

The Effect of Soft Soil Reinforcement Using Gravel Columns and Used Tire Columns in the Graha Lentera Holtekam Residential Area

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ABSTRACT

The rapid development of housing and commercial areas, such as housing developments (*KPR*) or shop houses (*Ruko*), on new land often faces challenges due to potential non-compliance with construction standards, increasing the risk of structural failures like land subsidence. This study aims to investigate the effectiveness of different reinforcement methods to enhance the soil's carrying capacity for safe, economical, and durable construction. Conducted in the engineering laboratory of Cenderawasih University, this research explores three soil conditions: soil without reinforcement, soil reinforced with a 6 cm diameter gravel column at depths of 4 cm and 8 cm, and soil reinforced with a 6 cm diameter used tire column at depths of 4 cm and 6 cm. The tests were performed using a hydraulic jack to apply vertical pressure until the soil showed no further settlement. The results indicate that the unreinforced soil had an ultimate load of 950 kPa with a *qijin* of 380 kPa, whereas the gravel column-reinforced soil reached the highest carrying capacity of 1,849 kPa with a *qijin* of 739.444 kN, a 95% improvement compared to unreinforced soil. The findings highlight the significant potential of gravel and used tire column reinforcement in increasing the load-bearing capacity of soil for construction purposes.

Keywords: Reinforcement of soft soils, gravel columns, used tires, bearing capacity, descent.

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INTRODUCTION

Development growth occurs massively in almost all regions of Indonesia, as well as in the Papua region, especially Jayapura City, where there is a high demand for decent and economical housing in terms of both cost and development. Currently, land prices are expensive, and this is compounded by the rising costs of construction materials. Consequently, it is inevitable that many new land clearings are being used as locations for housing development (*KPR*) or shop houses (*Ruko*) as residential and business places, which may technically not meet the requirements and standards for erecting construction buildings in these areas, especially on a large scale. This increases the potential for construction failures, such as land subsidence (*settlement*) (Liu et al., 2020; Shariati et al., 2024; Sovacool, 2013). In areas with soft soil types, instability of construction is likely, as seen in the Holtekam area, Muara Tami district, which is characterized by soft clay soil (Miranda et al., 2015; Tandel et al., 2012; Timilsina & Shah, 2016). Given these factors, it is necessary to find ways to increase the carrying capacity of the land so that it meets the requirements for constructing buildings that are safe, economical, and have a longer lifespan (Adhi, 2028; Amsri, 2017; Hardiyatmo, 2020).

From the explanation above, this forms the rationale and basis for improving soft clay soil through reinforcement efforts, which are hoped to be a viable alternative. Reinforcement is carried out to increase carrying capacity, with the aim of minimizing construction failures

and ensuring safe buildings (Darwis, 2017; Nurindah, 2017; Wibowo, 2021). Before reinforcement, field research must be conducted to obtain soil data as construction material. With this information, it becomes easier to determine the type of reinforcement needed to address problems arising from soil behavior under construction. This research aims to provide an alternative for soil reinforcement by selecting materials that are more economical and of good quality, such as using gravel and used tires as basic materials for soil reinforcement, with the hope of increasing soil carrying capacity and reducing the occurrence of subsidence or *settlement*.

Siregar et al. (2018) conducted research on the use of geotechnical soil improvement techniques for enhancing the bearing capacity of soft clay soils in construction projects. Their study primarily focused on the use of geogrid reinforcements and identified improvements in soil stability when geogrids were applied at varying depths. However, the study did not explore more cost-effective or locally available materials like gravel and used tires for soil reinforcement (Deb et al., 2011; El Mahallawy, 2012; Vahedian et al., 2014). The research also lacks a detailed comparison of different reinforcement materials and their impact on the long-term stability of the soil under heavy loads (Ohenhen et al., 2025; Ohenhen & Shirzaei, 2022). This study fills the gap by investigating alternative reinforcement methods, such as gravel and used tires, which are more affordable and locally accessible in Indonesia, especially in regions like Papua (Abidin et al., 2015).

Budi et al. (2020) explored the effect of using stone columns and cement-based stabilizers in soft clay soil. Their results showed significant improvements in soil strength and reduced settlement. However, their study did not consider environmental factors or the sustainability of the materials used (Bagheri-Gavkosh et al., 2021; Edmonds, 2018; Pacheco-Martínez et al., 2013). The high cost of stone columns and the environmental impact of cement-based stabilizers make them less suitable for widespread use, especially in economically constrained areas. The current research aims to address these limitations by using recycled materials like used tires, which are environmentally friendly and offer a lower-cost alternative for improving soil stability.

