ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA
Revista de la Construcción
Journal of Construction

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*Research Article*

# Soil stabilization using rice husk ash and cement for pavement subgrade materials

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**Received:** 05.10.22; **Accepted:** 28.11.22; **Published:** 30.04.23

**Citation:** Wibowo, D., Ramadhan, D., Endaryanta, Prayuda, H. (2023). Manuscript title. Revista de la Construcción. Journal of Construction, 22(1), 192-202. https://doi.org/10.7764/RDLC.22.1.192.

**Abstract:** This study employs rice husk ash and pozzolan cement as additional soil stabilization materials. This study aims to evaluate the bearing capacity of the soil to be used as embankment soil for subgrade pavement materials. The soil samples were collected from two different areas in the Yogyakarta region, Indonesia, namely the Wates and Imogiri regions. This study consists of experimental approach that defines a soil embankment for road subgrade with a trapezoid-shaped with top dimension of 10 cm x 20 cm, a base dimension of (20 cm x 40 cm), and a height of 10 cm. In addition, the specimens in this study were divided into two groups: the embankment with a 1 cm-thick sand base and the embankment without a sand base. The USCS classified the samples from Wates as OH-type or organic clays with moderate to high plasticity and by AASTHO as group of A-7-5 (22). The soil from Imogiri was categorized as inorganic silt or fine diatoms sand with OH clumps or AASTHO classified this soil as group A-7-5 (11). The addition of rice husk ash and pozzolan cement as stabilizing soil materials has a moderate effect on the engineering properties of the soil, particularly the bearing capacity and bearing capacity ratio of soil. This soil stabilization also demonstrates that the engineering properties of the stabilized soil significantly improved compared to the original soil without stabilization.

**Keywords:** Soil Improvement, rice husk ash, pozzolan cement, Yogyakarta, Embankment.

## 1. Introduction

Pavement is one of the main keys to the development of a country. The existence of pavement infrastructure is capable of sustaining continuous economic growth. Two types of pavement are divided based on their structural performance: rigid and flexible pavement (Ramli et al., 2018). Most road conditions in Indonesia are still located on ground level, so the road quality is still highly dependent on the soil around the foundation. This necessitates that the design, construction, and evaluation processes require soil strength properties in order to generate accurate calculations and analysis (Jaiswal & Lal, 2016; Onyelowe, Jalal, et al., 2021). However, soil behavior is highly complex due to various influencing factors, such as the age of deposition, geological history, and stress history, which affect the soil size, shape, and mineral composition (Mukherjee & Ghosh, 2021). Therefore, various studies have concluded that civil engineering structures built on weak or soft soils pose a high risk of structural failure and accidental fatalities (Chen et al., 2022; Geçkİl et al., 2022; Kumar & Gupta, 2016; Oyediran & Ayeni, 2020). The civil infrastructure directly interacting with soil requires special care during the design and monitoring stages.

Numerous structures are highly dependent on topographical and geographical conditions. Therefore, this becomes problematic during the construction and design process. Various structures are frequently required to be built on inadequate soil conditions to support the structure, resulting in settlement or failure. However, changing the configuration of the structure or location is also a problematic and inefficient task (Butt et al., 2016; Onyelowe, Ebid, et al., 2021; Ormeno et al., 2020). Therefore, a method that is both efficient and cost-effective is required to address the issues associated with infrastructure constructed in unstable topographic and geological conditions. Numerous methods for improving soil stabilization in the construction area include geotextile reinforcement and pozzolanic reinforcement. Several successful techniques for utilizing pozzolanic materials, such as Portland cement, lime, and fly ash, have been developed (Aziz et al., 2015; Kaplan et al., 2022; Kishor et al., 2022; Nguyen et al., 2020; Suksiripattanapong et al., 2017). This existing method proves that stabilizing the soil using pozzolanic material can increase the carrying capacity of the soil itself.

