

Research Article

# The Impact of Cement and Rice Husk Ash on the Unconfined Compressive Strength of Expansive Clay Soil

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**Abstract:** The soil in Kedungdandang Hamlet, Muncar, has previously been identified as expansive clay that is highly sensitive to changes in moisture content and exhibits significant shrink–swell behavior, which leads to a reduction in bearing capacity and structural damage such as cracking in floors and walls, therefore, soil improvement through stabilization is required. This study aims to determine the effect of adding cement and rice husk ash (RHA) on the mechanical properties of expansive clay soil by using 3% cement and 6%, 8%, and 10% rice husk ash based on the weight of the soil. The results of the unconfined compressive strength (UCT) test indicate that the natural soil has a  $q_u$  value of 28.62 kN/m<sup>2</sup>, which increases to 55.08 kN/m<sup>2</sup> with the addition of 3% cement and 6% RHA, to 62.66 kN/m<sup>2</sup> with 3% cement and 8% RHA, and reaches the highest value of 86.98 kN/m<sup>2</sup> for the mixture containing 3% cement and 10% RHA. This increase in  $q_u$  value indicates that the stabilization process improves the mechanical properties of the soil through a pozzolanic reaction, resulting in a more stable soil structure and a higher bearing capacity.

**Keywords:** Cement; Expansive Clay; Rice Husk Ash (RHA); Stabilization; Unconfined Compressive Strength

## 1. Introduction

Soil stability is one of the critical factors determining the safety of building construction (Hayati & Budhi, 2025). All structural loads are transferred to the soil layer through the foundation, making soil stability and bearing capacity fundamental aspects in civil engineering design (Pratama, 2021). Infrastructure development such as buildings and highways requires soil conditions with good bearing capacity to ensure structural reliability and extend the lifespan of the infrastructure (Setiawan & Akbar, 2025). However, not all areas have ideal soil conditions, especially in regions dominated by expansive clay soils. Expansive clay soils are known to have high swelling and shrinkage potential due to changes in moisture content (Raditya et al., 2017). This behavior leads to a decrease in bearing capacity, cracking in floors and walls, and damage to road pavements. According to research by Rahayu (2022), the soil in Kedungdandang Hamlet, Tapanrejo Village, Muncar District, Banyuwangi Regency, is classified as expansive clay soil with a Shrinkage Index (SI) value > 25%, indicating a high degree of expansiveness (Rahayu, 2022). With these characteristics, expansive clay soils have a significant potential to disrupt the stability of infrastructure built on them.

Problems with expansive clay soils can be addressed through soil stabilization efforts, one of which is the chemical stabilization method. This method involves adding specific chemicals to the soil to initiate a chemical reaction between them, resulting in the formation of new material with more stable and stronger technical characteristics compared to the original soil (Kurniawan et al., 2019). Stabilization using cement has been proven to improve the soil's bearing capacity through the process of cementation and the strengthening of the

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soil particle structure (Sugianto et al., 2022). On the other hand, rice husk ash is an agricultural waste material containing high silica ( $\text{SiO}_2$ ), approximately 91.72%, with active pozzolanic properties (Saleh & Harwadi, 2017).

Therefore, this study focuses on analyzing the effect of a combination of cement and rice husk ash on the mechanical properties of expansive clay soil in Kedungdandang Hamlet. The aim of this research is to determine the extent to which the addition of cement and rice husk ash can improve the strength of expansive clay soil based on the unconfined compressive strength (UCT) test, and to determine the optimal composition that provides the most significant improvement in bearing capacity and soil stability. The results of this study are expected to serve as a reference for utilizing agricultural waste as an alternative material for soil stabilization that is both economical and environmentally friendly.

