Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Landslide Risk Assessment and Mitigation - Kottayam-Kumili Road Case study

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Abstract. Landslide is the most common natural hazard occurring especially in hilly areas, particularly along highway corridors which adversely affects human life and the environment. Kerala state is a narrow segment of land in the south-western part of peninsular India that experiences several types of landslides, especially during the monsoon seasons, which mainly includes debris flow. In the Idukki district of Kerala, the occurrence of landslides is frequent mostly along with road cuts. Here in this paper, different topographical features of 5.7 km road cutting along Kottayam-Kumili Road from Chuzhuppu to Murinjapuzha are studied using QGIS software, and slope stability analyses have carried out using Slide2 software after obtaining geotechnical properties of soil. Results showed that the factors of safety of all the three slopes are below the safe value, which necessitates the design of suitable control measures to minimize landslide activities. Because of this, further stability analyses have performed involving the application of micropile reinforcement along the slopes as a scheme of control measures by integrating Slide2 with RSPile, which is a general pile analysis software. Factors of safety increased significantly, which shows the suitability of micropile reinforcement as an innovative method for slope stabilization.

Keywords: Landslide, QGIS, Slope stability, Factor of safety, Slide2; RSPile

1 Introduction

Generally, landslides refer to most types of mass-movement of land involving the movement of soil and rock materials down along a slope. Landslides can result from a wide range of ground movements triggered by geographical, morphological, physical, and human-induced factors [28]. Intense rainfall in a region causes rapid erosion and weathering of the rock mass, as well as an increases in groundwater level which reduces the stability of natural slopes [21].

Different methods of slope stability analysis include Limit Equilibrium methods, Limit Analysis method, Numerical analysis methods, and Artificial Neural Networks. During early 2000s, a working party of the Hong Kong Institution of Engineers developed a method for upgrading loose fill slopes using the technique of soil nailing [6]. The developmental advantages offered by soil nailing make it popular for upgrading hill slopes. A new stability number was introduced by Hassiotis et al. [12], which includes the pile reaction to determine the modified critical slip surface and safety factor of a pile reinforced slope. Possibility of slope stabilization and control of erosion through jute-geo-textiles is presented by Ashish et al. [4]. Use of micropiles is another method which can be used as an effective slope stabilizing technique. Suitability of micropile for landslide mitigation when used along with soil nailing is presented by Koushik et al. [16].

Landslides are frequently occurring in the Idukki district of Kerala, mainly along hill slopes and road cuttings causing severe damages to life and other properties [25]. The geographical features of the district such as dense forests, deep valleys, steep hills combined with heavy rainfall made 60% of its area susceptible to landslides (District Disaster Management Plan, Idukki, 2015). Also, several projects are also scheduled to be deployed in Idukki such as tourism development, hill highway projects and residential projects. However proper mitigation measures to control the adverse effects of landslides are not provided in the region.

In this study various surface and geospatial data is studied using Google Earth and QGIS and maps of various terrain parameters such as slope, relative relief, land use, and drainage pattern are prepared. These factors place an important role in the occurrence of landslide along with geotechnical properties of the soil. Landslide hazard zonation map of the area is extracted from the landslide zonation map in Kerala State Disaster Management Authority website and is analyzed using QGIS software. Density and shear strength parameters of the soil were determined from the samples collected from the field. Results of slope stability analyses using Slide2 were further discussed, as well as the design of micropile reinforcement in RSPile and its influence on stability of slope.

2 Study area

The study area includes 5.7 km road cutting along Kottayam-Kumili Road from Chuzhuppu to Murinjapuzha. The region varies in height from 600 m to 950 m above mean sea level. Latitude and longitude of the area lies between 9 ˚ 32’ 55.98” N and 76 ˚ 56’ 11.56” E at Chuzhuppu and 9 ˚33’ 15.65” N and 76 ˚58’ 20.01” E at Murinjapuzha. The area mainly consists of lateritic soil profile and hard rock in some locations. The area belongs to high hazard to medium hazard landslide zone according to the study conducted by Kerala Disaster Management Authority.

Fig. 1. Map of the study area

3 Geospatial data

Various surface and geospatial data are studied using Google Earth and QGIS and maps of various terrain parameters such as slope, relative relief, land use, and drainage pattern are prepared.

