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Design Optimization of a 4-Meter Cantilever Retaining Wall for Slope Stabilization in North Sumatra

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ABSTRACT

The slope failure occurring at the loading ramp area of the palm oil mill operated by *Perkebunan Nusantara* Nusantara resulted in significant operational disruptions, including delays in material handling and interruptions in processing activities. The failure was primarily attributed to the construction of the loading ramp over an unstable subsurface layer, which made the ground highly susceptible to deformation and slope instability. Consequently, a geotechnical investigation was required to determine an appropriate reinforcement strategy capable of restoring stability and ensuring the safe continuation of mill operations. This study evaluates the slope conditions before and after the installation of a cantilever retaining wall by employing numerical modeling based on the Finite Element Method (FEM). Two analytical scenarios were examined: the original unreinforced slope condition and the reinforced condition utilizing a 4-meter cantilever retaining wall. The results demonstrate that the unreinforced slope exhibited a safety factor below the minimum geotechnical design threshold, confirming its unstable condition. Following reinforcement, the safety factor increased to 1.506, thereby fulfilling standard stability requirements. These findings indicate that the installation of a cantilever retaining wall substantially enhances slope stability and effectively reduces the risk of future slope failures at the loading ramp area. The study underlines the critical role of appropriate retaining structures in maintaining the safety and continuity of industrial operations situated on geotechnically sensitive terrain.

Keywords: *cantilever wall; finite element method; retaining wall; slope failure; slope stability*

1. Introduction

The plantation sector plays a strategic role in Indonesia's economic development, contributing 96.86% of the total agricultural export value, with palm oil alone accounting for 73.83% of that contribution. North Sumatra Province is one of the country's major palm-oil-producing regions. According to the *Badan Pusat Statistik* (BPS), the province ranked fourth nationally in 2023 with a production volume of 7,873.63 tons. A significant portion of this output is supported by the palm oil mill operated by *Perkebunan Nusantara* in Labuhanbatu Selatan Regency, where fresh fruit bunches (FFB) are temporarily stored and processed into crude palm oil (CPO).

The mill operates two loading ramp areas; however, one of them has been forced to cease operations due to a slope failure beneath the platform. The failure resulted from the combination of a relatively steep natural

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slope (approximately 38°), the absence of adequate reinforcement, and the presence of sandy clay soil characterized by low shear strength. These conditions contributed to progressive soil movement that ultimately developed into slope instability, disrupting mill operations. Such interruptions affect production continuity, worker safety, and overall operational efficiency, highlighting the urgency of implementing an appropriate geotechnical mitigation strategy.

Retaining structures are widely used to enhance slope stability in conditions where soil strength is insufficient to resist lateral pressures or external surcharge loads [1]. Among the available options, cantilever retaining walls remain one of the most practical solutions due to their structural simplicity, cost-effectiveness, and suitability for supporting moderate heights under both static and operational loading conditions. Previous studies have shown that cantilever walls significantly improve slope resistance in comparable geological and geotechnical environments [2],[3],[4].

Accurate assessment of slope stability requires analytical techniques capable of representing soil nonlinearity and stress-dependent stiffness. The finite element method (FEM) is widely recognized as an effective tool for evaluating soil–structure interaction, as it provides insight into deformation patterns, failure mechanisms, and stress distribution [5],[6]. In this study, the Hardening Soil (HS) model is employed due to its ability to simulate the nonlinear behavior of sandy clay, particularly its stiffness variation under different stress states; features that cannot be adequately captured using simpler linear-elastic or Mohr–Coulomb models.

The objective of this research is to evaluate slope stability under two conditions: (1) the original unreinforced slope and (2) the reinforced condition using a 4-meter cantilever retaining wall. This case study illustrates how FEM analysis can be applied to determine whether the proposed retaining structure meets the safety margin requirements established in SNI 8460:2017. The findings are expected to contribute both academically and practically by providing insight into appropriate reinforcement strategies for plantation and industrial facilities located in geotechnically sensitive environments.

