Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam
Visakhapatnam Chapter

Analysis of Layered Slope Subjected to Rainwater Infiltration

G. M. Anil Kumar[1] and Adarsh S. Chatra[2]

[1]M.Tech Student, Dept of Civil Engineering, Basaveshwar Engineering College, Bagalokot-587103, E-mail: anilkumargm61@gmail.com
[2]Associate Professor, Dept of Civil Engineering, Basaveshwar Engineering College, Bagalokot-587103, E-mail: adarshchatra@gmail.com

Abstract. In recent years, the world has been hit with a series of natural hazards among them; rainfall-induced landslide is one of the major natural hazards occurring across the globe resulting into loss of life and damage to public properties. In India, landslides are frequent in the hilly regions of Himalayas, Western Ghats and other parts of India covering 15 per cent of the land area. From 15th to 17th August 2018, the Kodagu district received heavy rainfall for three successive days, resulting into landslides and floods. Madikeri-Mangalore National Highway was blocked near Madenadu area due to landslide. In the present study laboratory tests were conducted from the samples collected from the site. Two dimensional seepage analysis is carried out to perform seepage and stability analysis of the slope subjected to rainwater infiltration. It is found that the soil strength is reduced with increase in pore water pressure thus more unstable slip surface is located beneath the water table and resulting into decrease in factor of safety values with rainfall intensity and duration.

Keywords: landslide, pore water pressure, rainfall intensity, rainfall duration and volumetric water content.

1 Introduction

Slope failures and landslides are among the major natural disasters occurring more often in the world. According to Crozier (1986), the landslide is "outward and downward gravitational movement of the earth material without the aid of running water as a transporting agent". The Himalayan Mountains and the Western Ghats of India have been hit with series of landslides that destroy properties and life perennially. Landslides cause damages to river flow, natural vegetation, and communication and transportation network.

Rainfall is one of the most significant triggering factors for slope failure occurring in mountainous regions, resulting into threat or damage to lives and properties, as well as obstructs the vehicular movement (Lee and Nurly 2009). The wetting front movement toward deeper layer leads to loss of matric suction, lubricating the potential sliding surface, increasing the unit weight of soil which results into reduction of shear strength of soil of soil. Several researches performed seepage analysis using Finite Element Method (FEM) and slope stability analysis using Limit Equilibrium Method

(LEM) (Liu et al. 2012, Mahmood et al. 2015, Kakogiannou et al. 2016 Gupta et al. 2016, JianPing et al. 2009, Biran et al. 2010, Baba et al. 2012, Ahmad et al. 2013 and Regmi et al. 2015) to study the response of soil subjected to rainwater infiltration In the present study the slope is modelled to analyses the seepage and stability of slope subjected to rainwater infiltration.

2 Methodology

The methodology adopted for the case study involves the following phases: problem definition, data acquisition and seepage and stability analyses of the typical slope of the study area. The soil samples have been obtained as part of the field studies. The laboratory tests are performed on the soil samples to determine the hydraulic and mechanical properties needed in the seepage and stability analyses.

2.1 Rainfall data

The rainfall data of the Madenadu rain gauge station is collected from the Karnataka State Natural Disaster Monitoring Centre. Figure 1 shows the rainfall data of the Madenadu rain gauge station.

