SLOPE STABILITY ASSESSMENT OF LANDSLIDE USING PLAXIS 2D

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ABSTRACT:
Understanding slope stability becomes increasingly important when urbanization encroaches on marginal regions. This evaluation evaluates how Plaxis 2D, a finite element program, is used to analyze the danger of landslides and potential corrective actions.
Additionally, we investigate using Plaxis 2D to evaluate the stability of current slopes. Preventive measures are informed by the software used in studies to map likely failure slip circles and determine factor of safety. Examined is the effect of various slip surface search techniques on these outcomes. Plaxis 2D proves to be an invaluable tool for geotechnical engineers, facilitating comprehensive assessments of landslide risk and the formulation of informed mitigation strategies amidst increasing development on complex terrains.
Development on problematic soils like laterite, which are prone to erosion and slope failures due to seepage pressure, is forced by rapid urbanization and industry. With Plaxis 2D, this study analyzes slopes that have succeeded and those that have failed. The factor of safety and potential failure slip circles are calculated, and the stability of the current slopes is evaluated using Plaxis 2D. By analyzing the results of several slide surface search algorithms, the study seeks to provide corrective actions.
The primary goal is to determine the displacement in both vertical and horizontal directions, as well as the soil slope factor, using Plaxis 2D's Finite Element Method. In difficult terrain, this study helps guarantee slope stability and directs future development.

Keywords: Plaxis 2D, Factor of Safety, Landslide.

INTRODUCTION:

The necessity for sophisticated geotechnical analysis tools to comprehend the elements causing slope failures is expanding in response to the escalating frequency of landslides and their substantial effects on infrastructure and communities. This research focuses on the analysis of landslides using Plaxis 2D, a powerful geotechnical engineering tool that employs finite element techniques. Landslides are a serious risk because they frequently cause property damage, human casualties, and environmental impact. Thus, in order to assess slope stability, understand failure mechanisms, and develop workable mitigation strategies, a comprehensive analysis is necessary.

Plaxis 2D's capacity to model soil-structure interaction and geotechnical behavior makes it a helpful tool in this situation. This study's main goal is to use Plaxis 2D to perform a thorough investigation of landslides and identify the underlying geological and geotechnical causes that cause slope failures. The program makes it possible to build complex numerical models that may be used to simulate different situations and circumstances that could result in landslides.

The research process includes careful site investigations, factor of safety estimates, and finite element studies to accomplish this goal. With Plaxis 2D, we hope to explore the subtleties of slope stability and failure mechanisms in greater detail, providing useful data that might aid in risk assessments and the development of workable mitigation plans. We also consult pertinent literature and case studies to deepen our understanding as we explore the complex field of landslide analysis with Plaxis 2D. This study is at the forefront of geotechnical research since it incorporates previous research findings and makes use of Plaxis 2D's sophisticated capabilities.

Fig. 1: Landslide, (Source: The Economics Times)

LITERATURE REVIEW:

1) G L Sivakumar Babu, Pinom Ering, Ramesh Kulkarni, Yashwant Kolekar, Satyanarayana Murty Dasaka (2015)

On July 30, 2014, a catastrophic landslide in western India buried a town named Malin, which had about 40 dwellings. The avalanche also claimed about 160 lives. The area's high rainfall combined with the debris's mass movement caused the landslide. The report uses numerical and back analytical techniques to study slope collapse in the Malin area. To gather data that is representative of the area, a site investigation was carried out. FLAC 2D finite difference studies are employed to determine probable causes of failure for the failing slope. Based on the analysis, the failure of the slope was caused by a loss of suction strength at the point where the local soil and rock met.

