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ANALYSIS OF LOAD TRANSFER PLATFORM THICKNESS ON LOAD TRANSFER EFFECTIVENESS AND ROAD STABILITY IN SOFT SOIL

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ABSTRACT

Reinforcement of road embankments on soft soils is a common challenge in infrastructure projects, especially in conditions of low bearing capacity and large settlement potential. One widely used solution is the pile embankment system with the addition of granular Load Transfer Platform. This study aims to numerically evaluate the effect of variations in LTP quality and thickness on system performance. Modeling was conducted using the two-dimensional finite element method, with variations in CBR values of 40% and 45%, and LTP thicknesses of 1 m, 1.5 m, and 2 m. The parameters analyzed include the amount of embankment settlement, slope safety factor, axial force on piles, and visualization of arching effect. The results showed that increasing the quality and thickness of the LTP was able to reduce embankment settlement and increase the factor of safety, especially under short-term conditions. The axial force on the piles also increased as the stiffness of the LTP increased, although at a certain thickness it was thought that there was more optimal force attenuation. These findings indicate the importance of appropriate LTP configuration in the design of soft soil reinforcement systems.

Keywords: Pile embankment; load transfer platform; soft soil; embankment settlement; safety factor

ABSTRAK

Perkuatan timbunan jalan di atas tanah lunak merupakan tantangan umum dalam proyek infrastruktur, khususnya pada kondisi daya dukung rendah dan potensi penurunan yang besar. Salah satu solusi yang banyak digunakan adalah sistem pile embankment dengan penambahan load transfer platform (LTP) berbahan granular. Penelitian ini bertujuan untuk mengevaluasi pengaruh variasi kualitas dan ketebalan LTP terhadap kinerja sistem secara numerik. Pemodelan dilakukan menggunakan metode elemen hingga dua dimensi, dengan variasi nilai CBR sebesar 40% dan 45%, serta ketebalan LTP 1 m, 1,5 m, dan 2 m. Parameter yang dianalisis meliputi besarnya penurunan timbunan, faktor keamanan lereng, gaya aksial pada tiang pancang, serta visualisasi arching effect. Hasil penelitian menunjukkan bahwa peningkatan kualitas dan ketebalan LTP mampu menurunkan penurunan timbunan dan meningkatkan faktor keamanan, khususnya pada kondisi jangka pendek. Gaya aksial pada tiang juga meningkat seiring peningkatan kekakuan LTP, meskipun pada ketebalan tertentu diduga terjadi peredaman gaya yang lebih optimal. Temuan ini menunjukkan pentingnya konfigurasi LTP yang tepat dalam desain sistem perkuatan tanah lunak.

Kata kunci: Pile embankment; load transfer platform; tanah lunak; penurunan timbunan; faktor keamanan

1. INTRODUCTION

Soft soil is often a major obstacle in the construction of infrastructure such as roads and bridges due to its low bearing capacity and easy deformation. One solution that has proven effective is the pile embankment system, which is a method of filling on top of piles to reduce settlement and improve slope stability (Pham et al., 2021). In this system, an important element between the embankment and the pile head is the material that serves to efficiently transfer the load from the embankment to the piles. In general, two approaches are used using a reinforced concrete floor slab or using a granular layer known as a Load Transfer Platform.

LTP is designed to replace the structural function of concrete slabs by utilizing materials such as sand, gravel, or sirtu, which are capable of forming an arching mechanism so that most of the load from the embankment is transferred to the piles. In this study, it is assumed that the pile embankment system uses granular LTP as the load transfer medium instead of concrete slabs. This approach is commonly applied as it is more economical and flexible in field construction.

The load transfer performance of LTP is strongly influenced by the quality of the granular material and the thickness of the layer (Chen et al., 2020). However, studies that specifically discuss the combination of LTP quality and thickness are limited, especially regarding load distribution, settlement, slope stability, and pile axial force. Therefore, this study aims to evaluate the effect of varying LTP quality and thickness on the performance of pile embankment system through 2D numerical modeling based on finite element method. The analysis includes embankment settlement, slope safety factor, pile axial force, and visualization of arching effect as a basis for more optimal design recommendations.

Specifically, this study aims to determine the extent to which the thickness and quality of the LTP material can affect the effectiveness of load transfer from the embankment to the pile elements. Thus, the results of this study are expected to contribute in determining the most efficient LTP configuration in improving the performance of soft soil reinforcement systems using pile embankment.

Soft soil

Soil is a natural material composed of minerals, organic matter, and loose sediments, with generally weak intergranular strength due to the influence of carbonates, organic compounds, or oxides. The content of water or air in soil pores greatly influences its response to loads (Hardiyatmo, 2002).

Soft soils, which are a type of cohesive soil, are dominated by fine particles such as clays and silts, and are commonly found in low-lying areas such as swamps or tidal zones. They are characterized by low shear strength, high compressibility, and low permeability, making them prone to settlement and instability (Siska & Yakin, 2016). One indicator to assess the relative hardness of a soil is the N-SPT value, which provides an initial estimate of the soil's ability to withstand loads and is often used in field geotechnical investigations.

Pile embankment

Pile embankment is a soft soil improvement method that utilizes piles as the main support of the embankment. It is commonly applied to infrastructure such as roads and railroads built on soils with low bearing capacity (Han & Collin, 2005). Through the pile element, the load of the embankment is transferred directly to the stronger soil layer below, thereby reducing the vertical pressure on the soft soil and preventing excessive settlement.

