Geophysical Investigation and Management Plan of a Shallow Landslide along the NH-44 in Atharamura Hill, Tripura, India

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Abstract: In any effective landslide hazard mitigation plan, in-depth knowledge about the causes of instability is required. Consequently, it is essential to study geological, geotechnical, meteorological and anthropogenic factors that influence the landslide. For the present study a geophysical investigation has been carried out on a large landslide, on the slopes of Tertiary siltstones, mudstones, shales and sandstones at Atharamura Hill, Tripura. Different techniques have been used, including measurement of micro-slope using Total Station, clinometers and the LISCAD software for terrain modeling and determining the total volume of the material displaced and total area affected by landslides and analysis of soil properties to understand the present condition of the scarps. Results obtained through field investigation and laboratory testing revealed that the underlying cause of the slide could be (a) the adverse geological formation with unconsolidated sandy materials and occasional intersection of silt or clay layers, (b) the hydrological condition with continuous seepage through fractures, and (c) cutting of hill slopes for reconstructing and widening of the road (NH44). This latter anthropogenic influence has been triggered by an intense precipitation event during the monsoon season.

Keywords: landslide, instability, hazard, geophysical investigation, human interference

1 Introduction

In India, about 10% of total population was affected by natural disaster in 2008; among this 0.5% of the population were affected by landslides only. According to the Geological Survey of India (GSI 2009), 0.49 million km^2 or 15% of land area of this country is vulnerable to landslide hazard. Of the areas vulnerable to landslide hazard, 0.098 million km^2 are located in the North-East region.

Landslides are common hazardous phenomena in hilly area of Tripura especially in North and Dhalai districts. Almost every monsoon period, when heavy downpours occur, this phenomenon takes place. The hilly terrain of Tripura is prone to landslides due to its geological instability, neo-tectonic activity (Sen et al 2015) and extreme rainfall infiltration during monsoon season (Fookes and Wilson 1966, Varnes 1978).

Moreover, rapid developmental activities, such as, construction of roads and railways through highly rugged hilly terrains, have intensified these hazardous phenomena in recent decades. The landslide incidences have reportedly increased ever since the road and other infrastructural developments have accelerated in hill areas (Ghosh et al 2012). Such infrastructural developments have significant impacts on life and property in many parts of Himalaya, especially in those areas with high population densities and land use. During intensive field survey, it is found that most of the landslides occurred along the national highway (NH-44). Blocked and damaged

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roads as a result of landslide activity are common occurrences along the national highway corridors in Atharamura and Longtarai hilly areas following moderate to heavy rainfall (where moderate rainfall is defined as 2.5 - 7.6 mm per hour and heavy rainfall is >7.6 mm per hour).

Landslides are considered important and complex hazardous phenomena world-wide. Successful mitigation of this hazard can be made only with detailed knowledge and database of particular events. Most published works on landslide hazard mapping deal with landslide susceptibility mapping (Dahal et al 2008). Detailed knowledge and databases can be generated only through thorough investigation of the landslide sites or case studies of individual landslide events. These site-specific studies of different landslides are required because of the local geological and geographic heterogeneities found within a small area. This approach to landslide study helps to highlight the types and characteristics of landslides within the study area. Moreover, this approach helps to make decisions on remedial measures for this hazard. Many similar case studies have been carried out (Dutta 1966, Paul 1973, Chatterjee 1975, Basu and Sarkar 1985, Froehlich et al 1991, Bhattacharya 1999, Basu 2000, 2001, De 2002, De et al 2008, Okendro 2006, Anbarasu et al 2010, Ayala et al 2012, Barla et al 2013). The present study is the outcome of a systematic and detailed geophysical investigation to define every detail of the landslide. The geomorphological characteristics have been studied through measurement of micro-slope (facet or smallest unit of the slope), terrain modeling of the scar, determining the total volume of the displaced material and the total area affected by landslides. The seismo-tectonic and geophysical characteristics have been studied through the analysis of earthquake events in this region, geoelectrical resistivity of rocks, lithological and structural characteristics. The rainfall patterns have been considered in order to understand the influence of rainfall on landslide events. Human modifications of the slopes have also been studied and management plans have been proposed to reduce the hazard and associated damage.