2. Method

2.1 Study area

This study was conducted at the palm oil mill owned by *Perkebunan Nusantara* Nusantara in Labuhanbatu Selatan Regency, North Sumatra Province, located at coordinates 100°17'9.99" E and 1°41'27.70" N. The slope at the loading ramp area consists predominantly of sandy clay soil with relatively low shear strength, making it susceptible to deformation under surcharge load. The failure was initiated by a natural slope inclination of approximately 38° combined with the absence of any reinforcement system beneath the loading ramp. The location map of the study area is presented in Figure 1.

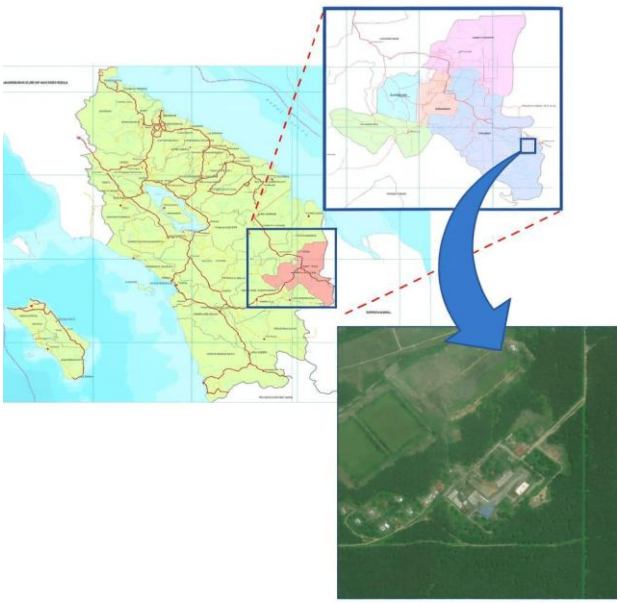

Figure 1. Study Area

2.2 Data used

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2.2.1 Field and Laboratory Investigation

Subsurface data were obtained through drilling and the Standard Penetration Test (SPT). Laboratory tests included soil index tests (grain size distribution, Atterberg limits, specific gravity, natural water content) and engineering property tests (direct shear, consolidation). All laboratory testing was carried out at the Soil Mechanics Laboratory, Department of Civil Engineering, Faculty of Engineering, Universitas Sumatera Utara.

2.2.2 Soil Parameters

Soil parameters derived from laboratory results were used directly as input for FEM modeling. The Hardening Soil (HS) model parameters include elastic modulus (E_{50}), oedometer modulus (E_{oed}), and unloading/reloading modulus (E_{ur}), along with c–φ strength parameters and Poisson's ratio. These parameters enable modelling of nonlinear stiffness and stress dependency, which are essential for representing sandy clay behavior under loading.

Table 1. Soil parameter

Soil parameters	Soil layers					Unit
	Layer 1 (soft sandy clay)	Layer 2 (firm sandy clay)	Layer 3 (stiff sandy clay)	Layer 4 (very stiff clay)	Selected backfill	
Depth	0 – 2,5	2,5 - 11	11 - 24	24 - 44		m
Soil model	Hardening soil	Hardening soil	Hardening soil	Hardening soil	Hardening soil	-
Drainage type	Drained	Drained	Drained	Drained	Drained	-
Dry soil weight (γ_{unsat})	13,14	12,65	13,53	13,14	16,67	kN/m^3
Saturated soil weight (γ_{sat})	18,63	19,04	19,02	18,14	18,14	kN/m^3
Poisson's ratio (v)	0,2	0,2	0,2	0,2	0,2	-
Cohession (c)	10,89	21,19	14,32	9,81	4,9	kN/m^2
Friction angle (φ)	9,56	13,85	1,24	7,44	35	°
Young's modulus (E)	1260	8190	18340	31500	50000	kN/m^2

2.2.3 Retaining Walls Parameters

The 4-meter cantilever retaining wall was designed based on SNI 8460:2017, incorporating concrete material properties, unit weight, Poisson's ratio, and compressive strength. The structural geometry, heel length, toe length, and stem thickness were modeled according to the final design specifications (Figure 1). A uniform surcharge load of 33.18 kN/m² was applied at the top of the slope. This value represents the combined effect of:

- the weight of fresh fruit bunches (FFB),
- static loading from haul trucks operating on the ramp, and
- the self-weight of the platform structure.

