Laboratory model test on the sand column for reinforcement system of flexible pavement

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Abstract

Flexible pavement failures in Indonesia are primarily attributed to weak subgrade conditions, necessitating soil reinforcement measures. This study aimed to enhance soil-bearing capacity through soil reinforcement experiments utilizing a mixture of sand columns, rice husk ash, and cement. A prototype was constructed, including a 1×1×1 m steel box, an IWF steel frame, a dial gauge, a steel plate, and a proving ring, to apply a load to soil arranged within the iron box using a 3-ton hydraulic jack. The study focused on a clay soil type (following the AASHTO method) and conducted soil reinforcement in four scenarios. The result shows that in all scenarios involving a sand column, Scenario 1: 3% sand, 3% rice husk ash, and 6% cement obtained a q_{ult} *is 0.23 kg/cm*^{2} *and BCR 114.94%; Scenario 2: 3% sand, 6% rice husk ash, and 3% cement obtained a* q_{ult} *is 0.12 kg/cm*^{2} *and BCR 11.49%; Scenario 3: 6% sand, 3% rice husk ash, and 3% cement obtained a* q_{ult} *is 0.14 kg/cm*^{2} *and BCR 26.44%; Scenario 4: 6% sand, 6% rice husk ash, and 0% cement obtained a* q_{ult} *is 0.24 kg/cm*^{2} *and a BCR of 116.09%. Notably, scenario 4, featuring a column composition of 6% sand, 6% rice husk ash, and 0% cement, achieved a significant increase in bearing capacity (*q_{ult}*) with a value of 0.24 kg/cm*^{2} *and a high Bearing Capacity Ratio (BCR) of 116.09%. Scenario 1 was the most effective in reducing moisture content by 4% relative to the original soil moisture content, with a mixture comprising 3% sand column, 3% rice husk ash, and 6% cement. The findings suggest that applying soil columns can enhance the performance of flexible pavements.*

Introduction

Indonesia actively invests in infrastructure, particularly transportation, to stimulate its economy. According to the 2021 World Bank report on "Indonesia Infrastructure Investment," a substantial portion of the national budget has been earmarked for enhancing transportation networks, including roads, ports, and airports. This strategic investment has yielded positive results, leading to improved connectivity, reduced transportation costs, and a significant boost in economic activity, contributing to the nation's overall economic growth.

As traffic volume increases in an area, it can lead to traffic congestion. Addressing traffic issues involves road maintenance, as roads experience wear and tear over time, affecting their foundational soil strength and surface quality. Road quality is relatively close to the pavement's integrity, which can be flexible or rigid. The pavement is crucial in distributing the loads exerted by vehicle wheels, spreading them evenly and efficiently to the underlying soil layer (Alimohammadi et al., 2021; Banerjee et al., 2022; Nur et al., 2021; Rifqi & Fitriani, 2020; Undang-undang Republik Indonesia, 2009).

Damage to flexible pavements is primarily attributed to several factors, including inadequate soil conditions, the region's susceptibility to high earthquake activity, and the malfunction of road drainage systems. If these issues go unaddressed, they can lead to settlement of the foundational soil layer and surface layer damage, often as cracks. Without timely intervention, this damage can extend to all layers of the flexible pavement, undermining the strength and stability of the foundational soil layer.

A soil reinforcement approach becomes a vital consideration to mitigate these challenges. Using soil reinforcement techniques represents a promising alternative, as it can significantly increase the load-bearing capacity of the subgrade layer. Therefore, a soil reinforcement method is needed as one of the suitable alternatives for use in the subgrade layer that can increase the bearing capacity value (Abdullah, 2023; Hashem & Abu-Baker, 2013; Ghanizadeh et al., 2022; Kusuma et al., 2022; Muntohar, 2016; Shakhan et al., 2022; Shirazi et al., 2020; Valipour et al., 2021; Yin et al., 2022).

Soropadan Village Road Section, Pengasih District, Kulon Progo Regency, Yogyakarta is one of the provincial roads that are important in the development of regional traffic, so the development of traffic flow in the area must be accompanied by an adequate level of road services so as not to interfere with the comfort and safety of road users. Several road sections were damaged, indicated by cracked and wave roads. Weak soil types caused damage to the road section in Soropadan Village. Based on this explanation, this study aims to determine the bearing capacity of subgrade soil without reinforcement, after which experimental models have been reinforced, and treat conditions in the field so that the road pavement layer can function optimally (Wibowo et al., 2023; Wibowo et al., 2023).

