RECENT TREND IN CIVIL ENGINEERING AND BUILT ENVIRONMENT
e-ISSN: 2773-5303

RTCEBE

Vol. 6 No. 1 (2025) 95-105
https://publisher.uthm.edu.my/periodicals/index.php/rtcebe

Evaluation of Soil Nail Slope Stability Using SLOPE/W and PLAXIS 2D Software

Aidil Shahmi Hashim[1], Mohd Fairus Yusof[1]*

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA*

*Corresponding Author: fairus@uthm.edu.my
DOI: https://doi.org/10.30880/rtcebe.2025.06.01.011

Article Info

Received: 08 January 2024
Accepted: 15 April 2024
Available online: 6 May 2025

Keywords

Slope stability, Soil nailing, Slipe circle failure, Factor of safety, SLOPE/W, PLAXIS 2D, Morgenstern-Price

Abstract

One crucial factor in geotechnical engineering is slope stability. Certain specialized software can be used in the geotechnical field for performing slope stability assessments. Nevertheless, the outcomes produced by any type of software could be differ. Thus, the purpose of this study was to evaluate the slope stability findings produced by the SLOPE/W and PLAXIS 2D software. Investigations were conducted into the effects of changing the embankment height (4, 6, and 8 meters) and soil nail angle (0, 15, and 30 degrees). The findings demonstrate that, for both software, the safety factor results for soil slopes strengthened with soil nails are greater than 1. In every scenario, a soil nail inclination of 30° yielded the safest slope, with the maximum FOS value recorded at 3.243. However, based on FOS values of 0.953 and 0.862, the natural slopes at heights of 6 and 8 meters are unstable. In conclusion, the FOS findings obtained from using SLOPE/W and PLAXIS 2D software are quite similar.

1. Introduction

Conducting stability analyses serves the primary objective of evaluating the safety and identifying the most cost-effective design for various types of slopes, including excavation, landfills, embankments, and road cuts (Serra, 2013). The instability of slopes is a persistent concern in many building and infrastructure projects, as such failures can result in significant repair and maintenance costs, as well as putting both employees and the public at danger (Dewedree & Jusoh, 2019). Geotechnical stability analysis is critical in determining the structural stability of various geotechnical constructions such as slopes, embankments, and retaining walls. PLAXIS and Slope/W are widely used software programs for conducting such analyses. PLAXIS is a powerful finite element analysis (FEA) software primarily designed for geotechnical applications, offering comprehensive soil modelling capabilities to simulate complex soil behavior and evaluate the stability of geotechnical structures under varying load conditions (Nalgire et al., 2020). In a recent study Zein & Karim, (2017), slope stability analysis for basic slope models built on untrained clay soils was compared using LE and FE data. By dividing the soil mass into smaller elements and considering soil parameters, boundary conditions, and applied loads, PLAXIS allows engineers to assess the integrity of constructions using the finite element method (Rawat & Gupta, 2016b). It provides a wide range of tools for geotechnical stability studies, including slope stability analysis, settlement analysis, consolidation analysis, and more. With its user-friendly interface and extensive features, PLAXIS has become a popular choice among geotechnical engineers.

2. Soil nailing approach in slope stability

Soil nailing is a more advanced approach than other slope stabilization techniques. To stabilize slopes and excavations, passive inclusions typically steel bars known as soil nails are used. When top-to-bottom construction offers benefits over conventional retaining wall technologies, soil nailing is frequently used to strengthen existing slopes or excavations (Kamal et al., 2023). To satisfy engineering criteria, the term "soil stabilization" refers to altering the natural soil using physical, chemical, biological, or a combination of approaches. The performance and load-bearing capability of the in-situ soil can be improved by using soil stabilization methods (Sharma, 2015).

According to a study conducted by Matthews et al.,(2014) titled "Slope stability analysis – limit equilibrium or the finite element method," they concluded that with advancements in computer technology and its application in geotechnical analysis, there is a need to explore more advanced methods for slope stability analysis. The study indicated that the finite element analysis (FEA) provides a more comprehensive approach. However, the traditional limit equilibrium method still produces accurate and reliable results. The selection of the analysis method depends on various considerations, including the complexity of the problem being modelled.

2.1 Finite Element (FE)

According to Serra, (2013) the finite element (FE) method is a numerical methodology used in science and engineering to solve differential equations and boundary value issues. In geotechnical engineering, the FE method has been adapted for analyzing geotechnical problems. However, within the geotechnical community, there is a perception that the FE method is highly complex, and there are doubts about its necessity when compared to the simpler limit equilibrium (LE) method

The FE approach maintains global equilibrium throughout the study until failure occurs, allowing progressive failure up to and including total shear failure to be monitored. This characteristic of the FE method enables a more comprehensive assessment of slope behaviour (Vinod, et all, 2017.)

Failure occurs naturally in regions where the shear strength of the soil is unable to withstand the applied shear stresses. In FE techniques, a mechanism called as 'c- reduction' is typically used to compute the factor of safety (FOS) or an equivalent reduction factor (RF). This method entails gradually lowering the soil strength parameters until failure occurs. By gradually reducing the shear strength, the FE method can determine the critical conditions at which the slope becomes unstable. The shear strength reduction approach allows for the calculation of the FOS or an equivalent RF, providing insights into the stability of the slope. (Liu et al., 2020).

2.2 Limit equilibrium (LE)

LE analysis is now used in most slope stability evaluations. These approaches include slicing the slope into small slices and using relevant equilibrium equations (force and/or moment equilibrium). The LE technique determines the appropriate soil parameters, and slope geometry, and then estimates slope stability using the Mohr-Coulomb criteria by comparing the forces producing failure to the resisting forces (Sofiyan Sulaiman et al., 2019).

