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Research Article

A Comparative Analysis of Cost Control and Performance Targets: A Case Study on Pile Foundation Installation in Swampy Area

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Abstract

Infrastructure development in Indonesia, particularly the construction of toll roads, continues to expand rapidly as part of the government's strategy to enhance regional connectivity and stimulate economic growth. One of the most ambitious projects is the Trans-Sumatra Toll Road, which stretches approximately 2,818 kilometers from Lampung to Aceh. A critical segment of this route, the Kayu Agung-Palembang-Betung Toll Road Phase II, Section 3, spans ±15.7 kilometers, with ±3.9 kilometers traversing swampy terrain. These swampy conditions pose significant engineering challenges, particularly in the installation of pile foundations, which are crucial for ensuring structural stability. This study aims to conduct a comparative analysis of two pile foundation installation methods used in swamp areas: the use of pontoon-mounted equipment and the use of temporary working platforms constructed from embankment fill. The analysis focuses on two key aspects cost efficiency and achievement of construction time targets. Findings indicate that the working platform method is superior in terms of both cost-effectiveness and time management. It also enables safer, more stable access for workers and supports overlapping construction activities, thereby improving overall efficiency. This research highlights the importance of selecting the appropriate foundation method based on geotechnical conditions and logistical constraints. The results are expected to inform future best practices for infrastructure development in challenging environments such as swamps.

Keywords: *Cost Control; Pile Foundation; Swamp Area; Working Platform*

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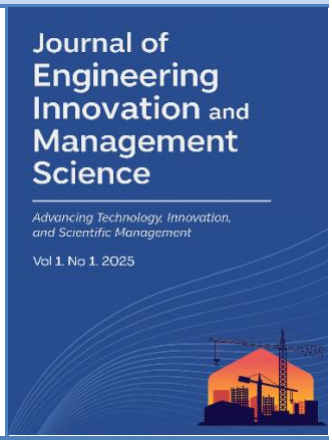

INTRODUCTION

The rapid development of transportation infrastructure in Indonesia, particularly toll roads, reflects the government's commitment to enhancing connectivity and regional economic growth (Endo et al., 2020; Sandee, 2016). The Trans-Sumatra Toll Road, with a planned length of 2,818 kilometers, is one of the strategic projects aimed at linking major cities across Sumatra Island, from Lampung to Aceh. Among the completed sections is the Bakauheni–Terbanggi Besar segment, inaugurated in 2019. Following the completion of this segment, construction moved forward to the Kayu Agung-Palembang-Betung Toll Road Project, Phase II, Section 3. This section covers a length of about 15.7 kilometers. Approximately 11.8 kilometers lie on dry land, while the remaining 3.9 kilometers traverse swampy terrain. These varying soil conditions pose unique engineering and logistical challenges. Pile installation is commonly carried out using either the drop hammer method or the jacked piling system until the pile reaches the hard soil layer. However, several challenges are encountered in the field, particularly related to soil conditions. Soft soil, former swamp areas, or backfilled land can significantly hinder the pile driving process. In the Kayu Agung–Palembang–Betung Toll Road Phase II, Section 3, approximately 3.9 kilometers of the segment pass through swampy areas. These conditions present considerable difficulties during the foundation installation stage, as illustrated in the **Figure 1** below:

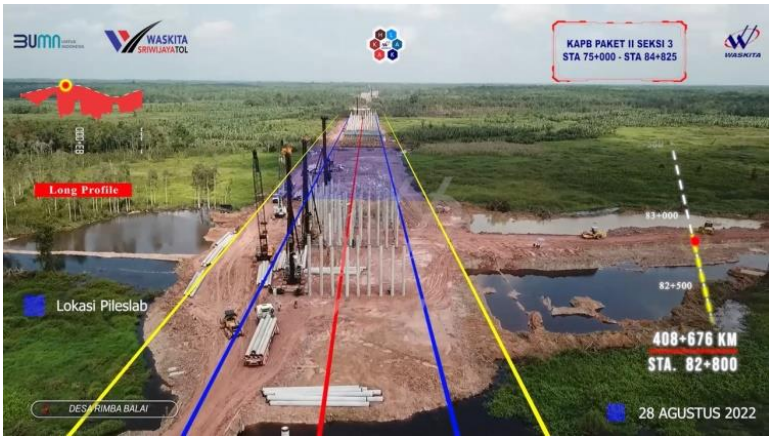

Figure 1. Swamp area at STA. 82+800 of the Kayu Agung–Palembang–Betung Toll Road Phase II, Section 3.

