Analysis of Implementation Methods and Effectiveness of Industrial Waste Utilization for Soil Stabilization in Local Roads

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ABSTRACT

Soil stabilization using additives is a method for enhancing the mechanical properties of soil. Previous studies have demonstrated that fly ash and rice husk ash can improve soil characteristics. However, these studies often occur only in laboratory settings. This research aims to directly evaluate the implementation methods and cost estimates. In this study, the percentages of fly ash used as an additive in the mixture were 15%, 20%, and 25% of the dry weight of the original soil, while the percentage of rice husk ash used was 5% of the soil's dry weight. A Sand Cone test was conducted to measure field compaction, followed by a 7 day curing period before performing the Dynamic Cone Penetrometer (DCP) test. Additionally, a California Bearing Ratio (CBR) test was conducted in the laboratory to compare the results. Among the various mixture combinations tested, the composition of 25% fly ash and 5% rice husk ash produced the best results, with a 142% increase in CBR value. Using a cultivator and pedestrian roller, the implementation cost was calculated at IDR 537,589 per cubic meter, making it the most efficient and effective option compared to other variations. It also demonstrated up to 41% cost efficiency compared to the conventional method using cement.

INTRODUCTION

One of the abundant mineral resources in Kalimantan is coal, which is widely used as fuel in Steam Power Plants (PLTU). Several PLTUs across Kalimantan, operated by the State Electricity Company (PLN) and private sectors, contribute significantly to electricity supply in the region. However, the increasing capacity of coal-fired power plants also leads to an increase in industrial waste, particularly fly ash, with PLTU Asam-Asam producing approximately 26,400 tons annually (Firoozi et al, 2017). Conventional waste management methods, mainly landfill disposal, are insufficient to address the escalating volume of fly ash.

Fly ash has been studied extensively as a construction material and soil stabilizing agent, showing promising results in improving the physical and mechanical properties of soft soil (Al-Khafaji et al, 2023). Previous studies indicate that fly ash can increase the California Bearing Ratio (CBR) of soil, especially when combined with cement, lime, or rice husk ash. Nevertheless, the use of cement poses high costs and environmental concerns due to CO_2 emissions during its production, prompting interest in more sustainable

alternatives using industrial waste materials (Mishra et al, 2024).

In the context of infrastructure development, particularly road construction on soft soils typical in South Kalimantan with low bearing capacity and high-water saturation, soil stabilization is critical. Soil-Cement Stabilization (SCS) is a widely used method to enhance soil strength, but conventional approaches often rely on heavy equipment, limiting applicability in low-budget or remote projects. This research aims to explore the effectiveness of combining fly ash and rice husk ash as alternative stabilizing materials for soft soil in environmental-friendly and cost-effective soil stabilization for local road construction in South Kalimantan (Zaini et al, 2023). The study also seeks simpler implementation techniques suitable for small-scale road projects, contributing to waste management and sustainable infrastructure development.

MATERIALS & METHODS
Research Methodology
The experimental setup for this study involved soil samples prepared in dimensions of 2 x 3 meters for each mixture, with a soil depth of 20 cm. The soil stabilization treatments consisted of varying combinations of rice husk ash, fly ash, and cement as detailed in Table 1 below. The stabilized soil samples were subjected to testing after a curing period of 7 days to evaluate their physical and mechanical properties.

Table 1. Sample

Sample Code	Rice Husk Ash (%)	Fly Ash (%)	Cement (%)
SPF1	5	15	-
SPF2	5	20	-
SPF3	5	25	-
SPF3S	5	25	4.7

Sample Collection
Soil samples were collected from Intan Banua Residence, located on Jl. H. Mistar Cokrokusumo, Bangkal, Cempaka District, Banjarbaru City, South Kalimantan. Fly ash was sourced from the Asam-asam PLTU in South Kalimantan, while rice husk ash was obtained from Cempaka Village, Banjarbaru.