Research Methods

The method carried out in this study consists of preliminary testing and prototype model testing in the laboratory at the Soil Mechanics Laboratory of Universitas Negeri Yogyakarta.

The preliminary test was conducted to test the soil properties that will be used as a reference for soil improvement (Table 1). The tests performed include soil properties, direct shear, Atterberg limit, soil compaction, and CBR. A loading test from laboratory scale modeling was then conducted to obtain the ultimate load of soil-bearing capacity. The laboratory-scale modeling was carried out on the original and treated soil to determine the settlement and ultimate load of the soil (Wibowo et al., 2023; Wibowo et al., 2023).

Table 1. Soil parameter data

Test parameters	Value
Moisture content (w)	23%
Dry density (γ_d)	14.7 kN/m^3
Wet density (γ_b)	18 kN/m^3
Liquid limit (LL)	55.76%
Plastic liquid (PL)	34.25%
Plasticity index (PI)	21.51%
Cohesion (c)	0.021 kg/cm^2
Friction angle (φ)	47.16°

1. Prepare soil testing equipment

The testing tools include 1×1×1 m steel boxes, an IWF steel frame, a dial gauge, a steel plate, and a proving ring. Furthermore, the soil loading has been arranged in an iron box using a hydraulic jack tool with a capacity of 3 tons. The load is installed on a steel plate set as a foundation model. The dial gauge was read for each 1mm settlement for a minute.

The dial gauge was read for each 1 mm settlement for a minute until it reached the ultimate load. Next, the iron plate load was applied periodically. The load addition was done simultaneously by reading the proving ring's value. The load addition was carried out per minute and stopped when the soil settlement was constant.

2. Preparing the materials

During the material preparation stage, the primary task involved collecting soil samples at Soropadan Village, in the Kulon Progo district. After soil sampling was completed, all the soil was subjected to solar drying until it reached a state of total dryness. Subsequently, the dried soil was pulverized and passed through sieve size No. 4.

After the sieve procedure, 60 kilograms of soil and 18 liters of water are selected to be mixed. After the soil reaches homogeneity through continuous mixing, it takes on a plastic consistency appropriate for field conditions.

After the soil and water have been thoroughly combined, the mixture is transferred to a steel box with a height of 5 cm. After that, the soil is compacted using wood. Then, this procedure is repeated until the soil reaches a vertical distance of 30 cm from the base of the steel plate box.

3. Soil test preparation

Before the test, water is applied to the soil sample within the steel container. Following the act of watering, the soil of the test specimen was allowed to sit for 24 hours to achieve a state of saturation with water.

4. Test variations preparation

Variations in additional reinforcement materials used in this study included sand, rice husk ash, and cement. Formulating the complementary material composition aims to improve the soil reinforcement tests.

It was mixing the original soil with added materials. The percentage of the mixing material was determined based on (Wibowo et al., 2020, 2021). The mixing process was carried out until the soil was plasticized. Then, it was saturated in the iron box and allowed for 24 hours to be ready for testing.

The scenario for the specimen is the following:

Scenario 1: 3% sand, rice husk ash 3%, and cement 6%.

Scenario 2: 3% sand, rice husk ash, 6%, cement, 3%.

Scenario 3: 6% sand, rice husk ash 3%, and cement 3%.

Scenario 4: 6% sand, rice husk ash 6%, and cement 0%.

In phases, each variation was combined and evaluated. Once the mixing is complete, create a column reinforcement arrangement by inserting a 20 cm aluminum pipe with a 1 cm diameter into the soil to perforate it and fill it with the mixed soil.

Figure 1. Laboratory modeling

The reinforcement for mixed column 1 was re-excavated following testing utilized as reinforcement for the subsequent column. This process is iterated until every reinforcement passes the tests. The following describes the configuration pattern for the arrangement of mixed column reinforcements, which can be seen in Figure 1 and Figure 2. The stage was tested with a loading test to determine the ultimate load value and calculate the bearing capacity of the subgrade layer and its settlement.

