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Stability Analysis of Landslide Susceptible Areas Using PLAXIS 2D

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Abstract

Landslide occurrences are largely controlled by different causative factors. Geotecnical 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 Thrissur district. For this, three different areas are selected viz-a-viz, Vilangan hills, Kuranchery and Akamala in Kerala. These study areas have experienced several slope failures in the past few years. With the help of soil data from laboratory experiments, rainfall data of the study area, and slope stability analysis using PLAXIS 2D software, the factor of safety of slopes in these study areas are obtained. 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: Land slide, Soil stabilization, PLAXIS 2D, Soil nailing

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1. Introduction

Slope stability analysis is a critical component of geotechnical engineering, particularly in landslide-prone regions, where the potential for catastrophic failures poses significant risks to infrastructure and human life. Understanding the factors that contribute to slope instability, such as soil properties, groundwater conditions, and external loads, is essential for designing effective mitigation measures. Plaxis 2D, a finite element software that offers a powerful platform for conducting detailed slope stability analyses, enabling engineers to model complex geological conditions and evaluate the safety of slopes under various scenarios. By employing numerical methods, Plaxis 2D allows for the simulation of stress-strain behavior within soil masses, facilitating the prediction of potential failure mechanisms and the calculation of safety factors. This software is particularly valuable in areas characterized by heterogeneous soil profiles, complex groundwater regimes, and the presence of pre-existing slip surfaces, which are often encountered in landslide-susceptible terrains.

The application of Plaxis 2D in slope stability analysis involves several key steps. Initially, a representative cross-section of the slope is generated, incorporating detailed geological data obtained from site investigations. This cross-section is then discretized into a finite element mesh, which allows for the numerical approximation of the continuous soil mass. Sub sequently, material properties, such as shear strength parameters (cohesion and friction angle), unit weight, and permeability, are assigned to each element based on laboratory and in-situ testing. Groundwater conditions are modeled by defining phreatic surfaces or pore pressure distributions, which significantly influence the effective stress state within the soil. External loads, such as surcharge loads from structures or seismic forces, can also be incorporated into the model to simulate realistic loading conditions.

Plaxis 2D employs various methods for evaluating slope stability, including the phi-c reduction method, which systematically reduces the shear strength parameters until failure occurs, and the safety factor is calculated. The software also enables the simulation of staged construction or excavation, allowing engineers to assess the stability of slopes during different phases of development. Furthermore, Plaxis 2D provides comprehensive visualization tools, including contour plots of displacements, stresses, and pore pressures, which aid in the interpretation of analysis results and the identification of critical zones within the slope. The ability to perform sensitivity analyses, by varying input parameters and assessing their impact on slope stability, is another significant advantage of Plaxis 2D, enabling engineers to evaluate the robustness of their designs and identify potential sources of uncertainty. In landslide-prone areas, the use of Plaxis2D allows for a more robust and accurate estimation of safety factor, and therefore, a more reliable design of mitigation measures.

1.1.Objectives of the Study

- To determine the index properties of proposed sites using geotechnical investigations.
- To validate the software PLAXIS 2D.
- To Create a detailed numerical model that replicates the geological and geotechnical conditions of the area,incorporating factors such as soil stratigraphy, groundwater levels, and potential external loads.
- To determine the factor of safety by utilizing the finite element method within PLAXIS 2D.
- To suggest the method of soil nailing if the proprosed slope is under the condition of failure

1.2. Scope of the Study

The slope stability analysis using PLAXIS 2D holds immense potential for advancing our understanding and mitigation of landslide risks.

- PLAXIS 2D allows engineers to model and analyze the stability of natural and man-made slopes.
- It helps identify potential slip surfaces, indicating the likely paths of landslides.
- It enables the analysis of heterogeneous soil types and complex stratigraphic geometries.
- PLAXIS 2D can simulate the effects of various triggering factors, such as: Rainfall, pore water pressure, Seismic activity, Changes in groundwater levels, External loads.
- The software aids in designing effective mitigation measures, such as:Retaining walls, Soil nailing, Drainage systems.

