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UTILIZATION OF PLASTIC WASTE AS SOIL STABILIZATION MATERIAL AND THEIR EFFECT ON UNCONFINED COMPRESSIVE STRENGTH VALUES

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ABSTRACT

The objective of this research was to improve the bearing capacity of the soil located on Kampung Juhut Street, Pandeglang Regency, which initially had a bearing capacity of 3.01%, through stabilization methods. The plastic powder was selected as an additive due to its non-cohesive characteristics, which counterbalance the cohesive nature of clay soil. The study aimed to identify the soil type and classification, evaluate the impact of soil physical properties, and examine the changes in unconfined compressive strength after incorporating plastic powder in proportions of 2%, 4%, 6%, 8%, and 10%, with curing durations ranging from 0 to 28 days. The results indicated that the soil belonged to the category of organic clay soils with moderate to high plasticity according to the USCS soil classification system. The plasticity index decreased from 22.9% to 12.2% at the 8% variation and 11.9% at the 10% variation. The initial unconfined compressive strength of the soil was 1.1 kg/cm^2. The greatest improvement was observed at the 8% variation, resulting in an unconfined compressive strength value of 3.4 kg/cm^2, indicating a highly rigid consistency.

Keywords: Bearing Capacity; Clay; Plastic; Unconfined Compression Strength

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1. INTRODUCTION

Soil strength is one thing that needs to be considered in the planning and work of civil building construction (Consoli et al.,2002). Choosing an incorrect location will affect construction, one of which is if the soil is soft clay. To overcome this by improving the soil, also known as soil stabilization (Mina et al., 2021). This study uses plastic as an additive because it has considerable tensile strength and can obtain a sizeable soil-bearing capacity. So plastic material is considered adequate to be used as a stabilizing agent.

Soil stabilization is a soil engineering method that aims to improve and maintain specific properties in the soil properties to always meet the required technical requirements. In this case, various technical matters are required in optimizing construction performance, including; soil bearing capacity, soil shear strength, settlement, soil permeability, and so on, which technical requirements are always related to the type and function of the construction (Darwis, 2017). Based on previous studies using plastic powder with variations of 1%, 2%, 3%, 4%, 5%, and 10%, the maximum unconfined compression strength value is found at a 5%

variation with a value of 2,192 kg/cm2. It reaches the optimum Limit for added materials at a variation of 10%, where the unconfined compression strength value decreased to 1,982 kg/cm^2. Subsequent studies used variations of 0%, 0.5%, 1%, and 2%, with the maximum unconfined compression strength value found in the 0.5% variation of plastic pieces, namely 3.134 kg/cm^2 (Kassa et al., 2020).

The study examined the impact of incorporating PET fibers from plastic bottles into clay soil, finding that increasing PET content reduced maximum dry density and optimum moisture content while decreasing cohesion, suggesting the potential for utilizing this method with a 1.5% limit on PET bottle waste (Mohammed et al., 2018). The study investigated the positive impact of incorporating waste plastic fibers (PET) of different sizes into flat sand, resulting in significant improvements in shear strength, cohesion, and friction angle, particularly with 5.6 mm plastic fibers at concentrations of 10% and 12.5% (Jin et al., 2019). The utilization of plastic fibers as soil reinforcement has shsown promising results in enhancing strength and reducing settlement (Laskar & Pal, 2013).Incorporating PET fibers into the soil as Fiber Reinforced Soil (FRS) provides a cost-effective and eco-friendly solution that enhances soil strength and engineering properties, with an optimal fiber percentage of 0-5%, and higher aspect ratios yielding better soil improvement (Karmacharya & Acharya, 2017; Memon et al., 2019).

Therefore, the authors are interested in researching the addition of plastic powder with mixed variations of 2%, 4%, 6%, 8%, and 10%. This study's location was chosen for sampling clay soil, namely Kampung Juhut Street, Karang Tanjung District, Pandeglang Regency. The DCP test results at the study site indicated that the soil had a bearing capacity of 3.01%. Based on the 2017 Highways Regulation No 02/M/BM/2017**,** the minimum bearing capacity for the subgrade is at least 6%. So, the soil in the study location needs to be stabilized. Figure 1 shows the location of the soil sampling used in this study.

Figure 1. Location Map and Road Conditions at the Research Location

This study aims to determine the effect of plastic powder with a mixture composition of 2%, 4%, 6%, 8%, and 10% on the value of unconfined compressive strength in clay with a curing time of 0 days, 7 days, 14 days, and 28 days.

