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Slope Stability Analysis of Landslide Susceptible Areas - A Study in the Western Ghats, Kerala

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Abstract. Landslide occurrences are largely controlled by different causative factors. Geotechnical properties of soil viz-a-viz type of soil, density, cohesion, angle of internal friction, hydraulic conductivity, etc. affect the natural stability of slopes and therefore, these data can be utilized to determine the susceptibility of a slope to landslides. In this project, an attempt is made to analyze the stability of slopes especially in landslide prone areas in the Western Ghats, Kerala. For this, three different areas are selected viz-a-viz, Alathur, Vennikkulam and Pananchery in Kerala. These study areas are experiencing repeated slope failures at the onset of every South-West monsoon. With the help of soil data from laboratory experiments, rainfall data of the study area, and slope stability analysis using GeoStudio® software (using SEEP/W and SLOPE/W), the factor of safety of slopes in these study areas are obtained. It is found that Alathur in Palakkad district is more prone to the landslide as compared to the other two places. Software modelling can provide analytic frameworks for quantifying and understanding the underlying patterns of landslides under various local conditions. The results obtained from stability analysis, is useful in categorizing study areas into different classes based on their susceptibility to landslides. Such a study would be helpful for future land use planning and landslide mitigation in the study areas.

Keywords: slopes, stability analysis, landslide, soil properties, GeoStudio®, SLOPE/W, SEEP/W, landslide susceptible areas, Western Ghats

1 Introduction

Slope stability analysis is performed to assess the safe design of human-made or natural slopes (e.g., embankments, road cuts, open-pit mining, excavations, landfills etc.) and the equilibrium conditions. Slope stability is the resistance of inclined surface to failure by sliding or collapsing [1] – [14]. The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, and determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures [15]-[16]. The slope stability analysis can be executed using different software like GeoStudio® (SLOPE/W) Software. GeoStudio® (SLOPE/W) is modern limit equilibrium software useful to handle complexity within an analysis. It is now possible to deal with complex stratigraphy, highly irregular pore-water pressure conditions, and various linear and nonlinear shear strength models, almost any kind of slip surface shape, concentrated loads, and structural reinforcement. The results from stability analysis can be utilized for developing landslide susceptibility maps. Landslide susceptibility maps (Figure 1.3) helps in determining the likelihood of occurrence of landslide in most vulnerable areas.

Fig. 1. View of a landslide affected area [1]

The Western Ghats, the most prominent orographic feature of peninsular India, occupies 47% of Kerala state. With a total area of 38,863 km^2, it is the third most densely populated (819 people/km^2) state in the country (Census of India 2001). Even though the region once supported typical tropical forests and grasslands, substantially vast area has been cleared and converted into monoculture plantations and agricultural fields from the early 19th century onwards. All 13 of the 14 districts of Kerala except the coastal district of Alappuzha are prone to landslides. About 8% (1,400 km^2) of area in The Western Ghats of Kerala is classified as critical zone for mass movements [14]. The region experiences several types of landslides especially during the monsoon seasons. The project work is based on examining three slopes for its stability in the Western Ghats region of Kerala.

2 Materials and methods

The soil samples were collected from three different districts i.e., Pananchery in Thrissur district, Alathur in Palakkad district, and Vennikulam in Pathanamthitta district, from the Western Ghats region of Kerala state (Fig 2). Disturbed soil samples were collected from different locations. These samples were thoroughly mixed to obtain a representative sample and analysis of this sample gave the average value for the entire area. The soil samples from study areas were characterized in the Geotechnical Engineering Laboratory of Department of Civil Engineering at Rajagiri School of Engineering and Technology, Kochi, Kerala, as shown in Table 1.

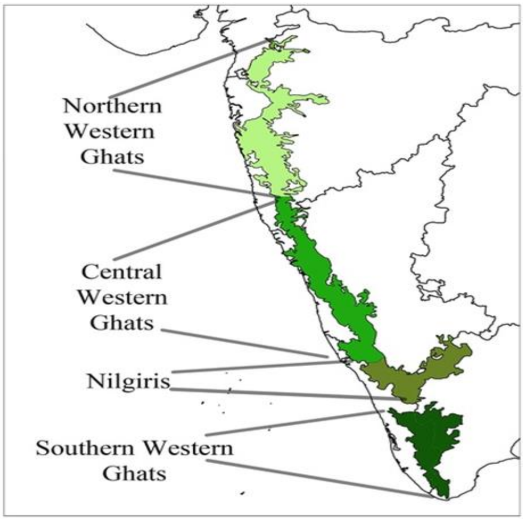


Fig 2: Western Ghats region of Kerala
[https://subratachak.wordpress.com/2017/02/04/deccan-plateau/]

Various index and engineering soil properties of the study areas were determined by following standard procedures and techniques. The steps involved were sample collection, laboratory tests, and software analysis. A composite sampling technique was used for soil collection. These collected samples were taken for laboratory tests to determine the values of soil properties like in-situ moisture content, specific gravity, dry density, cohesion, etc. These soil properties were utilized for slope stability analysis using GeoStudio® software.