Due to its simplicity and low number of needed factors, the limit equilibrium method (LEM) provides the foundation for most soil nail wall stability study techniques. The effects of 2D modelling of a 3D soil nailing problem were studied in detail, limit equilibrium and finite element methods were used in the analysis of a nailed soil slope, and the optimal design with limit equilibrium analysis for slope stability was presented. (Rawat & Gupta, 2016b).

The factor of safety (FOS) against slope failure is calculated by dividing the available shear strength by the mobilised shear strength. External forces acting on the soil mass determine mobilized shear stress, whereas soil type and effective normal stress influence available shear strength (Memon, 2018).

2.3 PLAXIS 2D

PLAXIS is a geotechnical analysis software application that evaluates slope stability and deformation using finite element analysis (FEA). It can do two-dimensional and three-dimensional studies, making it ideal for modelling complicated geotechnical conditions. PLAXIS is particularly good at modelling settings with inhomogeneous soil qualities and time-dependent behavior. It is crucial to highlight, however, that the PLAXIS models give a qualitative depiction of soil behavior and are prone to intrinsic numerical and modelling mistakes.

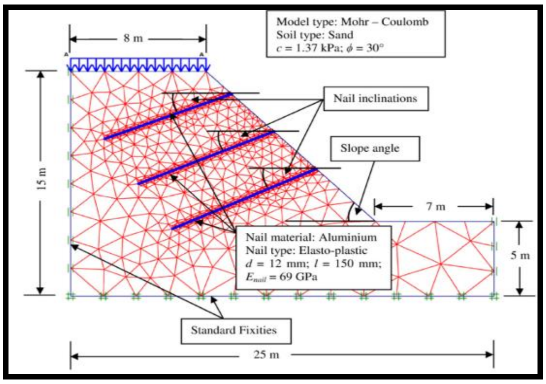


Fig. 1 *PLAXIS 2D numerical modelling for slope stability analysis using soil nailing approach.*

In Fig. 1, the numerical model was shown, which was used to analyze the slope stability using the soil nailing approach. The accuracy and dependability of the findings depended on the user's ability to model the scenario effectively, which included selecting precise soil characteristics and understanding the constraints of the "staged construction" method. To analyze the dependability of the produced results, careful judgment was required (Rawat & Gupta, 2016a).

2.4 SLOPE/W

Slope/W was a powerful software package used for geotechnical engineering analysis and determining slope stability. It was often utilized to assess the stability of slopes and embankments as well as to develop efficient reinforcing techniques by geotechnical engineers, civil engineers, and researchers. Slope/W offered a complete set of tools and capabilities to simulate and analyze a variety of slope-related challenges. This enabled engineers to make well-informed decisions and reduce potential risks.

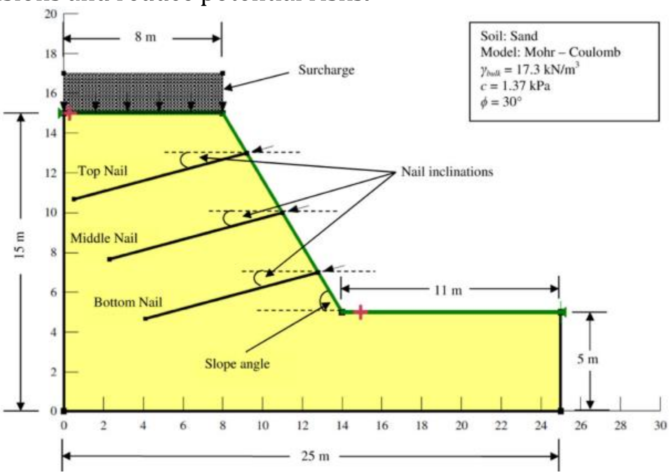


Fig. 2 *SLOPE/W numerical modelling for slope stability using soil nailing approach*

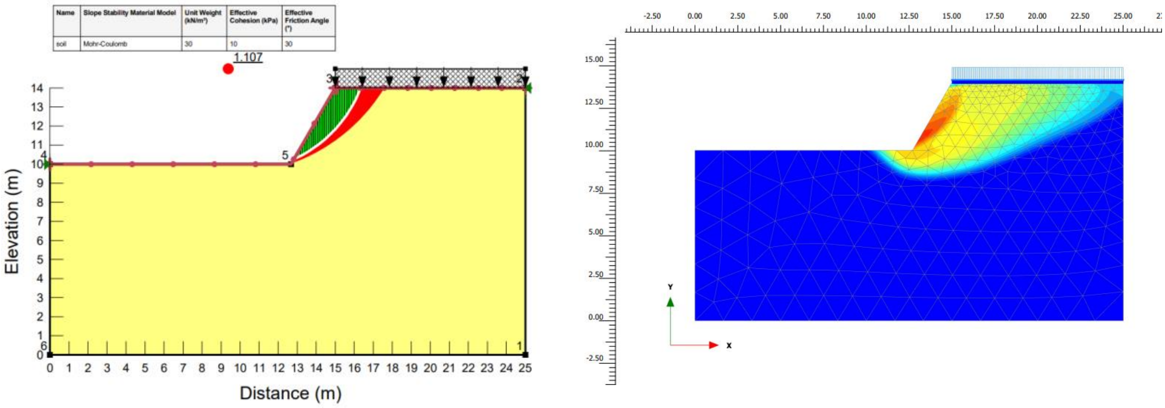
The performance and safety of infrastructure projects like roads, dams, and buildings are directly impacted by slope stability, making it a crucial component of geotechnical engineering. Slope/W enables engineers to evaluate elements impacting slope stability, such as soil parameters, groundwater conditions, and external stress, by using sophisticated numerical modelling techniques. Fig. 2 shown the numerical modelling for slope stability analysis that will be used in SLOPE/W software (Rawat & Gupta, 2016b).