2. METHODS

The sampled soil is classified as distributed disturbed soil. While the added material used is PET (Polyethylene Terephthalate) plastic waste in powder, which comes from mineral water bottles. The plastic powder was obtained from a plastic waste enumeration business in Tangerang Regency, Banten. About 10 kg were put in sacks at the Laboratory of the Department of Civil Engineering, Faculty of Engineering, University of Sultan Ageng Tirtayasa, Cilegon. Because the plastic powder obtained is mixed with small to large pieces of plastic so that the granules are uniform, the plastic waste is filtered first through sieve number 8 for testing for compaction and unconfined compressive strength, then sieve number 200 for testing the physical properties of the soil. The plastic powder used varied by 2%, 4%, 6%, 8%, and 10% by weight of dry soil. The type of plastic used is PET (Polyethylene Terephthalate). This material was chosen because plastic can improve the value of internal friction to increase soil strength but has no large value in cohesion (Kumar & Vageesh, 2017). Plastic waste can increase the value of unconfined compressive strength to a certain extent (Singh & Mittal, 2019).

Figure 2. Plastic Powder before and after Filtering

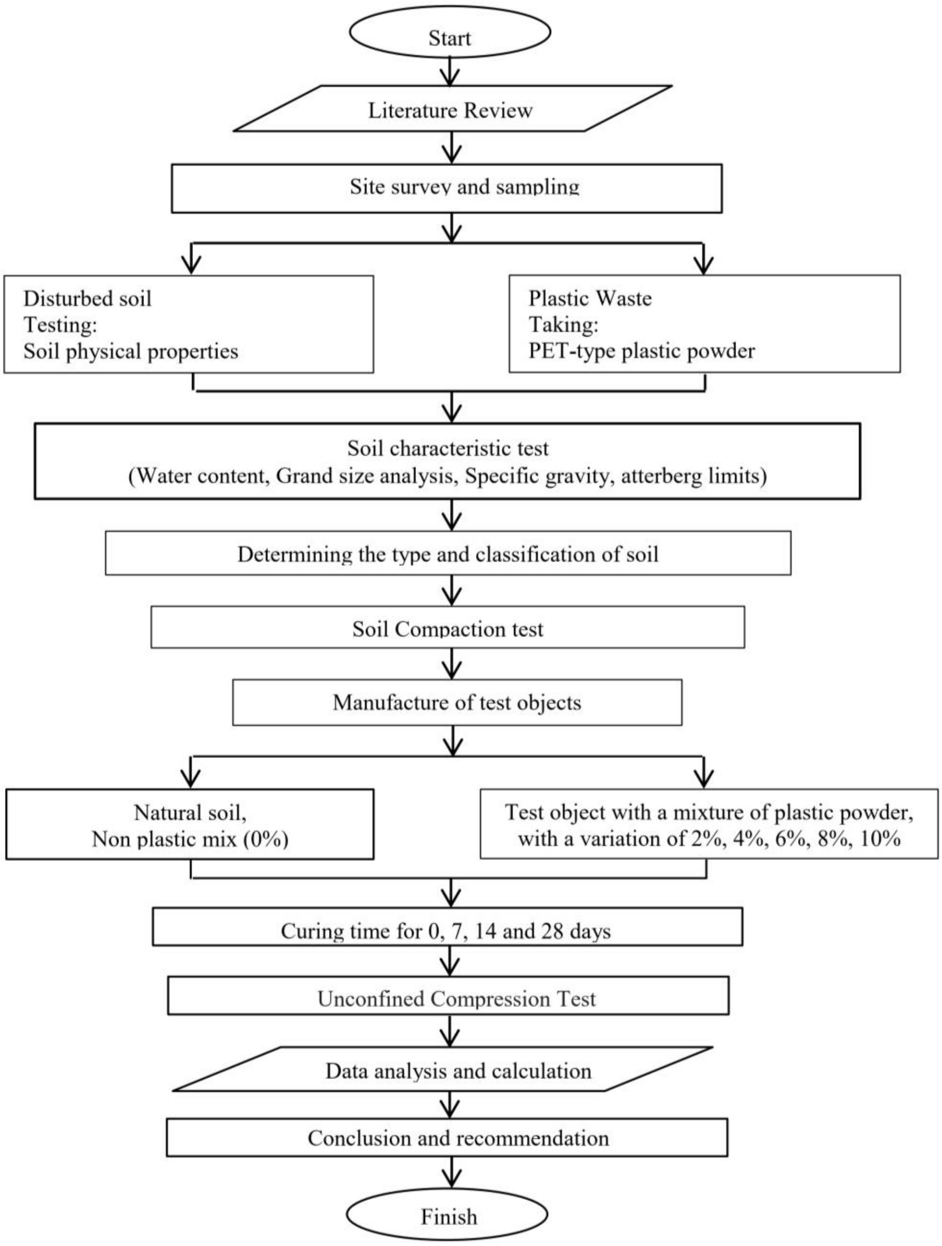

Figure 3. Research Flow Chart

Data calculations were carried out after obtaining data from laboratory test results. Furthermore, data management is carried out to determine the effect of adding plastic pieces to the value of the unconfined compressive strength test. Data calculations are adjusted to the applicable SNI provisions for each test:

1. Water content (SNI 1965:2008) (Badan Standardisasi Nasional, 2008c).
2. Specific gravity (SNI 1964:2008) (Badan Standardisasi Nasional, 2008b).
3. Analysis of grain size (SNI 3423:2018) (Badan Standardisasi Nasional, 2018).
4. Liquid limit (SNI 1967:2008) (Badan Standardisasi Nasional, 2008e).
5. Plastic limits (SNI 1966:2008) (Badan Standardisasi Nasional, 2008d).
6. Compaction (SNI 1742:2008) (Badan Standardisasi Nasional, 2008a).
7. Unconfined Compression Test (SNI 3638:2012) (Badan Standardisasi Nasional, 2012).