While previous studies provided valuable insights into soil reinforcement, they did not explore the potential of more sustainable and economical materials like gravel and used tires for soft soil improvement. This research fills the gap by offering a solution that is not only cost-effective but also locally sustainable, particularly relevant for housing developments in Papua. By utilizing these materials, the study contributes to the broader discussion on affordable, environmentally responsible construction practices in Indonesia.

This research aims to evaluate the effectiveness of using gravel and used tires as soil reinforcement materials to improve the carrying capacity of soft clay soils, which are prone to *settlement* issues. The goal is to provide an affordable, sustainable solution for enhancing soil stability, ensuring safe and durable construction in economically disadvantaged regions like Papua. The findings are expected to offer a viable alternative to conventional reinforcement methods, promoting both environmental sustainability and cost-effectiveness in construction projects.

METHOD

This research employed a quantitative experimental research design to evaluate the effectiveness of gravel and used tire columns as reinforcement materials for soft clay soils. The study aimed to assess the improvement in the carrying capacity of the soil and the potential to reduce settlement or land subsidence issues in construction. The research focused on the impact of these reinforcement materials on the soil's strength and stability under vertical load conditions. Laboratory experiments were conducted in the engineering laboratory of Cenderawasih University with a scale model of 1:50. The experiments were performed on soil samples obtained from the Holtekam area, Muara Tami district, Jayapura, which is known for its soft clay soil.

The population in this study consisted of soft clay soil samples from the Holtekam area, and the data sample included three types of soil conditions: unreinforced soil, soil reinforced with gravel columns, and soil reinforced with used tire columns. A purposive sampling technique was used to select soil samples based on their homogeneity and relevance to the study objectives. The sample size was determined by the amount of available soil in the laboratory and the number of different reinforcement variations tested. The experiment utilized a hydraulic jack as the primary research instrument to apply a vertical load to the soil samples, with load readings and settlement measurements taken at each stage.

To ensure the validity and reliability of the results, the construct validity of the experimental setup was confirmed by conducting initial tests to ensure that the applied loads and soil conditions reflected real-world scenarios. Reliability was ensured through repeated tests for each sample type. Data collection involved measuring the ultimate load-bearing capacity of the soil and the degree of settlement for each reinforcement variation. The procedure involved preparing the soil samples, applying the reinforcement materials, and applying vertical loads while recording the load readings and settlement data. The collected data were analyzed using descriptive statistical analysis and comparative analysis techniques with the help of SPSS software to determine the effect of different reinforcement materials on the soil's performance.

RESULTS AND DISCUSSION

Sondir Test Results

From the results of the Sondir test, we can classify the soil type as seen from the q_c and f_r values. For this test, it was obtained at a depth of 0 – 2.20 m including firm soil, 2.40 – 7.00 m deep with very soft soil, 7.20 – 16.40 m with firm soil, 16.60 – 21.80 m with stiff soil, 22.00 – 27.00 m with very stiff soil and 27.20 – 28.00 m with hard soil. If viewed from the q_c and f_r values, it can be concluded that the type of soil in the residential area of Graha Lentera Holtekam is a type of sandy clay soil and silt.

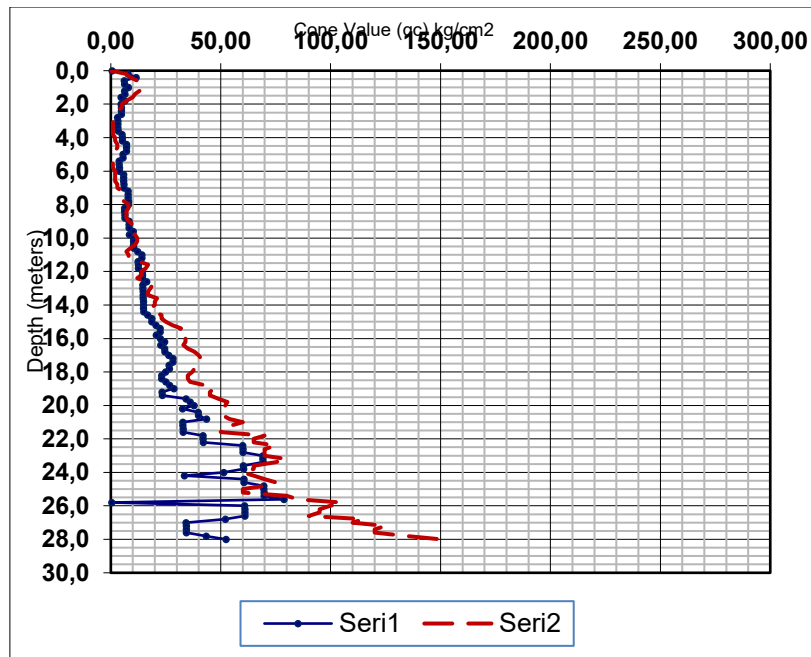


Figure 1. SPT Test Results Chart

Hand Drill Testing Results

Hand Drill testing was carried out at 1 point with a depth of 2 m. From the results of the Hand drill, the same type of soil was obtained, namely at a depth of 1 m of grayish-brown soil as well as at a depth of 2 m with grayish-brown soil. The results of this test can be seen in the Bore Log test.