## 2. Literature Review

Expansive clay soil has the property of swelling when wet and shrinking when dry, causing significant volume changes. This property leads to cracks, reduced shear strength, and potential damage to foundations, roads, and other structures (Dai et al., 2020; Rangan et al., 2023; Sudjatmiko & Alifia, 2025; Zhao et al., 2020). Damage caused by expansive soils can result in extremely high infrastructure repair costs worldwide (Almuaythir et al., 2025; Firoozi et al., 2017). A common approach to improving the mechanical properties of expansive clay soils is through chemical soil stabilization. Chemical stabilization is performed by adding chemicals such as lime, cement, fly ash, silica fume, industrial waste ash, and natural materials (e.g., calcined clay, zeolite, rice husk ash) to the expansive clay soil. This process triggers hydration reactions, cation exchange, flocculation, and pozzolanic reactions, which produce new cementitious compounds, strengthen soil particle bonds, and reduce plasticity and the swelling-shrinking potential (Anggraini et al., 2025; Barman & Dash, 2022).

Cement is a very common and effective chemical stabilization material used to improve the mechanical properties of expansive clay soils. Cement lowers the liquid limit, plasticity index, and swelling index, making the soil more stable and less prone to volume changes due to variations in moisture content (Sorsa, 2022). In addition to cement, rice husk ash (RHA) is also known as an alternative material with great potential for use in soil stabilization. RHA has been recognized as an environmentally friendly and cost-effective soil stabilization material, especially for expansive soils and soft soils. RHA is rich in amorphous silica, which reacts pozzolanically with calcium (from cement or lime), forming cementitious compounds that strengthen the soil structure (Anjum et al., 2025).

## 3. Materials and Method

To obtain a comprehensive understanding of the effects of cement and rice husk ash addition on the mechanical properties of expansive clay soil, this study was conducted through several stages arranged systematically. The sequence of these steps is illustrated in the research flowchart as shown in Figure 1.

This research was conducted through several stages to obtain optimal results, as follows:

a. Literature Review

The first stage involved gathering materials and methods used in the study through a literature review of books, similar research, and journals related to the topic.

b. Preparation of Test Materials

The preparation of test materials consists of two main steps: first, the collection of soil samples from Kedungdandang Hamlet, Tapanrejo Village, Muncar District. The soil samples were taken in a disturbed condition. The second part of the preparation involves the stabilizing materials, specifically cement and rice husk ash. The cement used was Portland Type 1 cement, while the rice husk ash was obtained by burning rice husks using a furnace

c. Physical Properties Testing of Soil

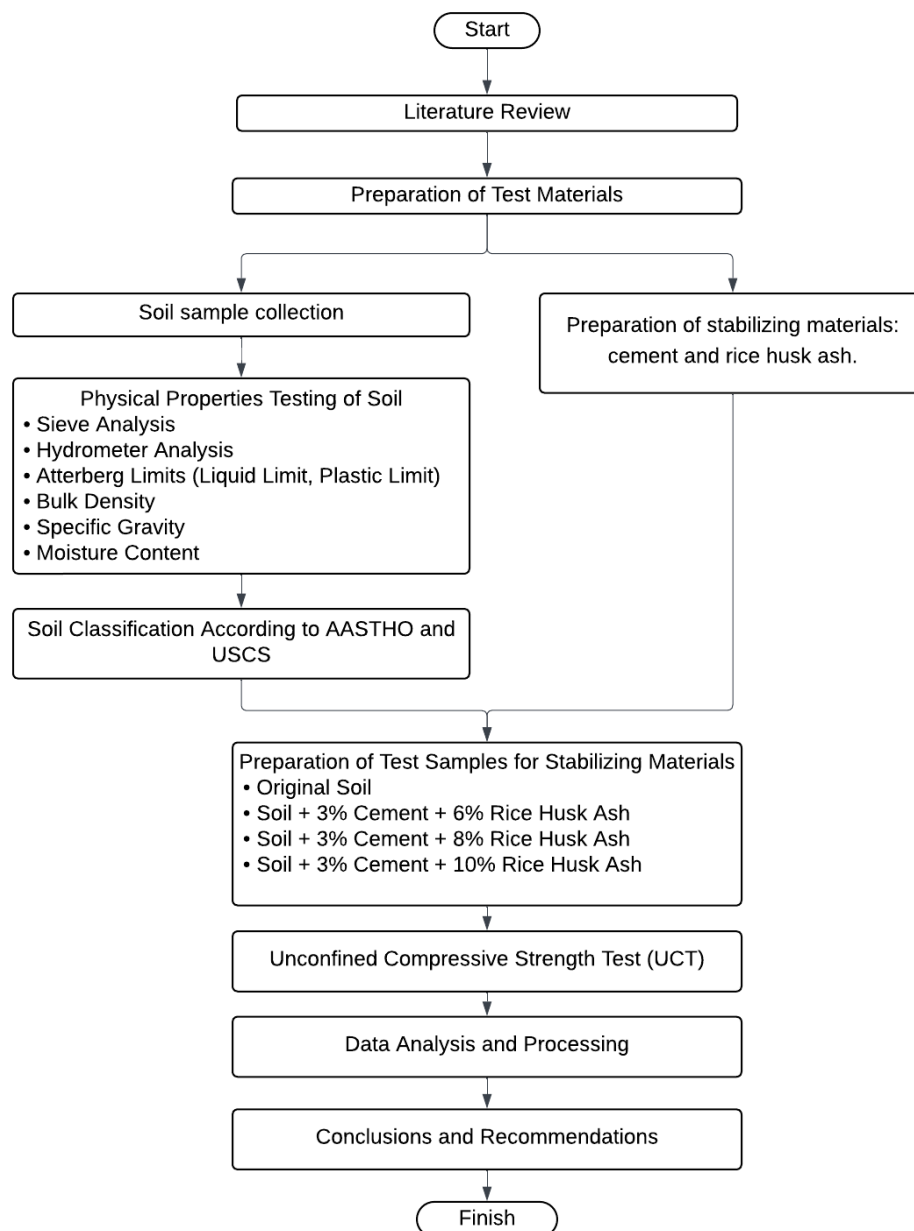
In testing the physical properties of the original soil, several tests were conducted, including sieve analysis, hydrometer analysis, Atterberg limits, bulk density, specific gravity, and moisture content. The explanation of each test is as follows:

