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Stabilization of Soft Soil with Rice Husk Ash on CBR Bearing Capacity and Soil Shear Strength Parameters

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Abstract. Bekasi Regency generally has an area with soft clay soil conditions, recognized as problematic soil known as expansive clay. As large-scale construction continues in the region, geotechnical issues associated with these expansive soils have become a concern. Stabilizing with additives increased the soil's bearing capacity and shear strength. The addition of agricultural waste material, rice husk ash (RHA), is intended to improve the soil through a pozzolanic reaction. This study examines soft soil's bearing capacity and shear strength value with 5%, 10%, and 15% rice husk ash. Index properties tests comprising water content, specific gravity, grain size analysis, and Atterberg limits. Engineering properties tests comprising proctor compaction, California Bearing Ratio (CBR), and UU Triaxial. The samples cured for two days before compaction and seven days after compaction. The test results indicated that the soil was classified as CH according to USCS and A-7-6 according to AASHTO. The highest CBR and Triaxial UU test results were found with an RHA content of 15%. CBR increased by 86.44% from 4.919% to 9.172%. Cohesion value increased by 90.31% from 0.185 kg/cm^2 to 0.352 kg/cm^2. This study indicates that RHA could increase bearing capacity and shear strength in soil stabilization.

Keywords: Soft Soil, Stabilization, Rice Husk Ash, CBR, Shear Strength Parameters

INTRODUCTION

Cikarang, a well-integrated residential, commercial, and industrial hub in Bekasi Regency, is developing extensively. This growth is not limited to industrial and commercial sectors but includes numerous residential complexes to accommodate workforce mobility. However, the area has long been a challenge for civil engineering projects due to its widely recognized 'problematic soil' known as expansive clay deposits common in West Java [1]. Bekasi Regency generally has an area with soft clay soil conditions [2]. As large-scale construction continues in the region, geotechnical issues associated with these expansive soils have become a concern.

Soft soil can become expansive if it contains more than 30% fine particles, such as clay, and has a liquid limit value approaching 50%. Based on the Unified Soil Classification System (USCS), this type of soil is categorized as either CL (low-plasticity clay) or CH (high-plasticity clay) category [3]. Soft soil has low bearing capacity and shear strength and is unstable due to its high-water content [4]. Problems such as cracks in the structure and construction subsidence can occur with these conditions. These problems will negatively impact construction work without any soil improvement. Therefore, soil stabilization is needed to improve the issue of low bearing capacity and shear strength in soft soil types in the area.

Previous studies on soil stabilization have described CBR for soft soil improvement with additional materials. Thus, there is a lack of comprehensive studies particularly addressing the impact of RHA on the shear strength parameters of soft soils, especially with a 15% RHA mixture. Most research has either focused on different soil types or used expensive additives such as lime and cement [5], [6], [7], [8]. RHA's environmental and economic benefits for soft soil stabilization remain underexplored.

Rice husk ash is the result of raw rice husk combustion. Rice husk ash can be used as an additional material for soil improvement compared to other materials at an affordable price. RHA that can stabilize soil is attributed to pozzolanic reaction [8]. Rice husk ash contains silica compounds (SiO_2) that can form a mixture and increase soil density and resistance properties [9].