Indonesia is tropical with numerous agricultural products, including rice producers and other processed plantation products. However, improper management of this agribusiness industry has a negative impact. Rice cultivation frequently results in residual processing waste such as rice husk and other waste. Developing countries such as China, India, Indonesia, Bangladesh, Vietnam, and Thailand account for the majority of the world's rice production (Chen et al., 2021). Until now, this waste has not been optimally utilized, so its processing remains a significant challenge. This research aims to use rice farming waste, specifically rice husk ash, as a component material for soil stabilization in several case studies in Indonesia. Employing rice waste as a soil stabilizer in India, Nigeria, China, and Indonesia has been the subject of many studies (Alhassan & Alhaji, 2017; Jain et al., 2020; Kumar Yadav et al., 2017; Ma et al., 2020; Muntohar et al., 2013; Muntohar & Khasanah, 2019).

The soil samples for this study were collected from two different research sites. Road infrastructure will be constructed at this location, so it is necessary to inspect the soil, particularly the subgrade soil used for the road pavement. According to the tests, the soil embankment is a trapezoidal road subgrade. This surface test is divided into sections: specimens without a sand layer and specimens with a 1 cm thick sand layer. In addition, variations were made for each specimen by adding 0%, 3%, 6%, and 9% Portland cement. This test determines the ultimate bearing capacity and the soil embankment bearing capacity ratio. In addition, the water content of the impervious embankment was evaluated for each variation and each soil with a sampling location.

## 2. Experimental program

### 2.1. *General information*

This study employs an experimental laboratory approach using embankment soil to construct specimens. Soil samples were collected from two locations in Yogyakarta, Indonesia: Wates and Imogiri. For each soil sample, stabilization was accomplished by incorporating rice husk ash and pozzolan cement. During the testing period, each specimen was provided with one cm-thick layer of sand and without a layer of sand. Table 1 provides information about research variations in general.

**Table 1.** General information about each specimen.

| Information | Source of specimens | |
|---|---|---|
| | Wates | Imogiri |
| ID | W | I |
| Rice husk ash (%) | 3%, 6%, 9%, 12% | 3%, 6%, 9%, 12% |
| Pozzolan Cement (%) | 0%, 3%, 6%, 9% | 0%, 3%, 6%, 9% |
| Sand base (cm) | 0 cm, 1 cm | 0 cm, 1 cm |

The soil embankment is a mound of soil that serves as a subgrade to support the roadway or pavement. By conducting this test, it is anticipated that an optimal and comprehensive proportion of soil stabilization from the two distinct locations can be determined. Indonesia as a developing country, continues to develop its infrastructure. With this test, it is hoped that it can be a reference for the process of soil stabilization, especially in sampling areas with the same type of soil.

### 2.2. *Investigation location and soil characteristics*

The sampling locations in this study were in two locations within the same province in Indonesia. Figure 1 shows maps of two sampling sites, site 1 in Wates and site 2 in Imogiri, Yogyakarta, Indonesia. These two locations have distinct soil compositions. Before the soil can be utilized, its characteristics must be examined. To classify the soil, tests are conducted to determine its fundamental properties, such as water content, specific gravity, liquid limit, and plastic limit. Table 2 shows the results of the index properties of the specimen in each location. ASTM D2216-19 (ASTM International, 2019) for testing water content, ASTM D7263-21 (ASTM International, 2021) for testing mass density, ASTM 438-17 (ASTM International, 2005b) for testing liquid limit, plastic limit, and plasticity index, ASTM D2487 (ASTM International, 2005a) for soil classification based on USCS, and ASTM D3282 (ASTM International, 1993) for soil classification based on AASTHO are used for testing the fundamental properties of this soil. According to the USCS classification, the soil sample from Wates was classified as OH, or organic clays with medium to high plasticity and organic silts, while the soil sample from Imogiri was classified as MH, or inorganic, organic silty clays with low plasticity. According to AASTHO standards, the Wates and Imogiri soil samples were classified as clayey.