2   Location of the Landslide

A large landslide has occurred along the slopes of Tertiary Surma deposits at Atharamura Hill in Tripura, India (Figure 1) in 2005. The Surma group of rock is characterized by the presence of thinly bedded repetition of sandstone, siltstone/shale, mudstone and ferruginous sandstone and it consists Bhuban and Bokabil formation (Nandy 1972). This slide is located about 9 km west from Ambassa, the district headquarters of Dhalai District. Intrinsic geological instability and intense rainfall are the main causes of this landslide. Boarder Road Organization (BRO) has taken some remedial measures to control this landslide, but it reactivates in every rainy season. The landslide scar is surrounded by vegetation and bushes. The whole landslide scar is composed of highly fragile rocks, which allow water to percolate readily and promotes deep weathering of the rocks. Formation of a thick top soil cover of about 1 to 3 m also helps to percolate rainwater downward. The altitude of the slide varies from 95 m - 129 m asl with a convex slope ranging from 15^0 to 75^0. The height of the scar is about 34 m and dip ranges between 40^0 and 45^0 in a S-SW direction. Unconsolidated sandy materials with occasional intercalation of moderate to poorly sorted silt or clay layers, continuous seepage through the fractures and cutting of hillslopes for reconstructing and widening of the road (NH-44) have been found responsible for the occurrence of such menace which is further triggered by heavy and concentrated rainfall during monsoon periods. The area receives rainfall mainly from SW monsoon which commences in June and lasts till September. Storms and thunder showers are common during pre monsoon season. Average annual rainfall is very high (2194 mm) in the study area and 70% of total annual rainfall occurs during the monsoon season (between June and September). In general, the temperature varies from 20 ºC to 34 ºC for the most part of the year. Maximum and minimum temperature recorded during the year 2010 is 34.1 ºC (April) and 9.2 ºC (January), respectively.
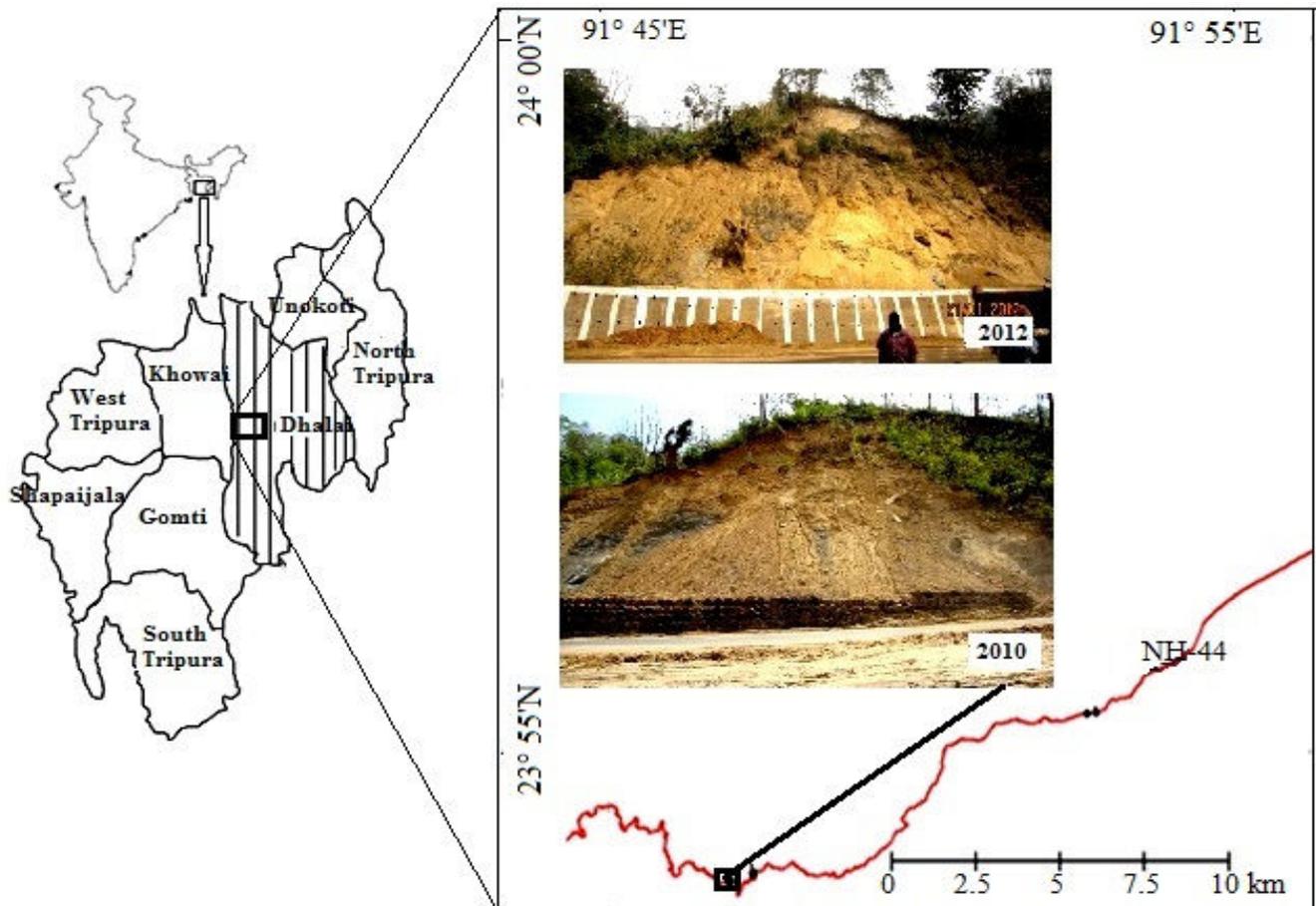
Figure 1. Location map of the Ambassa landslide

3 Methodology

The present study has been carried out by using different types of primary, as well as secondary data. The detailed field survey was conducted after a long gap following the landslide event. The field investigation was carried out from 2010 to 2013. During this time period spatio-temporal change of the landslide scar was estimated. Firstly, the location of the landslide scar was marked using GPS. In order to understand the geomorphological characteristics, the whole landslide scar was surveyed by using Total Station. Data of 84 points were recorded from the scar. These data were imported to LISCAD software and contouring at 2 m interval was carried out. In order to get the terrain condition of the scar, the Digital Terrain Modem (DTM) was prepared from these data sets. For understanding the relationship between geology and the landslide, the geological map of the study area

was based on the geological map of the Geological Survey of India (GSI) and Oil and Natural Gas Corporation (ONGC). The lineament map was prepared from IRS P6-LISS III image. The lineaments were extracted by image enhancing method and by using lineament extraction tool in PCI Geometica 10.1 software. The lineament buffer at 50 m, 150 m and 250 m were delineated and the landslide spot was superimposed. The lithological variation was also analyzed through field surveys. The seismic data of the last 20 years (1982 - 2011) were collected from the published report of disaster management plan, Govt. of Tripura (2011-12). The Geo-electrical resistivity survey has been carried out by using Soil Resistivity Meter (SRM). Geo-electrical mapping was done at two points. The instrumental reading was taken up to 5 m depth at 1 m interval. The rainfall characteristics of the study area were analyzed by using the rainfall data of Ambassa rain gauge station. The pre-

