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Numerical Analysis of Stability of Slopes Reinforced With Piles And Anchors

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Abstract. A Slope is an exposed ground surface that stands at an angle with horizontal. Slope stability refers to the condition of the inclined soil mass to withstand undergo movement. Slope stability analysis is very important. Slope stability is determined by factor of safety which expresses how much stronger a system is than it needs to be for an intended load. In this work, stability analysis of slope at Karikode in Ernakulam district is done. Reinforcement is added toimprove stability of slope. In this case, anchor and pile is provided to improve slope stability. The effect of spacing and angle of inclination of both anchor and pile is studied. The analysis is done using Geostudio software. Limit Equilibrium method is used here. Factor of safety is found using Morgenstern Price method.

Keywords: Geostudio; Anchor; Pile; Limit Equilibrium Method; Morgenstern Price Method.

1. Introduction

A soil slope is an inclined portion of the soil mass. Slopes can be created natural or engineered slopes. Stability of slope is very essential. It is crucial to analyse slopes' balance, shear strength, and ability to endure movement. Slope stability analysis is performed to evaluate the equilibrium conditions and the safe design of constructed or natural slopes. There are two types of forces acting in slope that is driving forces and resisting forces. Driving forces enhance the downslope movement that is gravity. Resisting forces discourage downward movement, that is the shear strength of the slope. Slope is stable when resisting forces are higher than driving forces. Various factors like earthquake, overloading, increase in lateral pressure, removal of underlying materials, etc lead to slope failure. Factor of safety determines stability of slopes, which is the ratio of the available shear strength to the active shear stress.

The slope is said to be globally stable if the safety factor, calculated along any potential sliding surface running from the top of the slope to its toe, is consistently larger than one. When these variables are integratedover a possible (or real) sliding surface, a safety factor can be used to illustrate the relationship between the available shear strength and the acting shearstress, which is what effectively determines how stable a slope is [1, 2]. If the safety factor, computed along any conceivable sliding surface running from the top of the slopeto its toe, is always greater than one, then the slope can be said to be globally stable [3, 4]. The safety factor's smallest value will be regarded as the slope's overall stability condition. Similar to this, a slope may be locally stable if any potential sliding surface that passes through a small area of the slope has a safety factor that is greater than one (for instance only within its toe) [5, 6]. Indicating marginally stable slopes that need attention, monitoring, and/or an engineeringintervention (slope stabilisation) to increase the safety factor and decrease the probability of a slope movement are values of the global or local safety factors that are close to one(typically comprised between 1 and 1.3, depending on regulations)[5, 7–9].

The slope's overall stability condition will be deemed to be represented by the safety factor's weakest value. Similar to this, if a safety factor greater than one is calculated along any potential sliding surface passing through a specific area of the slope, the slope may be locally stable. Values of the global or local safety factors that are near to one indicate slopes that are vulnerable to failure and need monitoring, or an engineering intervention (slope stabilization) to raise the safety factor and lower the likelihood of a slope movement. There are different slope stabilization methods like unloading, buttressing, reinforcement, retaining walls, drainage, vegetation and so on. Any established method that tries to improve the strength ofan unstable or insufficiently stable slope is referred to as slope stabilization.