3.1 Land use map

Land use is drawn as a polygon feature using QGIS software. The area includes agriculture, Forest, mining, rocky outcrop, and very small percentage of settlement. Major part of the area is covered by plantation and natural vegetation which will be a determinant factor when studying the land use. Plantations of the area mainly includes tea, coffee, and cardamom. In general, tea plantations are not susceptible to land disturbances, but coffee, cardamom, rubber etc. often suffer slope failures due to improper land management practices and cultivation of seasonal crops in vulnerable regions [1].

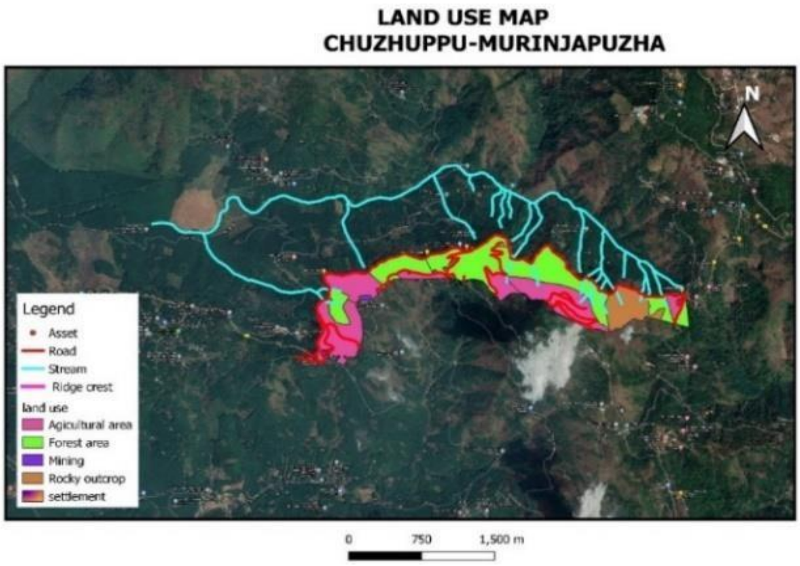

Fig. 2. Land use map

3.2 Slope map

Maximum Slope of the area is 74˚ and natural slope is between 30˚- 35˚. From the slope map prepared a major part of the area have extreme and steep slopes. Different classes of slope in degree are obtained from slope descriptor table prepared by Barcelona Field Studies Centre.

3.3 Relative relief

The actual variation of altitude in a unit area concerning its local base is represented by the term relative relief. Very low, medium, high, and very high relative relief indicate < 100, 100-200, 200-300, 300-400, and > 400 m respectively [29]. Here the relative relief map was compiled by choosing the points in one km intervals from Chuzhuppu to Murinjapuzha. Relative relief increases slope angle also increases. Relative relief in the first five stretches is above 400 m which is very high. Stretch 6 has a relative relief of 370 m which comes under the class of high. These high relative relief values indicate the chances of high soil erosion either as soil loss or landslides.

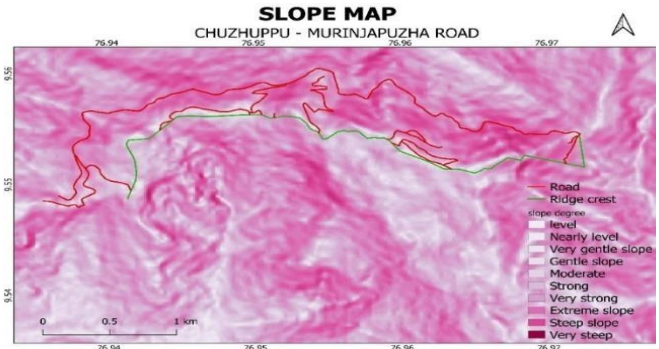

Fig. 3. Slope map

Fig. 4. Positions marked for relative relief calculation

3.4 Drainage map

Drainage density indicates the total length of the drainage channel in a unit area. The presence of high drainage densities is an indication of impervious strata, an abundance of rainfall, lack of vegetation, and active stream incision, all of which may be indicative of mass movements of land [1]. In the map prepared, mainly parallel pattern is shown, and it is very critical from point of view of slope stability since such areas undergo considerable erosion and lead to slope failure.

