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The Influence of Marble Waste Powder on Clay Soil Stabilization

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***Abstract*—Soil properties are critical in building and road construction, which often causes problems, particularly for clay-type soil. The poor condition of clay soil is indicated by its high plasticity, low shear strength, high volume changes, and high shrinking properties. In the current work, marble waste powder (MWP) was used as an additive to stabilize the soil. The investigation aims to study the effect of the weight percentage of MWP addition and to cure time on the soil stabilization properties. Soil samples were taken from Jalan Masjid Priyayi, Kasemen, and Serang. Variations of marble powder waste were 0, 7, 17, and 27%-wt with a curing time of 0, 7, 14, and 28 days. The soil tests were performed for sieve analysis, soil density, moisture content, Atterberg (liquid limit), soil compaction, and unconfined compressive strength (UCS) tests. The study results found that the soil was categorized as OH-type organic clay with high plasticity according to the Unified Soil Classification System (USCS) classification. The plasticity index value decreased with the increase in the content of MWP. The effect of curing time is highly influential in increasing the UCS value. The longer the curing time, the higher the UCS value. The highest UCS value obtained after adding 7% MWP with 28 days of curing was 3.427 kg/cm^2 from only 0.749 kg/cm^2 in the clay soil before mixing with MWP. The addition of low-cost MWP effectively improves clay soil stabilization.**

***Keywords*— Stabilization; UCS; marble powder waste.**

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I. INTRODUCTION

The subgrade, which has the properties of clay-type soil, has swelling and shrinking behavior according to changes in water content. If the clay dries, it will shrink, and a crack occurs; the soil will swell if the clay is exposed to rainwater [1]. This condition causes instability in pavement construction, resulting in cracked and bumpy roads [2]. In 2020 around 21.5% of road construction conditions in the Banten area were improper [3].

The results of the Dynamic Cone Penetrometer (DCP) test at that location showed an average CBR value of 1.967%, which did not meet the requirements for the CBR value for road pavement, which was at least 6% [1]. Therefore, it is necessary to strive for soil improvement, and all actions to change the original properties of the soil to be adapted to construction needs are soil stabilization efforts. There are soil stabilization methods, namely chemical stabilization and mechanical stabilization [2]. For chemical methods, one uses lime as an alternative material often used for soil stabilization [3] and carbide waste [4].

Indonesia had 1,252,830 m^3 of excavated materials in the form of marble in 2019 [5]. Processing the marble excavated material and producing finished products also produces waste, including marble powder containing CaO or lime compounds with 53.59% [6]. Refusing powdered waste is one of Indonesia's efforts to preserve the environment.

The soil stabilization method using waste has previously been carried out using a steel slag [7] using variations of 0%, 5%, 10%, 15%, 20%, curing time 0, 3, 14, 28 days, then adding marble powder with the variation is 0, 2%, 3%, 4%, 5% [8]. On the other hand, Aysegul Yorulmaz [9] added marble dust waste material, variations of 5, 10, 20, 30, and 50%, and curing times (0, 7, 30, and 60 days). Based on several research conditions, the Priyayi Mosque village road in Serang City uses marble powder with variations of 0%, 7%, 17%, and 27%, with curing times of (0,7,14,21,28) days following the concrete age pattern.

Soil is a layer between subsoil and bedrock that has soft mineral deposits. Several types of soil are glued together by material to have hard properties similar to hard rock. While soil is easy to take, it is excavated by hand and simple equipment [10]. Soil is formed due to changes in weather, vegetation over a long time, and terrain conditions. It takes knowledge of the original properties of the soil, grain size, color, texture, and consistency of the soil in question to be able to describe the soil. The soil is briefly divided into two parts based on the mechanical analysis results: coarse-grained and fine-grained [11]. Soil is defined as a material consisting of aggregates or granules of solid minerals that are not bound to each other and organic matter accompanied by liquids and gases that fill the spaces between the particles [12].

Clay mostly consists of microscopic and sub-microscopic particles in the form of flat plates [13]. Clay soils are characterized by very low permeability plasticity with a very wide range of water content, which is composed of very small particle aggregates that cannot be seen with the naked eye, which originate from the chemical decomposition of rock elements, are fine-grained, harden in a dry state and are hardened in dry conditions, soft when wet [14].