2. Materials And Methods

2.1. Software Used

PLAXIS 2D is a powerful finite element analysis (FEA) software specifically designed for geotechnical engineering applications. It is widely used by engineers, researchers, and consultants for the modelling and analysis of soil, rock, and associated structures. Developed by Bentley Systems, PLAXIS 2D offers a robust platform for simulating complex geotechnical problems, including deformation, stability, and groundwater flow in two-dimensional (2D) plane strain or axi symmetric conditions. Its versatility makes it a key tool in infrastructure, mining, tunnelling, foundation design, and soil-structure interaction projects. PLAXIS 2D employs the finite element method to simulate geotechnical behaviour accurately. The software allows users to create 2D models using geometric shapes, including soil layers, structural elements (such as retaining walls, piles, and soil nails), and external loads. It handles both linear and nonlinear material behaviour, making it suitable for complex geotechnical scenarios.

Soil and Rock Modeling, the software includes a wide range of constitutive models for simulating the behaviour of soil and rock. These models represent various stress-strain relationships, such as the Mohr-Coulomb, Hardening Soil, and Soft Soil models. Advanced models like the Hardening Soil model with small-strain stiffness (HSsmall) are particularly useful for capturing real-world soil behaviour under cyclic loading and small deformations.PLAXIS 2D excels at analysing the interaction between soil and structural elements. The software includes capabilities for steady-state and transient groundwater flow analysis. Engineers can simulate pore water pressure distribution, flow through embankments, and the impact of groundwater conditions on soil stability. The coupled flow-deformation analysis helps assess the effects of seepage on soil deformation.

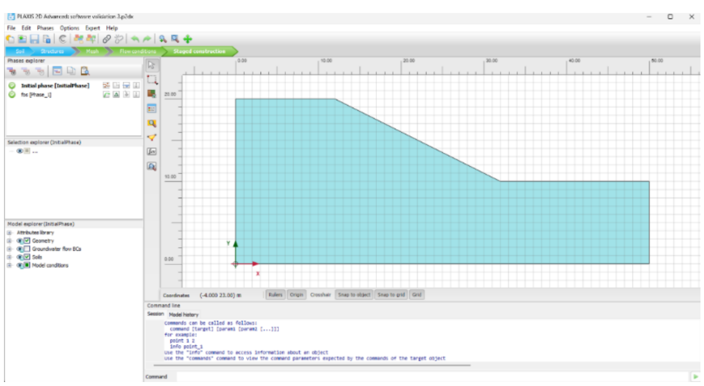


Figure 1: PLAXIS 2D

Analysing slope stability using PLAXIS 2D involves a series of steps, from model creation to result interpretation. Here's a breakdown:

Define the Geometry:

- Create the slope profile: Use the "Geometry lines" feature to draw the slope's cross-section, including the ground surface, any layers, and potential failure surfaces.Define the extent of the model domain, ensuring it's large enough to avoid boundary effects.

- Define soil layers: Draw the boundaries between different soil layers. If there are any structures, like retaining walls or geotextiles, add them to the geometry. Define boreholes to accurately represent the soil stratigraphy.

Define Material Properties:

- Soil parameters: Define the material properties for each soil layer, including: Unit weight (γ), Cohesion (c′), Friction angle (ϕ′), Dilatancy angle (ψ),Young's modulus (E), Poisson's ratio (ν). Select an appropriate soil model (e.g., Mohr-Coulomb, Hardening Soil).

Define Boundary Conditions:

- Polygons are used to delineate the boundaries of different soil layers within proposed model. This is crucial because different soil layers will have different material properties, which in turn affect how boundary conditions influence the model's behaviour. Accurately defining soil layer geometry with polygons,ensure that boundary conditions are applied to the correct materials.
- The overall extent of PLAXIS 2D model is often defined using polygons. This defines the external limits where displacement boundary conditions are applied (e.g., fixed horizontal or vertical displacements).

