Geological Investigation of the Landslide Hazard Prone Hill Slope in Mizoram

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Abstract

The landslide activity in Mizoram, especially during the monsoon, not only creates frequent disturbances to the traffic on the National Highway NH-54, but also causes damage to buildings, bridges, culverts, road, wide spread cultivated and non-cultivated slope surfaces etc. Since 1996 a portion of the National Highway at km. 209.00 has been facing continuous problem of sinking, creep and sliding. In the year 2003 about 150m stretch of the highway was severely damaged by landslide and sinking. It not only created problems to the moving vehicles but also enhanced risk and further instability of the hill slope in that area.

Hence a detailed geological and geotechnical landslide investigation was carried out by scientists of CRRI, so as to understand the exact causes and mechanism of slope failures. The major role of geological properties to create landslide hazard in this area has been highlighted in this paper. Based on detailed analyses of both field and laboratory data, the best remedial measures suitable to the existing geo-environmental condition were recommended to restore hill slope stability.

Introduction

Major portion of the state of Mizoram is mostly composed of alternate layers of very weak rock formation like slate, shale and sandstone. Severe influence of past tectonic activities on the rock formation is evidenced by complex type of structural geological features in the rock. Almost everywhere shattered and fragile nature of rock has developed due to the intersections of various weak planes of discontinuities. Such type rock formation is highly unsafe from slope stability point of view. Failures of such shattered rock slopes are highly unpredictable. It has been observed that even after the implementation of remedial measures repeated incidents of slope failures continues to occur unless proper investigation is carried out. Special emphasis on geological investigation should always be given for such problematic landslide areas so as to find out the exact cause and failure mechanism and also to suggest the most suitable remedial measures to the existing geo-environmental condition to restore stability of the hill slope.

On the National Highway-54 at km.209.00 at Lunglei in Mizoram a problematic landslide creates frequent hindrance to the moving traffic every year especially during the monsoon. Since 1996 even after the implementation of remedial measures in this landslide affected area the incident of slope failure to cause disturbances in traffic movement has not come into control. Here recurring incidents of slope failures have already affected about 350m long stretch of the national highway. In the year 2003 especially during the monsoon, the incidents of sinking and hill slope failures caused a complete halt of the traffic movements along this stretch of the National Highway for few days. Here some shops situated at the roadside got completely destroyed by the landslide activity. A portion of this highway started continuously sinking and proper stability could not be achieved even after laying twenty five truck loads of boulder in a

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particular sinking zone. Implementation of different types of remedial measures also could not give a satisfactory result for restoring stability of this sinking and slide prone stretch of the hill slope. A thorough detailed investigation of this problematic landslide was therefore carried out by a team of scientists of CRRI to suggest the best suitable remedial measures to restore stability of the hill slope for maintaining a smooth traffic movement on this national highway. The landslide and its surrounding areas were surveyed and landslide map was prepared up to the scale for further study. Various types of landslides related features, boundaries of slope areas which tend to slide and also the failed slopes etc. which are not actually visible from the road level were all marked on the map for further landslide studies. Special stresses on geological properties were given to understand the exact function of the rock properties to cause failure. Geotechnical studies were also performed to find out the mode of stability of the overall hill slope materials under worst possible natural condition. Several field data and samples were collected from different locations to conduct the study.