Soil classification is a way to determine the soil type to obtain soil properties [14]. Generally, soil classification is based on particle size obtained from sieve analysis (sedimentation tests) and plasticity. The Unified Soil Classification System and AASHTO (American Association of State Highway and Transportation Officials) are often used as references [15].

Soil stabilization is a process of increasing the cohesion and the frictional force between soil grains to improve the soil's ability to resist force loads [16]. The soft field's soil is easy to shape, has an inappropriate Atterberg limit value, and other soil properties unsuitable for construction work, so the soil must be stabilized. In principle, soil steadiness is an effort to improve poor soil quality, and stabilization can consist of one of the following actions [17]:

- Compactable soil,
- Adding certain materials for cohesion or soil shear resistance,
- Adding materials to the soil that can cause chemical and physical changes,
- Lowering the groundwater level,
- Replacing bad soil.

Marble waste is a leftover material from the marble stone industry, produced from the sawing or carving process and shaped by hand so that the fragments are gravel. Some are in the form of sand. PT. Sucofindo reported the composition of marble waste as presented in Table 1 [18].

TABLE I
MARBLE WASTE POWDER(MWP) CONTENT ELEMENT [18]

Compound	(%)
CaO	52.69
$CaCO_3$	41.92
MgO	0.84
$MgCO_3$	1.76
SiO_2	1.62
$A1_2O_3 + Fe_2O_3$	0.37

The unconfined compressive strength is the stress concentrated on the test object that collapses or when the strain reaches 15% [19]. The UCS method is used as a reference in research to obtain the value of the unconfined compressive strength of soils containing clay or silt. The purpose of the UCS test is to determine the strength of the soil in receiving a given compressive force until the soil is separated from its grains and to determine the value of soil strain due to the compressive force above it.

A UCS test was carried out on the original soil sample and the stabilized soil sample of marble waste and then measured its strength against the UCS value to determine the sample's strength, as shown in Table 2 [20].

TABLE II
CONSISTENCY OF CLAY IN TERMS OF UCS (QU)

Consistency	q_u (kg/cm^2)
Very soft	Less than 0.25
Soft	0.25 – 0.50
Medium	0.50 – 1
Stiff	1 – 2
Very stiff	2 – 4
Hard	Over 4

The purpose of this study was to determine the effect of adding marble powder waste with percentages of 0%, 7%, 17%, and 27% as soil stabilization material to the value of UCS with variations in curing time 0, 7, 14, and 28 days so that the percentage of the ideal mixture of marble powder waste to be added to clay soil as an alternative to improve clay soil on Jalan Masjid Priyayi Village, Kasemen District, Serang City.

II. MATERIALS AND METHOD

This study obtained soil samples from Masjid Priyayi Road, Kasemen District, Serang City. Masjid Priyayi is right beside the river and has potholes, as shown in Figure 1. We can see the research location on Google Maps with coordinates 6°04'56.4"S 106°11'26.4"E, as in Figure 2. Soil samples were taken from the soil on the side of the road, between the road and the river.

Fig. 1 Masjid Priyayi Road conditions

Fig. 2 Masjid Priyayi Road location at 6°04'56.4"S 106°11'26.4" E

First, the process started by digging the soil to a depth of approximately 5-10 cm from the ground surface. Then after being dug up, the soil is taken, which is put into a container in this study using a sack that had been prepared. The samples were packed and taken to the Civil Engineering Laboratory of Untirta, Cilegon. Marble powder waste (Figure 3) was collected at PT Jaya Abadi Granitama (Figure 4) in Cikande, Serang Regency, Banten Province.

Fig. 3 Marble Powder Waste.

Fig. 4 Marble factory

The soil taken from Jalan Masjid Priyayi Village was then tested as a physical soil test. This study included an analysis of the grain size (SNI 3423-2008), and water content (SNI 1965-2008) [21]. Unit Weight, soil density, plastic limit (SNI 1966-2008), and liquid limit (SNI 1967-2008). Testing the physical properties of the soil is to determine the physical properties of the soil that will be needed to classify the soil using the USCS classification system.

After physical soil testing, proceed with compaction testing using a standard proctor test. In addition to testing the original soil, they also tested the compaction of the soil. Each variation of the mixture was 0%, 7%, 17%, and 27% marble powder based on the dry weight of the soil. The aim is to obtain the maximum dry density of the soil and the optimum moisture content in the original and mixed soils. The soil used in the compaction test was air-dried for several days, and marble powder with 0%, 7%, 17%, and 27% variations.

