LANDSLIDES IN NILGIRIS: CAUSAL FACTORS AND REMEDIAL MEASURES

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Abstract

Landslide is a major natural hazard which affects 15% land area of the country. Himalayas and Nilgiris are most affected locations due to landslides in India. Rainfall is the major triggering factor for landslides in Nilgiris, whereas some of the Himalayan regions experienced landslides due to combination of rainfall and earthquake. Though the rainfall is a major triggering factor, some of the other causative factors are also responsible for triggering of landslides in Nilgiris. The present study gives an over view of the various causal factors involved in triggering of landslides in Nilgiris. It is found that, cutting of slope at toe, heavy loading on slope at crest, blocking of surface drainage system and choking of weep holes in retaining structures, improper planning and design/implementation of remedial measures, vegetation removal and dumping are possibly the main causal factors for most of the landslides in Nilgiris during heavy rainfall. The study also suggest, though the retaining walls are commonly adopted as remedial measures, cost effective subsurface drainage systems together with slope reinforcement might be effective solution to control the landslides in many locations. Present study also gives an over view on the use of numerical analysis pertaining to landslides in Nilgiris together with on-going detailed site specific geotechnical investigation.

Keywords: *Nilgiris, Landslides, Causal factors, Rainfall*

1 Introduction

Nilgiris district is located in Western Ghats in Tamil Nadu state in India and surrounded by Coimbatore and Erode districts of Tamil Nadu state on the east, Kerala state on the west and Karnataka state on the north. The district is a hilly region and the highest peak of Doddabetta lies at an elevation of 2595 meters from the Mean Sea Level (MSL) (Nilgiris 2011). Numerous landslides have occurred in Nilgiris in the past with the frequency of occurrence increased to alarming levels in last three decades. Some of them created severe damage to infrastructures like road, rail routes and buildings. As the Nilgiris district receives heavy rainfall both in South West and North East monsoons, rainfall is a major triggering factor for landslides in Nilgiris. Landslides occurred at more than three hundred locations of the district in November 2009 alone, which resulted in direct and indirect loss to the government and people (Ganapathy et al. 2010). Landslides in 2009 left fifty people dead and hundreds homeless. Mettupalayam - Ooty National highway (NH 67), the life line of Nilgiris and Mettupalayam-Coonoor rail route of Nilgiris Mountain Railway (NMR) got severely affected at many places (Fig. 1) (Chandrasekaran 2010, Elayaraja et al. 2015, Senthil kumar et al. 2015). The heavy rainfall in July 2009 (during Southeast monsoon) followed by very heavy rainfall in November 2009 (during Northeast monsoon) was the main triggering factor for the 2009 landslides in Nilgiris (Fig. 2) (IMD 2016). In addition to rainfall, there are some causal factors involved in triggering of landslides and are discussed in detail in the present study. Stability of slope can be increased by providing suitable remedial measures. The defects of existing remedial measures practiced in Nilgiris and suggestion of suitable advanced remedial measures have been discussed in this paper.

