Stability Analysis of an Unstable Slope at Kanjikuzhi, Idukki using GEO5 Software

Aswathi Shaju[1], Fabitha KJ[1], Shabhanam PS[1], Jerin Joseph[2] and Sheeja MK[2]

[1] Former B. Tech student, Department of Civil Engineering, Albertian Institute of Science and Technology, Kochi
[2]Assistant Professor, Department of Civil Engineering, Albertian Institute of Science and Technology, Kochi

Abstract. Landslide is an instant event during which mass movement of soil takes places down a slope, causing damage to life and property. Kanjikuzhi, Idukki district, is a highly susceptible landslide-prone area according to the District Disaster Management Plan Idukki, 2015. A sloping area was selected for soil sample collection, and the geotechnical parameters were determined in the laboratory. The terrain characteristics, which include the geometry of the slope, was determined using google earth pro and GPS visualizer. The modelling of the slope and its analysis was carried out using GEO5 software to find the factor of safety of the slope, which determines its stability. The slope was found to be unstable with a factor of safety of 1.35. A parametric study using three mitigationmeasures namely anchors, soil nail and anti-slide pile was carried out using the software. The parametric study revealed that the slope can be stabilized to a max-imum factor of safety of 1.81, 1.65, and 1.66 using the anchors, anti-slide piles, and soil nails, respectively.

Keywords: Slope stability; Landslide mitigation; Anchor; Anti-slide pile; Soil nail; GEO5 software

1 Introduction

1.1 Background

A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. The causes of landslides are usually related to the strength of the soil in the slopes. A slope instability results in loss of life and damage to infrastructure. The Western Ghat region of Kerala is susceptible to landslides, especially during the monsoon season. Most landslides have hit these mountainous regions of Kerala during heavy rainfall. The landslides have caused several fatalities and serious damage to the infrastructure in these regions. Several methods are available to stabilize the slope and increase the factor of safety. The most prominent mitigation measure includes soil nails, anchor blocks, and anti-slide piles.

An anchor is a structural member which transmits an applied tensile force to a capable soil mass. The tensile force is resisted by shear strength of the surrounding ground. The commonly used length of the anchor bar ranges from 9 to18 m, and the angle are in the range of 10 to 45° with respect to horizontal. The optimum condition of providing anchors is chosen through trial-and-error method done during the stabilization checks. Anti-slide piles are vertical structural elements that increase slope stability. The anti-slide piles are used to stabilize large landslides. Once installed, the anti-slide piles act as a wall that intersects a slip surface and helps prevent further landslides. The piles usually have a large cross-section, which may be circular or rectangular. The commonly used lengths are 9 to 50 m and pile spacing of about 5 to10 m. Soil nailing is a ground stabilization technique that can be used on either natural or excavated slopes. It involves drilling holes for steel bars to be inserted into a slope face which are then grouted in place. The length of nails varies from 4 to18 m, and nail angle is in the range 10-25° with respect to horizontal. The nails act as reinforcing, passive elements that are drilled and grouted sub-horizontally in the ground to support excavations in soil or in soft and weathered rock

This paper presents a study of an unstable slope from a landslide-prone area at Kanjikuzhi, Idukki district. A parametric study was conducted to analyze the change in stability of a slope when three different mitigation measures were used. The stability analysis of the slope was carried out using the GE05 software. GEO5 has a slope stability program that computes the stability of slopes and embankments with a circular or polygonal slip surfaces. In the present study, the GEO5 software was used to model a circular slip circle using Bishop's method and calculate the slope safety factor with and without mitigation measures. The geotechnical parameters of soil and the slope geometry are used for the stability analysis of the slope, including the characteristics of soils and the geometry of the slope.