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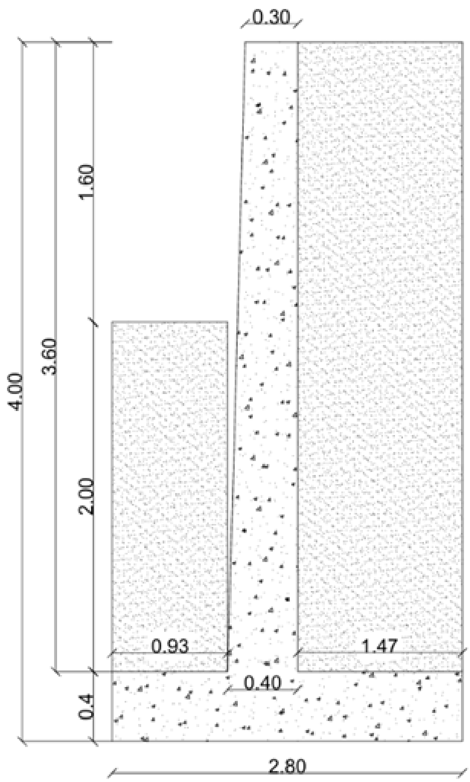

Figure 1. Design of Cantilever Retaining Wall

2.2.4 Numerical Modeling Procedure

The numerical analysis in this study was conducted using PLAXIS 2D, a widely applied finite element software in geotechnical engineering for evaluating soil–structure interaction. All simulations were performed under plane strain conditions, which appropriately represent the field geometry of the slope and the cantilever retaining wall. The model geometry including slope configuration, soil stratigraphy, and wall dimensions, was constructed using data obtained from field investigations and laboratory testing to ensure that the numerical representation accurately reflected the subsurface conditions at the project site.

The Hardening Soil (HS) model was selected to simulate the nonlinear mechanical behavior of sandy clay, particularly its stress-dependent stiffness, plastic straining, and distinct loading–unloading response. Each soil layer was assigned HS model parameters derived from laboratory tests, while the retaining wall was modeled as a linear-elastic material. Boundary conditions were applied by fully constraining the bottom boundary in both vertical and horizontal directions, whereas the two lateral boundaries were restrained horizontally but allowed vertical movement. This boundary configuration prevents artificial deformation while enabling the soil mass to respond naturally to loading.

A global finite element mesh consisting of 15-node triangular elements was generated. Mesh refinement was applied around the retaining wall, the toe of the slope, and anticipated shear localization zones to improve numerical accuracy. Initial stress conditions were established using the K_0 procedure to simulate realistic in situ stresses prior to loading. A uniform surface surcharge of 33.18 kN/m² was applied at the top of the slope to represent operational loading, including the weight of fresh fruit bunches (FFB), vehicle loads, and the structural load from the loading ramp platform.

The analysis was executed in staged construction phases, during which soil layers, structural elements, and surcharge loads were activated sequentially. Subsequently, the strength reduction method (SRM) was employed to determine the factor of safety by progressively reducing the shear strength parameters (c and φ) until numerical failure was observed. The modeling results include deformation contours, stress distribution patterns, and the computed factors of safety for both the unreinforced condition and the reinforced condition with the cantilever retaining wall.

