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A Comparative Study on Stability of Kootickal Slopes During 2021 Landslide By means of GeoStudio And Plaxis 2D

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Abstract. A landslide occurs when a mass of rock, debris, or earth slides down a slope under the influence of gravity. In the current study, Kootickal of Kottayam district has been selected where landslides and heavy floods occurred in 2021 due to a torrential downpour triggered by the formation of a low depression zone in the Arabian sea. In the current study, an analysis was performed using two different software packages (GeoStudio and Plaxis 2D), and stability characteristics were observed. Each software implements standards and partial factors differently and is used worldwide, so a comparison is necessary. The present study also discusses an analysis of software results and mitigation methods for reducing landslides. In order to determine whether a slope is stable against sliding, it is necessary to compare the software's output factor of safety with standards. Based on the analysis, the slope failed due to a reduction in the shear strength parameter of the soil due to water infiltration.

Keywords: landslide, slope stability analysis, GeoStudio, Plaxis 2D.

1 Introduction

In many countries, natural hazards such as floods and landslides are major challenges, and they are being addressed with immense resources and technologies[1–4]. It is well recognised that landslides triggered by rain are among the most catastrophic hazards on hilly terrains [3, 5, 6]. The most devastating landslides occur in developing countries and they cause significant damage and loss of life worldwide [7–9]. It is known that a lack of knowledge about these hazards has a significant negative impact on socioeconomic development in developing countries. Mathematical and numerical models have been developed today to identify and assess areas susceptible to rainfall-induced landslides [10, 11]. The stability of slopes can be affected by various factors, including rainfall, melting snow, temperature changes, tremors and vibrations on earth, volcanic activity, and anthropoid activity [12–15].

The phenomenon of landslides has been studied geotechnically and numerically over the years. At the crest and toe of the hill, informal settlements and unplanned hill cutting are responsible for most landslides' casualties. Numerical analysis is one of the valuable methods to investigate landslide risk. In addition to providing a fast and simple way for computing slopes with complex geometries, numerical methods using the plane strain model and ϕ-c reduction techniques can be effective in modeling slopes with complex geometries.

The current study aims to accomplish the following objectives:

- An investigation of the geotechnical aspects of the disaster.
- To do a comparative study on the stability of Kootickal slopes during 2021 landslides using GeoStudio And Plaxis 2D.
- An attempt to identify the reasons and to suggest precautionary steps to prevent such disasters.

2 METHODOLOGY

- Detailed geotechnical investigations are carried out.
- The disturbed soil samples are taken to identify the failure zones and determine their shear strength parameters.
- Laboratory tests are conducted on disturbed soil samples, such as grain size distribution and specific gravity.
- Experimental results are used to obtain input soil parameters for numerical modelling.
- Numerical modelling of the failed slopes using Plaxis 2D software is carried out.
- Precautionary steps to prevent landslides are suggested.

3 Study Area

The soil collected for the current study is from the selected landslide-affected areas, Kootickal and Kokkayar. On 16 October 2021, A successions of landslides struck the top eastern ranges of the Kottayam district. The leading cause of the landslide is assumed to be heavy rainfall due to the development of a low-pressure area in the Arabian Sea. This is the worst case of rain-related damage ever recorded in Kottayam. Koottickal panchayat in Kottayam was severely affected, two landslides caused the destruction of three houses and a tea shop reported in Plappally and Kavali. The catastrophe also resulted in the loss of 13 lives. Structural damages include the damages caused to five bridges and two footbridges. Figure 1 shows the landslide that occurred in Kootickal.

Topography: The place is located on NH 220 (Kottayam-Kumily Road), it is 2,000 feet (610 m) above sea level, 55 kilometers north of Kottayam and 5 kilometers from Mundakayam region.

