CEMENT DEEP MIXING METHOD OF SOIL STABILIZATION EFFECTING OF MONTMORILLONITE CONTENT ON THE BEARING CAPACITY OF GROUND IMPROVEMENT

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ABSTRACT

The Mekong Delta is the largest delta of Vietnam, covered Holocene sediment due to sedimentation of the Mekong river system. The minerals of soft clay in this area usually include: Montmorillonite (MMT), Illite, Chlorite, and Kaolinite... MMT in clay affect to the soil swelling properties. The developed swelling pressure will destroy the lightly construction and road surface. This research simulated the influence of MMT to the bearing capacity of soft ground improved by cement deep mixing (CDM) columns by laboratory model. To conduct this research, the laboratory model 1g has been studied and made. The different of MMT contents is changed from 6% to 15% for soft ground to research the changes to strength of soft ground improved by CDM columns. In addition, this research also investigates the optimum cement content to unconfined compressive strength (UCS) of the soil cement specimen with the different MMT contents.

Keywords: Montmorillonite, CDM, Soil cement mixing, Soft soil, Mekong Delta.

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1. INTRODUCTION

The Mekong Delta is located in the southern of Vietnam. As a delta area, most of the soil layers are categorized as the soft soil. The properties of the soil are high water content, low stiffness and less frictional angle and less cohesion as well.
During recently years, stabilization of soft ground by CDM method has became an increasing strongly developed in this area. There are many factors affect to mechanical properties of stabilized soil. The mineralogical properties of soil strongly affect the strength of treated soil (Terashi, M., 1997). The minerals of soil usually include: MMT, Illite, Chlorite, and Kaolinite, Quartz... MMT mineral affect to the soil swelling properties. According to Phan Thi San Ha et al. (2007), MMT content in Binh Chanh – Ho Chi Minh from 11.3% to 13.3%, in An Giang from 5% to 10% (James L. Post, 1971) and in Mekong Delta from 0% to 8% (Nguyen Huu Chiem).

There are many factors effect to mechanical properties of CDM specimens. This research investigates only the effect of Monmorillonite content based on water content, and curing time on mechanical properties of specimen, which is cured in freshwater conditions.

In this study, the unconfined compression test is used to investigate the optimum cement content of soil cement specimens. The series of laboratory model and finite element method are also used to simulate the influence of MMT content to the bearing the capacity of stabilized soil by soil cement columns.

2. MATERIALS

2.1. Soil

The soil is one of the typical soft soils in the Mekong Delta. The properties of soil are obtained by the laboratory tests, is given in Table 1.

| Table 1. The properties of the soil in the Mekong Delta |
|---|---|---|
| ID | Parameters | Value |
| 1 | Water content, W(%) | 45.14 |
| 2 | Wet unit weight, $\gamma_w$(kN/m³) | 17.43 |
| 3 | Dry unit weight, $\gamma_d$(kN/m³) | 12.01 |
| 4 | Initial void ratio, $e_o$ | 1.290 |
| 5 | Liquid Limit, LL(%) | 47.59 |
| 6 | Plastic Limit, PL(%) | 25.2 |
| 7 | Plasticity Index, IP(%) | 22.39 |
| 8 | Cohesive, c(kPa) | 6.7 |
| 9 | Friction angle, $\phi$(°) | 30°53' |
| 10 | MMT content(%) | 6 |

2.2. Bentonite

Bentonite is an absorbent aluminum phyllosilicate which in general terms are impure clay consisting mostly of MMT. Bentonite expands when wet - sodium bentonite can absorb the several hundred present of its dry weight in water. It is commonly used in drilling, to make slurry wall, and to form impermeable barriers. The properties of bentonite are given in Table 2.

| Table 2. Bentonite properties |
|---|---|---|
| ID | Parameters | Value |
| 1 | Specific Gravity Gs(%) | 2.73 |
| 2 | Liquid Limit, LL(%) | 405.1 |
| 3 | Plastic Limit, PL(%) | 51.5 |
| 4 | Plasticity Index, IP(%) | 353.6 |
| 5 | MMT content(%) | 65 |
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2.3. Cement

Portland cement PCB40 is used for this study. The properties of cement are given in Table 3.