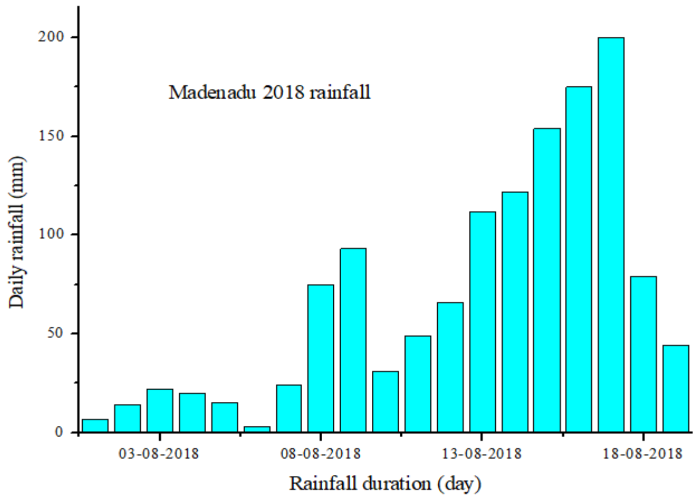

Fig. 1. The rainfall data of the Madenadu rain gauge station

2.2 Soil data

The Indian standard code procedure is used to perform the field and laboratory tests to obtain the required soil and hydraulic properties of the slope material [IS 2386-3 (1963), IS 2720-4 (1985), IS 2720-13 (1986), and IS 5529 (1985)]. The soil samples collected from the site are tested in the laboratory to evaluate: index, hydraulic and mechanical properties. The results from the laboratory tests obtained are the hydraulic properties and shear strength parameters which are used in the subsequent seepage and stability analyses. Table 1 shows the soil properties of the silty sand obtained from laboratory experiments

Table 1. Soil Properties

Property	Description
Classification	Silty Sand
Specific Gravity	2.6
Cohesion	5 kPa
Angle Of Internal Friction	26
Unit Weight	17 kN/m^3
Saturated Permeability	0.86 m/day
Saturated Water Content	0.332
Air entry value	32 kPa
Pore size distribution	1.5

The methodology of modelling the rainfall infiltration and slope stability analysis in the present study involves two parts. In the first part, the rainwater infiltration is allowed to take place on the slope surface. Transient seepage analysis is performed using Van Genuchten function through SEEP/W. In the second part, the output of the seepage analysis is utilized to evaluate the Factor of Safety (FOS) of the typical hillslope of the Madenadu by Morgenstern-price method using SLOPE/W. The hydraulic properties of the silty sand are used as input parameters for the seepage analysis. The data used for the seepage and FOS evaluation are obtained from the combination of literature survey, rainfall and soil data collection, slope geometry.

2.3 Slope stability analysis

The soil slope model is utilized to analyse the transient rainfall infiltration and pore pressure variation in the hillslope. Figure 2 shows the silty sand slope model of height 3 m underlain by Impermeable rock of 9 m. The transient pore pressures and degree of saturation needed in the limit equilibrium analysis are obtained under rainfall infiltration. The time-dependent infiltration analysis will provide the vertical profiles of matric suction and degree of saturation. These results are used in the finite slope method to obtain the FOS associated with the hillslopes of the study area.

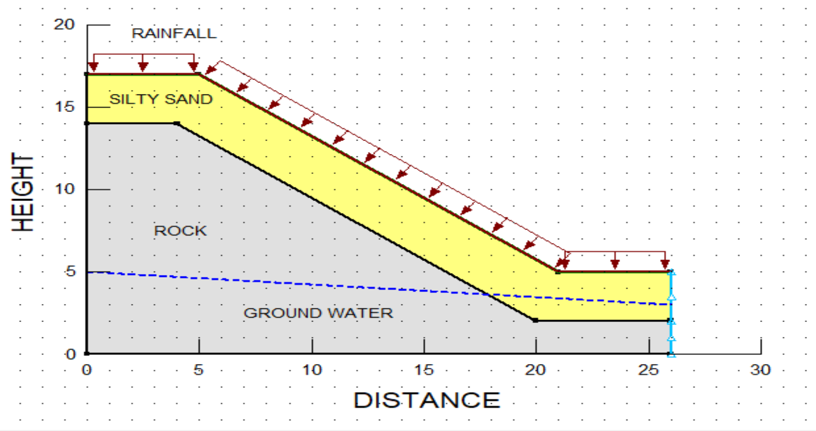

Fig. 2. The soil slope model

3 Results and Discussion

Limit equilibrium analysis is used to evaluate the Factor of Safety (FOS) of the rain-induced slope instability of Madenadu hillslope. The hydrological setting in the study area is deduced based on the available data from the Madenadu rain gauge station. The soil below the depth of 3 m is considered as the impermeable bedrock. The significant reduction in the values of FOS for soil slopes was reported. Therefore, in the present study, analyses are performed for the rain-induced shallow failures of the hillslopes of the Madenadu site.