2) Pinom Ering, G L Sivakumar Babu (2016)

The approach to back analyze the slope and determine the factors causing landslide beginning is presented in this research. A probabilistic technique based on Bayesian analysis is used to do back analysis. Probabilistic techniques can be used to back-analyze a wide range of unknown slope stability parameter sets. The probability distributions of the unknown parameters are imported into the analysis as random variables. These distributions are updated via Bayesian analysis in light of the observed slope behavior. The method evaluates the matric suction drop that resulted in the Malin slope landslide. The results show that the creation of positive pore pressures and an almost 100% decrease in matric suction are the main mechanisms responsible for the landslide. Due to the decrease in matric suction and the development of positive pore pressures, the mobilized shear strength of the soil drops below the threshold value required to keep the slope in an equilibrium state; hence, the slope failed.

3) S. Rawat, A. K. Gupta (2016)

This study focuses on the two most often used methods for slope stability assessments. An attempt has been made to draw attention to the differences between the results of the analysis of the reinforced slope stability obtained from the PLAXIS 2D finite element model and the SLOPE/W limit equilibrium model. The analysis is done on two 45- and 60-slope angles that had nails inserted at three distinct inclinations (0, 15, and 30 in each case). Every nail inclination and the slope angles are measured from the horizontal. A comparative analysis of stability parameters including critical slip surfaces, nail forces, and factor of safety has been conducted. When compared to the finite element method, the limit equilibrium method produces greater values of the factor of safety. For 45 slope and all nail inclinations, large nail forces are seen by the limit equilibrium approach; however, for 60 slope angle, the finite element method indicates an increase in the nail forces. Additionally, examined are the effects of additional parameters such as bending stiffness in finite elements, soil-nail interaction, and bond length in limit equilibrium.

4) L. Djerbal & R. Bahar (2016)

This study discusses landslides in the mountainous northern region of Algeria, with an emphasis on the Tizi-Ouzou region in particular, which is vulnerable to instabilities brought on by wintertime high precipitation or snowfall. This region's Azazga City is dealing with a serious landslide problem that is affecting important buildings including the regional hospital and polyclinic. Stretching across more than 260 hectares, the landslide has undergone periods of significant activity throughout 2012. It was most recently sparked by snow cover in March 2012 and intense rains in 2014. The study intends to establish the landslide reactivation threshold with respect to average monthly rainfall and unusual rainfall occurrences using PLAXIS2D software.

5) Manuel Neves, Victor Cavaleiro, Alexandre Pinto (2016)

In this work, the stability of an experimental embankment built with a significant amount of granitic residual soil in the area is numerically back-analyzed. As a component of the current investigation of this natural resource, the study entails a geotechnical assessment of the soil. The purpose of this research is to calculate the Margin of Safety for granitic residual soil slopes under various variables (properties, geometries, loads, and groundwater levels) using two alternative calculation methods (LEM and FEM). Moreover, the research assesses the efficacy of prevalent remediation methodologies; however, their suitability may differ. Through the use of SLOPE/W and PLAXIS 2D, the parametric analysis, which eliminates the combined impacts of different remedial approaches, offers insights into stability in situations of fluctuating groundwater levels and surcharge events.

6) Soumia Merat, Lynda Djerbal, Ramdane Bahar (2018)

An important geotechnical calamity that is commonly documented in many parts of the world is slope failure brought on by rainfall. Examining how rainfall and climate affect slope stability was the goal of this research. Reliability of this unsaturated slope in natural terrain was assessed using a critical indicator called the "safety factor," which is a measure of precipitation rate and duration. To investigate the slope's stability, the finite elements program PLAXIS2D was utilized. Using completely linked flow deformation analyses, the safety variables were assessed and compared to the several controlling elements, such as the severity and duration of the rainfall, the angles and heights of the slopes, the properties of the soil, and the soil's hydraulic conductivity. In this study, the results were discussed and the association was confirmed.