The soil layer's bearing capacity ratio (BCR) is computed using Eq. (1) and Eq. (2) from

Terzaghi's ultimate bearing capacity (Oloo et al., 1997).

$$q_{\text{ult}} = \frac{P_{\text{ult}}}{A} \quad (1)$$

$$BCR = \frac{q_{\text{ult}}}{q_0} \quad (2)$$

The q_{ult} refers to the ultimate soil bearing capacity, P_{ult} is the ultimate soil load, A is the load area, and q_0 is the ultimate bearing capacity of the tested soil.

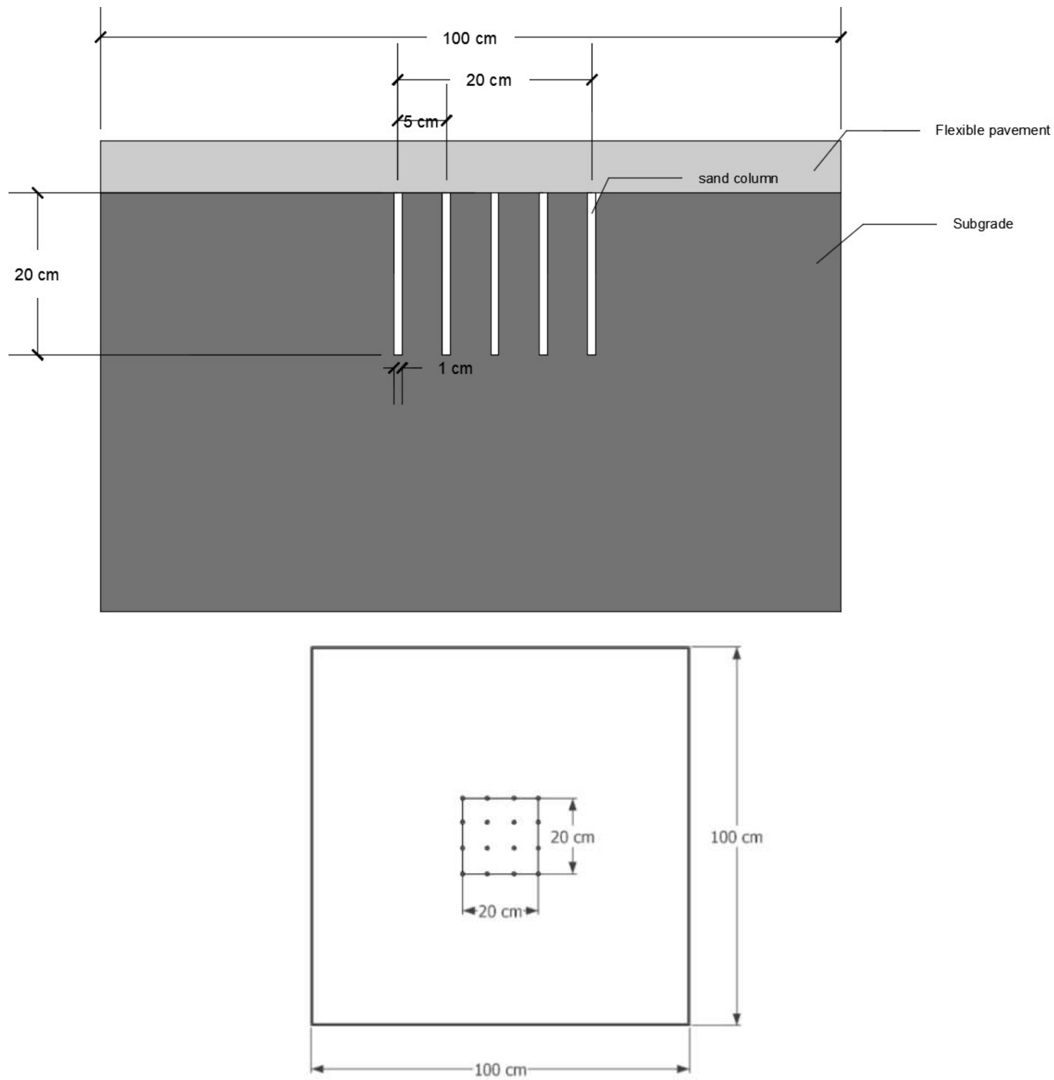

Figure 2. Sand column reinforcement configuration

Results and Discussion

The original soil classification was obtained by fraction passing the No. 200 sieve (Figure 3). Based on the Association of State Highway and Transportation (AASHTO) method, the soil is classified as A-7-5 (22),

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which has soil characteristics in the form of clayey soil, which is classified as basic soil with medium-poor criteria (Figure 4a).