There have been many studies of soil stabilization with additional materials. Research on the stability of swamp soil using rice husk ash (RHA) showed that RHA can improve the bearing capacity of the soil with a CBR value of 9.84% for 15% RHA due to the presence of silica compounds (SiO_2) that can fill the soil pores [10]. Previous research on rice husk ash (RHA) as a soil stabilization material with a mixture variation of 5%, 10%, 20%, and 30% of the dry soil weight showed that RHA could improve the index and engineering properties of the soil [8]. Rice husk ash has positive impacts as an alternative stabilization material in sustainability at an affordable price. The 10% addition of rice husk ash of the dry soil weight was recommended for soil with a clay/fine-grained content of >90%, LL ≥ 60%, and PI ≥ 30%. Soft soil stabilized with emulsified asphalt and tailings showed that optimum stabilization of a mixture of 8% emulsified asphalt and 6% tailings experienced an increase in CBR value of 7.10% during seven days of curing [4]. Emulsified asphalt and tailings with effective composition can be used as alternative materials to stabilize soft soil in road pavement structures. Recent research on recycled concrete aggregate (RCA) and fly ash as additional materials showed that the 15% RCA mixed soil sample continued to increase with a maximum CBR value of 33.75% [11]. Meanwhile, soil with a fly ash content of 5% had a maximum CBR value of 24.32% and gradually decreased. Previous research was conducted on expansive soil in Karawang Regency with a liquid limit (LL) value of 72.27%, plastic limit (PL) of 21.51%, and plasticity index (PI) of 50.77% [12]. The study results showed that soil with a mixture of fly ash and waste foundry sand (WFS) can reduce the plasticity index, increase the bearing capacity, and increase the shear strength of the soil. Research on sand and lime mixture as additional soil stabilization materials showed that the CBR value was increased with the soaked CBR of 42.1% and the unsoaked CBR of 66.13% for 20% sand and 5% lime for seven days of curing [13]. Previous research has been done by adding lime and palm shell fly ash as stabilization materials to improve peat soil [14]. The results showed that the more lime and palm shell fly ash added with the length of the curing time, the higher the CBR value obtained. Improvement of low plasticity clay soil with additional materials of rice husk ash (RHA) and sugarcane bagasse ash (SCBA) showed that a mixture of 5% RHA and 5% SCBA can increase the CBR value by 33.75% [9]. Research in the same year that was done using a mixture of gypsum plafond waste (GPW) showed that the highest value was a Soaked CBR value of 11.44% and an Unsoaked CBR of 15.75% in a mixture of 15% GPW [15]. Research on adding coconut fiber ash, brick dust, and Portland cement mixture as a stabilizing material to improve the properties of clay soil has been done [6]. The results showed that there was an increase in the plan CBR value of 5.54%, 6.69%, and 6.84% for 3-day curing with mixture variations of coconut fiber ash, brick dust, and Portland cement of 3%, 5%, 7% so that the mixture was good for soil stabilization. Research on brick dust as an additional material for laterite soil stabilization showed an increase in the average optimal CBR value of 25.03% with a mixture variation of 30% brick dust without any curing process [16]. Another study in the same year using a mixture of tire ash and cement on clay soil has been done [5]. The results showed increased CBR value, soil curing time, and tire ash waste mixture levels due to soil hardening.

The comparison table of the key advantages and disadvantages of various soil stabilization materials can be seen in **Table 1** as follows.

TABLE 1. Comparison Table of Various Soil Stabilization Materials

Materials	Advantages	Disadvantages
Rice Husk Ash (RHA)	Affordable, sustainable, CBR increased by > 100%	Careful proportioning to avoid strength reduction
Emulsified Asphalt & Tailings	Effective for road pavement, CBR increased by 83%	Longer curing time required
Recycled Concrete Aggregate (RCA) & Fly Ash	Sustainable CBR increased by 65.8%	Stability decreases over time
Sand & Lime	Effective for soft soils, CBR increased by > 100%	Precise mixture control
Gypsum Plafond Waste (GPW)	Cost-effective, CBR increased by > 100%	Limited research on long-term effects
Coconut Fiber Ash, Brick Dust & Portland Cement	CBR increased by > 100%	Requires optimal curing conditions
Brick Dust	CBR increased by > 100%	Large quantities for a significant effect
Tire Ash & Cement	CBR increased by > 100%	Potential environmental concerns

While many studies have focused on CBR, the shear strength behavior of RHA-stabilized soils has not been sufficiently explored. Additionally, the environmental and economic benefits of using RHA mixture as a stabilizer for soft soils, particularly in enhancing their shear strength, are under-researched. Addressing this gap will contribute valuable insights into sustainable, cost-effective soil stabilization for soft soils in construction applications.

The objective of this study focuses on the effect of rice husk ash on CBR bearing capacity and soil shear strength parameters. This research aims to determine how much influence the addition of rice husk ash has on the bearing capacity of the soil through CBR testing and soil shear strength parameters such as cohesion (c) and internal friction angle (∅).

METHODOLOGY

The research began with a preliminary survey and continued with problem formulation, literature study, and preparation of research methods. The disturbed soil sample was taken from a construction site in Sukamahi Village, Cikarang Pusat District, Bekasi Regency, West Java Province, Indonesia. The study was conducted in the Soil Mechanics Laboratory, PT Tunas Lima Warna, South Tangerang, Banten, and the Soil Mechanics Laboratory, Mercu Buana University, Jakarta.