Moisture Content Test Results

From the results of the soil property test, it was found that the moisture content contained in the soil was 52.07%. This moisture content test was carried out after the test soil sample was dried for 24 hours in the oven and taken dry weight.

Table 1. Moisture Test Results

Sample Number	Description	Unit	Soil		
			K	A	II
1	Weight of container + wet sample	gr	40.99	51.99	52.67
2	Weight of container + dry sample	gr	31.18	38.76	42.51
3	Weight of container	gr	12.64	12.94	12.89
4	Weight of water "1-2"	gr	9.81	13.23	10.16
5	Weight of dry sample "2-3"	gr	18.54	25.82	29.62
6	Moisture content "(4/5)×100"	%	52.91	51.24	43.42
7	Average	%	-	52.076	-

Specific Gravity Test Results

In addition to the moisture content from the results of the property test, it was also obtained that the soil density was 2.51% and the soil at the location of the housing site of Graha Lentera Holtekam is a type of organic clay soil.

Table 2. Soil Specific Gravity Test Results

Sample Number / Depth	Description	Symbol	Soil	
			I	II
1	Weight of Pycnometer + Sample	W2	69.90	69.97
2	Weight of Pycnometer	W1	55.30	55.65
3	Weight of Soil (W2 - W1)	Wt	14.60	14.32
4	Temperature	°C	20	20
5	Weight of Pycnometer + Water + Soil	W3	169.99	167.84
6	Weight of Pycnometer + Water at Tc	W4	161.13	159.30
7	W5 = W2 – W1 + W4	W5	175.73	173.62
8	W6 = W5 – W3	W6	5.74	5.78
9	Specific Gravity (Wt / (W5 – W3))		2.544	2.478
10	Average		-	2.511

Results of Plastic Limit and Plasticity Index (Atterberg Limit) Test

From the results of the Atterberg Limit test, the plastic limit value (PL) was 18.57% and the liquid limit (LL) was 76.55% so that the plasticity properties (PI) of the soil of 57.98% can be seen from the results of the Atterberg test.

Table 3. Atterberg Limit Test Results

Number of Blows	35	31	22	13		
Cup Number	6	2	25	7	50	A
Wt. of Cup + Wet Sample (gr)	24.25	32.61	30.05	39.95	26.50	24.06
Wt. of Cup + Dry Sample (gr)	20.01	24.50	22.40	26.90	24.45	22.32
Weight of Water (gr)	4.24	8.11	7.65	13.05	2.05	1.74
Weight of Cup (gr)	13.26	12.64	12.86	12.90	13.42	12.94
Weight of Dry Sample (gr)	6.75	11.86	9.54	14.00	11.03	9.38
Water Content (%)	62.81	68.38	80.19	93.21	18.59	18.55
Average Plastic Limit						18.57%

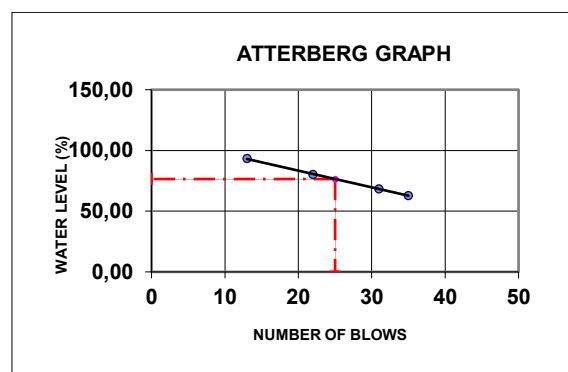


Figure 2. Graph of the Atterberg Test Results

Hydrometer Test Results

In the results of the Hydrometer test, the size of the fine-grained soil was obtained that passed the 200 inch filter and from the results of the Hydro filter a curve was made of the arrangement of soil grains as follows.

Triaxial Test Results

From the Triaxial test, a graph of the Mohr circle was obtained along with the known cohesion values and shear angle.

Compaction Test Results (Compact) (SNI 1743 : 2008)

From the results of the compaction test, the soil gamma value (γ_d) and optimal moisture content were obtained.