3. RESULTS AND DISCUSSION

3.1 Soil Property Data

Soil physical property testing is done to obtain soil physical property data needed for soil classification and determining suitability for specific uses, as well as to inform soil conditions from one area to another in the form of primary data. Table 1 shows data on soil properties.

Table 1. Natural Soil Test Results

Num.	Testing	Unit	Test Result
1	Water Content	%	43,4
2	Specific Gravity		2,6
3	Fill Weight		
	Soil Weight	gr/cm^3	1,9
	Dry Unit Weight	gr/cm^3	1,3
4	Grand Size Analysis (Passed sieve number 200)	%	51,6
5	Liquid Limit	%	64,5
6	Plastic Limit	%	41,6
7	Plasticity Index	%	22,9
8	Soil Compaction Test		
	Max Dry Unit Weight	gr/cm^3	1,1
	Optimal Water Content	%	34,9

3.2 Plasticity Index

The Plasticity Index (PI) is the difference between the liquid and plastic limits. Fine-grained soils are naturally in a plastic state, and the expansive soil category has a PI value of >30%. In this study, the natural soil plasticity index value was 22.9% and then decreased after adding the plastic powder to 12.2% at 10% and 11.9% at 10%. A change in the gradation of non-Cohesive plastic powder caused a decrease in value. Thus reducing the Cohesive properties of clay soil. The plastic powder does not stick to the soil when mixed. The mixed soil plasticity index values are shown in Table 2.

Table 2. Plasticity Index of Each Mixture

Variation of Plastic Powder	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Plasticity	Cohesive
			Value (%)		
0%	64,5	41,6	22,9	High Plasticity	Cohesive
2%	59,7	40,6	19,0	High Plasticity	Cohesive
4%	57,3	39,8	17,4	Moderate Plasticity	Cohesive
6%	53,3	37,7	15,6	Moderate Plasticity	Cohesive
8%	48,1	35,9	12,2	Moderate Plasticity	Cohesive
10%	45,8	33,8	11,9	Moderate Plasticity	Cohesive

Based on the table of Standard Plasticity Index for Highways, it can be concluded that after adding plastic powder, the soil on Kampung Juhut Street, Karang Tanjung District, Pandeglang Regency, can be used as subgrade soil at variations of 8% and 10%. The typical plasticity index values for highways are shown in Table 3.