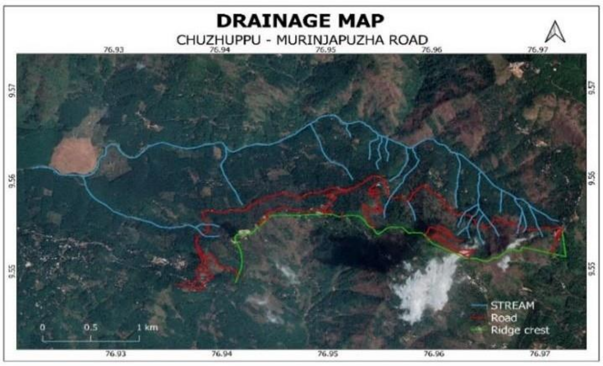

Fig. 5. Drainage map

3.5 Landslide hazard zonation map

Landslide hazard zonation map of the area extracted from the landslide zonation map in Kerala State Disaster Management Authority website and analyzed using QGIS software and is given in the figure. From the map prepared the studied area from Chuzhuppu to Murinjapuzha of Kottayam – Kumili Road belongs to medium hazard and a small portion in high hazard zones. This landslide hazard map can be used along with slope stability analysis results in Slide2 to find the areas that require immediate mitigative measures for slope protection.

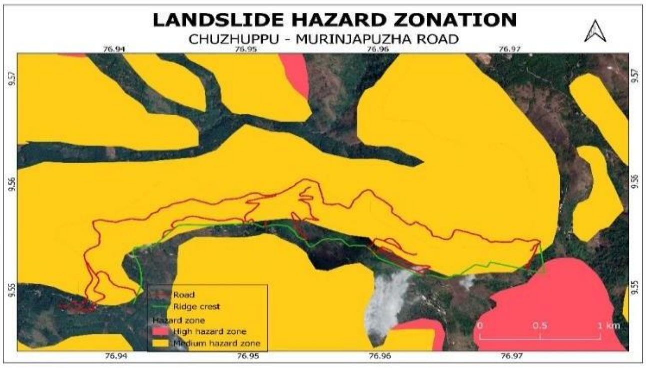

Fig. 6. Landslide hazard zonation map (Kerala State Disaster Management Authority)

4 Experimental results

Soil samples are collected from three different locations on Chuzhuppu–Murinjapuzha road using GI pipes for determining soil parameters. All these properties are determined in both the field and saturated conditions. The shear strength properties of the soil samples are determined by conducting the direct shear test. Results obtained from the laboratory experiments showed that there is a significant reduction in cohesion value in the saturated condition as compared to the field condition. It is inferred that when the water content increases to saturation the inter particle attraction force decreases decreasing the cohesion value. Experimental results of soil samples are given in table 1.

Table 1. Experimental result of soil samples in field and saturated condition

	Field condition					Saturated condition			
Location	γ (kN/m^3)	w (%)	G	c (kPa)	ϕ (Degree)	γ (kN/m^3)	w (%)	c (kPa)	ϕ (Degree)
1	17.4	20	2.3	15	36	18.06	31	8	31
2	18	21	2.35	12	32	18.33	30	7	32
3	17.43	20.2	2.4	15	35	18.07	33	6	31

5 Stability analysis

Stability of three different slopes were analyzed both in field and saturated conditions using Slide2 software. For the analysis some additional data such as the height of cut, slope of the cut cliff, natural slope, and the height of the slope are required. Height of the slope is obtained from Google Earth software. Natural slope angle of each locationis obtained from the slope data prepared in QGIS software using Digital Elevation Model. Slope of the road cut cliff is different from natural slope which is found out using inclinometers in each location.

Table 2. Details of slopes

Location	Height of slope (m)	Natural slope angle (degree)	Height of cut-cliff (m)	Cut slope (degree)
1	130	34.48	8	80
2	180	35.53	6	76
3	110	30.6	6	76

Results of analysis are given in table 3. All the values are above 1 and it can be said that all slopes are marginally stable against sliding in their present condition. However, during rainfall events soil in the slopes become saturated and their shear strength get reduced. This reduction in strength in saturated conditions is visible from the results obtained from stability analysis of saturated soil samples in each location.