Afterward, the UCS test sample was conducted for a sample size of 30 mm diameter and 72 mm height from each variation of soil compaction. After the soil sample was made, it was put into a tightly closed plastic bag for a curing period according to the specified time of 0 days, 7 days, 14 days, and 28 days. An unconfined compressive strength test was obtained from the soil compaction test, which was sampled and then removed with a jack. The UCS was checked by controlling the strain.

After conducting data analysis and calculations, conclusions can be drawn. The research flow chart is presented in Figure 5.

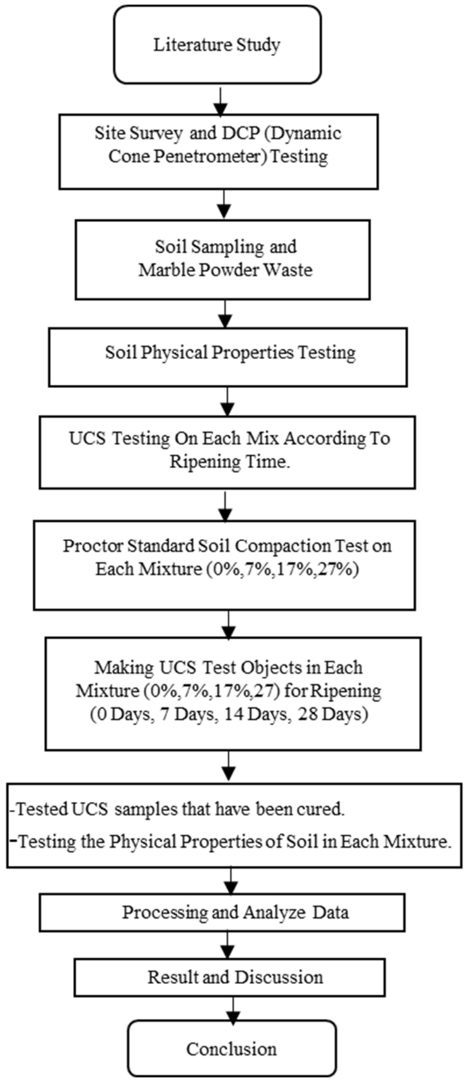

Fig. 5 Flow chart of research

III. Results and Discussion

A. Clay Soil Characteristic

Soil physical testing covered in this study were the analysis of grain size, plastic limit, specific gravity, soil density, and liquid limit. Soil physical testing is carried out to determine the physical properties of the soil that will be needed as data for the classification of the research soil. All soil physical testing was carried out at the Civil Engineering Laboratory of Untirta.

The soil grain size analysis results on Jalan Masjid Priyayi Village, Kasemen District, Serang City, are included in the category of fine-grained soil because the soil that passes the filter No. 200 is more than 50%, according to the USCS soil classification system. According to the USCS soil classification, the resulting data shows that Jalan Masjid

Priyayi Village, Kasemen District, Serang City is a fine-grained soil with a percentage of pass through the No. Sieve 200 reached 52.2%. The soil water content (w) and soil unit weight (γ) are 42.04% and 1.978 g/cm^3, respectively (Table 3).

TABLE III
SOIL PROPERTIES OF MASJID PRIYAYI VILLAGE ROAD

Soil Properties	Value
Grain size analysis	52.2%
Water content (w)	42.04%
Unit weight (γ)	1.978 g/cm^3
Specific gravity (Gs)	2.65
Liquid limit (LL)	62%
Plastic limit (PL)	32.76%
Plasticity index (PI)	29.24%
Optimum Moisture Content (w_{opt})	24%
Dry density (γ_{dry})	1.40 g/cm^3

Data from the results of the analysis of the plasticity index, grain size analysis, liquid limit, and plastic limit were then entered into the USCS soil classification system table. The soil in Jalan Masjid Priyayi Village, Kasemen District, Serang City is classified as OH soil, organic clay with high plasticity.

B. Effects of MWP addition

The soil-specific gravity (G_s) test has been carried out according to the soil mixture with each variation of marble powder waste. The results of the test are in Table 4.