Table 3. Standard Plasticity Index for Highways (Direktorat Jenderal Bina Marga, 2018)

Num.	Material	IP (%)
1.	*Subgrade*	≤ 15
2.	*Sub-base*	4 – 0
3.	*Base Course*	0 – 6

3.3 Soil Classification

Such as compaction characteristics, soil strength, unit weight, and so on. Based on the grain size analysis test, the weight value of the soil that passed sieve no. 200 is 51.6%, including fine-grained soils. The uniformity coefficient (Cu) is 1.7, and the gradation coefficient (Cc) is 0.2. In the Atterberg limit test, the liquid limit value is 64.5%, the plastic limit value is 42.6%, and the plasticity index is 22.9%. Based on the data described above, according to the USCS soil classification table, the soil on Kampung Juhut Street, Karang Tanjung District, Pandeglang Regency, is included in organic clay soils with moderate to high plasticity (SC)-Classification of soil based on USCS shown in Table 4.

Table 4. Classification of Soil according to USCS (Das, 1995)

Major Division			Group Symbol	Typical Name
Coarse-Grained Soils (More than 50% retained on No. 200 ASTM Sieve) (American Society for Testing And Materials, 2000)	**Gravels 50% or more of Coarse Fraction Retained on No. 4 ASTM Sieve**	**Clean Gravels**	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands More than 50% of the Coarse Fraction Passes the No. 4 ASTM Sieve	**Clean Sands**	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly-graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, and-silt mixtures
			SC	Clayey sands, sand-clay mixtures

3.4 Soil Compaction

The compaction increases the soil's strength, thereby increasing the bearing capacity of the foundation above it. The dry unit weight value of the natural soil was 1.1 gr/cm³, then decreased at 2% and 4% variation, respectively 1.1 gr/cm³ and 1.1 gr/cm³. This decrease in the dry unit weight of the soil occurs because the soil has gone through the practical addition of additives, which causes its binding ability to decrease so that it will reduce the adhesion between granules to the soil and water so that the soil will break easily. Furthermore, the maximum dry unit weight increased at 6%, 8%, and 10% with values of 1.1 gr/cm³, 1.1 gr/cm³, and 1.1 gr/cm³.

Meanwhile, the dry unit weight increased due to added materials filling the pore spaces in the soil, which were previously filled with water and air.

Based on the test results, the optimum water content value increases by adding 2% plastic powder because/ the clay is mixed with plastic powder. Then water is added, a segmentation (binding) process will occur, causing clumping, and the water content in the soil will also increase. Meanwhile, when the percentage of plastic powder increases, the required water content decreases because the plastic powder cannot absorb water, so the area for water absorption from the soil will decrease. The result of compaction testing is shown in Table 5.

Table 5. Soil Compaction Result Value

Variation of Plastic Powder	Optimal Water Content		Maximum Dry Unit Weight	
	Value	Percentage Increase	Value	Percentage Reduction
0%	35	0,00	1,1	0,00
2%	39,9	14,0	1,1	1,3
4%	39,1	11,9	1,1	2,1
6%	29,7	15,1	1,1	0,8
8%	26,5	24,1	1,1	0,7
10%	35,9	25,9	1,1	2,2

3.5 Unconfined Compression Test

This strength test determines how healthy the soil is under the applied compressive strength until it is separated from the grains and the strain caused by the pressure. Unconfined compressive strength is the compressive stress that occurs when the unconfined compressive strength test object collapses through the compression test. This standard, unconfined compressive strength is defined as the maximum load attained per cross-sectional area or load per cross-sectional area at 15% axial strain, whichever occurs first during the test. The axial strain (Ɛ1) is the ratio between the change in the height of the test object and the natural height of the test object, expressed in percent (Badan Standardisasi Nasional, 2012). The result of the unconfined compressive strength test is shown in Table 6 and Table 7.

Table 6. The Value of Qu based on Curing Time for Various Plastic Powders

Curing Time (days)	Variation of Plastic Powder	Unconfined Compression Strength (kg/cm^2)				Percentage Increase	Consistency
		Sample			Average		
		1	2	3			
0	0%	1,2	1,1	1,1	1,1	-	*Stiff*
	2%	1,3	1,3	1,3	1,3	6,3	*Stiff*
	4%	1,6	1,6	1,6	1,6	31,5	*Stiff*
	6%	1,9	1,8	1,8	1,8	53,0	*Stiff*
	8%	2,1	2,0	2,1	2,1	74,5	*Very Stiff*
	10%	1,8	1,7	1,7	1,8	45,9	*Stiff*
7	0%	1,4	1,5	1,5	1,5	-	*Stiff*
	2%	1,6	1,5	1,6	1,6	43,4	*Stiff*
	4%	1,7	1,7	1,7	1,7	33,6	*Stiff*
	6%	1,9	1,9	1,9	1,9	20,0	*Stiff*
	8%	2,1	2,1	2,2	2,1	5,7	*Very Stiff*
	10%	1,9	1,9	2,1	2,0	16,8	*Stiff*
14	0%	2,1	2,2	2,1	2,1	-	*Very Stiff*
	2%	2,2	2,2	2,2	2,2	108,4	*Very Stiff*
	4%	2,4	2,4	2,4	2,4	100,1	*Very Stiff*
	6%	2,4	2,5	2,5	2,5	96,6	*Very Stiff*
	8%	2,5	2,6	2,6	2,6	91,5	*Very Stiff*
	10%	2,4	2,4	2,5	2,4	98,1	*Very Stiff*