The working mechanism of this method relies on vertical load distribution through the piles. To improve load transfer efficiency, the area between piles is usually filled with granular material and reinforced with geosynthetics such as geogrids (Russell & Pierpoint, 1997). This reinforcement serves as a transitional element that spreads the load more evenly, and reduces the risk of localized deformation and collapse in soft soils. A visualization of the implementation of the pile embankment system can be seen in Fig. 1.

Figure 1. Implementation of pile embankments (Esseveld, 2024)

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Load transfer platform

One of the main components in a pile embankment system is the Load Transfer Platform, which is a granular layer placed on top of the piles and serves to distribute the load from the embankment to the piles more evenly and efficiently. The LTP is usually reinforced with geosynthetics to increase bearing capacity and reduce differential deformation (Han & Collin, 2005).

According to Collin's method, the design of LTP considers several conditions, including: the thickness of the LTP should be at least equivalent to the net distance between piles or 1.25 times larger; the use of at least three layers of reinforcement with a vertical distance between layers of at least 20 cm all vertical loads should be transferred to the piles and the initial strain on geosynthetics should be limited to 5%.

LTP is also known as reinforced granular mattress or geosynthetic-reinforced platform, which works through a combination of arching and membrane effects, effectively transferring loads to the pile elements (Kaluđer et al., 2015). Recent studies have shown that when LTP are reinforced with geotextiles or mortar columns, the vertical stresses form an arching pattern, with the highest concentration on top of the pile and decreasing between the piles, thus reducing the direct load on the subgrade (Frontiers, 2024).

Soil arching

Soil arching is a stress redistribution mechanism in which the vertical load of the embankment is transferred to a stiffer element, such as piles, through the formation of stress arches in the granular material. This phenomenon was first introduced by(Terzaghi, 1943) through trapdoor tests, then further developed by (Hewlett & Randolph, 1988) through the hemispherical arching model, which became a reference in modern granular platform design.

The effectiveness of arching is influenced by two main factors Load Transfer Platform thickness and granular material quality. A larger LTP thickness allows for a more stable stress arch to form and improves load distribution to the piles, thereby reducing settlement. Meanwhile, materials with high CBR and elastic modulus values promote a more active arching effect, as they are able to resist lateral deformation and direct stress more efficiently to the vertical support elements.

Geotextile

Geotextiles are permeable sheet shaped geosynthetic materials made from synthetic polymers such as polypropylene, polyester, or polyethylene, which are resistant to chemical and biological degradation (Sastrawinata & Andryan, 2020). In geotechnical engineering, geotextiles are widely used for stabilization, filtration, drainage, and reinforcement, including in the construction of embankments on soft soils.

In pile embankment systems, geotextiles play an important role as part of the Load Transfer Platform component. The installation of geotextiles at the base of the LTP aims to improve lateral load distribution, resist horizontal movement of granular materials, and strengthen the arching system between the embankment and the piles. Thus, geotextiles help to optimize load transfer from the embankment to the piles efficiently and prevent excessive deformation in the transition zone.

In this study, a woven geotextile with a tensile strength of 60 kN/m was used, which was selected for its ability to reinforce the LTP granular structure and maintain embankment stability on soft soil. Details of the woven geotextile used can be seen in Fig. 2.

Figure 2. Geotextile woven (Geofantex, 2024)

Finite element method

The Finite Element Method is a numerical approach widely used in geotechnical analysis to model soil response and its interaction with structures (Apriadi et al., 2019). This method divides the study area into small elements that are calculated individually, and then combined to obtain the overall system response. Through FEM-based software, effective stress distribution, soil deformation, pore water flow, and load response during the consolidation process are analyzed.

2. RESEARCH METHODS

This study was conducted numerically to analyze the effect of variations in the quality and thickness of the Load Transfer Platform on the effectiveness of the pile embankment system in soft soil. This study does not use laboratory tests in determining soil parameters or other materials, but rather uses secondary data sourced from similar studies as well as typical values and empirical correlations from relevant geotechnical literature. All analyses were conducted through computer modeling with a two-dimensional (2D) approach based on the finite element method, which was chosen because it was considered representative enough to describe the cross-sectional conditions of the road embankment, given the relatively flat contours of the existing soil at the study site.

The soft soil parameters in the model were assumed to represent very soft clay characteristics, with physical and mechanical properties obtained from relevant references. The granular materials in the LTP were modeled with two quality variations represented by the California Bearing Ratio (CBR) values of 40% and 45%. Other parameters such as specific gravity, inner shear angle, and modulus of elasticity were determined based on the general classification according to the CBR values. The model geometry consisted of subgrade, LTP, embankment, geotextile, and pile layers. In this study, the spacing between piles and the cross-sectional dimensions of the piles were predetermined and not varied, as one of the study limitations.

The modeling stage began with the preparation of geometry and the assignment of material properties, followed by the application of boundary conditions and construction stages in stages according to field conditions. Simulations were conducted for six combination scenarios, namely two variations of CBR values (40% and 45%) with three variations of LTP thickness (1 m, 1.5 m, and 2 m). Each scenario was analyzed to evaluate the maximum settlement at the embankment surface, slope safety factor, maximum axial force on the piles, and stress distribution pattern in the embankment indicating the formation of arching effect.

The results of each scenario were compared descriptively through graphs, tables, and stress contour visualizations. This analysis was used to assess the effect of thickness variation and LTP quality on the performance of the pile embankment system, as well as the basis for developing recommendations for the optimal design configuration in soft soil conditions.