3. Methodology

The research began with identifying the slope geometry and the soil properties. With this information, we were able to incorporate the Mohr-Coulomb approach, which is used in limit equilibrium method (LEM) and finite element method (FEM) software calculations from PLAXIS 2D and SLOPE/W to analyze the slope stability by comparing factor of safety (FOS) values and identifying the slip circle failure diagram.

3.1 Slope Geometry And Soil Properties

Slope geometry and soil properties were used in PLAXIS 2D and SLOPE/W to analyze the slope model in the software. A basic slope section was modeled for the purposes of this study by combining various distinct slope heights and the same gradients with the same type of soil conditions. The base length for this model was 25 m and the height varied from 10 m. The length of the load to the embankment was 10 m, and the length of the embankment was increased.



(a) **(b)**

Fig. 3 *Slope Geometry with surcharge load (a) SLOPE/W (b) PLAXIS 2D*

As shown in Fig. 3, the slope geometry from PLAXIS 2D and SLOPE/W was generated with a surcharge load of 10 kN/m^3. The slope angle was set to 60°. The model was run without soil nailing to generate the slip circle failure at three different heights: 4m, 6m, and 8m. The soil was set to undrained conditions, with no specified water level or rainfall. The slip circle appeared in the soil model when the surcharge load was applied to the embankment. Table 1 showed the soil properties used in the Mohr-Coulomb model, which served as fixed parameters for both software soil models.

Table 1 Soil properties used in Mohr-Coulomb Modelling

Property	Symbol	Value	Units	Description
Cohesion	c	10	kN/m^2	Soil's Cohesion
Unit Weight	γ	30	kN/m^3	Soil's Total Unit Weight
Phi	Φ	30	-	Soil's Friction Angle
Poisson's Ratio	ν	0.30	-	The ratio of lateral strain to linear strain
Reference Elastic Modulus	E_{ref}	30000	kN/m^2	Elastic modulus at the reference depth
Slope Angle	ø	60°	°	Angle of the slope
Surcharge	-	10	kN/m^3	Surcharge to the embankment

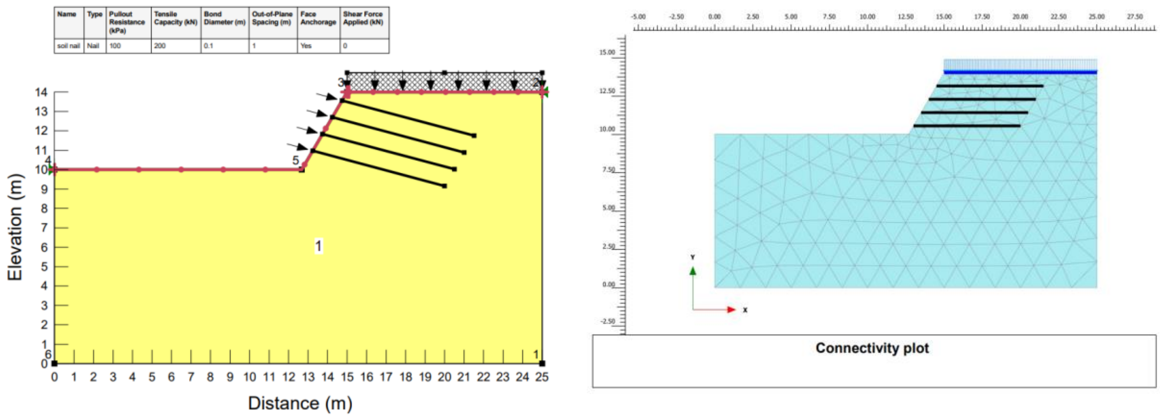
3.2 Soil Nail Parameter

This research was conducted with two types of soil conditions: normal soil and soil with soil nailing. Soil nailing was implemented with different nail inclinations with respect to the horizontal. The nail inclinations were set to horizontal inclination, and the cases of nail inclinations used were 0°, 15°, and 30° horizontal to the slope embankment. The soil nail parameters referred to Table 2. These parameters of the nail were used in nail modeling in PLAXIS 2D and SLOPE/W as reinforcement to the slope to ensure the stability of the slope from the software analysis.

Table 2 *Parameter of nail for soil nailing*

Nail Parameter	Grouted nail and facing	
	Value	Unit
Nail spacing (m)	1.0 x 1.0	m
Nail Length (m)	7.0	m
Tensile capacity of nails (kn)	200	kN
Pull out resistance of nails	100	kN/m^2
Yield Strength of reinforcement	415000	kN/m^2
Diameter of reinforcement d	20	mm
Drill hole diameter D	100	mm
Facing thickness t	200	mm
Material type	elastic	-
Elasticity modulus of reinforcement E_n	210000	kN/m^2
Elasticity modulus of grout (concrete) E_g	23000	kN/m^2
Axial stiffness, EA	2.3×10^6	kN/m
Bending stiffness, EI	110.64×10^3	$kN.m^2/m$

These parameters created a soil model with a surcharge load that was reinforced with soil nailing. As shown in Fig. 4, the slope model was created with soil nailing featuring different soil nail inclinations in SLOPE/W and PLAXIS 2D software.