Meanwhile, soil classification by the Unified Soil Classification System (USCS) (Figure 4b) is classified as fine-grain soil in the form of high-plasticity silt (MH) or high-plasticity organic clay (OH). They have fair to poor drainage characteristics and are considered poor subgrade material (Reimer, 1992).

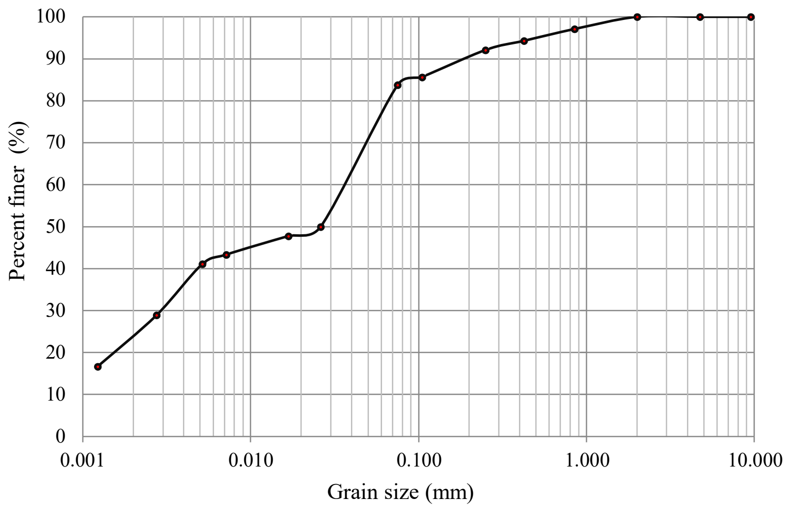
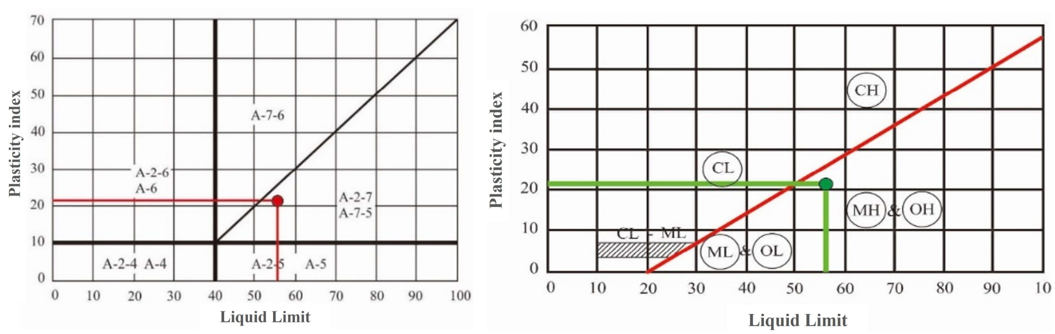


Figure 3. Grain size distribution



(a) (b)

Figure 4. a) Plasticity index of soil AAHSTO Method, b) USCS Method

The same laboratory tests were also conducted on the treated soil samples. The original soil with treated soil columns was added to increase the bearing capacity. The arrangement of the treated soil column can be seen in Figure 2.

An ultimate load test was conducted to determine the initial bearing capacity of the soil. Figure 5 shows that the ultimate load of the original soil is 43.8 kg, and the settlement is 11 mm, which is the soil's ability to retain the highest load before the soil collapses.

The loading results in varying settlements for each reinforcement are discussed as follows. According to Figure 5, the relationship between load and settlement on the original and treated soil is that the higher the load offered, the higher the settlement value that occurs on each soil. There is a significant reduction up to a particular level, indicating that a soil collapse has happened. Soil failure occurs when the sample reaches its ultimate limit, which can be observed through a significant increase in settlement.