Generate the Mesh:

- Mesh generation:Use the "Generate mesh" feature to create a finite element mesh of the model. Choose an appropriate element type (e.g., 6-node or 15-node triangles). Refine the mesh in areas of interest, such as the slope face and potential failure zones, to improve accuracy. Consider local refinement around structural elements.

Define Staged Construction and Calculation Phases:

- Initial phase: Generate the initial stresses using the K0 procedure or consider using gravity loading for more accurate initial stress states.
- Construction phases: Simulate the construction sequence of the slope, including any excavation or filling stages. Activate or deactivate structural elements as needed.
- Stability analysis phase (Safety analysis): Use the "Safety analysis" (Phi/c reduction) calculation type to determine the factor of safety. PLAXIS 2D reduces the soil shear strength parameters (c' and phi') until failure occurs. The factor of safety is calculated as the ratio of available shear strength to the minimum shear strength required for equilibrium.

Perform the Calculation:

- Run the calculation: Execute the calculation phases.Monitor the progress of the calculation and check for any errors.

Interpret the Results:

- Displacement and deformation: Examine the displacement vectors and deformed mesh to identify the failure mechanism.
- Shear stresses and strains: Analyze the shear stresses and strains to locate the critical slip surface.

- Factor of safety (FOS): Obtain the factor of safety from the safety analysis phase.A factor of safety greater than 1.0 indicates a stable slope, while a factor of safety less than 1.0 indicates instability.
- Incremental displacements**:** Examine the incremental displacements from the safety analysis to observe the development of the failure plane.
- Plastic points: Examine the plastic points to view where the soil has yielded.

2.2 Sites Selected for Soil Testing

Vilangan Hills

Vilangan Hills, located in Thrissur, Kerala, is a scenic hillock offering panoramic views of the city and surrounding landscapes. Known for its lush greenery and serene atmosphere, it serves as a popular destination for trekkers. The type of soil present in the area is laterite soil.Laterite soil is a type of soil that forms in tropical and subtropical regions under conditions of high rainfall and temperature. It is known for its distinctive reddish colour, which is primarily due to the high iron oxide content. Its strength, compaction characteristics, and workabilitycan make it an excellent material for road construction, foundations, and building blocks. The hill features a height of 70m with an angle of 33 degree.

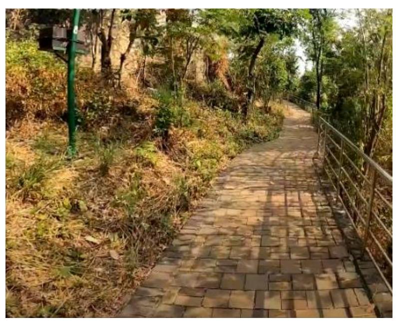


Figure 2: Vilangan hills

Kuranchery

Kuranjeri of Thrissur district have been selected where landslides occurred for the first time during Kerala flood in August 2018. Kuranjeri is a forest area situated in Thekkumkara/ Minaloor Panchayath of Thalapilly Taluk, Thrissur district, Kerala.The area consists of dry deciduous vegetation, teak being the major among them. The hill has a slope of 34˚ with a height of 152m from the MSL. Laterite have orange to red colour and clay of white colour. Soils exhibited medium to fine grained texture.

Figure 3: Kuranchery

Akamala

Akamala of thrissur district have been selected where numerous slope failures occured during the period of wayanad landslide occured on July 30, 2024. The Akamala Hills are part of the Western Ghats range, characterized by undulating terrain, rocky outcrops, and forested slopes. The hills have an average elevation of around 300–600 meters and are covered with a mix of tropical .

Figure 4: Akamala

3. Results And Discussion

3.1 Index Properties of Study Areas

The soil samples from the proposed sites are collected by means of core cutter and respective tests are conducted according to IS specifications to obtain the resulted values.

