



PLANNING MALAYSIA:

Journal of the Malaysian Institute of Planners

VOLUME 23 ISSUE 6 (2025), Page 303 – 316

EVALUATING THE IMPACT OF SOIL NAILING ON SLOPE STABILITY: INSIGHTS FROM MULTIPLE REGRESSION ANALYSIS

**Faris Hadi Muhamad Shahrulzaman¹, Mohd Khaidir Abu Talib²,
Muhammad Arif Azhar Zaihan³**

*^{1,2,3}Faculty of Civil Engineering and Built Environment,
UNIVERSITI TUN HUSSEIN ONN MALAYSIA*

*² Research Centre for Soft Soil (RECESS),
UNIVERSITI TUN HUSSEIN ONN MALAYSIA*

Abstract

Slope stability is a major issue in Malaysia because of the nation's varied topography and unpredictable weather. Landslides or slope failures can happen without warning even after years of apparent stability. The ineffectiveness of conventional slope stabilization procedures may call for investigating advanced methods like soil nailing. This numerical study exclusively focused on the systematic analysis of slope stability reinforced with soil nailing. Geo-Studio 2018 (SLOPE/W) is used to determine the slope's FOS with soil nails. Nail lengths of 6m, 9m, 12m, and 15m were evaluated, with a constant drillhole diameter of 150mm and a nail inclination of 10°. Slope angles of 30°, 60°, and 90° were considered, along with various soil types characterized by cohesion values of 0, 5, 10, and 15 kN/m² and friction angles of 5°, 15°, 35°, and 45°. The unit weight of the soil was consistently maintained at 17 kN/m³. Multiple regression analysis was employed to optimize the dataset, yielding an R-squared value of 0.80. The results demonstrated that the efficacy of soil nailing in enhancing slope stability was significantly influenced by nail length, slope angle, and soil properties. It was observed that longer nails and higher cohesion values contributed to improved stability, whereas steeper slopes and lower friction angles presented more significant challenges. These results highlighted the need to take into consideration a variety of elements in order to obtain optimal stability and offered crucial insights for developing and putting into practice soil nailing systems in a range of geotechnical settings. The study shows the impact of multiple regression analysis on geotechnical design optimization, especially in nail optimization. The study used this statistical technique to determine and measure the most important variables influencing soil nail performance. This method not only improved the accuracy of the design parameters but also provided a strong foundation for further study and real-world slope stabilization applications. A more sophisticated knowledge of the relationships between different design elements is made possible by the application of multiple regression analysis, which results in soil nailing solutions that are more dependable and efficient.

Keywords: Slope stability, Slope/W, soil shear strength parameter, soil nailing

¹ Corresponding author. Email: farishadi18@gmail.com

INTRODUCTION

Malaysia experiences frequent landslides due to its humid tropical climate, deeply weathered soil profiles, and rapid urban development in hilly regions (Ali et al., 2023; Kumar et al., 2021). Steep cut slopes, high-intensity rainfall, and heterogeneous residual soils increase the likelihood of slope failures, resulting in damage to infrastructure, economic losses, and safety risks to the public (Islam et al., 2022; Jambo et al., 2023). Historical records show that slope failures occur almost every year, often triggered by localized rainfall and aggravated by insufficient design considerations (Majid, 2020), based on Figure 1. Design-related deficiencies account for more than half of documented landslide cases in Malaysia, highlighting the need for improved engineering approaches. 29 out of 49 slope failures were caused by design-related problems, as shown in Table 1 (Gue & Tan, 2006). In addition to design errors, factors such as lack of skills, carelessness, and insufficient data often play a role in the persistence of these landslides (Jamaluddin, 2006). These occurrences are linked to those in Selangor, as evidenced in Table 1.

Table 1: Factor of landslide in Malaysia

Causes of Landslides	Number of Cases	Percentage (%)
Design errors	29	60
Constructions errors	4	8
Design and Construction errors	10	20
Geological features	3	6
Maintenance	3	6
Total	49	100

Source: (Gue & Tan, 2006)

Soil nailing has emerged as an effective reinforcement method for stabilising steep slopes, particularly in residual soils. It enhances shear resistance by mobilising friction and adhesion along the soil and nail interface, improving stability without requiring extensive excavation. The performance of a soil-nailed system is fundamentally influenced by soil shear strength parameters such as cohesion (c') and friction angle (ϕ') as well as nail configuration, including length, inclination, diameter, and bonding characteristics (Mizal-Azzmi et al., 2011; Shi et al., 2020). These parameters determine the pullout resistance and overall deformation behaviour of the reinforced mass (Dixon et al., 2014). Although empirical guidelines exist, the interaction between soil properties, slope geometry, and reinforcement design requires quantitative assessment to support safer and more efficient slope engineering.

