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Behavior Collapse Investigation of A Steel Sheet Pile with LISA FEA V8

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Abstract

The collapse of the Tank Area embankment led to the failure of the steel sheet pile installed on the west side of the planned position. Evidence suggested that the installation process of the sheet pile induced vibrations, which may have contributed to the failure. This study aimed to investigate the actual behavior of the failure through reverse analysis and finite element modeling techniques. These analyses helped identify the causes of the failure and provided reinforcement recommendations for improving the current condition. The findings revealed that the existing state, when evaluated with the current soil parameters, was prone to failure. During the land clearing process, a slip plane formed, resulting in a safety factor (SF) of 0.036. Despite the installation of the sheet pile, the condition continued to deteriorate due to significant lateral soil pressures, causing the sheet pile to collapse. However, when the SF increased to 1.431, which exceeds the necessary SF of 1.2, the stability of the sheet pile improved, and the value approached a stable limit of 0.984. Based on these findings, recommendations are made to enhance the stability and prevent further risks and deterioration.

Keyword: Collaps, FEM, Geotechnical , LISA, Sheet pile.

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1. Introduction

In the construction and civil engineering sectors, soil stability and structural integrity are crucial factors that significantly influence the safety and longevity of engineered projects. One of the most common challenges faced in projects involving embankments and sheet piles is the failure or collapse of these structures, which can lead to substantial damage, project delays, and increased costs. In particular, the collapse of steel piles installed at the planned location on the west side, caused by the failure of the Tank Area embankment, has drawn attention to the need for better understanding and prediction of the forces and behaviors at play. Additionally, there are signs of soil stress or pressure from the embankment wall near the drain hole, which exacerbates the situation. Coupled with this, the effects of vibration during the installation of sheet piles, particularly on the

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north side of the embankment wall, further complicate the stability of the structure. The failure of the embankment occurred due to multiple factors. One of the key issues was the inadequate strength of the support (H-Beam) that was attached to the sheet pile in the sump-pit. This support system was not robust enough to resist the pressures imposed by the surrounding soil and the embankment load, ultimately leading to the collapse of the embankment on the west side of the sheet pile. This situation highlights the importance of comprehensive analysis and modeling in understanding the complex behavior of such systems and preventing future failures [1] [2] [3].

To gain insights into the actual behavior that occurred during the collapse, advanced numerical modeling techniques are employed. Among the various tools available, Finite Element Analysis (FEA) software such as LISA has proven to be effective in simulating and analyzing the behaviors of structural and geotechnical systems. FEA, with its ability to model complex interactions between different materials and forces, enables the identification of potential failure mechanisms and offers valuable insights into the causes of structural failures. This has been demonstrated in several studies where FEA was used to simulate soil-structure interactions, particularly in projects involving sheet piles and embankments. The results obtained from FEA have been shown to closely match the findings from geotechnical-specialized software, further validating its effectiveness in predicting failure modes and understanding the behavior of the system under various loading conditions [4] [5].

In addition to FEA, simpler software such as NSLOPE has also been utilized in previous studies to identify sliding areas and assess slope stability. While NSLOPE may not provide the same level of detail as advanced FEA software, it serves as a useful tool for conducting initial assessments and understanding the overall behavior of the system. The combination of these tools allows for a more comprehensive analysis, providing both a detailed look at the behavior of the soil-structure system as well as a broad overview of the potential risks and failure areas [6] [7]. The motivation behind this research is to deepen the understanding of the failure mechanisms that led to the collapse of the embankment and to identify the factors that contributed to the inadequate performance of the support system. By using inverse analysis and modeling techniques, this study aims to reconstruct the behavior of the system and identify the underlying causes of the failure. Inverse analysis involves adjusting model parameters to match observed data, providing a more accurate representation of the actual conditions that led to the collapse. This approach helps in refining the understanding of soil behavior, structural response, and the interactions between the embankment and sheet piles [8].

Moreover, this research also seeks to evaluate the existing conditions and materials used in the construction of the embankment and support system. By performing a reinforcement analysis, the study aims to assess the adequacy of the materials and design and provide recommendations for improvements. Reinforcement analysis is essential in identifying areas where the existing system may be under-designed or where additional materials and support structures may be necessary to improve stability and prevent further failures [9] [10] [11]. A significant part of this research involves comparing the results from the finite element models with data obtained from real-world tests and previous case studies. This comparison helps validate the modeling approach and provides a means of cross-checking the results. Previous studies have demonstrated that FEA software such as LISA can accurately predict the behavior of complex geotechnical systems, and its results have been consistent with field observations and geotechnical software outputs. By incorporating data from these studies and comparing it with the findings from this research, a more reliable and accurate analysis can be developed [12] [13] [14].

