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THE EFFECT OF CEMENT TO DEVELOP STRENGTH OF GRATI SOFT SOIL

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ABSTRACT: Soft soils are identified as soils with high compression and low strength in high water content. Various methods are used to decrease compressibility and increase the bearing capacity. The Portland Cement (PC) as a soft soil stabilization material has been known for a long time. Although its cost is higher than lime or waste material such as fly ash, the content of the compounds in the cement is complete and the quality is more assured, so cement is still very reliable. This research aims to investigate the improvement in the strength of soft soils after the admixture of cement and changes in physical properties. Laboratory experiments are carried out such as a physical properties test, compaction, and CBR tests to determine the effects of cement content of 5%, 8%, 12%, and 15%. Furthermore, triaxial and unconfined compressive tests are also conducted to investigate several aspects related to strength, such as the curing time. Based on the triaxial test, there is an improvement in the shear strength of the soil, which the friction angle increases; nevertheless, the cohesion decreases. The shear strength and stiffness are directly proportional to the percentage of cement in the soil.

Keyword: Cement, Improvement, Soft, Friction, Cohesion

1. INTRODUCTION

Soft soil problems are found in various places in the world, and improved technology is developing very fast. There are some alternative methodologies such as prefabricated vertical drains (PVD), sand drains, and additive material. PVD and sand drains will work to accelerate consolidation and consequently increase the strength. PVD is extensively discussed by several experts [1-4] in the case of road structures with high embankments. Finite element programs are used to estimate soil conditions after using PVD, such as the stress, strain, and deformation of the soil. The vertical drain of the PVD can be modeled as a drain element having infinite permeability.

The other method that is widely used to improve the bearing capacity of soils and reduce compressibility is to use additive material. The additive materials that have been highly recommended are cement and lime because they increase the strength of the improved soil significantly. Researchers have conducted experiments with lime in different locations such as Malaysia [5] and Egypt [6-7]. Besides that, the curing time [8] is recommended as a significant factor in soil strength. Other researchers investigated cement as an additive to develop the stability of soft soils [7-10] from the surface to 30 m depth using the deep soil (DSM) method [11].

The objective of this research is to investigate the physical and mechanical properties of cement-improved soft soil collected from Kedaung Wetan and propose the relation between the ratio of the water and cement content to the shear strength parameter. Kedaung Wetan is a village in the Grati sub-district, Pasuruan, East Java, Indonesia. Grati is one of the districts that is passed by the Gempol Pasuruan Toll Road, which is part of the Trans Java Toll Road. That road has a length of 13.5 km and connects Grati and Tongas. SPT data for the area shows that soils up to 12 m deep are very soft soils and from 12 m to 16 m are categorized as soft soils, where previously there were paddy fields. This paper deals with the improvement of this soil to sustain the pavement structure and traffic load. The addition of cement always leads to a physical and chemical change in the mixture. The improved soil has high strength because of the cementation process. There is a process to select the optimum dosage of cement-based on strength criteria in the research.

2. EXPERIMENTAL INVESTIGATION

2.1 Characteristics of Soil Sample

The soil sample is high-plasticity silty soil with low shear strength, which is classified as soft soil. The properties of the soil are shown in Table 1 [12].

Based on [12], the compressive strength of natural soil depends on the moisture content of the soil, as given in Eq. (1):

$$q_u = -6.6\ \omega + 382.9\ \text{(kPa)} \quad (1)$$

where ω is the water content in percent. The soil will be in a soft condition ($25 < q_u < 50$ kPa) at $50.4 < \omega < 56.5\%$ water content and in a very soft condition ($0 \leq q_u < 10$ kPa) at a water content more than 56.5%.