(a) (b)

Fig. 4 *Slope model with soil nailing with difference soil nail inclination (a) SLOPE/W model with 15° nail inclination (b) PLAXIS 2D model 0° nail inclination*

4. Result and Discussion

In this chapter, the results between SLOPE/W and PLAXIS 2D were compared and presented. The results were divided into deformations, comparisons between natural slope and soil nailing approaches. The values of factor of safety and the differences in slip circles were evaluated.

4.1 Comparison Factor of safety between PLAXIS 2D and SLOPE/W

Comparing the factor of safety results for slope stability reinforced with soil nails between SLOPE/W and PLAXIS 2D requires assessing how each application models and assesses slope stability. Both software programs are frequently used in geotechnical engineering for slope stability studies, however they may differ in their underlying algorithms and approaches.

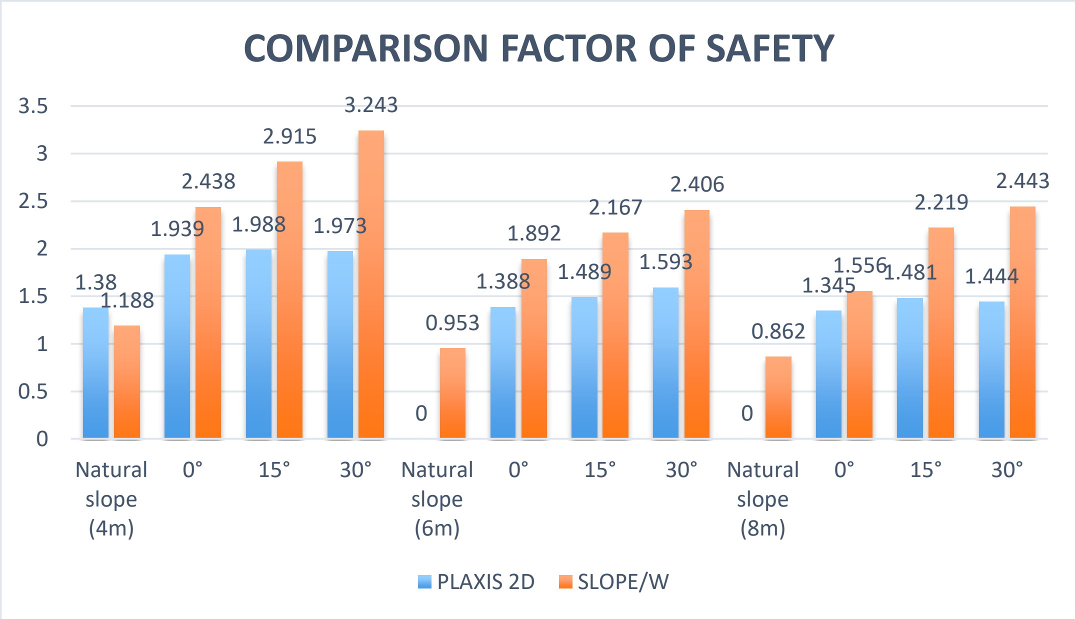


Fig. 5 *Comparison factor of safety between PLAXIS 2D and SLOPE/W*

The comparative analysis in Fig. 5 sheds light on the factor of safety values obtained from the slope stability analyses conducted using PLAXIS 2D and SLOPE/W software, particularly in the context of soil nail reinforcement. PLAXIS 2D, identified as likely utilizing the finite element method, is lauded for its ability to consider spatial variability in soil properties and provide a comprehensive representation of geotechnical conditions. In contrast, SLOPE/W employs the limit equilibrium method, specifically the Morgenstern-Price approach, simplifying complex soil-structure interactions into a more straightforward model. The results highlight critical insights into the natural slope stability conditions. SLOPE/W indicates that the natural slope, especially at 6m and 8m heights, experiences failure from the beginning, with a factor of safety below the minimum threshold of 1. Interestingly, PLAXIS 2D does not generate results for the natural slope at these heights, underscoring inherent instability.

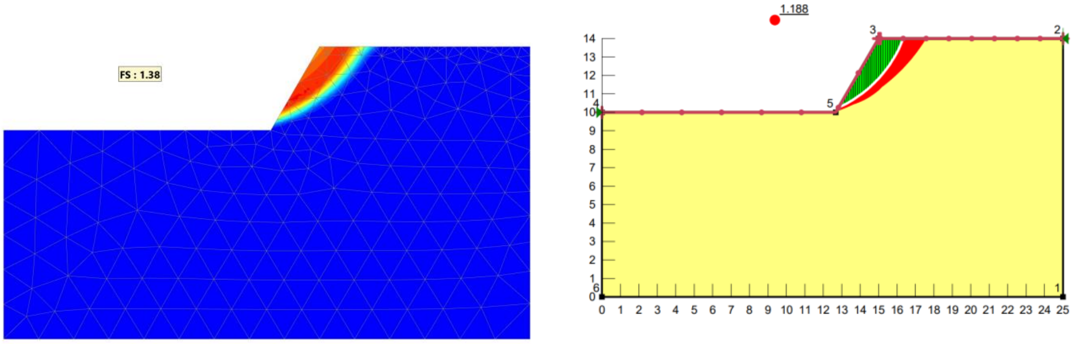
The analysis also underscores the significant influence of soil nail inclination on slope stability. Factor of safety values for slopes reinforced with soil nails at 0°, 15°, and 30° exhibit a proportional increase with the inclination. This observation leads to the compelling conclusion that the choice of soil nail inclination plays a pivotal role in determining the stability of the slope. Furthermore, the text emphasizes the disparate calculation methods employed by the two software tools. SLOPE/W calculates the factor of safety based on equilibrium conditions, comparing resisting and driving forces along potential failure surfaces. In contrast, PLAXIS 2D relies on numerical solutions to the governing equations of equilibrium and deformation, allowing for a more detailed assessment of stress and strain distribution within the slope.