Soil and rice husk ash (RHA) were used as the materials of this study. Soil samples were taken at a depth of 0 – 50 cm. After drying the soil sample from the field in the air and under the sun, the soil was sieved through a No. 4 Sieve (4.76 mm). Laboratory testing was conducted to determine the index and engineering properties of the original soil. Index properties testing includes water content (SNI 1965:2008), specific gravity (SNI 1964:2008), grain size analysis including sieve analysis (SNI 3423:2008) and hydrometer analysis (SNI 3423:2008), liquid limit (SNI 1967:2008), plastic limit (SNI 1966:2008), and plasticity index through Atterberg limits testing. Engineering properties testing includes proctor standard (SNI 1742:2008), unsoaked laboratory CBR (SNI 1744:2008 and SNI 1742:2008), and UU Triaxial (SNI 03-4813-1998). Proctor standard compaction is carried out on dry soil passing sieve No. 4 and compacted according to Method A SNI 1742:2008 and ASTM D698-12 with a total of 25 blows per layer using a 2.5 kg hammer and a mold with a diameter of 10.16 cm and a height of 11.64 cm [17], [18]. The CBR test of the original soil is carried out without curing. The variables of this study are shown in **Table 2**.

TABLE 2. Variables of The Study

Independent Variables	Soil
	RHA
Dependent Variables	CBR
	Cohesion

Soil stabilization samples were made by mixing soil with water and RHA. **Figure 1** illustrates the mixing procedure.

(a) (b) (c)

FIGURE 1. The Mixing Process for Soft Soil Stabilization, (a) Mixing Soil, Water, and RHA, (b) Curing Before Compaction, and (c) Curing After Compaction

Water is obtained from the results of standard compaction tests in the form of the optimum water content (W_{opt}) of the original soil based on the dry weight of the original soil. In this study, the RHA variation levels of 5%, 10%, and 15% of the dry weight of soft soil were likely chosen because they are commonly tested levels in soil stabilization research, provide a good range for evaluating RHA's impact, and reflect practical and effective dosages for improving soil strength [8], [9]. The rice husk ash was filtered using the No. 10 Sieve (2.00 mm). The mixed soil of RHA and the optimum water content of the original soil were put into plastic and cured for two days before compaction. After curing, the mixed soil compacted according to standard method B SNI 1742:2008 and

ASTM D698-12. Compaction was carried out in 3 layers with 56 blows per layer using a 2.5 kg hammer and a mold with a diameter of 15.24 cm and a height of 11.64 cm [17], [18]. Furthermore, the samples were cured for seven days after compaction. The requirement for safe bearing capacity of the laboratory CBR is ≥ 6% required by the Directorate General of Highways Works Design Manual. If the CBR is ≤ 6%, then the RHA content needs to be increased. However, if the CBR is ≥ 6%, the UU Triaxial test can be continued.

Sample preparation is carried out based on the needs and the variation levels of the RHA mixture. The number of samples used can be seen in **Table 3**, **Table 4**, and **Table 5** as follows.

TABLE 3. Number of Original Soil + RHA Samples Test

No	Types of Soil Testing	Sample	Number of Samples
1	Water Content	Original Soil	2
2	Specific Gravity	Original Soil	1
3	Sieve Analysis	Original Soil	1
4	Hydrometer Analysis	Original Soil	1
5	Liquid Limit	Original Soil	4
6	Plastic Limit	Original Soil	2
7	Standard Proctor	Original Soil	5
8	CBR	Original Soil + RHA	4
9	UU Triaxial	Original Soil + RHA	12
	TOTAL		**32**

TABLE 4. Number of CBR Test

No	Mixture Level	Curing Time (days)	Number of Blows	Number of Samples
1	Original Soil	0	3 × 56	1
2	Soil + 5% RHA	7	3 × 56	1
3	Soil + 10% RHA	7	3 × 56	1
4	Soil + 15% RHA	7	3 × 56	1
		TOTAL		**4**

TABLE 5. Number of UU Triaxial Test

No	Mixture Level	Number of Samples
1	Original Soil	3
2	Soil + 5% RHA	3
3	Soil + 10% RHA	3
4	Soil + 15% RHA	3
	TOTAL	**12**

RESULT AND DISCUSSION

The results of the index properties tests of the original soil in Sukamahi Village are shown in **Table 6**. The test result was not used because the water content was tested on disturbed soil samples.