Software modelling of rainfall-induced slope failure was carried out in GeoStudio® 2021. In this investigation, two components of GeoStudio® software were used i.e., SEEP/W and SLOPE/W. Several input parameters were required for both these analyses as shown in Table 2. SEEP/W analysis based on finite element method was first performed to determine the pore water pressure conditions of the slope and then SLOPE/W analysis based on limit equilibrium method to evaluate slope stability. Different steps involved in the modelling of SEEP/W and SLOPE/W is shown in the Figure 3.

Table 1. Properties of the soils used

Sr. No	Soil properties	Pananchery	Alathur	Vennikulam
1	Moisture content (%)	10	5.263	10.526
2	Specific gravity	2.083	2.220	2.353
3	Liquid limit (%)	26.367	28.237	31.552
4	Plastic limit (%)	14.28	12.92	19.09
5	Soil type	Clay of low plasticity	Clay of low plasticity	Clay of low plasticity
6	Coefficient of permeability (m/s)	3.74×10^{-5}	8.53×10^{-5}	3.91×10^{-4}
7	Maximum dry density (g/cc)	1.91	1.64	1.65
8	Optimum moisture content (%)	19.63	17.39	18.72
9	Effective cohesion (kPa)	29.42	8.34	39.23
10	Angle of internal friction	21^0	26^0	28.46^0

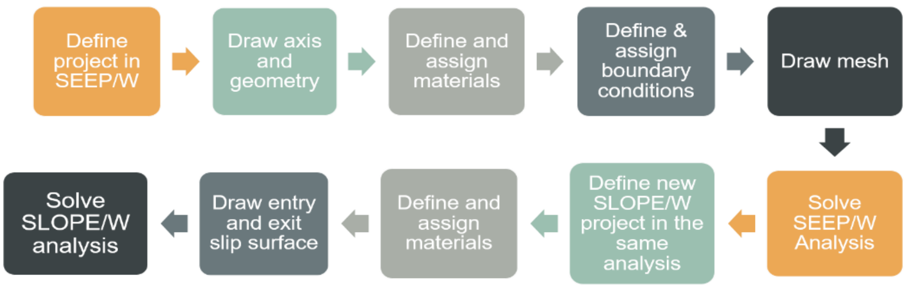


Fig. 3: Different steps involved in the modelling of SEEP/W and SLOPE/W

3 Results and discussions

Geotechnical characterization of the soils shows that the soil from Alathur has very low shear strength as compared to the other two samples. Figure 4 shows the grain size distribution and shear strength of different soils.

