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Implementing Innovative Strategies for Sustainable Infrastructure Development in Soft Soil Conditions: A Case Study in Kalimantan

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Infrastructure development on soft soil conditions in Kalimantan faces major challenges, including low soil bearing capacity, high technical risks, and construction cost overruns. These conditions require adaptive technical solutions combined with effective management strategies to ensure sustainable project delivery. This study examines an innovative approach integrating risk management, value engineering (VE), and Hydraulic Static Pile Driver (HSPD) technology to enhance cost and time performance in soft soil infrastructure projects. A case study was conducted on the construction of the Kapuas District Head Office Hall in Central Kalimantan, which utilized 30 × 30 cm minipile foundations installed to a depth of 24 meters using an 80-ton HSPD system. A descriptive-comparative analysis was applied through four stages: project risk assessment using a probability–impact matrix; cost analysis based on changes in the Cost Budget Plan (RAB); evaluation of HSPD performance compared to conventional hammer piling; and application of value engineering through function-to-cost ratio analysis. The results indicate that the integrated strategy achieved approximately 11% cost efficiency without compromising construction quality while improving schedule performance. The findings demonstrate that combining technological innovation and structured management strategies supports sustainable infrastructure development in soft soil regions of Kalimantan.

Keywords: innovative strategy, risk management, soft soil, sustainable infrastructure

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Introduction

Infrastructure development in areas with soft soil conditions, such as in Kalimantan, faces significant challenges, including low soil bearing capacity, potential cost overruns, and high technical risks. Soft soils, such as peat, have unique characteristics, including low shear strength, high compressibility, and long-term consolidation that can lead to differential settlement if not properly managed (Mesri & Ajlouni, 2007; Mohamad et al., 2021; Kolay & Rahman, 2016). Therefore, appropriate planning strategies are needed to address these geotechnical challenges, particularly in the design of foundations.

As part of Indonesia, which has one of the largest tropical peatlands in the world, covering approximately 20.6 million hectares (±206,950 km²), Kalimantan is one of the regions most affected by these soft soil conditions. However, much of this peatland has experienced degradation (Warren et al., 2017). This land degradation further increases uncertainty in the planning and execution of infrastructure construction, necessitating innovative approaches in construction to ensure project sustainability (Page et al., 2011).

To overcome these challenges, soil improvement techniques, such as the use of prefabricated vertical drains (PVD) combined with preloading vacuum, have proven effective in accelerating soil consolidation and improving shear strength (Indraratna et al., 2012; Amanda, Febrianty, & Rahman, 2018). However, in addition to soil improvement, innovative construction management also plays a vital role in mitigating the cost and time risks commonly encountered in soft soil projects.

In this context, this research focuses on the implementation of innovative strategies that integrate risk management, cost efficiency, and the use of environmentally friendly construction technologies, such as the Hydraulic Static Pile Driver (HSPD), which offers advantages in terms of minimal vibration and noise compared to conventional pile driving methods (White et al., 2002; Ishihara, 2018). By combining value

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engineering and this technology, this research aims to enhance cost and time efficiency while supporting environmental sustainability in infrastructure development on soft soils.

This study was conducted on the construction project of the Kapuas District Head Office Hall Building in Central Kalimantan, which uses 30x30 cm minipile foundations with a depth of 24 meters, driven using HSPD 80-ton technology. This project serves as a case study to analyze the implementation of innovative strategies in managing risk, cost, and time, as well as to evaluate the effectiveness of the technology in creating sustainable infrastructure.

Methodology

This study uses a qualitative-descriptive approach with a case study strategy. The case study approach is selected because it allows for a comprehensive understanding of the implementation of innovative strategies in infrastructure development that faces geotechnical challenges in soft soil conditions in Kalimantan.

The case study approach is utilized to explore contemporary phenomena in real-world settings where the boundaries between the phenomenon and the context are not clearly defined (Robert K. Yin, 2003; Lendra, Jesica & Febrianty, 2025; Febrianty et al., 2025). The research focuses on the construction of the Kapuas District Head Office Hall Building in Central Kalimantan, which represents an infrastructure project on soft soil with high technical and managerial complexity.