3. RESULTS AND DISCUSSION

Project general description

The toll road construction project in the Pekanbaru area studied is part of the Rimbo Panjang interchange with a total length of approximately 2.4 km. This study is focused on the segment between STA 1+900 to STA 2+200. In this area, soil investigation has been carried out in the form of two drill points around STA 1+900 and one CPTu test point at STA 2+175. Fig. 3 shows the top view of the road trajectory, while the soil testing location plan is shown in Fig. 4.

Figure 3. Top view of the toll road trajectory

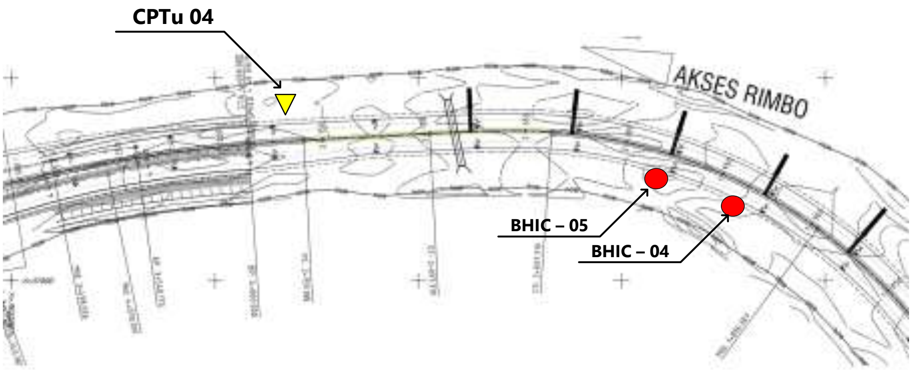

Figure 4. Location of testing points

Soil investigation results

The soil investigation results indicate the presence of a very soft clay layer to a depth of about 4 m, which is then followed by a sand layer with conditions ranging from loose to dense. Fig. 5 presents the interpretation results of two borings and one CPTu test point in the study area. Meanwhile, Fig. 6 displays the results of the dissipation test, which was used to determine the value of the permeability parameter in the very soft clay layer.

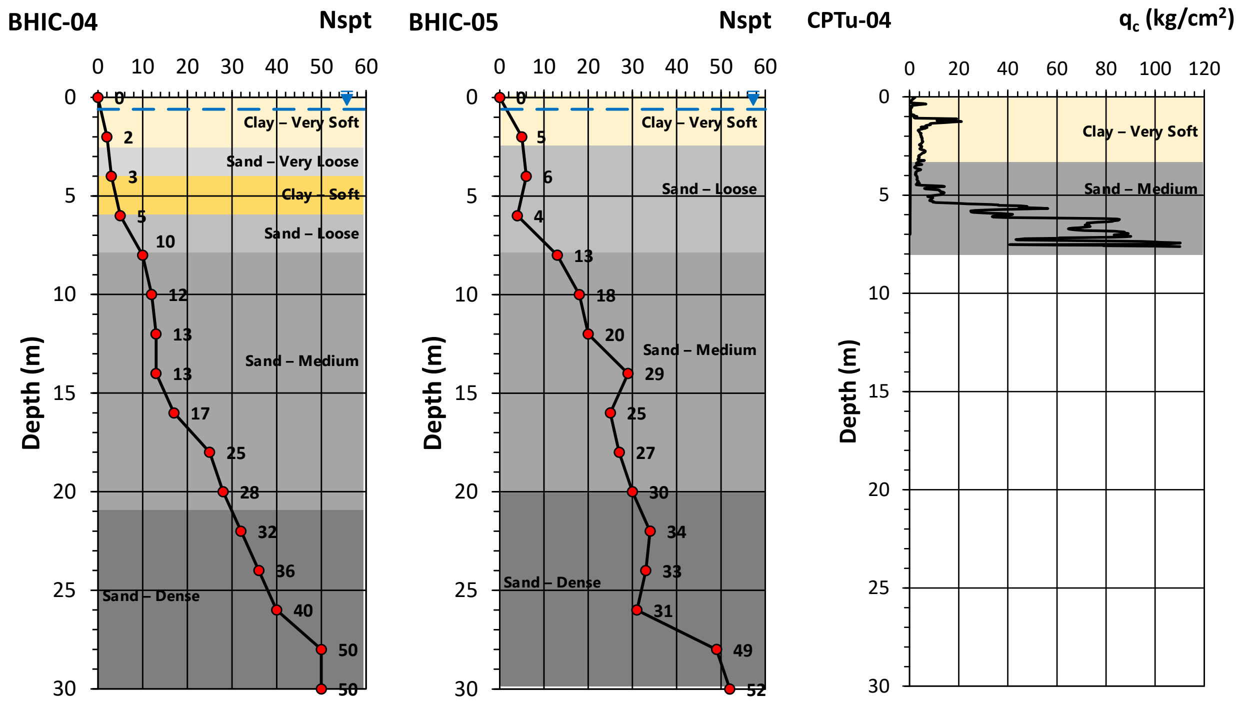

Figure 5. Interpretation of soil investigation results

Soil parameter

Soil parameters for numerical modeling are obtained from the interpretation of field investigation data. Each soil layer was identified based on depth and dominant soil type, so that its technical characteristics could be accurately determined. This process begins with the interpretation of soil stratification from the test results, to clearly recognize the layer arrangement. The results of this stratification interpretation form the basis for determining the soil parameters in each layer, as shown in Fig. 7.

In numerical modeling, two types of soil behavior models are used that are adapted to the characteristics of the materials in the field. The Soft Soil Model is applied for soft soils that exhibit gradual consolidation and plastic deformation behavior, while the Mohr-Coulomb Model is used for more rigid soil layers or as a comparison in the validation process.