The original soil has a maximum load capacity of 43.8 kg. If the load exceeds this limit, the soil will collapse. Meanwhile, the reinforced soil in scenario 1 has a load capacity limited to 49.5 kg, scenario 2 has a load capacity limited to 55 kg, and scenario 3 has a load capacity limited to 92 kg. Scenario 4 achieves a maximum load of 110 kg, while Scenario 1 achieves the a minimum load of 49.5 kg.

In scenario 4, the soil can bear a higher load than in scenarios 1-3. This condition is due to the increased amount of added materials, such as sand and rice husk ash, in scenario 4. Additionally, the sand functions as a drainage, while the rice husk ash behaves as a pozzolan, facilitating the interaction between soil particles. It is enhanced with additional components that reduce soil settlement.

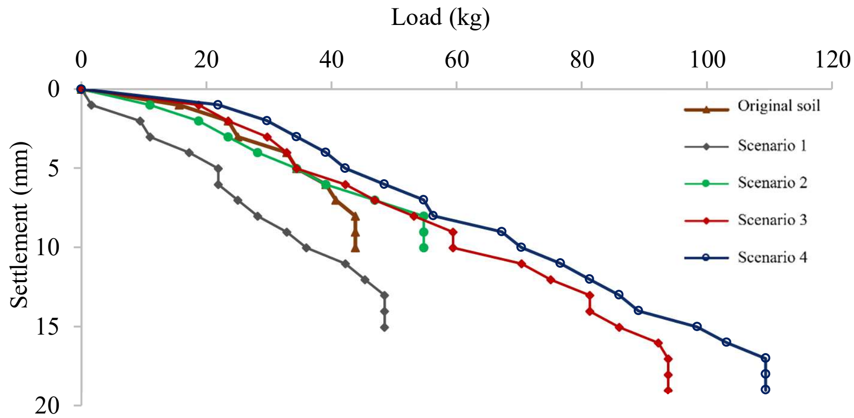


Figure 5. Load – settlement curve for the original and treated test

A soil moisture content assessment was performed on the sample following the loading test. The test results indicated that Scenario 1 is the most efficient for reducing moisture content, resulting in a 4% reduction from the initial moisture content, as seen in Figure 6.

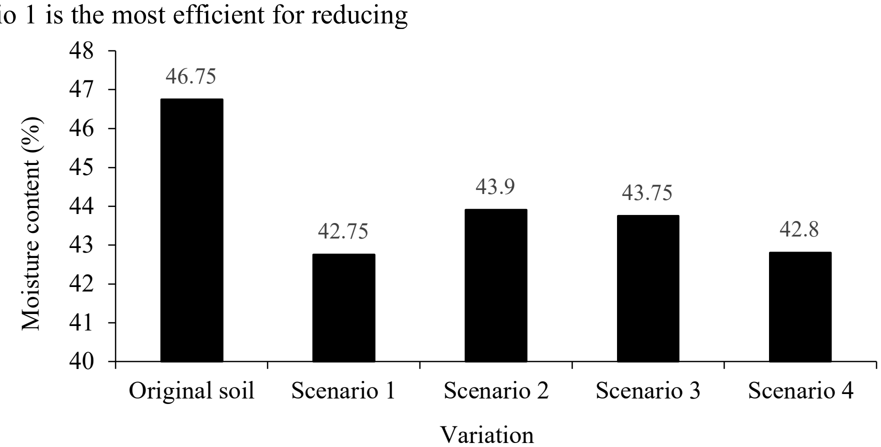


Figure 6. Moisture content comparison for each scenario

The ultimate soil bearing capacity and the Bearing Capacity Ratio (BCR) analysis using Equation (2) is conducted with a foundation load area of 400 cm². Introducing reinforced sand columns to the soil results in an enhanced soil-bearing capacity, which varies depending on the scenario. The result shows that in all scenarios involving a sand column, Scenario 1: 3% sand, 3% rice husk ash, and 6% cement obtained a q_{ult} is 0.23 kg/cm^2 and BCR 114.94%; Scenario 2: 3% sand, 6% rice husk ash, and 3% cement obtained a q_{ult} is 0.12 kg/cm^2 and BCR 11.49%; Scenario 3: 6% sand, 3% rice husk ash, and 3% cement obtained a q_{ult} is 0.14 kg/cm^2 and BCR 26.44%; Scenario 4: 6% sand, 6% rice husk ash, and 0% cement obtained a q_{ult} is 0.24 kg/cm^2 and a BCR of 116.09% (Figure 7 and 8).