Curing Time (days)	Variation of Plastic Powder	Unconfined Compression Strength (kg/cm^2)				Percentage Increase	Consistency
		Sample			Average		
		1	2	3			
28	0%	2,7	2,8	2,8	2,8	-	*Very Stiff*
	2%	2,9	3,0	2,9	2,9	171,8	*Very Stiff*
	4%	3,1	3,1	3,2	3,2	163,3	*Very Stiff*
	6%	3,3	3,2	3,4	3,3	158,5	*Very Stiff*
	8%	3,4	3,431	3,4	3,4	154,6	*Very Stiff*
	10%	3,2	3,285	3,3	3,3	159,4	*Very Stiff*

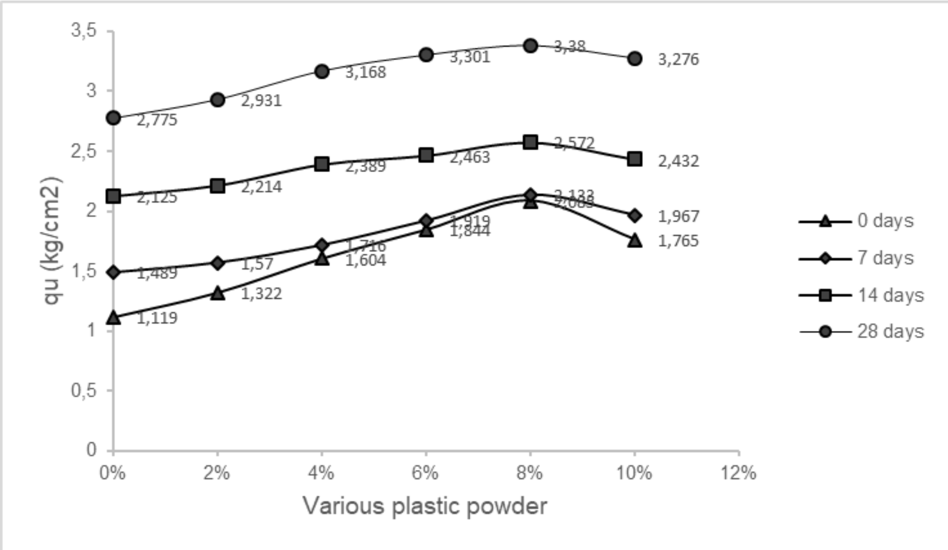

Figure 4. Graph of the Relation Between the Value of qu and the Variation of Plastic Powder

Based on the graph in Figure 4, shows that the addition of plastic powder to clay soils affects the value of unconfined compressive strength. The value of unconfined compressive strength increases as the percentage of plastic powder increases. This is because the plastic powder is a filler, so it will fill empty spaces in the soil, which causes its compressive strength value to increase when vertical pressure is applied. However, the soil reaches the limit of adding effective additives at a plastic content of 10% at each curing time. This suggests that the best amount of plastic powder should be added to a soil variation of 8% to increase the soil's bearing capacity. Because the texture of the combination does not attach as the amount of plastic powder increases, its binding power falls.