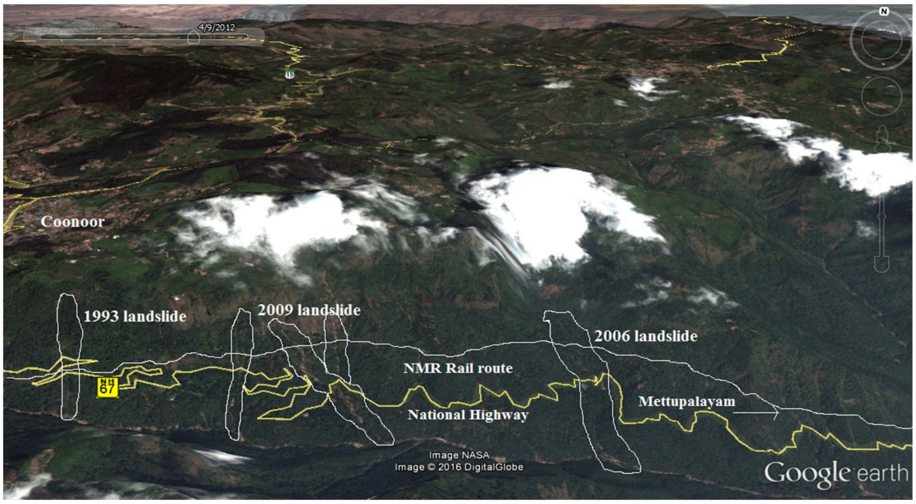

Figure 1. View of Mettupalayam – Coonoor road and rail network and major landslides occurred

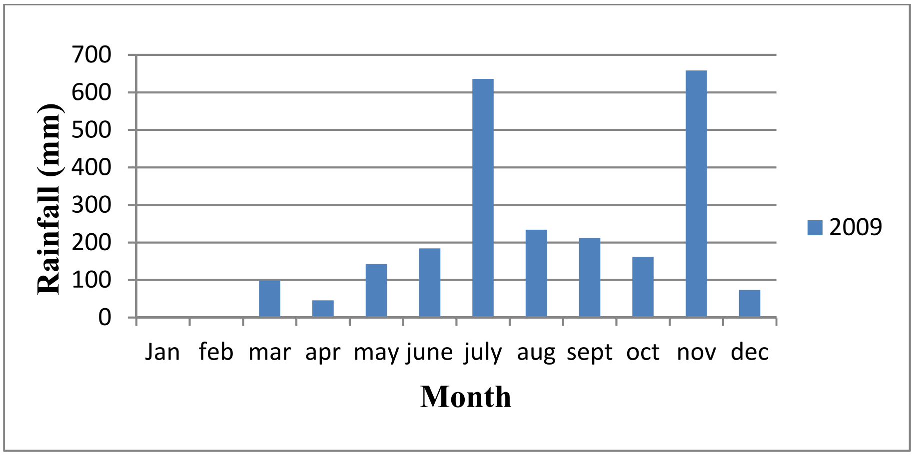

Figure 2. Nilgiris monthly rainfall during 2009

2 Causal factors involved in triggering of landslides in Nilgiris

In every slope, there are forces which tend to promote downslope movement and opposing forces which tend to resist movement. The factor of safety of a slope is a ratio of shear strength of the soil to the downslope shear stress, along an assumed or known rupture surface (Popescu 2002). Based on general definition of factor of safety, Terzaghi (1950) divided causes of landslide into two types, external and internal causes. External causes include the changes in geometry of slope, loading at the slope crest, unloading the slope toe, shocks and vibrations, drawdown, changes in water regime. Internal causes include progressive failure, weathering and seepage erosion. External and internal causes may involve in either increasing the shear stress or reducing the shear resistance and some of them can affect both terms of factor of safety simultaneously (Varnes 1978). The significant causal factors of landslides at Nilgiris are discussed below.

2.1 Excavation of slope at toe

Figure 3a and 3b shows the excavation of slope at toe for widening of road along Mettupalayam – Coonoor highway. Excavation of slope at toe reduces the shear strength of the soil due to yielding of soil mass (Sutejo and Gofar 2015). When rainfall infiltration saturates the slope, the shear stress increases thus increases the driving force. Decrease in shearing resistance and increase in shearing stress due to excavation of slope at toe and rainfall infiltration may lead to slope failure. Hence, the slope failure may end up with complete closer of road traffic in Nilgiris.

(a) (b)

Figure 3.View of excavation of slope at toe; (a) & (b) along Mettupalayam - Coonoor road network

2.2 Unplanned vertical cut

Figure 4a shows the vertical cut made all around the building located near Kattabettu for about 15.00m height. The lateral resistance of the slope has been completely removed all around the building due to unplanned vertical cut. Removal of lateral resistance will lead to reduction in shear resistance and increase in shear stress thus result in slope failure. A building located at the crest of a slope in Kodappamandu near Ooty has been collapsed due to vertical cut nearer to the foundation of the house (Fig. 4b). Loading at slope crest and vertical cut increase shear stress and reduce the shearing resistance of soil that led to slope failure during heavy rainfall in November 2009.