1.2 Literature review

Kumar and Premalatha (2021) conducted a study on the Stability analysis of slopes during monsoon in Nilgiris. In this study, two sites were selected where landslides occurred during the monsoon in November 2009. A detailed investigation was carried out once the index properties, chemical composition, and shear strength parameters were drawn. The critical surface for the slope was drawn graphically using the Fellenius method, and the same was incorporated into the software through coordinates. The analysis was carried out using wetting depths of 2, 3, and 5m at the edge of the slopes and shear strength parameters in GEO5 and PLAXIS 2D software. The analysis result showed that the infiltration of water into the slope results in the reduction of the shear strength parameter of the soil, leading to slope failure. Sharma et al. (2012) conducted a study on slope stability analysis using software GEO5 and C Programming language. The site selected was adjacent to national highway number NH 22, connecting Shimla to Dharamshala via Hamirpur. Factors such as soil cohesion, angle of internal friction, and unit weight of soil were found using lab experiments. Basic geometrical characteristics of the slope were found using a total station survey, and it was used to generate contour maps. The analysis was performed using Bishop's method. Varghese and Isaac (2008) conducted a study on FEM Analysis of Slopes in Idukki using GEO5. In this study, experimental analysis was done to reveal the given sample parameters like cohesion, angle of internal friction, Young's Modulus, and Poisson's ratio. Accordingly, various preventive or remedial measures were taken to stabilize such slopes. The main aim of the study was to evaluate the stability of the slope and its factor of safety before its failure and find out the failure mechanism if a slope has failed in order to propose the appropriate remedial measure and its design. According to Shiferaw (2021), decreasing slope angle and slope height increases the slope factor of safety and can change the shape of the likely slope failure. The increase in the factor of safety is at different rates, which can depend on soil type and slope geometry. Understanding the relationship between the slope height and angle decrease with the increase in the factor of safety is vital to implementing an efficient method of increasing the factor of safety for slope stability problems. In addition, the shape of slope failure has to be observed thoroughly, not to increase the sliding mass of soil for a likely slope failure, even though the factor of safety has increased. The factor of safety of slopes had increased with slope height, and angle decrease, the rate of increases and thus the efficiencies are different which depended on the type of soil and geometry. Rawat and Gupta (2016) used the Finite element method to study the response of unreinforced and soil nailed slope when gradually increasing surcharge load is applied on sand soil slopes of angles 45° and 60°, the soil nails were installed at different inclinations of 0°, 15°and 30°. It was concluded that out of unreinforced and reinforced slopes for both 45° and 60° slope inclination, the reinforced slope undergoes rotational failure. An increase in load carrying capacity was found to be maximum for 0° nail inclination for both 45° and 60° slope and was maximum for 60° slope than 45° slope, i.e., soil nailing is more effective on greater slopes.

2 Methodology of study

An unstable slope was identified in the report prepared by the district disaster management plan, Idukki, 2015. Soil samples were collected from the site to determine the geotechnical properties. The geometry of the slope was found using google earth pro. The soil properties and the slope geometry served as the input for the GEO5 software. The FOS was determined using the GEO5 software for the unstable slope. A parametric study was conducted using three mitigation methods namely earth anchors, anti-slide piles, and soil nails to stabilize the unstable slope. An Earth Anchor acts as a structural member and transmits the applied tensile force to stable ground. The tensile force is resisted by shear strength of the surrounding ground. Anti-slide piles act as vertical structural elements, and prevents the sliding of the soil mass. The pile intersects a slip surface and helps prevent further landslide. Soil nailing is a ground stabilization technique that can be used on either natural or excavated slopes. It involves drilling holes for steel bars to be inserted into a slope face which are then grouted in place.

3 Study area and soil properties

3.1 Selection of study area

The study area was finalized from the district disaster management plan, Idukki, 2015. A slope was selected from the study areas based on the observation made during the visit to the area. Idukki district experiences extreme rainfall every year. This has resulted in flooding and landslide hazards leading to deaths and severe destruction of property. The slope under study is located in Kanjikuzhi, Idukki district, Kerala, which covers a total area of 227.51 sq. km. The slope is shown in Fig. 1.

Fig. 1. Slope in Kanjikuzhi

3.2 Geometry of slope

The geometry of the slope was obtained by plotting the coordinates. The coordinates that were required for plotting the different points in a study area slope were obtained using google earth pro. The google earth pro file was input into a GPS visualizer, an online utility that creates maps and profiles from geographic data to get a GPX file (GPS data file). Then the GPX file is converted into an excel file using an appropriate converter. The altitude, longitude, and latitude were obtained from a Microsoft excel file. The coordinates were then manually entered in GEO5 software to generate the slope geometry. The plot of the cartesian points for generating the geometry of the slope in GEO5 software is given in Fig 2.