7) Chetan R. Shah, Sandip S. Sathe, Prashant. B. Bhagawati and Santosh S. Mohite (2019)
An analysis of Malingoan village in Maharashtra, India, utilizing case studies reveals significant findings. On July 30, 2014, a devastating landslide occurred in the village, which is situated in the Pune district of Maharashtra, India. To evaluate slope stability and soil characteristics, soil samples were taken from the top, middle, and bottom of a hill slope. The landslide was primarily triggered by excessive rainfall, which adversely affected the geotechnical properties of the soil. The slope was found to be unstable and prone to failure, with a factor of safety less than one. The slope was determined to be unstable based on the examination of maps showing the area's land use and cover both before and after the landslide. Adopting non-agricultural land for agricultural use and using inappropriate farming methods were the main causes of land slide in the research area. A practically workable way to prevent such a calamity in the same topographical features is provided by this research.

8) Saurabh Rawat, Pankaj Sharma, Ashok Kumar Gupta (2019)

On August 13, 2017, in the vicinity of Kotropi village (Mandi District, Himachal Pradesh, India), extensive rains and pre-existing minor landslides are believed to have triggered a debris flow-type landslide. With the loss of two state transportation buses and 47 lives, the catastrophic landslide occurred. An enormous 1153 meters of slope run-out spanning over 190 meters of slope width completely submerged a 300-meter section of National Highway-154 in debris. The current study endeavors to mitigate Kotropi slope failure by utilizing helical soil nails. In this preliminary study, Kotropi soil undergoes both chemical and geotechnical testing. Failed slopes are stabilized with helical soil nails, each measuring 20 mm in diameter and 6 m in length, where deemed appropriate. The stability of slopes reinforced with helical soil nails is evaluated using the limit equilibrium approach to determine the factor of safety. Additionally, numerical modeling validation is performed using the finite element subroutine PLAXIS 2D. The factor of safety obtained from numerical modeling is 1.54, which differs from our estimations of 1.67. Furthermore, the maximum horizontal slope deformation is reduced from 0.13 to 0.06 meters.

9) Xiangyu Chen, Lulu Zhang, Limin Zhang, Yuande Zhou, Guanlin Ye, Ning Guo (2021)
This study presents a model that clarifies the failure mechanism of shallow landslides caused by rainfall, from the point of initiation to the point of final flow collapse. Slope failure is indicated by a fully developed plastic shear band, which is the result of increased pore pressure from rainfall. The study employs a two-phase approach to tackle the issue of simulating the entire progressive failure: linked hydro-mechanical finite element analysis for step 1 and massive deformation finite element analysis for step 2, with the application of an equivalent strength method to guarantee physical continuity. The model's ability to evaluate changes in pore pressure, displacement, plastic strain, and factor of safety during rainfall infiltration as well as predict ultimate flow-like deformation without a preset slip surface is demonstrated when it is tested against two real rainfall-induced landslide incidents.

10) Samprada Pradhan, David G. Toll, Nick J. Rosser, Matthew J. Brai (2022)
Unplanned hill slope excavation for local road development increases the risk of shallow rainfall-induced landslides in Nepal's mountainous terrain. This study examines a landslide that occurred in July 2018 on a steep road cut and was caused by rainfall infiltration. The study shows that the steep road cut and the decrease in soil suction brought on by rainfall at depths of less than 1.7 meters combined to cause the slope collapse. Combining field and laboratory experiments with PLAXIS 2D finite element models led to this outcome. The numerical back-analysis shows that the slope without the road cut had a starting factor of safety that was around 35% higher than the

slope with the road cut, and that it stayed stable with a factor of safety that was about 170% greater after rainy events. This demonstrates how road reductions raise the risk of landslides and highlights the significance of putting suitable solutions into place.