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The research methodology involves conducting several finite element simulations using LISA, along with inverse analysis techniques, to better understand the collapse and its underlying causes. The modeling will take into account various factors such as soil properties, material strength, load conditions, and the effects of vibration during sheet-pile installation. The goal is to create a model that accurately reflects the actual conditions at the site and to identify the specific behaviors that led to the failure. Once the modeling phase is complete, the next step will be to perform reinforcement analysis, which involves testing various strategies for strengthening the existing system. This analysis will explore different materials and structural modifications that could improve the stability of the embankment and prevent future collapses. The aim is to develop practical recommendations for reinforcement strategies that can be implemented in future projects involving similar conditions. In conclusion, this research aims to provide a deeper understanding of the factors contributing to the collapse of the embankment and to propose solutions that enhance the safety and stability of similar geotechnical systems. Through the use of advanced finite element modeling and inverse analysis, this study will contribute to improving the design and construction practices for embankments and sheet piles, offering valuable insights into soil-structure interactions, material behavior, and the overall performance of geotechnical systems under varying conditions. By combining state-of-the-art software with real-world data, this research seeks to bridge the gap between theoretical analysis and practical application, ensuring more reliable and durable civil engineering solutions in the future.

2. Materials and Method

Slope stability analysis using the Limit Equilibrium Method has been carried out since the mid-1930s. Bishop's method developed in the 1950s is based on moment equilibrium. This method is calculated by approaching the surface of the collapsing plane surface considered to be circular. Other methods such as the simplified Janbu method are based on force equilibrium conditions, this method is very suitable for layered soil conditions [7] [8] [9] [10] [11] [12]. NSLOPE is a simple Slope Analysis Program that can be used to analyze a slope with multi-layer soil properties. The software is very easy to use because it requires only very minimum data. If accurate soil properties data are not available, user can use predefined soil properties provided. To cover all possible soil types, a database of typical soil types covering most of soil types in the field was created, based on published data in several textbooks. The soil parameters here are typical values, and the actual parameters should be used instead if available [7] [13].

In this study, Figure 1 shows the condition the research methodology encompassed comprehensive field data collection, specifically acquiring as-built drawings, followed by the determination of crucial soil parameters derived from extensive soil investigation results. A detailed analysis was then conducted focusing on the behavior and existing conditions, emphasizing a thorough examination of both the initial state and the structural conditions immediately following collapse. This research particularly involved a rigorous re-analysis of the prevailing post-collapse circumstances, aiming to meticulously identify the underlying problems that occurred. The primary objective of this re-analysis was to obtain optimal reinforcement solutions directly applicable to sheet piles that had experienced structural failure [14] [15].

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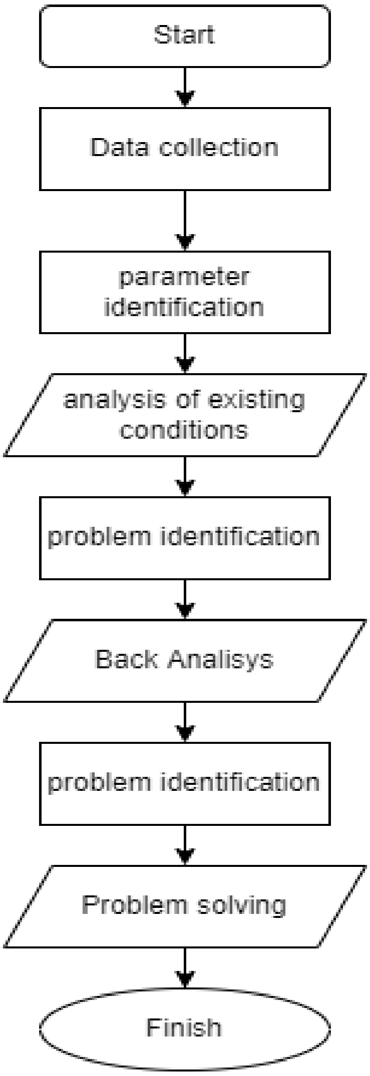

Figure 1. Flow Chart Analisys

This research is based on several normative references and conducts a back analysis of the collapse condition. It involves a behavioral analysis of the site conditions at the time of the collapse, utilizing geotechnical software such as NSLOPE (licensed) and LISA FEA V.8 (licensed) to model and simulate the failure process. These tools were employed to assess the geotechnical characteristics of the site, evaluate the forces and stresses at play, and determine the factors that contributed to the collapse. The back analysis aims to accurately recreate the conditions leading to the failure, providing valuable insights into the underlying causes and potential solutions for improving the site's stability [12].