Slope stabilization techniques are used to improve a slope's Factor of Safety to a level that is appropriate. For a slopeto be more stable, discrete, anchored concrete blocks are arranged in a pattern as anchors. The anchors' prestressing enhances the effect of friction and generates forces that directly oppose slope movement. Long, vertical columns make up piles. Additionally, it can be applied to stabilise slopes. In order to resist induced lateral loads brought on by the movement of an unstable slope, pilings must be properly built. The impact of slope angle on a non-reinforced slope is investigated in this article. Additionally, the reinforced slope's influence on the application of reinforcements anchors, and piles on the slope stability is also studied. This work makes use of the Geostudio programme. An integrated piece of software called Geostudio is ideal for modelling slope stability, deformation of ground, and mass and heat movement in rock and soil. Geoslope's programme is called Geostudio. Here, the most popular technique for examining slope stability in both two and three dimensions is the limit equilibrium method. This technique determines possible failure mechanisms and safety aspects for a specific geotechnical circumstance. Geostudio creates an integrated project that combines analysis and geometries. There are multiple modelling environments in this programme. Geostudio defines geometry by importing CAD files or using drawing tools. Additionally, it supports various geometries.The programme is effective and supports parallel problem-solving. Effective graphing, visualisation, and data management are used to interpret the results. There are five subroutines in SLOPE/W: Geometry, Soil strength, Pore water pressure, Soil-structure interaction or reinforcement, Imposed loading.

1. Literature Review

AusilIo et al. [10] studied stability of slopes with and without piles using kinematic approach. It was found that slope with piles had more factor of safety. He examined the stableness of piled earth slopes, and the kinematic approach of limit analysis is applied. The stability of slopes that have been strengthened with piles is then examined. Expressions are created that allow for the evaluation of the force required to raise the safety factor to a specified level and the best place for piles within the slope. Koerner et al. [11] used soil anchors connected to a geosynthetic surface covering which is tensioned thereby stabilizing the encapsulated soil and providing tensile reinforcement. Abdelaziz et al. [12] studied the effect of pile position, diameter and inclination on stability of slope using 3D analysis. Piles are frequently utilised to increase or stabilise slope stability. In the article, pile-stabilized slopes are examined numerically. Three-dimensional (3D) finite element analysis is used to investigate the effects of various factors on the stability of slopes stabilised by piles. A 3D finite element model was produced using the PLAXIS finite element programme. The pile's ideal position and inclination are determined by the study to provide maximum stability. It shows that at a certain pile length, adding more pile is unnecessary, and that the diameter of the pile has a minimal effect on the safety factor of piled-slopes.

Salmasi et al.[5] found factor of safety of homogeneous slopes. The effect of cohesion, angle of internal friction, unit weight and angle of slope on safety factor. It was found for both dry and drainage conditions. According to the results, lowering the water table level and eliminating the hydrostatic pressure on the slope would lead to a reduction in the safety factor. Pratama et al. [13] studied the effect of anchor number and anchor length on factor of safety. Halder et al. [8]studied slope stability in different approaches like limit equilibrium method, finite element method and analytical method. Finite element method is the most accurate among these. Benmebarek et al. [14] studied the effect of pile position and length on factor of safety by 2D and 3D numerical analysis. He understood to optimise a row of piles in cohesive-frictional slope stabilisation, studied numerical simulations utilising PLAXIS 2D and 3D have been carried out. The results show that the fixed pile head near the centre of the slope increases stability and shortens the pile's ideal length. The improved cohesive-frictional slope safety factor is slightly augmented by piles with free heads. In 3D analyses, it is demonstrated that when the spacing ratio (S/D) exceeds 12 (S: pile spacing, D: pile diameter), the soil will flow between the piles and the arching effect will completely disappear. The restriction of 2D analysis for cohesive-frictional slope reinforced with pile is illustrated by comparing the findings.

2. Methodology

Soil sample for this study was taken from a slope in Karikode, Ernakulam. Preliminary tests were conducted like sieve analysis, specific gravity, natural moisture content and atterberg limit tests. Direct shear test was conducted to find the values of cohesion and angle of internal friction of collected sample. Geostudio software is taken in this project for analysis. Validation of software was done. Validation was done using the journal Prediction of sliding type and critical factor of safety in homogeneous finite slopes by Salmasi et al.[5]. In the mentioned journal, factor of safety of three slopes with angle of slope 30^0, 45^0, 60^0 was determined. Cohesion, angle of internal friction, unit weight are 25kPa, 14^0, 15kN/m3 respectively. Validation results are shown in Table 1.