Discription of the slide area

Starting from km. 209.00 on the National Highway NH-54 near Lunglei in Mizoram, about 350m long stretch of highway and the adjoining downhill slope area were severely affected either by creep, sinking, debris slide or rockslide etc. The hill slope here comprises of reddish to buff, pale yellowish and greyish thinly bedded soft slate and shale which are steeply dipping inside the slope. The rocks are closely spaced jointed, folded and highly shattered in nature. The uphill slope area is comparatively harder and competent from stability point of view than the downhill slope region which was evidenced by the cut slope face vertically standing to a height of about 10 to 15m adjacent to the National Highway without any support of retaining wall as seen in Fig1. Slightly above this vertical cut face the ridge of the slope is visible without any sign of damage. Beyond this ridge the entire uphill slope dips downwards and away from the highway towards the uphill direction to meet a nalla flowing from the higher reaches of Lunglei side. This flowing nalla passes underneath a bridge which connects the PWD road with the National Highway before reaching this portion of the uphill slope as seen in the plan. At the junction point of the PWD road and the National Highway, this uphill slope surface becomes almost flat and merged with the road level; thereafter it becomes steeper and rocky in nature once again towards the other extreme end of the highway ie; the Lunglei side at chainage km209.350. Just before this rocky portion many houses on the downhill slope got completely destroyed by this landslide but they were reconstructed. Similarly rockslide also damaged two houses on the uphill slope area at the extreme right end of this stretch of the highway. Major portion of the downhill slope region is mostly composed of dominating soft red thick soil present in a loose state and intermingled with some highly shattered rock blocks. The slope is covered with dense vegetation. Besides soil erosion, creeping of the entire debris materials are evidenced by the tilting of trees at different locations on the downhill slope area. In future saturation and erosion may definitely cause a gigantic landslide in this area if proper remedial measures are not implemented immediately. During the heavy monsoon in the year 2003 the entire stretch of the highway from km209 at Aizawl side to km209.350 towards the Lunglei side was severely damaged by landslide activity. About 150 m. stretch of the highway was affected by sinking as well as sliding. The boundary of this sinking cum sliding zone starts at a distance of about 29m. from the extreme one end ie; starting from the Aizawl side of the National Highway. At chainage km 209.100, a big pothole marked as 'A' was developed at the shoulder portion of the highway adjoining the vertical cut slope face as seen in Fig.1. A large extent of this shoulder portion surrounding the pothole has already sunk. Enormous amount of rainwater from the uphill region flows along this sunken shoulder portion of the road and passes very rapidly deeper into the downhill slope area through the pothole due to the lack of road side drain. Especially during the monsoon continuous entrance of voluminous amount of rain water through this pothole created excess pore water pressure within the downhill slope materials and consequently hill slope failures occurred in this area. In the peak monsoon period during emergency about twenty five truck loads of boulders were laid down as a temporary remedial measure in this sunken zone and the pothole area to maintain a steady traffic movement on this highway. Permanent remedial measures are still now needed here to completely remove the problem of sinking and sliding. After thorough investigation it was observed that most of the slope failures occurred at the downhill region and consequently sinking with minor sliding occurred towards the higher reaches at three different locations at distances 14m 37m and 46m respectively from one end of the stretch of the highway ie; towards the Aizawl side at km209.00. It is observed that besides erosion and creep the downhill slope area is also vulnerable to slide but it is not actually visible from the road level due to the good growth of vegetation in this area. Sometimes the scattered tension cracks are also present in a semicircular pattern. Due to the untreated condition of the tension cracks multiple small scale failure of slope materials accumulated in a curvilinear fashion nearby the focal point of these tension cracks. Similarly step like features were also developed due to small scale failure of the slope materials along aseries of tension cracks at different levels. Long time impact of erosion and slope failure along the untreated tension cracks have created number of small gullies and a few major erosion channels also on the downhill slope region. The influence of creep or mass movement activity is clearly visible by the tilted nature of trees in this area. At the extreme lower level towards the right flank of the downhill slope area, the impact of erosion and scouring action at the basal portion of the partly constructed chute caused complete damage of the entire chute. The slumped slope surface with lot of tension cracks facing the nalla may create further landslide disaster in future. The width of the nalla is gradually decreasing here due to large scale mass movements of the hill slopes present on both sides of the nalla. The mass movement activity is clearly evidenced by both tilted bamboo trees on the slope surface at one side of the nalla as well as the slumped, bluged and fissured debris slope on the other side of the nalla as seen in photo Fig.1. On the left flank towards the downhill side the lower portion of the slope covered with teak plantation has already failed and deep erosion channel is also developing which may initiate a large-scale slope failure of the entire teak plantation in future if it remains untreated. This area needs immediate treatment. At further lower level towards the downhill portion the earlier implemented remedial measures like wire crated gabions and drum retaining structures etc. got completely damaged due to lack of proper yearly maintenance. The damaged slope is facing a great risk of instability. Immediate treatment of this area is required to restore stability otherwise its failure will further aggravate the landslide related problem towards the upper reaches of the hill slope. At the extreme downhill toe region a vast flat stable grassy land is present with the support of a very stable old undisturbed toe wall which is directly facing the flowing nalla as seen in Fig.1. This flat surface is quite stable whereas the remaining hill slope slightly above this area is comparatively unstable and needs urgent treatments. Multidirectional nature of mass movement activities of the downhill slope region are evidenced by tilted trees, fan shaped nature of both convex accumulated and concave failed debris slope surfaces, collapse of widely scattered irregular tension cracks and development of step like uneven surfaces etc. Gulley formation due to the long