Table 4. Compaction Test Results

LIGHT / WEIGHT	A-III	A-III	A-III	A-III
Mold Number	A-III	A-III	A-III	A-III
Number of Layers	5	5	5	5
Blows per Layer	56	56	56	56
Wet Soil Weight (gr)	6000	6000	6000	6000
Initial Water Content (%)	10.30	10.30	10.30	10.30
Water Added (%)	13.45	15.45	17.45	19.45
Water Added (ml)	171.35	280.15	388.94	497.73
WET DENSITY	Value 1	Value 2	Value 3	Value 4
Soil + Mold Weight (gr)	10173	10480	10533	10503
Mold Weight (gr)	6257	6257	6257	6257
Wet Soil Weight (gr)	3916	4223	4276	4246
Mold Volume (cm³)	2074.96	2074.96	2074.96	2074.96
Wet Density (kg/cm³)	1.89	2.04	2.06	2.05
Dry Density ($\gamma_d = \gamma_b \times 100 / (100 + w)$)	1.63	1.72	1.69	1.63
WATER CONTENT	I	7	D	E
Wet Soil + Cup Weight (gr)	78.87	77.36	78.54	95.10
Dry Soil + Cup Weight (gr)	69.74	67.30	66.62	78.50
Water Weight (gr)	9.13	10.06	11.92	16.60
Cup Weight (gr)	12.90	13.30	12.90	12.90
Dry Soil Weight (gr)	56.84	54.00	53.72	65.60
Water Content (%)	16.06	18.63	22.19	25.30
Zero Air Void Line	2.04	1.94	1.82	1.72

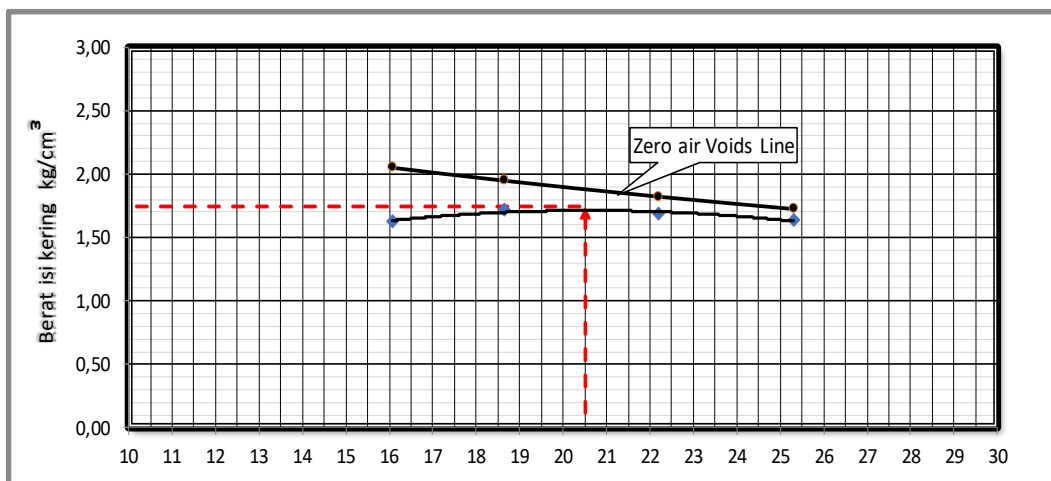


Figure 3. Graph of Laboratory Compaction Test Results

Results of Soil Modeling Without Reinforcement

The original soil with no reinforcement is loaded gradually and it is seen how much of a decrease occurs to the load provided vertically by the hydraulic jack.