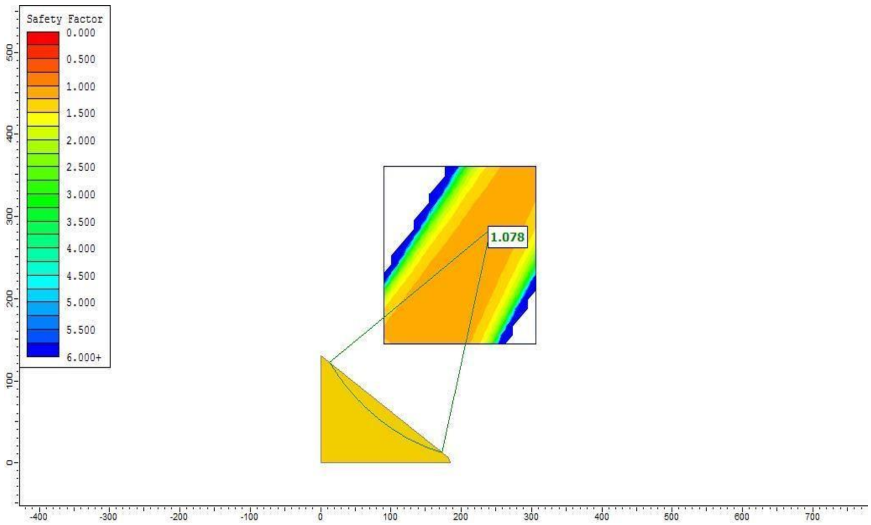

Fig. 7. Result of stability analysis in field condition in location 1

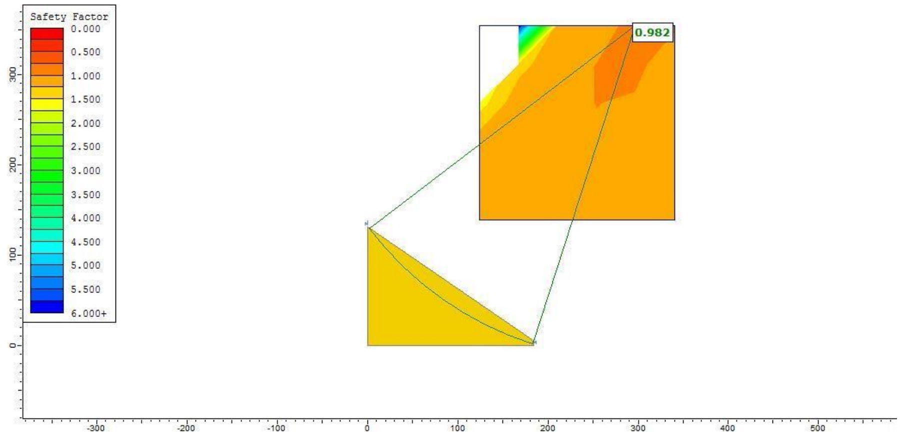

Fig. 8. Result of stability analysis in saturated condition in location 1

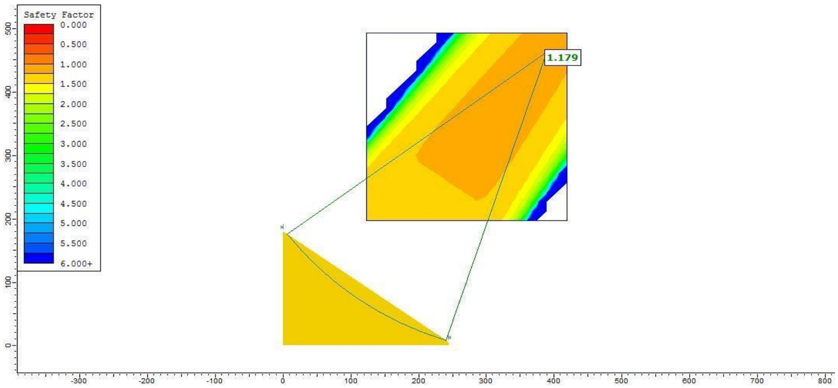

Fig. 9. Result of stability analysis in field condition in location 2

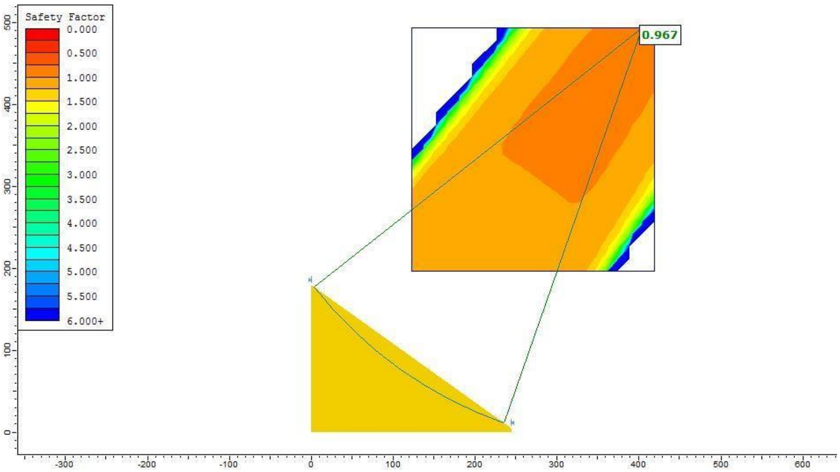

Fig. 10. Result of stability analysis in saturated condition in location 2

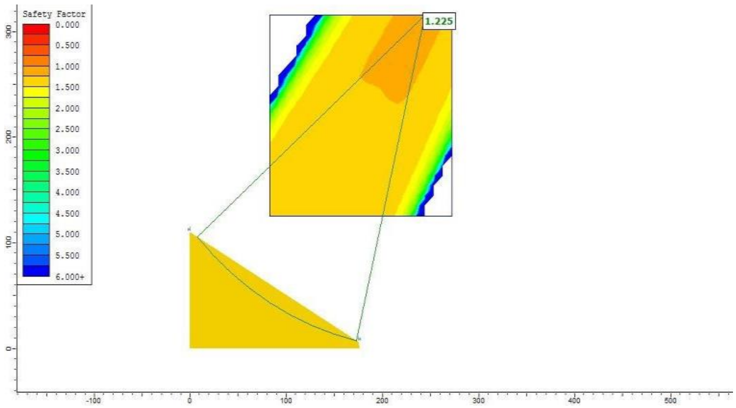

Fig. Fig. 11. Result of stability analysis in field condition in location 3

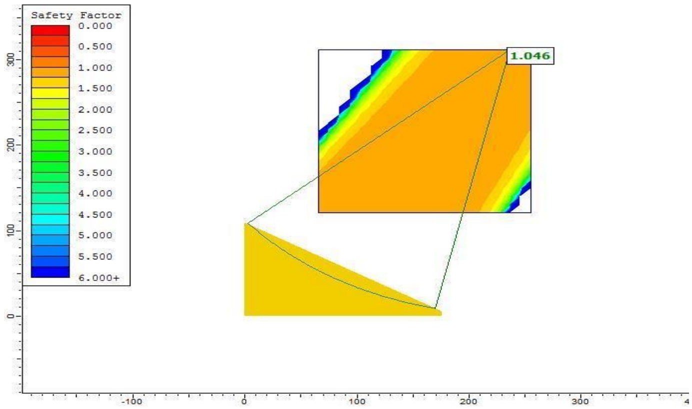

Fig. 12. Result of stability analysis in saturated condition in location 3

6 Design of micropile

Micropile is a small-diameter pile usually less than 300 mm, which can be used as a slope stabilization method for remote areas or where difficult site access is a concern. Design of the micropile is based on the reference manual published by FHWA (Federal Highway Authority), US Department of Transportation and is done in RSPile software. Micropiles are designed so as to get a minimum FS of 1.5 at each slopes. Here micropiles of diameter 300 mm are provided at equal spacing and 0.6 m out of plane spacing is provided. Number of piles required can be obtained from different slope stability analysis. M30 concrete is chosen so as to get 30 MPa compressive strength. A single bar is typically used with yield strengths of 420, 520 and 550 MPa. Bar sizes range in diameter from 25 mm to 63 mm (FHWA manuel). Here single reinforcing bar of Fe550 and 50 mm diameter is provided. A mild steel casing of wall thickness 12 mm is also provided. Length of the micropile in each location varies according to the depth of critical slip surface which can be find out using the formula given below.

$$L_{total} = L_{above} + L_{below} \qquad \text{(FHWA manual)}$$

Stability analysis with piles

For the stability analysis of slopes, already modeled geometry with saturated soil properties as material properties is opened in Slide2. RSPile is selected as the support type which is imported corresponding to each location from the RSPile file.