3. Results And Discussion

In this study, the initial analysis carried out was an analysis of existing conditions adjusting the soil parameters from the results of soil investigations carried out at the scene to obtain the behavior that occurred during soil collapse, identification of this behavior to determine the behavior of the soil when the work was carried out [5] [16] [17] [18] [19] [20] [21] [22] [23] [24].

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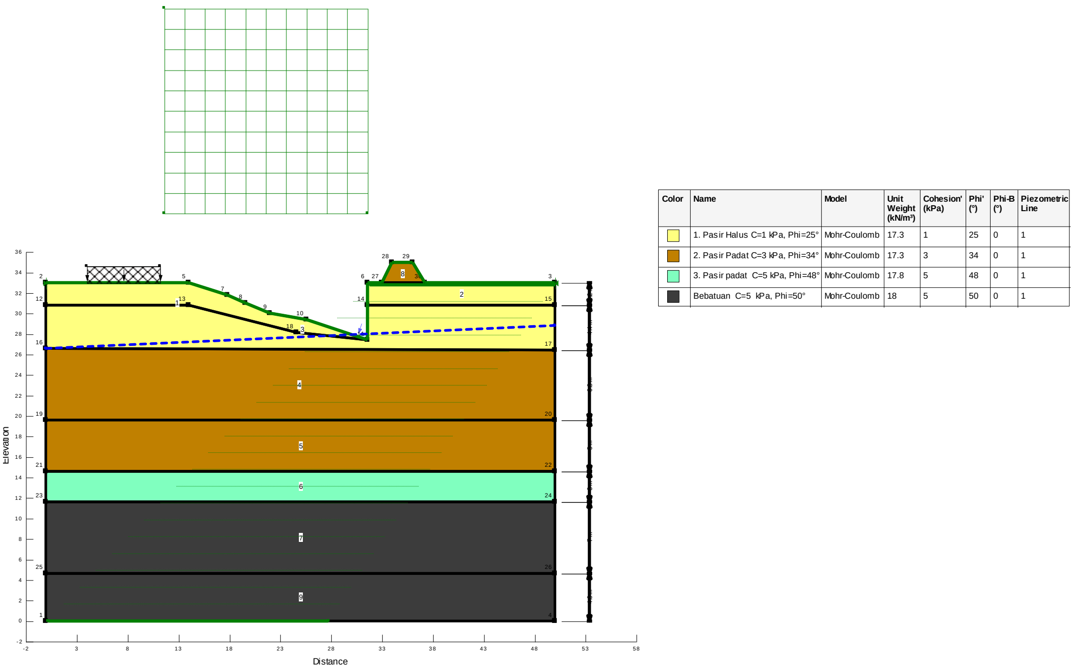

Figure 2. Modeling existing conditions

The Figure 2 is made according to the results of data collection such as shop drawings, photo documentation, and refers to some geometric data in previous documents and soil parameters based on previous planning data.

Table 1 Soil Material parameters in geotechnical software

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
Yellow	1. Pasir Halus C=1 kPa, Phi=25°	Mohr-Coulomb	17.3	1	25	0	1
Brown	2. Pasir Padat C=3 kPa, Phi=34°	Mohr-Coulomb	17.3	3	34	0	1
Light Green	3. Pasir padat C=5 kPa, Phi=48°	Mohr-Coulomb	17.8	5	48	0	1
Dark Gray	Bebatuan C=5 kPa, Phi=50°	Mohr-Coulomb	18	5	50	0	1

From the results of the analysis using geotechnical software, existing soil with initial soil parameters is obtained, where the dominant soil type is sand to a depth of 30 meters with a linear NSPT value increasing to NSPT 50 and continues to be consistent at NSPT 60 at a depth of 18-30 m. It appears the formation of slip zoning on the existing soil with the white color path with a safety factor(SF) of 0.336, this value is re-checked using NSLOPE software (licence) with the same soil parameter value and loading concept, the resulting value is a safety factor(SF) of 0.375 (figure 6) with a value the difference ratio is 1.1160. With the value obtained, it is known that the condition of the existing ground opening indicated the potential for slipping because the SF value <1.2 as required by the SNI geotechnical engineering for handling slope failure on residual soil and rock Pd T-09-2005-B. So the condition in Figure 5 shows the condition of collapse or the formation of a slip plane. With a slice width of 0.1152 m, mid-height 5.2332 m, base length 0.1921 m, base angle 53.153°.