monsoon and monsoon (May - September) rainfall variation of 13 years (2001 - 2013) were studied. In order to understand the landslide-rainfall relationship, the daily and cumulative rainfall analysis of the months of May and June, 2010, was also carried out. The management plans were proposed mainly based on field investigation. For recommended slope gradient (vertical distance divided by horizontal distance), a cross section was taken across the middle of the scar and separated into six segments. Slope distance and slope angles were measured at all segments and soil samples were collected and tested in soil testing laboratory. A litho-column along the cross section was also prepared. Based on the slope length, slope angle, soil characteristics and lithological properties, the gradient of the cut slope segments was recommended. For drainage system of the landslide, the present drainage condition was studied and, based on the field survey, a new drainage system was proposed. The existing length of the retaining wall was measured and the horizontal and vertical extension was proposed.

4 Geophysical and Seismic Characteristics of the Landslide Area

4.1 Lithology and structural characteristics

The rock type in the landslide prone area is part of the Tertiary Bhuban formation (Figure 2A). That formation consists of unconsolidated sandy materials with occasional intercalation of moderate to poorly sorted silt or clay layers. The whole slope is composed of highly weathered and fragile shale and mudstone. They are relatively weak in resistance and favour the development of landslides. In some parts of the slope, coarse grained sand with mud balls (Plate 1A) was also found. The whole landslide scar is mainly composed of huge thickness of laminated siltstone, shale with narrow bands of sandstone; occasionally lenticular structure of medium to coarse sandstone with mudstone (Plate 1B). The present study area is characterized by the presence of large number of strike-slip fault. Most of the fault lines are in SW − NE direction. The altitude of the slide varies from 166 m - 191 m asl with a convex slope ranging from 15° to 75°. Dip of the rock strata ranges between 40° to 45° in SSW direction. The alignment of the bedding indicates two major directions from which deposition started, i.e., northwest to southeast, and north to southeast trends. The present landslide is located within 150 m buffer zone of fault line (Figure 2B).

4.2 Seismic events

North-eastern part of India is one of the six most active tectonic areas in the world and experiences earthquakes frequently. It is placed in zone 5, the highest seismic hazard zone in seismic hazard zonation map of India (Figure 3). It lies at the junction of Himalayan arc to the north and
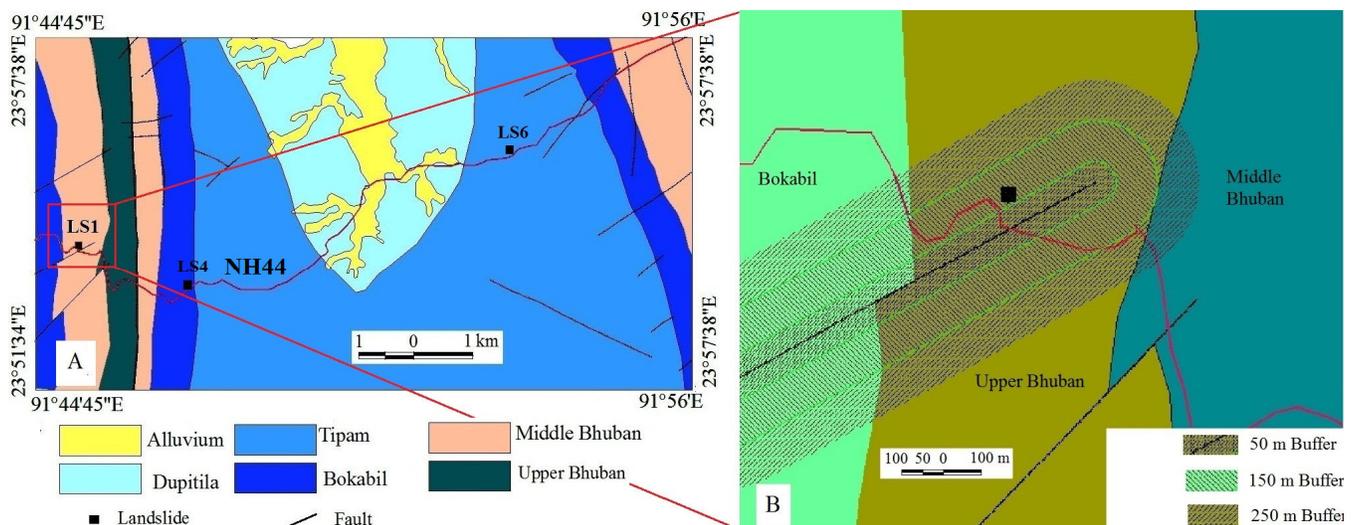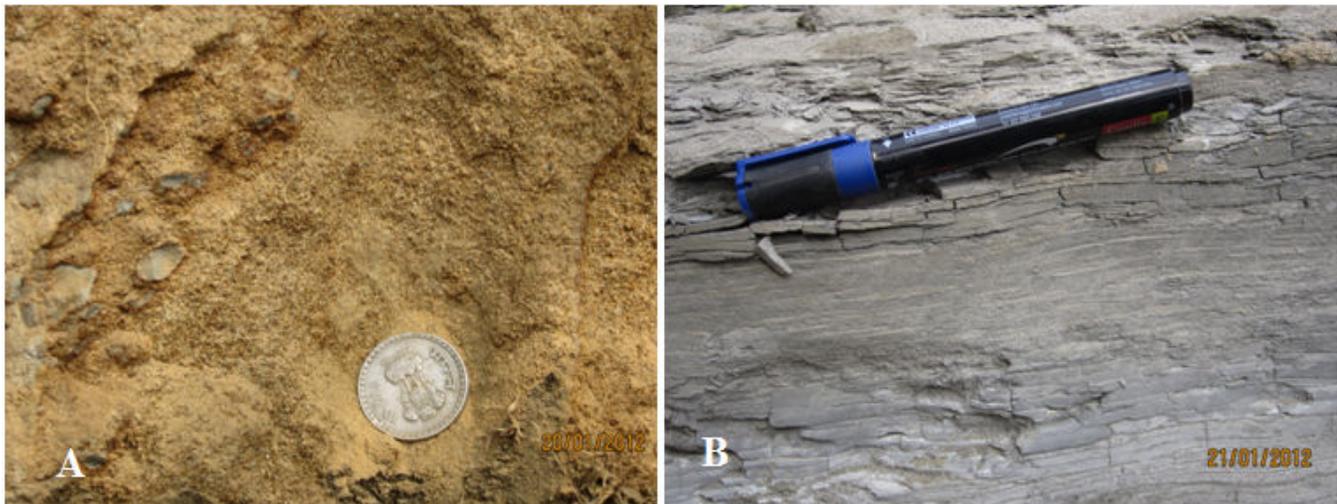