According to Figure 7, in Scenario 4, treated soil has the highest ultimate soil bearing capacity (q_{ult}) with a value of 0.24 kg/cm² and a Bearing Capacity Ratio (BCR) of 116.09%. Conversely, Scenario 2 exhibits the lowest q_{ult} value at 0.12 kg/cm² and a BCR of 11.49% (Figure 8).

The addition of material affects the ultimate bearing capacity of the soil. Increasing the value of soil's ultimate bearing capacity (q_{ult}) of soil by strengthening additional materials has varying values. The increase in soil-bearing capacity is attributed to the incorporation of rice husk ash, a pozzolanic material known to act as a binder and harden the soil. In addition to its cementitious properties, water-absorbent sand reduces the soil's plasticity and enhances its overall stability (Soares et al., 2015).

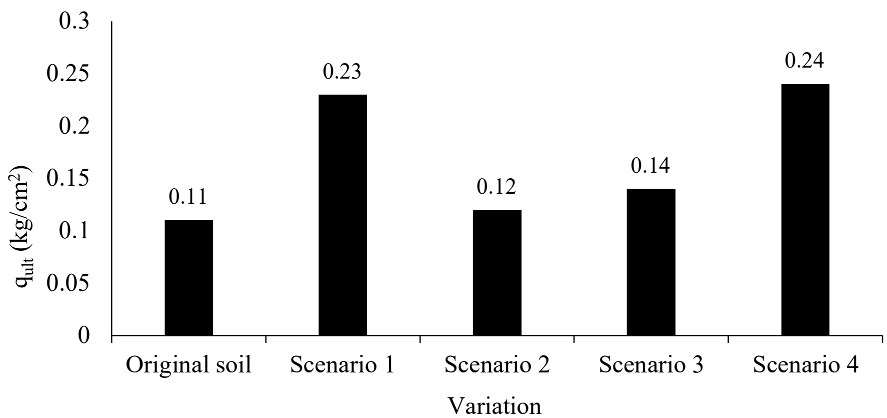


Figure 7. Ultimate bearing capacity comparison

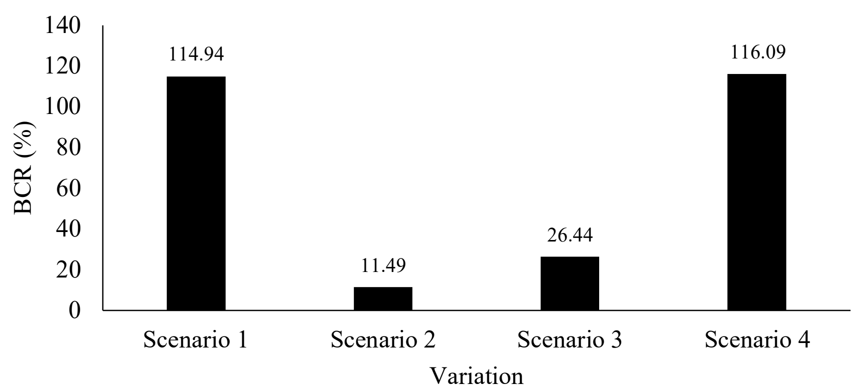


Figure 8. BCR comparison of mixed sand column variations

Conclusion

The experimental study of clay soil (AASHTO method) for flexible pavement was performed as a reinforcement process employing a combination of sand columns, rice husk ash, and cement across four scenarios. Among these scenarios, Scenario 4 showed the most promising outcome, with a sand column composition of 6% sand, 6% rice husk ash, and 0% cement, achieving the highest bearing capacity of 0.24 kg/cm² and a remarkable Bearing Capacity Ratio (BCR) value of 116.09%. In contrast, Scenario 1 effectively reduced moisture content by 4% relative to the initial moisture level through a mixture of 3% sand column, 3% rice husk ash, and 6%.

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