In construction projects involving swampy terrain, the choice of foundation method is critical due to poor soil bearing capacity and limited accessibility. As (Karami et al., 2020) emphasized, infrastructure performance is highly influenced by the selection of appropriate construction materials and techniques, especially in environments with challenging geotechnical conditions such as swamps. Pile foundations are commonly used to transfer structural loads to deeper, more stable soil layers (Dutta & Nanda, 2022; Kennedy & Udo, 2024). However, installation in wet and unstable conditions often requires specialized approaches. Two commonly used methods are pile installation using pontoon-mounted equipment and the construction of temporary working platforms through land embankment (Daryaei et al., 2020; Monteiro et al., 2021). Each method presents unique advantages and limitations in terms of cost, time,

and efficiency (*Advantages and limitations of utility assessment methods in rheumatoid arthritis.*, 2007; Möller, 2011). An effective foundation solution must be tailored to site conditions and project constraints. Thorough planning is essential to avoid structural failures, particularly in regions with highly saturated soils. These challenges must be considered from both technical and financial perspectives.

Simultaneously, time and cost efficiency are essential in the successful execution of large-scale infrastructure projects(Kassem et al., 2020; Umar et al., 2024). Contractors must develop acceleration strategies, particularly for sections of land that are already free from administrative and land acquisition barriers (Sharma & Trivedi, 2023). In this context, integrated cost control and scheduling tools—such as bar charts, S-curves, and network planning are employed to ensure that the project meets deadlines without compromising quality (Wang et al., 2016). Moreover, the selected construction method must allow for overlapping tasks and safe access for workers in swamp areas. These considerations make the foundation method not only a structural issue but also a key factor in project management performance. Efficient decision-making depends on accurate cost estimation, execution timing, and adaptation to site specific risks. These aspects are interrelated in achieving overall project success. Therefore, evaluation of construction methods should be comprehensive, and evidence based.

While previous studies have examined pile foundation behavior in soft soils and various equipment technologies, few have conducted comparative analyses focusing specifically on swamp areas in toll road projects. There is limited empirical evidence evaluating the performance of pontoon-based pile driving versus platform-based installation under similar site conditions. Moreover, existing studies tend to focus either on geotechnical performance or cost implications, but rarely integrate both dimensions with construction timeline considerations. This gap limits decision-makers in choosing the most appropriate, cost-effective, and time efficient method for foundation installation in swampy terrains. This study aims to analyze and compare the effectiveness of two pile foundation installation methods pontoon-mounted equipment and working platform construction within the context of the Kayu Agung Palembang Betung Toll Road Phase II, Section 3. The comparison focuses on cost control and achievement of project time targets. The results are expected to inform best practices in foundation construction for swamp environments, contributing to more efficient planning and execution of similar infrastructure projects in the future.

METHODS

The implementation of pile foundation works in both dry land and swamp areas involves a set of critical variables that influence project efficiency, cost, and time performance. These variables include, but are not limited to, the duration of pile installation activities, the cost implications of embankment soil procurement, and the time and cost required to mobilize and reposition pontoon equipment between pile driving points. One notable constraint identified in swamp-based pile driving operations is the extended repositioning time of pontoon equipment, which may take up to 2.5 hours for each movement. Furthermore, insufficient deployment of construction machinery in such areas has been observed to negatively impact productivity, causing delays and deviations from the planned schedule.

Given these site-specific challenges, a thorough and methodical analysis of influencing factors is essential to ensure that the execution of works remains aligned with the project's time schedule and cost projections. This analysis should incorporate a detailed review of the construction sequence, as the optimization of work phases can allow for overlapping tasks, thereby reducing idle time and minimizing indirect costs. By integrating these considerations into project planning, it becomes possible to enhance resource utilization, improve scheduling accuracy, and achieve greater cost-effectiveness in foundation construction, particularly in challenging swamp terrains.

RESULT AND DISCUSSIONS

Implementation Analysis of Pile Foundation Work in Swamp Areas on the Kayu Agung–Palembang–Betung Toll Road Phase II Section 3

The analysis of pile foundation installation in swamp areas along the Kayu Agung Palembang Betung Toll Road Phase II Section 3 was conducted by comparing two methods: installation using pontoon vessels and installation using a platform created from embankment fill. The comparison considered aspects such as execution time, total cost, and practical feasibility in field conditions. One of the key considerations is the road alignment, which requires specific construction strategies. An example of platform construction activity prior to pile foundation installation is shown in **Figure 2**.