1) Sieve Analysis

Sieve analysis is a method used to determine the distribution of soil particle sizes through a sieving process. A 500-gram soil sample is sieved using a series of sieves to determine the quantity and distribution of soil particles retained on each sieve (Badan Standardisasi Nasional, 2008a).

## 2) Hydrometer Analysis

Hydrometer analysis is a test for fine-grained soils with a particle diameter  $<0.075$  mm or passing sieve No. 200. This test aims to determine the particle size distribution of fine-grained soil (Badan Standardisasi Nasional, 2008a).



**Figure 1.** Research Flowchart.

## 3) Atterberg Limits

The Atterberg limits, commonly known as the liquid limit, plastic limit, and shrinkage limit, are used to classify and describe the consistency of fine-grained soils (Hayati & Budhi, 2025). In this study, tests were conducted for the liquid limit and plastic limit. The plasticity index is the difference between the liquid limit and the plastic limit of the soil (Badan Standardisasi Nasional, 2008b).

## 4) Bulk Density

Bulk density refers to the ratio between the mass of soil and its volume in its natural field condition, expressed in  $\text{g}/\text{cm}^3$  (Hayati & Budhi, 2025).

## 5) Specific Gravity

The specific gravity of soil ( $G_s$ ) is the ratio between the weight of soil particles and the weight of an equal volume of water at a specified temperature (Hayati & Budhi, 2025). Specific gravity is important because soils contain many important minerals with specific gravities that need to be known for their respective concentrations.

- 6) Moisture Content  
Moisture content ( $w$ ) is the percentage ratio of the weight of water ( $W_w$ ) to the weight of the soil particles ( $W_s$ ) in the soil (Hayati & Budhi, 2025). The results of the moisture content test can be applied to determine the consistency and behavior of the material and its properties. Excessive moisture content will make the mixture of soil and water very soft.
- d. Soil Classification According to AASTHO and USCS  
The soil classification stage involves grouping the soil type. The classification is done according to the soil classification tables based on AASHTO and USCS standards. The soil classification system is obtained after conducting the physical tests on the soil sample. In this test, the original soil sample is used without the stabilizer additives.
- e. Preparation of Test Samples for Stabilizing Materials  
This study used cement and rice husk ash as stabilizing materials for the expansive clay soil in Kedungdandang Hamlet, Muncar District, Banyuwangi Regency, with different mix percentages. For each mix variation, 3 test samples were prepared for comparison. The mix variations consisted of 3% cement and 6%, 8%, and 10% rice husk ash by weight of the soil. The variation of the stabilizer mix used in the study can be seen in Table 1.

