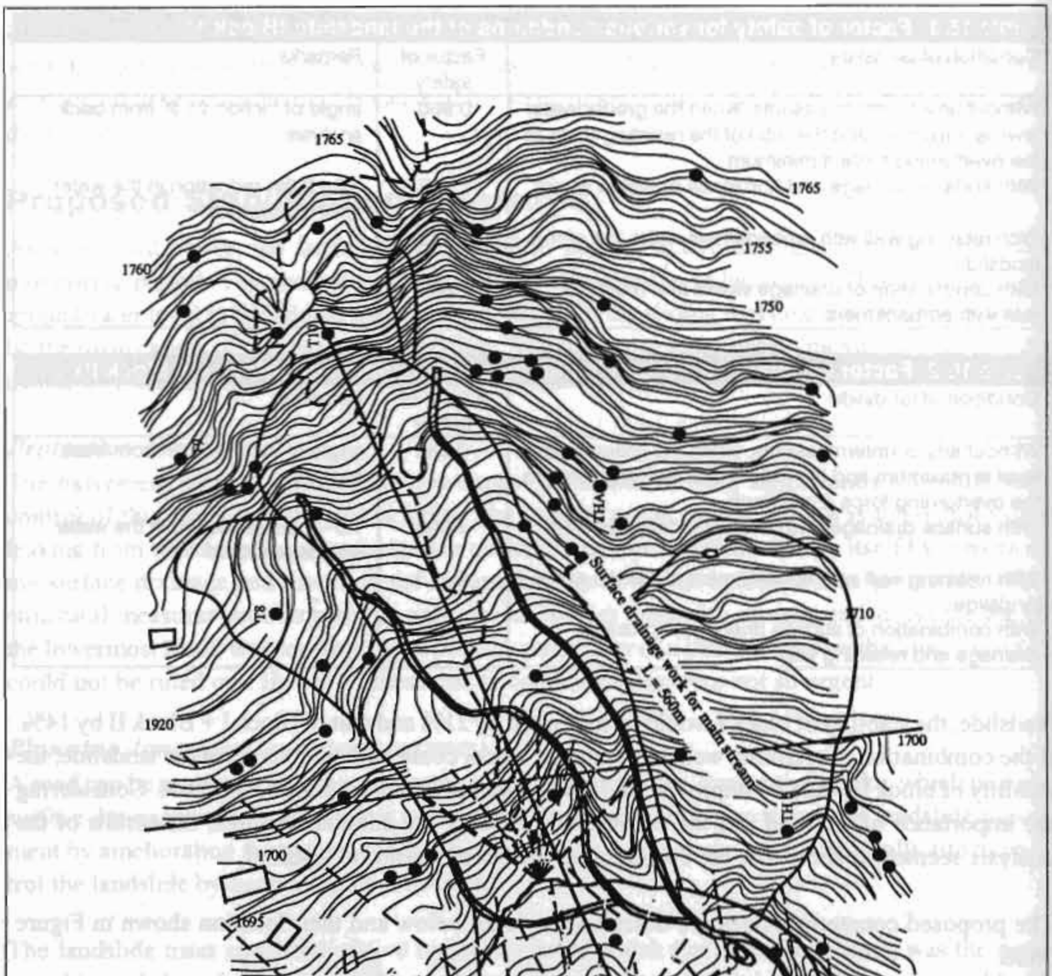

Figure 16.16: Map showing location of countermeasures proposed to stabilise the landslide

The size and priority of the proposed construction works are shown in Table 16.3.

Table 16.3: Proposed construction work		
Type of prevention work	Size	Priority
Gabion retaining/toe wall	43 m	First
Loading embankment	4000 m³	First
Surface drainage along stream	560 m	First
Surface drainage along landslide area	150 m	First
Road side drain cum irrigation structure	150 m	First
Horizontal drainage boring works	560 m	Second
Bio-engineering works	1.5 ha	Second

Impact of Countermeasures

All the countermeasures proposed by the DPTC were carried out by the Department of Roads, His Majesty Government of Nepal in the fiscal year 1996/97 (pre-monsoon). Subsequent monitoring data obtained from both simple and automatic extensometers indicated that there was no significant movement of the landslide mass during the 1997 monsoon period. This suggests that the landslide had been stabilised by the countermeasures.

Conclusion

Detailed investigations and hazard assessments are planning tools for the implementation of countermeasures to safeguard a road against destruction by an active landslide. In the case considered here, any delay in installing the countermeasures would have accelerated the development of further landslide blocks and increased the costs of stabilisation.