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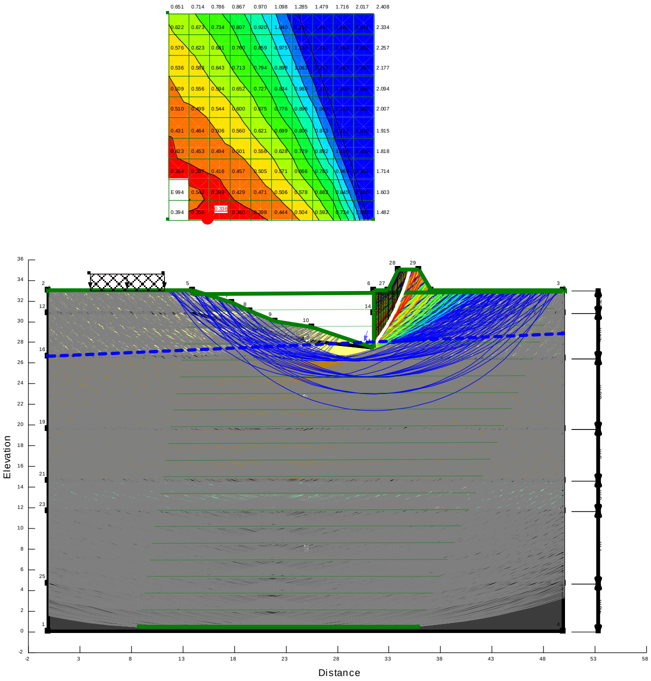

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	1. Pasir Halus C=1 kPa, Phi=25°	Mohr-Coulomb	17.3	1	25	0	1
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	3. Pasir padat C=5 kPa, Phi=48°	Mohr-Coulomb	17.8	5	48	0	1
	Bebatuan C=5 kPa, Phi=50°	Mohr-Coulomb	18	5	50	0	1

Figure 3. Behavior of existing soil with initial soil parameters

To validate the above incident, the researcher analyzed the condition of the sheet pile installation with material parameters adjusting the initial planning data with the same modeling geometry.