Figure 2. **Embankment placement for platform construction before pile foundation installation.**

Table 1. Unit Price Analysis of Pile Foundation Installation in Swamp Areas Using Pontoon Equipment

No	Work Description	Unit	Quantity	Unit Price (Rp)	Total Cost (Rp)
A	Labor				
	Foreman	Hour	0,2146	16.250	3.487,25
	Skilled Worker	Hour	0,8586	15.000	12.879,00
	General Worker	Hour	2,5757	13.750	35.415,88
B	Materials				
	Welding Rods	Kg	0,4167	44.370	18.488,98
	Joint Coating	M^2	0,0837	50.000	4.186,67
	3 mm Joint Plate	Kg	0,8000	12.000	9.600,00

C	Equipment				
	Pontoon + Engine	Hour	0,2146	450.000	96.570,00
	Crane	Hour	0,1465	350.000	51.275,00
	Diesel Vibro Hammer	Hour	0,1583	650.000	102.895,00
	Generator set	Hour	0,02583	150.000	23.745,00
	Welding Set	Hour	0,0358	50.000	1.790,00
	Auxilliary Equipment	Ls	1,00	10.000	10.000,00
		Total			370.332,77

Source: *Unit Price Analysis*

Table 2. Total Cost of Pile Installation Using Pontoon Equipment in Swamp Areas

Installation of Pretensioned Circular Reinforced Concrete Piles in Swamp Areas, Diameter 60 cm	**Coef**	**Unit**	**Volume**	**Unit Price**	**Total (Rp)**
Material					
Concrete (fc' 30 MPa)	0.03	m^3	2,751.23	1,130,580.00	3,110,489,559.42
Labor					
Precasr beam Installation	0.08	Point	8,761.89	250,000.00	2,190,472,524.09
Subcontract					
Pontoon Based Pile Driving	1.00	m	105,142.68	370,332.77	38,937,780,427.98
Platform Fill (Include for accees or mobilization area)	1.00	m^3	105,142.68	53,927.28	5,670,059,287.98
Total Project Cost					49,908,801,799.46
Cost per linear meter					474,676.90

From the above calculation, it is determined that the pile foundation installation using pontoon equipment results in a cost of Rp 474,676.90 per linear meter, based on field unit price analysis. When compared with self-managed (direct hire) methods, the subcontract unit cost tends to be higher. In full-slab toll road projects, using a platform is often preferred since the fill serves not only for pile work but also as an access road for other construction activities, facilitating overlapping tasks. The sequence of work (shown below) supports indirect cost efficiency:

a. Platform embankment

b. Pile installation

c. Pile head work

d. Full slab erection

The details of pile installation using platforms are presented in Table 3.

Table 3. Total Cost of Pile Foundation Installation Using Platform

Installation of Pretensioned Circular Reinforced Concrete Piles in Swamp Areas, Diameter 60 cm	**Coef.**	**Unit**	**Volume**	**Unit Price**	**Total (Rp)**
Material					
Concrete (fc' 30 MPa)	0.03	M3	2,751.23	1,130,580.00	3,110,489,559.42

Labor					
Precasr beam Installation	0.08	Point	8,761.89	250,000.00	2,190,472,524.09
Subcontract					
Pile Driving (Platform Method)	1.00	M	105,142.68	141,932.29	14,923,141,273.60
Platform Fill	5.20	M3	382,719.36	61,283.28	23,454,298,498.41
Total Project Cost					**43,678,401,855.52**
Cost per linear meter					**415,420.28**

Thus, the unit cost of pile foundation installation using platform-based methods amounts to **Rp 415,420.28 per linear meter**, which is lower than the pontoon method.

Figure 3. Pile Foundation Installation in Progress Using Platform Method

Field implementation challenges often arise when project teams focus primarily on major work items with significant weight in the work breakdown structure, resulting in delays to smaller, minor work items that often require more time than anticipated. Early recognition of this issue is essential to ensure timely execution of all project components.

Work Sequence and Remaining Volumes

1. **Platform Embankment**
   - Remaining volume: 59,500 m³
   - Production capacity (2 sets of equipment): 942 m³/day
   - Duration needed: 32 days
2. **Pile Installation**
   - Remaining volume: 670 points
   - Production capacity (3 sets): 10 points/day
   - Duration needed: 23 days
3. **Pile Head Work**
   - Remaining volume: 67 grids

- 1 grid completed by 1 foreman group in 4 days
- Duration needed (6 groups): 45 days

4. **Full Slab Erection**
   - Remaining volume: 670 slabs
   - Crane capacity: 10 slabs/day
   - Duration needed (3 sets): 23 days