TABLE 6. Results of Original Soil Index Properties

No	Test	Aspect	Result	Unit
1	Specific Gravity	Specific Gravity (G_s)	2.69	gr/cm^3
2	Grain Size Analysis	Gravel	0.00	%
		Sand	5.96	%
		Silt	51.50	%
		Clay	42.53	%
		Passed No. 200	94.04	%
3	Atterberg Limits	Liquid Limit (LL)	79.01	%
		Plastic Limit (PL)	29.82	%
		Plasticity Index (PI)	49.20	%

Figure 2 shows the grain size distribution of the original soil. The soil in Sukamahi Village is included in the fine-grained soil group because more than 50% of the soil passes the No. 200 mesh, which is 94.04%.

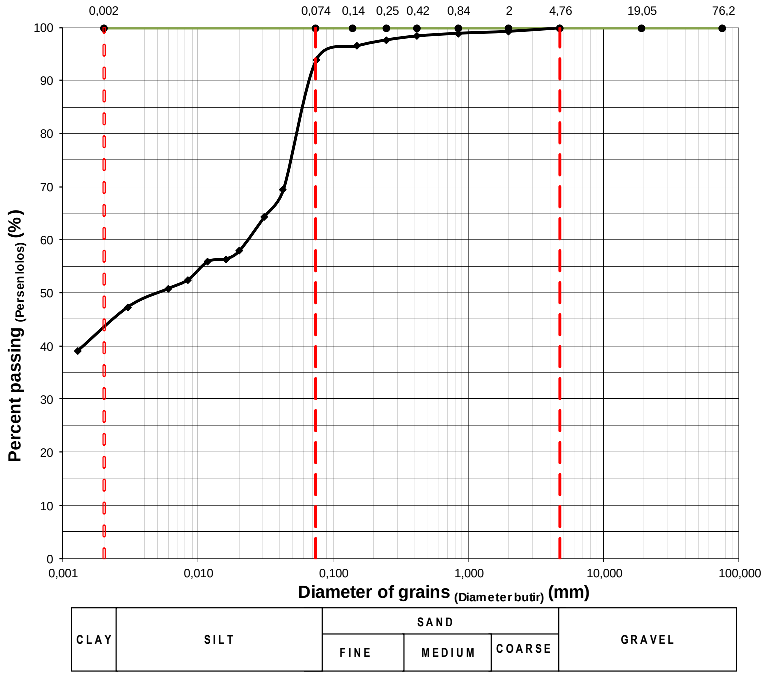

FIGURE 2. Grain Size Analysis Curve of the Original Soil

Table 7 shows the classification of the liquid limit (LL) values of the original soil. Based on the LL value of 79.01%, the original soil has a very high expansivity level with a range of > 60% and 70% - 90%, according to Chen (1965) and IS: 1498 [19]. Meanwhile, according to Snethan et al. (1977), the original soil has a high expansivity level of > 60%.

TABLE 7. Liquid Limit Classification of the Original Soil

Swell Potential	Liquid Limit (%)		
	Chen (1965)	Snethan et al. (1977)	IS: 1498 (1970)
Low	< 30	< 50	20 – 35
Medium/marginal	30 – 40	50 – 60	35 – 50
High	40 – 60	> 60	50 – 70
Very High	> 60	–	70 – 90

Table 8 shows the classification of plasticity index (PI) values of the original soil. Based on the PI value of 49.20%, original soil has a very high level of plasticity with values of > 35% and > 32%, according to Holtz & Gobbs (1956) and IS 1498 [19]. Meanwhile, according to Chen (1988), native soil has a high level of plasticity with a range of 20% to 55%.

TABLE 8. Plasticity Index Classification of the Original Soil

Swell Potential	Plasticity Index (%)		
	Holtz and Gibbs (1956)	Chen (1988)	IS: 1498 (1970)
Low	< 18	0 – 15	< 12
Medium/marginal	15 – 28	10 – 35	12 – 23
High	25 – 41	20 – 55	23 – 32
Very High	> 35	> 35	> 32

In this study, the value of LL was 79.01%, and the PI was 49.20%. These results are similar to the research on expansive soil in Karawang Regency [12]. According to the grain size analysis test, the original soil in Sukamahi Village can be classified as expansive soil.