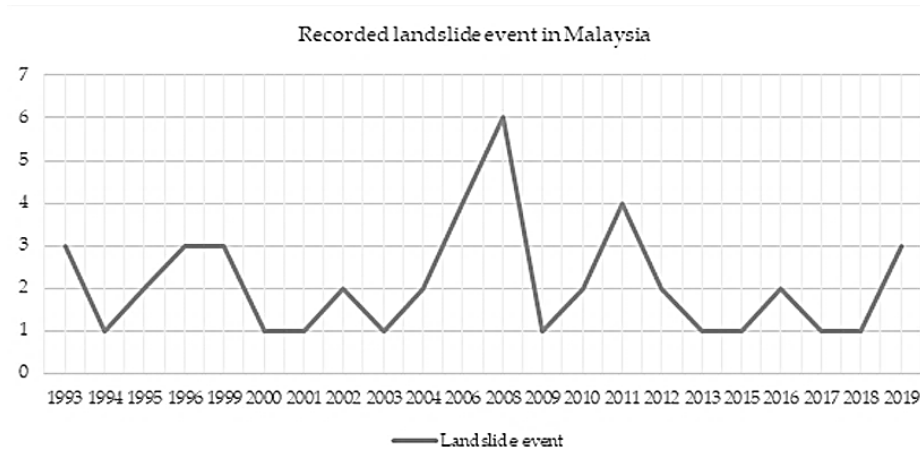


Figure 1: The Malaysian landslide record from 1993 to 2019
Source: (Majid, 2020)

Modern geotechnical analysis tools such as SLOPE/W allow a detailed evaluation of slope stability using the Limit Equilibrium Method (LEM), particularly the Morgenstern–Price method, which incorporates non-circular failure surfaces and inter-slice forces. Slope stability can also be assessed through site inspections, laboratory testing, numerical modelling, and the determination of the Factor of Safety (FOS). Previous studies have highlighted that the FOS is a critical parameter in evaluating the overall stability of a slope (Abbas, 2014; Johari & Javadi, 2012). However, numerical outputs alone may not fully reveal the relative importance of contributing variables, particularly when multiple soil and geometric factors interact simultaneously. This motivates the integration of statistical approaches such as Multiple Linear Regression (MLR), which enables parametric evaluation and identification of dominant predictors influencing the FOS (Ja’afar & Mohamad, 2021). Recent studies have demonstrated the usefulness of regression-based methods for correlating shear strength parameters, slope geometry, and reinforcement characteristics with FOS (Khan & Wang, 2021; Mohamed et al., 2023).

Despite increasing interest in regression-based approaches, limited studies have explored the combined effects of soil shear strength parameters and soil-nailing configurations across diverse slope conditions representative of Malaysian terrain (Bathini & Krishna, 2022; Sahoo et al., 2022). Moreover, empirical models developed elsewhere may not be directly applicable to residual soils, which exhibit significant variability and stress-dependent behaviour (Patil et al., 2021).

Therefore, this study aims to provide a comprehensive assessment of soil nail performance through numerical modelling and regression analysis by

evaluating the influence of soil shear strength, slope angle, and soil nail length on the Factor of Safety (FOS) using SLOPE/W, developing a MLR model that quantifies the contribution of each parameter to slope stability, and identifying the most influential variables governing soil nail performance to assess the practical reliability of the regression model for preliminary design optimisation. Nguyen et al. (2021) demonstrated that predictive modelling techniques are useful for estimating soil shear strength, supporting the wider use of quantitative methods in geotechnical studies. Through these combined objectives, the study offers insights into the behaviour of soil-nailed slopes under varying design and soil conditions. It provides a data-driven foundation for improved geotechnical decision-making in Malaysian slope engineering practice (Alfat et al., 2019).

RESEARCH METHODOLOGY

This part describes how to reach the goals. Ultimately, this method aims to direct the creation of safer slopes in geotechnical engineering by understanding the factors affecting slope stability using Geostudio and multiple regression. GeoStudio has become increasingly important, particularly in SLOPE/W, for analyzing and designing adequate slope stability. In order to enhance the FOS of the slope, this study incorporated soil nailing into the design, utilizing Limit Equilibrium Method (LEM) through SLOPE/W software to evaluate all slope designs and suggest the most effective preventative and corrective actions. The Morgenstern-Price Method was selected among the various LEM because it was effective in handling non-circular critical slip surfaces, included both inter-slice forces, assumed an inter-slice force function, allowed the selection of various inter-slice force functions, and measured the FOS for both force and moment balance.