Geomorphology: Natural boundaries divide the district into highlands, midlands, and lowlands. Kanjirapally taluks have highland and midland areas with forest trees. These trees are underlain by forest soil, followed by weathered crystalline rock fragments and weathered bedrock below 5m thick laterite. In addition to having a vesicular structure, they consist primarily of iron and aluminium oxides that have been hydrated. Despite

Kottayam's tropical climate, which is moderately pleasant and moderate, it doesn't have any distinct seasons. In this district of Kerala, the average annual temperature ranges from 20^{0}C to 35^{0}C as a result of high to moderate humidity levels. Pre-monsoon rains in this district feature lightning and thunder during the months of March, April, and May, when it is warmer.

Fig. 1. Shows landslide at Kuranjeri on 16/10/21.

Rainfall: According to the table below, it rained heavily during the occurrence of the landslide in the Kottayam district collected from Mundakayam RH Station.

Table 1. Rainfall data of the year 2021.

Month	September	October	November
Rainfall (mm)	415.6	1270	821.8

4 Materials and Methods

The experimental program includes collecting soil samples from landslide-affected sites, and different tests are to be carried out on the collected soil samples. Sample testing was performed for the samples which were taken from slopes near the landslide that had failed and from a slope adjacent to the landslide that had remained stable to determine soil engineering properties and indexes. Laboratory tests was conducted on the collected soil samples. The engineering properties as well as the index properties of the collected samples were determined. The grain size distribution curves were also plotted. The total shear strength parameters such as cohesion intercept and angle of internal friction were calculated from the results of the laboratory direct shear test on the disturbed samples. The soils were classified based on the test results obtained from the laboratory index property determination tests. The experimental investigation results were thereafter used to calculate the input soil parameters for numerical modelling.

The preliminary test includes

- Determining soil density with a core cutter
- Calculation of Moisture Content
- Determination of Specific Gravity
- Grain Size Distribution: Sieve Analysis
- Direct shear tests

The analysis of test results obtained from the laboratory experiments helps to determine the factor of safety values that were observed and compared. Two geotechnical software, GeoStudio and PLAXIS 2D, are used in this study. Both software studies were conducted using soil properties, and the data collected from the field and the corresponding safety values factor were observed and compared. Soil properties used for the study is listed in Table 2.

Table 2. Soil properties

	Location	**Bulk Density(kN/m³)**	**Water Content (%)**	**Specific Gravity**	**Soil Classification**	**Angle of shearing resistance(Φ)**
KOKKAYAR	1	19.44	20.75	2.3	Poorly graded sand	30°
	2	19.79	23.14	2.22	Poorly graded sand	29°
	3	19.02	16	2	Poorly graded sand	28°
KAVALI	1	19.29	13.51	2.88	Poorly graded sand	27°
	2	18.24	13.33	2.5	Poorly graded sand	37°
	3	20.35	18	2.5	Poorly graded sand	37°
PLAPPALLY	1	19.92	20	2.7	Poorly graded sand	39°
	2	18.11	19.17	2.5	Poorly graded sand	35°
	3	19.71	19.33	2.66	Poorly graded sand	38°

4.1 Plaxis 2D

Geotechnical engineers can analyse deformation, stability, and flow using PLAXIS 2D, an authoritative and comprehensible finite element package. Enhancements to the output facilities enable the presentation of numerical results in a detailed manner. The

PLAXIS package requires minimal training for new users to begin using it. Many geophysical applications are available, including excavations, embankments, foundations, tunnels & mining and reservoirs.

4.2 GeoStudio

Software such as GeoStudio is instinctive and easy to use. The GeoStudio software allows you to duplicate the stabilityof slope and deformation of the ground. The GeoStudio programs implement basic geotechnical approaches that are applicable worldwide. In addition to simplifying a designer's work, GeoStudio offers comprehensive compliance with all requisite approaches while simultaneously simplifying their work.

5 Results and Discussion

5.1 Plaxis 2D Analysis

PLAXIS 2D software is used to determine the displacement profile and safety factor. The slope is analysed as a plane strain model. Displacements and strains in the z-direction are assumed to be zero. However, normal stresses in the z-direction are completely considered for the analysis. The model considered for the Plaxis 2D analysis was mohr-Columb model. The input parameters were obtained from the test results of soil samples.

