Rain induced landslides in the Nilgiris District of Tamil Nadu, India

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ABSTRACT

Rain induced landslides are most common problem worldwide and usually triggered when there is continuous and intense rainfall in the area of steep slopes with less permeable fine-grained soils. Nilgiris is one such district in the state of Tamil Nadu (TN), India which encounters frequent landslides specially during monsoon season (October - November). This paper aimed to discuss the study related to the detailed geotechnical investigation carriedout in the Nilgiris slopes. Study revealed that the soil characteristics, rainfall intensity and duration playing a crucial role in triggering these landslides in the region. One of the critical location is Marappalam, where detailed geotechnical investigation are carried out and the failure mechanism was identified based on the numerical analysis. It was found that, continuous low intensity rain for days followed by large intensity rain is the main triggering factor for the large landslides in the Nilgiris. There is a reduction in matric suction resulting in the development of positive pore pressure. This in turn reduces the shear strength of the soil triggering a progressive failure. Based on the study, it is found that, low permeable loose and soft soil possibly the main reason for large scale slope failures. Mechanism of the 2009 Marappalam landslide is investigated using landslide simulation program LS-RAPID. The failure mechanism observed in the numerical simulation conform well with the observed motion.

1 INTRODUCTION

Nilgiris is a part of Western Ghats and one of the oldest mountain ranges located at the tri-junction of Tamil Nadu, Karnataka and Kerala states of India. The Nilgiris district has a long history of landslide events causing enormous damages to life and properties. Since the Nilgiris district is located in the tropical zone, it receives rainfall during both southwest (June to September) and northeast (October to December) monsoons. The average annual rainfall of this district is relatively very high and many landslides gets triggered by these heavy intense rainfall. There are many factors namely steep slopes, heavy rainfall, deforestation and unplanned urbanization, toe cutting and erosion and in many cases improper design of slopes are mostly responsible for various landslides in Nilgiris. Among many factors, rainfall is seen to be the most crucial factor for landslides in the region. These rain induced landslides are usually caused by the excess pore pressure and the corresponding seepage force due to heavy rainfall. Heavy rain leads to excess pore pressure and subsequent decrease in matric suction. This reduces the effective stress in the soil leading followed by decrease in the shear strength of the soil mass triggering slope failure and landslides. One of the critical location, landslide at Marappalam occurred in 2009 continuous high amount of five day antecedent rainfall followed by a very high magnitude of rainfall on the day of the slide. The location of the Nilgiris district map in the Tamil Nadu state in India is shown in Figure1(a) and the location of Marappalam region is shown in Figure 1(b). The mentioned landslide damaged part of the Coonoor-Mettupalayam National Highway (NH-67) and also large part of the railway track. Figure 1 (c) shows the Marappalam 2009 landslide view with the damaged road. Detailed geotechnical investigation were carried out in the region and the failure mechanism was identified based on the numerical analysis. It was found that, low intensity continuous rain for days and subsequent heavy rains were the usual reason for the large landslides in the Nilgiris including the Marappalam 2009. Failure mechanism of this Marappalam (2009) landslide is investigated numerically and the mechanism from the simulation are found to be conforming with the observed motion.

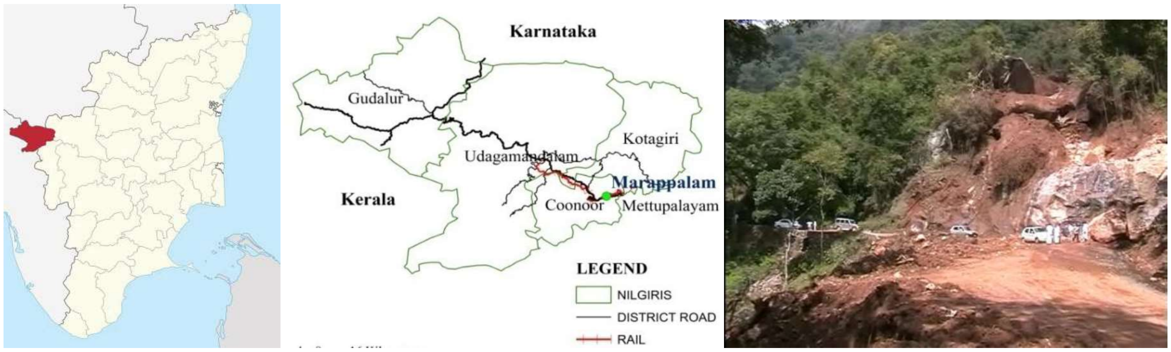

Figure 1: (a) Tamilnadu district map in the southern part of India highligtinng the Nilgiris district in red colour (b) Marappalam region in the Nilgisris district showing the rail and road networks (c) Marappalam 2009 landslide, view of the damaged road.