**Table 1.** Test Mix Variations.

Code	Test Sample Variation	Sample Count
A1	Original soil	3
A2	Original Soil + 3% Cement + 6% Rice Husk Ash	3
A3	Original Soil + 3% Cement + 8% Rice Husk Ash	3
A4	Original Soil + 3% Cement + 10% Rice Husk Ash	3

- f. Mechanical Properties Testing of Soil  
The mechanical properties of the soil were tested through the Unconfined Compressive Strength Test (UCT). This test was conducted to improve the bearing capacity of clay soil in Kedungdandang Hamlet, Muncar. The UCT was performed based on SNI 3638-2012. The relationship between the unconfined compressive strength,  $q_u$ , of the clay soil and its consistency can be seen in Table 2.

**Table 2.**  $q_u$  Parameters Based on Soil Consistency (Aulia & Istiatun, 2025).

Consistency	$q_u$ (kN/m <sup>2</sup> )
Hard Clay	>400
Very Stiff Clay	200-400
Stiff Clay	100-200
Medium Clay	50-100
Soft Clay	25-50
Very Soft Clay	<25

To determine the unconfined compressive strength ( $q_u$ ) of the soil, the formula in Equation (1) can be used (Listyawan et al., 2023). In this equation,  $k$  represents the proving ring calibration value,  $R$  is the maximum reading, and  $A$  is the cross-sectional area of the soil sample.

$$q_u = \frac{k \times R}{A} \quad (1)$$

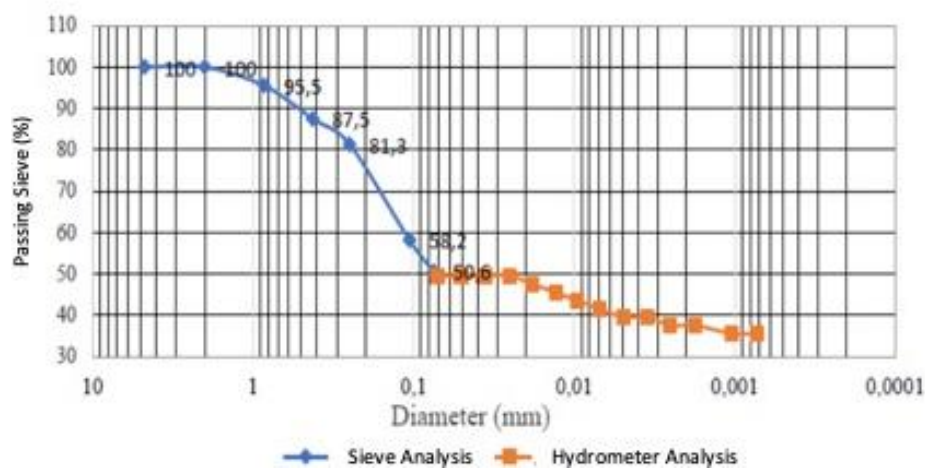
## 4. Results and Discussion

### Results of Physical Soil Properties Testing

The physical properties tests in this study included several types of tests, such as sieve analysis, Atterberg limits, specific gravity, bulk density, moisture content, and hydrometer analysis. The results of these tests were used for soil classification according to USCS and AASHTO standards, using the original soil samples. A summary of the results of the physical soil tests is provided in Table 3, while the results of the sieve and hydrometer analysis are shown in Figure 2 as a combined particle size distribution curve of the soil.