Table 1. Validation Results

S No	Cohesion (kN/m^2)	Angle Of Internal Friction(^{0})	Unit Weight (kN/m^3)	Angle Of Slope (^{0})	FOS (Salmasi et al.[5])	FOS From Validaton	Percentage Variation (%)
1	25	14	15	30	2.1421	2.165	1.07
2	25	14	15	45	1.9124	1.760	7.97
3	25	14	15	60	1.6223	1.657	2.14

Firstly, in Geostudio, geometry of slope was modeled. After modelling, materials were applied. Reinforcement like anchors and piles were provided in needed case. Finally entry and exit slip surface was provided and factor of safety was determined. Limit Equilibrium method is applied here. Morgenstern Price method is used for analysis. A total of five situations are studied. In this study, effect of angle of slope on factor of safety is studied. The effect of spacing and angle of inclination of anchors are found. Also the effect of length, diameter and spacing of piles are also studied in this analysis. Anchoring into the bedrock under the likely shear surface can effectively make the slope stable. Forces that directly oppose potential slope movement by amplifying the effect of friction at this surface are produced by prestressing the anchor. Anchoring method can also be used profitably when artificial slopes are made while building roads, etc., and in open pit mines, the. If the slope faces are fastened with anchors as excavation progresses, steeper gradients can be produced. This is not only economical when compared to earthmoving for unanchored, flatter gradients, but also saves space. Anchoring is most useful when the topmost strata need to be stabilized when itcomes to existing or freshly developed steep rock slopes. A prestressed surface layer of rock may very well replace concrete retaining walls at a far lower cost if not subjected to weathering. The vertical members called piles also improve slope stability by increasing resisting forces.

3. Results and Discussions

Soil collected is laterite. The results of index properties are shown in Table 2.

Table 2. Index Properties

S No	Preliminary Tests	Results
1	Natural moisture content	17.6%
2	Specific gravity	2.64
3	Liquid limit	45%
4	Plastic limit	30%

The effect of spacing of anchor is studied. These results are shown in Table 3.

Table 3. Effect of spacing of anchor on factor of safety of slope

S No	Spacing (m)	Factor of safety when anchor is provided
1	1	1.969
2	1.25	1.866
3	1.5	1.702
4	1.75	1.260
5	2	1.105

The effect of angle of inclination of anchor is shown in Table 4. Maximum factor of safety is obtained when anchor is inclined at 15^0

Table 4. Effect of angle of inclination of anchor on factor of safety of slope

S No	Angle of inclination (^{0})	Factor of safety when anchor is provided
1	10	2.829
2	15	2.869
3	20	2.409
4	25	2.065
5	30	1.828

The effect of length, diameter and spacing of pile on factor of safety are found as shown in, Table 5, Table 6, Table 7.

Table 5. Effect of length of pile on factor of safety of slope

S No	Length of pile (m)	Factor of safety when pile is provided
1	4	1.157
2	6	1.966
3	8	2.253
4	10	2.339
5	12	3.458

Table 6. Effect of diameter of pile on factor of safety of slope

S No	Diameter Of Pile (m)	Factor of safety when pile is provided
1	0.3	1.893
2	0.4	2.025
3	0.5	2.562
4	0.6	2.933
5	0.7	3.645

Table 7. Effect of spacing of pile on factor of safety of slope

S No	Spacing of pile (m)	Factor of safety when pile is provided
1	1.4	1.723
2	2	2.172
3	2.8	4.213
4	4.2	3.339
5	5.6	3.185