Physical and Mechanical Soil Testing
Physical properties of the soil were analyzed in the laboratory following standard ASTM procedures including:
1. Water Content (ASTM D 2216-71): Determining the moisture percentage in soil by comparing the weight of water to the weight of solid particles.
2. Specific Gravity (ASTM D 854-02): The ratio of soil particle density to the density of water.
3. Bulk Density (ASTM D 2937-83): The total soil weight divided by its volume.
4. Particle Size Distribution (ASTM D 422-63): Classifying the soil based on particle sizes.

Mechanical properties were also tested to understand soil behavior under load, including:
1. Compaction Test (ASTM D 698): To determine the optimum moisture content for maximum soil compaction.
2. Sand Cone Test (ASTM D 1556): To measure in-situ soil density after stabilization.
3. Dynamic Cone Penetrometer (DCP) Test (ASTM D 6951): To assess the California Bearing Ratio (CBR) value on field conditions.
4. Laboratory CBR Test (ASTM D 1833): To measure the CBR value in controlled laboratory conditions for comparison purposes.

Field Stabilization Procedure
Field trials were conducted with the following steps:

1. Site Preparation: Clearing the land and marking plots of 2 x 3 meters.
2. Mixing: Soil was mixed with additive materials according to the specified percentages.
3. Compaction: The stabilized soil was compacted using a pedestrian roller, followed by sand cone density testing.
4. Curing: Compacted soil was covered and allowed to cure for 7 days.
5. Testing: After curing, DCP testing was carried out to determine field CBR values.

Data Analysis

Data analysis included evaluation of soil mechanical properties based on compaction, sand cone, DCP, and CBR tests. Execution methods were observed directly during fieldwork. Budget analysis was conducted by calculating construction costs for each mix variation using the guidelines from the Directorate General of Construction No. 30 Year 2025 and the South Kalimantan Regional Unit Price List

RESULT

Material Characterization

Initial material examinations were conducted to ensure the suitability and quality of the base soil, fly ash, and rice husk ash used in this study. The base soil revealed physical properties essential for stabilization analysis, including a specific gravity of 2.646 and particle size distribution as shown in Table 2. The maximum dry density was determined as 1.765 g/cm³. Fly ash exhibited 2.88% moisture content, 6% fineness, and a specific gravity of 3.049 g/cm³, influencing its performance as a stabilizing agent (Muhuddin et al, 2020). Rice husk ash showed a high moisture content of 66.67% and water absorption capacity of 56.25%, parameters critical to its interaction when mixed with soil.

Table 2. Particle Size Distribution

Sieve Number	Passing Percentage (%)
½	100,00
⅜	97,27
No. 4	89,59
No. 8	78,54
No.10	75,52
No. 16	64,72
No.40	23,39
No. 200	2,28

Optimum Moisture Content

The standard Proctor test was applied to establish the optimum moisture content for the soil prior to mixing with additives. The optimum moisture content was found to be 14.82%, which was consistently used across all sample variations to achieve maximum dry density and optimal compaction (Ohadian et al, 2024).

Soil Stabilization Process

Field preparation began by clearing all vegetation manually and loosening the soil to a depth of 20 cm with a cultivator. Admixtures, including fly ash and rice husk ash, were then evenly applied based on predetermined mixing ratios (see Table 1) and thoroughly mixed using mechanical means. Water was added to reach the optimum moisture content, although achieving uniform water distribution was challenging due to limited control over water application, occasionally resulting in runoff (Ahmad et al, 2024). Subsequent compaction using a pedestrian roller effectively densified the soil, superseding less efficient methods like manual tamping. The compacted soil was then cured under plastic covers for seven days to maintain moisture and enhance stabilization (Islam et al, 2024).

Field Density Evaluation

Sand cone tests conducted after 15 passes of compaction revealed that most samples had not met the required density threshold according to BM 2018 specifications. Additional compaction (up to 25 passes) was carried out; however, improvements in soil density remained marginal (Hasan et al,

2021). These findings suggest limitations influenced by material properties, moisture control, and mixing uniformity affecting achievable compaction.