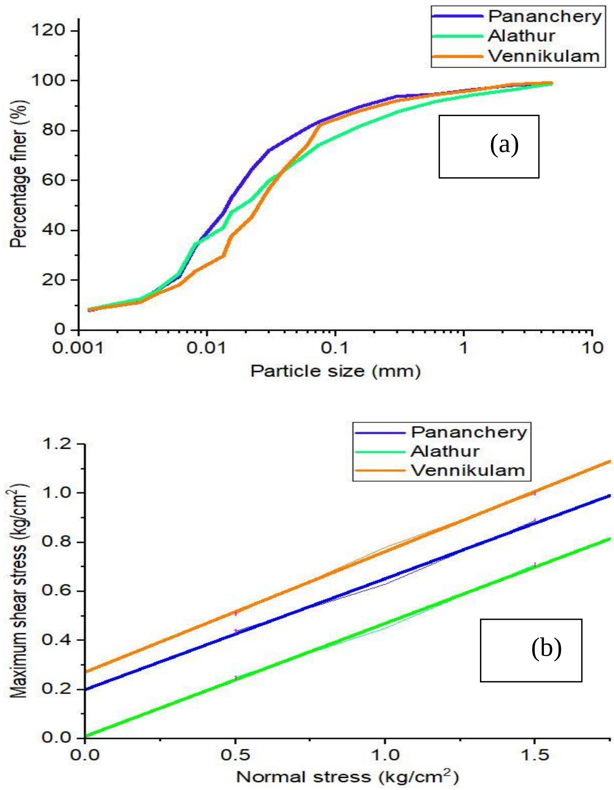


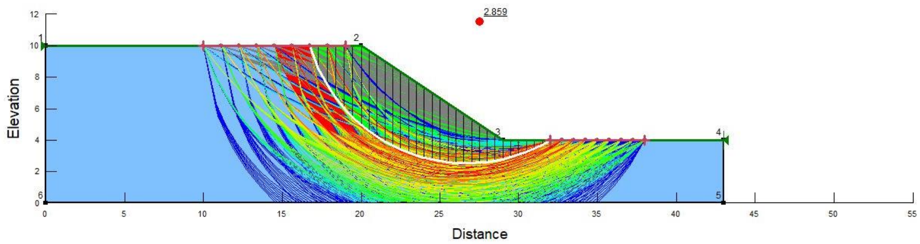
Fig. 4. (a) Grain size distribution curves and (b) shear strength distribution of different soils used in this study

Table 2. Input parameters for slope stability modelling

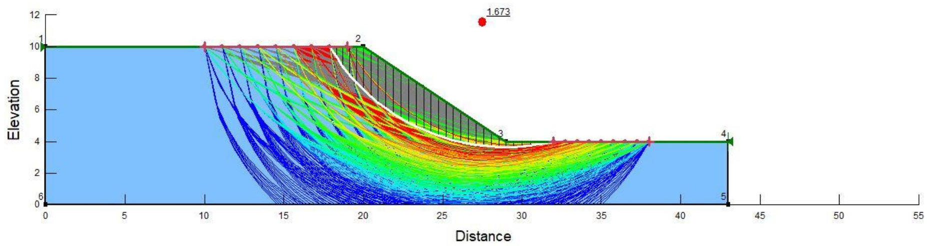
Input parameters	Pananchery	Alathur	Vennikulam
SEEP/W			
Rainfall flux* ($m^3/s/m^2$)	1.90 x 10^{-7}	1.61 x 10^{-7}	$1.71x10^{-7}$
Saturated hydraulic conductivity, K_x (m/s)	4.03	9.19	42.136
Water content (%)	10	5.3	11
SLOPE/W			
Unit weight (kN/m^3)	18.583	20.497	20.333
Effective cohesion (kPa)	29.42	8.34	39.23
Effective friction angle	21°	26°	28.46°

**(https://mausam.imd.gov.in/)*

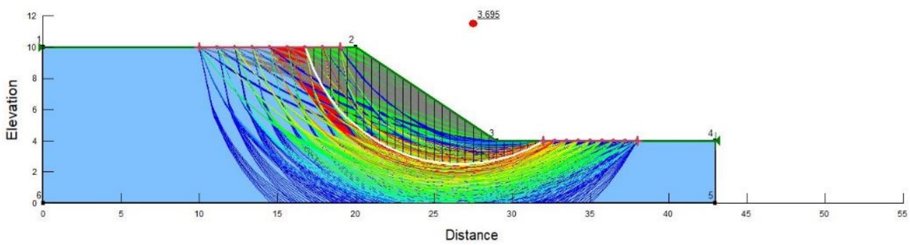
Built in finite element algorithm used in the SEEP/W and SLOPE/W solves the problem. As shown in the Figure 5, by solving the analysis in SLOPE/W window, the results were obtained in the form of slip surfaces indicated by different colours (Fig 5) and each colour indicating a range of factor of safety values as obtained from the output values. The critical slip surface was drawn in white colour. Also, the results were represented with the pore-water pressure conditions along with their critical slip surface (Fig 6). The factor of safety of the critical slip surfaces of the study areas are shown in Table 3. The factor of safety value is minimum for Alathur and hence is more susceptible to landslides among the three study areas.