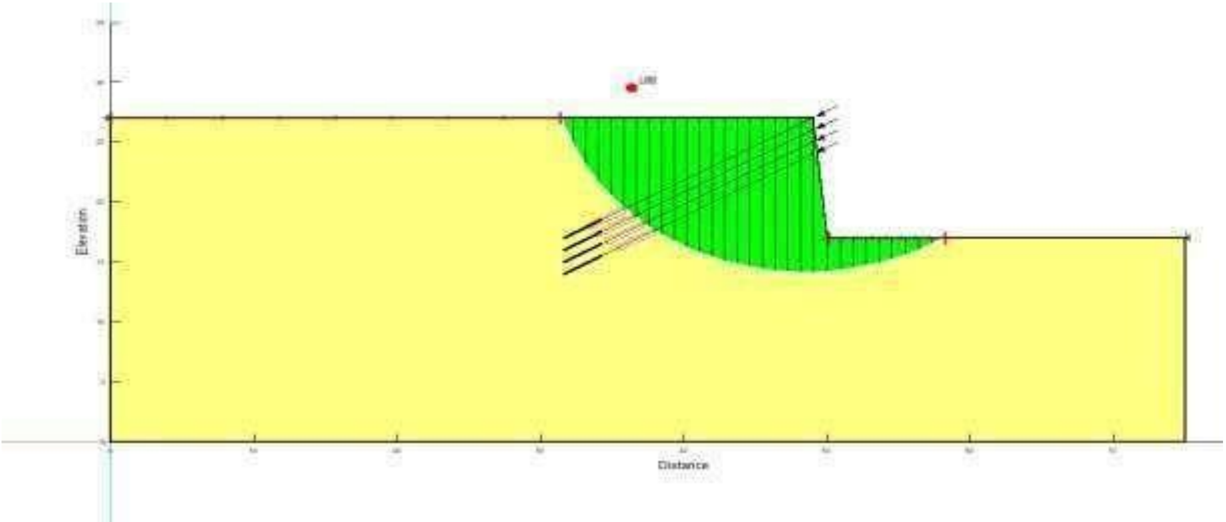

Fig 1. Factor of safety of slope when anchor is spaced at 1m.

Anchor was spaced between 1 to 2m and factor of safety was found. Maximum factor of safety of was obtained when anchor was spaced at 1m as shown in Fig1.

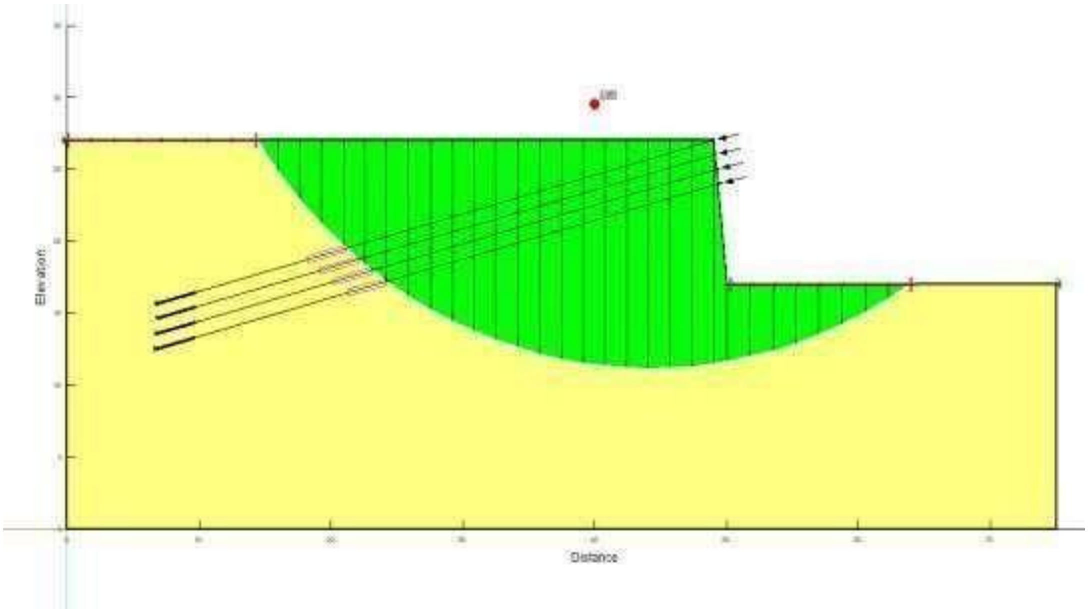

Fig 2. Factor of safety of slope when anchor was inclined at 15^0.