In conclusion, the comparative analysis provides a nuanced understanding of the strengths and limitations of PLAXIS 2D and SLOPE/W in evaluating slope stability, with a specific focus on the impact of soil nail reinforcement. The findings highlight the importance of considering both the software's calculation methods and the inherent characteristics of soil nail systems in geotechnical engineering analyses.

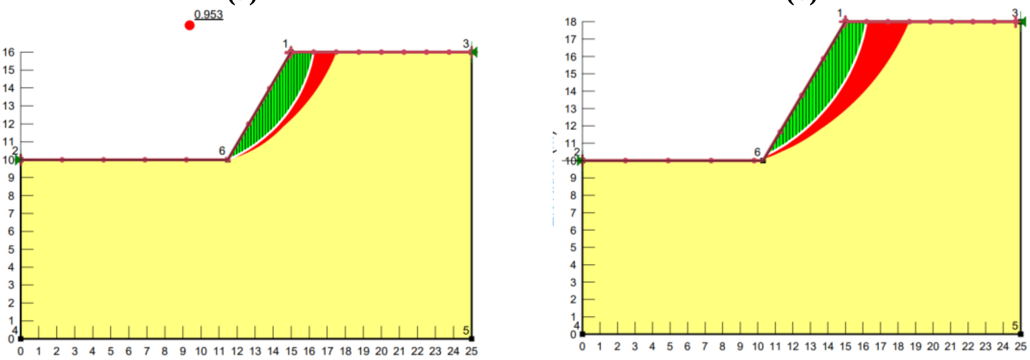
4.2 Comparison of slip circle failure

Slip circle failure was the position where failure was possible to occur in the slope. By implementing the model into the PLAXIS 2D and SLOPE/W software, the slip circle failure could be identified and analyzed. In PLAXIS 2D, the critical failure could be identified by the contrast of the slope color, but in SLOPE/W, only the slip circle failure area and the safety map in the slope model were shown.

Recent Trend in Civil Engineering and Built Environment Vol. 6 No. 1 (2025) p. 95-105



