Effect of organic content and cement quantity on the shear behavior of artificially cemented soil

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Abstract: Most of the soil in the universe contain organic matter that results on the negative effects on the shear behavior of soil. The objective of this research is to study the effect of organic content and proportion of cement of artificially cemented soil. A compaction and direct shear test without curing period were undertaken on the soil with 6, 11, 16, and 21% organic content. Direct shear test results show that the soil cohesion decrease and internal friction angle slightly increase as increasing of organic content. The direct shear test of artificially cemented soil with 21, 28, 42, and 56 curing time was then performed to investigate the effect of cement quantity on the shear behavior of cemented soil. The cement content was 25, 50, 75, and 100 kg/m³. The more cement quantity added to the soil, cohesion and friction angle of artificially cemented soil improves. There is also improvement of the shear stress due to the increase of cement proportion. Similarly, shear strength of stabilized soil improves inherent with curing period due to the short and long-term pozzolanic reactions.

Keywords: organic content, cement quantity, cohesion, friction angle

1. Introduction

Soil with high organic content has usually negative chemical, physical and mechanical characteristics. It has a low degree of acidity (pH), low specific gravity, low unit weight, high void ratio, and high compressibility [1]. This soil also has the low bearing capacity, low shear strength, and high settlement even though preloading is applied to the soil [2-8]. Moreover, the behavior of soil is affected by the term of organic matter [9-10]. Therefore, the effort to improve engineering behavior of organic soil is continuously in progress. Soil improvement by admixtures such as cement, lime, rice husk ash, fly ash, bagasse ash, or combination of those agents is a good alternatives to upgrade engineering properties of soil, and it has been done by [11-16].

Over the last few decades, many research regarding soil improvement with admixtures concerning shear strength, bearing capacity and compressibility have been carried out [17-20]. A few research concentrated on creep behavior of stabilized soil that is dependent on the term of the binder, binder content, stress level applied during creep stage, natural organic content, and the curing condition has been performed [7,22]. To overcome the negative influence of the creep deformation in the soil, two main methods have been done. One method consists of anticipating the creep phenomenon by preloading with a mechanical surcharge or by vacuum [23]. The second approach is performed by reducing creep
deformation with soil improvement that is generally done by installing a vertical drain with soil having better characteristics of existing soil, such as stone columns, deep mixing columns, or concrete piles. The installation of deep mixing columns has been successfully performed to avoid creep deformation of soil foundation [24]. However, the study regarding shear behavior due to organic content and binder quantity has been generally ignored by some researchers. Therefore, the purpose of this research is to study the effects of organic content and binder quantity on the shear strength of cement stabilized soil.

2. Methods

2.1. Engineering Properties of Soil

The soil used in this research was taken from Wates, Kulonprogo regency, a special region of Yogyakarta Indonesia. The soil sample has high content of silica (SiO$_2$ = 61%), alumina (Al$_2$O$_3$ = 17%) and ferrit (Fe$_2$O$_3$ = 5%), and its degree of acidity (pH) is 4.6(Table 1). The high content of pozzolanic materials is expected to accelerate the cementous reaction in cemented soil. The low pH, however, will delay the pozzolanic reaction [20,24]. Moreover, the soil sample has high natural organic content (OC = 16.05%) that results on the low shear strength of soil ($\theta_u < 25$ kPa). The soil is dominated by silt (64%) and clay (5%), sand (34%) and slightly gravel is less than 2%. And the soil is high plasticity clay, plasticity index = 36%, plastic limits = 41.8%, and liquid limits = 77.8% (Table 2).