Moving peg and simple extensometers proved to be effective low cost methods for measuring landslides; the displacement data recorded using simple and automatic extensometers showed similar trends. Moving peg displacement, automatic extensometer displacement, and recorded data of rainfall show that There was a direct relationship between the movement of the landslide and the amount of accumulated rainfall (and consequent rise in groundwater level), as shown by displacement and rainfall measurements. A stability analysis of Block I and a combination of Block I and Block II for the conditions before and after completion of the proposed countermeasures, indicated that the countermeasures would increase the Factor of Safety to 1.303 and 1.234 from 0.95 and 0.98, respectively. These values were considered acceptable, given the budget constraints and the limitations of the investigation.

It is recommended that in future landslide investigations be carried out prior to road construction in Nepal's hills so that necessary stabilisation countermeasures can be planned and constructed at the same time a road is built, and the costs included in the road construction costs.

Appendix: Details of Monitoring Equipment

Moving pegs

'Moving pegs' are square wooden posts with a marker nail in the top embedded in concrete (Figure 16.A1) in a predetermined pattern in an area of potential movement. The outside pegs are fixed in stable ground. The initial coordinate of each peg is surveyed and calculated in terms of distance and the horizontal angle. In this case study, the pegs were located in rows, one row in each of the two unstable blocks.

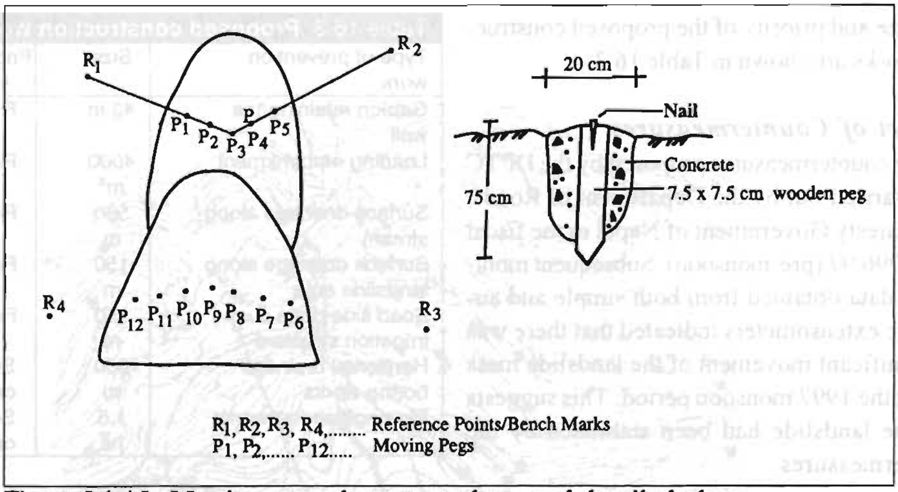

Figure 16.A1: Moving pegs: layout on slope and detailed plan

Automatic extensometers

An extensometer is a device for measuring the relative displacement between points on a landslide and a point on stable land. This method is used widely to analyse the speed of sliding masses. Normally a number of extensometers with self-recording systems are installed between the main scarps. They record the motion continuously and these values are used to calculate strain rates. This instrumentation is one way of warning of an impending slide event.

Extensometers are made up of an invar wire, mechanical gears, and a clock driven by a spring (Figure 16.A2). A self-plotting small drum is attached, which rotates as the invar wire stretches. The instrument is relatively simple and a continuous record can be kept. Movements of more than 0.2 mm are recorded together with the time of movement (to within 2.4 hours, or the nearest 1/10th of a day). The instrument is usually set 1m above the ground surface and the invar wire is connected from the pulley of the extensometer to another post. The span between the posts is normally less than 5m. The invar wire and its supports should be protected by vinyl chloride pipe. Rainfall data are often collected in parallel so that the affect of rainfall on surface displacement can be assessed.

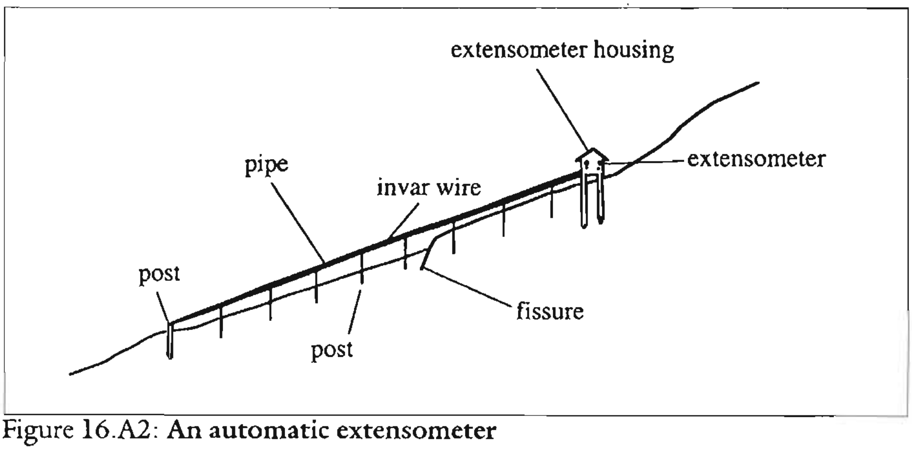

Figure 16.A2: An automatic extensometer

Automatic extensometers are widely used in developed countries (Japan, for example) but are difficult to protect in the field.