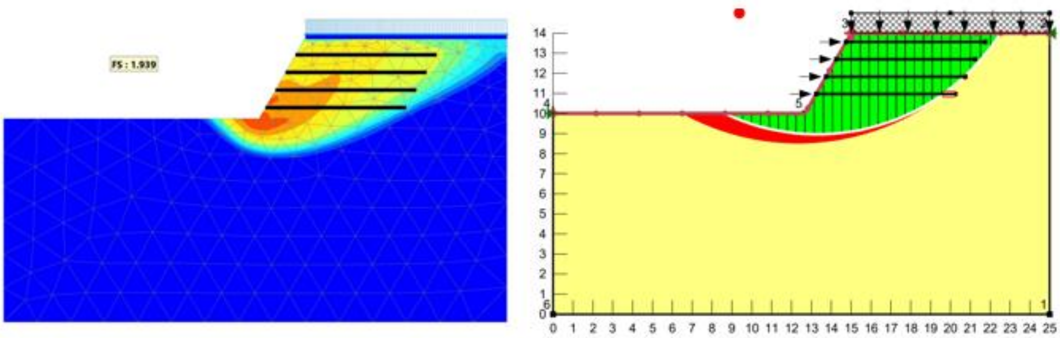
(a) **(b)**



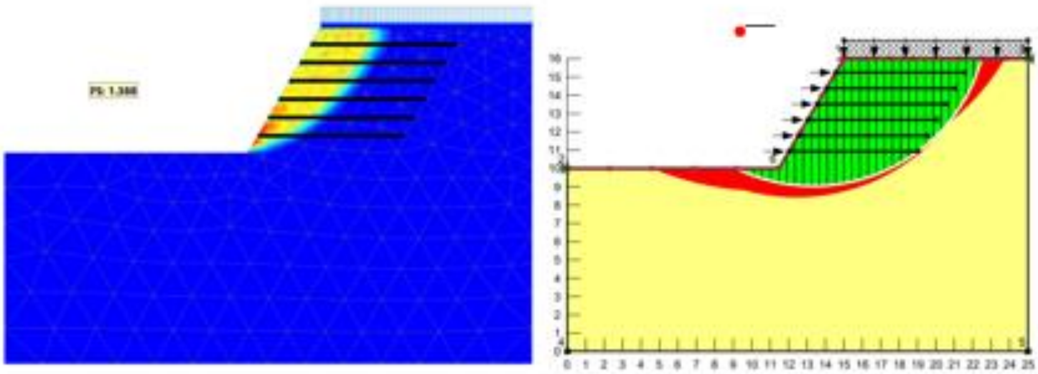
(c) **(d)**

Fig. 6 *Comparison factor of safety between PLAXIS 2D and SLOPE/W*

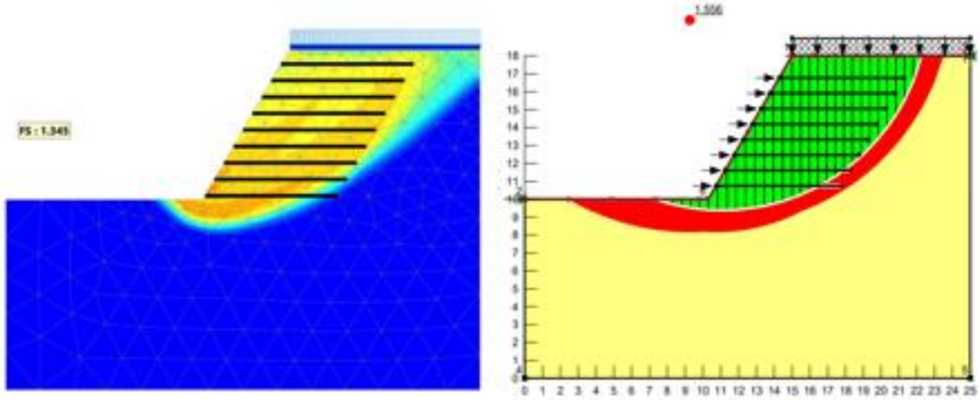
Fig. 6 (a) and (b) shown the slip circle for 4m height of embankment for natural slope have a same slip circle pattern. However Fig. 6 (c) and (d) only shows SLOPE/W natural slope model for slip circle diagram. In PLAXIS 2D the natural slope for 6m and 8m height of embankment appears to be collapse in the software and the analysis cannot be done and the slip circle diagram cannot be generated.



a)



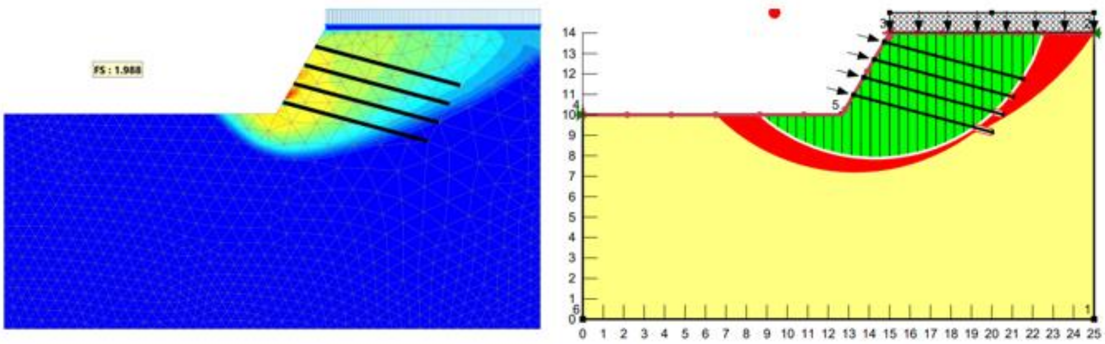
b)



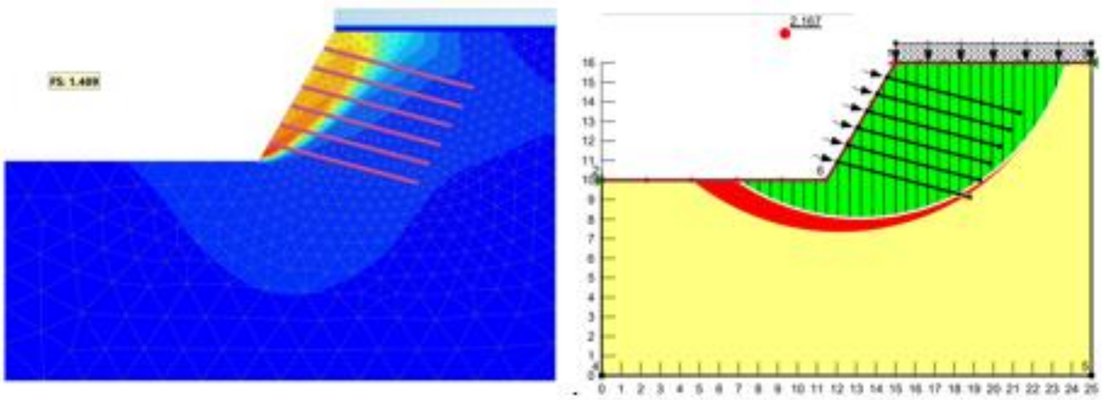
c)

Fig. 7 *Comparison Slip Circle for 0° nail inclination between PLAXIS 2D and SLOPE/W a) 4m b) 6m c) 8m*

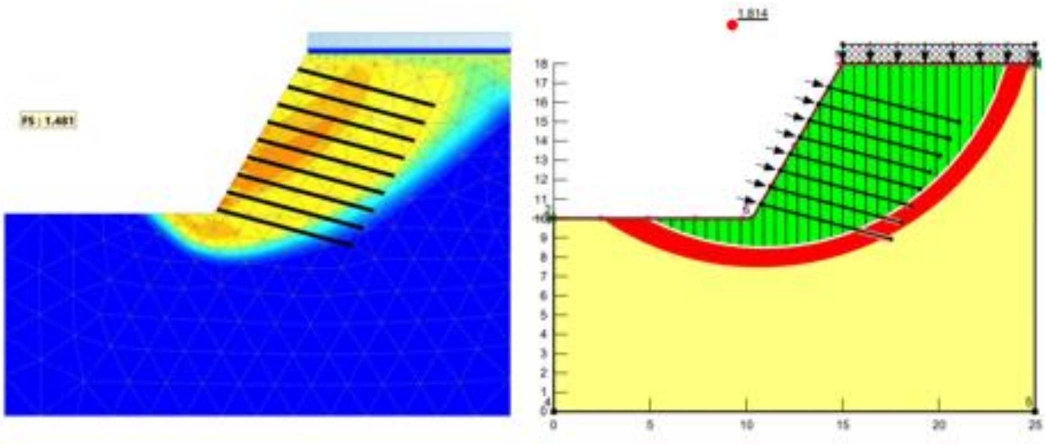
Fig. 7 show the slip circle failure for 0° nail inclination for 4m, 6m and 8m cases. In PLAXIS 2D the slip circle failure happen along the surcharge load area for 4m and 8m cases and exceed the bottom of the nail. For 8m case the slip circle failure only appeared at the edge of the slope embankment. Slip circle failure for all case in SLOPE/W appeared only near the bottom of the soil nail. This can indicated the failure happen start at the bottom of the surcharge load area until it exceed the slope of embankment. For 6m case of embankment generated difference slip circle diagram. In PLAXIS 2D the slip circle end at the bottom of the slope but in SLOPE/W show the slip circle failure happen exceed the bottom of the slope embankment.