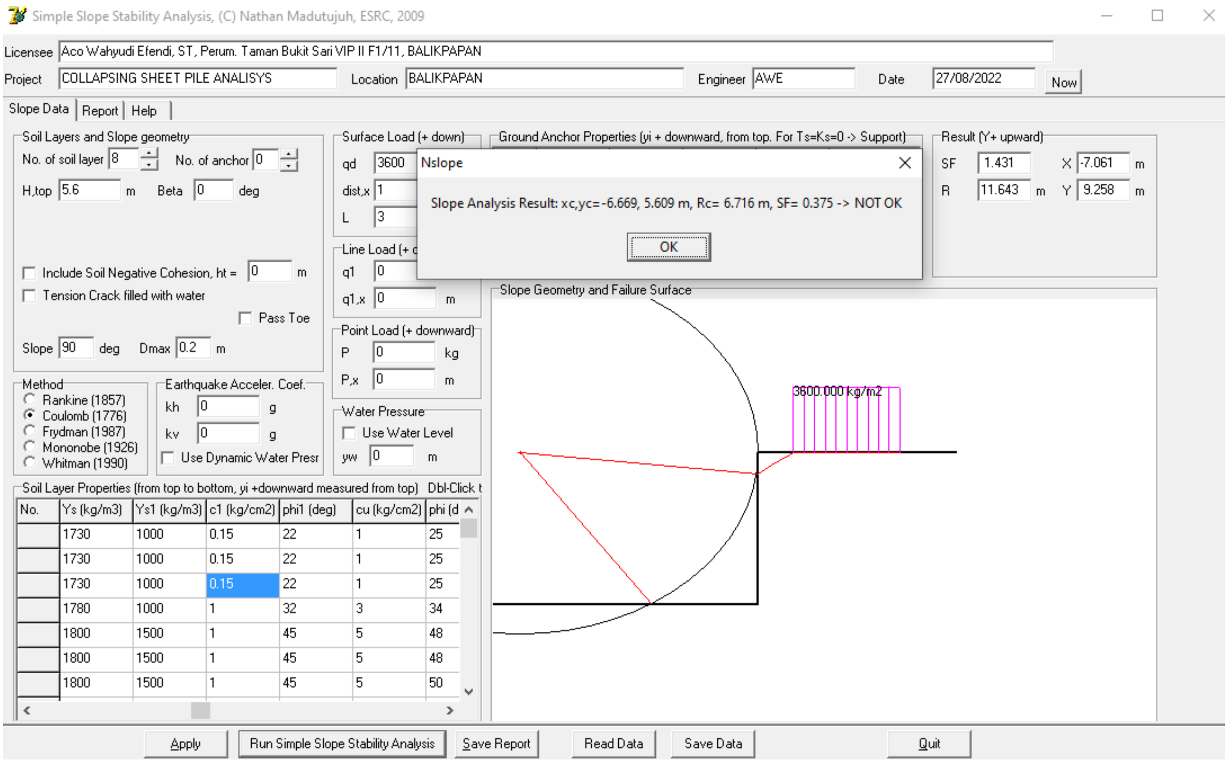

Figure 4. NSLOPE analysis results as validation

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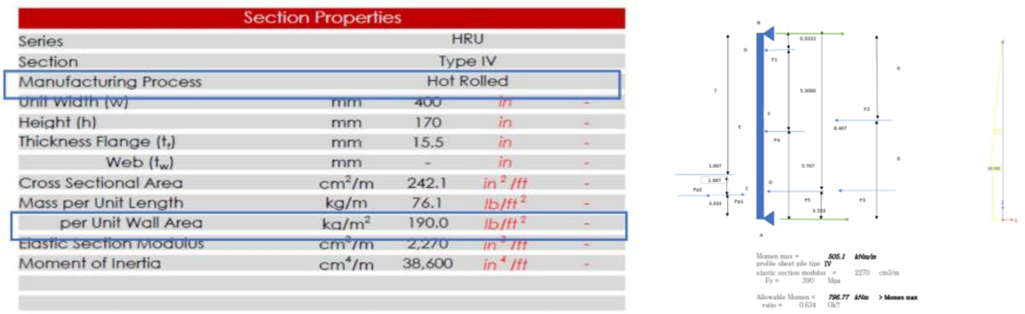

Section Properties				
Series		HRU		
Section		Type IV		
Manufacturing Process		Hot Rolled		
Unit Width (w)	mm	400	in	-
Height (h)	mm	170	in	-
Thickness Flange (t_f)	mm	15.5	in	-
Web (t_w)	mm	-	in	-
Cross Sectional Area	cm^2/m	242.1	in^2/ft	-
Mass per Unit Length	kg/m	76.1	lb/ft^2	-
per Unit Wall Area	kg/m^2	190.0	lb/ft^2	-
Elastic Section Modulus	cm^3/m	2,270	in^3/ft	-
Moment of Inertia	cm^4/m	38,600	in^4/ft	-

(a) (b)

Figure 5. (a) sheet pile material (b) sheet pile material capability parameters

The moment capacity is 796.77 kNm(figure 5b), if the moment capacity is correlated as a lateral load along a 12 m sheet pile, it will have the ability to withstand lateral forces that occur is 66.392 kN or 6639.2 N.

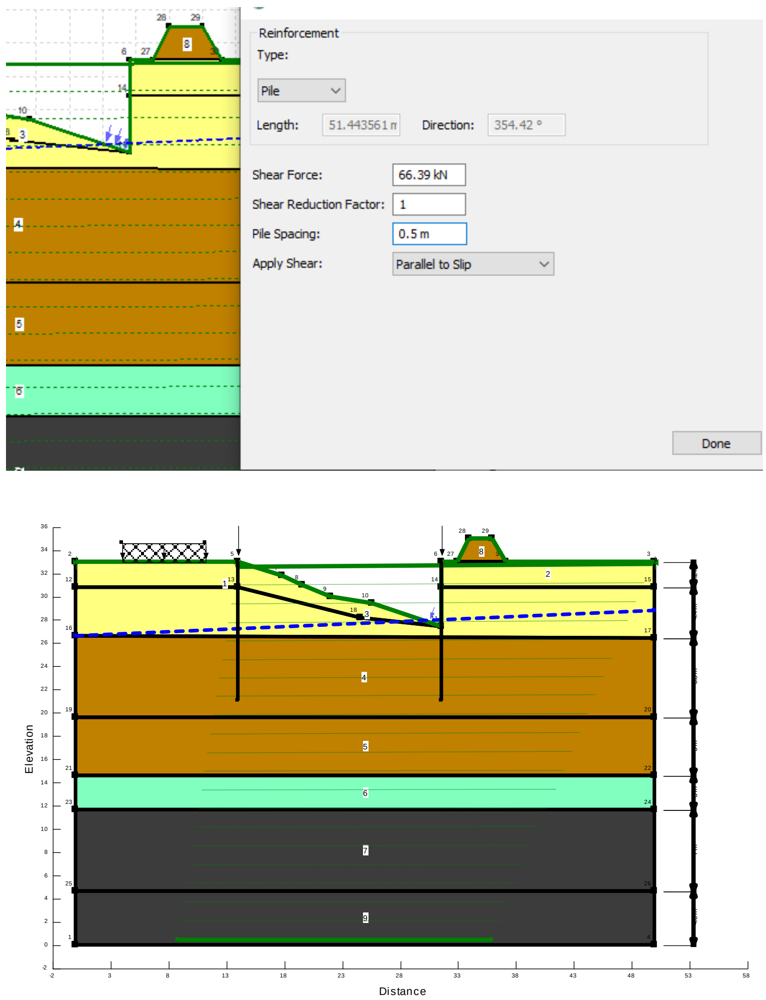

Figure 6. Sheet pile modeling

Sheet pile modeling adjusts from the plan drawings, to the position and geometry according to the shop drawings. according to figure 6. Figure 7 shows that after the sheet pile is installed, there