The descriptive approach is used to explain the field conditions, risk factors, and cost dynamics that occur during project implementation. The combination of both approaches allows the researcher to systematically explain the application of value engineering (VE) and Hydraulic Static Pile Driver (HSPD) technology as cost-efficiency strategies and environmentally friendly technologies.

The stages of this research include:

1. Risk Identification: Risks are classified into technical, cost, time, and environmental categories using document analysis and field observations.
2. Cost Comparison Analysis: Evaluating the budget dynamics (initial RAB of IDR 37.9 billion, revised to IDR 42.8 billion, and finally achieving efficiency to IDR 38.0 billion) to determine the main factors contributing to cost overruns and potential savings opportunities.
3. Construction Technology Evaluation: Comparing the performance of the HSPD method with conventional hammer pile driving in terms of energy efficiency, vibration, and environmental impact.
4. Value Engineering Application: Evaluating the function-to-cost ratio of each work item to optimize costs without compromising quality.
5. Validation: The results are validated through expert judgment from construction management and geotechnical experts to ensure the practical applicability of the findings for soft soil projects.

Expert Panel

An expert panel was consulted to validate the findings and ensure the results are grounded in practical and expert-based knowledge. The panel consists of professionals with significant experience in geotechnical engineering and construction management (Table 1).

Table 1 Expert Panel

Panel Expert	Latest Education	Institution/ Company	Position	Experience (Years)
1	PhD	University A	Geotechnical Lecturer	36
2	Master's Degree	Construction Company B	Director	20
3	Master's Degree	Construction Company C	General Manager	20
4	PhD	Construction Company D	Director	21
5	Bachelor's Degree	Construction Company E	Director	25

Data Types and Sources

The data for this research consists of both primary and secondary data:

1. Primary Data: Limited field observations and interviews with design consultants and construction service providers to gather information on foundation work, technical constraints, and risk management strategies.
2. Secondary Data: Includes planning documents, technical justification documents, project budget estimates (RAB), specifications for the heavy equipment used (HSPD 80 ton), and unit cost standards for construction work in 2024/2025.

Data Collection Instruments and Techniques

The instruments and techniques for data collection include:

1. Interview Instrument: A semi-structured questionnaire designed to gather information on technical aspects, risk management, and cost-efficiency practices.
2. Observation Instrument: A technical note sheet to document the foundation work on-site.
3. Documentation Instrument: Project RAB, construction drawings, and technical reports on the foundation work.
4. Triangulation Technique: A combination of interviews, observations, and document reviews to enhance the validity of the findings.

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Data Analysis Techniques

The analysis follows these main steps:

1. Risk Identification: Classifying project risks into technical, cost, time, and environmental categories. Analyzing the potential impact and likelihood of risks based on project documents and expert interviews.
2. Cost Comparison Analysis: Comparing the dynamics of the initial RAB (IDR 37.9 billion), revised RAB (IDR 42.8 billion), and the final efficient RAB (IDR 38.0 billion). Identifying new cost items and eliminating non-essential items to achieve cost savings.
3. Construction Technology Evaluation: Analyzing the use of HSPD 80 ton as an innovative pile driving method that minimizes vibration and environmental impact. This is compared with conventional hammer piling in terms of technical, social, and environmental aspects.
4. Value Engineering Application: Using the value engineering process to evaluate the cost efficiency of each work item. Identifying essential functions and eliminating non-value-adding activities to optimize project costs.
5. Validation: Results are validated through expert judgment, involving construction management consultants, contractors, and academic experts to ensure that the proposed strategies are applicable and practical for soft soil projects.

Location of Study

The case study for this research was conducted on the Kapuas District Head Office Hall Building in Central Kalimantan. This location represents an infrastructure project built on soft soil. The site is illustrated in Figure 1.

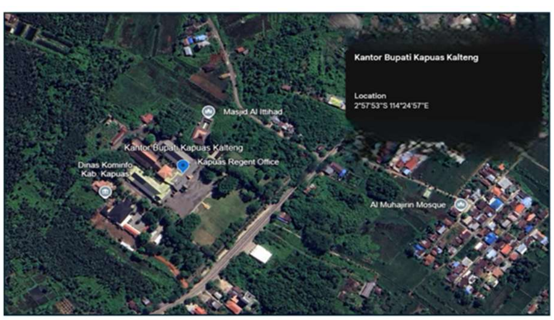

Figure 1 Location of the Kapuas District Head Office Hall Building in Central Kalimantan.

