Innovative: Journal Of Social Science Research
Universitas Pahlawan Tuanku Tambusai

LETTER OF ACCEPTANCE (LoA)

No: 1808/INNOVATIVE/IV/2025

The Editor in Chief of Innovative Journal has been received the article:

In the name of	**:**	**Fikri Ramadhan[1], Tika Ermita Wulandari[2]**
Title	:	The Effect of The Preloading Method on Soil Consolidation Time at Binjai-Pangkalan Berandan Toll Road Sta 38+825
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Bangkinang, April 24th 2025
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INNOVATIVE: Journal Of Social Science Research
Volume 5 Nomor 2 Tahun 2025 Page 3346-3355
E-ISSN 2807-4238 and P-ISSN 2807-4246
Website: https://j-innovative.org/index.php/Innovative

The Effect of The Preloading Method on Soil Consolidation Time at Binjai-Pangkalan Berandan Toll Road Sta 38+825

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Abstrak

Pembangunan infrastruktur sering kali menghadapi tantangan akibat kondisi tanah lunak, seperti yang terjadi pada Proyek Pembangunan Jalan Tol Binjai-Pangkalan Berandan di STA 38+825. Tanah lunak memiliki permeabilitas yang rendah, daya dukung yang rendah, dan masa konsolidasi yang lama, sehingga diperlukan perbaikan tanah sebelum pembangunan. Salah satu metode yang umum digunakan adalah preloading, yaitu pemberian beban awal dengan timbunan sementara untuk mempercepat proses konsolidasi tanah. Penelitian ini bertujuan untuk menganalisis pengaruh metode preloading terhadap percepatan waktu konsolidasi tanah dan besarnya penurunan tanah di lokasi proyek. Analisis dilakukan dengan pendekatan analitis berdasarkan data uji tanah lapangan, seperti data boring log, data Standard Penetration Test (SPT), dan parameter tanah lainnya. Perhitungan dilakukan dengan menggunakan Teori Konsolidasi Satu Dimensi Terzaghi. Hasil penelitian menunjukkan bahwa metode preloading dapat mempercepat proses konsolidasi tanah hingga mencapai 90% konsolidasi dalam waktu 249 hari. Total penurunan yang diamati selama proses preloading adalah 65,246 cm. Temuan ini menunjukkan bahwa metode preloading efektif pada kondisi tanah lunak untuk meningkatkan stabilitas tanah sebelum fase konstruksi utama dimulai.

Kata Kunci: *Preloading, Konsolidasi Tanah, Penurunan, Jalan Tol Binjai-Pangkalan Berandan, Metode Perbaikan Tanah*

Abstract

Infrastructure development often faces challenges due to soft soil conditions, as encountered in the Binjai-Pangkalan Berandan Toll Road Construction Project at STA 38+825. Soft soil has low permeability, low bearing capacity, and a long consolidation period, making soil improvement necessary before construction. One commonly used method is preloading, which involves applying an initial load with temporary embankments to accelerate the soil consolidation process. This study aims to analyze the effect of the preloading method on the acceleration of soil consolidation time and the magnitude of soil settlement at the project site. The analysis was conducted using an analytical approach based on field soil test data, such as boring log data, Standard Penetration Test (SPT) data, and other soil parameters. The calculations were performed using Terzaghi's One-Dimensional Consolidation Theory. The results show that the preloading method can accelerate the soil consolidation process to achieve 90% consolidation in 249 days. The total settlement observed during the preloading process was 65.246 cm. These findings indicate that the preloading method is effective in soft soil conditions to improve soil stability before the main construction phase begins.

Keywords: *Preloading, Soil Consolidation, Settlement, Binjai-Pangkalan Berandan Toll Road, Soil Improvement Method*

INTRODUCTION

Infrastructure development, particularly in large-scale projects such as toll roads, often encounters challenges posed by soft soil conditions. These soils typically exhibit low bearing capacity, low permeability, and extended consolidation periods, all of which threaten the stability and serviceability of civil engineering structures. Such challenges are evident in the Binjai–Pangkalan Berandan Toll Road Construction Project at STA 38+825, where geotechnical investigations have revealed the presence of saturated, soft clay layers prone to significant settlement. If not addressed appropriately, these conditions can lead to excessive differential settlement, structural damage, and long-term maintenance issues.

One widely applied and effective method to mitigate the effects of soft soils is preloading, where temporary embankments or loads are applied to the ground surface to accelerate the consolidation process and improve soil strength before the construction of permanent structures. According to Bergado et al. (1996), preloading is especially effective when used in combination with prefabricated vertical drains (PVDs), which provide pathways for pore water to escape, significantly reducing the time required for consolidation.