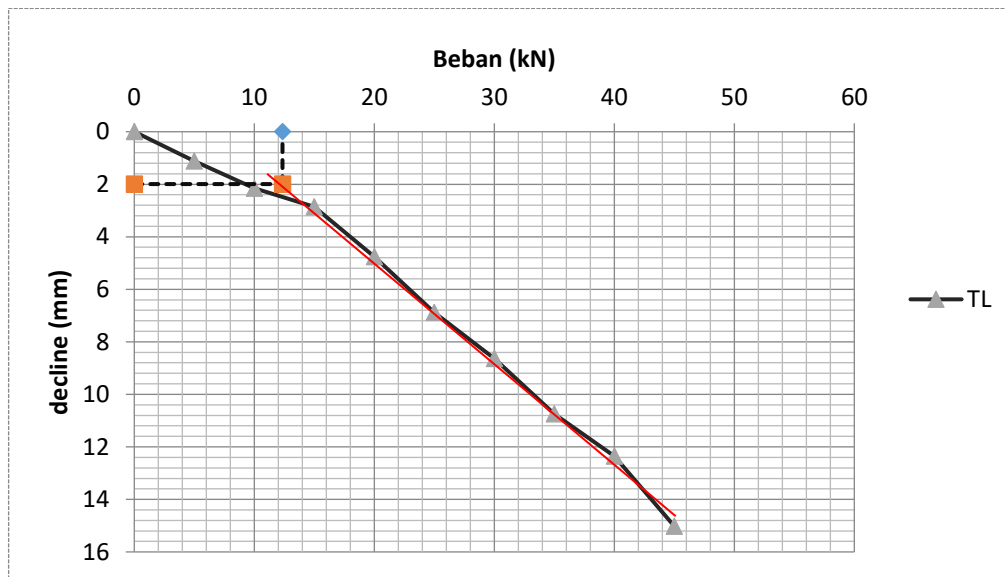


Figure 4. Graph of the Relationship of Decline and Ground Load Without Reinforcement.

The graph shows that the ultimate load (p_u) on the original soil is 13.68 kN with a decrease of 1,861 mm or 4.0 %, with a plate area (P) of 24 cm long and (L) of 6 cm wide, so to determine the value of the carrying capacity is to refer to Terzaghi's analysis, with the equation:

$$\begin{aligned}
 P_u &: 13.68 \text{ kN} \\
 A &: 24 \times 6 \\
 Q_{ult} &: 13.35/144 = 0.0950 \text{ kN/cm}^2 = 950.00 \text{ kpa} \\
 \text{With Q permission} \\
 Q_{ijin} &: (950.00 \times 1)/2.5 \\
 &: 380.00 \text{ kN}
 \end{aligned}$$

From the equation above, it is obtained that the ultimate carrying capacity of the original soil is 950.00 Kpa with a maximum ultimate load of 380.00 kN.

Soil Reinforcement of Gravel Columns with Depth Variation of 4 cm

The original soil was reinforced with a gravel column with a varying depth of 4cm and with a hole diameter of 6 cm, the results of the analysis from the reinforcement experiment can be seen on the graph of the relationship between the load and the drop that occurred during the loading experiment. The Vertical axis indicates the decrease (mm) and the Horizontal axis indicates the load value (kg).

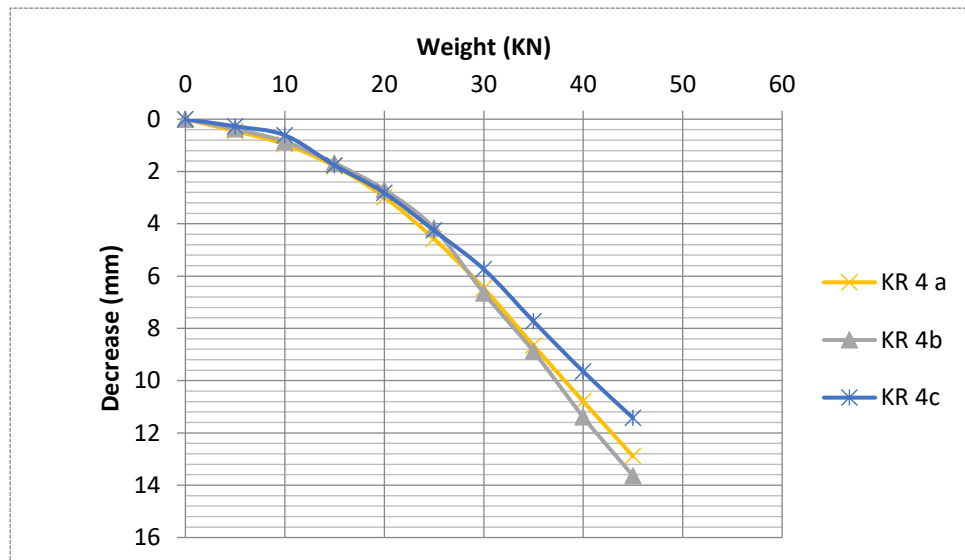


Figure 5. Graph of Relationship of Decline and Reinforced Soil Load of Gravel Columns With 4cm Depth Variation

Table 5. Comparative recapitulation of the Carrying Capacity of permits and the increase in carrying capacity values from the Modeling of Gravel Columns with a depth of 4cm and Original Soil

Model	Type	Qijin (kN)	Bearing Capacity (BCR)
Original Soil	1	380.00	0%
Gravel	4a	615.28	62%
Gravel	4b	570.83	50%
Gravel	4c	543.06	43%

From the above recapitulation, it was found that the reinforcement of the 4a gravel column received a qijin bearing capacity value of 615.28 kN with an increase in carrying capacity of 62%, and a decrease of 1.75 mm or 3.5%, the 4b qijin gravel column of 570.83 kN with an increase in carrying capacity value of 50% and a decrease of 1.85mm, or 3.7%, then the 4c qijin gravel column of 543.06 kN with an increase in carrying capacity value of 43% and a decrease of 1.070 mm or 2.1%.