All the slopes were modelled and analysed using the software Plaxis 2D. The analysis shows that the safety factor of all nine landslide slopes is less than 1. 015. According to the literature, a FOS less than 1.4 is uncertain for the hills and dams, and a FOS less than 1.0 is unsafe. The calculated FOS states that nearly all slopes are supposed to fail, and some are likely to fail. Heavy rainfall might make slopes with more than 1 FOS unstable. Due to the lack of clay matter in the slopes, the FOS is the minimum. Hence due to the absence of a cohesion parameter, the significant shear strength is provided only from the friction angle.

Based on the numerical analyses, failure patterns are observed for each case. It is observed that for slopes, the failure surface intersects at the toe of the slope (toe failure). Sandy soils with moderate to high friction angles and little cohesion, accompanied by steep slopes, are commonly affected by this failure. Several studies have suggested that hills with slope angles greater than the internal angle of friction tend to collapse. In the current research, the Φ values of the prevailing slopes are smaller than the slope angles, contributing to the slope's instability. Figure 2 shows the factor of safety values of slopes 1,5, and 8.

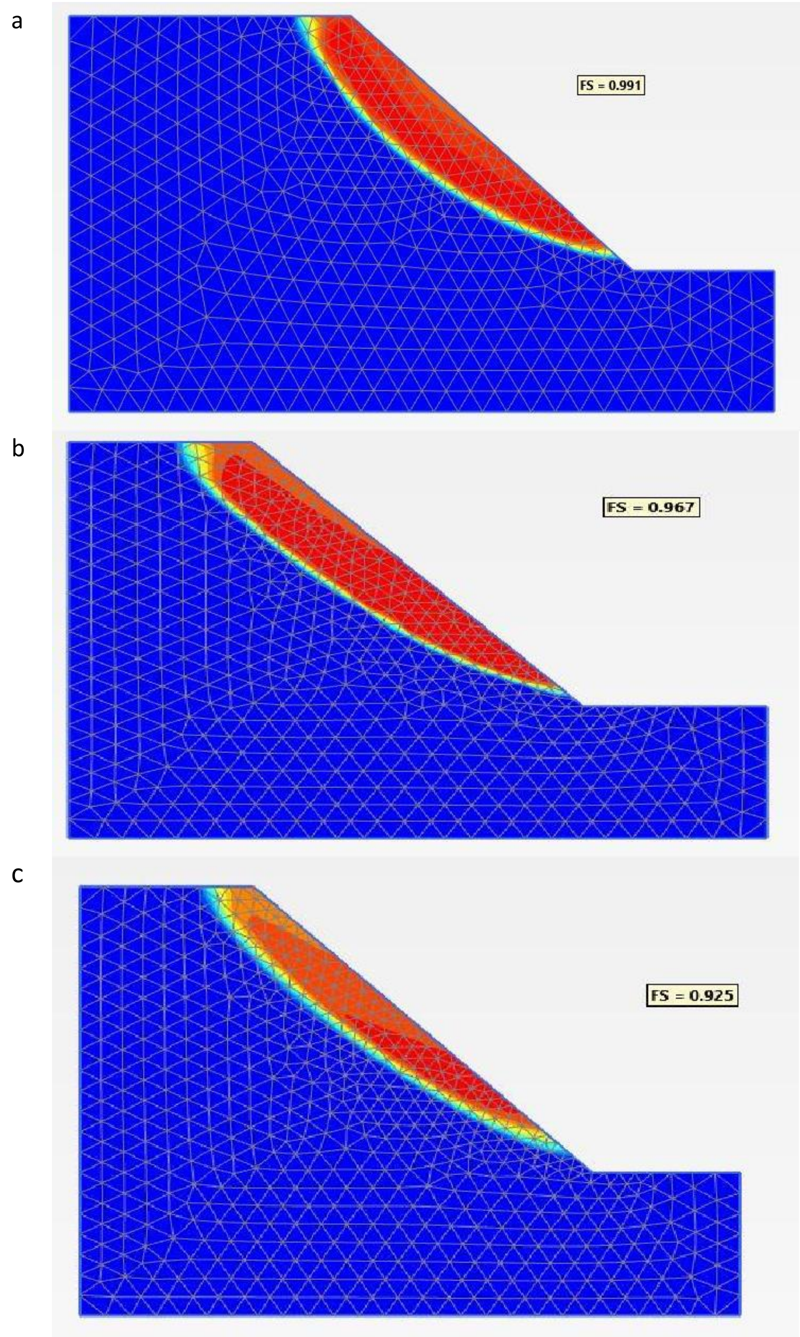


Fig. 2. a) Factor of safety of slope 1 b) Factor of safety of slope 5 c) Factor of safety of slope 8