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3. Results and Discussion

3.1 Initial condition of the slope

The initial slope condition was analyzed to assess its stability prior to the implementation of any reinforcement measures. The numerical model incorporated the existing slope geometry, the stratification of soil layers, and a surcharge load of 33.18 kN/m² applied on the loading ramp surface. The analysis revealed that the slope had a factor of safety (FS) of 0.9683, which is below the minimum requirement of FS ≥ 1.25 specified by SNI 8460:2017 for static loading conditions. An FS value lower than this threshold indicates that the available shear resistance is insufficient to counteract the driving forces acting on the slope, placing the system in a marginally stable to clearly unstable state.

The deformation analysis further substantiated this instability. A maximum displacement of 364.45×10^{-3} m was observed near the slope face, indicating significant soil movement under operational loading. The displacement vectors exhibited a downward and outward pattern, characteristic of shallow rotational failure in sandy clay soils with low shear strength. Such deformation behavior reflects progressive weakening of the soil mass, particularly under surcharge conditions imposed by the loading ramp operations.

Taken together, these findings confirm that the existing slope without any structural reinforcement is unable to maintain long-term stability and poses a substantial risk of continued deformation and potential failure under routine operational loads.

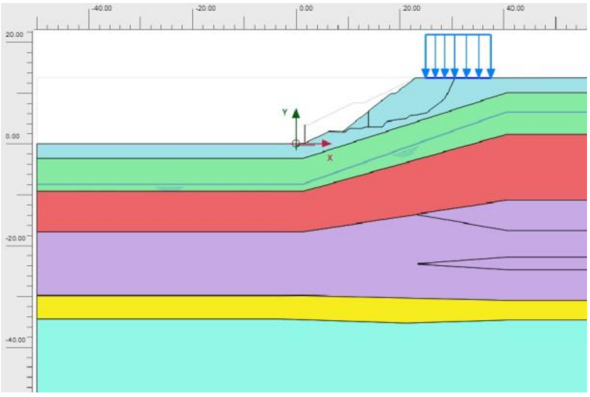

Figure 2. Existing slope modeling

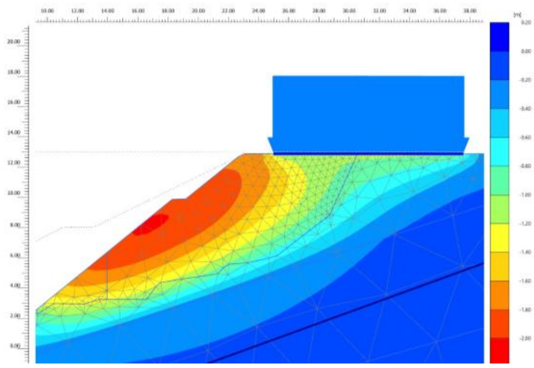

Figure 3. Displacement pattern of the existing slope

3.2 Stability analysis of cantilever retaining wall

A cantilever retaining wall with a height of 4 meters was designed to improve slope stability. The wall was evaluated for its structural stability through overturning, sliding, and bearing capacity analysis using parameters derived from Rankine's theory and Vesic's bearing capacity formulation. All stability checks yielded values above the required minimum criteria, indicating that the wall design is structurally safe under static loading conditions.

- Factor of Safety against Overturning = 3.211 (> 2.0)
- Factor of Safety against Sliding = 1.85 (> 1.5)
- Factor of Safety for Bearing Capacity = 3.78 (> 3.0)

These results confirm that the retaining wall is capable of maintaining equilibrium against lateral and vertical forces induced by soil pressure and surcharge loads.

In addition, lateral earth pressure distribution along the wall height was computed using Rankine's active and passive coefficients. The computed values show that passive pressure at the toe provides substantial resistance against sliding, although its effectiveness depends on the available soil depth in front of the wall.