Soil Reinforcement of Gravel Columns with Depth Variation of 8 cm

The original soil was reinforced with a gravel column with a depth varying of 8 cm and with a hole diameter of 6 cm, the results of the analysis from the reinforcement experiment can be seen on the graph of the relationship between the load and the drop that occurred during the load experiment. The Vertical axis indicates the decrease (mm) and the Horizontal axis indicates the load value (kN).

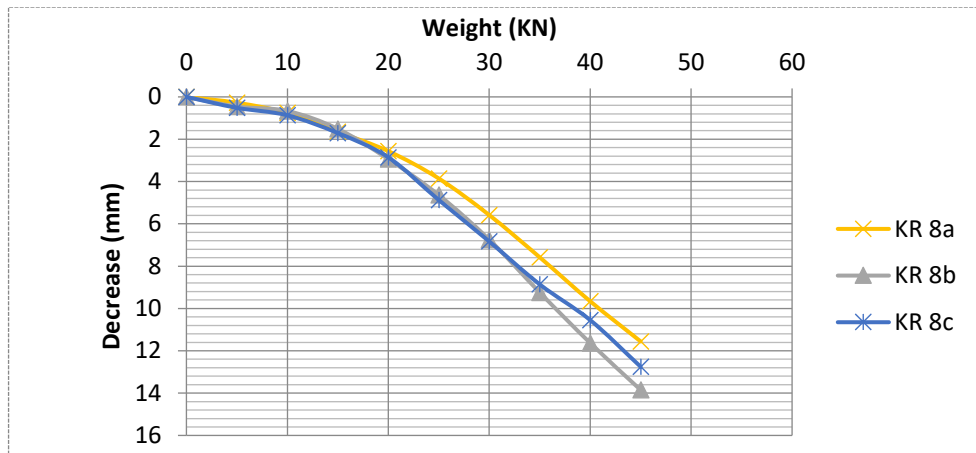


Figure 6. Graph of Relationship of Descent and Reinforced Soil Load Gravel Columns With 8cm Depth Variation

Table 6. Recapitulation of Comparison of Carrying Capacity of Permits and Increase in Carrying Capacity Values from Modeling Gravel Columns with a Depth of 8cm and Original Soil.

Model	Type	Qijin (Kg/cm ²)	Bearing Capacity (BCR)
Original Soil	1	380.00	0%
Gravel	8a	739.44	95%
Gravel	8b	574.17	51%
Gravel	8c	711.05	87%

From the recapitulation above, it was found that the reinforcement of the 8a gravel column received a qijin carrying capacity value of 739.44 kN with an increase in carrying capacity value of 95%, and a decrease of 2.33 mm or 4.7%, the 8b qijin gravel column of 574.17 kN with an increase in carrying capacity value of 51% and a decrease of 1.45 mm or 3.0% then the 8c qijin gravel column of 711.05 kN with an increase in carrying capacity value of 87% and a decrease of 1.65 mm or 3.3%.

Ground Reinforcement of Used Tire Columns with Depth Variation of 4 cm

The original soil is given a reinforced waste tire column with a depth varying of 4 cm and with a hole diameter of 6 cm, the results of the analysis from the reinforcement experiment can be seen on the graph of the relationship between the load and the drop that occurred during the loading experiment. The Vertical axis shows the decrease (mm) and the Horizontal axis indicates the load value (kN).

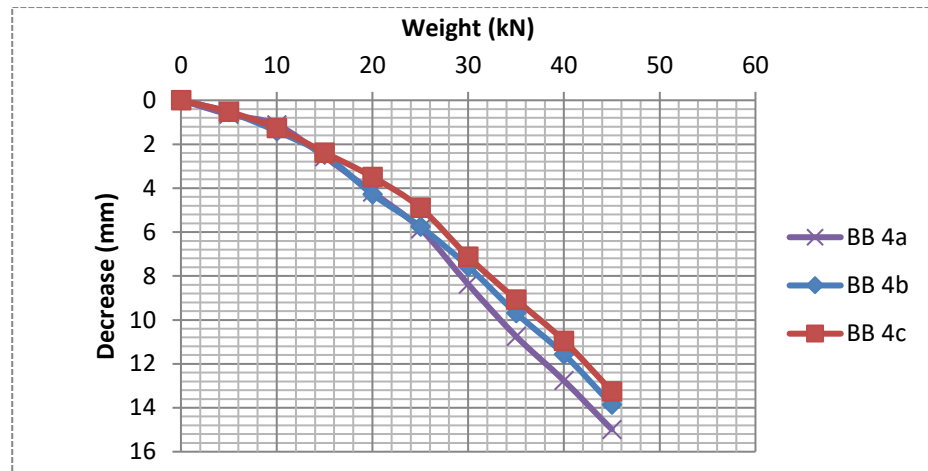


Figure 7. Graph of Descent and Ground Load Relationship Reinforced Used Tire Columns with 4cm Depth Variation.