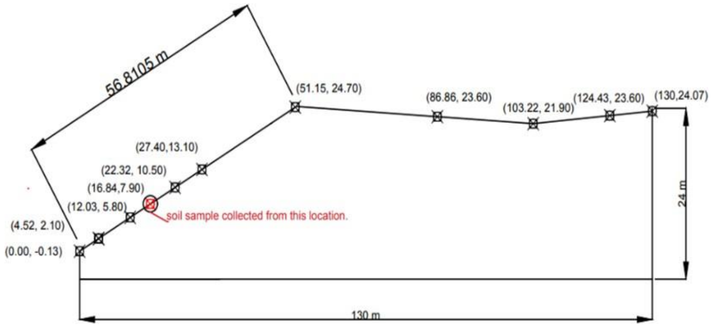

Fig. 2. Geometry of the slope with soil collection location.

3.3 Soil properties

Detailed experimental investigations were carried out on soil samples obtained from a location on the slope (Fig. 2). A pit was dug at the site, and the density of the soil was found using the core cutter method. The soil was collected and sealed in containers for conducting laboratory tests. Sieve analysis and hydrometer analysis revealed the soil type as SW-SM as per. The shear parameters, i.e., cohesion and angle of friction, were determined using direct shear tests. The in-situ water content of the soil was found using an oven dry test and specific gravity using a pycnometer test. The geotechnical properties of the soil are as given in table 1.

Table 1. Geotechnical properties of the soil collected from the slope.

Property	Result
Specific Gravity	2.71
Water Content	19.84%
Field Density	17.5 kN/m³
Angle of Internal Friction	32.94°
Cohesion	0.095 kPa

4 Details of parameters

4.1 Anchors

The parametric study on stabilization of slope using anchor is done by varying the free length (L) of anchor and the slope (α) of the anchor. The tensile capacity and diameter of the anchor were kept constant during the study. The tensile capacity of the anchor was taken as 240 kN. A total number of 126 cases were modeled. The variable parameters and their range are given in Table 2.

Table 2. Details of anchor variable parameters.

Sl. No.	Parameter	Symbol	Range
1	Anchor Spacing	b (m)	1, 2 and 3
2	Free Length	L (m)	3,6,9,12,15 and18
3	Anchor slope	α (°)	7.5, 10, 12.5, 15, 17.5, 20 and 22.5

4.2 Anti-slide Pile

The analysis of slope stabilized using anti-slide piles was carried out by considering maximum bearing capacity as a constant of 300 kN. A total of 108 cases were modeled. The variable parameters and their range are given in Table 3.

Table 3. Details of anti-slide variable parameters.

Sl. No.	Parameter	Symbol	Range
1	Diameter of anti-slide pile	d (m)	0.5, 0.75 and 1
2	Length of anti-slide pile	L (m)	3, 6, 9, 12, 15 and 18
3	Anti-slide pile spacing	b (m)	5, 6, 7, 8, 9 and10

4.3 Soil Nailing

The slope stabilization analysis using soil nails included constant parameters tensile strength of nail (300 kN), pull-out resistance (25 kN/m) and nail head strength (40 kN).

A total number of 126 cases were modeled. The details of the variable parameters are given in Table 4.

Table 4. Details of soil nailing variable parameters.

Sl. No.	Parameter	Symbol	Range
1	Soil nail spacing	b (m)	1, 2 and 3
2	Soil nail length	L (m)	3, 6, 9, 12, 15 and 18
3	Soil nail inclination	α (°)	7.5,10,12.5, 15, 17.5, 20 and 22.5

5 Results and Discussion

5.1 Stability of unreinforced slope

The unreinforced slope was found to be unstable with a FOS of 1.35, which is less than 1.5 which is required for a stable slope. The results show that the slope is highly susceptible to slope failure. Since the slope is not stable, mitigation measures need to be adopted to stabilize it.