2.3 Loading the slope at crest

Figure 5a and 5b shows slope failure at Kothagiri and Nondimedu where buildings constructed at slope crest are on the verge of failure. Failure occurred, due to loading of slope at the top, under heavy rainfall. Building weight present on the slope crest adds to gravitational load which increase the driving force and causes slope failure. If overloading occurs away from the crest of the slope the influence is minimal but if it is within the vicinity of the crest of the slope its effect cannot be ignored as observed from figure 5a and 5b.

(a) (b)

Figure 4. View of vertical cut; (a) all around the building (b) near to building foundation

(a) (b)

Figure 5. View of slope failure due to laoding the slope at crest; (a) Kothagiri (b) Nondimedu

2.4 Blocking of drainage systems

Drainage of water is one of the most effective techniques which increase stability of slopes. Figure 6a, 6b and 6c shows blocking of surface drainage systems (drainage pipes and drainage culverts) along Metupalaym - Coonoor national highway and Aravankadu location. Blocking of drainage system allows the rain water to infiltrate into the slope, leads to build up of pore water pressure and thereby increases the driving force.

(a) (b) (c)

Figure 6. View of blocking of surface drinage pipe and drinage culvert ; (a) & (b) along Mettupalayam–Coonoor road network (c) Aravankadu location

2.5 Vegitation removal and Dumping of loose soil

Figure 7a shows removal of vegitaion in a slope located at Chinnabikatty near Coonoor. Generaly plant roots provide a strong interlocking network to hold unconsolidated materials together and prevent flow (Coppin and Richards 1990). In addition to that, plants are useful in removing of water from the soil which increases the shear strength. The removal of slope vegetation in Nilgiris may result in increasing either the rate of erosion or the frequency of slope failure. Figure 7b shows the dumping of loose soil on the slope surface near Coonoor. The additional weight due to dumping increases the shear stress. Whenever excavation of slope is made at the toe for widening of road, the unstable loose soil mass on the slope surface slide down and will disturb the road traffic.

(a) (b)

Figure 7. View of Causal factors ; (a) removel of vegitation on slope surface (b) dumping of loose soil on the slope surface

3 Remedial measures

The remedial measures implemented so far in Nilgiris are construction of retaining walls and gabion walls (Fig. 8a & 8b). It was observed that the weep holes provided in the retaining walls often got blocked with fine particles. This could be due to malfunctioning of the filtering arrangement provided in the weep hole during the time construction of retaining walls. The similar problem has been observed in many locations throughout the district.

(a) (b)

Figure 8. Remedial Measures; (a) View of retaining wall (b) View of gabion wall

Surface drainage systems provided throughout the district is also blocked due to lack of maintenance. Excess pore pressure and seepage forces during the heavy rainfall decrease the effective stress of the soil and thus reduce the shear strength, consequently resulting in slope failure (Anderson and Sitar 1995, Cascini et al. 2010, Chandrasekaran et al. 2013a). Hence a proper subsurface drainage system and their periodic maintenance can be an effective solution in stabilization of slopes to avoid the slope failure under the influence of rainfall in Nigiris (Bhandari, 2006). India's first subsurface drainage system by horizontal drains is implemented in Porthimund dam in Nilgiris district. The landslide occurred on the downstream side of dam in 1979 due to the excess hydrostatic pressure build up in the soil mass due to the seepage of drain water at the higher reaches of the slope (Natarajan et al. 1984). In order to dissipate the excess hydrostatic pressure from the soil mass overlying the bed rock, the subsurface drainage technique with horizontal drains in combination with vegetative turf has been implemented as appropriate remedial measures to control the landslides (Natarajan et al. 1984). The same technique needs to be implemented in other locations in Nilgiris. In addition to the sub surface drainage system some of the additional techniques including internal slope reinforcement consist of soil nails and stabilizing piles have to be explored. Slope failure due to vertical cut can be controlled by adopting nailing technique. The sliding mass above the failure surface can be strengthened by placing passive piles embedded into sufficient depth in the stable layer below. The loads can be transferred to the more stable underlying layers and the soil movements can be resisted by piles which act as a barrier (Kourkoulis et al. 2011). So far the present paper discussed about different causal factors involved in triggering of landslides in Nilgiris and different remedial measures were suggested to control the effects of landslides in Nilgiris. The following sections will give an over view of numerical analysis pertaining to 2009 landslides in Nilgiris and study on evaluation of potential of earthquake induced landslides in Nilgiris carried out by authors. The on-going research work on detailed site specific geotechnical investigation being carried out by authors is also discussed in the following sections.