Figure 3 shows the porewater pressure variation on the interface at summit, backslope and toeslope of the hill at a depth of 3 m i.e. soil-bedrock interface. The porewater pressure at summit and backslope varies from -50 kPa to 0 and 5 kPa respectively and at the toe, pressure varies from 10 kPa to 30 kPa . The pore water pressure is positive because the toe point lies under the groundwater table. At initial rainfall condition up to 9th day (09/08/2018), there are no significant changes in pore pressure due to low intensity rainfall. After 9th day of rainfall there is gradual increase of rainfall intesity which again leads to increase in pore pressure till 17th day (17/08/2018). Maximum pore pressure reached on 17th day of rainfall which remains constant after 17th day of rainfall. At summit and backslope there is a loss of matric suction due to the low pore pressure which causes loss of shear strength of soil particles. Evaluation of volumetric water content on the interface at summit, backslope and toeslope of the hill is shown in Figure 4. Volumetric water content at the toe slope is 0.3 throughout the rainfall duration due to the effect of the water table, it is under completely saturated state.

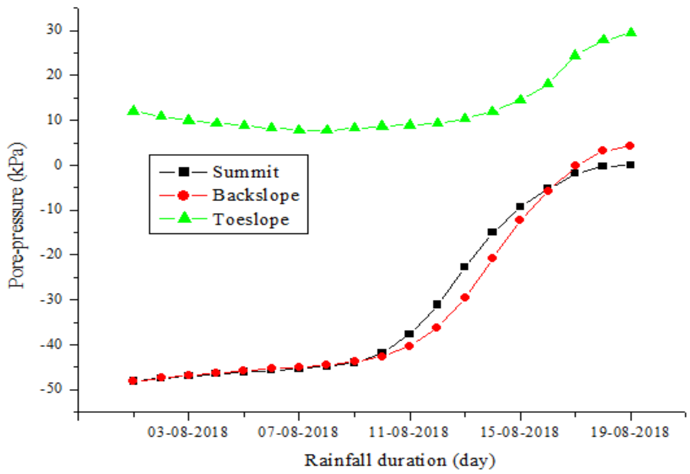

Fig. 3. Pore water pressure evolution on the soil bedrock interface at different positions

Volumetric water content at summit and backslope rising from 0.055 to 0.3 and both having a negligible difference. At summit and backslope, there is no change in volumetric water content up to 10th day (10/08/2018) of rainfall and after it reaches a value of 0.3 i e., saturated state on 17th day. Due to the disappearing of the unsaturated zone, the water table suddenly raises in slope which act as the lubricant in the interface.

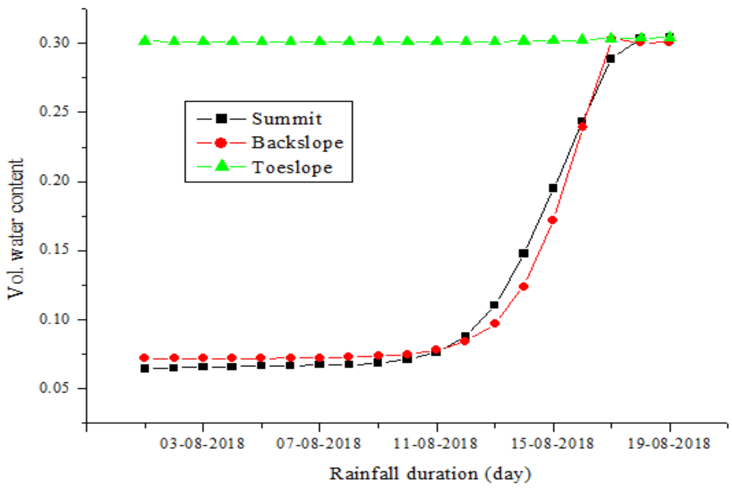

Fig. 4. Evolution of volumetric water content on the intersection line.