The effect of different soil nail parameters on slope stability with varying slope angles and soil types was examined using SLOPE/W software. In this study, a total of 300 different slope designs were carefully evaluated. Then, a cross-section of the soil slope was identified for a stability check and to determine the best preventative and remedial measures. Table 2 shows the data parameters for slope and soil properties in this study.

The main properties of soil shear strength essential for slope stability assessments are cohesiveness, friction angle, and unit weight. Each of these factors greatly influences slope stability. Cohesion values of 0, 5, 10, 15, and 20 kN/m² were investigated in this work. The cohesion value of non-cohesive soils, like loose sands, is 0 kN/m², meaning there is no intrinsic attraction between the particles. The 5 to 20 kN/m² range encompasses a variety of cohesive soils, from low to high cohesion, including silts and clays with different levels of particle attraction. Identifying patterns and thresholds where changes in cohesion significantly affect slope stability, as indicated by incremental values (5, 10, 15,

20 kN/m²), the study contributes to our understanding of the relationship between soil cohesion and the FOS.

Table 2: Data parameters for slope and soil properties

Slope angle, β (°)	Slope Height, H (m)	Soil properties		
		Friction Angle, ϕ (°)	Cohesion, c' (kPa)	Unit weight, γ (kN/m ³)
30	7	5	0	17
		15	5	
60		25	10	
		35	15	
90		45	20	

To represent a wide range of soil types and their shear strength properties, the friction angles of 5°, 15°, 25°, 35°, and 45° were chosen. A friction angle of 5° is used to depict very loose, poorly graded soils with little internal friction, such as loose sands or silts. A 15° friction angle, characteristic of loose to medium-dense sands, denotes more compacted soils with significant internal friction. Medium-dense to dense silty sands have a 25° friction angle, a balance between loose and heavily compacted soils. Strong particle interlocking at a 35° friction angle is a symptom of dense, well-graded sands and gravels with high internal friction (Ihnatov, 2022). The maximum resistance to shear pressures, found in extremely dense, well-compacted soils or rock-like materials with unusually high internal friction, is represented by a friction angle of 45°. To get insight into the effects of friction angle variations on slope stability, the research will analyze these incremental values to ascertain how these changes impact slope stability.

For this investigation, a unit weight of 17 kN/m³ was chosen. A unit weight of 17 kN/m³ indicates an intermediate density prevalent in medium-dense or silty sands (Shiferaw, 2021). A height of seven meters was specified, and angles of 30°, 60°, and 90° were considered regarding slope inclinations. The moderate inclinations commonly found in man-made slopes, including cut slopes, dams, and natural terrains, are represented by a slope 30° (M. I. Khan & Wang, 2021). Understanding the stability of steeper slopes, which may be more likely to collapse, is made easier by the 60° slope. Some natural and manufactured situations have moderate to severe slopes, which are less frequent. The 90° slope is essential for many geotechnical applications because it provides insight into the stability of almost vertical or near-vertical faces, frequently found in cliffs, retaining walls, and other constructed structures. A height of 7 meters was chosen to guarantee uniformity across all slope angles and offer a clear comparison of

stability data. The various slope angles and soil characteristics considered in the slope analysis are compiled in Table 3.

The primary parameter used in this study to examine how soil nails affect different slope stabilization techniques is soil shear strength. The objective is to identify the most effective drill hole diameter for slope repair and the ideal soil nail length and inclination. Table 3 lists nail design characteristics utilized in GeoStudio to examine the Factor of Safety (FOS).

Table 3: Soil nail parameter

Inclination of soil nail, i (°)	Drillhole Diameter, D_{DH} (m)	Length of Soil Nail, L_N (m)
10	0.15	6, 9, 12, 15

This range of inclination works incredibly well to guarantee stability in Malaysia's diverse soil types. A 10° inclination for soil nails was chosen because it falls within the range recommended by the Federal Highway Administration (FHWA) and Geoguide 7. Soil nails are usually set at angles ranging from 10° to 20° from the horizontal, with 15° being the most often used angle, according to the FHWA (Noor & Jamain, 2019). The grout may flow from the drill hole's base to its top at varying angles. Inclinations lower than 10 degrees are often avoided to lessen the possibility of grout voids. According to Geoguide 7, soil nails are frequently angled downward (between 5 and 20 degrees) for appropriate grouting in low-pressure or gravity environments (Elahi et al., 2022). 0.15 m drill hole diameter of soil nail had been chosen according to FHWA and Geouide 7. A soil nail drill hole's normal diameter is 6 inches, although it can be expanded to 8 inches or more if needed, according to the FHWA (M. Khan & Wang, 2021). The steel bar will be placed in the drilled holes, with a diameter ranging from 100mm to 300mm and spaced between 1m and 2m apart (Rashad et al., 2023).