Detailed results of the Plaxis 2D analysis are shown in Table 3.

Table 3. The factor of safety and failure types of different slopes from Plaxis 2D Analysis

Slope No.	Location	Slope	Factor of Safety	Failure Type
1	**Kokkayar 1**	42.176°	0.991	Toe Failure
2	**Kokkayar 2**	42.176°	0.962	Toe Failure
3	**Kokkayar 3**	42.176°	1.015	Toe Failure
4	**Plappally 1**	41.6°	0.964	Toe Failure
5	**Plappally 2**	41.6°	0.967	Toe Failure
6	**Plappally 3**	41.6°	0.949	Toe Failure
7	**Kavali 1**	44.27°	1.014	Toe Failure
8	**Kavali 2**	44.27°	0.925	Toe Failure
9	**Kavali 3**	44.27°	0.917	Toe Failure

5.2 GeoStudio Analysis

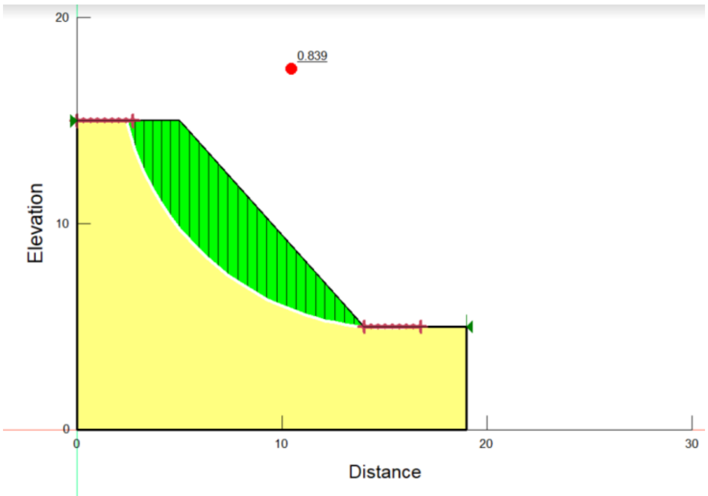
Plaxis 2D delivers more accurate results than GeoStudio based on both results. Plaxis 2D shows improved results over GeoStudio as it delivers the amount of deformation onthe consistent slope (total displacement values). From the observed conditions, it is no-ticed that the slope analysed from GEOStudio shows a value of 1.240, which is just beyond the fundamental safety factor value. Kerala has experienced heavy rains due tolow pressure and gusty winds, causing flooding and landslides, eventually making the ground less steady at the top. Top surface flora could reduce erosion intensity and re-duce damage from top surface erosion by reducing erosion intensity and environmental impact. Also, Existing slopes near failed slopes could be protected with methods such as geogrids, soil nailing, soil anchoring, stone columns, etc.

Table 4. The factor of safety and failure types of different slopes from GeoStudio Analysis