Table 7. Recapitulation of Comparison of Carrying Capacity and Increase in Carrying Capacity Value from Modeling of Used Tire Columns with a Depth of 4cm and Original Soil

Model	Type	Qijin (kN)	Bearing Capacity (BCR)
Original Soil	1	380.00	0%
Used Tires	4a	487.50	28%
Used Tires	4b	510.00	34%
Used Tires	4c	588.75	55%

From the recapitulation above, it was found that the reinforcement of the 4a used tire column received a permit carrying capacity value of 487.50 kN with an increase in carrying capacity of 28%, and a decrease of 1.84 mm or 3.7%, the 4b used tire column of 510.00 kN with an increase in carrying capacity value of 34% and a decrease of 1.845 mm or 3.7%, then the 8c used tire column of 588.75 kN with an increase in carrying capacity value of 55% and a decrease of 2.02 mm or 4.0%.

Ground Reinforcement of Used Tire Columns with Depth Variation of 8 cm

The original soil was given a reinforced column of used tires with a varying depth of 8 cm and with a hole diameter of 6 cm, the results of the analysis of the reinforcement experiment can be seen on the graph of the relationship between the load and the drop that occurred during the loading experiment. The Vertical axis indicates the decrease (mm) and the Horizontal axis indicates the load value.

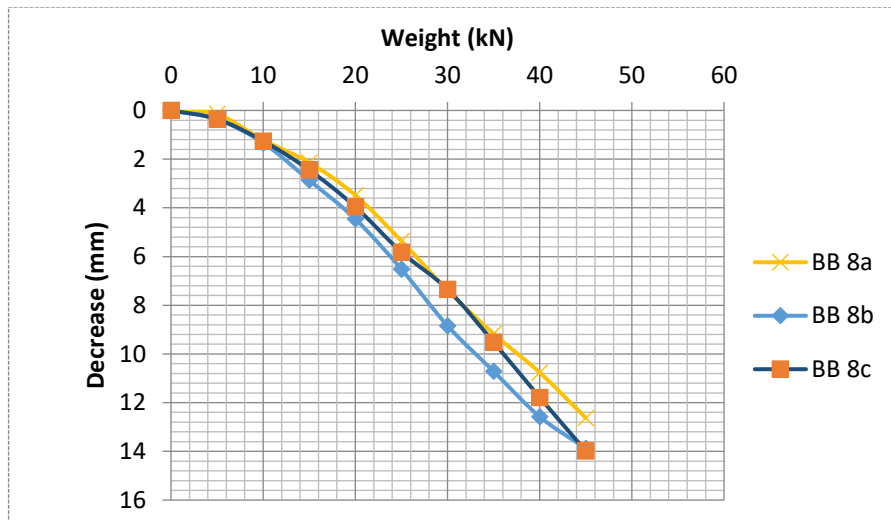


Figure 8. Graph of Relationship of Descent and Reinforced Ground Load Used Tire Columns With 8cm Depth Variation.

Table 8. Recapitulation of Comparison of Carrying Capacity of Permits and Increase in Carrying Capacity Value from Modeling of Used Tire Columns 8 cm Depth and Original Soil.

Model	Type	Qijin (kN)	Bearing Capacity (BCR)
Original Soil	1	380.00	0%
Used Tires	8a	520.56	37%
Used Tires	8b	515.28	36%
Used Tires	8c	560.42	47%

From the recapitulation above, it was found that the reinforcement of the 8a used tire column received a qijin carrying capacity value of 520.56 kN with an increase in carrying capacity of 37% and a decrease of 2.38 mm or 4.8%, the 8b qijin used tire column of 515.28 kN with an increase in carrying capacity value of 36% and a decrease of 2.49 mm or 5.0%, then the 8c qijin used tire column of 560.42 kN with an increase in carrying capacity value of 47% and a decrease of 2.23 mm or 4.5%.