a)



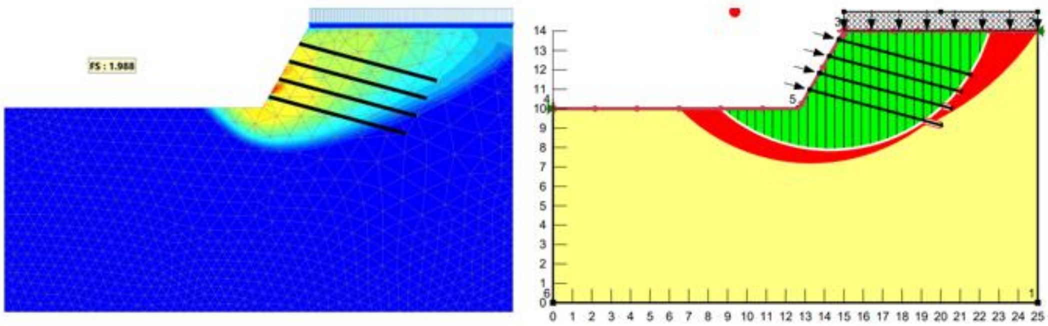
b)



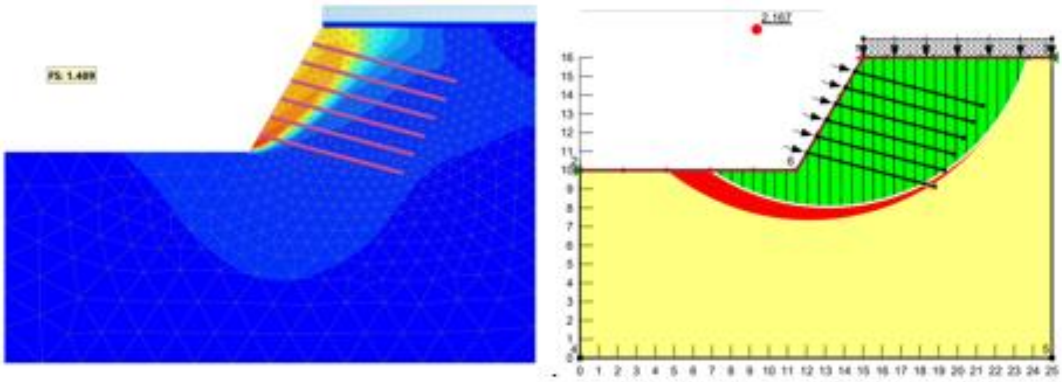
c)

Fig. 8 *Comparison Slip Circle for 15° nail inclination between PLAXIS 2D and SLOPE/W a) 4m b) 6m c) 8m*

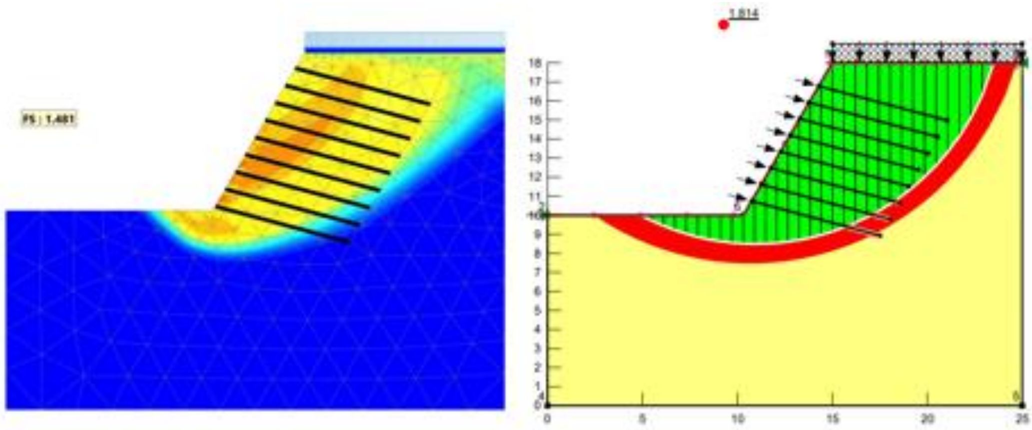
Slip Circle for 15° nail inclination shown in Fig. 8 for both of software and every case. Based on the diagram all the slip circle appear along under the surcharge load area. But in 6m case in PLAXIS 2D, the critical slip circle failure happen at the edge of the slope. However the slip circle failure started to appear and exceed the slope embankment but in a lowest effect of failure.



a)



b)



c)

Fig. 9 *Comparison Slip Circle for 30° nail inclination between PLAXIS 2D and SLOPE/W a) 4m b) 6m c) 8m*

Fig. 9 illustrated the slip circle in 30° of nail inclination. As shown in the diagram below the critical failure that happen to the slope in PLAXIS 2D was the lowest rather than 0° and 15° nail inclination cases. However in SLOPE/W for 4m cases, the safety map did not appear to the model. These indicate the soil nail inclination with 7m length and the slope height make this model have a stable slope. This can compared with the PLAXIS 2D model that the critical failure only happen at the slope between the nail only.