Anchor was inclined at different angles and factor of safety was found. Fig 2 shows maximum factor of safety obtained when anchor is inclined at 15^0.

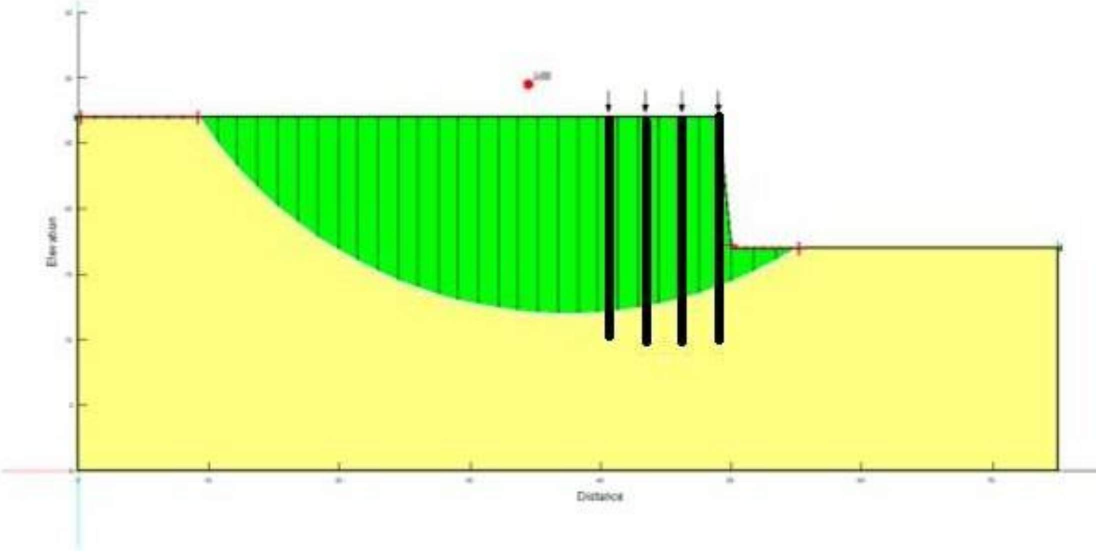

Fig 3. Factor of safety of slope when 12m length pile is provided.