5.2 Anchors

Figure 3 shows the variation of FOS for the three different anchor spacings.

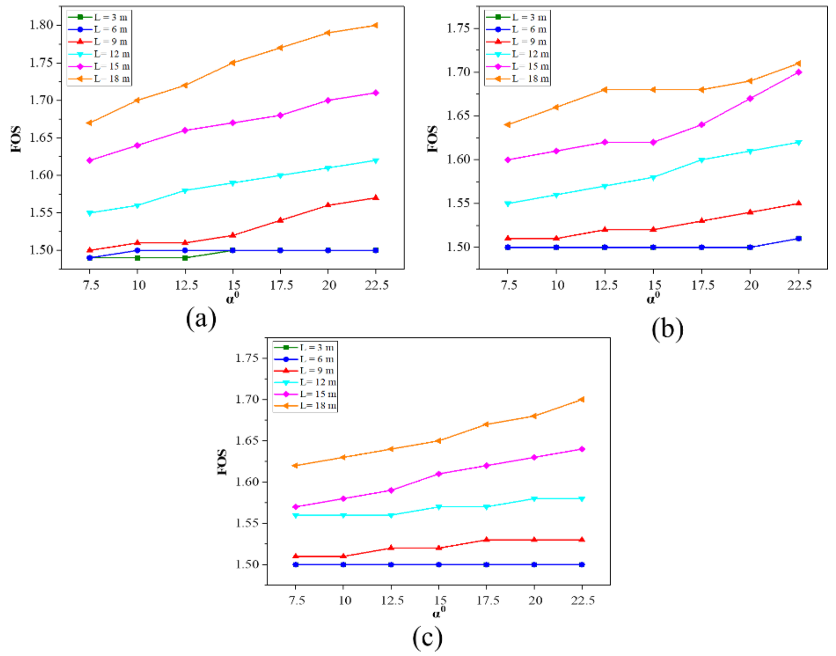

Fig. 3. Variation of FOS with respect to anchor slope of anchor for spacing (a) b = 1m (b) b = 2m and (c) b = 3m

The FOS of slope stabilized with anchors varies with the change in its length, slope, and spacing. A maximum FOS of 1.81 was obtained for an anchor spaced at 1m and length of 18m, and slope of 22.5° (Fig. 3(a)). It was observed that the FOS increased with an increase in the slope and a decrease in the spacing for anchor length greater than or equal to 9m. However, for the length of the anchor less than 9m, there was almost no change in the FOS with an increase in slope angle.

5.3 Anti-Slide Pile

The output of the analysis of the anti-slide pile in terms of FOS is presented in tables 5 to 7.

Table 5. Variation of FOS for anti-slide pile with d = 0.5m

Pile Spacing (m)	L= 3m	L=6m	L=9m	L=12m	L=15m	L=18m
5	1.58	1.58	1.65	1.65	1.65	1.65
6	1.58	1.58	1.64	1.64	1.64	1.64
7	1.58	1.58	1.63	1.63	1.63	1.63
8	1.58	1.58	1.62	1.62	1.62	1.62
9	1.58	1.58	1.62	1.62	1.62	1.62
10	1.58	1.58	1.61	1.61	1.61	1.61

Table 6. Variation of FOS for anti-slide pile with d = 0.75 m

Pile Spacing (m)	L= 3m	L=6m	L=9m	L=12m	L=15m	L=18m
5	1.58	1.58	1.63	1.65	1.65	1.65
6	1.58	1.58	1.63	1.64	1.64	1.64
7	1.58	1.58	1.63	1.63	1.63	1.63
8	1.58	1.58	1.62	1.62	1.62	1.62
9	1.58	1.58	1.62	1.62	1.62	1.62
10	1.58	1.58	1.62	1.62	1.62	1.62

Table 7. Variation of FOS for anti-slide pile with d = 1 m

Pile Spacing (m)	L= 3m	L=6m	L=9m	L=12m	L=15m	L=18m
5	1.58	1.58	1.64	1.65	1.65	1.65
6	1.58	1.58	1.63	1.64	1.64	1.64
7	1.58	1.58	1.63	1.63	1.63	1.63
8	1.58	1.58	1.62	1.62	1.63	1.63
9	1.58	1.58	1.62	1.62	1.62	1.62
10	1.58	1.58	1.61	1.61	1.61	1.62

The FOS of slope stabilized with anti-slide piles vary with the change in anti-slide pile length, spacing, and diameter. An optimum FOS of 1.65 was obtained for the anti-slide piles of diameter 0.5m spaced at 5m (Table 5). It was observed that for a given diameter the FOS increases with increase in the length up to a certain value after which it becomes almost constant. An anti-slide pile length of 9m can be said to be the optimum.