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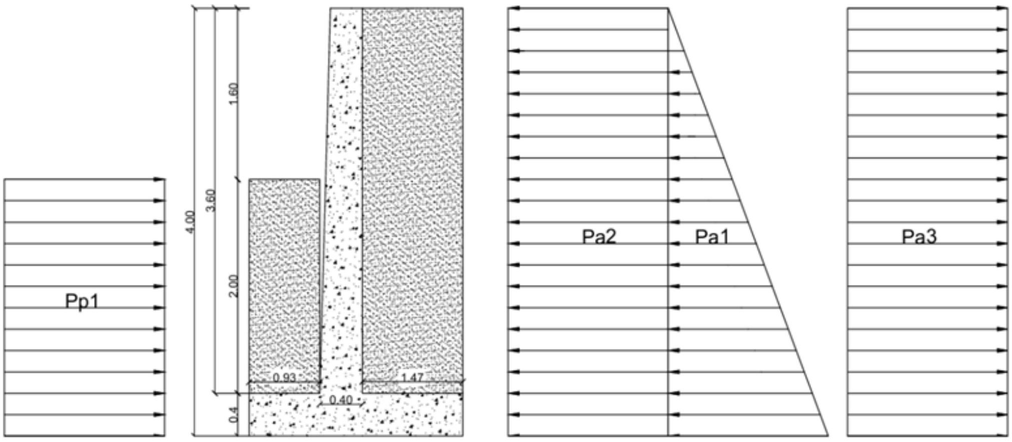

Figure 4. Distribution of lateral earth pressure

1. Analysis of vertical forces and wall moments

Table 2. Vertical forces and moments of cantilever wall

No. strip	Area	Weight	Moment arm from point O	Moment about point O
	(m^2)	(kN)	(m)	(kNm)
1	1,08	25,92	1,18	30,585
2	0,18	4,32	1,00	4,305
3	5,292	95,99	2,06	198,234
4	1,12	26,88	1,4	37,632
			$\sum V = 153{,}117$	$\sum M_R = 270{,}757$

2. Lateral earth pressure

$$K_a = \tan^2(45 - \frac{\phi}{2})$$
$$= 0{,}271$$
$$K_p = \tan^2(45 + \frac{\phi}{2})$$
$$= \tan^2(45 + \frac{35}{2})$$
$$= 3{,}690$$

Table 3. Active earth pressure calculation summary

Active Earth Pressure	Force (kN)	Distance to O (m)	Moment (kNm)
P_{a1}	39,519	1,33	52,560
P_{a2}	32,519	2	65,038
P_{a3}	-20,406	2	-40,812
$\sum$	20,406		84,312

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Table 4. Passive earth pressure calculation summary

Passive Earth Pressure	Force (kN)	Distance to O (m)	Moment (kNm)
P_{p1}	192,786	0,8	154,228
P_{p2}	45,181	1,2	54,217
$\sum$	237,968		208,447

3. Stability analysis of the retaining wall

$$FS_{overturning} = \frac{\sum M_R}{\sum M_0} = 3{,}211 > 2 \text{ (Safe)}$$

$$FS_{sliding} = \frac{\sum F_r}{\sum P_h} = 1{,}85 > 1{,}5 \text{ (Safe)}$$

$$q_u = c' N_c s_c d_c i_c g_c b_c + D_f \gamma N_q s_q d_q i_q \, g_q b_q + \frac{1}{2}\gamma B' N_\gamma \, s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

$$q_u = 287{,}600$$

$$q_{maks} = \frac{\sum V}{B}\left(1 + \frac{6e}{B}\right)$$

$$q_{maks} = 76{,}051$$

$$FS_{bearing} = \frac{q_u}{q_{maks}} = 3{,}78 > 3 \text{ (Safe)}$$

3.3 Slope condition with retaining wall

After the retaining wall was integrated into the numerical model, a significant improvement in slope stability was observed. The factor of safety increased from 0.9683 to 1.506, exceeding the required minimum threshold. This improvement confirms that the retaining wall effectively enhances the slope's shear resistance by reducing lateral soil movements and redistributing stresses away from the potential failure zone.