Figure 2. (A) Geology of the area. (B) Fault buffer with the landslide location (Source: Geological map of ONGC and GSI)

Plate 1. (A) Coarse grained sands with occasional mud balls, (B) Laminated siltstone with occasional very thin laminated sands

Table 1. The recent seismic events in and around Tripura from 1980 to 2011 (with the magnitude and depth ranges)

Sl. No.	Year	Latitude	Longitude	Depth	Magnitude
1.	1882	25.40	91.50	32.0	5.0
2.	1984	24.20	93.50	31.0	5.7
3.	1984	25.40	91.50	34.0	5.0
4.	1984	24.70	92.90	3.00	5.5
5.	1986	23.90	93.00	30.0	5.2
6.	1986	25.10	91.10	17.0	5.2
7.	1986	25.40	92.20	47.0	5.3
8.	1988	24.70	91.60	33.0	5.8
9.	1989	24.40	92.40	10.0	5.0
10.	1992	25.20	92.20	33.0	5.0
11.	2011			88.0	6.6

Source: Published report of disaster management plan, Govt. of Tripura (2011-12)

Burmese arc to the east. The region has experienced 11 earthquakes (M≥5) during the last thirty years (Table 1). Besides, several hundred small and micro earthquakes have been recorded in the region. The present study area is tectonically very active and a number of fault lines run through this region.

4.3 Geo-electrical resistivity

Geo-electrical mapping is an important tool for geotechnical survey of an area. Geological and structural variation can be understood through electrical resistivity of rocks. In the present study area two points were selected for Vertical Electrical Sounding (VES) survey and data generation. On the basis of the recorded resistivity values, the soil/ rocks of this area have been divided into three electro layers namely top soil (resistivity up to 20 Ωm), soft rocks (resistivity below 40 Ωm), medium rocks (resistivity below 80 Ωm). The first Vertical Electric Sounding (VES) point shows the

minimum resistivity of 2.2 Ωm that is recorded at the 5 m depth (Figure 3A). At 4 m depth, the resistivity is 31.4 Ωm. At the top (1 m depth) the resistivity was recorded 11.2 Ωm and gradual increase has been recorded up to 4 m depth, but at 5 m depth sharp decrease is recorded. The maximum resistivity is recorded at 4 m depth. Thus, within a 1 m depth (4 - 5 m) the maximum variation in resistivity was recorded. This kind of sharp negative change in electrical resistivity proves the existence of water bearing strata or very wet soil in these areas (Mukherjee et al 2011). These variations of the resistivity values at different depth suggest that the area belongs to very high geological complexity.

In the second VES point the top soil has a comparatively lower resistivity than in the first VES point. In this point, the minimum (8.48 Ωm) resistivity was recorded at the top at 1 m depth. The resistivity of the rocks gradually increases with the gradual increase of depth. The maximum resistivity (54.8) was recorded at 5 m depth (Figure 3B). The pseudo profile of VES points 1 and 2 is shown in Figure 4.

5 Morphological Characteristics of the Landslide

The whole landslide failure surface is very complex in nature. Middle portion of the slide experiences translational displacement due to continuous seepage and flow of water and the southern part shows block movement due to presence of fractures. In order to understand the geomorphological characteristics of the slide, contour lines at 2 m interval (Figure 5). The terrain condition was studied through terrain modeling (Figure 5) of the whole scar, which basically represents 3D representation of topographic surface. The numbers of facets are more in left side of the scar which represents relatively rough condition of the scar. The slope of the scar varies from 15^0 to 75^0. From the Digital Terrain Model it is found that the height of the scar ranges from 95 m to 129 m asl. The shape of the whole scar is semi-circular. Field investigations reveal that the landslide covered 1,500.7 m^2. Horizontal length of the surveyed scar was 69 m.
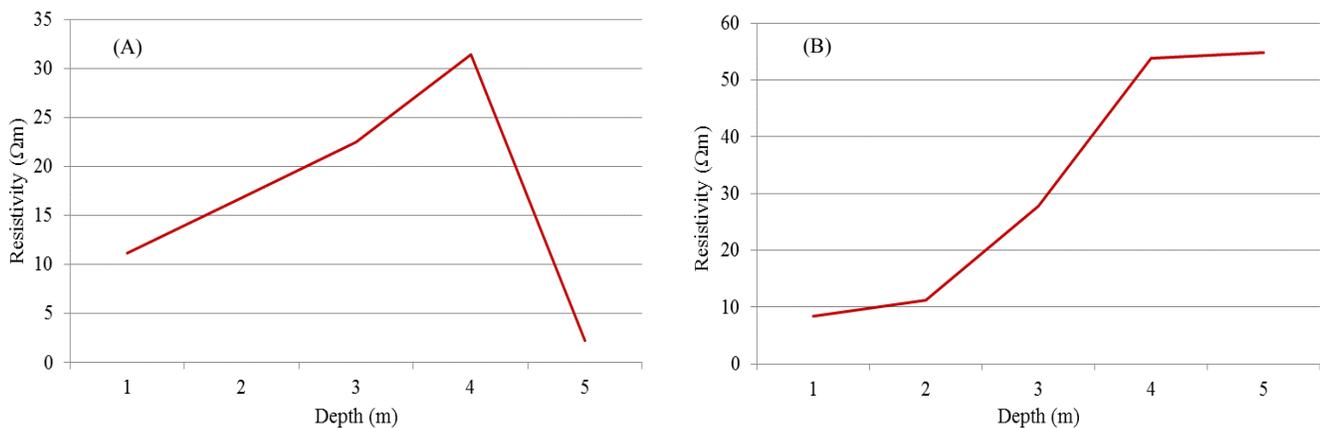