Results and Discussion

The results of this study, derived from document analysis, construction cost data, and the evaluation of foundation technologies used in the Kapuas District Head Office Hall Building project in Central Kalimantan, focus on four main aspects: risk identification, budget dynamics, construction technology evaluation, and cost-efficiency strategies through value engineering.

Identification of Key Risks

The risks encountered in this project can be classified into four main categories: technical, cost, time, and environmental (Table 2). The key technical risk is the low bearing capacity of the soft soil, which can cause differential settlement and structural cracking (Mesri & Ajlouni, 2007; Mohamad et al., 2021). To mitigate this, the use of minipile foundations and HSPD technology was implemented. Additionally, the installation of piles requires precision, and any failure in pile connections could reduce the foundation's capacity.

Table 2 Risk Identification and Mitigation Strategies in the Kapuas District Head Office Hall Project

Risk Category	Risk Factor	Main Impact	Mitigation Strategy
Technical	Low bearing capacity	Differential settlement, structural cracking	Minipile foundations (24 m depth), HSPD technology
Technical	Pile connection and installation	Reduced foundation capacity	Pile integrity testing, strict supervision
Cost	Escalating material prices	Increase in RAB from IDR 37.9B to IDR 42.8B	Value engineering (VE), unit price evaluation, purchase control
Cost	Additional work	RAB exceeds the budget	Eliminate non-essential items, design efficiency
Time	Heavy equipment mobilization	Delayed schedule	Adaptive scheduling, logistical coordination
Time	Extreme weather	Delay, rework	Buffer time, temporary drainage
Environmental	Pile driving vibration and noise	Social disturbance, potential conflict	HSPD/press-in piling
Environmental	Site space conflicts	Community rejection, additional costs	Re-plan site facilities, coordinate with local authorities

The findings confirm that the project faced a range of interrelated risks. The HSPD method was particularly effective in minimizing environmental impact, as it significantly reduced noise and vibrations compared to conventional hammer piling methods (White et al., 2002; Ishihara, 2018).

Budget Comparison Analysis

The budget analysis revealed a significant fluctuation in the project's budget estimate (Figure 2). Initially, the estimated budget was IDR 37.9 billion, which was later revised to IDR 42.8 billion due to changes in design and material price increases. However, after applying value engineering techniques, the final RAB was reduced to

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IDR 38.0 billion, representing a cost savings of approximately 11%.

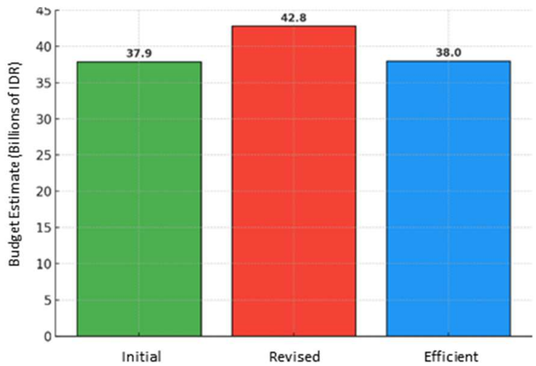

Figure 2 Comparison of the initial, revised, and efficient budget estimates in billions of IDR.

The increase in costs was primarily due to the addition of items such as geotextile, sand backfilling, and worker facilities (e.g., mess and material storage). Through value engineering, non-essential items were eliminated, resulting in significant cost savings without compromising the essential functionality of the building.

Construction Technology Evaluation

The use of HSPD technology for pile driving was evaluated against the conventional hammer method. The evaluation focused on several factors including technical performance, cost efficiency, and environmental impact (Table 3).

The HSPD method offered significant advantages, including a faster pile installation rate, lower environmental impact (minimal noise and vibration), and better suitability for soft soil conditions. The total cost using HSPD was IDR 1.84 billion, compared to IDR 2.05 billion with the conventional hammer method, providing a savings of 9-12%. Moreover, the risk of rework was minimized with HSPD, reducing downtime and improving overall project efficiency.