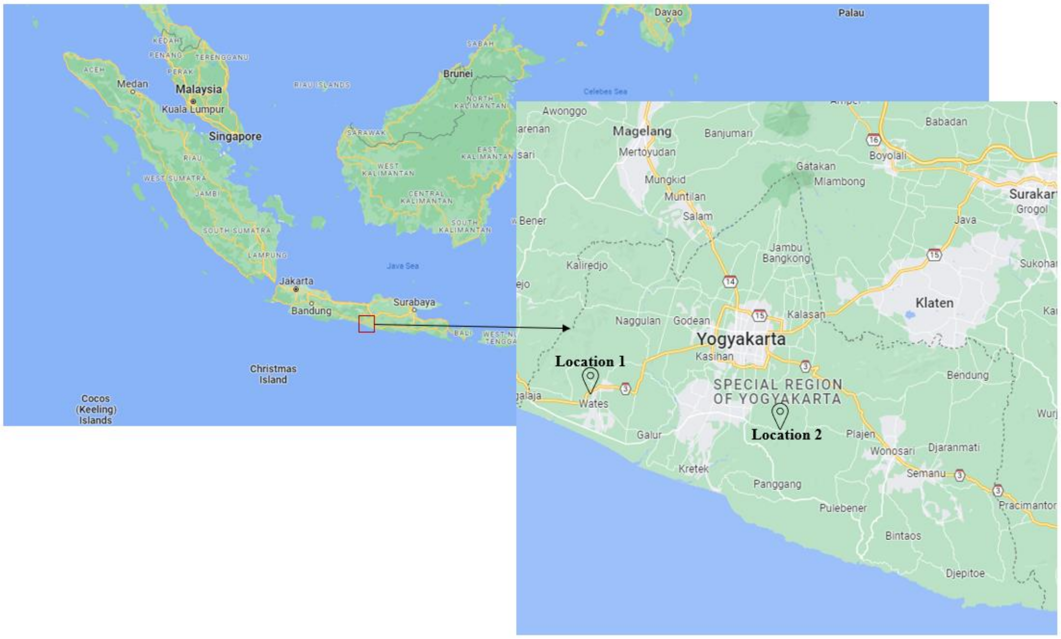


**Figure 1.** Investigation locations (Location 1 at Wates, Location 2 at Imogiri) Yogyakarta, Indonesia.

**Table 2.** Index properties of soil from investigated locations.

| Properties | Source of specimens | |
|---|---|---|
| | Wates | Imogiri |
| Water content (%) | 33.90 | 42.50 |
| Mass density | 2.64 | 2.62 |
| Liquid limit (%) | 55.76 | 51.17 |
| Plastic limit (%) | 34.25 | 34.10 |
| Plasticity index (%) | 21.51 | 17.07 |
| Soil classification based on USCS | OH | MH |
| Soil classification based on AASTHO | A-7-5 (22) | A-7-5 (11) |
| OMC (%) | 23 | 34 |

### 2.3. *Materials and mix proportions*

This study utilized soil samples from two distinct case study locations. The soil was stabilized by utilizing pozzolanic materials, such as rice husk ash and pozzolan cement. This variation of added material is utilized identically in both case study sites. Two embankment tests were conducted at each location, with an additional 1cm of sand and one without the sand base. As shown in Table 3, the chemical composition of the rice husk ash and pozzolan cement added material in this study is identical to that of previous studies. Table 4 shows the proportion of the mixture for each specimen. Note that the mixture utilized for specimens with and without a 1 cm thick sand embankment is identical. In this study, the rice husk ash (RHA) variation was 0%, 3%, 6%, 9%, and 12% of the total specimen weight. While the used variations of pozzolan cement are 0%, 3%, 6%, and 9%, respectively.

**Table 3.** Chemical compositions of rice husk ash and cement.

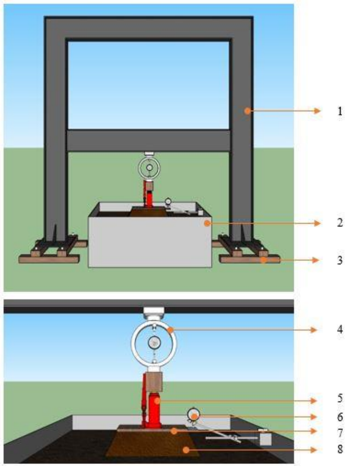
| Constituent (%) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | MnO | LOI |
|---|---|---|---|---|---|---|---|---|
| RHA (Muntohar et al., 2013) | 89.09 | 1.75 | 0.78 | 1.29 | 0.64 | 0.85 | 0.14 | 2.05 |
| Cement (Manaf & Indrawati, 2011) | 67.71 | 15.81 | 2.99 | 2.14 | 0.53 | 2.55 | - | 4.95 |