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is still slippage movement with a factor of safety factor of 0.984<1,2(Fail) with a slice width of 0.15731 m, mid-height 5.4902 m, base length 0.21172 m, base angle 42.012 °. This condition provides information that the sheet pile is indicated to be unable to withstand the formation of the slip plane, because the sliding force that occurs is potentially greater than the ability of the sheet pile itself. In the results of modeling with the Geotechnical Limit Equilibrium Method software, modeling is also carried out using finite element method software using LISA FEA V.8 (Licence), modeling according to the modeling geometry using Geotechnical LEM with the same parameters and loading.

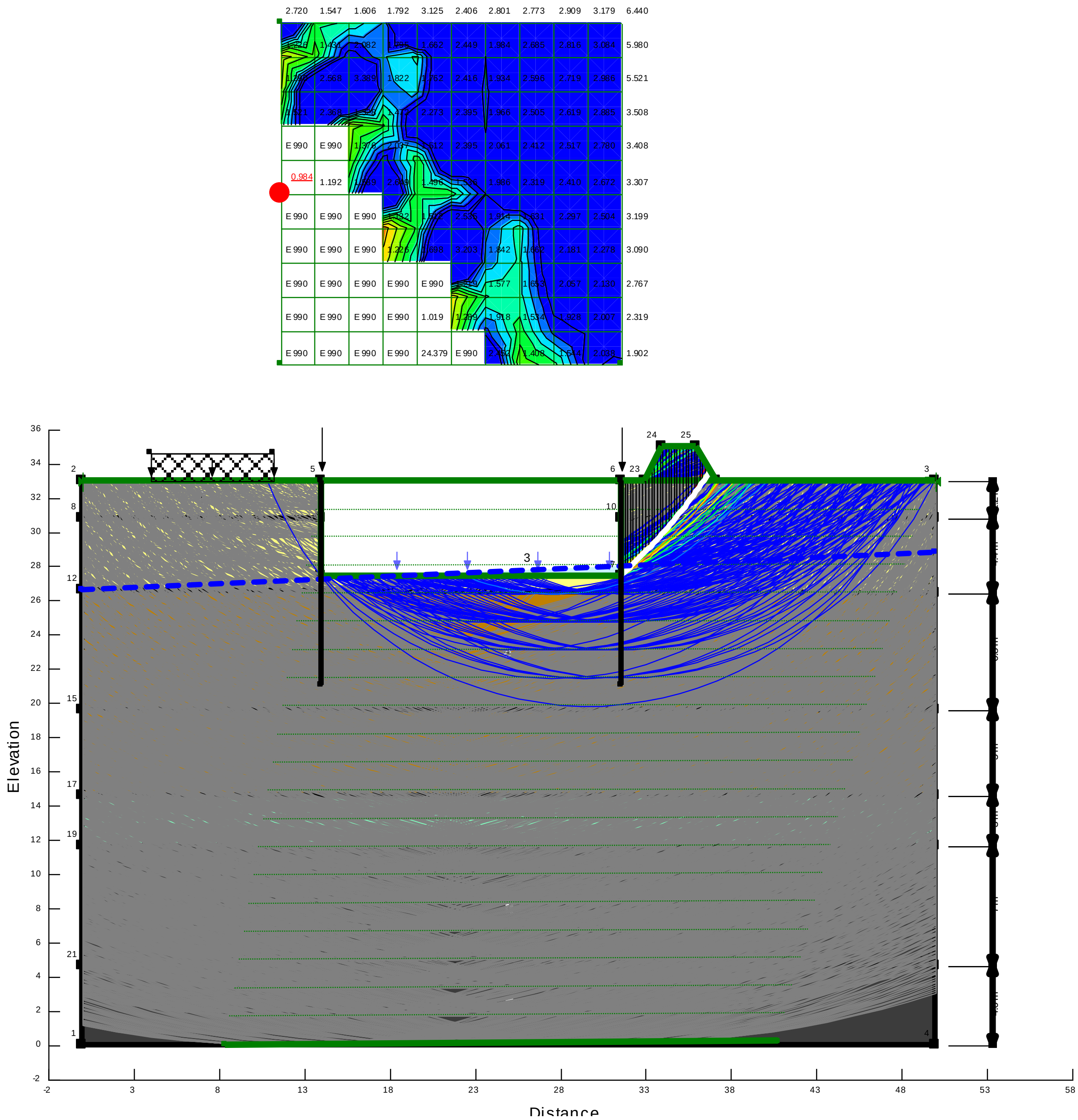

Figure 7. Analisys result

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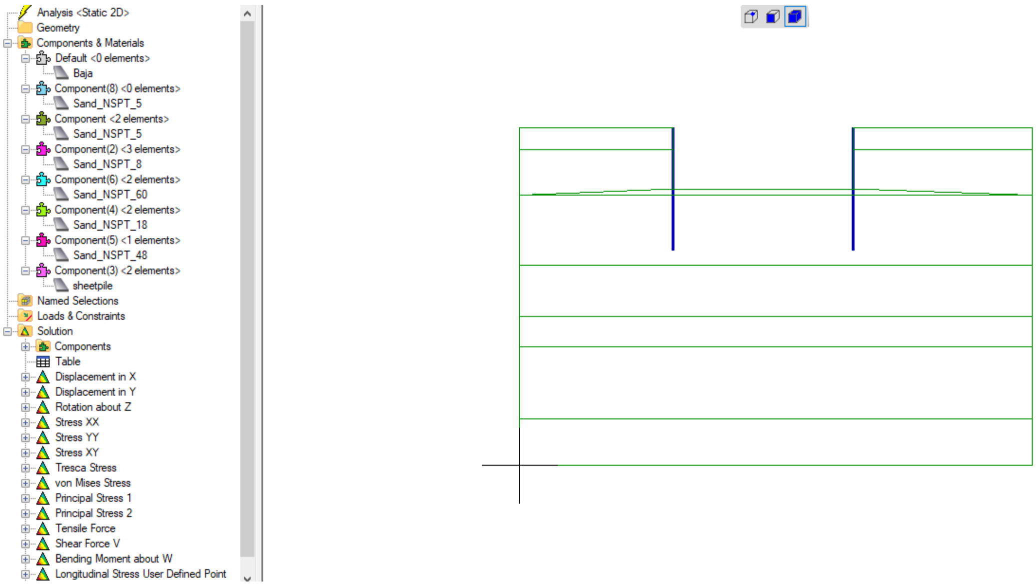

Figure 8. Modeling dan parameters with LISA FEA V.8

LISA FEA V.8 software shows the behavior that occurs on the soil and the installed sheet pile, There was a movement of 0.02 mm in a lateral direction and a decrease of 0.324 mm, seen in figure 7.