Table 1 Physical characteristics of soil sample

Parameter	Unit	Value
Liquid limit	%	56
Plastic limit	%	43
Shrinkage limit	%	11
Saturated density	kN/m^3	17.2
Coefficient of permeability	cm/sec	0.00037
Maximum dry density	kN/m^3	12.5
Optimum water content	%	31
Coefficient of consolidation	cm^2/sec	0.001
Coefficient of compression		0.445
Water content (undisturbed)	%	50.5
Compressive strength (undisturbed)	kPa	49.4

2.2 Methodology

Laboratory experiments are conducted to investigate the changes in natural soil after being mixed with cement. The key to success in getting the maximum strength is to determine the percentage of additives that are most representative by considering various aspects that influence them. The compaction test (ASTM D1557) was carried out to define the optimum water content for each percentage of additive replacement, i.e., 5%, 8%, 10%, 12%, and 15%. To investigate the plasticity and mechanical behaviour of the improved soil, liquid limit, plastic limit (ASTM D4318), unconfined compressive (ASTM D2166), California Bearing Ratio (ASTM D1883), and triaxial tests (ASTM D2850) have been developed. The triaxial test was run to obtain the shear strength parameter and an unconfined compressive test was performed to obtain the compressive strength. The experiments were carried out after the samples had been treated for 4, 7, 14, and 28 days.

3. RESULT AND DISCUSSION

3.1 Pozzolanic Effect on Soil Plasticity

Three stages occur when the soil is mixed with cement, namely: absorption of water by the calcium in the cement, which occurs quickly, producing heat and reducing the soil water content. The second stage is the replacement of ions, where negatively charged soil will attract Ca in the cement quickly, causing an increase in the cohesiveness of the soil grains. The third stage is the pozzolanic reaction, where silica and alumina in the soil will react with calcium silicate hydrate. This formation occurs continuously over a long period and causes the soil to become hard.

The pozzolanic reaction is a chemical reaction that occurs in PC after the addition of pozzolan, and this reaction changes the conversion of silica-rich precursors without cementing properties to calcium silicate with cementing properties.

In chemical terms, a pozzolanic reaction occurs between calcium hydroxide, also known as portlandite ($Ca(OH)_2$), and silicate acid (written as H_4SiO_4 or as $Si(OH)_4$) as in Eq. (2):

$$Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 \cdot 2H_2O \quad (2)$$

or

$$CH + SH \rightarrow C\text{-}S\text{-}H$$

The product $CaH_2SiO_4 \cdot 2H_2O$ is calcium silicate hydrate, also abbreviated as C-S-H in the chemical notation of cement. The pozzolanic reaction is a long-term reaction, which involves dissolved silicic acid, water, and CaO or $Ca(OH)_2$ or another pozzolan to form a strong cementation matrix. This process is often irreversible. A large number of free calcium ions and high pH of 12 or above are required to start and maintain a pozzolanic reaction. This is because, at a pH of around 12, the solubility of silicon and alumina ions is high enough to support the reaction.

The presence of water in soil pores affects the technical properties of fine-grained soils, which are defined within the boundary that distinguishes the properties of the soil, namely the liquid limit as the lower limit of viscous flow and the plastic limit as the lower plastic behaviour. These two limits of plasticity are used to describe the physical properties of fine-grained soils, which separate them from coarse-grained soils.

Table 2 Soil plasticity

Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Natural soil	56	43	13
5	54	42	12
8	52	42	10
10	51	41	10
12	50	41	9
15	46	41	5

The values of the liquid limit, plastic limit, and index of plasticity are reduced as the cement content is increased [13], as shown in Table 2. The natural soil was clayey soil (A-7-5), changed to silty soil (A-5) of 5–8% and silty or clayey gravel and sand (A2-5) of 10–15% cement content based on the AASHTO (American Association of State Highway and Transportation Officials) classification. A poor subgrade layer improved to a fair or good layer. The presence of cement reduces the clay effect and the silt content becomes more dominant.

3.2 Pozzolanic Effect to Develop the Strength

Remediation of clay soil with cement is a chemical process that can change the structure of the soil by forming larger aggregate grains that will have a very beneficial effect. Chemical events occur between the soil and cement when both are mixed by adding an amount of water.