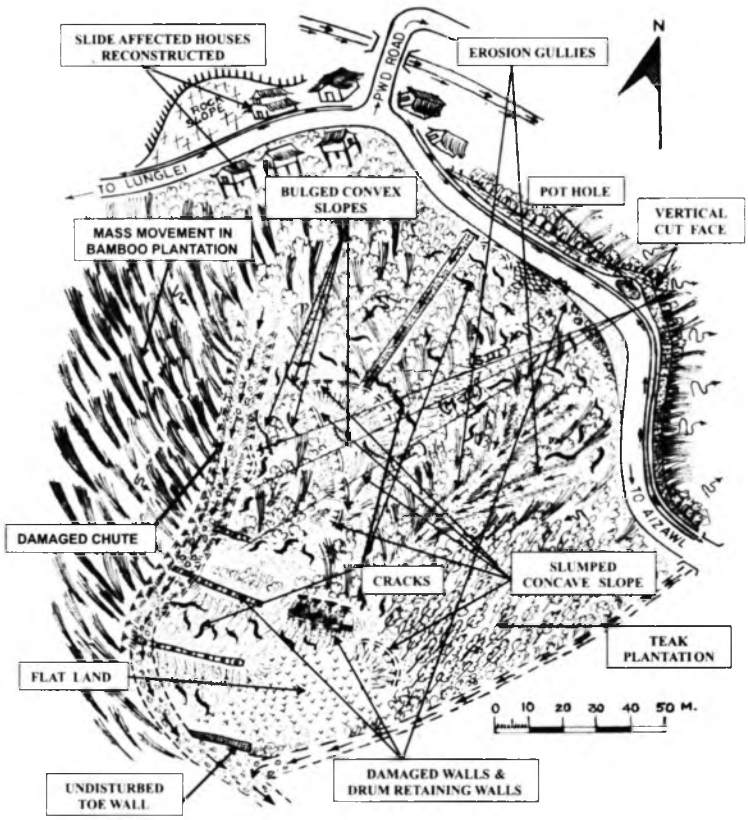

Fig. 1

time impact of erosion is enhancing further instability of the vast downhill slope area.