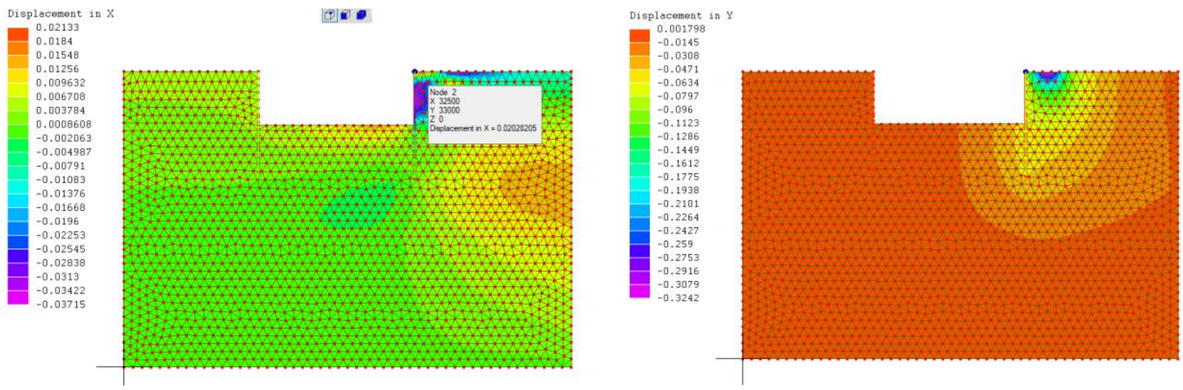

Figure 9. Behavior of soil movement

Given that the behavior observed in the field aligned with the analytical conditions, this study's researchers meticulously analyzed a specific condition improvement method, as conceptually

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illustrated in Figure 10. This comprehensive process commenced with stockpiling materials in dug wells positioned below ground level, specifically at the bracing support level, followed by the precise lifting of H-Beam buffer supports. Subsequently, the area was refilled to ground level, facilitating the installation of a 20 mm steel plate to serve as the stable foundation for pile driving equipment. A new set of sheet piles was then systematically installed on the west side, necessitating the retrieval of a previously fallen pile from the same western area. The methodology further dictated the removal and subsequent re-installation of sheet piles along the north, east, and south perimeters, before proceeding with the excavation of sump pits to a depth of 3.2 meters below ground level, culminating in the secure installation of additional H-Beam support stands.