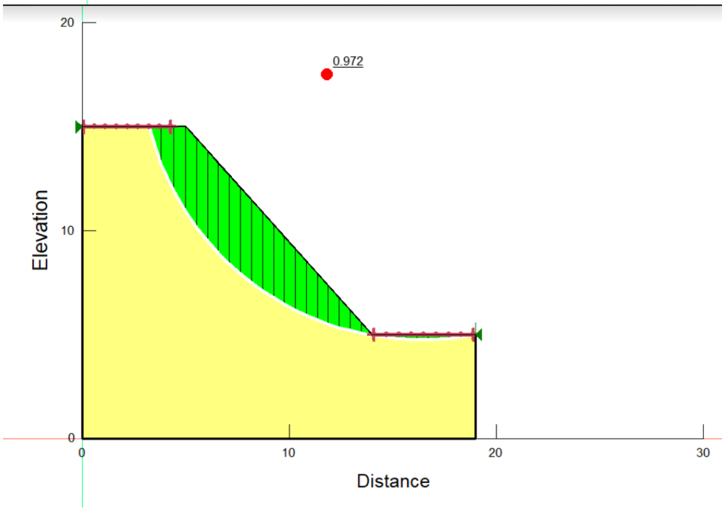
Slope No.	Location	Slope	Factor of Safety	Failure Type
1	**Kokkayar 1**	42.176°	0.839	Toe Failure
2	**Kokkayar 2**	42.176°	0.785	Toe Failure
3	**Kokkayar 3**	42.176°	0.875	Toe Failure
4	**Plappally 1**	41.6°	1.176	Toe Failure
5	**Plappally 2**	41.6°	0.972	Toe Failure
6	**Plappally 3**	41.6°	1.146	Toe Failure
7	**Kavali 1**	44.27°	0.767	Toe Failure
8	**Kavali 2**	44.27°	1.101	Toe Failure
9	**Kavali 3**	44.27°	1.240	Toe Failure

Figure 2 shows the factor of safety values of slopes 1,5, and 8.

a


0.839
20
10
0
Elevation
0
10
20
30
Distance

b


0.972
20
10
0
Elevation
0
10
20
30
Distance

c

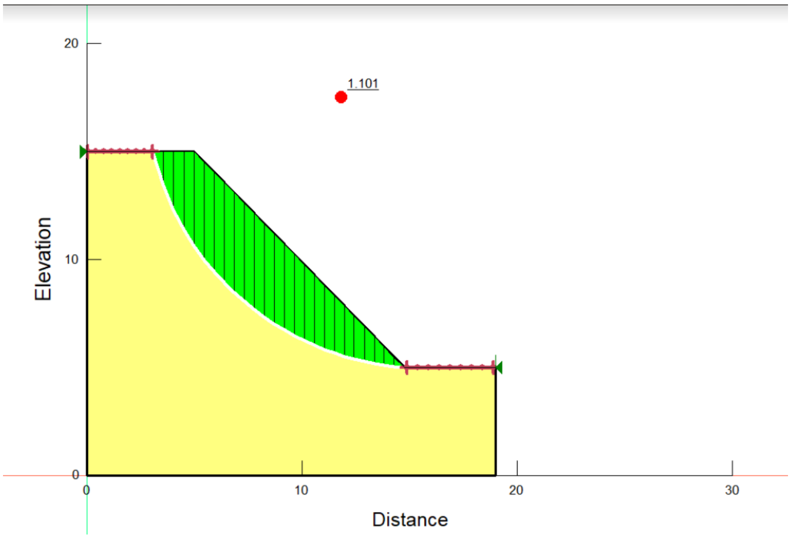


Fig. 3. a) Factor of safety of slope 1 b) Factor of safety of slope 5 c) Factor of safety of slope 8

6 Conclusions

The conclusions of the current study can be summarized as follows based on the analysis performed:

- The slope angles on all existing hill slopes exceeded 40°, and based on the numerical analysis, most slopes were susceptible to failure.
- For the 1st slope, the FOS is 0.991 from plaxis 2D and 0.839 from GeoStudio; the maximum FOS obtained from Plaxis 2D analysis is 1.015 and the maximum FOS is 1.176 from GeoStudio.
- In this study, the water table was presumed to be at ground level; any change in the water table would reduce the safety factor.
- Slopes adjacent to failed slopes are predictably susceptible to failure due to similar soil properties.
- The factor of safety increases with an increase in c and φ values.
- Existing slopes near failed slopes could be protected with methods such as geogrids, anchoring, stone columns, etc.
- Planting vegetation and maintaining proper drainage are effective and environmentally friendly approaches to reducing landslides.

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