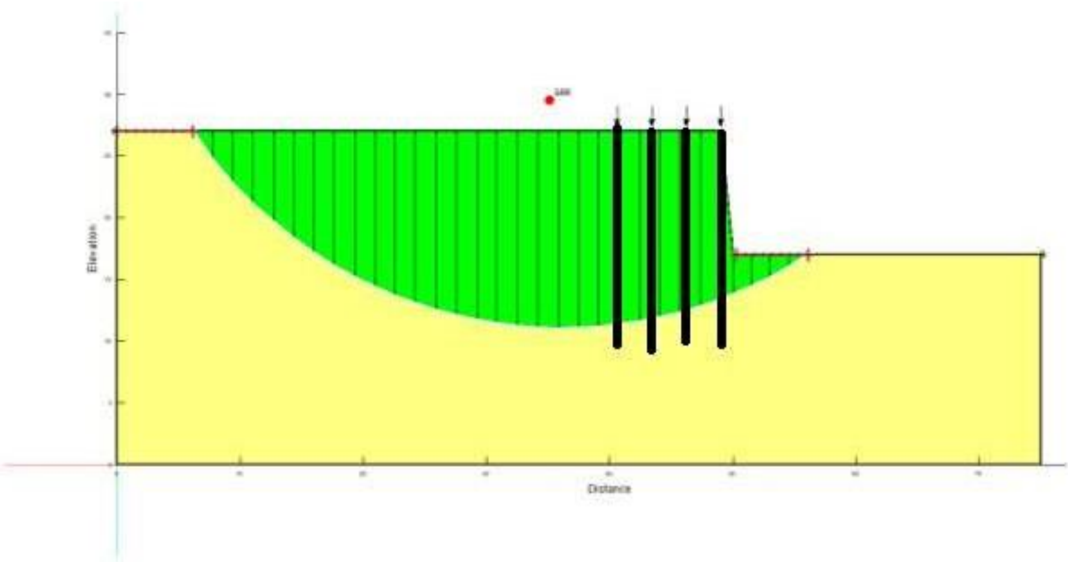

Fig 4. Factor of safety of slope when 0.7m diameter pile is provided.

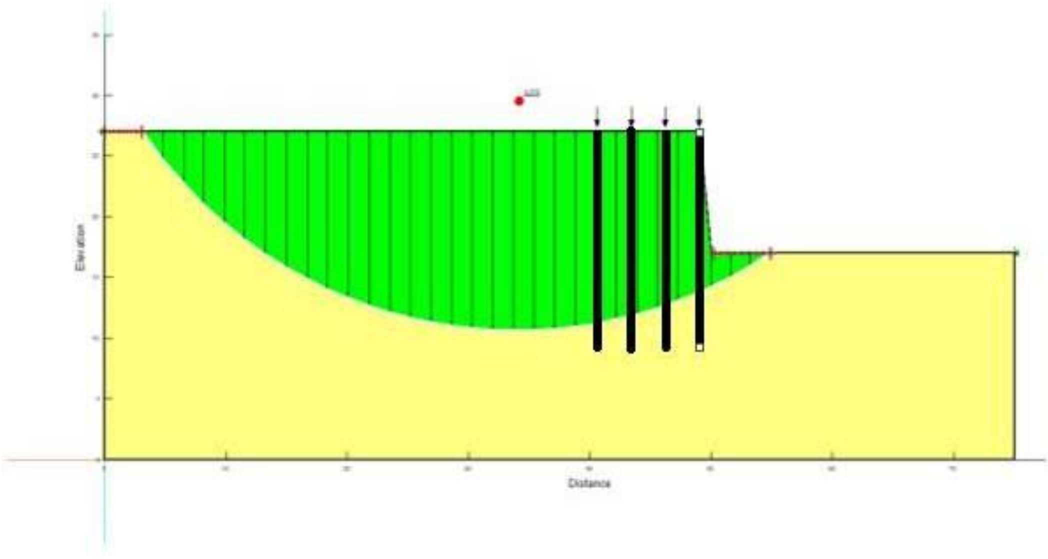

Fig 5. Factor of safety of slope when pile is spaced at 2.8m.

Piles of different lengths like 4m, 6m, 8m, 10m, 12m were provided and factor of safety was found. Maximum factor of safety was obtained when 12m length pile is provided as shown in Fig 3. Piles of different diameter from 0.3m to 0.7m were provided and factor of safety was found. Maximum factor of safety was obtained when 0.7m diameter pile is provided as shown in Fig 4. Factor of safety was also found spacing from2 times diameter to 8 times diameter. Maximum factor of safety was obtained when pile was spaced at 4 times diameter that is 2.8m as shown in Fig 5.

4. Conclusions

From the study it can be concluded that

- Slope stability is determined by factor of safety.
- Factor of safety depends on many factors like cohesion, angle of internal friction, unit weight, angle of slope etc.
- In order to improve stability, reinforcement can be provided like soil nail, pile, anchors etc.
- Maximum factor of safety obtained when anchor is spaced at 1m.
- Maximum factor of safety obtained when anchor is inclined at 15^0.
- Maximum factor of safety obtained when 12m length pile is provided.
- Maximum factor of safety obtained when 0.7m diameter pile is provided.
- Maximum factor of safety obtained when pile is spaced at 4 times diameter that is 2.8m.

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