The maximum deformation of the reinforced slope decreased drastically to 0.01531 m, representing an improvement of more than 60% compared to the unreinforced condition. The displacement contours shifted from a rotational failure pattern to a more localized deformation zone concentrated near the wall, indicating the successful interception of the critical slip surface. The foundation settlement of the retaining wall was also evaluated, yielding a maximum value of 0.05241 m. This magnitude is within acceptable limits for granular–clayey soil conditions and complies with SNI 8460:2017, which allows settlements below approximately 0.075 m for similar structures. The low settlement value is attributed to the increased stiffness of the underlying soil layers and the redistribution of stresses facilitated by the wall base.

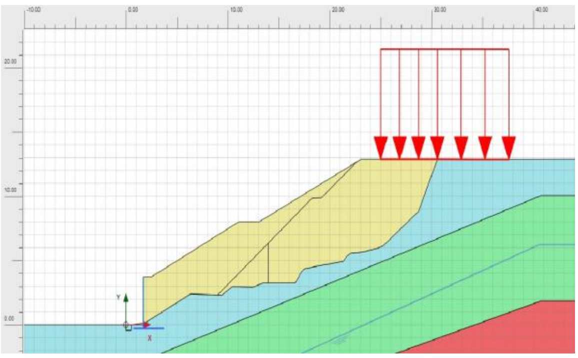

Figure 5. Slope modelling with cantilever retaining wall

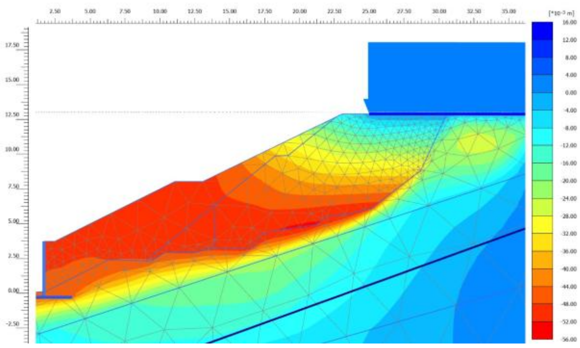

Figure 6. Displacement pattern of the reinforced slope

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Overall, the comparison between the unreinforced and reinforced slope conditions demonstrates the substantial influence of the cantilever retaining wall on slope performance. The wall provides structural restraint that limits soil displacement, enhances shear strength mobilization, and intercepts the critical slip surface. The reduction in deformation and increase in safety factor confirm that the retaining wall acts as an effective stabilization measure in sandy clay soil profiles characteristic of the study area.

The observed improvements align with previous studies [2],[3], further supporting the suitability of the cantilever system for medium-height slopes subjected to operational surcharges. By combining FEM simulation with proper design evaluation, this study provides a comprehensive assessment that can serve as a reference for similar industrial slope applications [7], [8]. The findings underline the importance of integrating advanced modeling techniques with practical reinforcement solutions to ensure slope stability in challenging soil conditions [9],[10].

The analysis conducted in this study indicates that the slope beneath the loading ramp is inherently unstable when left unreinforced. Finite element modeling produced a factor of safety (FS) of 0.9683, which falls below the minimum requirement of FS ≥ 1.25 as specified by SNI 8460:2017 for static conditions. The deformation pattern exhibited a shallow rotational movement concentrated within the sandy clay layer, reflecting insufficient shear resistance under the applied surcharge. This condition confirms that the existing slope is unable to safely withstand operational loads associated with daily activities at the palm oil mill. After installing a 4-meter cantilever retaining wall, slope stability improved substantially. The FS increased to 1.506, meeting the required stability threshold. The maximum deformation was significantly reduced, and the settlement at the retaining wall foundation remained within acceptable limits prescribed by prevailing geotechnical standards. These improvements demonstrate that the cantilever retaining wall effectively redistributes lateral earth pressures, controls deformation, and enhances overall slope performance under operational loading [11]. Therefore, the implementation of a cantilever retaining wall not only stabilizes the slope but also ensures compliance with safety standards, providing a reliable solution for similar geotechnical challenges [12],[13].