Figure 3. Geo-electrical resistivity of VES point 1 (A) and VES point 2 (B). Source: Field data
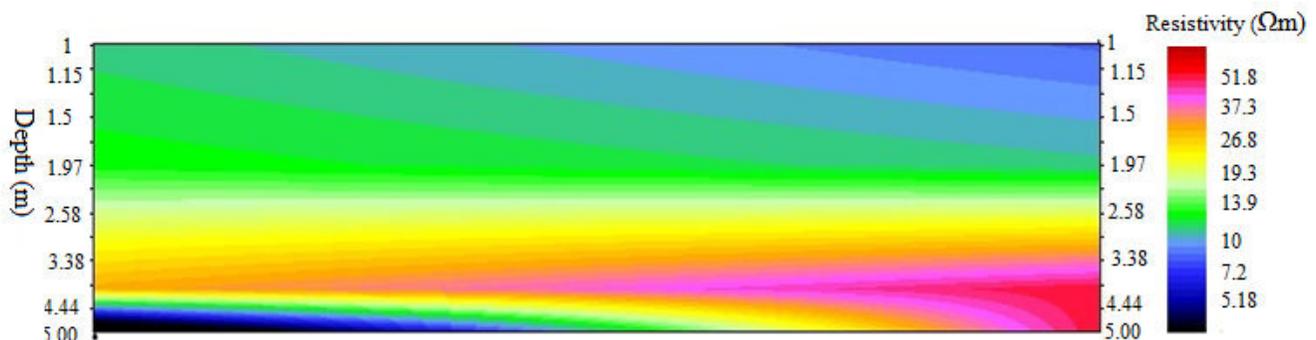

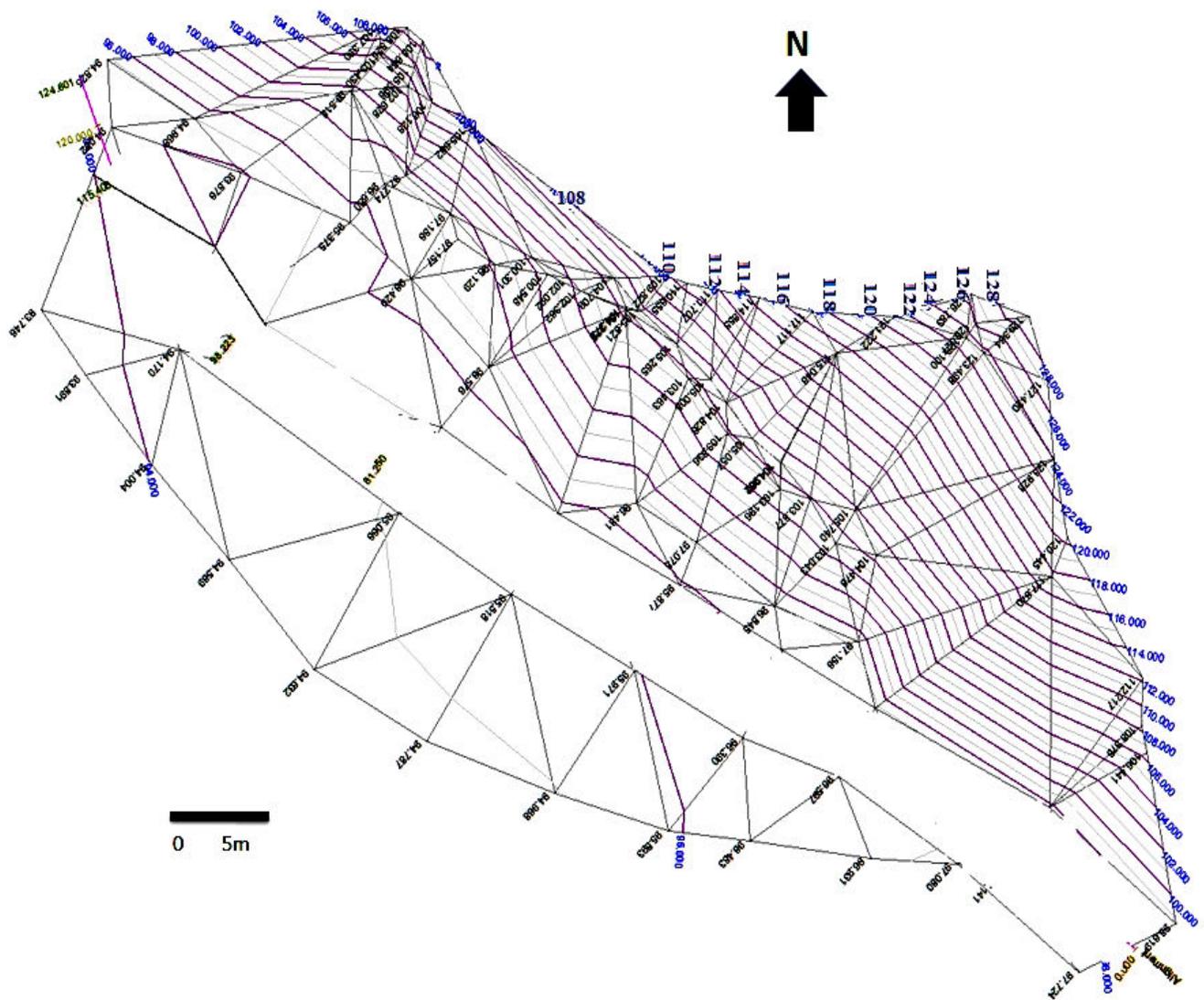Figure 4. Pseudo profile of geo- electrical resistivity survey of point 1 and 2. Source: Field data