Cost Efficiency through Value Engineering

The application of Value Engineering (VE) in this project focused on identifying work components with high costs but low contribution to primary building function, and then proposing alternatives that preserve essential performance while reducing expenditures. Following the VE framework recommended by SAVE International (2015), the study categorized items into primary and secondary functions and prioritized cost reduction on components that do not significantly affect structural integrity or core service delivery.

As summarized in Table 4, the cost-saving measures were concentrated in three groups: secondary architectural works (mainly landscaping), operational support facilities, and minor structural components. The largest savings were achieved by optimizing temporary/auxiliary facilities (e.g., reducing permanent facilities into modular or rental-based solutions), which contributed approximately IDR 2.0 billion in savings. Additional savings were obtained by eliminating or reducing landscaping-related items that were considered non-essential to the building's primary function (about IDR 1.1 billion), and by optimizing minor structural components through redesign and work-sequencing adjustments (about IDR 1.7 billion).

Table 3 Comparison of Initial, Revised, and Efficient Budget Estimates (RAB) for the Kapuas District Head Office Hall Project

Aspect	HSPD (Hydraulic Static Pile Driver)	Conventional Hammer Pile Driver
Working Principle	Static press-in (hydraulic press-in)	Dynamic hammer impact (drop hammer)
Pile Capacity	±75 tons per point	±60 tons per point
Average Penetration Rate	4–5 meters per hour	2.5–3 meters per hour
Vibration and Noise	Low (60–65 dB)	High (>90 dB)
Total Cost (estimated)	±IDR 1.84 billion	±IDR 2.05 billion
Cost Efficiency Potential	9–12%	—
Risk of Rework	Low	High
Environmental Impact	Low (environmentally friendly)	High (social disturbance)
Suitability for Soft Soil	Very good	Limited

Table 4 Value Engineering Cost Reduction by Work Component

Work Component	Function	Cost Reduction (IDR)
Secondary Architectural Work	Landscaping (paving blocks, pots, etc.)	IDR 1.1 billion
Operational Support Facilities	Material storage, worker mess, permanent generator	IDR 2.0 billion
Minor Structural Components	Additional beams, geotextile layers	IDR 1.7 billion

Overall, the distribution of savings in Table 4 indicates that VE in this case did not merely "cut costs," but reallocated resources toward value-generating components, consistent with the value-for-money logic in construction decision-making (Shen & Liu, 2003; Wao, 2015). The findings also align with recent studies emphasizing that VE becomes more effective when it is positioned as a systematic decision process, rather than ad-hoc budget trimming, particularly under uncertainty and design changes (Gouda Mohamed et al., 2024; Abdel-Razek et al., 2024).

Discussion

The findings of this study indicate that infrastructure development on soft soil in Kalimantan involves interrelated multidimensional risks, encompassing technical, financial, temporal, and environmental aspects. The primary technical risks, namely low bearing capacity and pile connection quality, directly affect the potential for differential settlement and structural cracking. These findings are consistent with Mesri and Ajlouni (2007) and Wani and Mir (2019), who emphasize that tropical peat soils exhibit high compressibility and low shear strength, necessitating adaptive foundation systems such as press-in piling using Hydraulic Static Pile Driver (HSPD) technology.

The selection of HSPD in this project reinforces the arguments of White et al. (2002) and Ishihara (2018), who demonstrate that press-in piling methods significantly reduce vibration and noise levels, maintaining them below approximately 65 dB, compared to impact hammer systems that may exceed 90 dB. This technological choice is particularly relevant in environmentally sensitive and urban-adjacent areas, thereby aligning with the principles of sustainable infrastructure development in soft soil regions such as Kalimantan.

From an economic perspective, the study identified a substantial budget escalation in the project's Cost Budget Plan (RAB), increasing from IDR 37.9 billion to IDR 42.8 billion before being reduced to IDR 38.0 billion through the implementation of value engineering. This pattern confirms previous findings by Cantarelli et al. (2010), Kazemi et al. (2023), and Eliasson (2025), which indicate that infrastructure cost overruns are commonly driven by material price escalation, design modifications, and insufficient early-stage cost control. The results further support the value engineering literature applied in infrastructure contexts (Shen and Liu, 2003; Wao, 2015; Gouda Mohamed et al., 2024).