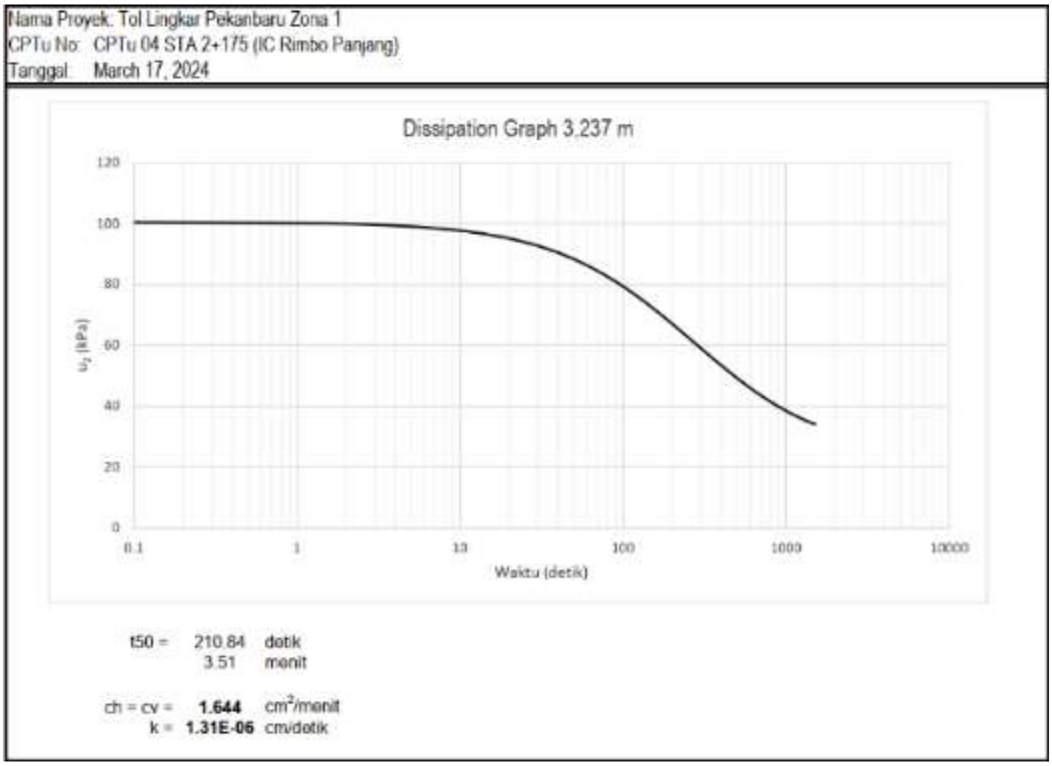

Figure 6. Pore pressure dissipation test curve from CPTu for soil consolidation analysis

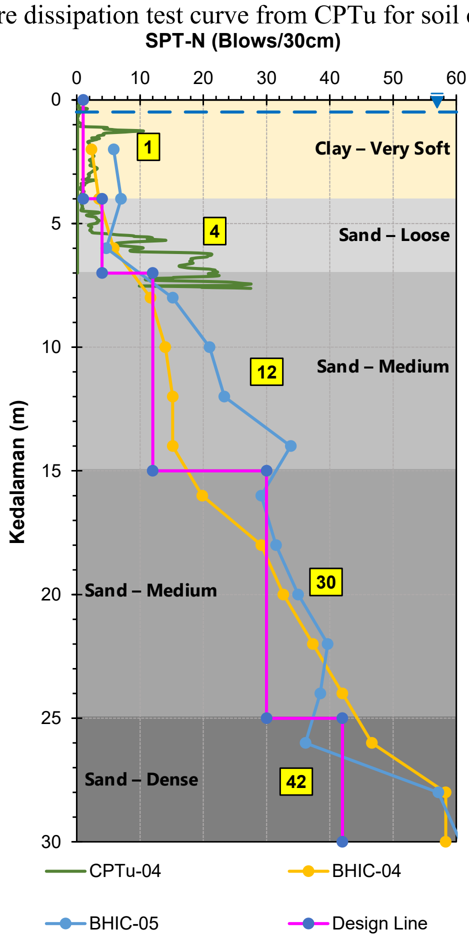

Figure 7. Interpretation of soil stratification

The combination of these two models allows for simulations that are more representative of actual field conditions, especially in predicting long-term settlement and embankment response to construction loads. Some soil parameters were determined directly from field and laboratory test results, while others were obtained through empirical correlations and typical values based on identified soil types.

Table 1 presents the technical parameters of each interpreted soil layer, while Table 2 contains the embankment soil parameters used in the numerical modeling. While Table 3 presents the technical parameters of the Load Transfer Platform material used in the modeling.

Table 1. Soil layer parameters

Depth (m)	Nspt	Soil Type	γ [kN/m^3] unsat	γ [kN/m^3] sat	c' (kPa)	φ' (˚)	E (kN/m^2)	Cc	Cs	Kv (m/day)	Kh (m/day)
0 - 4	1	Clay	15	16	0.6	24	300	0.84	0.17	7.55E-4	1.13E-3
4 - 7	4	Sand	16	17	1	27	3064	-	-	8.64E-1	1.73E+0
7 - 15	12	Sand	17	18	1	32	9192	-	-	8.64E-1	1.73E+0
15 - 25	30	Sand	18	19	1	39	22980	-	-	8.64E-1	1.73E+0
25 - 30	42	Sand	19	20	1	42	32172	-	-	8.64E-1	1.73E+0