5.4 Soil Nailing

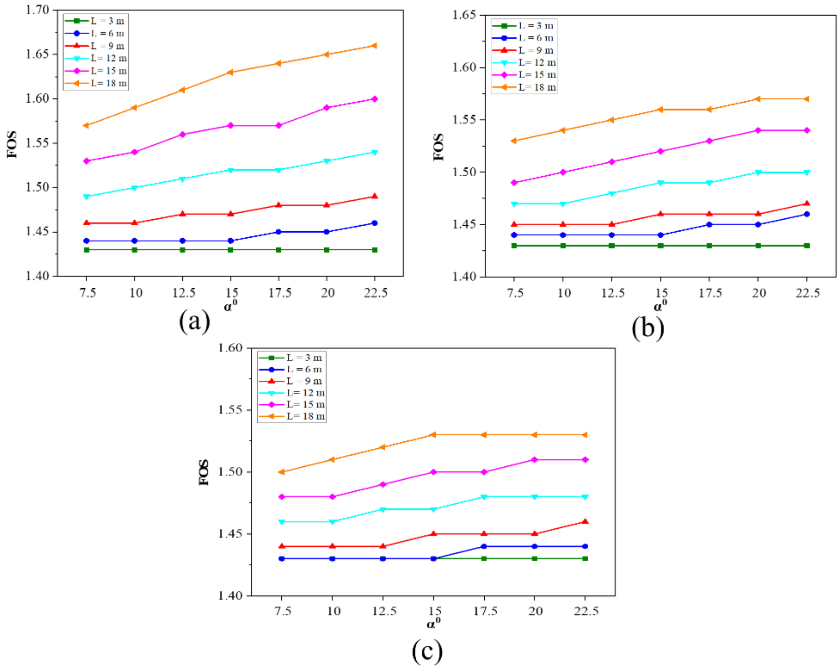

Fig. 4. Variation of FOS with respect to soil nail inclination for spacing (a) b = 1m (b) b = 2m and (c) b = 3m

Figure 4 shows the variation of FOS for the three different anchor spacings. The FOS of slope stabilized using soil nailing varies with the change in length, slope, and spacing. For soil nail length 3m the FOS remains a constant with increase in soil nail inclination for all the spacing values. In case of 6m soil nails, there is no change in the FOS with increase in soil nail inclination up to 15° after which it increases. For the soil nail length greater than 9m there is almost a linear increase in the FOS with increase in the inclination angle. A maximum FOS of 1.66 was obtained for soil nails spaced at 1m and length of 18m at an inclination of 22.5° (Fig. 4(a)).

6 Conclusions

At Kanjikuzhy, a highly susceptible area was identified from the report prepared by the district disaster management plan, Idukki,2015. A slope stability analysis was carried out using GEO5 software with and without mitigation measures. From the study following conclusions can be drawn.

- When the slope was analyzed, FOS was found to be 1.35 indicating that it is unstable.
- The FOS of the slope stabilized using the anchor increases with an increase in its length and decrease in spacing.
- The highest FOS, 1.71 is given by an anchor having spacing 1m, length of 18m, and slope angle of 22.5°.
- The FOS of the slope stabilized using the anti-slide pile increases with an increase in its length up to a certain value after which it becomes a constant. A maximum FOS of 1.65 can be achieved using anti-slide piles.
- The stability provided by the soil nail improves linearly for soil nail lengths greater than 9m with an increase of nail inclination.
- A maximum FOS of 1.66 was obtained for soil nails spaced at 1m and length of 18m at an inclination of 22.5°.

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