In Malaysia, the length of soil nails used for slope stabilization is influenced by standard engineering practices, design guidelines, and site-specific conditions. While general design methods suggest consistent nail lengths between 6 to 9 meters, the actual length should be determined based on the slope angle, soil shear strength parameters, and geotechnical properties to ensure optimal performance (Yılmaz & Yuksek, 2007). The best length should be customized to the slope's angle and the surrounding soil properties to guarantee optimum performance. If deeper reinforcement is required due to weaker soil layers or higher loading conditions, soil nails can extend up to 12 meters. This longer length helps reach more stable soil strata, increasing the pullout resistance of the nails, and ultimately enhancing the Factor of Safety (FOS) for the slope (Sari, 2018).

RESULT AND DISCUSSION

Upon completing the design and analysis of the slope models, results were generated for each iteration of the design process. The main aim of this section is to evaluate and improve soil stability by determining the most effective soil nail length. A Multiple Linear Regression (MLR) analysis was performed using the Factor of Safety (FOS) values obtained from SLOPE/W as the dependent variable to assess the relative significance of the parameters influencing slope stability (Sari, 2018). The application of MLR in this study follows established statistical procedures, including significance testing, beta coefficient evaluation, and goodness-of-fit assessment, consistent with regression methodologies commonly applied across empirical research disciplines (Montuori et al., 2023). The approach allows a quantitative assessment of how each parameter contributes to overall slope performance. The analysis, carried out in Excel, provided a detailed understanding of the individual and combined effects of independent variables such as nail length, cohesion, friction angle, and slope angle (Wisaeng & Muangmeesri, 2025).

The regression coefficients obtained from the analysis quantify the sensitivity of the FOS to variations in each parameter, while the associated p-values indicate the statistical significance of their influence (Braun & Wang, 2020). The results establish a clear hierarchy of parameter significance, with soil nail length and cohesion showing highly significant p-values below 0.01, reflecting their strong and statistically robust contribution to slope stability (Chakraborty & Goswami, 2017). The regression model indicates that nail length, cohesion, and friction angle possess positive coefficients, signifying that increases in these parameters enhance FOS and improve slope stability, whereas slope angle exhibits a negative coefficient, showing that steeper slopes reduce stability and increase the likelihood of failure. Among all variables, soil nail length demonstrates the highest positive effect (+0.0665), confirming its dominant role in reinforcement design and its strong correlation with overall slope performance. These findings highlight that nail length exerts the most substantial influence on slope stability, while cohesion and friction angle act as critical supporting parameters. Overall, the multiple regression approach effectively quantifies the combined effects of soil shear strength and geometric parameters on slope performance, providing a reliable analytical framework for evaluating stability in soil-nailed systems (Gupta et al., 2024).

By comparing experimental FOS values with predicted FOS derived from 300 slope models, the regression analysis visually represents how slopes respond under various stability conditions. Equation (1) describes the relationship between FOS and the key soil and slope parameters, illustrating the maximum resistance to failure across different combinations of soil shear strength, slope

angles, and soil nail lengths. This relationship is further illustrated in the correlation graph shown in Figure 2.

$$FOS = 0.0422\phi' + 0.0562C' - 0.0137\beta + 0.0665L_N + 0.388 \quad (1)$$

The symbol ϕ' represents the friction angle of the soil in degrees ($^{\circ}$), c' denotes the cohesion of the soil in kilonewtons per square meter (kN/m^2), β is the angle of the slope in degrees ($^{\circ}$), and L_n indicates the length of the soil nail in meters (m).

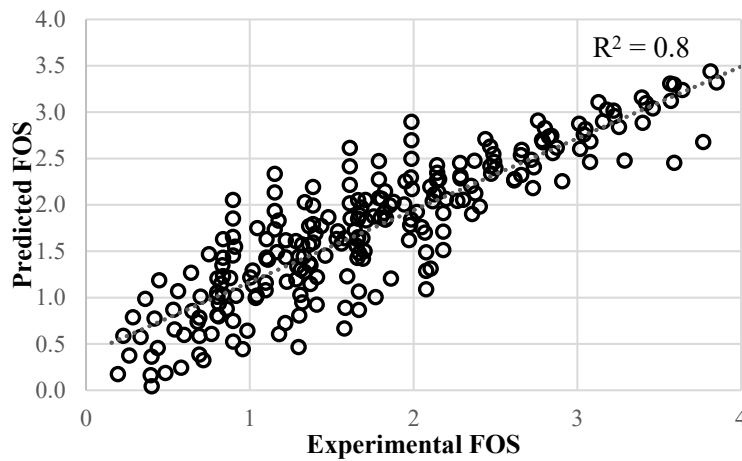


Figure 2: Correlation between actual FOS and predicted FOS.
 Source: Author's calculation