Figure 5 shows variations in FOS values with rainfall duration. At 17th day of antecedent rainfall, safety factor value reaches less than 1. Typically, slopes with a FOS 1.5 are said to be stable. Slopes with FOS values between 1.3-1.5 are said to be moderately unstable and FOS values between 1.0-1.3 are said to be inherently unstable. A FOS value of 1.0 indicates that the slope is at failure (Hoek 2007). Due to rainfall, the matric suction decreases resulting into reduction of shear strength values. The decrease in shear strength of soil results into decrease in the FOS of the slope and subsequently triggers landslides. It can be stated that the failure is due to loss of matric suction in the soil and a significant rise in groundwater.

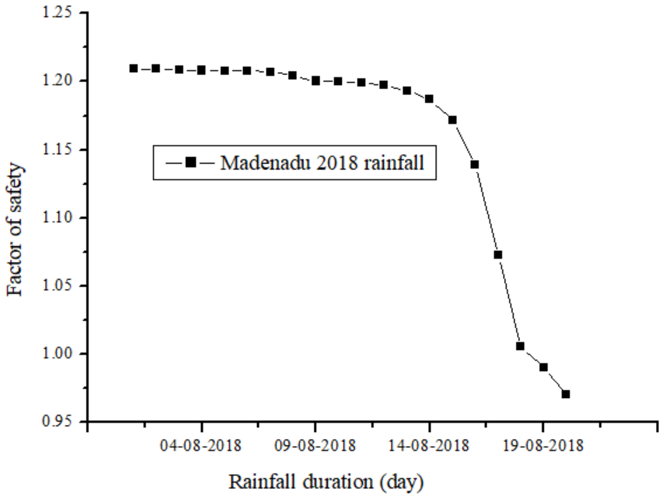

Fig. 5. Safety factor for time-varying rainfall.

4 Conclusions

In the present study combined seepage and slope stability analysis have been performed using SEEP/W and SLOPE/W respectively for different rainfall intensities and duration collected from the rain gauge station. The variations of pore pressure, saturation and FOS values are evaluated for partially saturated soils. Based on the results presented following conclusions are drawn:

1. The rainwater percolates into the soil layer which acts as the lubricant at the interface between the two different layers which causes soil mass to slide of.
2. The FOS and the matric suction decreases with rainfall duration to a minimum values less than 1 on the day of slope failure. The distribution of infiltrated rainwater in soil mass could be a reason for the sudden response of failure mechanism to rainfall.

3. The loss of suction from the unsaturated to saturated state causes a reduction in shear strength and raising of groundwater level causes a reduction of effective stress in the soil is the main reason for the slope failure.
4. The rainfall intensities and duration, saturated permeability of the soil, matric suction, and initial pore water pressure are understood as the main controlling factors for instability of slope.