METHODOLOGY:

1. The methodology employed in this study entails conducting a thorough reverse investigation of a slope failure in Malin Village to ascertain soil strength features and pore water pressure conditions at the failure point. The Duncan and Stark approach is applied to retroactively determine cohesion at failure and calculate the friction angle from the plasticity index. Shear strength parameters are then derived using Bishop's method of slices, while a rotating model is utilized to visualize the failure surface geometry. Factor of safety against sliding is computed using a limit equilibrium approach, and the results are validated through the utilization of FLAC 2D software. Mesh refinement techniques are employed to ensure the accuracy of displacement and stress data, with the analysis confirming the reliability of the back analysis. Additionally, pre-slide shear strength values are computed using FLAC, taking stability constraints into account, and subsequently compared with post-slide features. The investigation reveals that the decline in strength characteristics leading to failure can be attributed to intense rainfall infiltration, resulting in a reduction in matric suction within the unsaturated region of the slope. Furthermore, pertinent literature is examined to provide context for the results and address the effect of landslides caused by rainfall on slope stability

2. This study's methodology involves a thorough examination of how rainfall-induced infiltration causes landslides to begin on sloped terrain. With FLAC2D software, a coupled fluid-flow mechanical analysis is carried out, simulating the collapsed slope in Malin Village through the use of finite difference techniques. This research considers actual rainfall data along with the local soil stratigraphy to understand the impact of antecedent rainfall circumstances, intensity, and duration on slope stability. The rainfall data is split into two successive events with different durations and levels of intensity.
   The results of the FLAC analysis are the input for the probabilistic back analysis, which employs Bayesian analytic techniques to identify failure mechanisms. The slope stability model uses finite difference approaches to handle uncertain input components such as cohesion, friction angle, and matric suction as random variables specified by their probability density functions.

3. Using nails that were slanted at 0°, 15°, and 30° from the horizontal, physical testing was conducted on dirt slopes that were nailed at 45° and 60° angles in this investigation. Next, numerical models were created using SLOPE/W and PLAXIS 2D v8.1, respectively, software tools. To ensure precision, factors such as the safety factor, critical slip surfaces, and nail forces were compared between the two methods and verified by means of experimental data. The impact of variables like bond length and the interaction between the soil and the nail was also taken into account. The methodology's overall goal was to methodically assess and contrast the two approaches' analytical performance in determining the stability of soil- nailed slopes under various circumstances.

4. This study's approach is examining a landslide that occurred in Azazga, a city in northern Algeria. Because of its hilly topography and wet winters, this area is vulnerable to these kinds of disasters. The study focuses on determining the landslide reactivation threshold concerning average monthly rainfall and exceptional rainfall using PLAXIS2D software. The geological characteristics of the region, including clayey and marshy lands overlaying flysch deposits, are

considered. The PLAXIS2D software is used to do numerical modeling with finite element analysis to predict the impact of weather conditions, namely an increase in the water table level, on the stability of the site. The model comprises four layers of soil with specific parameters, and boundary conditions are applied to replicate real- world conditions accurately. Through this approach, the aim is to understand the relationship between weather conditions and landslide activity, providing insights for hazard mitigation and infrastructure protection in landslide-prone regions like Azazga.

5. The method used in this work involves numerical computations using limit equilibrium techniques (LEM) and finite element analysis (FEM) to assess slope stability. Commercial software, specifically PLAXIS 2D for FEM and SLOPE/W for LEM, was used for this. Numerous SLOPE/W approaches were used, including the simplified procedures of Fellenius, Bishop, and Janbu. All analyses were performed in accordance with the most recent standards, EC7-BSI 2010, and they were conducted using Design Approach 1 Combination 2, which is crucial for assessing slope stability. The main stability metric was not a lump Factor of Safety (FoS), but rather Margin of Safety (MoS). The goal of this thorough method was to assess slope stability in a variety of scenarios and shed light on the distinctions between FEM and LEM studies.