Table 2. Backfill soil parameters

Material	Soil Type	Nspt	γ [kN/m^3] unsat	γ [kN/m^3] sat	c' (kPa)	φ' (˚)	E (kN/m^2)	Kv (m/day)	Kh (m/day)
Timbunan	Lempung	8	16	17	4.8	28	6128	8.64E-4	1.73E-3

Table 3. Load Transfer Platform parameters

Material	Soil Type	CBR (%)	γ [kN/m^3] unsat	γ [kN/m^3] sat	c' (kPa)	φ' (˚)	E (kN/m^2)	Kv (m/day)	Kh (m/day)
LTP	Sand	40	17	18	5	35	22980	8.64E-1	1.73E+0
LTP	Sand	45	17	18	5	42	25853	8.64E-1	1.73E+0

Road embankment stability and settlement modeling

Geotechnical modeling in this study was conducted using Finite Element Method-based software, which allows visualization and analysis of soil behavior and the effectiveness of reinforcement systems close to field conditions. The modeling location was focused on STA 1+950, the point with the highest embankment elevation of about 7 m, which was used to represent the critical area. The cross section of this location is shown on Fig. 8.

The reinforcement configuration used is the embankment pile system, which consists of 30 × 30 cm square piles, with a spacing of 0.9 m between piles and a depth of 14 m. Above the pile head, a Load Transfer Platform was installed as a load transition medium, using granular material in the form of sirtu with a minimum CBR value of 40%. The LTP was reinforced by two layers of woven geotextile with a tensile strength of 60 kN/m, then covered by a 7 m high embankment constructed with a slope of 1V:2H. The schematic geometry and arrangement of the system elements are shown in Fig. 9.

In this modeling, six variations of combinations were carried out based on two main parameters, namely the quality of the LTP granular material represented through CBR values of 40% and 45%, and the thickness of the LTP which was varied to 1 m, 1.5 m, and 2m. Each combination was used to assess the effect on the performance of the pile embankment system.

A number of key parameters were evaluated, including vertical settlement of the embankment, slope safety factor, axial force on the piles, and vertical stress distribution in the cross-sectional plane to observe the effect of soil arching. The results of this analysis are expected to provide a deeper understanding of the contribution of LTP to the effectiveness of load transfer and embankment stability in soft soils. Geotechnical modeling in this study was carried out with the help of Finite Element Method-based software, which is able to describe the soil response to loads and reinforcement in a manner close to actual conditions in the field.

Modeling results

Analysis was conducted on six modeling scenarios with varying thickness and material quality of the Load Transfer Platform, in order to evaluate the performance of the pile embankment system in efficiently distributing loads on soft soil. Three main parameters were evaluated: slope factor of safety, embankment settlement, and axial force on the piles, as well as one visual aspect stress distribution pattern showing the formation of arching effect.