Analyses and mechanism of slope failure

The landslide affected area and the surrounding hill slopes were thoroughly investigated from both geological, and geotechnical aspects to understand the exact causes and mechanism of failure. Several field data were collected from disturbed, stable and failure prone vulnerable locations. The rock formation of the entire hilly terrain surrounding this landslide was severely affected by past tectonic activities which are evidenced by different types of structural geological features. Highly weathered and shattered soft slate is the main dominating rock type in this area. The finer component is mainly composed of silt and less clay. Appreciable amount of clay is also present at some locations. Data pertaining to different structural geological features like folds, type and trend of different joint planes, shear planes, slope angles and their directions etc. were all collected for the purpose of detailed geological studies. In the field both chevron and recumbent types of folds were observed. Probably influence of two generations of folding actually has made the rock highly shattered and fragile in nature. Intersection of various planes of discontinuities has caused highly shattered nature of the rock formation. Different structural geological data were plotted along with the (f) value of the finer matrix of the debris materials on the stereonet diagram as seen in Fig.2 with a view to study the formation of different type of rock blocks by the intersection of different planes of discontinuities and their nature of behavior on the hill slope in worst environmental condition. From the stereonet diagram it is observed that a number of thinly bedded and closely spaced jointed rock blocks are formed due to the intersection of various planes of discontinuities and they are prone to slide or creep in wedge fashion. The direction and type of movement of these rock blocks are actually controlled by the existing geological properties of the rock formation and are also marked in the stereonet diagram. In this area small scale wedge type of failures are occurring in a scattered manner towards the south west direction. Due to the influence of past tectonic activities the rock blocks have become highly shattered and fragile in nature. Rapid fragmentation of these rock blocks are therefore taking place when they start sliding along with the overlying surficial slope materials. These brittle rock blocks generally slide like fan shaped spread up debris. Very clear picture of rock block sliding in a wedge fashion is not visible in this area. The slide debris therefore more or less looks like planner type of debris failure. Generally shallow types of failures are occurring in this area. For carrying out detailed geotechnical investigations of the landslide affected area, both disturbed and undisturbed soil samples were collected from different locations. Five pits were made to collect undisturbed soil samples to know specially the field moisture content in addition to other geotechnical properties. Grain Size analyses, liquid limit, plastic limit, plasticity index, direct shear test etc. were all carried out for characterization of the hill slope material and also to get typical parameters for determining the factor of safety and mechanism of hill slope failure. Typical laboratory data of the representative samples are shown in Table 1. The test results in the laboratory shows that the slope material contains appreciable amount of clay about 12 to 31% and it has Plasticity Index around 20. In general the soil from the slide area can be classified as CI i.e. the clay with intermediate plasticity. Samples for different laboratory tests were prepared as per IS: 2720. The grain size curves of different samples shows fines up to 75%. The samples were remoulded at maximum dry density and optimum moisture content to get

Table 1: Engineering Properties of Slope Material

Site	Grain size analysis				Atter-berg Limits		Sp. Gr.	Natural moisture Content	Standard Procter Test		Direct Shear Test	
	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	PI		(%)	Max. Dry Density (g/cc)	Opt. moisture Con. (%)	Cohesion (C) kg/cm2	Angle of Internal Friction
Pit1	1	24	45	31	45	18	2.69	21	1.6	21	0.35	30
Pit2	6	22	50	22	45	17	2.69	13				
Pit3	26	37	25	12	43	16	2.69	16				
Pit4	16	27	41	16	41	15	2.68	21				
Pit5	10	19	49	22	45	17	2.67	15				
oose soil on lope	1	22	57	19	48	18	2.69	16				
iray Soil	26	24	36	15	34	12	2.67	9				