The model demonstrates a high level of reliability, as indicated by its coefficient of determination (R^2) of 0.8, which explains approximately 80% of the variability in the actual FOS values based on the predicted values. In a scatter plot, the line of best fit illustrates the model's predictions, and the closer the data points are to this line, the higher the model's accuracy. With an R^2 of 0.8, most points lie near the line, reflecting strong predictive performance. In engineering and the physical sciences, R^2 values above 0.70 are generally considered indicative of a good model fit, and values ranging from 0.70 to 0.99 are commonly interpreted as demonstrating strong explanatory power (Gupta et al., 2024). The significant R^2 value confirms that key design factors, including nail length, slope angle, cohesion, and friction angle, account for a substantial portion of the variance in slope stability (Wu et al., 2020).

Considering the inherent complexity and variability of soil behaviour and slope conditions, an R^2 of 80% is regarded as adequate within geotechnical engineering applications. Although a theoretical ideal may approach 90% or higher, values between 75% and 80% are generally sufficient for practical design purposes, particularly when using multiple linear regression. The focus should be on developing an interpretable and reliable model that enables safe and effective design decisions rather than pursuing a perfect statistical fit. This model provides a sound foundation for forecasting slope stability and informing design optimisation, as evidenced by its capacity to capture a substantial portion of the underlying relationships between independent parameters and FOS (Hamilton et al., 2015; Tian et al., 2024).

Shear strength parameters, specifically cohesion and friction angle, must be considered in combination with varying slope angles and soil nail lengths to ensure optimal stability. The model's R^2 value supports the identification of suitable slope designs that minimise failure risk while satisfying the safety requirements of the Jabatan Kerja Raya (JKR). To visualise these interactions, Figure 3 presents the relationship between soil nail length (L_n) and friction angle (ϕ') for different combinations of slope angle (β) and cohesion (c'), calculated for a target FOS of 1.5. This figure was generated using Equation (2), derived by rearranging Equation (1) to solve for the required nail length, providing a practical tool for understanding the influence of soil properties and slope geometry on slope stability.

$$L_N = \frac{1.5 - 0.0422\phi' - 0.0562c' + 0.0137\beta - 0.388}{0.0665} \quad (2)$$

The required length of soil nails is primarily governed by the soil's friction angle, cohesion, and slope inclination. Soils with higher friction angles exhibit greater inter-particle resistance to sliding, reducing the need for long nails as the soil mass provides sufficient shear strength to maintain stability. Conversely, soils with lower friction angles are inherently less stable and therefore require longer nails to achieve the desired Factor of Safety (FOS). Slope geometry exerts a significant influence on reinforcement demand, where gentle slopes with approximately 30° inclination typically require shorter nails due to lower gravitational driving forces, while very steep or vertical slopes approaching 90° demand substantially longer nails to resist increased sliding tendencies. Cohesion further contributes to stability enhancement for higher cohesion values, such as 15 kN/m^2 , strengthen soil bonding and reduce reliance on external reinforcement, whereas soils with negligible cohesion depend heavily on

frictional resistance and reinforcement length to remain stable (Pun & Shiu, 2007). Integrating these parameters enables engineers to optimise soil nail lengths to achieve both structural safety and economic efficiency. This optimisation ensures adequate support without excessive material use, thereby promoting cost-effective slope design. In weaker soils characterised by low friction and cohesion, longer nails become essential to maintain equilibrium and minimise the likelihood of slope failure. The results underscore the importance of tailoring soil nail length to site-specific conditions and geometric configurations to achieve stable, efficient, and sustainable slope reinforcement designs.