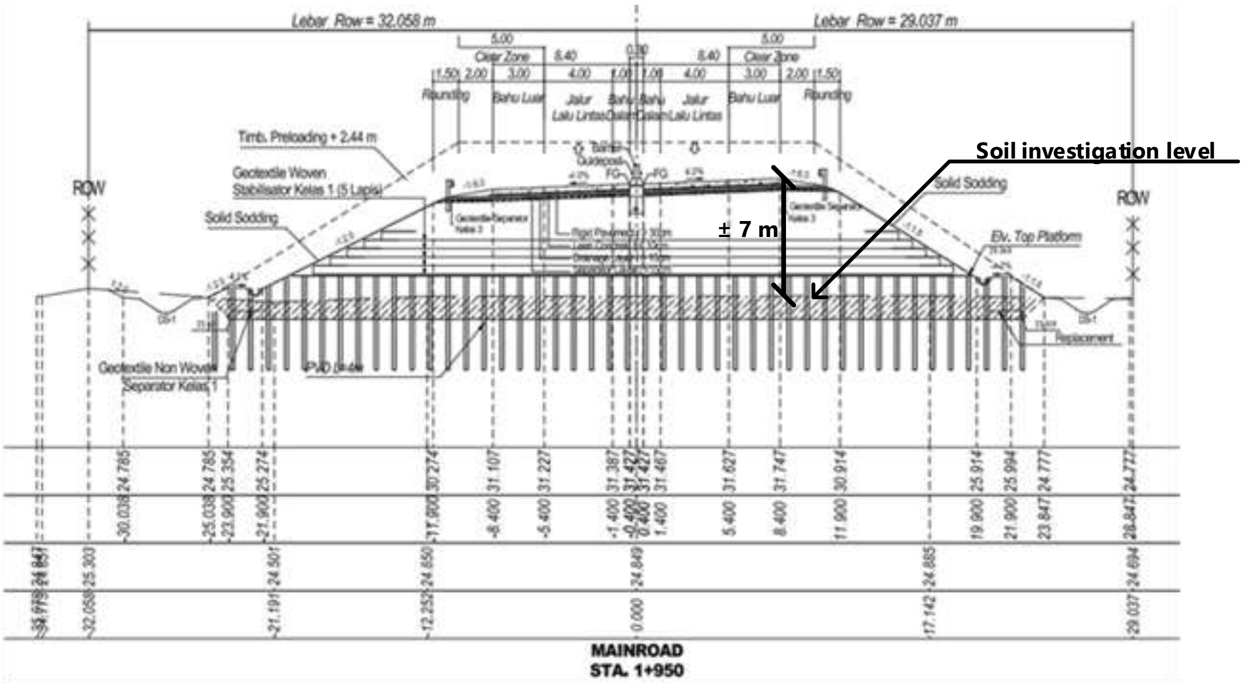

Figure 8. Cross section STA 1+950

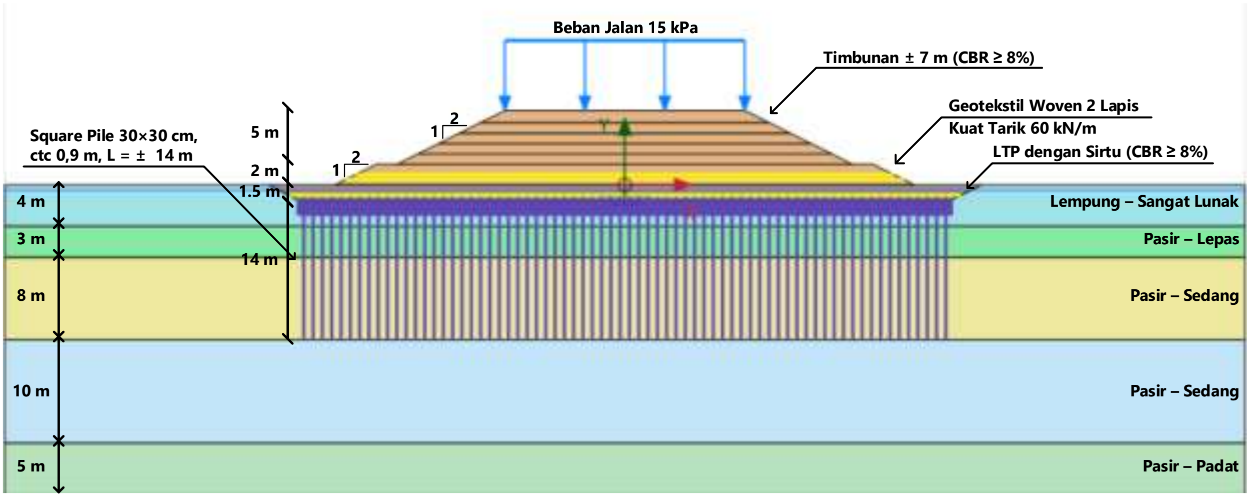

Figure 9. Pile embankemnt modeling

The slope factor of safety values for all scenarios can be seen in Fig. 10, which is used as a basis for comparing the stability of the embankment. This factor of safety indicates the resistance of the slope to collapse during the construction process and is strongly influenced by the stiffness of the LTP and the effectiveness of load transfer to the piles.

Fig. 11 presents the settlement graph of the embankment surface. These results show how much vertical deformation occurs due to the combination of loading and soft soil characteristics, and how the variation of LTP affects the control of this deformation.

Meanwhile, Fig. 12 shows the magnitude of axial force in the piles, which is a key indicator of the effectiveness of load transfer from the embankment through the LTP to the pile elements. The larger axial force indicates that the load was optimally transferred to the foundation system through the arching mechanism.

Finally, Fig. 13 presents a visualization of the stress distribution pattern in each model, showing the formation of the arching effect. This pattern shows how the load from the embankment is not directly transmitted to the subgrade but rather transferred to the piles through the LTP. The difference in arching patterns between variations illustrates the extent to which the LTP configuration is able to produce efficient stress distribution.