PROPERTIES	VALUES		
	Villangan hills	**Kuranchery**	**Akamala**
Specificgravity	2.66	2.3	1.196
Uniformity coefficient,C_u	5.45	4.4	13.5
Coefficient of curvature,C_c	0.7	0.44	0.8
Liquid limit	55	37	36
Plastic Limit	22	23	25
Plasticity index	33	14	11
Moisture content	12.01	7.2	15.7
Classification	SC	SC	SC

Bulk density(KN/m^2)	15.90	19.20	19.40
Saturated density (KN/m^2)	18.90	20.37	23.30
Youngs modulus,E (KN/m^2)	7241	7250	11750
Poisons ratio (μ)	0.3	0.3	0.3
Angle of internal friction(φ)	25.36	18	21
Angle of dialectancy(ψ)	0	0	0
Cohession ,C (KN/m^2)	18.5	13.20	15.70

Table 1. Index Properties of Soil

3.2 Software Validation

Data validation is a critical step in the analytics world to ensure a smooth data workflow. Any inconsistencies in data at the beginning of the process may impact the final results, making them inaccurate. Therefore, checking the accuracy and quality of data before processing it is extremely important.

In this study, the performance of PLAXIS software is investigated. First its performance was evaluated for modeling a simple embankment. Values of soil properties are provided in the software according to the journal. In this the cohesion value is kept at 20 and phi value is varying (10,20,30,40).The resulted 4 values of FOS is used to plot a graph.

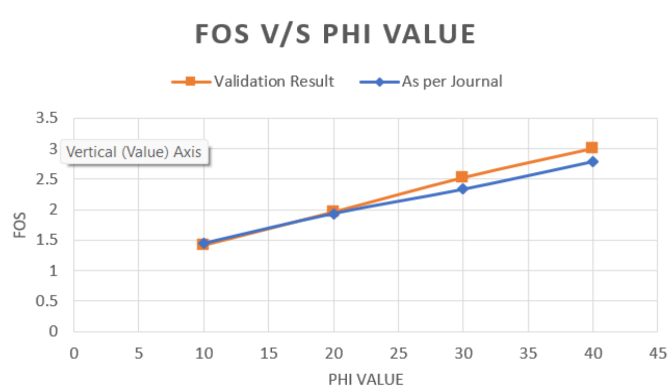
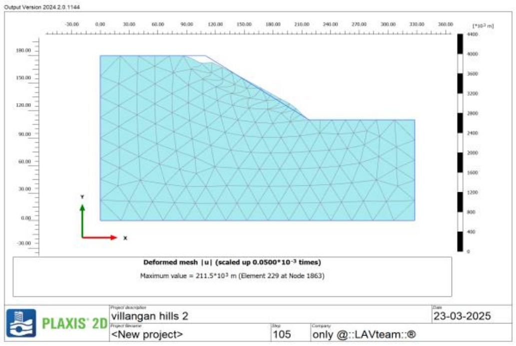


Figure 5: FOS of Software Validation

3.3 Stability Analysis

Vilangan Hills



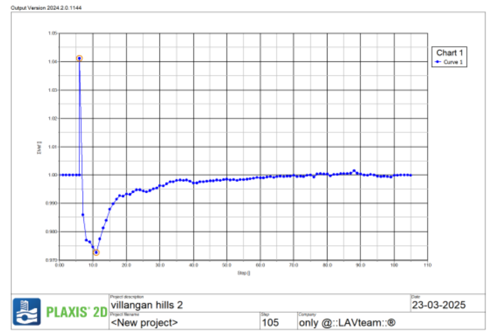
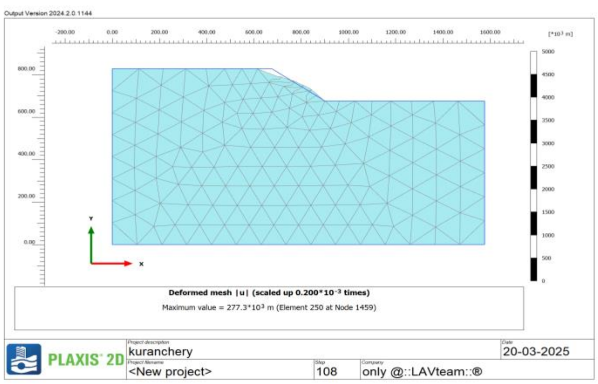