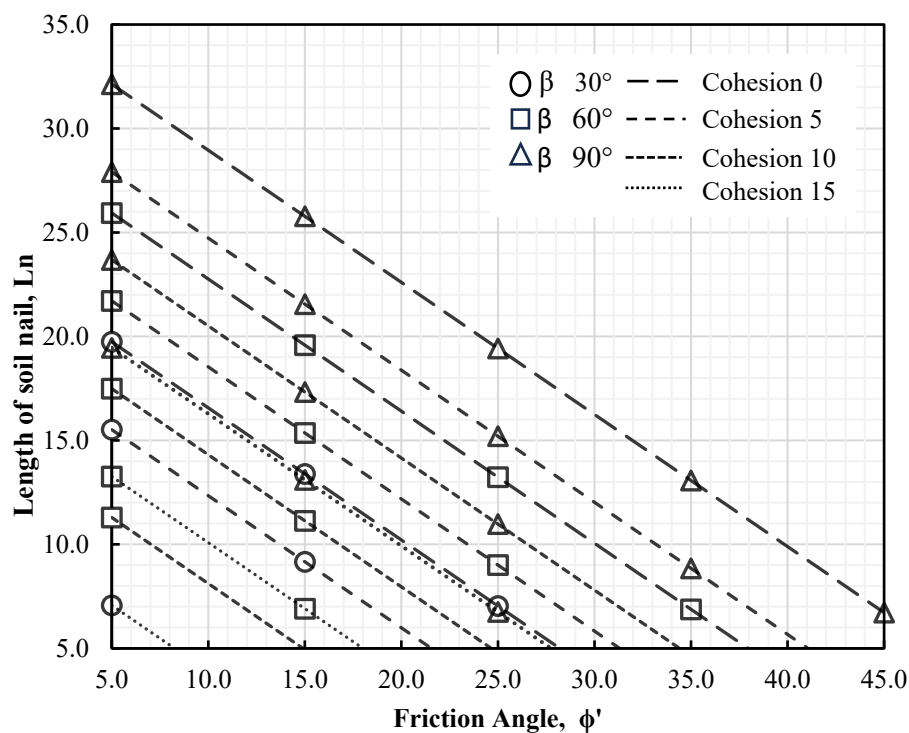


Figure 3: Impact of soil nail length on slope stability using various shear strength parameters
 Source: Author's calculation

CONCLUSION

This study employed multiple regression analysis to comprehensively evaluate the influence of soil nailing on slope stability, revealing that slope angle, soil nail length, and soil shear strength parameters significantly affect the FOS. Steeper slopes and soils with lower friction angles present greater stability challenges,

whereas longer soil nails and higher cohesion values enhance stability, while gentle slopes require shorter nails due to lower gravitational driving forces (FHWA, 1998). The main contribution of this research lies in the development of a predictive regression model that integrates soil shear strength, slope geometry, and reinforcement length, achieving an R^2 value of 0.8 and explaining 80% of the FOS variability. This provides a quantitative framework for optimizing soil nail length across various soil and slope conditions, offering practical design guidance and advancing slope stabilization practices beyond conventional empirical methods. However, the study is limited to residual soil conditions typical of Malaysian sites and does not consider long-term factors such as weathering, groundwater fluctuations, or seismic loading that may influence slope performance. Future research should therefore expand the model to include these geotechnical and environmental variables, validate its performance through field observations, and develop site-specific design recommendations. Overall, this study establishes a robust, interpretable framework for understanding the interaction between soil properties, slope geometry, and reinforcement design, contributing to safer, more cost-effective, and optimized slope stabilization in geotechnical engineering practice.

ACKNOWLEDGEENTS

This research is supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Geran TIER1 (Q859), Geran Penyelidikan Pascasiswazah GPPS (Q791) and GPPS (Q666). Special gratitude to the Research Management Centre (RMC), Faculty of Civil Engineering and Built Environment (FKAAB) and Research Centre for Soft Soil (RECESS) of UTHM for the guidance, encouragement, and valuable support.

REFERENCES

- Abbas, J. M. (2014). Slope stability Analysis using numerical method. *Journal of Applied Sciences*, 14(9), 846–859. <https://doi.org/10.3923/jas.2014.846.859>
- Alfat, S., Zulmasri, L. O. M., Asfar, S., Rianse, M. S., & Eso, R. (2019). Slope stability analysis through variational slope geometry using Fellenius Method. *Journal of Physics Conference Series*, 1242(1), 012020. <https://doi.org/10.1088/1742-6596/1242/1/012020>
- Ali, S., Kasim, N., Anuar, A. a. S., Ruslan, M. I., Azahar, W. N. a. W., & Ramli, A. B. (2023). Development Of Cumulative Rainfall Threshold for Landslide Occurrence In Peninsular Malaysia. *Planning Malaysia*, 21. <https://doi.org/10.21837/pm.v21i30.1417>
- Bathini, D. J., & Krishna, V. R. (2022). Performance of Soil Nailing for Slope Stabilization-A Review. *IOP Conference Series Earth and Environmental Science*, 982(1), 012047. <https://doi.org/10.1088/1755-1315/982/1/012047>