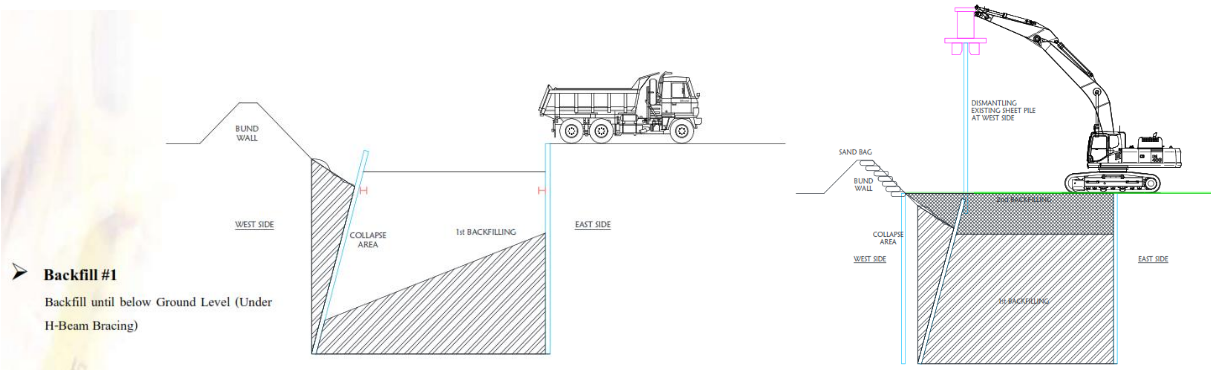
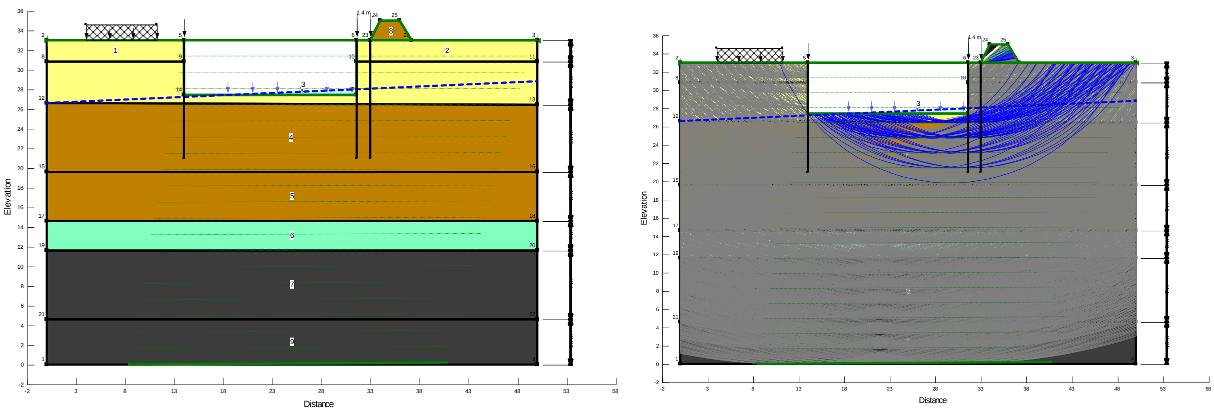


Figure 10. Work method

Figure 10 shows the restoration of condition and installation of additional sheet piles behind the failed sheet piles, the modeling on geotechnical software adjusts to Figure 10, as shown below (Figure 11).



(a) (b)

Figure 11. (a) restoration modeling (b) behavior of restoration condition

Shows that the condition has stabilized the slope to the slip plane with the addition of a sheet pile behind the failed sheet pile, with a factor of safety value of 1.431 and a reduced slice width of 0.069874 m mid-height 0.04213 m base length 0.089226 mbase angle 38.454 °.

Because the Factor of Safety value is 1.431 > 1.2, it can be judged that the repair conditions proposed in the previous document can be implemented because the Factor of Safety value is greater than required.

Conclusion

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The analysis results indicate that the existing conditions, when assessed with the current soil parameters, were prone to failure. During the land clearing process at the site, a slip plane formed, resulting in a safety factor (SF) value of 0.036. Even after the installation of the sheet pile, the condition continued to deteriorate due to significant lateral soil loads, leading to the sheet pile's failure, with the SF value increasing only to 0.984, which is close to the stable limit. Based on the proposed remediation method of adding additional sheet piles behind the failed pile, the results demonstrated an improvement in the pile's stability. This reinforcement method increased the pile's capacity, restoring the SF value to 1.431, which exceeds the required SF of 1.2. Therefore, it is recommended to implement this reinforcement strategy to enhance the stability of the sheet pile and mitigate potential failure risks in similar situations.

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