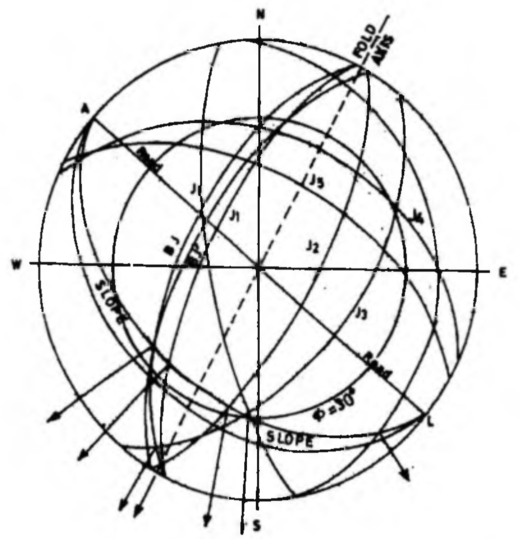

Fig.2. Stereodiagram of Different Planes of Discontinuities

the shear strength parameters as per IS: 2720. The tests were conducted by direct shear apparatus at slow speed to simulate it with drained conditions. The Mohr's envelop for typical soil sample indicates a cohesion (c) of 35 kPa and the angle of internal friction (ϕ) of the order of 30°. Different properties of soils viz; the cohesion, friction and density were determined for the Stability analysis. The analyses have been carried out for different slopes with different combinations of overburden materials. Two different types of debris materials such as the upper debris material in slightly loose state and the underlying lower debris materials with more consolidated and little denser in nature were considered for the stability analyses. Whole mass was considered to be in maximum saturated condition with the water table touching nearly the top surface. Such type of saturation level was purposely considered for analytical purpose to achieve the worst possible environmental condition which may occur during the heavy monsoon especially in the month of August. Different properties of soil / rock have been used for the stability analysis as shown in Table 2. Varying depth conditions for both loose and underlying more consolidated debris materials were considered for predicting the ultimate result of factor of safety contributed due to the interactions and peculiar type of behavior of the accumulated non-uniform debris materials on the landslide affected hill slope. The densities of 19 kN/m^3 and 22 kN/m^3 have been considered for the entire surface material and the lower strata of the hill slope respectively. On the overall it was observed that the softer finer matrix of the debris was mostly silty in nature. At some places appreciable amount of clay were also seen whose intermediate Plasticity Index of around 20, Cohesion (c) of 35 kPa and the angle of internal friction (ϕ) of the order of 30° were also determined by the laboratory test. Stability analyses were carried out using GEO 4 software for three different types of slope profiles such as steep, moderate and gentle slopes marked as III-S, M-III, III cross section lines respectively as seen in Fig.1. The slopes were considered to be composed of homogeneous soft soils only for the purpose of geotechnical analyses. Although in reality the entire area was composed of debris of

Table 2: Properties of Soil /Rock used for Stability Analysis

S.No.	Description of Property	Value
	Properties of Surface Strata	
1	Density of soil	16 kN
2	Cohesion (C)	35 kPa
3	Angle of Internal Friction (ϕ)	30 Degree
4	Density of Rock	19 kN/m^3
	Properties of Lower Strata	
1	Density of Rock	19 KN/m^3
2	Cohesion (C)	50 kPa
3	Angle of Internal Friction (ϕ)	40 Degree

soft rock fragments and soil yet a single uniform homogeneous mass of soil slope was considered to represent the high risk condition for the stability analyses. Because of high rainfall area the stability analyses were performed under worst condition by considering maximum saturation of the soft soil slope. The safety factor values obtained by stability analyses along three different slope profiles are observed to be quite high and greater than 1 For achieving the best realistic result about the factor of safety of this landslide affected area, the structural geological properties of the rock formations were considered during the prediction of failure mechanism in addition to the engineering properties of the debris materials. From both field and laboratory studies it is predicted that possibility of deep seated circular type failure is almost negligible in this area whereas shallow type of failure will frequently occur because of the unfavorable geological properties of the rock formation. Hence it will definitely be possible to restore stability of the hill slope in this area.

Remedial measures

After detailed investigation, different types of remedial measures were suggested to stabilize the landslide affected area as seen the plan in Fig.3. It was also suggested that the implemented remedial measures which