2 GEOLOGY, GEOMORPHOLOGY AND HYDROGEOLOGY OF NILGIRIS

Nilgiris is a hilly district spread over a geographical area of around 2550 sq. km in the western part of Tamilnadu, India. Important geomorphic units identified in the district are namely Structural hills, Ridges, Valley fills, Pediments, Hill top valley and Erosional plains. The Nilgiri plains are about 300m. above MSL with many peaks with an average elevation of 1370m. above MSL. There are two types of landforms found namely Doddabetta landform and Ootacamund landform (Chandrasekaran et al.,2013). Doddabetta landform consist of steep slope and rock escarpments with or without soil cover and Ootacamund land form consist of gentle slope with thick soil formation. The soils of Nilgiri district broadly classified into five major types namely Lateritic, Red sandy, Red loam, black soil, Alluvial and Colluvial soil. Large part of the district covered with Lateritic soil that is formed by process of weathering. The yellowish to reddish brown lateritic soil formed due to intensive weathering is overlain on parent rock with a thickness varies from less than one meter to thirty meter (Jaiswal, 2011). The rock underlain is mostly charnockite and granetiferous quartzo-felspathic gneiss belonging to archaean metamorphic rocks (Gupta et al. 2003). Weathered, fissured and fractured gneisses and charnockites with recent alluvial and colluvial formations constitute the important aquifer systems in the district. The alluvial deposits mostly comprising sand with admixtures of silt and clay are confined mainly to the course of major river and streams. The colluvial materials like sands and gravels are seen in the valley portions. Ground water depth of these shallow aquifers ranges from 5 to 20m. Ground water found to occurs under phreatic conditions in the weathered mantle and under semi-confined conditions in the fractured zones. The thickness of these weathered mantle is varying from less than a meter to as much as 20m.

3 GEOTECHNICAL CHARACTERISATION

Marapalam region is frequently affected by landslides specially during the monsoon season. The 2009 Landslide occurred due to very high amount of five day antecedent rainfall of more than 300mm followed by a very high magnitude of rainfall of more than 400mm on November 10, 2009. To understand the exact cause and related mechanism, a detailed geotechnical investigation is carried out for the Marappalam site in Nilgiris (Senthilkumar et al. 2017). As part of the investigation various insitu geotechnical and geo-physical tests were carried out. Standard penetration test (SPT) N value of the top soil up to 3.00 m depth was found to be around 5 to 15 and the corresponding shear wave velocity based on MASW was seen between 200 to 400 m/s, indicating the soil is relatively loose to medium dense. Based on the complete geotechnical laboratory investigation, soils were classified as Silt with sand (ML), Sandy silt (ML), and Silty sand (SM) as per USCS classification system The natural moisture content in the residual soil layer was found to be in the range 16-20% even in the dry season possibly due to high atmospheric moisture. The soil was found to have fines content of 40–80% and the permeability value found to be around 10^{-4}cm/s indicating a low value. The Atterberg limits show that, the soil was also having low plasticity. The strength test results on the cylindrical cores collected from the bed rock showing medium to high-strength rock. The uniaxial compressive strength value found to in the range 100 to 135 MPa. The laboratory value of shear wave velocity of intact rock from BH-3 with depth of coring 16.0-17.5m was found to be around 1150 m/s. The shear wave velocity observed from MASW test for the same depth was found to be around 1070 m/s. The weathering profile of Marappalam residual soil slope was also investigated as per six-grade weathering classification (Sajinkumar et al. 2011).

Based on the formation microfabric characterization, 0 to 3m depth was governed mostly by clay and silt size clusters with voids showing highly porous structure possibly due to high degree of weathering.

Table 1: Soil Properties as found at the Marappalam site

Description	Values
Specific gravity	2.64-2.69
Clay %	6-18
Silt %	37-60
Sand	11-54
Liquid Limit W_L (%)	37-48
Plasticity index (I_P) %	12-15
USCS Soil classification	SM/ML (Silty sand/ Sandy silt)
Natural moisture content (%)	16-19
Hydraulic conductivity (cm/s)	(3.8×10^{-5})- (5.0×10^{-5})

3 RAIN INFILTRATION AND LANDSLIDE THRESHOLD

To study the behaviour of unsaturated soil slope under rainfall infiltration, stability analysis has been performed under transient seepage condition and coupled analysis has been performed to capture the fluid and soil interaction (Senthilkumar et al., 2018). The slope has been numerically modelled based on the input parameters obtained from field as well as laboratory investigations and analysed for two successive rainfall events consist of a long duration low intensity rainfall (first rainfall event) and a short period high intensity rainfall (second rainfall event) events. An empirical rainfall threshold relationship is also developed based on daily and five days antecedent rainfall with respect to landslide events occurred at Marappalam region in past twenty five years. The rainfall threshold equation for Marappalam location is represented by linear mathematical equation as given below (Senthilkumar et al., 2018),

$$R_T = 225 - 2.04\ R_{5ad}$$

Where, R_T is the rainfall threshold in mm and R_{5ad} is the five days antecedent rainfall in mm. The threshold analysis based on daily and five days antecedent rainfall in conjunction with past landslide events occurred in this region revealed that, either very high amount of daily rainfall or a very high amount of persistent rain is usually required to trigger landslide. The threshold indicates that, when the daily rainfall crosses 225mm, there is a possibility of landslide occurrence even when, there is no antecedent rainfall. When the five days antecedent rainfall (R_{5ad}) exceeds 110mm, even with a continuous normal rainfall would be capable of triggering a landslide in this Marappalam region.