6. To assess slope stability in scenarios resulting from precipitation, this work employs numerical simulation and analysis. Commercial software such as SLOPE/W and PLAXIS 2D were utilized to conduct coupled hydro-mechanical research and limit equilibrium approaches. The slope model in question included unique soil properties, beginning and boundary conditions, and shape. Soil behavior was characterized by the Mohr-Coulomb model, and undrained testing was used to determine the soil characteristics for the top layer. PLAXIS2D was used to produce the initial stresses, and the proper boundary conditions were implemented. The study's objective was to identify the processes that control landslides caused by rainfall while accounting for factors including slope geometry, groundwater availability, and rainfall patterns. To understand how monthly rainfall affects the slope.

7. A thorough methodology was used in this investigation of the July 30, 2014, landslide disaster in Malingoan village, Maharashtra, India, to evaluate the slope stability and pinpoint the landslide's causes. Soil samples were collected from the bottom, middle, and top of the hill slope in order to identify their properties and evaluate slope stability. The effect of excessive rainfall on the geotechnical properties of the soil was analyzed. The hill slope's instability was shown by factor of safety calculations, showing that it was prone to failure. In order to comprehend the changes in the terrain and pinpoint unstable areas, maps of land use and land cover were also examined before and after the landslide. The study found that changes in land usage and improper farming methods were significant.

8. The study's technique includes the use of helical soil nails to mitigate the Kotropi slope failure. First, geotechnical and chemical testing was done on the Kotropi soil to see if it could be stabilized with helical soil nails. Helical soil nails with particular dimensions were then selected for stabilizing the failed slope depending on favorable soil conditions**.** The stability of the helical soilnailed slope was evaluated using both limit equilibrium method (LEM) computations and finite element method (FEM) numerical modeling with PLAXIS 2D. The factor of safety was obtained using both approaches, and the numerical modeling confirmed the results of the LEM

calculations. Furthermore, the impact of soil nailing on the deformation of horizontal slopes was evaluated. This all-encompassing strategy sought to offer an efficient.

9. This paper proposes a model for shallow landslides triggered by rainfall, which helps to explain the failure process from the point of start to the point of final flow failure. A completely developed plastic shear band, caused by increasing pore pressure from rainfall, indicates the beginning of slope failure. A two-step approach is used to solve the problem of simulating the complete progressive failure process. First, the first response of the slope to rainwater infiltration is simulated using coupled hydro mechanical finite element analysis. Second, the final flow-like deformation is captured by big deformation finite element analysis. The analysis maintains physical continuity by employing the equivalent strength method. The validity of the model is assessed by contrasting it with two real-world instances of rainfall-induced landslides. The results demonstrate how the model's.

10. The method consists of three main steps. A comprehensive geotechnical field study was conducted near the landslide crown in attempt to reconstruct the subsurface condition of the slope prior to the landslide. This research included trial pit excavation, standard penetration tests (SPTs), and borehole drilling. For geotechnical characterization, including mechanical and hydraulic parameters, soil samples were gathered. Second, a program of field monitoring was put in place to evaluate in-situ hydrologic changes by employing real-time measurements of soil volumetric water content and rainfall. Finally, using the estimated soil parameters, several hydro-mechanical computations were performed using the finite element program PLAXIS 2D. The in-situ observations and predicted volumetric water content responses in the numerical modeling approach were used to calibrate the numerical model using observed rainfall data.

Fig. 2: Landslide (Sourse: India TV News)

APPLICATIONS:

1) Geotechnical Modeling: Using complicated geometry, soil profiles, and boundary conditions, engineers may build intricate numerical models of slopes and embankments using PLAXIS 2D. Through the input of site-specific data gathered from field studies, engineers are able to precisely model how slopes would behave under different loads and environmental scenarios.

2) Stability Analysis: Using PLAXIS 2D, engineers may do thorough stability analyses of embankments and slopes, evaluating elements including deformation patterns, critical failure surfaces, and factor of safety. With the use of appropriate soil models and boundary conditions, engineers may evaluate the stability of slopes under both static and dynamic loading situations, including impacts from rainfall and seismic activity.