- Braun, M., & Wang, X. (2020). A review of fatigue test data on weld toe grinding and weld profiling. *International Journal of Fatigue*, 145, 106073. <https://doi.org/10.1016/j.ijfatigue.2020.106073>
- Chakraborty, A., & Goswami, D. (2017). Prediction of slope stability using multiple linear regression (MLR) and artificial neural network (ANN). *Arabian Journal of Geosciences*, 10(17). <https://doi.org/10.1007/s12517-017-3167-x>
- Dixon, N., Spriggs, M. P., Smith, A., Meldrum, P., & Haslam, E. (2014). Quantification of reactivated landslide behaviour using acoustic emission monitoring. *Landslides*, 12(3), 549–560. <https://doi.org/10.1007/s10346-014-0491-z>
- Elahi, T. E., Islam, M. A., & Islam, M. S. (2022). Parametric assessment of soil nailing on the stability of slopes using numerical approach. *Geotechnics*, 2(3), 615–634. <https://doi.org/10.3390/geotechnics2030030>
- FHWA, 1998, "Manual for Design & Construction Monitoring of Soil Nail Walls", FHWA-SA-96-69R U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.
- Gue, S.S. & Tan, Y.C. (2006), "Landslides: Abuses of The Prescriptive Method", International Conference on Slope 2006, KL, 7-8 Aug 2006
- Gupta, A., Stead, T. S., & Ganti, L. (2024). Determining a meaningful R-squared value in clinical medicine. *Deleted Journal*. <https://doi.org/10.62186/001c.125154>
- Hamilton, D. F., Ghert, M., & Simpson, A. H. R. W. (2015). Interpreting regression models in clinical outcome studies. *Bone and Joint Research*, 4(9), 152–153. <https://doi.org/10.1302/2046-3758.49.2000571>
- Ihnatov, S. (2022). The sands of medium density and sandy loam density differences investigation while cement injection and pressuremetry crimping. *Budownictwo I Architektura*, 21(4), 043–050. <https://doi.org/10.35784/bud-arch.3048>
- Islam, F., Iqbal, M. F., Mahmood, I., Shahzad, M. I., & Shah, S. U. (2022). Application of frequency ratio, information value, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Murree region, Sub-Himalayas. *Research Square (Research Square)*. <https://doi.org/10.21203/rs.3.rs-2218881/v1>
- Ja'afar, N. S., & Mohamad, J. (2021). Application Of Machine Learning in Analysing Historical and Non-Historical Characteristics Of Heritage Pre-War Shophouses. *Planning Malaysia*, 19. <https://doi.org/10.21837/pm.v19i16.953>
- Jamaluddin, T. A. (2006). Human factors and slope failures in Malaysia. *Bulletin of the Geological Society of Malaysia*, 52, 75–84. <https://doi.org/10.7186/bgsm52200611>
- Jambo, U. M., Khanan, M. F. A., Baharuddin, Z., Rahman, M. Z. A., Azmy, S. N., & Kadir, W. H. W. (2023). Geospatial approach for Landslides Vulnerability Assessment of Physical Infrastructures in Sireh Park, Johor Bahru. *Malaysian Journal of Society and Space*, 19(4). <https://doi.org/10.17576/geo-2023-1904-04>
- Johari, A., & Javadi, A. (2012). Reliability assessment of infinite slope stability using the jointly distributed random variables method. *Scientia Iranica*, 19(3), 423–429. <https://doi.org/10.1016/j.scient.2012.04.006>
- Khan, M. I., & Wang, S. (2021). Slope Stability Analysis to Correlate Shear Strength with Slope Angle and Shear Stress by Considering Saturated and Unsaturated Seismic Conditions. *Applied Sciences*, 11(10), 4568. <https://doi.org/10.3390/app11104568>