**Table 3.** Summary of the Physical Test Results for Original Soil.

No	Soil Physical Test Parameter	Value	Unit
1.	Liquid Limit	57,78	%
2.	Plastic Limit	37,50	%
3.	Plasticity Index	20,28	%
4.	Bulk Density	1,79	gram/cm <sup>3</sup>
5.	Specific Gravity	2,66	
6.	Moisture Content	46,52	%



**Figure 2.** Soil grain size distribution curve.

Based on Table 3, the Atterberg limit tests yielded a liquid limit (LL) of 57.78%, a plastic limit (PL) of 37.50%, and a plasticity index (PI) of 20.28%. Based on these values, soils with a plasticity index (PI) > 17% are classified as clay with high plasticity. The bulk density test resulted in an average bulk density of 1.79 g/cm<sup>3</sup>. The specific gravity was found to be 2.66, and the average moisture content was 46.52%.

Based on these physical properties data of the original soil, the soil can be classified according to AASHTO and USCS standards. The results are as follows:

a. Classification According to AASHTO

The classification according to AASHTO is based on the sieve analysis results, which show that 50.7% of the soil passed through sieve No. 200, which is greater than 35%. Therefore, it is classified as clay soil within groups A-4, A-5, A-6, and A-7. Based on the liquid limit of 57.78% (> 41%) and a plasticity index of 20.28% (> 11%), the soil falls into the A-7 group. With a plastic limit of 37.50% (> 30%), the soil is classified as A-7-5. Thus, according to AASHTO classification, the soil in Kedungdandang Hamlet is classified as A-7-5, and A-7-6, falling into the category of clayey soil.

b. Classification According to USCS

The classification according to USCS is based on sieve analysis, liquid limit, and plasticity index. According to the sieve analysis, 50.7% of the soil passed through sieve No. 200, which places it in the fine-grained fraction. Based on the liquid limit of 57.78% (greater than 50%), the soil is categorized into groups MH, CH, and OH.

### Results of Mechanical Soil Properties Testing

Mechanical Properties Testing was conducted using the Unconfined Compression Test (UCT) for each variation. Each variation test used 3 sample specimens. The results are as follows:

a. Unconfined Compressive Strength Test of 100% Original Soil

**Table 4.** Unconfined Compressive Strength Results for 100% Original Soil Variation.

No	Variation	Sample	Unconfined Compressive Strength (kN/m <sup>2</sup> )
1	A1 (100% Original Soil)	A1.1	28.30
		A1.2	29.36
		A1.3	28.20

Table 4 shows the unconfined compressive strength results for the 100% original soil variation, based on 3 test samples, with values of 28.30 kN/m<sup>2</sup>, 29.36 kN/m<sup>2</sup>, and 28.20 kN/m<sup>2</sup>, yielding an average value of 28.62 kN/m<sup>2</sup>. Based on its consistency, sample A1 is classified as soft clay.

b. Unconfined Compressive Strength Test of Original Soil + 3% Cement + 6% Rice Husk Ash

**Table 5.** Unconfined Compressive Strength Results for Original Soil + 3% Cement + 6% Rice Husk Ash.

No	Variation	Sample	Unconfined Compressive Strength (kN/m <sup>2</sup> )
1	A2 (Original Soil + 3% Cement + 6% Rice Husk Ash)	A2.1	55,44
		A2.2	55,01
		A2.3	54,80

Table 5 shows the unconfined compressive strength results for the soil + 3% cement + 6% rice husk ash variation. With 3 test samples, the compressive strength values were 55.44 kN/m<sup>2</sup>, 55.01 kN/m<sup>2</sup>, and 54.80 kN/m<sup>2</sup>, with an average value of 55.08 kN/m<sup>2</sup>. Based on its consistency, sample A2 is classified as medium clay.

c. Unconfined Compressive Strength Test of Original Soil + 3% Cement + 8% Rice Husk Ash

**Table 6.** Unconfined Compressive Strength Results for Original Soil + 3% Cement + 8% Rice Husk Ash.

No	Variation	Sample	Unconfined Compressive Strength (kN/m <sup>2</sup> )
1	A3 (Original Soil + 3% Cement + 8% Rice Husk Ash)	A3.1	62,53
		A3.2	62,86
		A3.3	62,60

Table 6 shows the unconfined compressive strength results for the soil + 3% cement + 8% rice husk ash variation. With 3 test samples, the compressive strength values were 62.53 kN/m<sup>2</sup>, 62.86 kN/m<sup>2</sup>, and 62.60 kN/m<sup>2</sup>, with an average value of 62.66 kN/m<sup>2</sup>. Based on its consistency, sample A3 is classified as medium clay.