| No | Chemical matter | (%)  |
|----|-----------------|------|
| 1  | SiO$_2$         | 61   |
| 2  | Al$_2$O$_3$     | 17   |
| 3  | Fe$_2$O$_3$     | 5    |
| 4  | Ca(OH)$_2$      | 8    |
| 5  | MgO             | ---- |
| 6  | OC              | 16.05|
| 7  | pH              | 4.6  |
| 8  | LO              | 5.8  |

| Physical terms | Quantity |
|----------------|----------|
| Water content, w (%) | 81.5 |
| Max. Dry density., $\gamma_{k_{max}}$ (gr/cc) | 1.26 |
| Spec. gravity, G | 2.61 |
| Liquid Limits, $w_L$ (%) | 77.8 |
| Plastic Limits, $w_F$ (%) | 41.8 |
| Plasticity Index, $I_p$ (%) | 36.0 |
| Fines Content, FC (%) ,<0.075 mm | 64 |

2.2. Characteristics of Ordinary Portland Cement (OPC) and Organic Materials

OPC is hydraulic agents that harden when interacting with water, and forms water resisting compound when it receives its final sets. It is used as hydraulic material that reacts with water, and it generates a high quantity of reaction products in the form of gels. Gels formation as the products of pozzolanic reaction, is due to high silica (SiO$_2$ = 41.3%), alumina (Al$_2$O$_3$ = 15.2%), and high calcium hydroxide, Ca(OH)$_2$ = 44.8% in the OPC. Therefore, the pozzolanic reactions are responsible to improve shear strength parameter of stabilized soil. Compared to non-hydraulic materials such as lime or gypsum that absorbs water after hardening, OPC is more durable and produces a high compressive strength of mortar.
or concrete. Organic material was taken from local plant shop, and its chemical contents are: C=81.4%, N=5.1%, P₂O₅ = 4.8%, K₂O = 1.3%, CaO = 8.2%, MgO = 0.7%, S= 0.8%, and Zn = 450 ppm.

3. Experimental Programs

Experimental program presented in this study was undertaken with disturbed soil samples. The mineral composition and soil gradation were maintained to reduce the deviation between soil samples and natural soil. First, the original soil was sieved passed through #10 sieve (opening diameter 2.00 mm) to remove residues, than the soil was mixed with water to get enough liquidity index. The organic content that exist in the soil sample was spoiled by burning the soil at 300°C, then the soil without organic content was used to make artificial organic soil. The organic content mixed in the artificial soil is 6, 11, 16 (natural organic content), and 21%. Then, the soil with organic content (OC) were tested with standard compaction test, and direct shear test to investigate the effect of organic content, the maximum dry density (MDD), and optimum water content (OMC). Also the effect of OC to shear strength parameter was investigated. Soil with 6, 11, 16, 1nd 21% organic content were then mixed with ordinary Portland cement (OPC) with the proportion of: 25, 50, 75 and 100 kg/m³. Then, the cemented organic soil samples were cured with 21, 28, 42 and 56 days curing period. The long period of curing (56 days) is required to get perfect pozzolanic reactions, because the formation of calcium-silicate-hydrate (C-S-H) and aluminum silicate hydrate (C-A-H) happens at long period of curing. Table 3 shows the artificially cemented samples.

| Organic Content (%) | 25 | 50 | 75 | 100 |
|---------------------|----|----|----|-----|
| 6                   | ✓  | ✓  | ✓  | ✓   |
| 11                  | ✓  | ✓  | ✓  | ✓   |
| 16                  | ✓  | ✓  | ✓  | ✓   |
| 21                  | ✓  | ✓  | ✓  | ✓   |

Each sample was cured on 21, 28, 42 and 56 curing times, then all samples were tested on the direct shear apparatus to study especially the effect of organic content and cement proportion on the cohesion and internal friction angle. To get the reliable results, all the tests were performed at least twice. The cement-stabilized organic soil samples for direct shear test were prepared as follow: to get a homogenous soil-OPC-water proportion, the oven-dried disturbed soil and the specified proportion of OPC were carefully mixed using manual mixer; the paste of stabilized soil samples then compacted in the PVC (inner diameter = 6.3 cm, the height = 13.8 cm) in six layers; the soil then extracted and cut into six pieces (13.8/6 = 2.3 cm thick) to meet the direct shear samples. The samples were than cured on 21, 28, 42 and 56 days- curing-times, and the direct shear tests were performed.