Dynamic Cone Penetrometer (DCP) Testing

DCP assessments demonstrated an increase in soil bearing capacity following stabilization. Compared to the control soil with a CBR of 4.09%, samples with fly ash and rice husk ash showed enhanced CBR values, with the highest of 9.90% noted in the mixture containing 25% fly ash and 5% rice husk ash (SPF3). Interestingly, the addition of cement in the SPF3S sample did not yield a further increase, possibly due to field limitations such as uneven moisture distribution (Seco et al, 2021).

Table 3. Share calculation

No	Code	CBR
1	Soil	4,09%
2	SPF1	6,31%
3	SPF2	6,57%
4	SPF3	9,90%
5	SPF3S	9,60%

Laboratory CBR Testing

In controlled laboratory conditions, all stabilized samples exhibited significant strength gains over the untreated soil. The SPF3S formulation displayed the highest CBR value of 12.00%, underscoring the positive effect of cement addition under optimal mixing and curing. Discrepancies between laboratory and field CBR values highlight challenges in replicating ideal conditions on-site, particularly regarding moisture regulation and mixture homogeneity (Nguyen et al, 2020).

Table 4. Laboratory CBR Testing

No	Code	CBR
1	Soil	4,30%
2	SPF1	7,40%
3	SPF2	7,50%
4	SPF3	8,00%
5	SPF3S	12,00%

Cost Analysis

Economic evaluations factored material quantities, labor, and equipment costs based on local pricing. Results revealed that mixtures without cement (e.g., SPF3) achieved considerable cost saving up to 25% lower than traditional cement-based stabilization while maintaining substantial improvements in soil strength (Zada et al, 2023). Although cement-containing mixtures (SPF3S) provided higher strength, the associated cost increase was substantial, suggesting that the non-cement mixtures offer a more balanced approach between performance and budget constraints.

Table 5. Unit Price Analysis for Work

No	Sample Code	Price per m³ (IDR)
1	Cement with heavy equipment	Rp 755,447.91
2	Cement without heavy equipment	Rp 716,923.04
3	SPF1	Rp 468,250.05
4	SPF2	Rp 502,919.69
5	SPF3	Rp 537,589.34

Methodological Challenges and Recommendations

Field implementation faced several challenges impacting method effectiveness:

- Soil loosening was hindered by residual roots, necessitating preliminary manual clearance to optimize mechanical cultivation effectiveness.
- Water application lacked precision, causing excess surface runoff and inconsistent moisture content critical for compaction success. The use of controlled water spraying equipment is recommended to enhance uniformity.
- Excess moisture adversely affected compaction quality despite increased roller passes, highlighting the

importance of adhering strictly to optimum moisture content parameters. Addressing these issues through improved site preparation, water management, and mixing techniques is essential for replicating laboratory success in practical applications (Zaini et al, 2024).

CONCLUSION

This study concluded that the mixture containing 25% fly ash and 5% rice husk ash (SPF3) yielded the highest California Bearing Ratio (CBR) value of 9.90%, indicating this composition as the most optimal for improving the load-bearing capacity of soil in environmental road construction compared to other formulations. Conventional stabilization methods that primarily use cement incur a cost of around Rp755,447 per cubic meter. Meanwhile, the SPF3 mixture achieved comparable technical performance at Rp537,589 per cubic meter, demonstrating the potential to reduce costs by approximately 41% through the use of industrial waste materials such as fly ash and rice husk ash while maintaining or exceeding conventional performance levels. The implementation of soil stabilization using cultivators and pedestrian rollers is highly recommended for environmental road projects due to their efficiency in terms of time, cost, and equipment mobilization. Cultivators enable effective blending of soil and stabilizers, while pedestrian rollers provide optimal compaction, especially in confined areas. Moreover, these tools are easier to operate in locations with limited access and do not require large supporting equipment, making them suitable for small to medium-scale projects in residential areas.

For future research, it is suggested that each mixture be tested independently and in greater detail, particularly regarding the determination of the optimum moisture content unique to each stabilizing material combination. This approach is essential since different additives exhibit varying capacities to absorb and retain moisture, which directly impacts soil compaction and strength. Additionally, subsequent studies should include direct comparisons to conventional stabilization methods using 100% cement to objectively evaluate both technical and economic performance. Furthermore, large-scale field trials are recommended to more accurately observe the behavior of stabilized soils under actual environmental conditions, thereby enhancing the reliability of technical recommendations and supporting the practical application of industrial waste-based soil stabilization in road construction projects. These strategic insights aim to balance technical efficacy with cost efficiency, promoting sustainable and effective soil stabilization solutions tailored to resource availability and project needs.