4 Numerical analysis pertaining to 2009 landslides in Nilgiris

Rainfall induced landslides have occurred at more than three hundred locations in Nilgiris during north east monsoon in November 2009 resulted in loss of 50 lives and property loss of about three hundred crores (Chandrasekaran et al. 2013b). In order to understand its failure mechanism and effects of rainfall and other causal factors, numerical analysis has been performed by Chandrasekaran et al. (2013b). Different case histories have been identified where the landslides occurred in 2009 which includes slope failure which supported railway track at Aravankadu (Fig. 9a), failure of retaining structure supporting building at Coonoor (Fig. 9b) and slope and retaining wall failure which supported a road network (NH-67) at Chinnabikkaty (Fig. 9c) (Chandrasekaran et al. 2013b). Soil samples have been collected from three landslide locations and laboratory investigations have been carried out. From the laboratory investigations, it is observed that soils have high fines content and low values of hydraulic conductivity. The classification of soil for three locations are Silty sand (SM) for Aravankadu, Lean clay with sand (CL) for Coonoor and Sandy silt (ML) for Chinnabikkaty. A finite element analysis has been carried out using PLAXIS 2D programme for all three locations. Numerical analysis reveals that increase in pore pressure under heavy rainfall reduces the shear strength of the soil and consequently resulted in progressive failure of slope at Aravankadu site. The combined effect of surcharge load of building and high pore pressure under heavy rainfall led to intense shearing of slope at Coonoor and Chinnabikatty sites (Chandrasekaran et al. 2013b).

(a) (b) (c)

Figure 9: View of case history sites; (a) Slope failure at Aravankadu (b) Retaining wall failure at Coonoor (c) Slope failure at Chinnabikkaty (Chandrasekaran et al. 2013b)

4.1 Evaluation of potential of earthquake induced landslides in Nilgiris

As per IS classification of seismic zones, Nilgiris comes under zone III (IS 1893-2002). Though the landsides occurred in this region are rainfall induced, seismicity of this region and past history of earthquakes in and around Nilgiris insists the importance of potential of earthquake induced landslides in Nilgiris. Study on evaluation of potential of earthquake induced landslides in Nilgiris has been carried out by Elayaraja et al. 2015. The peak ground acceleration (PGA) at bedrock level for Nilgiris has been evaluated using deterministic seismic hazard analysis considering a study area of 350 km radius with Ooty as centre. Corresponding to maximum considerable earthquake of 6.8, the PGA at bed rock level is 0.156 g (Elayaraja et al 2015). Ground response analysis has been carried out on selected locations (seven sites) in Nilgiris by one dimensional equivalent linear method using SHAKE 2000 programme by considering the site amplification due to hilly terrain. From the ground response analysis, it was observed that the PGA of surface motion got amplified to 0.44 g in Ooty site and 0.64 g in Coonoor site compared to 0.39 g of the input motion. The bracketed duration of time history of surface acceleration has increased to 18 s in Ooty site and 20 s in Coonoor site compared to that of 8s of input motion (Elayaraja et al 2015). Seismic displacement analysis of slope has been carried out for all selected locations using Newmark's method. Ground response analysis and displacement analysis results reveal that out of seven sites considered, Ooty and Coonoor sites have high seismic landslide hazard and other five sites have moderate hazard (Elayaraja et al. 2015).