4. Results and Discussion

4.1. Compaction Test

Standard Proctor compaction test was performed to investigate the effect of organic content on MDD and OMC of untreated soil. Figure 1 presents the relation between moist unit weight and MDD with organic content. It shows that the more organic matter the less the moist unit weight and MDD, beside the soil void ratio increases due to organic content. The moist unit weight of original soil is 1.26 gr/cc decreases to 1.05 gr/cc for soil + 21% OC, on the same condition MDD decreases from 1.56 gr/cc to 1.24 gr/cc. Those negative effects are due to the more pore of soil containing organic content, which indicates that 21% OC is enough to negatively changes the behavior of soil. It is different from the findings of [22] which indicates that 3- 4% organic content is enough to change soil properties. The optimum water

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content (OMC) improves when the proportion of organic content increases. The OMC of soil + 6% OC is 31.5%, it increases to 62.2% for soil + 21% OC. This is because of properties of organic matter that absorbs water in the soil.

4.2. Direct Shear Test

4.2.1. Effect of Organic Content. The direct shear test was undertaken to search the changes of shear strength parameters of both original soil and cement stabilized soil. The cohesion of soil decreases when the organic content increase (Fig. 2). Cohesion of the soil + 6% OC is 45 kPa, it decreases to 32 kPa for soil + 21% OC. This behavior is because of the organic material enlarge the distance between soil particles that results on the high volume of pore especially surrounding the organic material. However, the friction angles improves from 6.84° for soil + 5% OC to 11.5° for soil + 20% OC. The improvement is almost linear with the improvement of organic content. This behavior might be due to the friction characteristic of organic fiber (Fig. 3). The study about slag-fly ash stabilized clayey soil concluded that organic matter disturb the nucleation and cementation in stabilized soil that result on small increment of shear strength parameter [24].
4.2.2. The effect of Cement Quantity. Fig. 4 presents the relation between friction angle (φ) and cement content of artificially cemented soil with 21 days curing time, and the relation between cohesion (c) and cement content on the same curing time is presented on Fig. 5. Both cohesion and friction angles increase proportional with binder quantity due to partial formation of calcium silicate hydrate (C-S-H). On 11% OC, for example, cohesion increases from 60 kPa for 25 kg/m³ OPC to 101 kPa for 100 kg/m³ OPC (68.3 %), and internal friction angle improves from 6.8° to 9.3° (36.8%). However, the improvement of those shear strength parameters is not significant due to not enough time to get perfect pozzolanic reactions. In this period, there is only cation exchange reaction that is the changes of K⁺ or Na⁺ in the soil and Ca²⁺ or Mg²⁺ that exist in the OPC. Due to the cation changes, plasticity index (PI) of stabilized soil decrease, that result on decreasing of degree and potential swelling of the soil. Similar to unstabilized soil, the more organic content, the less cohesion and friction angles. It is similar to the finding of [5].

**Figure 3.** Friction angle – Organic Content

**Figure 4.** Friction angle vs Cement content on 21 days curing time

**Figure 5.** Cohesion vs Cement content on 21 days curing time
For 42 days curing period (Fig. 6 and 7), there is significant improvement of shear strength parameters. On 11% OC, for example, the 62 kPa cohesion of soil + 25kg/m^3 OPC increases to 136 kPa for soil + 100 kg/m^3 OPC (119.4% improvement). This significant improvement is due to the second stage of pozzolanic reactions, that is the formation of calcium aluminum silicate hydrate (C-A-S-H). Cement particles is heterogenic substance containing tri calcium-silicate (C_3S), tri calcium aluminate (C_3A), and tetra calcium aluminate (C_4A) which improve soil shear strength. When OPC fill the pore containing water, there will occur quick hydration that is also called as premier hydration. The formation of calcium silicate hydrate (C-S-H) and aluminum silicate hydrate (C-A-H) happen in this stage. Therefore, in short term of curing period the improvement of shear strength parameters is not significant. During long period, the secondary pozzolanic reaction, the formation of calcium aluminate silicate hydrate (C-A-S-H) occur that result on significant improvement of both cohesion and internal friction angle. The result of pozzolanic reaction bind the cement grain during hardening process followed by the formation of matrix skeleton that cover soil particles, then flocculation process occur that result on significant improvement of shear strength. Therefore, improvement of cohesion and internal friction angle is very much dependent on the curing time. The longer curing period, the more significant improvement of cohesion and internal friction angle.