4. Conclusions

This study evaluated the stability of the slope beneath the loading ramp of the palm oil mill operated by *Perkebunan Nusantara Nusantara* using finite element analysis with the Hardening Soil model. The results demonstrate that the existing unreinforced slope is incapable of sustaining operational loads, as indicated by a factor of safety of 0.9683, which falls below the minimum requirement stipulated in SNI 8460:2017. The deformation pattern exhibited a shallow rotational failure mechanism within the sandy clay layer, confirming that the soil's shear resistance was insufficient under the applied surcharge. The installation of a 4-meter cantilever retaining wall significantly improved the overall performance of the slope. The factor of safety increased to 1.506, and deformation was substantially reduced, with wall settlement remaining within acceptable limits. These findings confirm that the cantilever retaining wall effectively redistributes lateral stresses, enhances structural confinement, and mitigates slope displacement, thereby restoring the required stability for safe mill operations. The results underscore the importance of geotechnical reinforcement in areas where weak soil conditions, surcharge loading, and steep natural slopes coexist. The study further demonstrates the usefulness of finite element modeling as a decision-support tool for assessing slope stability and designing appropriate mitigation measures. Future research should incorporate seismic loading, groundwater fluctuation effects, and high-resolution monitoring data to improve prediction accuracy and provide a more comprehensive understanding of long-term slope behavior.

Despite the encouraging analytical outcomes, several limitations of the study need to be recognized to ensure a balanced interpretation of the results. The groundwater level was treated as constant throughout the analysis and seasonal variations were not considered. In practice, fluctuations in groundwater elevation can significantly influence pore water pressure distribution and consequently alter slope stability conditions. In addition, the analysis did not incorporate seismic or other dynamic loading effects. This omission is important because the study area may be subject to seismic activity, and excluding earthquake induced forces can lead to an underestimation of potential failure mechanisms and structural demand. The constitutive modeling approach also introduces certain constraints. Although the Hardening Soil model offers a more realistic representation of soil behavior compared to simple linear elastic models, it remains limited in its ability to capture long term soil responses such as creep, aging effects, and progressive failure processes. These phenomena can be critical in retaining structures that are expected to perform safely over extended service periods. Furthermore, the numerical model did not explicitly simulate construction sequence effects. Factors

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such as variability in compaction quality, construction induced stresses, and the possibility of differential settlement were not addressed, even though they may have a substantial influence on the actual field performance of the retaining wall.Another important limitation relates to the absence of long term monitoring data. Without post construction instrumentation or observational records, it is not possible to validate the numerical predictions or to evaluate the long term behavior and performance of the retaining structure under real operational conditions. As a result, the findings of this study should be interpreted within the context of these assumptions and simplifications, and future investigations are encouraged to incorporate variable groundwater conditions, dynamic loading scenarios, construction staging, and long term monitoring to strengthen the reliability of the analysis.

Based on the results of the study, several practical recommendations can be put forward to enhance the reliability and long term performance of the retaining wall system. Continuous and systematic monitoring should be implemented to observe wall displacement, settlement, and drainage behavior over time, as this will help ensure that the structure continues to perform in accordance with the design intent and allows early detection of potential issues. Effective drainage management is also essential, particularly through regular inspection and maintenance of the drainage system behind the wall, in order to prevent the accumulation of excess pore water pressure that could adversely affect structural stability. For sites located in regions with potential seismic exposure, future evaluations should incorporate seismic loading through dynamic analysis to better assess the wall response under earthquake induced stresses and deformations. In addition, the stability of the system could be further improved by considering higher quality backfill materials or the use of geosynthetic reinforcement, especially in situations involving higher surcharge loads or constrained construction conditions. Surface protection measures, such as erosion control techniques and the application of vegetative cover, are also recommended to minimize surface erosion and reduce the risk of shallow slope instability around the retaining structure. Finally, periodic review of operational loads is necessary, including loads from trucks, construction equipment, and fresh fruit bunch storage, to ensure that actual field conditions remain consistent with the design assumptions adopted in the numerical model.