TABLE IV
SPECIFIC GRAVITY (g_s) IN EACH MIX

MWP (%)	Gs
0	2.650
7	2.622
17	2.605
27	2.581

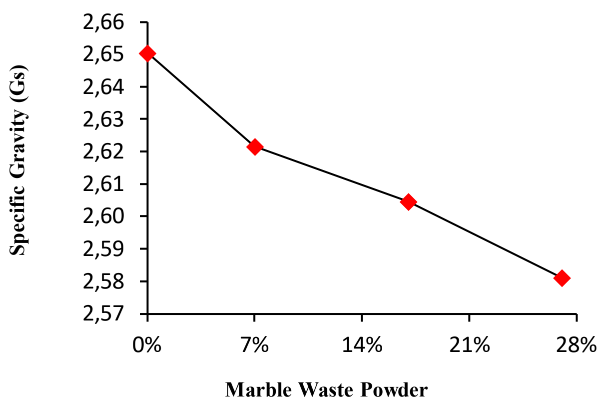

Fig. 6 Graph of Specific Gravity Value for Each Mixture

The soil is included in organic clay based on the graph results in Figure 6 from the tests carried out. The decrease in the value of soil-specific gravity (Gs) was due to a change in the volume of clay grains which became larger due to the clotting reaction. Solid grain volume weight (γ_s) is the ratio between dry soil weight (Ws) and soil grain volume (V_s); if the value of (W_s) remains, the value of (V_s). Increases, then the value of s will decrease. While (Gs) is the ratio between the weight of the volume of solid grains (γ_s) and the weight of the volume of water (γ_w), if the value of s decreases while the value of w remains, then the value of Gs will also decrease [21].

Based on the data obtained in Table 5, soil mixture with each variation of marble powder waste, the liquid limit value decreases as the marble powder waste content increases. The liquid limit value is used to find the plasticity index value for soil classification [22], [23].

TABLE V
LIQUID LIMIT VALUE ON EACH MIXTURE

MWP (%)	Liquid limit (%)
0	62
7	56
17	50
27	48

Based on the data obtained, it can be seen in Table 6 that the plastic limit value increases with the increase in the content of marble powder waste as a soil mixture. The plastic limit value is used to find the plasticity index value used for soil classification [22], [23].

TABLE VI
PLASTIC LIMIT VALUE ON EVERY MIXTURE

MWP (%)	Plastic limit (%)
0	32.76
7	35.09
17	36.39
27	3.44

Based on the data obtained in Table 7, soil mixture with each variation of marble powder waste, it is known that the plasticity index value has decreased, as seen in Figure 7. As the content of marble powder waste increases, adding marble powder waste positively affects the soil plasticity index value on Masjid Priyayi Village Road, Kasemen District, Serang City.

TABLE VII
IP VALUES ON EVERY MIX

MWP (%)	Plasticity Index (PI)
0	29.24
7	20.91
17	13.61
27	10.56

The addition of marble powder waste is 27% because it has an IP value of 10.56%, and soil with 17% marble powder waste because it has a value of 13.61%. Besides these requirements, the stabilized soil can subgrade following applicable requirements. The pattern of decreasing the plasticity index value was similar to the “marble dust on black cotton soil” study [22]–[24]. The value of the Plasticity Index continues to decrease due to cation exchange which causes flocculation in the clay soil, which reduces the thickness of the clay particle layer [25]. The increase in MWP content would lead to higher ion exchanges [26]

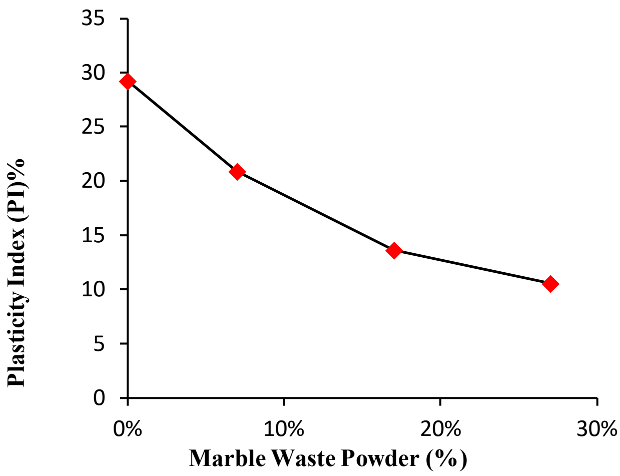

Fig. 7 Variation of PI with the percentage of MWP

The compaction test results are obtained from the compaction graph, namely the relationship between dry density and water content, which forms a parabolic curve. The Maximum Dry Density (MDD) $(\gamma_d)_{maks}$ and Optimum Moisture Content (OMC) (w_{opt}) of each mixture was obtained, as shown in Table 8.