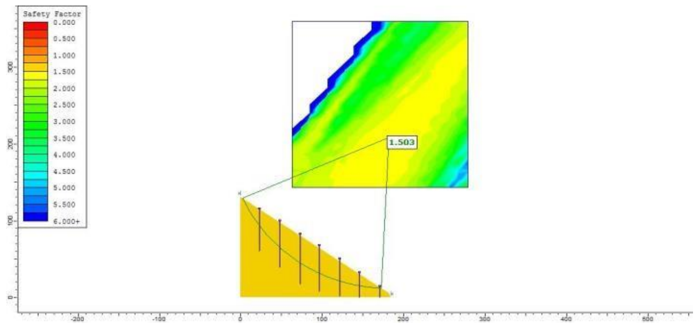

Fig. 13. Result of stability analysis with micropiles in locations 1

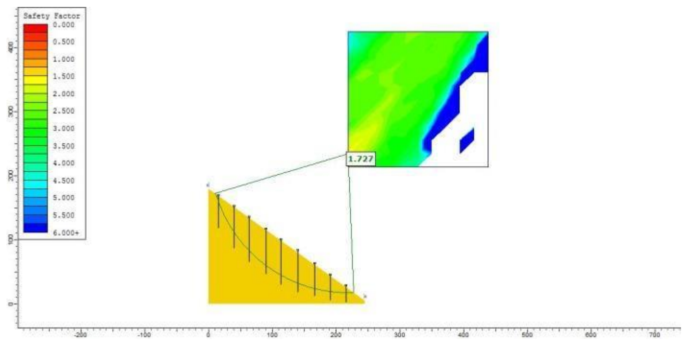

Fig. 14. Result of stability analysis with micropiles in locations 2

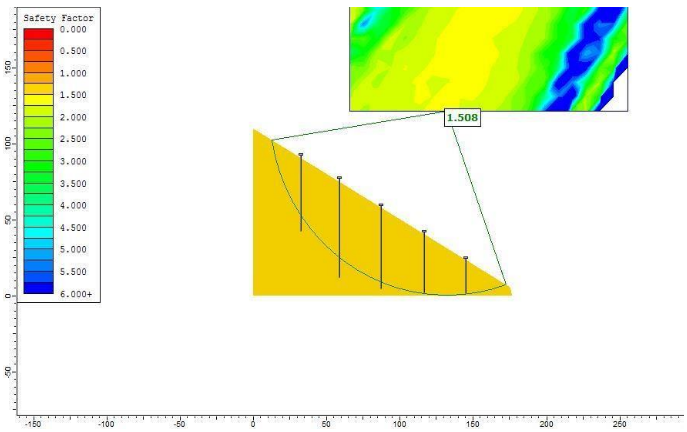

Fig. 15. Result of stability analysis with micropiles in location 3

Table 3. Comparison of FS

Location	FS Without piles		FS With piles
	Field condition	Saturated condition	
1	1.078	0.982	1.503
2	1.179	0.967	1.727
3	1.225	1.046	1.508

Table 3 shows that all the factors of safety values after stabilizing with piles exceeding 1.5, which is sufficient for preventing sliding.

7 Conclusion

From different topographical features collected and results of slope stability analysis in different conditions of soil, and the effect of micropile reinforcement, of the area from Chuzhuppu to Murinjapuzha of Kottayam-Kumili road, following conclusions are drawn:

- Based on limit equilibrium analyses in Slide2 software, it can be summarized that the road-cut is somewhat stable in present condition and may fail in a rainfall event.
- Under normal field conditions all the sectors have factors of safety values which are above the safe limit. However, in saturated conditions FS values reduced significantly which may lead to slope failure. The slope failure of soil slopes occurring in saturated conditions may be attributed to the significant reduction in cohesion value.
- Landslide susceptibility data show that the selected area belongs to medium hazard and a small portion in high hazard region indicating the probability of failure during a rainfall event.
- Based on the topographical features and slope stability analyses results, it can be inferred that the selected road cut is vulnerable to landslide which can be largely improved by reinforcing with micropiles.
- After stabilizing the slopes with micropiles of diameter 300 mm, FS increased to 1.503, 1.727 and 1.508 respectively in selected locations which gives a percentage increase of 53%, 78%, and 44%.
- Considering this increase in stability with other advantages of micropile which mainly include its requirement of limited wok area, limited equipment access, and its capacity to penetrate through any ground type, it can be used as an effective slope stabilising method.
- Considering the economical side, conducting more analyses by decreasing the number of the piles, changing the locations and diameter of steelreinforcement can be done to get a more economical and effective solution.

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