4 LANDSLIDE SIMULATION

Numerical simulation for landslides is carried out using LS-RAPID (Sassa, 2010). Input parameters for the numerical analysis is derived from the laboratory tests. Since the soil at sliding surface found to have low permeability and was saturated by heavy rainfall before the landslide event, for laboratory investigation, the samples were prepared ensuring fully saturated condition (Senthilkumar et al., 2017). Using numerical simulation, the complete motion could be simulated for Marappalam 2009 landslide. The initiation of landslide first found to occurred at 3.0s and the movement of the mass starts after initiation with a velocity of 4.5 m/s. Here the strength reduction were in progress together with shear displacement. At 10.40s velocity increased to 21.3 m/s and a relatively small mass of earth material was started sliding towards the valley due to progressive failure. The initial failure zone extended further due to continuous reduction in the shear resistance. The slide attained the peak velocity of 68.3m/s at 20.5s and the remaining mass also started moving toward the valley as shown in Figure 2a. At 31.9s the velocity of mass attend was 34.00 m/s and almost complete mass at the scarp had reached near the valley with no further reduction in the shear strength. The deformation continues to take place with this constant shear resistance as shown in the Figure 2b. At 42.2s the attend velocity was equal to 13.8 m/s and virtually all the unstable earth mass formed at the head scarp had reached into the valley. Finally, at 66.7s the movement of the mass came to a complete halt. This simulation could capture the complete process of sliding of the Marappalam 2009 slide in the similar line as what observed during actual slide.

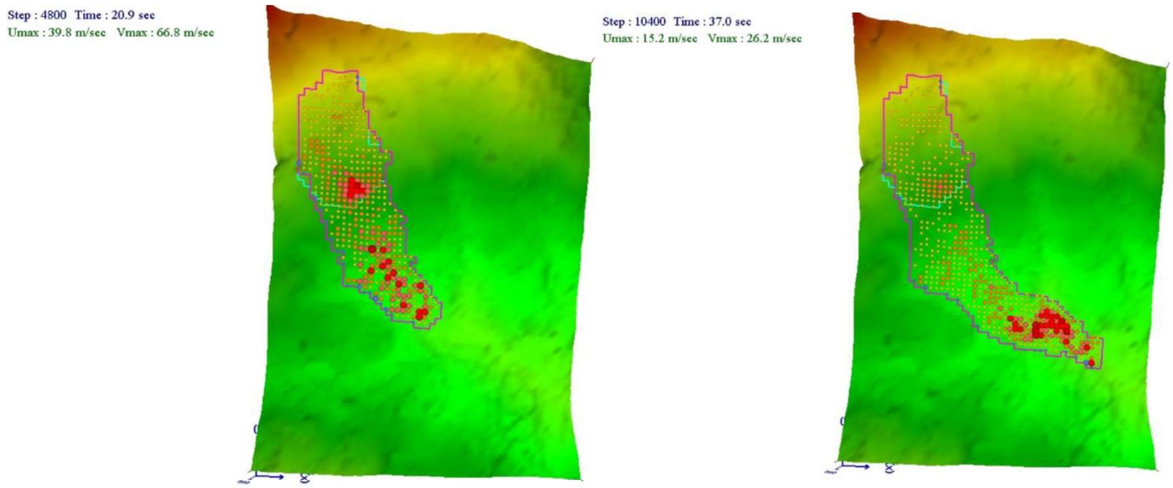

Figure 2: Results of simulation analysis a) landslide initiation d) landslide motion with deposition of debris in river valley

4. CONCLUSIONS

Nilgiris district in the state of Tamil Nadu (TN), India encounters frequent landslides specially during monsoon season. This paper discussed the study related to the detailed geotechnical investigation carried out in the Nilgiris slopes and corresponding numerical simulation. Study revealed that the soil characteristics, rainfall intensity and duration playing a crucial role in triggering these landslides in the region. One of the critical location is Marappalam where regular landslides are occurring. A detailed geotechnical investigation were carried out in this region and the failure mechanism for 2009 landslide was identified based on the numerical analysis. It was found that, continuous low intensity rain for days followed by large intensity rain was the main triggering factor for this large landslide in 2009 in the Marappalam. Based on the study, it is found that, law plastic loose and soft soil layer could be the main reason behind these large scale slope failures. Failure mechanism of the Marappalam (2009) landslide was also investigated using landslide simulation program LS-RAPID. The failure mode, travel distance and area of landslide observed from the simulation were conforming with the observed motion.

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