The implementation of value engineering in this case supports the theoretical framework proposed by Shen and Liu (2003), which stresses that successful value management depends on the project team's ability to accurately distinguish between primary and secondary functions. In the Kapuas District Hall project, value engineering was implemented by preserving core structural functions, such as foundation systems and roof framing, while eliminating secondary components such as paving blocks, decorative landscaping elements, and permanent generator installations that did not significantly contribute to operational performance.

The resulting efficiency of approximately 11% of the revised RAB demonstrates that value engineering is not merely a cost-cutting mechanism but rather a function optimization strategy aligned with the value-for-money (VfM) principle. This finding reinforces the conclusions of Wao (2015) and Gouda Mohamed et al. (2024), which suggest that value engineering becomes more effective when integrated with Building Information Modelling (BIM) for simultaneous cost–function analysis.

The application of 4D BIM played a critical role in visualizing the time and cost implications of design modifications in real time. This observation aligns with Bryde et al. (2013) and Wang et al. (2024), who demonstrate that BIM integration enhances project coordination and can reduce rework risks by up to 30%. Through digital visualization and scheduling simulations, design adjustments and logistical planning were managed more effectively.

From a time-management perspective, schedule deviations caused by extreme weather and heavy equipment mobilization were estimated at 20–25 days. However, mitigation strategies such as buffer time allocation and adaptive scheduling reduced the final deviation to below 10% of the total project duration. This supports Whitlock et al. (2021), who argue that 4D BIM scheduling improves logistical management and project control under geographically challenging conditions.

Moreover, the integration of value engineering and HSPD technology generated social and ecological benefits. Reduced noise levels and the elimination of non-essential work components not only improved cost efficiency but also minimized community disturbances. These findings are consistent with Afolabi et al. (2024), who highlight the importance of low-disruption construction strategies in delivering sustainable infrastructure projects.

Overall, this study strengthens the theoretical position of Shen and Liu (2003) and SAVE International (2015), which assert that value engineering achieves optimal results when embedded within an integrated construction management system that incorporates digital technology and structured risk control. The combined application of Value Engineering (VE), BIM, HSPD technology, and Risk Management constitutes an innovative strategy that enhances cost efficiency, time performance, and environmental sustainability. This integrated framework offers a replicable model for adaptive and sustainable infrastructure development in soft soil regions such as Kalimantan.

Conclusion

This study demonstrates that the integration of risk management, value engineering (VE), and Hydraulic Static Pile Driver (HSPD) technology effectively reduces cost and time deviations without compromising construction quality. The implemented strategy resulted in approximately 11% cost efficiency from the revised project budget while maintaining structural performance in accordance with technical standards.

The combined approach proved effective in supporting sustainable infrastructure development in soft soil regions of Kalimantan by balancing three essential dimensions: functional performance, cost efficiency, and environmental sustainability. Based on the case study findings, the integration of technological innovation and structured management strategies represents a viable model for infrastructure projects constructed on geotechnically challenging soils.

Practical Implications

The findings provide practical contributions to construction management practices in regions with similar geotechnical conditions. The application of value engineering and HSPD technology is recommended for public buildings, bridges, and government infrastructure projects constructed on soft soil, as these approaches reduce vibration risks, schedule delays, and cost inefficiencies.

From a managerial perspective, the results emphasize the importance of collaboration among design consultants, contractors, and project supervisors in integrating value engineering and 4D BIM from the early planning stage. Such integration enables transparent forecasting of cost and schedule revisions and enhances proactive risk control throughout project implementation.

Recommendations for Future Research

Future studies are recommended to develop and test BIM 5D-based digital models integrating cost–time–performance analysis simultaneously to improve project estimation accuracy and risk prediction across various soft soil structures in Indonesia.

Further research may also explore the development of a Knowledge Risk Management (KRM) model to systematically document the implementation experiences of value engineering (VE) and HSPD technology in infrastructure projects. The integration of KRM with BIM 5D platforms is expected to generate a dynamic, cross-project national knowledge base that supports data-driven decision-making, reduces cost and schedule deviations, and strengthens transparency in sustainable project management.

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