5. Acknowledgements

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6. Conflict of Interest

The authors declare that there is no conflict of interest associated with this publication.

References

[1] L. W. Abramson, T. S. Lee, S. Sharma, and G. M. Boyce, *Slope Stability and Stabilization Methods*, 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, 2002.

[2] L. Hakim, P. P. Putra, and D. Nurtanto, "Slope reinforcement on the riverbank area of Sultan Agung Street, Jember Regency, using a cantilever retaining wall," *Bentang*, vol. 9, no. 2, pp. 115–128, 2021. [Online]. Available: http://jurnal.unismabekasi.ac.id/index.php/bentang

[3] J. Damara, M. Abdurrozak, and A. Amalina, "Slope stability analysis of an embankment with cantilever retaining wall reinforcement using PLAXIS 8.6," in *Proceedings of the Civil Engineering Research Forum*, vol. 3, 2023.

[4] R. Malawy, S. Gandi, and F. Sarie, "Analysis of the use of cantilever walls to overcome slope failure in Muara Teweh City, North Barito Regency," *Jurnal Kacapuri*, vol. 4, 2021.

[5] R. B. J. Brinkgreve, S. Kumarswamy, W. M. Swolfs, and D. Waterman, *PLAXIS 2D Manuals*. Exton, PA, USA: Bentley Systems, 2018.

[6] M. Budhu, *Soil Mechanics and Foundations*, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons, 2011.

[7] X. Du and J. F. Chai, "Stability Evaluation of Medium Soft Soil Pile Slope Based on Limit Equilibrium Method and Finite Element Method," *Mathematics*, Oct. 2022, doi: 10.3390/math10193709

JCE-PIM JOURNAL OF CIVIL ENGINEERING AND PUBLIC INFRASTRUCTURE MANAGEMENT

[8] S. Li, Z. Zhao, B. Hu, T. Yin, G. Chen, and G. Chen, “Three-Dimensional Simulation Stability Analysis of Slopes from Underground to Open-Pit Mining,” *Minerals*, Mar. 2023, doi: 10.3390/min13030402

[9] V. S. Ghutke, A. Mandal, and A. Patel, “Seismic Loading and Reinforcement Effects on the Dynamic Behavior of Soil Slopes,” Komunikácie, Nov. 2024, doi: 10.26552/com.c.2025.008

[10] N. S. Latha, “Numerical Studies on Stability of Sand Slopes,” ECS transactions, Apr. 2022, doi: 10.1149/10701.15309ecst

[11] A. Rizki, B. Alam, N. Khoirullah, I. Sophian, and Y. Firmansyah, “Soil slope reinforcement using cantilever retaining wall on the west ring road of sadawarna dam, subang district,” Feb. 2024, doi: 10.24198/gsag.v7i3.50433

[12] R. Tarigan, Parman, M. A. S. Harahap, and A. Amrizal, “Effectiveness of Using Wire Rope Slings in Improving the Stability of Cantilever Retaining Walls,” *International Journal Of Research In Vocational Studies*, Jan. 2025, doi: 10.53893/ijrvocas.v4i4.381

[13] M. I. Yefa Imam Haryono, D. P. Solin, and H. Farichah, “Perbandingan Stabilitas Dinding Penahan Tanah Tipe Bronjong dengan Tipe Kantilever di Kabupaten Probolinggo,” *Jurnal Talenta Sipil*, Aug. 2025, doi: 10.33087/talentasipil.v8i2.1011