Figure 5. Digital Terrain Model with contour lines of the landslide. Source: Field survey by Total Station

6   Rainfall Characteristics

Intense rainfall lasting for a few hours leads to saturation of porous soil and causes a decrease in shear strength of the slope forming materials. In case of the present landslide, the closest rain gauge station (Ambassa) is located about 10 km east from the landslide location. According to the local respondents, in 2010 this landslide was reactivated after a cumulative rainfall 215.4 of mm from 1st - 6th June, 2010. This amount of rainfall accounted 46.05% of the total rainfall of this month. High amount of rainfall is also recorded in the month of May, 2010. It is 525 mm, which is 66% higher than the annual average rainfall 325 mm of this month (Figure 6). Before that, from 20th - 31st March, 2010, within ten days,

445.8 mm cumulative rainfall has been recorded, which is accounted 84.78% of the total rainfall of this month. The average annual rainfall is very high in the study area. The area receives rainfall from monsoon. Generally in the month of June, July and August, the amount of average rainfall and number of rainy days are very high. The highest rainfall is recorded as 900.3 mm in the month of June in the year of 2010. The amount of monthly rainfall varies in great extent. During the years of 2001 - 2013, the average amount of rainfall for the months of May, June, July, August and September were 412.85 mm, 555.03 mm, 414.09 mm, 399.7 mm and 27.7 mm, respectively. In the months of May and June 2010, it is observed that 809.1 and 900.3 mm rainfall exceeded the average rainfall. In the month of
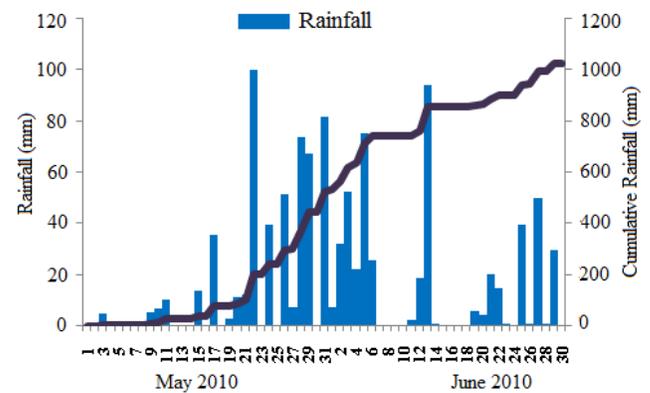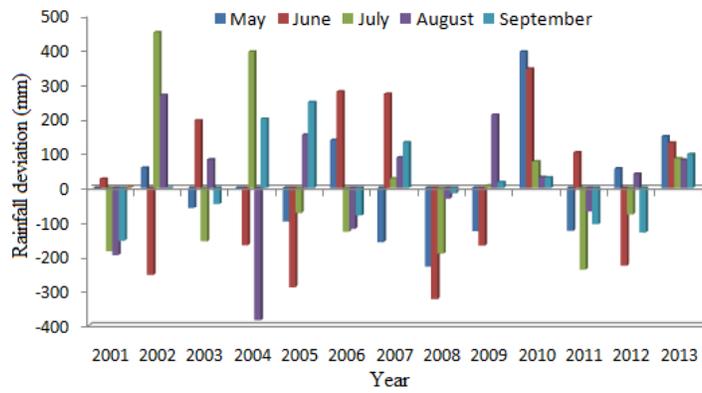
Figure 6. Rainfall variation in the month of May, June, July, August, and September from the year of 2001 to 2013 at Ambassa rain-gauge station
Source: Agricultural Department, Govt. of Tripura

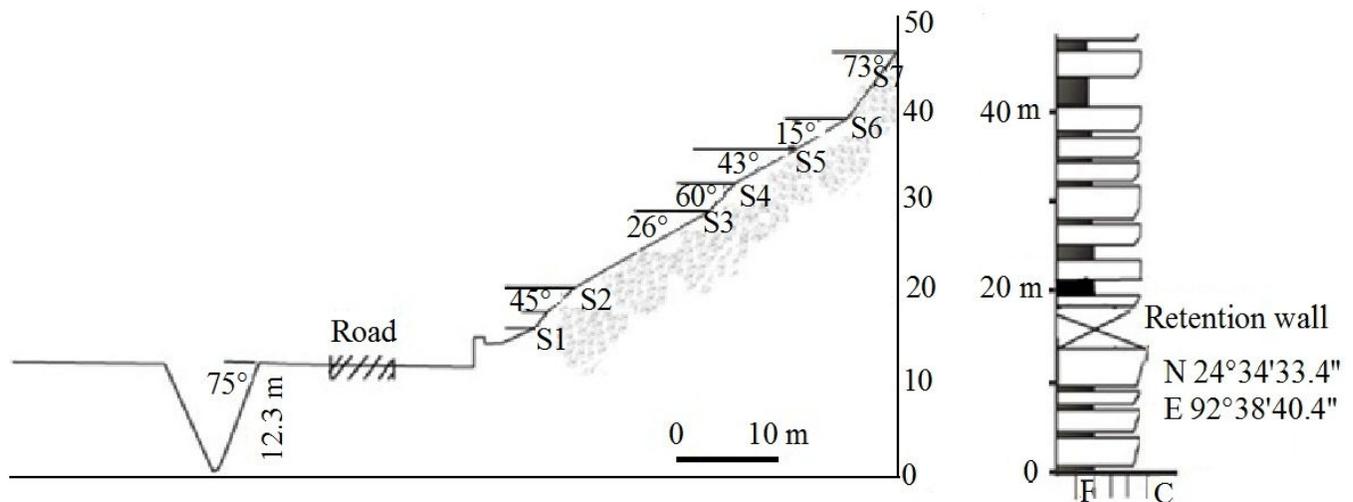Figure 7. Daily and cumulative rainfall distribution in the month of May and June, 2010