<table>
<thead>
<tr>
<th>ID</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific surface(cm2/g)</td>
<td>≥ 3300</td>
</tr>
<tr>
<td>2</td>
<td>Time of setting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial set (min)</td>
<td>≥ 45</td>
</tr>
<tr>
<td></td>
<td>Final set (h)</td>
<td>≤ 10</td>
</tr>
<tr>
<td>3</td>
<td>Chemical (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MgO</td>
<td>≤ 5.0</td>
</tr>
<tr>
<td></td>
<td>SO3</td>
<td>≤ 3.5</td>
</tr>
</tbody>
</table>

3. METHOD TEST

3.1. Unconfined Compression Test

Generally, the unconfined compressive strength of soil cement is between 50kPa and 4,000kPa, which is 50 to 100 times greater than that of pre-improved soil but still much lower than that of concrete.

The focus of the material design is that the quality of the product must be achieved to satisfy the minimum strength and other design requirements. Although the soil cement mixing contractor often determines the mix design, it is important for the design engineer to understand the factors contributing to the strength of the soil cement.

In this study, the soil cement specimen is made with the diameter of 50mm and the height of 100mm, which different conditions: Cement content is 5%, 10%, 15%, 25%; Bentonite content is 0%, 5%, 10%, 15% (MMT content is 6%, 9%, 12%, 15% respectively); water content is 80%; curing condition is freshwater. The influence of cement content on the unconfined compressive strength was investigated by a series of unconfined compression tests have been performed in laboratory at 28 days of curing.

In this test method, unconfined compressive strength is the maximum axial load attained per unit area or the load per unit area at 5% axial strain, whichever occurs first during performance of a test. In a laboratory compression axis, form the mixture of cement soil vertical axis is compressed with increasing force until it happens to destroy or deform along the axis reaches 5%.

Samples compressed application form with a height of cylindrical samples. Use axial compressors to carry out experiment. Speed up the compression pressure is controlled so that the speed of deformation along the axis around from 0.5% to 2%/minutes. Deformation rate should be selected so that the time samples were not exceed 15 minutes. Calculation of results: Compressive stress of the sample is calculated by the formula:

\[ q_u = \frac{P}{A} \]

Where \( q_u \): unconfined compressive stress, (kPa); \( P \): axial load applied to specimen, (kN); \( A \): corresponding average cross-sectional area, (m²).

In total, 48 unconfined compression tests were performed. The results are shown in Figure 1 and Figure 2. The UCS of soil cement specimens decreases almost linearly with the increasing of MMT contents. Based on the Fig. 1, the optimum cement content can be determined when the soft soil has different MMT contents.
To clearly understand the affection of MMT, a series of X-ray CT is scanned for soil cement specimens at initial the unconfined compression test for 28 days curing, which specimens are made from kaolinite clay, bentonite content is 0%, 5%, 10%, 15% (MMT content 0%, 3.3%, 6.5%, 9.8% respectively), cement content is 20%, total water-to-cement, wT/c=3 and 5. The position of X-ray CT is shown in Fig. 3.

In this system of X-ray CT scanner used in this research, the collimated X-ray penetrates from all around the circumference of the specimen by rotating and traversing the specimen table. The detected analog data are changed to digital values and then, a coefficient of X-ray absorption in each spatial unite called a “voxel” which is unit volume whose size is 0.293mm x 0.293mm square, with its width of X-ray attenuation is calculated. The coefficient of absorption is used in order to calculate the following so called “CT-value”:

\[
CT\text{ - value} = (\mu_t - \mu_w)k/\mu_w
\]

Where \(\mu_t\) is coefficient of absorption at the scanning point, \(\mu_w\) is coefficient of water, and \(k\) is a constant called Hounsfield unit. Hera, this constant is fixed at a value of 1000. Thus the CT-value of air should be -1000 because the coefficient of absorption for air is zero. Likewise, this value for water is 0 from the definition of Eq. (2). It is well known that the CT-value has a linear relationship with material density.
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![Figure 4. Density of specimens by X-ray CT image, wT/c=3](image)

The CT-value of soil cement specimen is not so much different by changing MMT content, but large change when increasing the total water-to-cement (Fig. 5 and Fig. 7). The CT-value of soil cement specimen changed the mean value of 842, 853, 844, 836 when MMT content change 0%, 3.3%, 6.5%, 9.8% respectively with wT/c=3; Otherwise with wT/c=5, this value change 653, 686, 675, 668. The result of X-ray CT method showed the density of soil cement decrease when the soil has much MMT mineral, this reason affect to unconfined compressive strength of soil cement specimens.

Fig. 6 shows the same relationship for CDM specimens, in which all the samples were scanned at 20 different height and the average CT-value was calculated using these CT-value in each sample. This result shows a linear relationship among all the results, so the change of the density of the specimen can be discussed with the CT-value.