**Table 4.** Mix design.

| Specimen ID | Soil (%) | RHA (%) | PC (%) |
|---|---|---|---|
| RHA0PC0-W | 100 | - | - |
| RHA3PC9-W | 88 | 3 | 9 |
| RHA6PC6-W | 88 | 6 | 6 |
| RHA9PC3-W | 88 | 9 | 3 |
| RHA12PC0-W | 88 | 12 | - |
| RHA0PC0-I | 100 | - | - |
| RHA3PC9-I | 88 | 3 | 9 |
| RHA6PC6-I | 88 | 6 | 6 |
| RHA9PC3-I | 88 | 9 | 3 |
| RHA12PC0-I | 88 | 12 | - |

### 2.4. *Equipment and experimental procedures*

This study employs experiments in which each specimen is subjected to uniaxial loading. The objective is to discover and investigate the causes and effects of the influence of the research subject. In the process, a comparison will be made between the results of multiple samples and those of previous experiments. The experiment used an embankment from soil stabilized with rice husk ash and cement as reinforcement. A soil embankment is a barrier that serves as a foundation for the pavement with a trapezoidal shape. This trapezoidal shape aims to spread the compressive load of 2 V: 1 H. While the size of the trapezoid is 10 cm x 30 cm, the bottom is 20 cm x 40 cm, the height is 10 cm. Figure 2 shows the experimental setup for the embankment test in each specimen, while Figure 3 shows of the experimental setting up in laboratory for this study.



Notes:
1. Loading frame
2. Specimen Box
3. Loading frame support
4. Proving ring
5. Hydraulic Jack
6. Dial gauge
7. Loading plate
8. Embankment soil

**Figure 2.** Experimental setting up.

(a) Setting up front view (b) Setting up top view

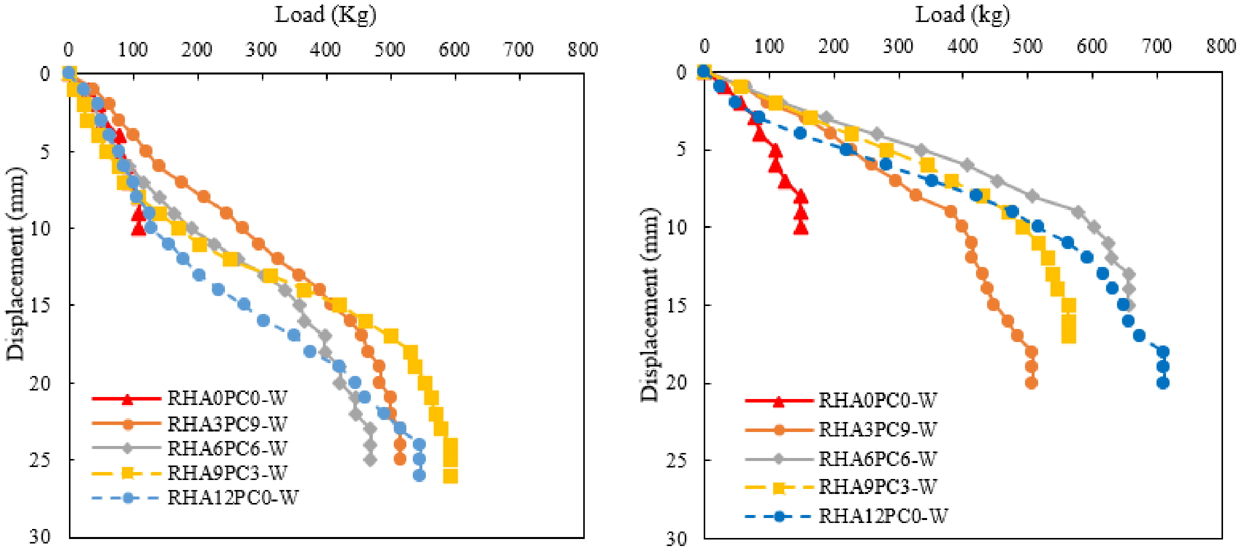
**Figure 3.** Experimental setting up.