Figure 8. Ground condition of landslide slope. Source: Field data

June, the amount of rainfall was higher than the normal rainfall in the year of 2001, 2003, 2006, 2007, 2010, 2011 and 2013. The maximum deviation of rainfall is observed in July, 2002 and the amount is 429.31 mm (Figure 7). This excessive rainwater acts as an agent to initiate and accelerate the movement of slope materials. The loose soil allows the rainwater to percolate downward and thereby, subsurface layers get wet and slippery and as a result the slope materials start to move downward. It is observed that the slope is composed of highly fragile rocks and coarse textured soil that allows rain water to percolate downward. This increases the pore water pressure and changes the consistency and shear resistance of the slope material.

7 Management Plan of the Landslide

7.1 Earth works

Earthwork consisting of cutting/removing of unstable soil or rock mass from the slope in order to reduce the load and shear force is often necessary. Slope gradient is a key factor in influencing the relative stability of a slope. Slopes are often irregular and complex, with gradients varying greatly throughout a given landslide scar profile. In the present study, each slope profile section is treated as a separate management and restoration unit. The slope (Fig. 8) has been separated in to six segments. The slope gradients of the cut slope have been determined on the basis of existing slope length, lithology and soil

Table 2. Recommended slope gradient for cut slope

Slope segment	Ground slope condition			
	Lithology	**Soil type**	**Slope length**	**Slope gradient (V: H)**
S1-S2	Unconsolidated Sandstone with clay alteration (Bhuban Formation)	Medium sand (Moderately well sorted)	6 m	1: 0.5 - 1:1.2
S2-S3		Medium sand (Well sorted)	15.4 m	1.2:1.5
S3-S4		Fine sand (Poorly sorted)	8.3 m	1:1.2 - 1:1.15
S4-S5		Fine sand (Poorly sorted)	5 m	1:1.2 - 1:1.15
S5-S6		Medium sand (Moderately well sorted)	3.2 m	1:0.8 - 1:1.0
S7-S8		Medium sand (Moderately sorted)	8 m	1:1 - 1:1.2

Source: Field data and laboratory testing

Plate 2 (A). Construction of sub-surface drain (left side)**;** Plate 2 (B). Construction of retention wall with horizontal drilled drains (right side). Source: field survey

characteristics. The recommended cut slope gradient ranges from 1:0.8 to 1:1.2 (V:H, Table 2).

In the present study filling work is not recommended, because the whole slope is made of unconsolidated sandy materials with alternation of thin bedded silt and clay stone. During monsoon season, due to continuous seepage of rainwater, these unconsolidated materials may become heavier and lead to further failure.

7.2 Subsurface drains and horizontal drilled drain

The present study area receives high annual rainfall (about 2100 mm). Rain water infiltrates into the slope and increases the pore water pressure. Landslides are closely related to short-term rainfall and surface drainage may be an effective measure. In the present study (Plate 2A and B), the whole slope is made up of unconsolidated material, on which surface drains could not be constructed. Thus, instead of only surface drains, subsurface drains and horizontal drilled drains for slope management are also recommended (Figure 9). The subsurface drainage collects the seepage water from surface runoff and reduces the pore water pressure. As the present study area receives high amount of rainfall, it is recommended that the length of the horizontal drilled drain should be equal to the length of the landslide scar.

7.3 Retaining wall

Retaining wall can be constructed to act as an effective barrier to arrest debris or small rock fragments and to prevent displacement at the foot of the landslide. In case of the present landslide, the retaining wall should be extended across the foot of the landslide scar. From the field investigation, it was found that a small section (21 m) of retaining wall had been constructed. Moreover, both ends of the retaining wall are open. Thus, it is recommended that the retaining wall should be extended across the landslide scar (i.e. as far as both ends of the scar). At right side