Figure 6: Deformation Mesh of Vilangan Hills using Plaxis 2D   Figure 7: Factor of Safety of Vilangan Hills (FOS1)

Kuranchery



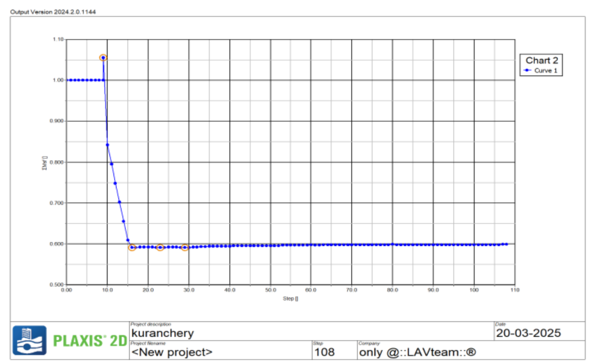
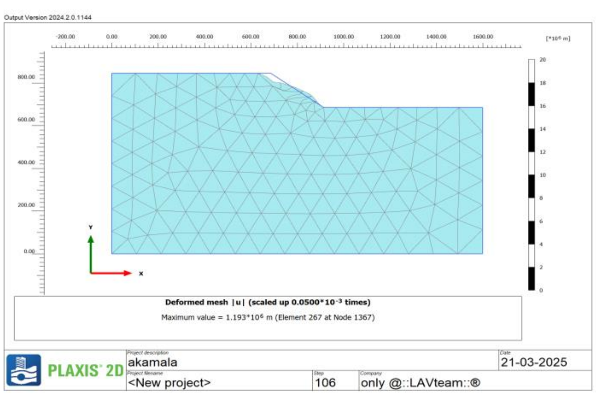


Figure 8: Deformation Mesh of Kuranchery using Plaxis 2D   Figure 9: Factor of Safety of Kuranchery (FOS -0.598)

Akamala



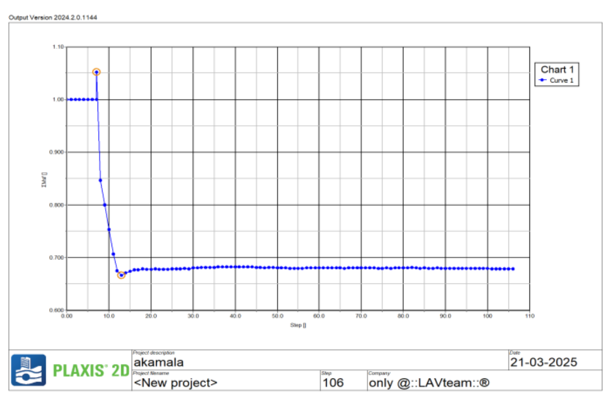


Figure 10: Deformation Mesh of Akamala using Plaxis 2D   Figure 11: Factor of Safety of Akamala (FOS =0.675)

3.3 Soil Nailing

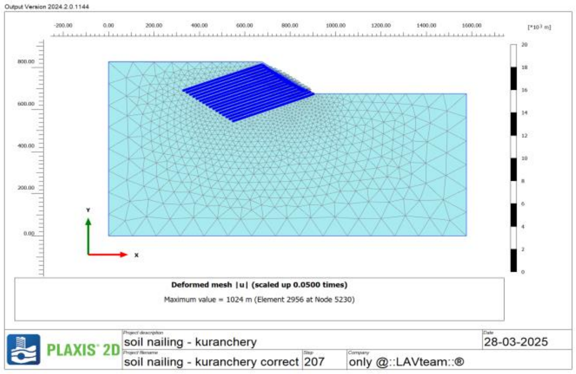
Nail Parameters

Nail parameters	Value	Unit
Material model	Elastic	_
Nailing type	Grouted	_
Yield strength of reinforcement(f_y)	415	Mpa
Nail diameter	0.02	m
Horizontal spacing of nails	4	m
Declination w.r.t horizontal	20	Degree
Modulus of elasticityof nail(E_n)	200	Gpa
Modulus of elasticityof grout (E_g)	22	Gpa
EA1	15707.96	KN/m
EI	0.3927	KN/m