Indraratna and Rujikiatkamjorn (2008) further explain that preloading induces overconsolidation in clayey soils, thereby increasing both stiffness and shear strength—two parameters that are essential in bearing heavy infrastructure loads. This enhancement is particularly useful in high embankment applications such as toll roads and airports.

Das (2006) notes that preloading is among the most economical and practical techniques for improving soft ground, especially in areas with thick clay deposits where deep foundations would be cost-prohibitive. However, Neville (1995) emphasizes that its effectiveness is highly dependent on time duration and the magnitude of the applied load, thus making real-time monitoring crucial to avoid premature or overextended loading phases.

An important variation of this technique, vacuum preloading, is highlighted by Gouw (2004) as beneficial in constrained environments where the construction of large embankments is not feasible. This method uses vacuum pressure to simulate loading and has been successfully implemented in many coastal infrastructure projects.

In terms of predictive modeling, Tan et al. (2018) emphasize the use of plane-strain numerical modeling to evaluate and optimize the performance of preloading systems, including surcharge height and PVD spacing. Supporting this, Jamsawang et al. (2016) demonstrated through 3D modeling that preloading not only reduces vertical settlement but also minimizes horizontal displacements, which is critical for maintaining embankment integrity during and after consolidation.

Indraratna et al. (2015) also underscore the value of field instrumentation, such as piezometers and settlement plates, in tracking pore water pressure dissipation and predicting U90 (90% consolidation) with high accuracy using both empirical and numerical approaches.

Historically, the U.S. Army Corps of Engineers (1983) has recommended preloading as a standard ground improvement technique for soft soils, citing its effectiveness in achieving long-term stability and reducing post-construction settlement. Similarly, Stamatopoulos and Kotzias (1985) reported that proper preloading modifies the stress history of the soil, thereby enhancing its future load-bearing performance and reducing settlement risks in service.

Given this background, the current study seeks to analyze the effectiveness of the preloading method in accelerating the consolidation process and determining the time required to achieve 90% consolidation at the STA 38+825 segment of the Binjai–Pangkalan Berandan Toll Road. This research focuses solely on the mechanical aspect of the preloading method without involving cost analysis, and the findings are intended to serve as practical references for similar geotechnical challenges in infrastructure development.

RESEARCH METHOD

Location and Research Map

The location chosen for this research is the Binjai - Pangkalan Berandan Toll Road Construction Project at STA 38 + 825, located in Binjai Regency, North Sumatra Province is one of the areas on the island of Sumatra. Where based on the results of field soil investigations in the form of sondir and boring tool test results, the location includes the type of soil and soil improvement is needed first before toll road construction. The construction location of the Binjai - Pangkalan Berandan Toll Road Development Project STA 38 + 825

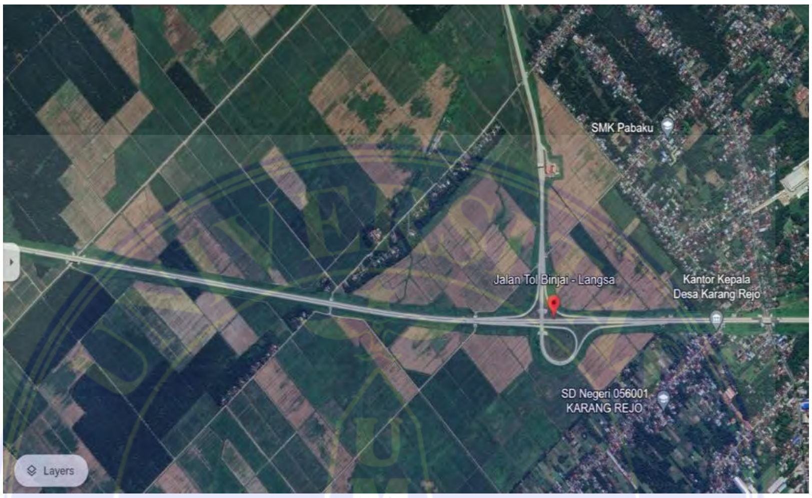

Figure 1. Research Location

Source : Google Earth,2024

Research Stage

In writing this Final Project, the author conducts several stages and implementation so as to achieve the purpose and objectives of the research as described in Chapter I, the purpose of writing this Final Project is to determine the speed of consolidation decline and stability problems that occur in the soil if repairs are made and after if repairs are made to accelerate so that the soil is able to withstand the load above it. By using the Preloading method, which is based on field testing data, and data processing. In achieving these objectives, the following stages are carried out:

1. First Stage : Collecting various types of literature in the form of books or scientific writings related to this Final Project.
2. Second Stage : At this stage, data collection is carried out from the results of soil investigations in the form of boring results on the ground and data on the specifications of the materials used. The data was obtained from PT Hutama Karya Infrastructure (Persero) Tbk.
3. Third Stage : Conduct analysis in accordance with the data obtained by PT.Hutama

Karya Infrastructure (Persero) Tbk and data obtained from interviews in the field based on reference sources (journals and books related to soil) related to the writing of the task

Research Thinking Framework

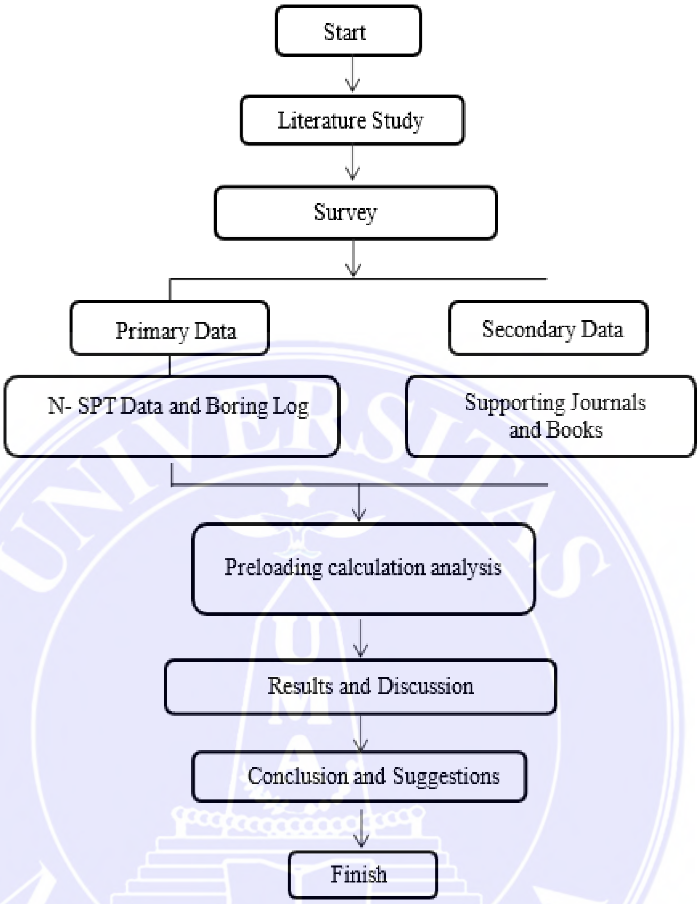

Figure 2. Framework of Thinking

Source : Researcher Data, 2024

RESULTS AND DISCUSSIONS

This section provides a comprehensive analysis of the rate of settlement, consolidation time, and the degree of consolidation for two layers of sandy loam soil at the STA 38+825 of the Binjai-Pangkalan Berandan Toll Road project.

1. Sandy Loam Layer (0–3 m)

For this upper soil layer, a 3-meter high embankment was constructed in three stages. The effective vertical stress (Po) was first determined using:

$Po = \gamma \times H$

$Po = 1.71 \times 1.5 = 2.565\ T/m^2$

Each stage added a 1-meter load increment, resulting in:

$\Delta p1 = 1 \times 1.5 = 1.5\ T/m^2$

$\Delta p2 = 2 \times 1.5 = 3.0\ T/m^2$

$\Delta p3 = 3 \times 1.5 = 4.5\ T/m^2$

Using Terzaghi's consolidation theory, the settlement (Sc) was calculated by:

$Sc = (Cc \times H \times \log((Po + \Delta P)/Po)) / (1 + e_0)$

With Cc = 0.326 and e_0 = 1.25, the first stage gave:

$Sc = (0.326 \times 3 \times \log((2.565 + 1.5)/2.565)) / (1 + 1.25) \approx 0.087\ m = 8.7\ cm$

The time factor (Tv) for 7 days (604800 s) with Cv = 0.0232 cm^2/s and Hdr = 150 cm:

$Tv = (t \times Cv) / Hdr^2 = (604800 \times 0.0232) / 150^2 \approx 0.6236$

Using the Tv-U relationship for U > 60%:

$Tv = 1.781 - 0.933 \log(100 - U\%)$

$0.6236 = 1.781 - 0.933 \log(100 - U\%) \rightarrow U \approx 82.61\%$

$St = 8.7 \times 0.8261 \approx 7.2\ cm$

For stage 2, the reduced thickness was 2.928 m, resulting in:

$Sc \approx 0.1427\ m = 14.27\ cm$

$Tv \approx 0.6547 \rightarrow U \approx 83.89\%$

$St = 14.27 \times 0.8389 \approx 11.97\ cm$

Cumulative settlement = 7.2 + 11.97 = 19.17 cm

For stage 3, thickness became 2.8083 m:

$Sc \approx 0.179\ m = 17.9\ cm$

$Tv \approx 0.7117 \rightarrow U \approx 86.00\%$

$St = 17.9 \times 0.8600 \approx 15.4\ cm$

Cumulative = 19.17 + 15.4 = 34.57 cm

By day 28 (Tv = 1.423), consolidation reached:

$U \approx 97.58\%$

$St = 17.9 \times 0.9758 \approx 17.46\ cm$

Final cumulative settlement = 36.63 cm

2. Sandy Loam Layer (3–17 m)

For the deeper soil layer, total effective pressure was calculated as:

$Po = (1.71 \times 3) + (1.45 \times 7) = 15.28\ T/m^2$

Preloading Δp values remained the same for all stages.

First layer (H = 14 m, e_0 = 1.87, Cc = 0.48):

Sc ≈ 0.0952 m = 9.52 cm

Tv ≈ 0.0263 → U ≈ 18.3%

St ≈ 1.74 cm

Second layer (H = 13.9826 m):

Sc ≈ 0.1821 m = 18.21 cm

Tv ≈ 0.0264 → U ≈ 18.34%

St ≈ 3.34 cm

Cumulative = 5.08 cm

Third layer (H = 13.9492 m):

Sc ≈ 0.2615 m = 26.15 cm

Tv ≈ 0.0265 → U ≈ 18.37%

St ≈ 4.803 cm

Cumulative = 9.88 cm

The settlement and degree of consolidation were monitored continuously. At day 28, U = 25.98% with a settlement of 11.88 cm. By day 84, U = 58.10%, and by day 112, U = 67.54% with cumulative settlement of 22.74 cm. Eventually, on day 252, consolidation reached 91.21%, and the total settlement reached 65.246 cm.

The preloading method significantly accelerated the soil consolidation process. The upper soil layer reached nearly full consolidation within 28 days, while the deeper layer required approximately 249 days to reach 90% consolidation without PVD, indicating the effectiveness of staged preloading as a stand-alone ground improvement technique.

The results above emphasize the contrast in consolidation behavior between the shallow and deeper sandy loam layers. The upper layer, with its shorter drainage path and higher permeability, responded rapidly to preloading and achieved nearly complete consolidation in under a month. In contrast, the deeper layer, with greater thickness and lower permeability, exhibited a prolonged consolidation timeline. The gradual increase in settlement over time highlights the importance of monitoring and maintaining preload for extended durations to achieve target consolidation levels. These findings underline the suitability of staged preloading as a cost-effective ground improvement method, particularly in projects where construction timelines can accommodate the natural progression of soil consolidation without the use of vertical drains.

These findings are in line with the principles outlined by Terzaghi (1943), who emphasized that the rate of consolidation is highly dependent on the coefficient of consolidation (Cv), the drainage path, and the magnitude of the applied load. The shallow layer's rapid consolidation is consistent with his theory, given the shorter drainage path (Hd) and favorable soil structure.

According to Mesri and Castro (1987), consolidation behavior is significantly influenced by soil compressibility (Cc) and initial void ratio (e_0). The results observed in this study reflect those dependencies, where a lower initial void ratio and higher compressibility in the upper layer resulted in more immediate settlement under applied loads.

Holtz and Kovacs (1981) also noted that preloading without vertical drains can still achieve significant improvement in soft soils, provided that sufficient time is allowed. The results from the deeper sandy loam layer confirm this view, as consolidation beyond 90% was attainable after prolonged monitoring and maintained surcharge.

In summary, the analysis is not only consistent with theoretical expectations but also reinforces established geotechnical understanding from experts in the field. The staged preloading method proved effective for both shallow and deep soft soil improvement, validating its application in similar ground conditions for infrastructure development.

CONCLUSION

Based on the results obtained in the previous chapter regarding the effect of the application of the *Preloading* method on the settlement time of soil consolidation on the Binjai- Pangkalan Brandan Toll Road Project. Then some conclusions can be drawn according to the formulation of this research problem as follows:

1. The time taken to achieve 90% consolidation using the *preloadinng* method is 249 days.
2. The amount of soil settlement that occurred using the *preloading* method lasting 249 days was 65.246 cm.

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