3) Rainfall-Induced Landslide Assessment: By simulating elements including infiltration, pore water pressure development, and slope deformation, PLAXIS 2D makes it easier to simulate rainfall-induced landslides. Through the simulation of brief water seepage through the slope during rainfall events, engineers can evaluate the effects of rainfall intensity, duration, and infiltration patterns on the slope's stability.

4) Sensitivity Analysis: By altering input factors including soil characteristics, groundwater conditions, and loading scenarios, engineers can carry out sensitivity assessments using PLAXIS 2D. Engineers can determine important parameters and gauge the reliability of stability evaluations under a range of circumstances by evaluating the sensitivity of slope stability to various factors.

5) Dynamic Analysis: Using PLAXIS 2D, engineers may do dynamic assessments of embankments and slopes, capturing the behavior of groundwater and soil over time in response to seismic activity or rapid loading conditions. In order to determine a slope's resistance to dynamic loading and the likelihood of slope instability due to explosion or seismic activity, dynamic assessments are useful.
6) Back-Analysis and Calibration: By contrasting numerical model output with field data from landslide incidents, PLAXIS 2D makes back-analysis and calibration easier. To get a near match between simulated and real results, engineers can iteratively modify the model's parameters and assumptions, calibrating the model and enhancing its accuracy for upcoming stability evaluations.

7) Mitigation develop: Engineers can develop and assess slope stability mitigation strategies, such as vegetation cover, drainage systems, and reinforcement techniques, using PLAXIS 2D. Through numerical model implementation simulation, engineers may evaluate the efficacy of these methods in mitigating the danger of landslides and improving slope stability.

PREVENTIVE MEASURES:

1) Soil Nails and Helical Soils: To reinforce and stabilize slopes, install soil nails, which are steel bars or rods that are grouted into the soil. Make use of helical soil nails, which are screwed into the soil and have helical plates that increase stability and load-bearing capability, especially in difficult soil situations.

2) Reinforced Retaining Walls: By bucking lateral soil pressure, reinforced retaining walls stabilize slopes and stop mass displacement. For efficient slope stabilization, make use of strategies like mechanically stabilized earth walls, anchored retaining walls, and soldier pile and lagging walls.

3) Soil-Cement Mixtures or Shotcrete: In regions where soil erosion and weathering are common, apply soil-cement mixtures or shotcrete to slopes to offer extra support, erosion control, and surface protection.

4) Geosynthetic Reinforcements: To increase soil stability, improve slope performance, and stop surface erosion and failure, install geosynthetic reinforcements like geogrids or geotextiles. Reduce pore water pressure in slopes and control surface water runoff with geocomposite drainage systems to lessen the chance of instability

5) Implement Rockfall Protection Measures: To reduce the risk of landslides caused by rockfall and safeguard communities and infrastructure, put in place rockfall protection measures such catch fences, barriers, or rock bolting systems. Create and implement rockfall attenuator devices to lessen the possibility of slope damage and hazards by absorbing and dispersing the kinetic energy of falling rocks.

6) Systems for Draining Surface Water: Build surface water drainage systems, such as ditches, culverts, and channels, to divert runoff off of slopes, avoid saturation, and lower the chance of instability. Install subsurface drainage systems to manage groundwater flow and relieve high pore water pressure on slopes, such as horizontal or French drains.

7) Techniques for Modifying the Terrain: By constructing sturdy, stepped designs that lessen the impacts of gravity and erosion, terracing or benching can be used to modify the geometry of the slope and lower the danger of slope failure. Optimize stability and lower the likelihood of landslide start by redistributing soil mass and reshaping slopes through the use of contouring or grading.

8) Methods of Ground Improvement: Use ground enhancement methods to improve slope stability, soil characteristics, and bearing capacity, such as vibro-compaction, deep soil mixing, or soil compaction. Use grouting, cement injection, or chemical treatment to stabilize weak or expansive soils and reduce the chance of slope instability.