The experiment phase in this study was conducted in a test box measuring 100 cm x 100 cm and 40 cm in height, with a 4 mm thick plate filled with 30 cm of saturating soft soil to simulate the original soil media in the field. A three-ton hydraulic jack is used to apply a load to the soil embankment during the implementation stage of testing the soil embankment. A proving ring indicates the magnitude of the load used in the soil embankment model, and a dial gauge is used to read the amount of soil subsidence every 1 mm/minute at the top of the soil embankment. This loading continues until the soil embankment visually collapses or becomes stagnant or there is neither a decrease nor an increase in load for three consecutive cycles. Observations were made for each instance of soil subsidence, and the corresponding load value was recorded on the proving ring.

## 3. Results and discussions

### *3.1. Load displacement relationship*

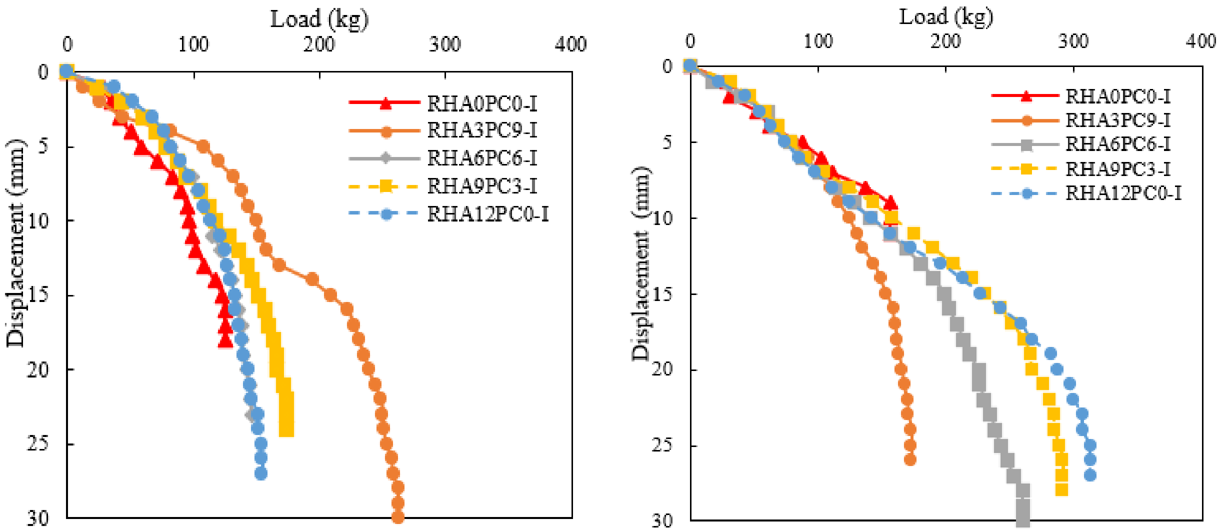
Soil stabilization is one of the techniques used to enhance the bearing capacity through the implementation of particular treatments. With soil reinforcement, it is expected that the soil conditions will become more stable and that the engineering properties will be improved, allowing it to be used as a foundation of infrastructure, such as pavement. There are numerous methods for stabilizing soil, including chemical, physical, mechanical, and thermal. By conducting an embankment test, it is possible to evaluate the efficacy of soil stabilization. The effectiveness of this test to determine the relationship between uniaxial load and deformation is relatively high. This soil test applies to subgrade pavement. In pavement construction, sand is frequently applied to a certain depth in the subgrade portion of the structure. This study applied a 1 cm thick layer of sand to the subgrade surface to accommodate these conditions. Figure 4 shows load-displacement test results on the soil from Wates. Figure 4a shows load-displacement results for specimens without a sand base, while Figure 4b shows the results of load-displacement relationships for specimens with a 1 cm thick sand base. The results of this test indicate that the maximum load a soil sample can support without stabilization is approximately 100 kg without base sand and 150 kg with 1 cm of base sand. This indicates that the soil at this location has a relatively low load-bearing capacity. In the sample stabilized without base sand, the soil load could support an increase from 400 to 600 kg. This demonstrates that soil stabilization is able to increase the soil bearing capacity. The same applies to specimens with a 1 cm thick base sand. The increase in the soil's load-bearing capacity is also from 400 to 700 kg. Compared to specimens without base sand, soil containing base sand tends to withstand the higher load. This Wates soil test results indicate that the displacement increases as the load increases.