(a) Pananchery



(b) Alathur

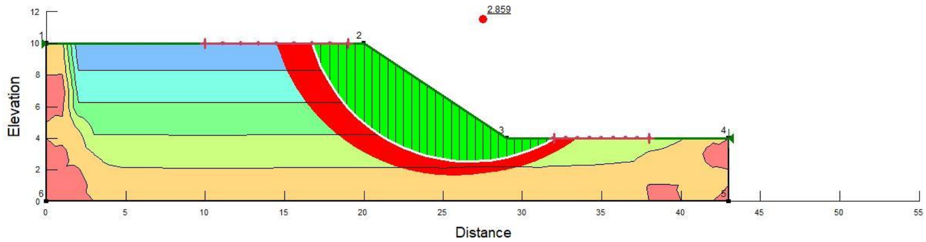


(c) Vennikkulam

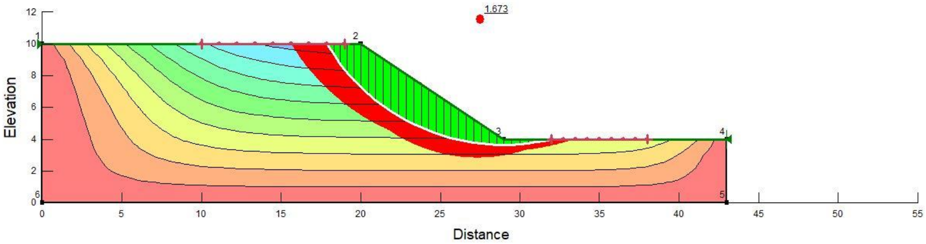
Fig 5: Factor of safety of slip surfaces of slope (from SLOPE/W) for different soils used in this study

Table 3: Factor of safety of slopes obtained from SLOPE/W

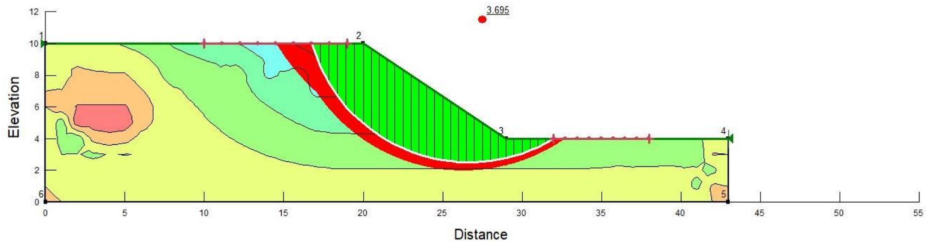
Study Area	Factor of safety
Pananchery	2.859
Alathur	1.673
Vennikulam	3.695



(a) Pananchery



(b) Alathur



(c) Vennikkulam

Fig 6: Pore water pressure (from SLOPE/W) at the slope for different soils in this study

4 CONCLUSION

The results of laboratory investigations were used to characterize the soil samples and the factor of safety values of these study areas were obtained from software modelling. These factor of safety values might be utilized for comparing the landslide susceptibilities among the three study areas. This comparison helped in identifying highly prone areas. Implementing remedial measures like slope geometry modification, installation of piles, retaining walls, etc. in highly susceptible areas can prevent the occurrence of rainfall-induced landslides in future.

There are some limitations for this study. For a slope stability analysis, the most important inputs are realistic shear strength parameters of the soils. For this undisturbed samples are required. However, in this study disturbed soil samples were used due to non-availability of the equipment for undisturbed sampling. Since, this study was a part of undergraduate project work, the time-constraint cannot be ignored and the soil characterization and the drained triaxial tests were conducted within the limits of an undergraduate's soil mechanics laboratory available in the Rajagiri School of Engineering and Technology.

The factor of safety (FS) for the three locations were found in the range of 1.67 to 3.70. It is reported in the literature that the values of FS may range between 2.5-3.5. [17]. It is likely that the high factors of safety might have resulted from the high values of effective cohesion considered in the analysis. It is possible that the actual values of cohesion are much lower and actual factors safety are less and there could be a landslide risk. These are considered as the limitations of the current study. For completeness of the current study, some slope protection or landslide remedial measures were suggested by the authors, in general. Determination of some of the parameters might have affected by the human errors, in preparing testing samples, which were beyond the control.

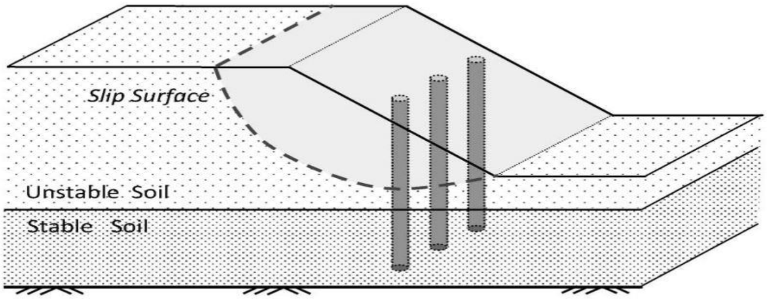


Figure 5.1 : Row of stabilizing piles embedded within a slope that is prone to failure [16]

The GeoStudio® software (SLOPE/W and SEEP/W)was used as a tool to predict the landslide susceptibility of three regions of the Western Ghats region in Kerala, depicting the difference in susceptibility values for the three different landslide prone regions. With the use of additional conditioning factors and more sampling from different areas of Western Ghats, the results can be made more accurate and realistic and hence can serve as an effective tool for large scale landslide susceptibility map preparation. Methodology used in this investigation can pave the way to save human life and their livelihoods from the impacts of massive landslides.

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