REFERENCES

1. Mishra, A. Dixit, A.K. Singh, S.K. Das, Strength, deformation, and environmental impact assessment of cement stabilized mine overburden soil, J. Clean. Prod. (2024), https://doi.org/10.1016/j.jclepro.2024.141475.
2. Ohadian, N. Khayat, M. Mokhberi, Study of strength characteristics and micro-structure analysis of soil stabilized with wastewater and polymer, Int. J. Pavement Res. Technol. (2024), https://doi.org/10.1007/s42947-023-00296-w.
3. Seco, A., del Castillo, J. M., Espuelas, S., Marcelino-Sadaba, S., & Garcia, B. (2021). Stabilization of a Clay Soil Using Cementing Material from Spent Refractories and Ground-Granulated Blast Furnace Slag. Sustainability, 13(6), 3015. https://doi.org/10.3390/su13063015.
4. Ahmad, S., Mohd Ghazi, S. A., Syed, M., & Al-Osta, M. A. (2024). Utilization of fly ash with and without secondary additives for stabilizing expansive soils: A review. Results in Engineering, volume 22, 102079.

5. D.T. Nguyen, N.T. Nguyen, H.N.T. Pham, H.H. Phung, H. Van Nguyen, Rice husk ash and its utilization in soil improvement: an overview, J. Min. Earth Sci (2020), https://doi.org/10.46326/jmes.2020.61(3).01.

6. Firoozi, A. A., Guney Olgun, C., Firoozi, A. A., & Baghini, M. S. (2017). Fundamentals of soil stabilization. International Journal of Geo-Engineering, 8, 1-16.

7. M. Hasan, M.S.I. Zaini, N.A.A. Hashim, A. Wahab, K.A. Masri, R.P. Jaya, M. Hyodo, M.J. Winter, M. Sholichin, R. Haribowo, Stabilization of kaolin clay soil reinforced with single encapsulated 20mm diameter bottom ash column, IOP Conf. Ser. Earth Environ. Sci. (2021), https://doi.org/10.1088/1755-1315/930/1/012099

8. M.S.I. Zaini, M. Hasan, Effect of optimum utilization of silica fume and lime on the stabilization of problematic soils, Int. J. Integr. Eng. (2023), https://doi.org/10.30880/ijie.2023.15.01.032.

9. M.S.I. Zaini, M. Hasan, Effectiveness of silica fume eggshell ash and lime use on the properties of kaolinitic clay, Int. J. Eng. Technol. Innov (2023), https://doi.org/10.46604/ijeti.2023.11936.

10. Muhiddin, A. B., & Tangkeallo, M. M. (2020, July). Correlation of unconfined compressive strength and California bearing ratio in laterite soil stabilization using varied zeolite content activated by waterglass. In Materials Science Forum (Vol. 998, pp. 323-328).

11. R. Al-Khafaji, A. Dulaimi, H. Jafer, N.S. Mashaan, S. Qaidi, Z.S. Obaid, Z. Jwaida, Stabilization of soft soil by a sustainable binder comprises ground granulated blast slag (GGBS) and cement kiln dust (CKD), Recycling (2023), https://doi.org/10.3390/recycling8010010.

12. S. Islam, S. Ara, J. Islam, An experimental investigation on utilization of ladle refined furnace (LRF) slag in stabilizing clayey soil, Heliyon (2024). Heliyon, Volume 10, Issue 4, e26004. https://doi.org/10.1016/j.heliyon.2024.e26004.

13. U. Zada, A. Jamal, M. Iqbal, S.M. Eldin, M. Almoshaogeh, S.R. Bekkouche, S. Almuaythir, Recent advances in expansive soil stabilization using admixtures: current challenges and opportunities, Case Stud. Constr. Mater. (2023), https://doi.org/10.1016/j.cscm.2023.e01985.

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