(c) Without base sand (d) With 1 cm base sand

**Figure 4.** Load displacement relationship for soil embankment (wates).

Figure 5 illustrates the relationship between load and displacement for Imogiri soil. According to the USCS classification, the soil is MH-type soil. The results of this test indicate that the sample stabilized with rice husk ash and pozzolan cement can withstand a higher workload than the unstabilized soil. This resembles the pattern observed when testing soil derived from Wates. However, compared to the soil at Wates, the more extensive soil at Imogiri can support a lighter load of 100-350 kg. This is due to the nature of the soil and the possibility of an uneven working process during the stabilization procedure. The improvement in soil properties following stabilization with rice husk ash is also consistent with the findings of previous studies (Behak & Musso, 2016; Brahmachary et al., 2019; Ewa et al., 2018; Hidalgo et al., 2020; Sani et al., 2020; Taha et al., 2021). The effect of rice husk ash on the geotechnical properties of subgrade may be highly dependent on its chemical properties, especially its silica and organic content. However, the results of this test indicate that the stabilized soil properties have been enhanced. Additionally, using rice husk ash for soil positively affects the environment because it reduces the amount of agribusiness waste discarded as material.

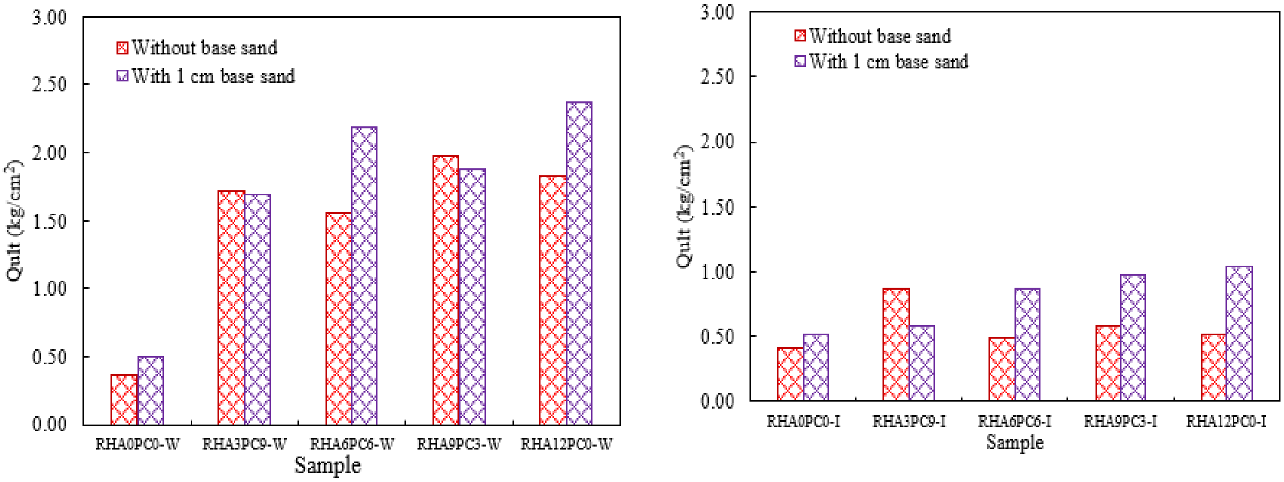


(a) Without base sand (b) With 1 cm base sand

**Figure 5.** Load displacement relationship for soil embankment (Imogiri).

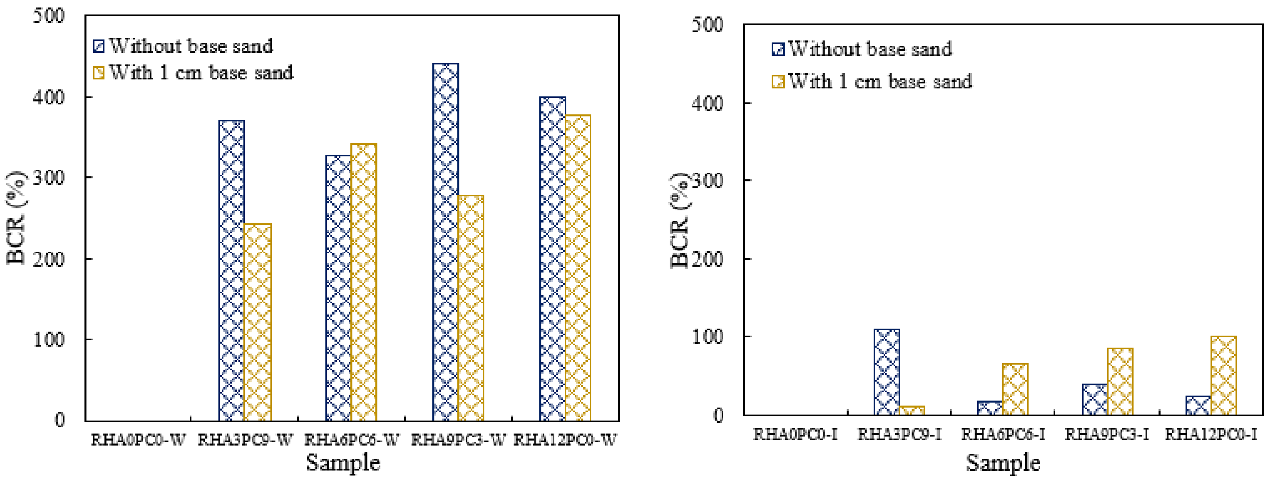