Based on the test results performed in the laboratory, according to the USCS classification system, the percentage of soil passing sieve No. 200 is 94.04% ≥ 50% with an LL value of 79.01% > 50% and PI = 49.20%. So, the original soil was classified as CH, which is inorganic clay of high plasticity or fat clay. According to the AASHTO classification system, the percentage of soil passing sieve No. 200 is 94.04% ≥ 36%, with an LL value of 79.01% ≥ 41% and PI of 49.20% ≥ 11%. The original soil was classified as A-7-6, clayey, with a fair to poor rating.

From the data obtained, it can be identified that the original soil in Sukamahi Village is soft clay soil with a very high level of expansivity (expansive clay soil). This follows the soft soil distribution map showing that Bekasi Regency has an area with a distribution of soft clay soil conditions [2].

Standard compaction testing was carried out according to Method A SNI 1742:2008 as three layers with 25 blows per layer using a 2.5 kg hammer. If water is added to the soil when compacted, it will moisturize the soil particles so that the particles move. The movement between soil particles will form a denser position and increase the soil's dry density (γd) along with the increasing water content. After reaching a certain water content, adding water content tends to decrease the soil's dry density (γd). The water content that reaches the maximum dry density is called the optimum water content (W_{opt}). The W_{opt} value obtained affects the test after adding rice husk ash because the optimum water content value was used to determine the water content in the CBR test. The compaction test results will form a relationship curve between water content (W) and dry soil density (γ_{dry}).

Figure 3 shows a graph of the curve between water content and the original dry density of the soil. From the standard compaction test, the optimum water content (OMC) value was 33.01%, and the maximum dry density (MDD) was 1.22 gr/cm^3 in the original soil sample in Sukamahi Village. The optimum water content value of the original soil was used for CBR testing of the original soil and RHA mixed soil.

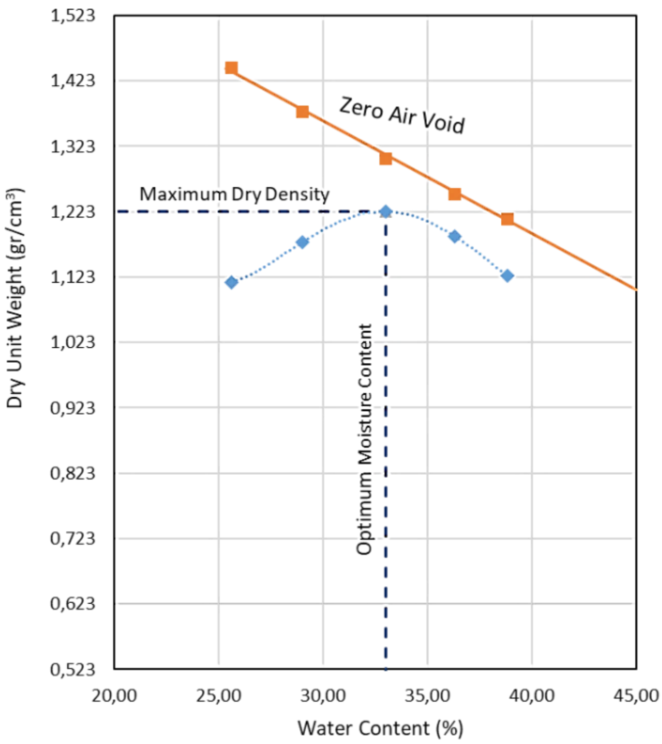

FIGURE 3. Standard Proctor Compaction of the Original Soil Graphic

The CBR test conducted in this study was unsoaked CBR. The soil that passed sieve No. 4 and dried was then stabilized by adding rice husk ash (RHA) of 5%, 10%, and 15%. Compaction was performed according to Method B SNI 1742:2008 in 3 layers with 56 blows per layer using a 2.5 kg hammer.