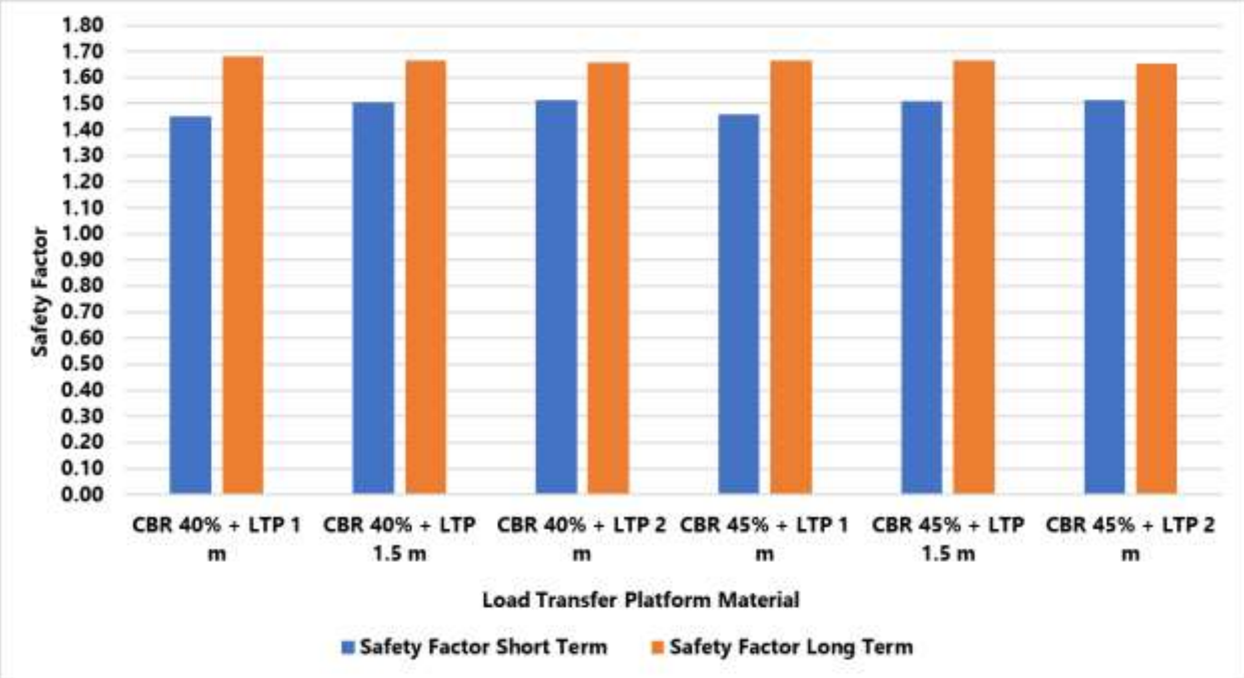

Figure 10. Comparison of post-construction safety factor values

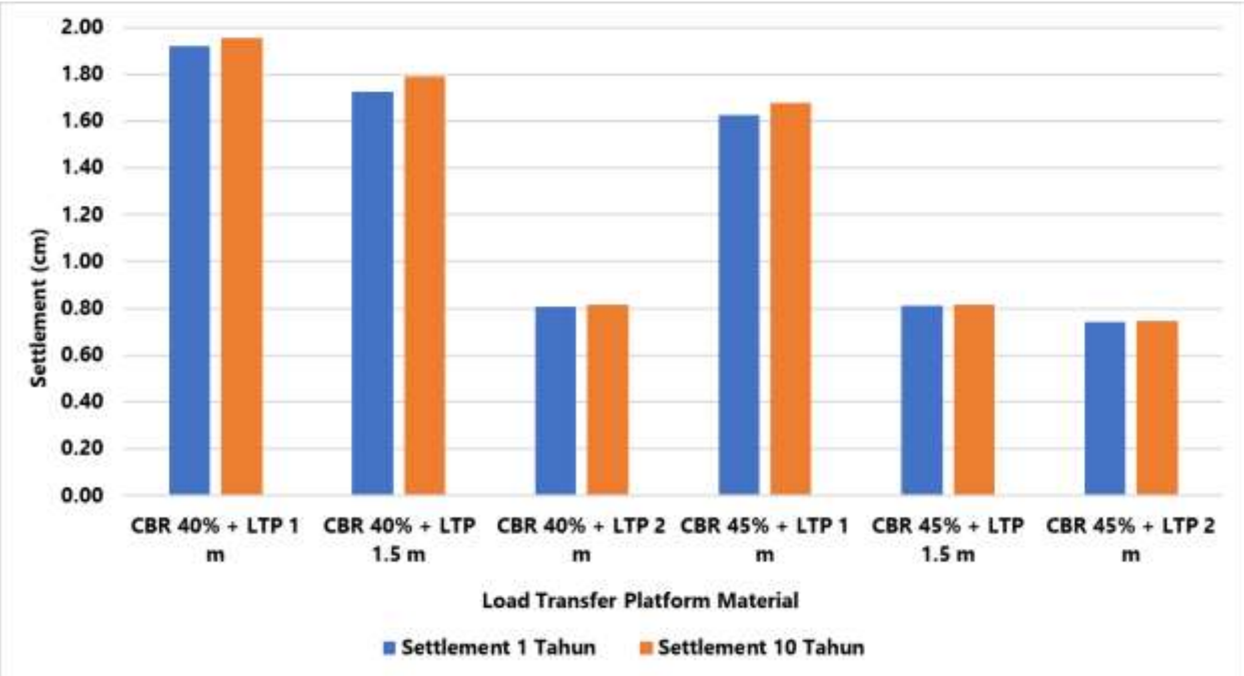

Figure 11. Comparison of post-construction settlement

Table 4 presents the recapitulation results of all the modeling that has been carried out, which aims to evaluate the effect of variations in thickness and material quality on the performance of the pile embankment reinforcement system.