### *3.2. Ultimate carrying capacity and bearing capacity ratio*

Figure 6 shows the ultimate carrying capacity analysis results for each sample. Figure 6a shows the results for the ultimate carrying capacity of the Wates region, while Figure 6b shows the results for the Imogiri region. The ultimate carrying capacity calculation reveals that the Wates and Imogiri soils have a Qult of less than 0.5 kg/m$^2$. The test results indicated that stabilization of the soil with rice husk ash and pozzolan cement results in a substantial increase in its ultimate carrying capacity. This demonstrates that the engineering properties of the soil have improved, thereby increasing the soil's carrying capacity. In soils from the Wates region, the increase in carrying capacity is between three and five times larger than the capacity of the original soil. This significant increase was observed in all samples containing various proportions of rice husk ash and pozzolan cement. In addition, specimens with soil from the Imogiri region demonstrated an increase in soil-bearing capacity. However, the increase in the carrying capacity of the soil in the area tends to be less than that of the stabilized soil in the Wates area. The low increase in the soil carrying capacity can be attributed to the initial soil condition, the condition of the stabilizing material, and the processing method. It can also be concluded that stabilizing OH-type soil with rice husk ash and pozzolan cement is more effective than stabilizing MH-type soil.



(a) Soil from Wates (b) Soil from Imogiri

**Figure 6.** The ultimate carrying capacity of stabilized soil.



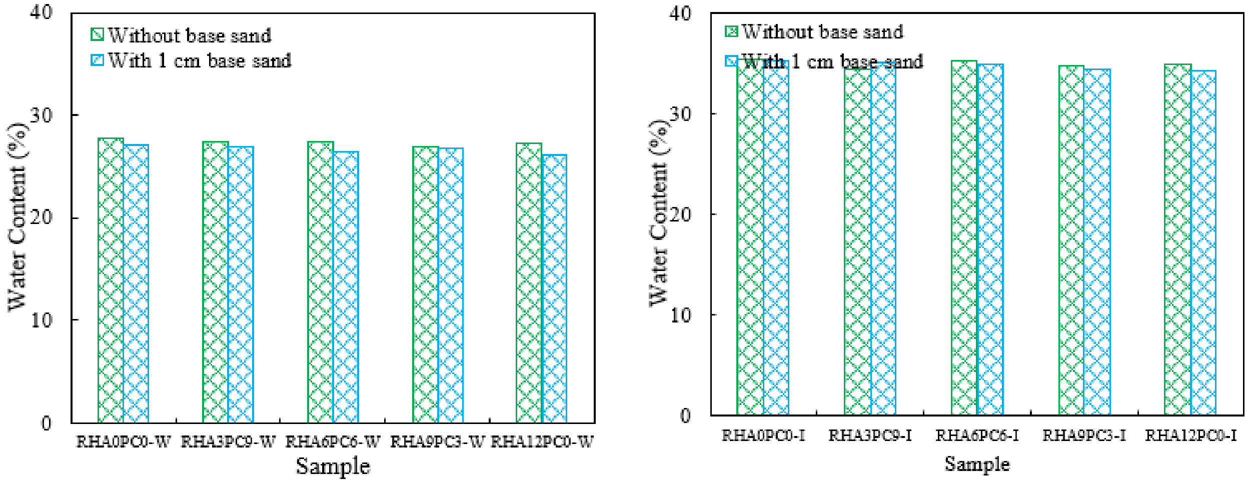
(a) Soil from Wates (b) Soil from Imogiri