- Khan, M., & Wang, S. (2021). Slope Stability Analysis to Develop Correlations between Different Soil Parameters and Factor of Safety Using Regression Analysis. *Polish Journal of Environmental Studies*, 30(5), 4021–4030. <https://doi.org/10.15244/pjoes/131203>
- Kumar, V., Cauchie, L., Mreyen, A., Micu, M., & Havenith, H. (2021). Evaluating landslide response in seismic and rainfall regime: a case study from the SE Carpathians, Romania. *European Geosciences Union Journal*. <https://doi.org/10.5194/nhess-2021-230>
- Majid, N. A. (2020). Historical landslide events in Malaysia 1993-2019. *Indian Journal of Science and Technology*, 13(33), 3387–3399. <https://doi.org/10.17485/ijst/v13i33.884>
- Mizal-Azzmi, N., Mohd-Noor, N., & Jamaludin, N. (2011). Geotechnical approaches for slope stabilization in residential area. *Procedia Engineering*, 20, 474–482. <https://doi.org/10.1016/j.proeng.2011.11.190>
- Mohamed, M. H., Ahmed, M., Mallick, J., & AlQadhi, S. (2023). Finite element modeling of the Soil-Nailing process in Nailed-Soil slopes. *Applied Sciences*, 13(4), 2139. <https://doi.org/10.3390/app13042139>
- Montuori, P., Cennamo, L. M., Sorrentino, M., Pennino, F., Ferrante, B., Nardo, A., Mazzei, G., Grasso, S., Salomone, M., Trama, U., Triassi, M., & Nardone, A. (2023). Assessment on practicing correct body posture and determinant analyses in a large population of a metropolitan area. *Behavioral Sciences*, 13(2), 144. <https://doi.org/10.3390/bs13020144>
- Morgenstern, N. R., & Price, V. E. (1965). The analysis of the stability of general slip surfaces. *Géotechnique*, 15(1), 79–93. <https://doi.org/10.1680/geot.1965.15.1.79>
- Nguyen, Q. H., Ly, H., Ho, L. S., Al-Ansari, N., Van Le, H., Tran, V. Q., Prakash, I., & Pham, B. T. (2021). Influence of data splitting on performance of machine learning models in prediction of shear strength of soil. *Mathematical Problems in Engineering*, 2021, 1–15. <https://doi.org/10.1155/2021/4832864>
- Noor, M. M., & Jamain, M. F. (2019). Pull out and creep behaviour of soil nailing – a case study. *Journal of Mechanical Engineering*, 16(1), 189–211. <https://doi.org/10.24191/jmeche.v16i1.6072>
- Patil, U. D., Shelton, A. J., III, & Aquino, E. (2021). Bioengineering solution to prevent Rainfall-Induced slope failures in tropical soil. *Land*, 10(3), 299. <https://doi.org/10.3390/land10030299>
- Pun, W. K., & Shiu, Y. K. (2007). *Design practice and technical developments of soil nailing in Hong Kong*. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong.
- Rashad, A., Mahmoud, A., Hasham, M., & Mahmoud, T. (2023). EFFECT OF SOIL NAILING ON THE SLOPE STABILITY OF ROAD EMBANKMENTS UNDER TRAFFIC LOAD USING THE OPTIMIZED LEM. *Journal of Advanced Engineering Trends*, 42(2), 219–231. <https://doi.org/10.21608/jaet.2022.119755.1139>
- Sahoo, A. K., Pramanik, J., Jayanthu, S., & Samal, A. K. (2022). Slope stability predictions using machine learning techniques. *IEEE Conference Publication*, 133–137. <https://doi.org/10.1109/icac3n56670.2022.10074079>

- Sari, M. (2018). Stability analysis of slopes prone to circular failures using logistic regression. In *Advances in Science, Technology & Innovation/Advances in science, technology & innovation* (pp. 355–357). https://doi.org/10.1007/978-3-030-01665-4_82
- Shi, G., Gu, G., Zhou, H., Tao, Z., Pan, H., Tang, T., & Yin, Q. (2020). Stability monitoring and analysis of high and steep slope of a hydropower station. *Geofluids*, 2020, 1–16. <https://doi.org/10.1155/2020/8840269>
- Shiferaw, H. M. (2021). Study on the influence of slope height and angle on the factor of safety and shape of failure of slopes based on strength reduction method of analysis. *Beni-Suef University Journal of Basic and Applied Sciences*, 10(1). <https://doi.org/10.1186/s43088-021-00115-w>
- The role of financial ratios in signaling financial distress. (2024). *International Research Journal of Economics and Management Studies*, 3(1). <https://doi.org/10.56472/25835238/irjems-v3i1p148>
- Tian, W., Ge, J., Zhao, Y., & Zheng, X. (2024). AI Chatbots in Chinese higher education: adoption, perception, and influence among graduate students—an integrated analysis utilizing UTAUT and ECM models. *Frontiers in Psychology*, 15. <https://doi.org/10.3389/fpsyg.2024.1268549>
- Wisaeng, K., & Muangmeesri, B. (2025). University rankings prediction using hybrid feature selection based on machine learning methods. *International Journal of Analysis and Applications*, 23, 112. <https://doi.org/10.28924/2291-8639-23-2025-112>
- Wu, T., Yu, J., Lu, J., Zou, X., & Zhang, W. (2020). Research on inversion model of cultivated soil moisture content based on hyperspectral imaging analysis. *Agriculture*, 10(7), 292. <https://doi.org/10.3390/agriculture10070292>
- Yilmaz, I., & Yuksek, A. G. (2007). An example of artificial neural network (ANN) application for indirect estimation of rock parameters. *Rock Mechanics and Rock Engineering*, 41(5), 781–795. <https://doi.org/10.1007/s00603-007-0138-7>

Received: 2nd September 2025. Accepted: 14th September 2025