Figure 4 shows the curve between the variation of the RHA mixture and γ_{dry} based on the compaction carried out for the unsoaked CBR test. From **Figure 4**, the γ_{dry} value of the original soil can be seen as 1.223 gr/cm^3, then shows a decrease in γ_{dry} along with an increase in the RHA mixture content of 5% to 15%. The γ_{dry} decreases with the addition of RHA because RHA has a relatively low specific gravity, around 1.95 gr/cm^3 [8]. Several factors from the pozzolanic reaction can also produce larger particles with larger cavities so that the density is lower.

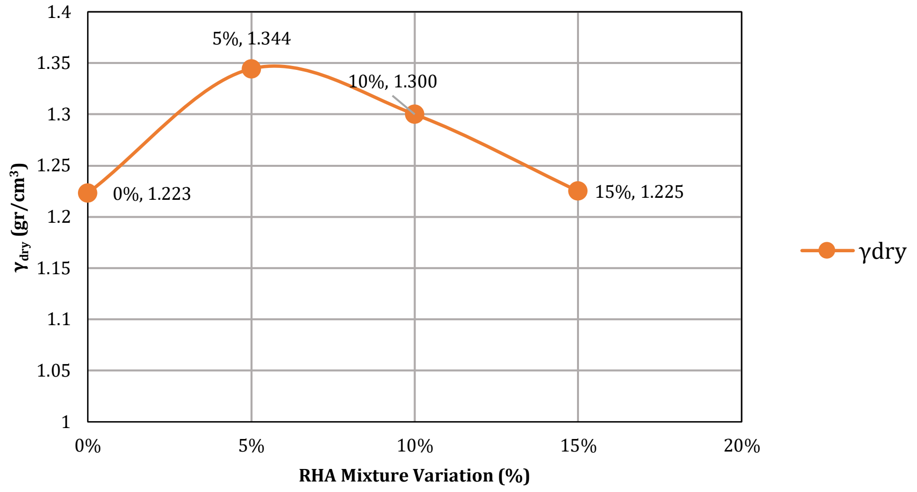

FIGURE 4. Variations of RHA compared to γ_{dry} Graphic

Table 9 shows the results of the maximum CBR test of the original soil and variations of RHA mixed soil. The maximum CBR value of the original soil is 4.919%, so it does not fulfill the requirements for a safe CBR bearing capacity value because the result is ≤ 6%. The increase in CBR value occurred after the addition of RHA.

TABLE 9. CBR Test Results of the Original Soil and RHA

No	Mixture Level	Maximum CBR (%)
1	Original Soil	4.919%
2	Soil + 5% RHA	7.087%
3	Soil + 10% RHA	7.879%
4	Soil + 15% RHA	9.172%

Figure 5 shows the curve between the variation of the RHA mixture and the unsoaked CBR. The CBR value at the addition of 5%, 10%, and 15% RHA increased successively to 7.087%, 7.879%, and 9.172% with a percentage increase of 44.07%, 60.17%, and 86.44% of the original soil. So, all levels of the mixture variation after adding RHA have met the requirements for good CBR-bearing capacity with results ≥ 6%. The highest CBR value is at the RHA mixture variation level of 15% on a percentage increase of 86.44%, where the CBR value of the original soil is 4.919% to 9.172%. The addition of rice husk ash (RHA) affects increasing the CBR-bearing capacity of the soil. This is because the water content contained in the soil during curing time will decrease along with the increasing bonding of the soil pores [10]. This condition shows that the greater the level of RHA variation mixture, the higher the CBR value will be.