To be conclude, PLAXIS 2D and SLOPE/W analysis with 30° soil nail inclination consistently yield the favourable stability result. The critical failure that generated in this case have the lowest critical failure can be happen to the slope. The difference of the area of slip circle affected by the soil inclination and the height of the slope. Although in PLAXIS 2D, the critical failure can be seen clearly in this soil model. In SLOPE/W the slip circle diagram only shows the area of the slip circle happen. This indicate the limitation between these software in order to identify the critical area that happen to the slope.

5. Conclusion and Recommendation

5.1 Conclusion

In summary, the comparative study between PLAXIS 2D and SLOPE/W, with a focus on soil nail reinforcement, highlighted distinct qualities of both geotechnical engineering instruments. The investigation revealed key differences in their approaches. Firstly, the impact of soil nail inclination on slope stability was a focal point, showing a proportional increase in factor of safety values with higher inclinations. This emphasizes the pivotal role of soil nail design in optimizing slope stability based on project-specific needs.

Secondly, PLAXIS 2D employs finite element analysis, offering a comprehensive depiction of soil-structure interactions, while SLOPE/W utilizes the limit equilibrium technique, simplifying complex interactions into a more straightforward model. Thirdly, the factor of safety for a natural slope at the 4m case exceeded the minimum value of 1, but for 6m and 8m, both software generated values below 1, indicating slope instability. Specifically, SLOPE/W produced values of 0.953 for 6m and 0.862 for 8m. Additionally, the soil nailing approach stabilized the slope, surpassing the minimum factor of safety. At a 30° soil inclination, SLOPE/W generated the highest FOS value of 3.243.

Lastly, PLAXIS 2D offers a more realistic slope stability analysis with complex geometry and parameters, ensuring accurate results. In contrast, SLOPE/W is user-friendly, requiring simpler parameters and analysis stages but lacking the complexity of PLAXIS 2D, which demands more computational resources.

5.2 Recommendation

This research focuses on evaluating software programs for geotechnical analysis, specifically in slope stability assessment, and offers recommendations for enhancing accuracy in future studies. It emphasizes the importance of selecting software based on project-specific needs, with SLOPE/W being efficient for certain analyses and PLAXIS 2D's finite element approach proving advantageous for intricate scenarios.

The study underscores the need for geotechnical engineers to carefully choose computational approaches, highlighting the computational efficiency and simplicity of equilibrium-limit methods like SLOPE/W, while recognizing the nuanced and comprehensive assessment provided by PLAXIS 2D. The research suggests a practical implementation approach, advocating for a combined use of SLOPE/W for initial assessments due to its speed and simplicity, followed by PLAXIS 2D for more detailed analyses in critical areas. This tailored approach ensures reliable and informed decisions for successful geotechnical projects.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

References

Dewedree, S., & Jusoh, S. N. (2019). Slope stability analysis under different soil nailing parameters using the SLOPE/W software. Journal of Physics: Conference Series, 1174(1).

Kamal, A., Zaman, Z. K., Nur, A., Faisal, R. A., Naqib, M., Rahimi, N., Hakimi, A., & Nor, M. (2023). Numerical Analysis of Soil-Nailing from Bamboo for Slope Stabilisation Using Plaxis 2D Software. Multidisciplinary Applied Research and Innovation, 4(2), 63–72.

Liu, S., Su, Z., Li, M., & Shao, L. (2020). Slope Stability Analysis Using Elastic Finite Element Stress Fields. Engineering Geology, 273

Matthews, C., Farook, Z., & Helm, P. R. (2014). Slope stability analysis-limit equilibrium or the finite element method: Technical Paper. Ground Engineering.

Memon, Y. (2018). A Comparison Between Limit Equilibrium and Finite Element Methods for Slope Stability Analysis. http://dx.doi.org/10.13140/RG.2.2.16932.53124

Nalgire, T., P. P, D., A.A, M., & P.D, H. (2020). Slope Stability Analysis by GeoSlope. HELIX, 10(1), 71–75.

Rawat, S., & Gupta, A. (2016a). An experimental and analytical study of slope stability by soil nailing. Electronic Journal of Geotechnical Engineering, 5577-5597.

Rawat, S., & Gupta, A. K. (2016b). Analysis of a Nailed Soil Slope Using Limit Equilibrium and Finite Element Methods. International Journal of Geosynthetics and Ground Engineering, 2(4). https://doi.org/10.1007/s40891-016-0076-0

Serra, M. P. (2013). Geotechnical Stability Analysis Using Student Versions of FLAC, PLAXIS and SLOPE/W Bachelor of Engineering (Civil). Thesis., University of Southern Queensland.

Sharma, P. (2015). Theoretical Analysis of Soil Nailing: Design, Performance and Future Aspects. International Journal of Engineering Research and General Science, 3(6), 644-653.

Sofiyan Sulaiman, M., Devi Miniandi, N., Hafidz Yusoff, A., Ayob, M., & Kasa, A. (2019). Slope Stability Evaluations Using Limit Equilibrium and Finite Element Methods. International Journal of Advanced Science and Technology, 28(18), 27–43.

Vinod B R, P Shivananda, Swathivarma R, Bhaskar MB. (2017). International Journal of Application or Innovation in Engineering & Management (IJAIEM), 6(9), 006–010.

Zein, A. K. M., & Karim, W. A. (2017). Stability of slopes on clays of variable strength by limit equilibrium and finite element analysis methods. International Journal of GEOMATE, 13(38), 157–164