CONCLUSION:

Investigating landslide incidents brought on by rainfall infiltration is a complex task that necessitates the use of integrated strategies and thorough analysis. Together, these studies demonstrate the vital role that intense rainfall plays in causing slope failures, which are frequently made worse by things like road cuts, inappropriate land use, and unstable soil characteristics. Through the application of sophisticated techniques including numerical modeling, field monitoring, and reverse analysis, scientists have been able to clarify the intricate processes that underlie the beginning and advancement of landslides, providing important information for initiatives aimed at mitigating and preventing disasters. The terrible landslide that occurred on July 30, 2014, in Malin village, Maharashtra, India, is a sobering reminder of the disastrous effects of improper slope stability management.

A thorough examination and analysis found that the main cause of the landslide, which resulted in a considerable loss of life and property damage, was the torrential rainfall that had occurred over the previous week. These results were confirmed by numerical modeling with FLAC2D and back analysis using Bishop's method of slices, which showed a significant drop in soil strength as a result of rainfall-induced infiltration. The study emphasizes the necessity of comprehensive strategies to effectively avert future disasters by highlighting the significance of taking into account unsaturated soil mechanics and rainfall intensity-frequency analysis when determining slope stability.

Analogously, the Malingoan village in Maharashtra, India, landslide research highlights the negative effects of inappropriate land use practices on slope stability. It was discovered that unstable farming practices and land conversion were significant contributing factors to the tragedy through field inquiry and analysis of soil samples. In regions with similar topographical features, the study highlights the significance of implementing scientifically sound land management techniques to improve slope stability and lower the danger of future landslides. The serious instability issues that the Algerian province of Azazga is facing draw attention to the necessity of taking preventative action in order to reduce risks and shield residents and infrastructure from slope disasters.

Researchers showed a relationship between rainfall and landslide activity using GIS methodologies and numerical modeling, which shed light on the dynamics of slope instability in the area. The study emphasizes how important it is to employ proactive disaster mitigation strategies and make informed decisions in order to address the increasing issues brought on by slope instability in mountainous regions. Furthermore, the investigation of reinforced slopes using both limit equilibrium and finite element methods provides significant new insights into the design of reinforcement and slope mitigation. By analyzing the benefits and drawbacks of different analytical methodologies, researchers highlight the importance of complete slope stability assessments in order to ensure effective slope reinforcement and lower the likelihood of failure.

The Kotropi landslide study in India demonstrates how well helical soil nails work to stabilize slopes. Installing helical soil nails has been shown to greatly increase slope stability, reduce deformation, and successfully reinforce slope structures through geotechnical and chemical soil investigations and factor of safety evaluations. Furthermore, a new model for comprehending shallow landslides caused by rainfall provides important insights into the failure mechanism from the point of initial flow failure to the point of final flow failure. The model offers a strong framework for evaluating variations in pore pressure, displacement, plastic strain, and factor of safety during rainfall infiltration, thereby assisting in the prediction and mitigation of the effects of rainfall-induced landslides. This is achieved by identifying critical factors, such as plastic shear bands triggered by increased pore pressure from rainfall.

Lastly, research on the Kanglang landslide in Nepal provides insight into the causes and mechanisms of slope failures brought on by rainfall, especially when road cuts are present. Researchers highlight the importance of informed land-use planning and disaster mitigation strategies to reduce the risk of rainfall-induced landslides by demonstrating the significant role that road cuts and rainfall play in causing slope failures through integrated approaches that combine laboratory testing, coupled flow-deformation analyses, and field investigation. To summarize, the integration of results from many research projects emphasizes the significance of anticipatory actions, well-informed choices, and thorough evaluations of slope stability in reducing the catastrophic effects of landslides caused by precipitation.

These research contribute to the development of effective measures for disaster prevention and mitigation, ultimately protecting lives and infrastructure in susceptible locations globally, by deepening our understanding of landslide mechanisms and triggers.

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