5 On-going detailed site specific geotechnical investigation on landslides in Nilgiris

Geotechnical investigation is crucial in landslide studies to understand various causative factors, their failure mechanisms and design suitable site specific remedial measures. A detailed site specific geotechnical investigation is being carried out on landslides in Nilgiris. Different types of landslide (as per Varnes 1978 classification of slope movements) case histories have been identified under this research work. They are debris flow type landslide occurred at Marappalam in 2009 (Fig. 10a), Debris avalanche type landslide occurred at Achanakkal in 2009 (Fig. 10b) and earth slide type landslide occurred at Madithorai location in 2009 (Fig. 10c).

(a) (b) (c)

Figure 10. View of landslides in Nilgiris; (a) Marapalam landslide (b) Achanakkal landslide (c) Madithorai landslide

Subsurface investigation has been carried out by making boreholes up to bedrock and Standard Penetration Test (SPT) has been conducted at every 1.50m depth. Detailed geophysical investigation has been carried out using Multichannel Analysis of Surface Wave test (MASW) for all three locations. Soil and rock core samples have been collected for laboratory investigation which includes various index and engineering properties of soil/rock samples and determination of residual shear parameters of soil using multiple reversal direct shear test. X-ray diffraction (XRD) analysis and scanning Electron Microscopic (SEM) analysis were performed to identify the mineral compositions of soils and its micro fabric nature. Piezometers have been installed in drilled boreholes to monitor the pore pressure variation under heavy rainfall. An attempt has been made to identify the inter-connection between rainfall (daily and antecedent) and landslide occurrence by establishing correlations between them. Numerical analysis using finite element and limit equilibrium programmes would be performed to understand the failure mechanism and evaluate the factor of safety of the slope. The progressive failure analysis of landslide will be carried out using landslide simulation model LS-RAPID. Different remedial options including geotextiles and reinforcement techniques would be implemented numerically and a suitable option will be suggested which provides better results in terms of safety and stability.

6 Summary

The present study gives an over view of the various external and internal causes involved in triggering of landslides in Nilgiris. These external and internal causes, either reduce the shearing resistance or increase the shearing stress or affecting both simultaneously. As observed, rainfall is a major triggering factor for landslides in Nilgiris. To dissipate the excess pore pressure generated and reduce the seepage forces during the heavy rainfall, sub surface drainage systems need to be explored. In addition to rainfall, other causal factors such as excavation of slope at toe, loading of slope at crest, blocking of surface drainage system and weep holes of retaining structures, improper planning and design of remedial measures, vegetation removal and waste dumps may also be responsible for triggering of landslides. The awareness of landslides causal factors should be increased among architects, planners, engineers and builders especially in landslide prone areas. It is also observed that the periodic maintenance of surface drainage system and weep holes of retaining structure should be done to keep them clean and reduce the influence of water in triggering of landslides. Excavation of slope at toe is observed in many places especially along transport corridors for widening of roads. Internal slope reinforcement shall be practiced for vertical cut to increase the stability of soil. To stabilize the sliding mass above the failure surface and avoid rotational and translational earth slide, passive piles can also be adopted. In general the remedial measures should be site specific and properly designed and maintained periodically to improve overall stability and safety. The numerical analysis carried out in Nilgiris explains how rainfall and other factors involved in triggering of landslides. Ground response and displacement analysis reveals that Ooty and Coonoor sites have high seismic hazards and other sites of moderate hazard. The on-going detailed site specific geotechnical investigation on landslides in Nilgiris will be useful to understand the failure mechanism of landslides and would help in identifying suitable site specific remedial measures.

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