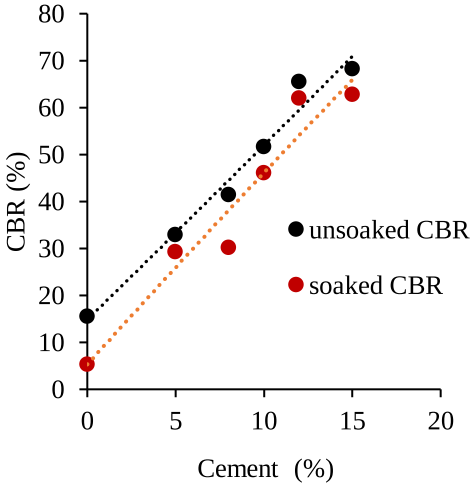


Fig.1 Percentage of cement versus CBR

The result of the CBR test in soaked and unsoaked conditions shows the performance was acceptable as in Fig.1 and is in linear relation with the cement content. The pozzolanic reaction gives higher stability in the case that the soaked CBR is not much different from the unsoaked CBR.

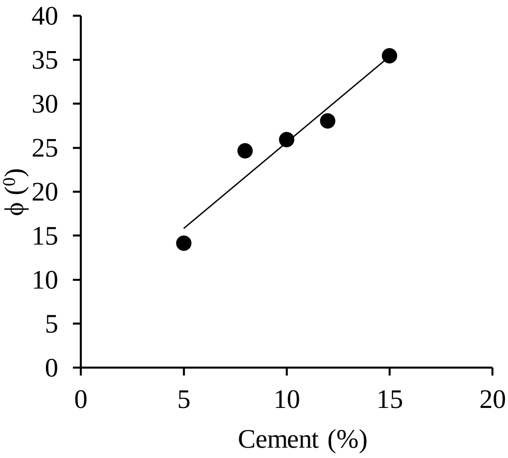


Fig.2 Influence of cement on friction angle

The physical properties test result established a change of soil type (clay to granular soil), then a triaxial test was conducted to investigate the influence of cement on the shear strength parameter. The value of the friction angle increases with the presence of cement, as shown in Fig.2, but the cohesiveness reduces as shown in Fig.3.

In concrete technology, it is well known that the strength of hardened concrete is determined by the ratio of free water content to the cement content in the mix. When analogous to this problem, the ratio of water and cement content in the mixture.

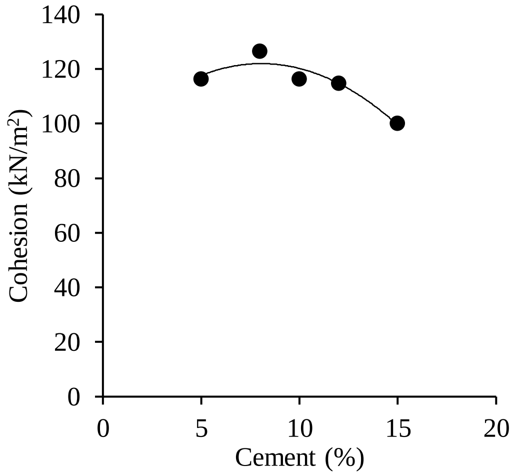


Fig. 3 Influence of cement on cohesion

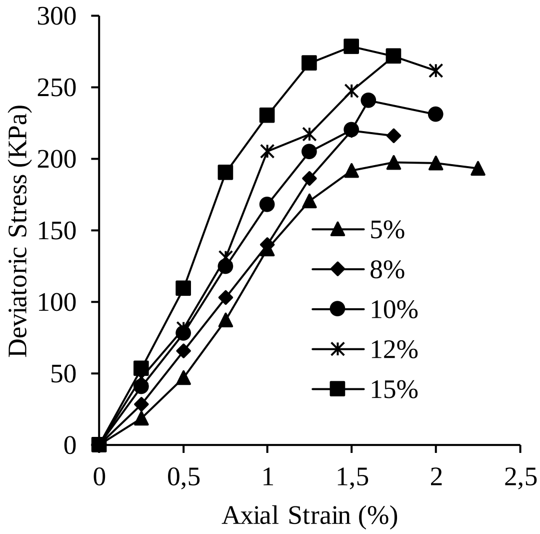


Fig. 4 Deviatoric stress and strain of cement-improved soil

The axial stress-strain relationships between cement-treated soils are shown in Fig. 4. It was noted that the failure strain changed irregularly, but the compressive stress and secant modulus increased with the addition of cement content, as shown in Table 3.