4.2.3. Shear Stress. Fig. 8 is presentation of shear stress vs normal stress of artificially cemented soil with 21% organic content and 21 days curing time. It indicates that the improvement of both cohesion and internal friction angle depends on the cement quantity. The more OPC proportion, C-S-H; C-A-H, and C-A-S-H formation is intensively in progress to improve shear strength parameters of artificially cemented soil. For 21% OC without cement, the cohesion is 48kPa and 5.5° of internal friction. By addition 25 kg/m^3 of cement, there is improvement of cohesion (52 kPa) and internal friction angle (6°). The percentage of improvement is less than 10%. However, there is significant improvement for 75 kg/m^3 cement content, cohesion increase to 80 kPa (67%) and 8.2° (60%) for internal friction angle. As a results
the improvement of cohesion and internal friction angle, the shear stress improves. Refer to Fig 10., for normal stress of 0.70 kg/cm² the shear stress is 0.56 kg/cm² for 25 kg/cm³ OPC and 1.09 kg/cm² for 100 kg/m³ OPC. The percentage of improvement is 94.6%.

Fig. 8. Shear vs Normal Stress 21% OC on 21 days curing time

4.2.4. Stress- Deformation. Fig. 9 is presentation of shear stress-lateral deformation obtained from the direct shear test for 21% OC and 21 days curing time for the samples with different percentage of OPC (25, 50, 75 and 100 kg/m³). In general, stiffness of cement stabilized soil increase with respect to percentage of OPC, then artificially cemented soil behaves as a brittle material with less strength after failure. Therefore the stabilized soil is characterized as high strength- small strain, whereas the original soil is noted as small strength – large strain. For the same lateral deformation, 2 mm, the required shear stresses are 6 kPa for untreated soil, 50 kPa for 25 kg/m³ OPC, 70 kPa for 50 kg/m³ OPC, 80 kPa for 75 kg/m³ OPC and 100 kPa for 100 kg/m³ OPC. Also, the longer time period, the stiffness of cemented soil increases. Then, it can be concluded that the stiffness of stabilized soil is not only dependent on cement quantity, but also dependent on the curing time. The binder quantity generate the pozzolanic reaction. The amount of CaO in the OPC can effectively react with silica (SiO₂) in the soil followed the formation of calcium-silicate hydrate and calcium-aluminum-silicate hydrate, which in the form of gel making the cemented soil stronger and stiffer. The increases of curing time improve the stiffness of stabilized soil, because development of pozzolanic reactions required enough time to occur. The longer time period, the effective the generation of pozzolanic reaction.

Fig. 9. Shear Stress vs Lateral deformation : 21% OC and 21 days curing time
5. Conclusions
From a series of experimental works, results and discussion the following conclusions can be presented: the results of Standard Proctor compaction test indicate that the increase of organic content (OC) decrease the maximum dry density (MDD), and increases of optimum water content (OMC) of untreated soil. Based on the result of direct shear test, the cohesion and internal friction angle of cemented soil increases proportional with cement content and curing period, followed by the improvement of shear strength. The stiffness of stabilized soil improves also with respect to cement quantity and curing period, therefore it behaves as high stress-small strain material. This phenomenon is different from that of untreated soil that behaves as small stress-high strain material. Regarding to the optimum cement content (OCC), it is not recommended to use the OCC to get the best artificially cemented soil.

Acknowledgement
The authors would like to deliver special thanks to The minister of Research and Higher Education Republic of Indonesia for the funding of the research through the Fundamental Research of Higher Education Grant. Thank is also addressed to Research Institute and Public Affairs of Universitas Atma Jaya Yogyakarta.

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