The failure mode of CDM specimen is brittle failure. The maximum strain is 1.5%. The X-ray CT images clearly see the cracks in sides CDM specimens are shown in Fig. 9.
Figure 6. Density of specimens by X-ray CT image, wT/c=5

Figure 7. CT-value of specimens, wT/c=5

Figure 8. CT-value-density relationship for CDM

Figure 9. The cracks in sides CDM specimens, wT/c=5
3.2. Laboratory Model Test

The main reason for model test is the difficulty to perform extensive quantitative field tests of reasonable costs. With laboratory model tests the most important factor affecting the behavior of the columns can be determined. In order to confirm the validity of the proposed homogenization method, 1g-model test of the improved ground with soil cement columns are conducted. The model is designed based on the models of Ailin Nur I.o, Hafez M.A., Norbaya S. (2011), K.Omine, H.Ochiai (1999), Kitazume, M., Okano, K., and Miyajima, S. (1999), Mirja Kosche (2004), S.Larsson (1999).

Figure 10. Schematic of laboratory model test

In model ground preparation, dry clay power with 0%, 5%, 10%, 15% bentonite in weights was mixed with freshwater to slurry a water content of approximately 80% (Fig. 11). This slurry was poured in the test box with 300 mm in height (Fig. 13). They had a draining sand layer in the bottom (Fig. 12). Pressure was applied at the top to consolidate the slurry. The consolidation pressure was increased in step 0kPa, 2.5kPa, 5.0kPa, 10.0kPa (Fig. 14).

Figure 11. Slurry Figure 12. Sand layer
Figure 13. Soil layer Figure 14. Consolidation
The water content of the consolidated soil was approximately from 49 to 50% and the wet unit weight was from 17.2 to 17.4kN/m³. After the consolidation was completed, the surface of soft soil was flattened through a trimmer and some of the soil was removed to bring its height 200mm. The soil was ready for constructing soil cement columns inside (Fig. 15a). The soil cement columns were prepared using a technique similar to the ones used to construct bored piles. Before drilling, the guide plate that was used to assure the accuracy of geometry was placed carefully on top of the consolidated soil (Fig. 15b). The auger of the drill is continuous with the diameter of 20mm and the length of 300mm (Fig. 15c). The hole is kept by plastic tube (Fig. 15d). The columns material was injected into pre-bored using a injection pump (Fig. 15e). The holes were filled up through inserting the 300mm long hose with 15mm outer diameter to the bottom of each hole (Fig. 15f).

![Figure 15](image1.png)  
**Figure 15.** The process of making soil cement columns

Continue done with 31 other columns. Finally, the stabilized soil in laboratory model was kept in room temperature for curing 28 days.

The system test was performed using loading mechanism that was specifically designed for this research. It is composed of an oil pressure supplier, a pressure transducer, a loading piston and a controller (Fig. 16). The bearing capacity of stabilized soil is the maximum axial load attained per unit area or the load per unit area at 5% axial strain, whichever occurs first during performance of a test.

The results of research is showed that with the same cement content, the bearing capacity reduces when the MMT content increased (Fig. 17). When MMT content increases 9% (from 6% to 15%) then the bearing capacity of stabilized soil will decrease 2.6 times (from 66kPa to 25kPa). The bearing capacity of stabilized soil increases 3.3 times to unstabilized soil, from 20kPa to 66kPa with MMT content 6%. Otherwise, only increase 1.25 times with MMT 15%.
This result is shown that: The MMT mineral in soil is the large affection to improved soil by Deep Mixing Method.

![Figure 16. Laboratory model](image16)

**Figure 16.** Laboratory model

![Figure 17. The bearing capacity of stabilized and unstabilized soft soil](image17)

**Figure 17.** The bearing capacity of stabilized and unstabilized soft soil

## 5. CONCLUSIONS

Based on the study described above, the conclusions of this study are listed as follow:

The unconfined compressive strength of soil cement specimens decreases almost linearly with the increasing of MMT contents. Based on the Fig. 1, the optimum cement content can be determined when the soft soil has different MMT contents.

The CT-value of soil cement specimen is decreased when MMT content increase, it means the density of soil cement decrease when the soil has much MMT mineral. The unconfined compressive strength decreases by decreasing of CT-value. The X-ray CT images clearly see the cracks in sides CDM specimens, the failure mode of CDM specimen is brittle failure.

The bearing capacity reduces when the MMT content increased.

The developed methodology and the results obtained in this study may be used for the design and calculation the soil structures interaction immersed tunnels with soft clay bed.

## REFERENCES