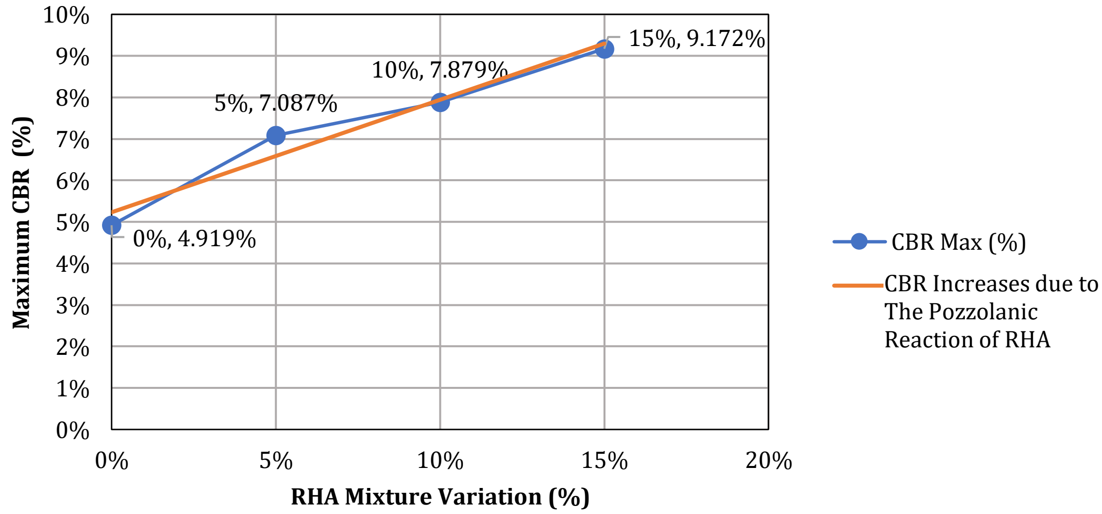

FIGURE 5. Variations of RHA compared to CBR Unsoaked Graphic

Table 10 shows the cohesion value (c) from the UU Triaxial test based on the RHA mixture content. The original soil cohesion value is 0.185 kg/cm^2.

TABLE 10. Cohesion Value (c) based on RHA Mixture Level

No	Mixture Level	Cohesion, c (kg/cm^2)
1	Original Soil	0.185
2	Soil + 5% RHA	0.312
3	Soil + 10% RHA	0.314
4	Soil + 15% RHA	0.352

Figure 6 shows the curve between the RHA mixture variation and the cohesion value. The cohesion value at the addition of RHA 5%, 10%, and 15% increased successively to 0.312 kg/cm^2, 0.314 kg/cm^2, and 0.352 kg/cm^2 with a percentage increase of 68.60%, 69.68%, and 90.31% of the original soil. The highest growth in c value was shown at the RHA mixture content of 15% with an increase percentage of 90.31%, where the c value of the original soil was 0.185 kg/cm^2 to 0.352 kg/cm^2. Because the original soil sample was categorized as clay soil, the internal friction angle (∅) value does not reflect the effect on the soil shear strength parameters. This is because in saturated soil conditions such as clay soil, the internal friction angle (∅) value of the soil can reach zero. So, in the UU Triaxial test, only the cohesion value (c) is obtained.

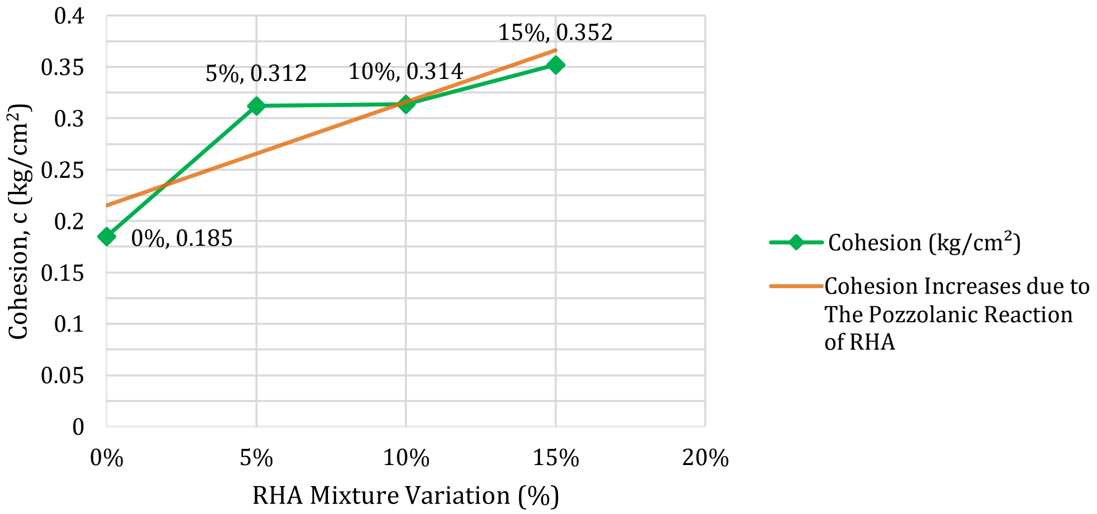

FIGURE 6. Variations of RHA compared to Cohesion Graphic

When the RHA mixture is increased, the cohesion value is increased. This is due to the increase in the attractive force between soil particles, which increases the distance between molecules. The greater the density, the greater the cohesion obtained [8].