Table 7. The Value of qu is Based on Variations in Plastic Powder for Curing Time

Variation of Plastic Powder	Curing Time	Unconfined Compression Strength (kg/cm^2)				Percentage Increase	Consistency
		Sample			Average		
		1	2	3			
0%	0 days	1,2	1,1	1,1	1,1	-	*Stiff*
	7 days	1,4	1,5	1,5	1,5	21,2	*Stiff*
	14 days	2,1	2,2	2,1	2,1	30,9	*Very Stiff*
	28 days	2,7	2,8	2,8	2,3	18,7	*Very Stiff*
2%	0 days	1,3	1,3	1,3	1,3	-	*Stiff*
	7 days	1,6	1,5	1,6	1,6	13,5	*Stiff*
	14 days	2,2	2,2	2,2	2,2	35,2	*Very Stiff*
	28 days	2,9	3,0	2,9	2,9	89,4	*Very Stiff*
4%	0 days	1,6	1,6	1,6	1,6	-	*Stiff*
	7 days	1,7	1,7	1,7	1,7	53,3	*Stiff*

Variation of Plastic Powder	Curing Time	Unconfined Compression Strength (kg/cm^2)				Percentage Increase	Consistency
		Sample			Average		
		1	2	3			
	14 days	2,4	2,4	2,4	2,4	11,4	*Very Stiff*
	28 days	3,1	3,1	3,2	3,2	37,2	*Very Stiff*
6%	0 days	1,9	1,8	1,8	1,8	-	*Stiff*
	7 days	1,9	1,9	2,0	1,9	80,4	*Stiff*
	14 days	2,4	2,5	2,5	2,5	50,9	*Very Stiff*
	28 days	3,3	3,2	3,4	3,3	5,5	*Very Stiff*
8%	0 days	2,1	2,0	2,1	2,1	-	*Very Stiff*
	7 days	2,1	2,1	2,2	2,1	106,2	*Very Stiff*
	14 days	2,5	2,7	2,6	2,6	85,1	*Very Stiff*
	28 days	3,4	3,3	3,4	3,4	46,4	*Very Stiff*
10%	0 days	1,8	1,8	1,7	1,8	-	*Stiff*
	7 days	1,9	2,0	2,0	2,0	65,1	*Stiff*
	14 days	2,4	2,4	2,5	2,4	38,8	*Very Stiff*
	28 days	3,2	3,3	3,3	3,3	9,1	*Very Stiff*

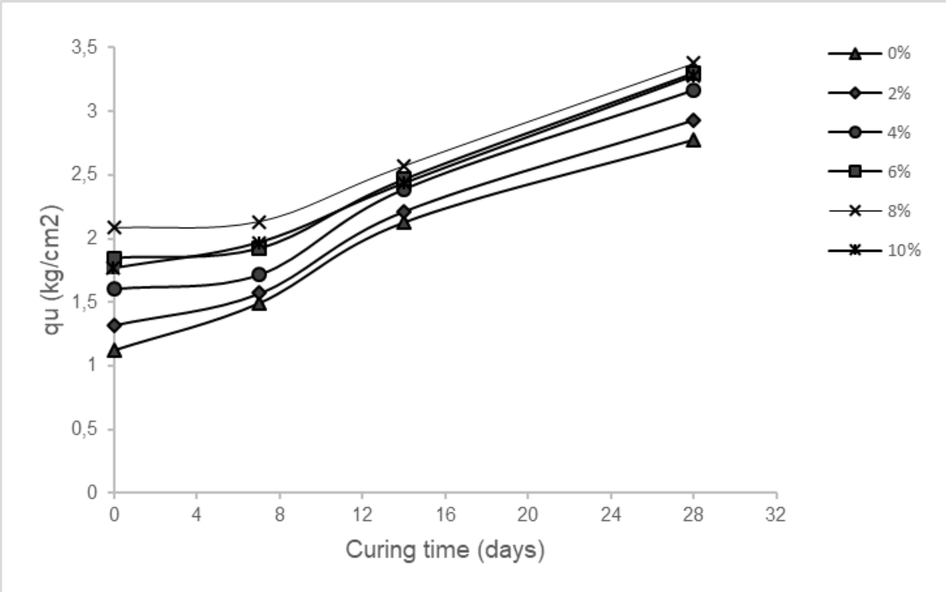

Figure 5. Graph of the Relation between the Value of qu and Curing Time

The curing time impacts the soil strength, as shown by the graph in Figure 5. During the curing process, the qu value of each type of plastic powder is constantly increasing. Water and ground air is further eroded and lost during curing, causing the mixed plastic powder to fill the unconfined space. As a result, the longer the curing time, the value of unconfined compressive strength increases. The qu value and clay consistency are shown in Table 8.