Discussion

This study demonstrates that the choice of pile foundation installation method significantly affects the efficiency of construction projects, particularly in swampy areas characterized by low soil bearing capacity and limited accessibility. The analysis indicates that the use of a working platform yields a lower cost per linear meter compared to the pontoon method. Furthermore, the platform method allows for overlapping tasks, which contributes to reduced construction time. The provision of safer and more stable access to the site also enhances on-site productivity and occupational safety. The efficiency gained through this method positively influences not only a single stage of construction but also the overall management of resources and scheduling. These findings emphasize the importance of selecting construction methods that are responsive to site-specific conditions in order to achieve optimal project outcomes. The urgency of this research stems from the strategic need to develop sustainable infrastructure in regions with challenging geotechnical conditions, such as swamps. Although various foundation technologies have been widely implemented, few empirical studies have provided a direct comparison between platform-based and pontoon-based approaches in swamp environments. This study contributes to addressing that gap by offering field-based data and comprehensive analysis to support technical decision-making in similar projects. As toll road development continues to expand across Indonesia, the results of this research are expected to provide valuable insights for planners, contractors, and stakeholders in selecting efficient and context-appropriate construction methods.

Implication

The findings of this study present significant implications for the planning and execution of infrastructure projects in swampy areas, where geotechnical limitations often pose considerable challenges. The demonstrated advantages of using working platforms—particularly in terms of reduced costs and shortened construction time—indicate that method selection should be based not solely on structural requirements but also on overall project efficiency and adaptability to site conditions. By enabling safer access, smoother logistics, and simultaneous task execution, the platform method offers a strategic solution that enhances project performance in difficult terrains. This insight can serve as a guiding reference for construction professionals seeking practical and cost-effective alternatives in similar environments. Furthermore, the outcomes of this research contribute to the broader discourse on infrastructure development by emphasizing the value of evidence-based decision-making. Project stakeholders, including planners, contractors, and regulatory bodies, are encouraged to integrate empirical analysis into their feasibility assessments

and technical planning processes. Adopting such an approach ensures that selected construction methods align with both technical demands and contextual realities on the ground. As infrastructure expansion continues in regions with complex land conditions, these findings support the need for adaptive construction strategies that promote not only efficiency but also resilience and sustainability across diverse project settings.

Limitation and Suggestion for Further Research

While this study offers valuable insights into the comparative efficiency of pontoon-based and platform-based pile installation methods in swampy areas, it is important to recognize certain limitations that may influence the scope of its applicability. The research was conducted within the context of a specific infrastructure project, focusing on a single geographic segment with particular soil and environmental conditions. As a result, the findings may not fully reflect the variability encountered in other regions with different geotechnical characteristics or logistical challenges. Moreover, the study concentrated primarily on cost and time performance, without incorporating broader dimensions such as environmental impact, occupational safety considerations, or long-term structural behavior under operational loads. To enhance the applicability and comprehensiveness of future studies, further research is recommended to include a wider range of project sites and to examine additional factors that influence construction performance. Incorporating environmental sustainability indicators, such as soil disturbance, material waste, and emissions, would provide a more holistic understanding of the implications of each method. In addition, long-term performance monitoring and the application of predictive modeling tools could help assess the durability and risk profiles of different foundation techniques. Such expanded research efforts would contribute significantly to the development of more adaptive, cost-effective, and sustainable engineering practices, particularly in complex and environmentally sensitive terrain.

CONCLUSION

Based on the analysis conducted, the installation of pile foundations using a platform is more effective in terms of both execution time and construction cost compared to installation using pontoon equipment. The cost analysis shows that the unit price per meter for pile foundation work using pontoons amounts to Rp 474,767.90, while the cost for pile foundation work using a platform is Rp 415,420.28. This results in a cost differedarince of Rp 59,257 per meter. The effectiveness of the platform method is further supported by the site conditions, as the toll road alignment crosses swamp areas that pose significant challenges for pontoon-based operations. Additionally, the use of a platform provides access for other concurrent construction activities, allowing for overlapping tasks and improving overall project efficiency.

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AUTHORS CONTIBUTIONS STATEMENT

All authors made substantial contributions to the conception, design, and execution of the research. Ridwan M. Abduh led the conceptual framework, coordinated field data collection, performed technical and cost analysis, and drafted the initial manuscript. Ratna Widyawati contributed to the development of the research methodology, conducted a comprehensive literature review, and provided analysis on construction scheduling and sequencing. Arief Andriansyah was responsible for data validation, visualization (figures and tables), and contributed to the interpretation of field findings. All authors critically reviewed, edited, and approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. All contributions were conducted independently and without any financial, commercial, or institutional influence that could be perceived as a potential conflict. The research was carried out solely for academic and professional purposes.

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