Simple extensometers

Type A

The type A simple extensometer is made of wooden planks and posts (Figure 16.A3). The basic principle is the same as that of the automatic extensometer. The wooden plank held between fixed posts has a flexible joint. Once the instrument is set up a line is marked at the joint position of the plank. The date of measurement is written on the plank. The difference between new and previous marks indicates the displacement of the landslide block.

Although not as accurate as an automatic extensometer, this instrument gives an idea of landslide movement in relation to time.

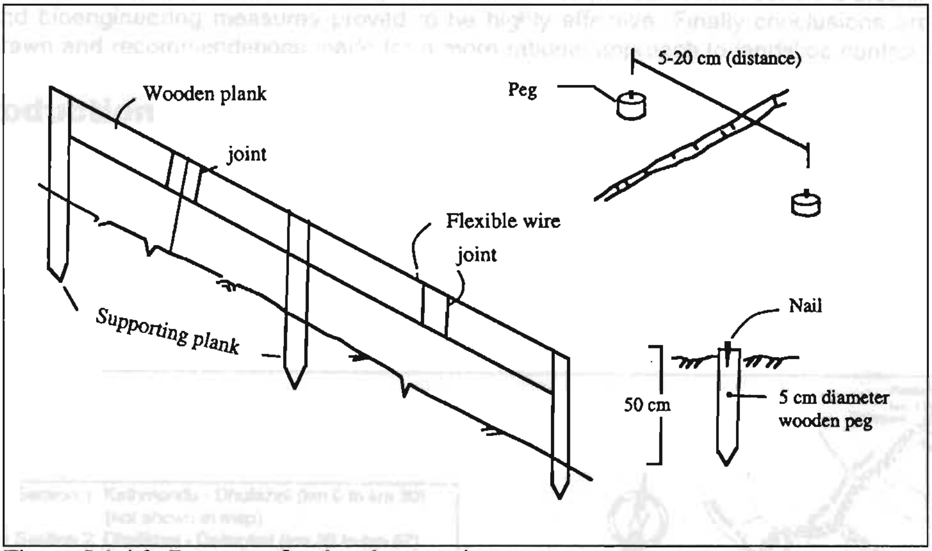

Figure 16.A3: Layout of a simple type A extensometer

Type B

This type of extensometer is simpler, cheaper, and more easily maintained than type A. A set of wooden pegs is set up in the unstable part of the slope to measure the extension of the ground. The length of each set is measured weekly and any increase or decrease recorded.

Tiltmeters

Tiltmeters are used to indicate small ground fluctuations. Their main purpose is to judge whether a potential landslide is stable or whether it is moving into a more active or final stage. One common type is a bubble tiltmeter. The basic layout is shown in Figure 16.A4.

Tiltmeters should be installed on the upper slope of a potentially sliding block along the line of extension of the principal measuring line to examine the possibility of landslide enlargement. A tiltmeter may also be installed on the sliding block itself or one slope of the block.

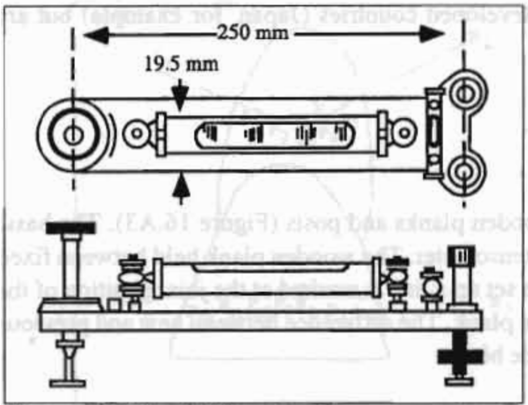

Figure 16.A4: **A tiltmeter for measuring ground displacement**

Tiltmeter data are used to produce a diagram of tilt variation and the accumulation of tilt over time. This data can be compared with rainfall and groundwater levels to see if there is any correlation.

Groundwater surveys

Groundwater levels can be measured manually. Self-recording float or water pressure type recorders are also available. Perforated PVC pipe wound with geonet is installed inside a borehole and the level of the groundwater is recorded using a manual or automatic water logger (a piezometer).