Table 11 shows the level of clay soil consistency based on the cohesion value. Based on the level of consistency, the original soil in Sukamahi Village is classified as soft soil because it has a cohesion value range between 0.125 kg/cm^2 – 0.25 kg/cm^2 [20]. The cohesion value of the soil after being given the addition of 5%, 10%, and 15% RHA increased successively to 0.312 kg/cm^2, 0.314 kg/cm^2, 0.352 kg/cm^2. So, all levels of mixture variations are classified as medium soil because they have a cohesion value range between 0.25 kg/cm^2 – 0.5 kg/cm^2.

TABLE 11. Consistency of Clay Soil Based on Cohesion Value

Clay Soil Consistency	Undrained Cohesion, C_u	
	kPa	kg/cm^2
Very Soft	< 12	< 0,125
Soft	12,5 – 25	0,125 – 0,25
Medium	25 – 50	0,25 – 0,5
Stiff	50 – 100	0,5 – 1,0
Very Stiff	100 – 200	1,0 – 2,0
Hard	> 200	> 2,0

Rice husk ash contains a significant amount of silica (SiO_2). During the curing time, the pozzolanic reaction between the rice husk ash and clay minerals granules caused the bonding of soil particles, creating larger, denser aggregates [21]. RHA particles help occupy the voids between soil particles, enhancing the compaction process of the soil. This decrease in void space is crucial because it helps to enhance the soil's structural integrity and improve its load-bearing capacity [7]. The less space for water infiltrations further contributes to the increased shear strength of the compacted soil, leading to an improvement in the soil's cohesion (c) [8]. Adding rice husk ash (RHA) as a soft soil stabilization material has a good effect in increasing the CBR bearing capacity of the soil and increasing the soil shear strength parameters indicated by the cohesion value (c).

In regions with high rice production, like Indonesia, rice husk ash can be an alternative material for soil stabilization. RHA is agricultural waste that is more affordable, and it reduces environmental disposal problems [22]. In addition, rice husk ash can also reduce environmental pollution because the results of rice husk ash use make it economically valuable, especially in developing countries, due to the low cost of materials and availability of labor [23]. Incorporating RHA into clay soil significantly enhances its bearing capacity [7]. This improvement is crucial for constructing stable foundations with weak or expansive soils [22].

CONCLUSION

Based on the testing of soil index properties, the results showed that the original soil in Sukamahi Village is included in the CH category, namely inorganic clay soil with high plasticity or fat clay according to USCS, and is included in the A-7-6 category, namely clayey soil with fair to poor conditions according to AASHTO.

Adding rice husk ash (RHA) as a soft soil stabilization material increases the CBR bearing capacity and soil shear strength parameters. Based on the testing of soil mechanical properties, 5% RHA can increase the bearing capacity of the unsoaked CBR value of the original soil from 4.919% to 7.087% on a percentage increase of 44.07% from the original soil CBR value. These results have met the requirements for CBR bearing capacity ≥ 6% only with the lowest mixture content of 5% RHA. The highest CBR value was found at a mixture content of 15% RHA, which is 9.172%, with a percentage increase of 86.44% from the original soil CBR value.

Adding 5%, 10%, and 15%, RHA increased the soil shear strength parameters. The soil cohesion value (c) from the UU Triaxial test experienced the highest increase of 90.31% from the original soil cohesion value of 0.185 kg/cm^2 to 0.352 kg/cm^2 at a mixture content of 15% RHA. Because the original soil sample is included in the clay soil category, the internal friction angle value (∅) does not reflect its effect on the soil shear strength parameters. Thus, it can be concluded that the higher the RHA mixture content, the bearing capacity and soil shear strength parameters indicated by the cohesion value will increase.

Based on this study's findings, it is recommended that future research test the physical properties of the soil after stabilization. Considering this study only tested unsoaked CBR, additional CBR tested under soaked conditions is suggested to assess the behavior of rice husk ash-stabilized soil when exposed to moisture. Further research on other soil types is recommended to determine the influence of stabilization outcomes.

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