TABLE VIII
SOIL COMPACTION TEST RESULTS OF EACH VARIATION OF MWP

MWP (%)	**W_{opt} (%)**	**$(\gamma_d)_{maks}$ (g/cm^3)**
0	24.0	1.40
7	25.0	1.36
17	27.4	1.34
27	29.0	1.31

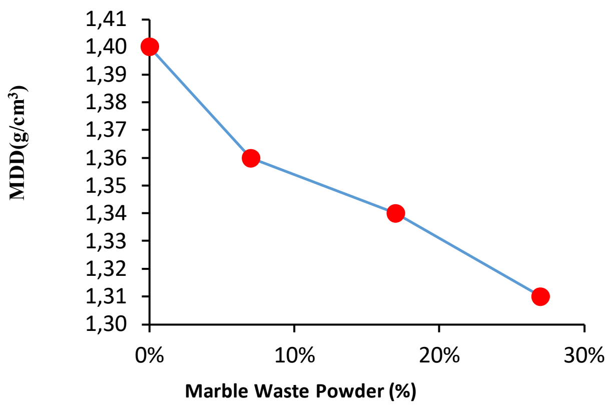

Fig. 8 Variation of MDD with the percentage of MWP

The MDD value decreases due to a change in the total clay volume, which becomes more significant due to the clotting reaction (Figure 8). So that the number of pores in the soil increases. Density (γd) is the ratio between the dry weight of the soil (Ws) and the total volume of wet soil (Vt); if the value of Ws remains constant while the value of Vt increases, then the value of d will decrease. Therefore, the greater the addition of marble waste, the more significant the decrease in the value of MDD.

The effect of adding Marble Powder Waste to the soil is that it can increase the value of the optimum water content and reduce the MDD weight [27]. This is probably due to mineral exchange between layers [28].

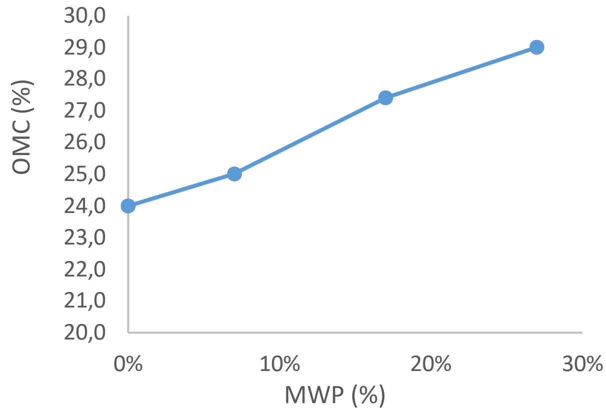

Fig. 9 Variation of OMC with the percentage of MWP

The increase in the value of the optimum moisture content (OMC) can be seen in Figure 9. When clay is mixed with marble waste and water, a segmentation process (binding) will occur, causing clumping, and the water content in the soil will also increase. Therefore, the greater the addition of marble waste, the greater the increase in the value of the OMC [28].

C. *Effects of Curing Time*

The unconfined compressive strength test object is a flat surface pressed up by a UCS tool until a collapse occurs or a maximum decrease of 15% of the height of the test object before being pressed. The data obtained from the UCS is then calculated and analyzed. The results of the calculation and analysis of the value of q_u in kg/cm^2 with added marble powder waste can be seen in Table 9 of the curing period below:

TABLE IX
RECAPITULATION OF THE VALUE OF QU ON THE ADDITION OF MARBLE WASTE POWDER AND CURING PERIOD

Specimen Name	**Unconfined Compressive Strength (kg/cm^2)**			
	0 day	7 days	14 days	28 days
CS+0% MWP	0.749	1.090	1.273	1.467
CS+7%MWP	2.393	2.727	3.060	3.427
CS+17%MWP	2.100	2.510	2.750	3.026
CS+27%MWP	1.897	2.280	2.453	2.880

From Table 9, The unconfined compressive strength increases due to cement compounds (calcium silicate hydrate) formed from the chemical reaction between calcium carbonate in marble powder waste, water, and soil [29]. The test results show that adding marble powder waste affects the compressive strength of the soil. The optimum q_u value at the addition of 7% marble powder waste decreased at the levels of 17% and 27%; this is due to the agglomeration reaction that occurs when it exceeds the optimum level causing the granules to become uniform and their strength to weaken as shown in Fig. 10.