Based on [14-15], there was a relation between the ratio of the water (ω) and cement content (p_c) with the compressive strength (q_u) and secant modulus (E_s). The mathematical equations for the parameters in the regression model are presented as Eq. (3) and (4):

$$q_u = \frac{A}{(w/p_c)^B} \quad (3)$$

$$E_s = \frac{M}{(w/p_c)^N} \quad (4)$$

Table 3 Mechanical properties of stabilized soft soil

Cement	Failure strain	Compressive strength	Secant modulus
%	%	kPa	MPa
5	1.75	197.5	5.64
8	1.5	219.7	7.32
10	1.6	240.7	7.52
12	1.75	271.6	7.76
15	1.5	278.5	9.28

where A, B, M, and N are empirical constants.

The relationship between w/p_c and q_u from the unconfined compressive test results is presented in Fig. 5, and Es and w/p_c in Fig. 6, which are formulated in Eq. (5) and (6) as follows:

$$q_u = \frac{312.5}{(w/p_c)^{0.285}} \; ; \; R^2 = 0.949 \quad (5)$$

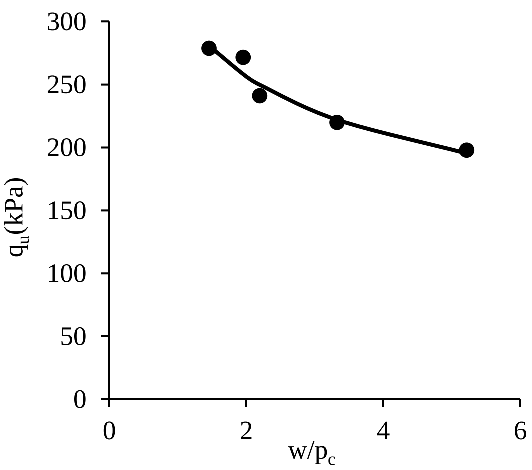


Fig.5 Fitted curve of strength development in cement-stabilized soil.

$$E_s = \frac{10.231}{(w/p_c)^{0.343}} \; ; \; R^2 = 0.911 \quad (6)$$

3.3 Shear Strength Parameter Estimation

The hypothesis [16] of w/p_c as the major parameter is used to predict the mechanical properties of specimens stabilized cement. This research proposed a formulation to develop the formulation of friction angle and cohesion based on the w/p_c parameter.