Table 8. Consistency and Strength of Clay Soil (Hardiyatmo, 1992)

Consistency	qu (kg/cm^2)
Very Soft	< 0.25
Soft	0.25 – 0.5
Medium	0.5 – 1
Stiff	1-2
Very Stiff	2-4
Hard	> 4

The natural soil's unconfined compressive strength value without curing time is 1.1 kg/cm^2. The soil is in Stiff consistency with an unconfined compression strength value of 1-2 kg/cm^2, then increases with increasing plastic powder with unconfined compression strength values of variations 2%, 4%, 6%, 8%, 10% were 2.8 kg/cm^2, 2.9 kg/cm^2, 3.2 kg/cm^2, 3.3 kg/cm^2, 3.4 kg/cm^2, 3.3 kg/cm^2 at 28 days of curing. The optimum value was obtained at 8% variation with an unconfined compression strength value of 3.4 kg/cm^2, with a Very Stiff consistency. From the results of these calculations, it can be concluded that adding plastic powder can increase the bearing capacity of the research site due to an increase in the value of Qu, which was initially Stiff soil consistency to Very Stiff.

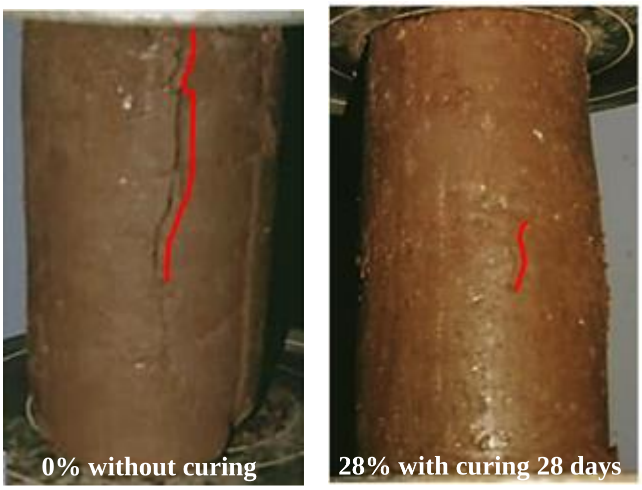

Figure 8. UCT Sample

Figure 8 shows the UCT sample where at 0% variation without curing, it can be seen that the failure pattern that occurs is "brittle failure" where the diameter of the sample does not change either before or after being tested. In the 10% variation with 28 days of curing, the failure pattern includes "barrel failure" where the sample diameter becomes larger, and the sample is shaped like a barrel.

4. CONCLUSION

Based on the results of research conducted at the Civil Engineering Laboratory, Faculty of Engineering, Sultan Ageng Tirtayasa University, it can be concluded that soil stabilization on Kampung Juhut Street, Karang Tanjung District, Pandeglang Regency uses PET plastic powder as an additive, as follows: (1) From the data from the test results for the natural soil characteristics, the soil type was obtained based on the USCS classification, which is included in organic clay soils with moderate to high plasticity (SC); (2) The addition of plastic powder to clay affects the physical properties of the soil based on the Atterberg limit values and the specific gravity values of the soil. The liquid limit value of the soil is 64.5% to 45.8 at a 10% mixture variation. The plastic limit value is 41.6% to 33.9% at a 10% variation. Then the plasticity index value decreased from 22.9% to 12.2% at an 8% variation and 11.9% at a 10% variation, so the mixture could be used as subgrade soil. Meanwhile, the value of soil-specific gravity increased from 2.6 to 2.7 at a 10% variation; (3) The results of tests and calculations that have been carried out show that adding plastic powder to clay affects the value of unconfined compressive strength. Without curing, the unconfined compressive strength value of the natural soil is 1.1 kg/cm^2. The soil is in Stiff consistency with an unconfined compression strength value of 1-2 kg/cm^2, then increases with increasing plastic powder up to a percentage of 8% with a qu value of 3.4 kg/cm^2 during curing 28 days, included in the consistency of Very Stiff with an unconfined compression strength value of 1-2 kg/cm^2. From the results of these calculations, it can be concluded that adding plastic powder can increase the bearing capacity of the research site due to an increase in the value of Qu, which was initially Stiff soil consistency to Very Stiff. (4) Based on the plasticity index and the unconfined compression strength value, the best mixture of soil and plastic powder is the 8% mixture variation.

REFERENCES

American Society for Testing And Materials. (2000). D4318 - 00: Standards, for Liquid Limit, Plastic Limit, and Plasticity Index of Soils This c of soils, ASTM D 4318-00. *ASTM International*, *04*, 1–14.