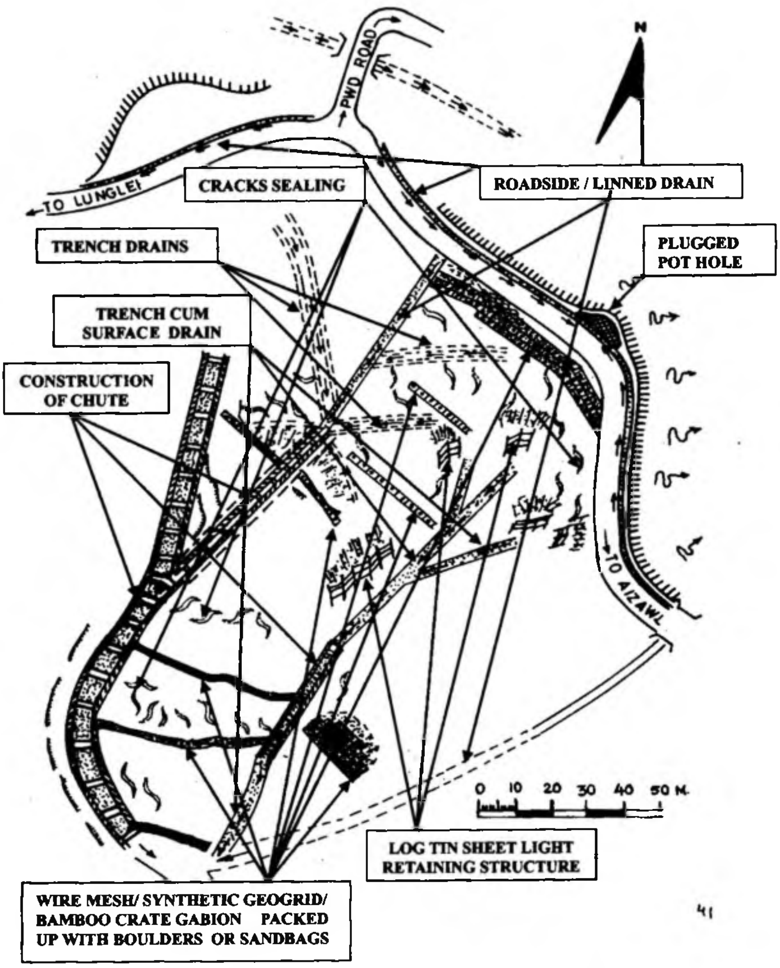

Fig. 3. Plan of the landslide area with remedial measures

were partly or completely destroyed should be repaired immediately. At several locations loose debris materials prone to erosion must be compacted. Plugging of the existing big pothole on the shoulder portion of the road, sealing of tension cracks, construction of road side drains, culverts, surface drain, feeder drains, step like chute etc. were suggested for different locations. Both heavy and light retaining structures like masonry walls, wire crate walls, drum retaining structures, bamboo crate walls, perforated tin sheet and log retaining structures, etc. were also suggested for different suitable locations. Similarly bamboo piling and benching, lime columns installation and erosion control by vegetative turfing using jute/coir geogrid mantle were also suggested and are shown in the plan in Fig.4.

Conclusions

It is concluded from the study that both sinking and landslide activities are highly dependent on the geological properties of the rock formation in this area. The influence of past tectonic activity has made the rock jointed, folded and shattered in nature. Some minor faults and curved shear planes are also present in the rock. From the stereonet diagram it is observed that highly shattered rock blocks of different dimensions are formed here due to the intersection of various planes of discontinuities which are prone to creep or slide like wedge type of failure. During the monsoon ingress of huge amount of rain water deeper into the hill slope through these weak planes of discontinuities increases the pore water pressure within the hill slope materials and consequently reduces the strength of the shattered rock blocks which in turn enhance them to either creep or slide. The softer materials lying over the rock formation also start creeping with the development of different types of features like tension cracks, sinking zones, potholes and tilting of the trees etc. on the slope surface. Due to lack of treatment of these vulnerable slope surfaces landslide probabilities keep on increasing with time. Afterwards all of a sudden slope failures occur in different locations erratically and create tremendous problem to the moving traffic in this area. Wedge type of failure is comparatively less visible due to highly shattered nature of the rock formation. Absence of back tilted slided slope surface, presence of long erosion gulley and development of rugged terrain due to collapse of multidirectional scattered tension cracks etc. are indicating mostly non circular shallow failure of hill slope materials. From detailed study of the landslide and its surrounding areas it is observed that very deep seated circular type of failure is not occurring in this area but the entire area is facing a great threat of landslide hazard due to the lack of suitable engineering remedial measures which are required to be implemented immediately. Proper yearly maintenance will also be required for retaining stability of the hill slope in this area. As the slope failures are shallow in nature it is therefore not very difficult to control the landslide activity in this area.

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