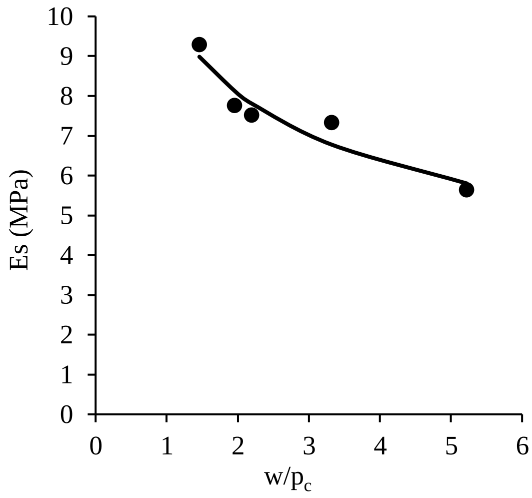


Fig.6 Fitted curve of secant modulus development in cement- stabilized soil

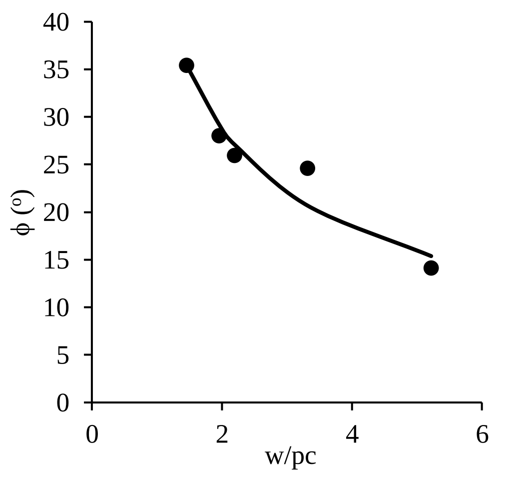


Fig.7 Fitted curve of friction development in cement-improved soil

Figure 8 and Eq. (7) give the relation of friction angle and w/p_c.

$$\phi = \frac{45.33}{(w/p_c)^{0.654}} \; ; \; R^2 = 0.909 \quad (7)$$

The relationship between soil cohesion and w/p_c derived a different regression with the friction angle which there is an optimum value of w/p_c where the cohesion is the highest as shown in Fig.8. The formulation representing the best fitting curve is in Eq. (8).

The formulations in Eq. (8) can be used to estimate the cohesion based on w/p_c:

$$\boldsymbol{c} = -5.3\left(\frac{w}{p_c}\right)^2 + 39.4\frac{w}{p_c} + 55.3; R^2 = 0.97 \quad (8)$$

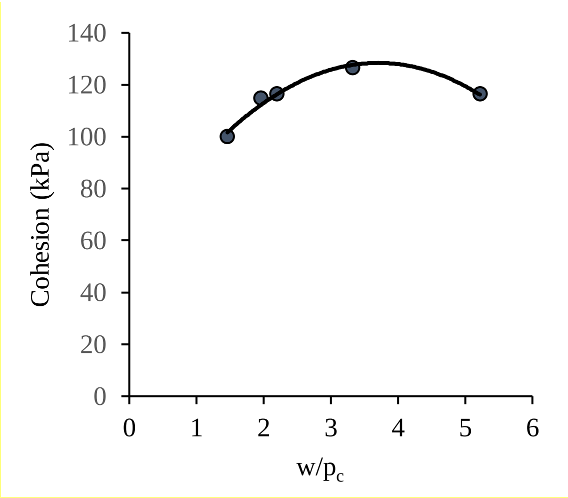
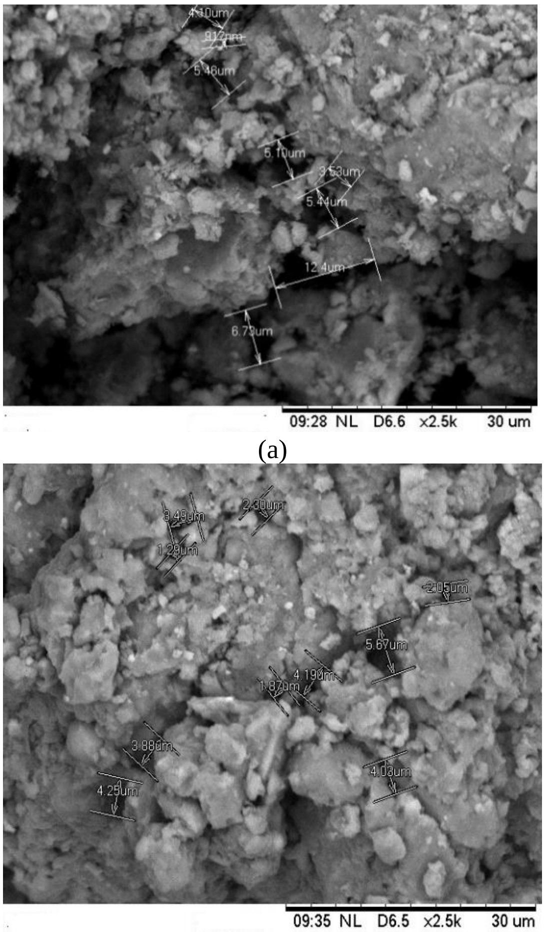