References

1. Ahmad, M., Ansari, M. K., Singh, T. N.: Instability investigations of basaltic soil slopes along SH-72, Maharashtra, India. Geomatics, Natural Hazards and Risk, Vol. 6, pp. 115–130 (2013).
2. Acharya, K. P., Bhandary, N. P., Dahal, R. K., Yatabe, R.: Seepage and slope stability modelling of rainfall induced slope failures in topographic hollows. Geomatics, Natural Hazards and Risk ISSN: 1947-5705 (Print) 1947-5713 (Online) (2016).
3. Baba, K., Bahi, L., Ouadif, L., Akhssas, A.: Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods Applied to a Railway in the Moroccan Rif. Open Journal of Civil Engineering, pp. no.27-32 (2012).
4. Borja, R. I., Liu, X., Joshua: White Multiphysics hillslope processes triggering landslides. Acta Geotechnica, 7:261–269 (2012).
5. Collins, B. D., Znidarcic, D.: Stability analyses of rainfall-induced landslides. J Geotech Geoenviron Eng, 130:362–372 (2004).
6. Fredlund, D. G., Rahardjo, H.: Soil Mechanics for Unsaturated Soils. John Wiley & Sons, New York (1993).
7. Gupta, V., Rajinder, K. B., Amir, M. K., Kumar, V., Saini, A. S., Tandon, S. R., Pabst, T.: Finite element analysis of failed slope by shear strength reduction technique a case study for Surabhi resort landslide, Mussoorie township, Garhwal Himalaya. Geomatics, Natural Hazards and Risk, 7:5, 1677-1690 (016).
8. Janardhana, M., Vinutha, D. N., Al-Qadhi, A. A.: Landslide in Coorg district of Karnataka. International Journal of Innovative Research in Science Engineering and Technology, ISSN(Online): 2319-8753 ((2007).
9. Kakogiannou, K., Sanavia, L., Nicot, F., Darve, F., Schrefler, B. A.: A porous media finite element approach for soil instability including the second-order work criterion. Acta Geotechnica, 11:805–825 (2016).
10. Lee, M. L., Nurley, G. A.: Simple model for preliminary evaluation of rainfall-induced slope instability. Engineering Geology, 108:272−285 (2009).
11. Lee, M. L., Ng, K. Y., Huang, Y. F., Li, W. C.: Rainfall-induced landslides in Hulu Kelang area. Malaysia Nat Hazards 70:353–375 (2014).
12. Matthews, C., Farook, Z., Helm, P.: Slope stability analysis by limit equilibrium and the finite element method. Technical paper ground engineering (2014).
13. Mahmood, K., Kim, J. M., Ziaurrehman, Ashraf, M.: The effect of soil type on matric suction and stability of unsaturated slope under uniform rainfall. KSCE Journal of Civil Engineering, 20(4):1294-1299 (2015).
14. Parise M., Iovine, G. R., Reichenbach, P., Guzzetti, F.: Introduction to the special issue Landslides: forecasting, hazard evaluation, and risk mitigation. Nat Hazards, 61:1–4 (2012).

15. Rouaiguia, A., Dahim, M. A.: Numerical Modeling of Slope Stability Analysis. International Journal of Engineering Science and Innovative Technology (IJESIT) Vol 2, Issue 3, pp.533-542 (2013).
16. Regmi, R. K., Jung, K.: Application of dynamic programming to locate the critical failure surface in a rainfall-induced slope failure problem. KSCE Journal of Civil Engineering, 20(1):452-462 (2015).
17. Shin H., Kim, Y. T., Park, D. K.: Development of rainfall hazard envelope for unsaturated infinite slope. KSCE Journal of Civil Engineering, 17(2):351-356 (2012).
18. Sun, J. P., Liu, Q. Q., Li, J. C.: Effects of rainfall infiltration on deep slope failure. Chinese Academy of Sciences, vol. 52 no. 1 108-114 (2009).
19. Yagoda-Biran, G., Hatzor, Y. H., Amit, R., Katz, O.: Constraining regional paleo peak ground acceleration from back analysis of prehistoric landslides: Example from Sea of Galilee, Dead Sea transform. Tectonophysics- The International Journal of Integrated Solid Earth Scienses, pp. 81–92 (2010).
20. Hoek E.: Practical rock engineering (2007). e-book www.rocscience.com
21. Karnataka State Natural Disaster Monitoring Centre: An autonomous body, affiliated to the department of revenue, govt. of Karnataka (2018).
22. GeoSlope International Ltd.: SEEP/W user's guide for finite element seepage analysis. GEO-SLOPE International Ltd., Calgary, Alta.
23. GeoSlope International Ltd.: SLOPE/W user's guide for slope stability analysis. GEO-SLOPE International Ltd., Calgary, Alta.
24. IS 2386-Part 3: Determination of specific gravity, Bureau of Indian Standard, New Delhi (1963).
25. IS 2720-Part 4: Classification of soil by wet sieve analysis, Bureau of Indian Standard, New Delhi (1985).
26. IS 2720-Part 13: Determination of shear parameters using direct shear test, Bureau of Indian Standard, New Delhi (1986).
27. IS 2720-Part 17: Determination of permeability of soil using varying head permeability test, Bureau of Indian Standard, New Delhi (1986).
28. Deccanherald: https://www.deccanherald.com/state/mangaluru/landslides-trigger-fear-among-kodagu-residents-749174.html