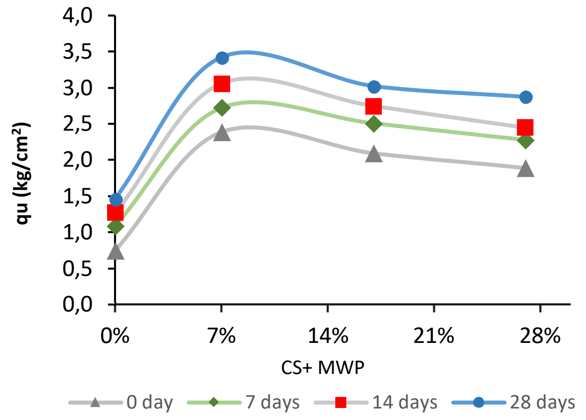

Fig. 10 The effect of increasing the MWP mixture on the UCS (q_u) value

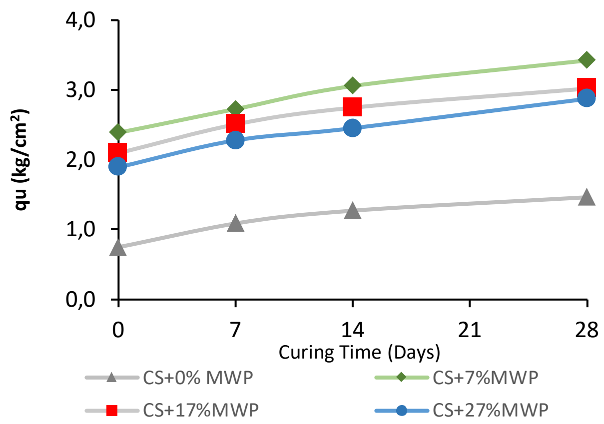

Fig. 11 Effects of MWP and curing time on unconfined compressive strength of mixtures

From the recapitulation data of the previous q_u value, it can be concluded that adding marble powder waste or curing time will affect the q_u value. The effect is in the form of an increase in the value of q_u (soil strength) obtained from the curing time and the addition of marble powder waste. It is proven by the curing time for 28 days and adding 7% marble powder waste produces a q_u value of 3,427 kg/ cm^2 (CS+7%MWP). The q_u value increased from 0.749 kg/ cm^2 at a percentage of 0%, and a curing time of 0 days can be seen in Fig. 11. It can be concluded that the addition of marble powder was optimum at 7% variation and decreased at 17% and 27% variations. However, the decrease in value at 17% and 27% variation was not lower than that of the original soil. The UCS value decreased due to insufficient moisture content to maintain the pozzolanic reaction to obtain further strength [30].

The q_u value of the soil before mixing with marble powder waste was 0.749 kg/cm^2 categorized as medium consistency with a q_u value of 0.5 - 1 kg/cm^2. The q_u value increased after mixing 7% marble powder waste to 3.427 kg/cm^2, which is categorized as a very stiff consistency with a q_u value of 2 - 4 kg/cm^2. It was proven that marble powder waste affects the soil stabilization process because it can increase the value of q_u, which was originally classified as medium to very stiff consistency. The effect of using the optimum water content in each mixture on the value of free compressive strength is to make the value of q_u more objective because the water content used in each mixture is the optimum water content in each mixture.

IV. Conclusion

The soil type taken from Jalan Masjid Priyayi classifies as organic clay OH according to USCS standards. The clay soil has a plasticity index of 29.24%, categorized as soil with high plasticity. The addition of 7% marble powder waste and a curing time of 28 days increased the UCS value to 3.427 kg/cm^2 from initially 0.749 kg/cm^2 in the original soil condition. The plasticity index value was 20.91%, categorized as the type of soil with high plasticity. Adding 7% marble waste powder is suitable as a clay stabilizer material in the Priyayi Mosque area of Serang City.

Nomenclature

CS	Clay Soil	
MWP	Marble Waste Powder	
MDD	Maximum Dry Density	g/cm^3
OMC	Optimum Moisture Content	%
UCS	Unconfined Compressive Strength	kg/cm^2
USCS	Unified Soil Classification System	

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