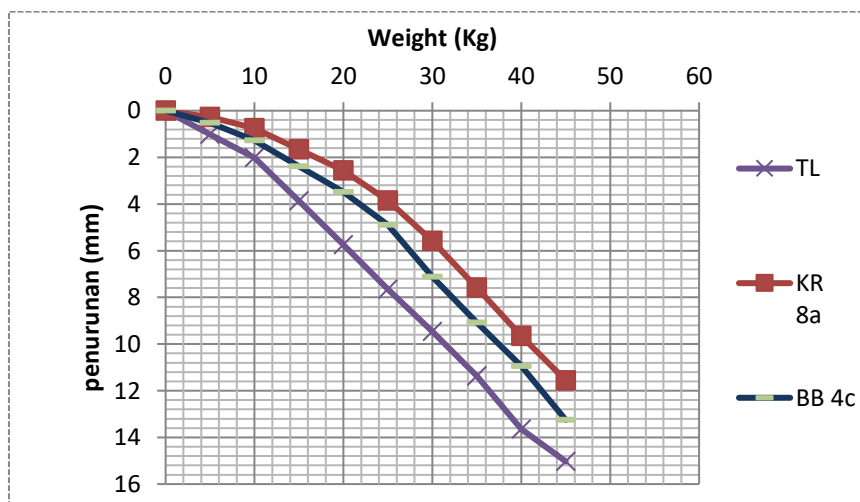


Figure 9. Graph of Soil Settlement Relationship Without and With Reinforcement

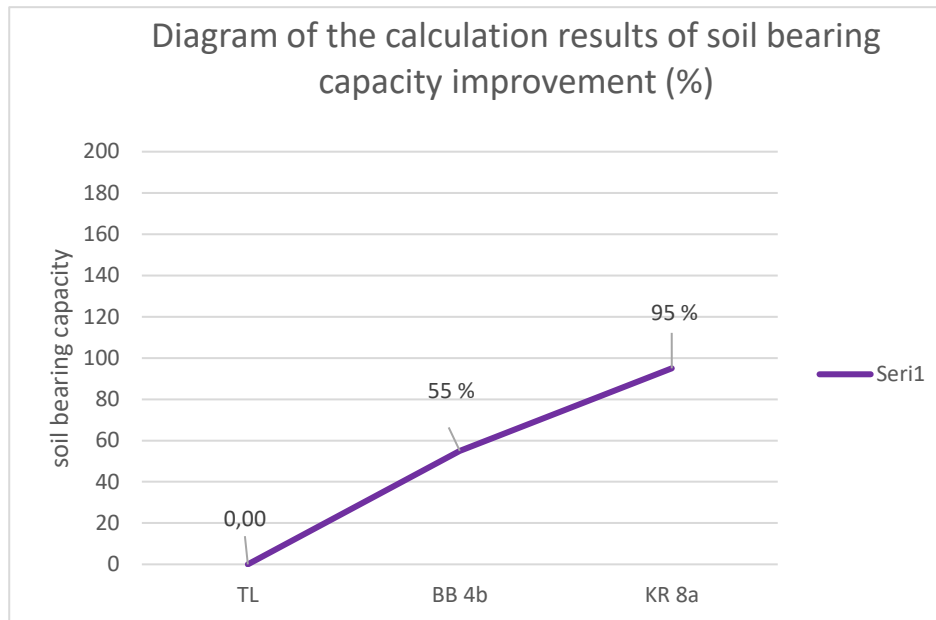


Figure 10. Diagram of Calculated Soil Bearing Capacity Improvement (BCR)

From the results of soil reinforcement with and without reinforcement, the value of the increase in carrying capacity for reinforcement with used tires obtained a carrying capacity increase value (BCR) of 1,472 Kpa or 55 % compared to the ground without reinforcement of 950.00 Kpa or 0.00%, then reinforcement with gravel columns obtained the largest carrying capacity increase value (BCR) which was 1,849 Kpa or 95% compared to soil without reinforcement.

CONCLUSION

The analysis of soft soil reinforcement in Holtekam revealed significant improvements: unreinforced soil had a bearing capacity of 950.00 kPa (*qijin*: 380.00 kN, settlement: 4.0%), while gravel column reinforcement (KR8a) achieved 1,849 kPa (*qijin*: 739.444 kN, 95% increase, settlement: 4.7%) and used tire columns (BB4c) reached 1,471 kPa (*qijin*: 588.75 kN, 55% increase, settlement: 4.0%), demonstrating gravel's superior effectiveness. These results highlight the potential of both materials to enhance soil stability, though gravel columns performed best. Future research should investigate long-term environmental and cost impacts of these reinforcements, as well as optimize depth and diameter parameters for varied soil conditions to improve scalability in construction projects.

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