- d. Unconfined Compressive Strength Test of Original Soil + 3% Cement + 10% Rice Husk Ash

**Table 7.** Unconfined Compressive Strength Results for Original Soil + 3% Cement + 10% Rice Husk Ash.

No	Variation	Sample	Unconfined Compressive Strength (kN/m <sup>2</sup> )
1	A4 (Original Soil + 3% Cement + 10% Rice Husk Ash)	A4.1	87,19
		A4.2	86,85
		A4.3	86,92

Table 7 shows the unconfined compressive strength results for the soil + 3% cement + 10% rice husk ash variation. With 3 test samples, the compressive strength values were 87.19 kN/m<sup>2</sup>, 86.85 kN/m<sup>2</sup>, and 86.92 kN/m<sup>2</sup>, with an average value of 86.98 kN/m<sup>2</sup>. Based on its consistency, sample A4 is classified as medium clay.

The summary of the unconfined compressive strength tests, starting from the original soil and soil stabilized with a mixture of cement and rice husk ash (RHA), can be seen in Table 8.

**Table 8.** Summary of Unconfined Compressive Strength Testing.

No	Code	Average Unconfined Compressive Strength (kN/m <sup>2</sup> )	Increase from Original Soil (%)
1	A1	28.62	0.00
2	A2	55.08	92.45
3	A3	62.66	118.92
4	A4	86.98	203.91

Based on Table 8, in the unconfined compressive strength tests on the soil in Kedungdandang Hamlet, Muncar District, Banyuwangi, the unconfined compressive strength of the stabilized soil was higher than that of the original soil. For the original soil, the average unconfined compressive strength from 3 samples was 28.62 kN/m<sup>2</sup>. For the soil with a mixture of 3% cement + 6% rice husk ash, the average unconfined compressive strength from 3 samples was 55.08 kN/m<sup>2</sup>, showing an increase of 92.48% compared to the original soil. For the soil with a mixture of 3% cement + 8% rice husk ash, the average unconfined compressive strength was 62.66 kN/m<sup>2</sup>, showing an increase of 118.93% compared to the original soil. For the soil with a mixture of 3% cement + 10% rice husk ash, the average unconfined compressive strength from 3 samples was 86.98 kN/m<sup>2</sup>, showing an increase of 203.91%. The highest unconfined compressive strength result was obtained from the variation with the soil mixture of 3% cement and 10% rice husk ash.

## 5. Conclusion

Based on the results of the study, the unconfined compressive strength with the addition of cement and rice husk ash has an impact on improving the unconfined compressive strength of the soil in Kedungdandang Hamlet, Tapanrejo Village, Muncar District, Banyuwangi. The unconfined compressive strength value of the original soil from the three samples was found to be 28.62 kN/m<sup>2</sup>. In the test of soil with a mixture of 3% cement + 6% rice husk ash, the unconfined compressive strength of the three samples was 55.08 kN/m<sup>2</sup>. In the test of the original soil with a mixture of 3% cement + 8% rice husk ash, the value was 62.66 kN/m<sup>2</sup>. In the test of the original soil with a mixture of 3% cement + 10% rice husk ash, the value was 86.98 kN/m<sup>2</sup>. This increase indicates that the pozzolanic reaction between cement, rice husk ash, and soil particles can improve the mechanical properties of the soil by forming a denser and stronger structure, thus transforming soft clay into medium clay. Therefore, in this study, the mixture of 3% cement and 10% rice husk ash is the most optimal composition for increasing the bearing capacity of expansive clay soil. However, this study is limited to variations in the stabilizer content without considering the curing time and other types of soil that may exhibit different responses. Therefore, these results provide a foundation for further

research by reviewing variations in the mix materials, cement and rice husk ash content, and the effect of curing time on the unconfined compressive strength of the soil.

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