it should be extended 54 m more and at middle part by 15 m and at left side by 12 m. The field survey also revealed that the height (3 m) of the retaining wall is not adequate to arrest the annual accumulation of debris. Therefore, it is suggested that the height of the retention wall should be extended at least one meter more (Figure 10). The existing retaining wall has been constructed by providing only a single row of horizontal drill drains which may be choked by debris during rainfall. Thus three or four rows of horizontal drill drains are recommended in order to safely drain infiltrated water from the scar.
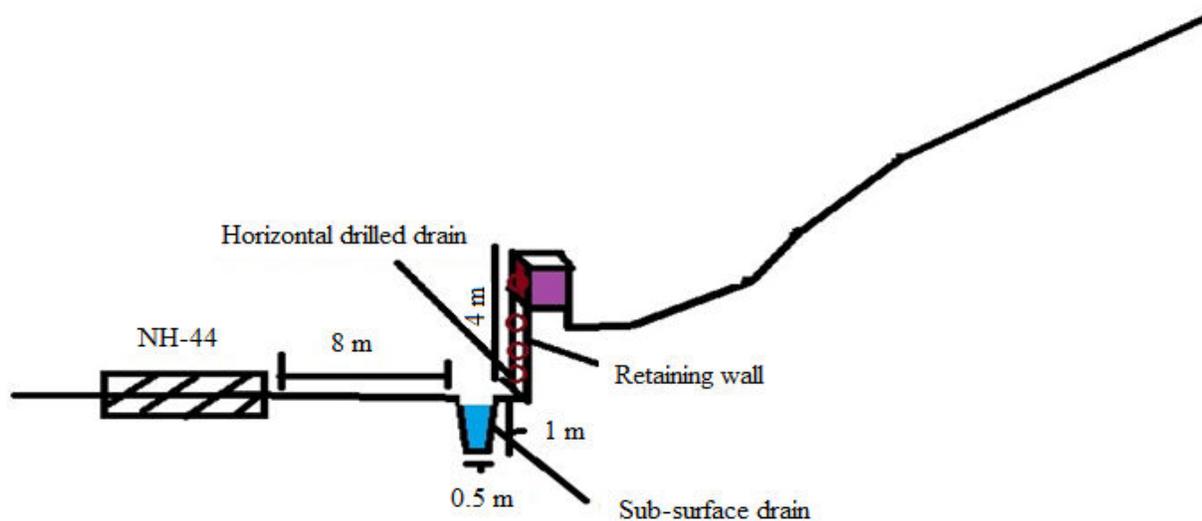

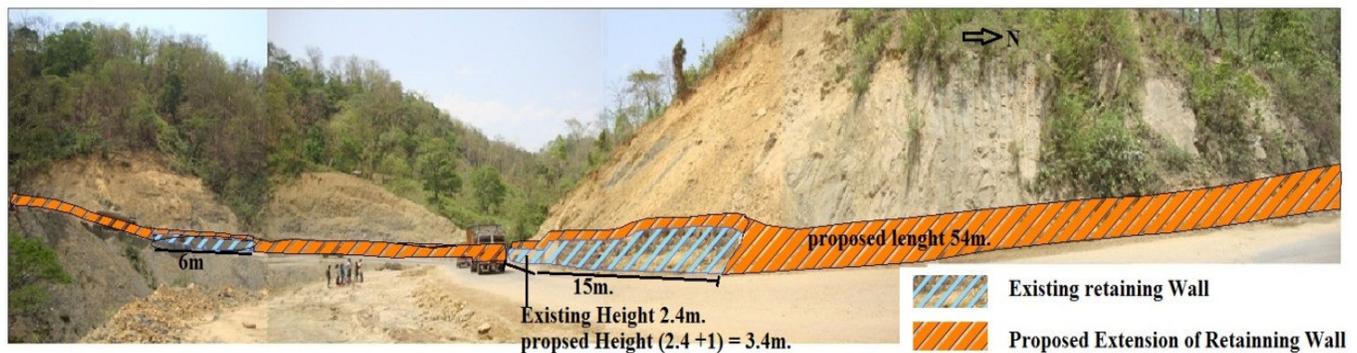Figure 9. Proposed drains for the landslide

Figure 10. Proposed extension of retaining wall for the landslide

8   Discussion and Conclusion

Landslides are most complex phenomena and their successful management depends on in-depth knowledge about the hazard. The landslide events

in Atharamura hill, Tripura, have a substantial effect on the operation of road and rail network and frequently cause disruption of transport and communication system. The existing slide poses a threat to the regular road transportation system in

the hilly area of Tripura. Heavy rainfall during monsoon season acts as the triggering factor for the occurrence of this hazard. The whole landslide scar is mainly composed of huge thickness of laminated siltstone, shale with narrow bands of sandstone; occasionally lenticular bedding structure with medium to coarse grain sandstone with mudstone. The height of the slide varies from 166 m to 191 m asl with a convex slope ranging from 15° to 75°. Dip of the rock strata ranges from 40° to 45° in SSW direction. The investigation on the landslide reveals that fragile geological structure and intense rainfall are the main causes of this landslide. In 2010 this landslide was reactivated and 215.4 mm of cumulative rainfall was recorded from 1st - 6th June, 2010. The landslide is located within 150 m buffer zone of a fault line which indicates the significant role of neo tectonic activities for the development of landslide events. Moreover, uncontrolled movement of heavily loaded vehicles may play an additional role in creating disturbance along the fault (Sen at al 2015). Variation of geo-electrical resistivity shows the geological complex character of this area. The first Vertical Electric Sounding (VES) point shows that the resistivity ranges from 2.2 Ωm (5 m depth) to 31.4 Ωm (4 m depth) and at second point it varies from 8.48 Ωm (1 m depth) to 4.8 Ωm (5 m depth). Therefore, this research work can be helpful for the effective landslide hazard management. Through intensive investigation some management plans such as construction of sub-surface drainage, construction and extension of retaining wall, cutting/filling of slope on the basis of quantitative assessments are recommended. Although some slope management plans have been suggested to prevent the further occurrences of landslides, cutting of hillside slopes should be stopped. Before the construction of new roads or the widening of the existing roads, local geological conditions such as amount of dip, direction of dip, lithological formation and soil characteristics should be studied properly and engineering techniques should be implemented. The result obtained through the present study can be used as basic data to assist slope management, road construction and land use planning. Collaboration management work on landslide

hazard reduction between regions, concerned departments, universities, research centers, non-governmental organizations and local peoples in landslide-prone areas is required for prevention, mitigation and better management of this hazard.

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