**Figure 7.** Bearing capacity ratio of stabilized soil.

Figure 7 shows the bearing capacity ratio of each stabilized soil originating from Wates and Imogiri, Indonesia. The data pattern generated through the bearing capacity ratio analysis aligns with the ultimate carrying capacity analysis results. The ratio of the bearing capacity of Wates stabilized soil, which ranges from 200 to 450%, has increased significantly. In the meantime, the soil from Imogiri experienced a moderate increase. The BCR values of soils from the Imogiri region ranged from 10% to 110%. The significant difference in BCR values between the two locations was attributable to their distinct soil types. In addition, the condition of the chemical and organic composition of the added materials, in this case, rice husk ash and pozzolan cement, can also contribute to this issue.

### *3.3. Water content*

In the process of implementing soil embankment testing, water content is one of the crucial factors. Figure 8 shows the water content tests conducted on samples from Wates and Imogiri. The results of testing the stabilized soil water content indicate that the soil in the Wates region contains between 25% to 28% water. The water content of stabilized soil is always lower than that of the original soil. This is because the material added as a soil stabilizer absorbs water during the stabilization process, reducing the water content. The specimen with a sand base also indicates that the water content is lower than the specimen without a sand base, but the difference is insignificant, with a disparity is less than 2%. Similar patterns of moisture content were obtained for Imogiri soils. However, the soil in the Imogiri region has a higher water content, which ranges between 34% to 36%. This water content test indicates that one of the reasons the increase in soil-bearing capacity for Imogiri samples is lower than in the Wates region is the lower water content of the Imogiri. During the testing of embankment soil, the high-water content is one factor that causes the soil's carrying capacity to decrease.



(a) Soil from Wates (b) Soil from Imogiri

**Figure 8.** The water content of stabilized soil.

## 4. Conclusion

The following conclusions can be drawn based on the experimental results carried out on the embankment soil for the road pavement subgrade.

1) This study utilized soil samples from two locations, namely Wates and Imogiri. USCS classified the samples from Wates as OH-type soils or organic clays with moderate to high plasticity and by AASTHO as group A-7-5 (22). The soil from Imogiri was categorized as inorganic silt or fine diatoms sand with OH clumps, while AASTHO classified this soil as group A-7-5 (11).
2) As a soil stabilizer, rice husk ash and pozzolan cement positively affect both soil samples. The bearing capacity of the soil and the resulting bearing capacity ratio has increased compared to the original unstabilized soil. Additionally, as a stabilizing material, rice husk ash positively impacts environmental pollution by reducing agricultural waste.
3) The test results revealed that stabilizing soil with rice husk ash and pozzolan cement had a more significant effect on Wates soil than on Imogiri soil. This may result from differences in soil type, soil moisture content, and the chemical and organic properties of each constituent material.
4) The water content test results revealed that the addition of rice husk ash and pozzolan cement decreased the water content. This is due to the fact that this stabilizing material absorbs water from the soil. Despite this, the soil in Imogiri contained more water than in Wates.

**Author contributions:** Dian Eksana Wibowo: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Supervision, Funding acquisition. Dymas Agung Ramadhan: Conceptualization, Methodology, Investigation, Writing – review & editing, Visualization. Endaryanta: Conceptualization, Writing – review & editing, Supervision. Hakas Prayuda: Supervision, Writing – review & editing.

**Funding:** Not Applicable

**Acknowledgments:** The authors would like to express appreciation to all of the technicians from the geotechnical engineering laboratory, Department of Civil Engineering, Faculty of Engineering, Yogyakarta State University.

**Conflicts of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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