Table 2: Nail Parameters

Soil Nailing- Kuranchery

Providing a soil nailing of 16 numbers with 15m spacing and 2 m horizontal spacing.



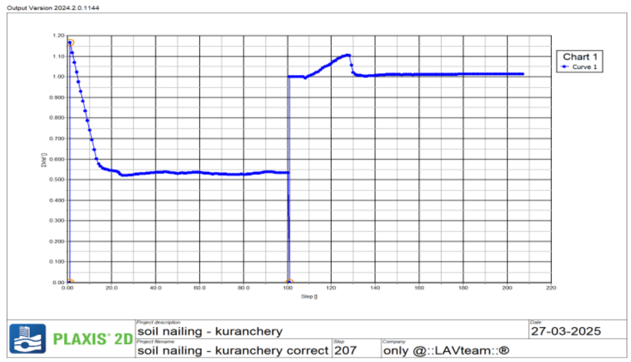


Figure 12: Deformed Mesh of Kuranchery after Soil Nailing

Figure 13: Factor of Safety of Kuranchery after Soil Nailing (FOS – 1.014)

Soil Nailing- Akamala

Providing a soil nailing of 16 numbers with 15m spacing and 2 m horizontal spacing

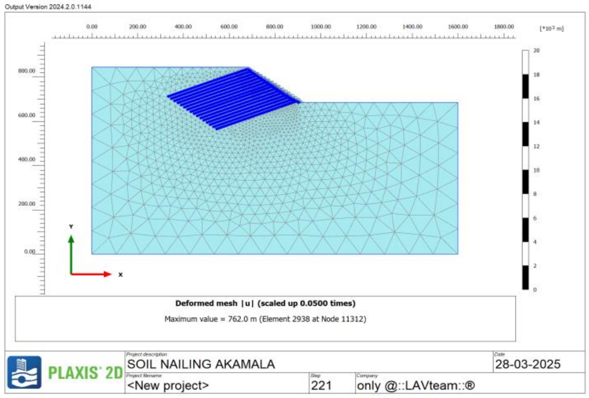


Figure 14: Deformed mesh of Akamala after Soil Nailing

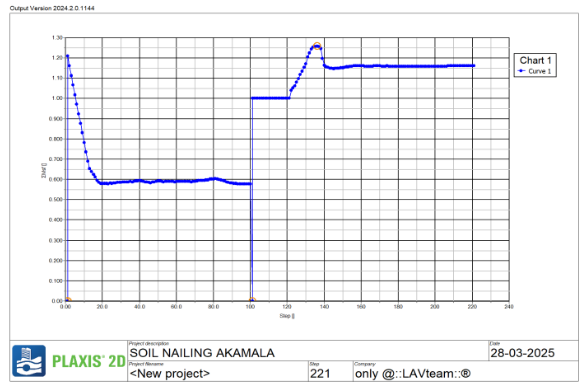


Figure 15: Factor of Safety of Akamala after Soil Nailing (FOS- 1.161)

4. Conclusions

This study confirms that introduction of soil nailing ito slopes which are prone to failure (with FOS < 1) increases the slopes FOS by great time. Key findings include:

1) Slope of Akamalawith FOS of 0.6751 improves to FOS -1.161 after soil nailing.

2) Slope of Kuranchery with FOS of 0.5983 improves to FOS - 1.014 after soil nailing.

3) It is found out that as the number of nails used in soil nailing increases the FOS of the corresponding slope also increases.

4) It was found that as the horizontal spacing between nails used decreases the FOS of the corresponding slope also increases

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