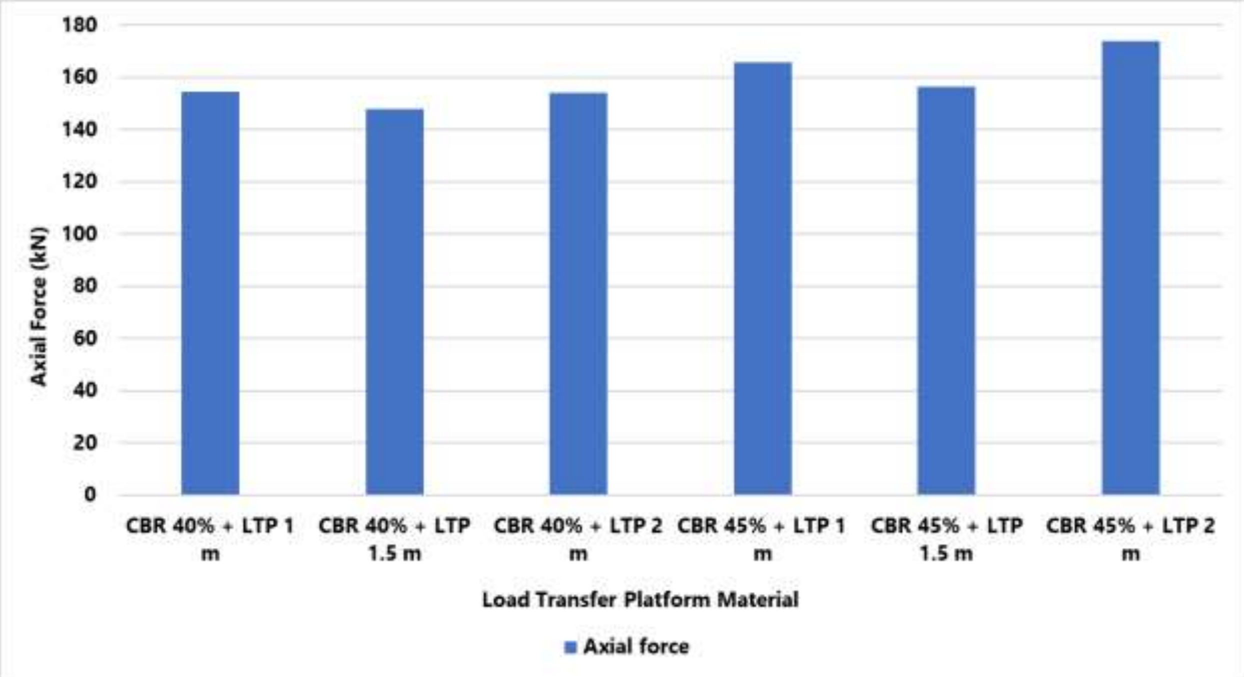

Figure 12. Axial force magnitude comparison

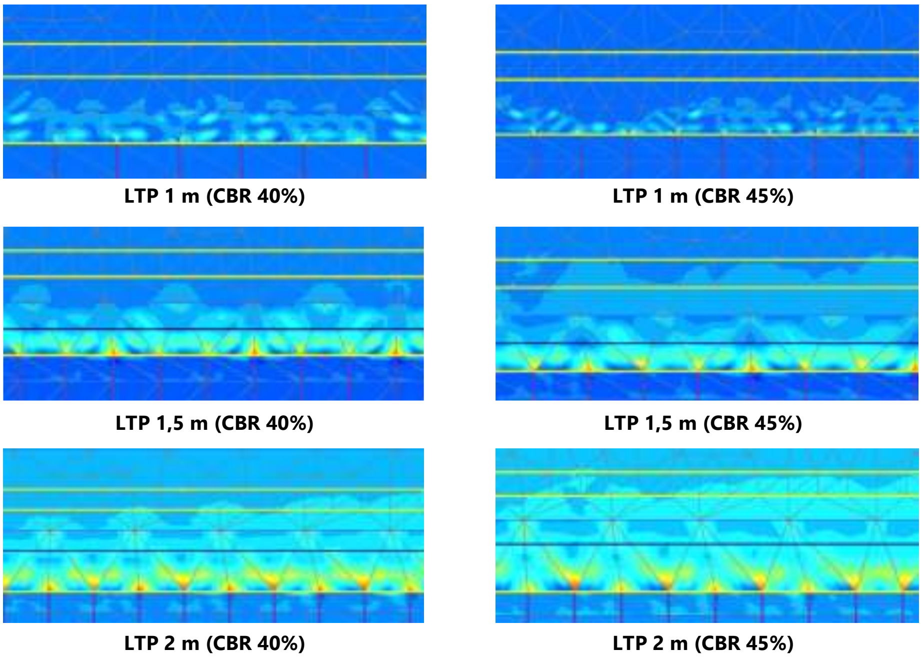

Figure 13. Stress distribution pattern and arching effect around the pile

Table 4. Recapitulation of modeling results

LTP meterial criteria	Settlement (cm)		Safety Factor		Axial Force (kN)
	1 Year	10 Years	Short Term	Long Term	
LTP 1 m (CBR 40%)	1.92	1.95	1.45	1.68	154.6
LTP 1.5 m (CBR 40%)	1.73	1.79	1.50	1.67	148
LTP 2 m (CBR 40%)	0.81	0.82	1.51	1.66	154.1
LTP 1 m (CBR 45%)	1.62	1.68	1.46	1.67	165.7
LTP 1.5 m (CBR 45%)	0.81	0.82	1.51	1.67	156.6
LTP 2 m (CBR 45%)	0.74	0.75	1.52	1.65	174

4. CONCLUSION AND SUGGESTION

Based on the results of the research and analysis that has been carried out, the following conclusions are obtained:

1. The numerical modeling results show that the material quality and thickness of the load transfer layer have a significant influence on the performance of the pile embankment system on soft soil. The higher the CBR value and the thicker the layer, the smaller the embankment surface settlement tends to be. For example, the settlement after 10 years in the 40% CBR configuration with a thickness of 1 m was recorded at 1.95 m, while in the 45% CBR with a thickness of 2 m it was only 0.75 m. This shows that increasing the stiffness and thickness of the load transfer layer is effective in reducing the vertical deformation due to loading.
2. The slope safety factor values also showed an increase as the characteristics of the load transfer layer improved, especially under short-term conditions. The values increased from 1.45 to 1.52, reflecting the improved stability of the embankment during the construction period. However, under long-term conditions, all variations produced relatively similar values, falling within the range of 1.65 to 1.68. This indicates that the influence of the load transfer layer configuration on stability is more dominant in the early phase before the soil undergoes full consolidation.
3. The magnitude of the axial force on the piles also tends to increase with the increase in the quality and thickness of the load transfer layer. The highest value of 174 kN was recorded in the 45% CBR configuration with a thickness of 2 m, while the lowest value of 148 kN occurred in the 40% CBR with a thickness of 1.5m. This pattern suggests that in addition to functioning as a load-distributing medium, the load transfer layer is also expected to partially reduce the vertical force under certain conditions. A thickness of 1.5 m appears to be a transitional configuration that reduces the axial load more optimally. Conversely, if it is too thick, the self-weight of the granular layer may become an additional load that increases the stress on the \

Some suggestions that can be considered for further research are as follows:

1. It is necessary to conduct a more complete soil investigation, not only relying on borings and CPTu data, but also including laboratory tests such as consolidation tests, direct shear tests, and soil physical properties. This is important so that the soil characteristics at the site can be determined more accurately and representatively.
2. The effect of earthquake loading on embankment stability needs to be further reviewed, especially since the study area is located in a region with seismic potential. The addition of dynamic analysis can provide a more comprehensive picture of embankment performance under earthquake conditions.

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