Fig.8 Fitted curve of cohesion development in cement-stabilized soil



(a)

(b)

Fig. 9 Scanning electron microscope images at 2500× magnification: (a) natural soil; (b) cement stabilized soil

Figure 9 shows the SEM (Scanning Electron Microscope) test of the natural soft soil and cement improved soil. Soil pores in the natural soil are around 5.1 - 12.4 um, and 1.87 - 5.67 um for stabilized soil (10% cement). The soil pores size distribution of soil become smaller that affects the bulk density of soil. However, the hight shear strength parameters can be achieved by improving density.

3.4 Influence of Curing Time in Developing Strength of Soil

Figures 10 showed the strength developed is tested at 4, 7, 14, and 28 days. The results of the data analysis determined that the optimum cement content in the soil mixture is 10%.

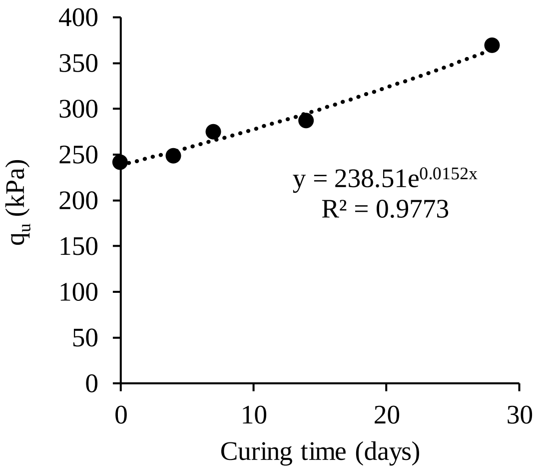


Fig.10 Effect of curing time on the compressive strength

The pozzolanic processes take some time to achieve significantly high strength. The improvement ratio of the strength of the soil improved with 10% cement (240,7 kPa) and natural soft soil (49.4kPa) is 3,87. If the curing was carried out for 28 days, the improvement ratio become 6.4. The soaked CBR test is a test to identify the effect of water on improved soil (Fig. 11). Without curing reduction CBR (unsoaked and soaked CBR) was around 6%. By taking a lot of time of curing, the influence of water is insignificant. It means after 24 days curing, the improved soil becomes more stable.

4. CONCLUSION

Improvement of soft soil by adding cement additives has reduced the plasticity of the soil, as evidenced by the change in soil classification from clayey soil to silty soil. The structure of the clay soil modifies by forming larger aggregates due to the cementation process. The results of the unconfined compression and triaxial test have developed the same phenomenon in which the stiffness and strength of soil increase. The value of w/p_c is directly proportional to the friction angle and inversely proportional to cohesion.

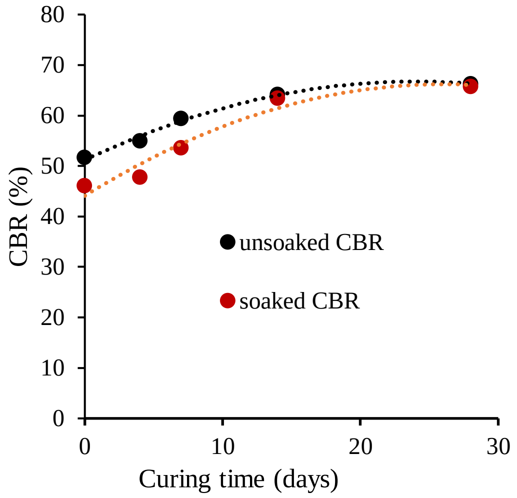


Fig.11 Curing time to develop the strength

Regression function q_u and E_s were formulated by the ratio of water and cement content (w/p_c) as shown in Eq. (5) and Eq. (6). The regressions also were developed to the friction angle and cohesion, which is defined in the mathematical equation as Eq. (7) and Eq. (8). The curing time has increased the strength of improved soil and give it high durability.

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