Badan Standardisasi Nasional. (2008a). SNI 1742:2008 tentang *Cara Uji Kepadatan Ringan untuk Tanah*. Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2008b). SNI 1964:2008 tentang *Cara uji berat jenis tanah.* Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2008c). SNI 1965:2008. tentang *Cara uji penentuan kadar air untuk tanah dan batuan di laboratorium*. Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2008d). SNI 1966:2008. tentang *Cara uji penentuan batas cair tanah*. Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2008e). SNI 1967:2008. tentang *Cara Uji Penentuan Batas Cair Tanah.* Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2018). SNI 3423:2018. tentang *Cara uji analisis ukuran butir tanah*. Jakarta: Badan Standarisasi Nasional.

Badan Standardisasi Nasional. (2012). SNI 3638:2012. tentang *Metode Uji Kuat Tekan-Bebas Tanah Kohesif*. Jakarta: Badan Standarisasi Nasional.

Consoli, N. C., Montardo, J. P., Prietto, P. D. M., & Pasa, G. S. (2002). Engineering Behavior of a Sand Reinforced with Plastic Waste. *Journal of Geotechnical and Geoenvironmental Engineering*, *128*(6), 462–472. https://doi.org/10.1061/(ASCE)1090-0241(2002)128:6(462)

Darwis, H. (2017). *Dasar–Dasar Teknik Perbaikan Tanah*. Yogyakarta: Pustaka AQ.

Das, B. M. (1995). *Mekanika Tanah Prinsip-prinsip Rekayasa Geoteknik*. Jakarta: Erlangga.

Direktorat Jenderal Bina Marga. (2018). Spesifikasi Umum 2018. *Edaran Dirjen Bina Marga Nomor 02/SE/Db/2018*, *Revisi 2*, 6.1-6.104.

Hardiyatmo, H. C. (1992). *Mekanika Tanah I.* Jakarta: Gramedia Pustaka.

Jin, D. C., Kalumba, D., & Chebet, F. C. (2019). Laboratory investigation of recycled polyethylene terephthalate (PET) as soil reinforcement material. *17th European Conference on Soil Mechanics and Geotechnical Engineering, ECSMGE*. https://doi.org/10.32075/17ECSMGE-2019-0768

Karmacharya, R., & Acharya, I. P. (2017). Reinforcement of soil using recycled polyethylene terephthalate (PET) bottle strips. In *Proceedings of the IOE Graduate Conference, Lalitpur, Nepal*, *8914*, 2350–8906.

Kassa, R. B., Workie, T., Abdela, A., Fekade, M., Saleh, M., & Dejene, Y. (2020). Soil Stabilization Using Waste Plastic Materials. *Open Journal of Civil Engineering*, *10*(01), 55–68. https://doi.org/10.4236/ojce.2020.101006

Kumar, A. B. G., & Vageesh, H. P., (2017). Effect of Discarded Plastic Waste as Stabilizer on Engineering Properties of Effect of Discarded Plastic Waste as Stabilizer on Engineering Properties of Cohesive Soil. *International Journal of Engineering Technology Science and Research*, *4*(12), 779–786.

Laskar, A., & Pal, S. K. (2013). Effects of waste plastic fibers on compaction and consolidation behavior of reinforced soil. *Electronic Journal of Geotechnical Engineering*, *18 H*, 1547–1558.

Memon, A. N., Hindu, A. K., Memon, N. A., Amur, M. A., & Memon, U. H. (2019). Potential of Waste Plastic (PET) Bottle strips as reinforcement material for clayey soil. *In Second International Conference on Sustainable Development in Civil Engineering, MUET, Pakistan*, 359-361.

Mohammed, M. A., Rahman A. R. E.., & Mohammed, I. Y. (2018). Evaluation of the Effect of Plastic Bottle (Pet) Waste on Stabilization of Clay. *International Journal of Engineering Sciences & Research Technology*, *7*(8), 101–110.

Mina, E., Fathonah, W., Kusuma, R. I., & Nurjanah, I. A. (2021). The utilization of lime and plastic sack fiber for the stabilization of clay and their effect on CBR value. *Teknika: Jurnal Sains Dan Teknologi*, *17*(2), 289. https://doi.org/10.36055/tjst.v17i2.13025.

Singh, K., & Mittal, A. (2019). Soil Stabilisation Using Plastic Waste. *Lecture Notes in Civil Engineering*, *32*, 91–96. https://doi.org/10.1007/978-981-13-7017-5_10.