EVOLUTION OF SHEAR STRENGTH WITH VARYING CEMENT DOSAGES IN DREDGED MARINE SOILS

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Abstract
Cement is widely applied in soil treatment to enhance its geotechnical properties. The treatment techniques of dredged marine soils (DMS) are an essential and necessary in assuring the effectiveness for a long-term solution. Particularly the application of it as a backfill material. The reuse of DMS as geomaterial will minimize the impact to environment. The disposal of DMS into the ocean or on land are unsatisfactory in managing its large quantity which indicates a high demand on new ocean and land disposal. DMS are classified as contaminated waste that contain of organic matter and heavy metals. Contaminated DMS can harm aquatic organism, animals and human. It must be disposed safely to ensure the contaminants are not released. This paper presents a cement-treated of Kuala Perlis DMS (3.4 LL) with varying dosage of cement (2.5 – 40 %) at different curing period (1, 168, 336 and 672 hours). It shows the undrained shear strength ($s_u$) value of cement-treated DMS throughout the curing process. The results for cement dosage above 20 % shows a good improvement in $s_u$ value and the strength development were found increased after 168 hours of curing. It was explained that the lowest water-cement ($w/c$) ratio tend to have a higher $s_u$ value of the cement-treated DMS.

Keywords: Dredged marine soils; Cement-treated DMS; Undrained shear strength; Water-cement ratio

INTRODUCTION

Large volume of unwanted dredged marine soils (DMS) with high initial water content were produced annually from the maintenance works of ports and waterways, as well as the dredging of rivers and lakes. Their initial water content is about 2 to 3 times of liquid limit ($LL$). These works are crucial in keeping harbors and waterways navigable, preventing flood of river and restoring the ecosystem of degenerative water bodies (Zhu et al., 2007; Bian et al., 2016). The DMS from dredging works are often dispose by dumped in the sea or stored at on land disposal sites (Rekik and Boutouil, 2009). Disposal of this DMS is costly and always poses a significant challenges when to find a suitable sites to dispose the waste. DMS are exhibit with low shear strength, high compressibility and their natural water content are higher than its LL (Zhu et al., 2007; Kang et al., 2015; Kang et al., 2016; Kang et al., 2017). Rather than disposed or stored the waste, it can be reuse or recycle as a geo-waste-material with suitable pre-treatment such as cement-treated method (Chan et al., 2012).

Cement-treated soils are known as one of economical and environment-friendly solutions. Cement mixing method make these waste materials useful as a geomaterial for various construction works. It is widely applied to enhance the properties of soil foundation structures such as embankments, earth dams and river levees (Bian et al., 2016; Ho et al., 2017). Cement-treated soils possess certain extent of structures as a result of the cement hydration and pozzolanic reactions (Zhu et al., 2007; Chiu et al., 2008). Cement hydration occurred rapidly when the pore water encountered with cement. The hydrated calcium silicates (CSH), hydrated calcium aluminates (CAH), hydrated calcium aluminium silicates
(CASH) and hydrated lime / calcium hydroxide \((\text{Ca(OH)}_2)\) are known as the major hydration products. It leads to a rise of pH value of the pore water caused by the dissociation of \(\text{Ca(OH)}_2\). The silica and alumina from the pozzolanic materials were dissolved by the strong bases. It is similar as the reaction between a weak acid and strong base. The hydrous silica and alumina will then react with calcium ions liberated from the hydrolysis of cement from insoluble compounds (secondary cementitious products) and hardens with time (Horpibulsuk et al., 2011). Generally, the short-term strength development is mainly attributed by cement hydration. While, for long-term strength development is mainly attributed by pozzolanic reaction between clay minerals and \(\text{Ca(OH)}_2\) formed by cement hydration (Ho et al., 2017; Horpibulsuk et al., 2003). Furthermore, cement treatment leads to a flocculation of the fine fractions in soils and increases their particle size and modifies their plasticity (Rekik and Boutouil, 2009).

The strength mobilization of cement-treated clay is influenced by many factors. Such as the quantity of cement used, the mixing methods of admixtures, the curing conditions and characteristics of the nature of soils (Kang et al., 2015). Water content of soils considerably influence the strength of cement-treated soils (Ho et al., 2017). This parameter is usable in interpret quantitatively other mechanical properties of the cement-treated soils, such as yielding and shear strength (Chiu et al., 2008). The strength of cement-treated soils were relied on the proportion of water-cement \((w/c)\) ratio. It is an important factor in determining the ultimate strength and stiffness gain of the soil. High ratio of \(w/c\) leads to the lower strength in soils. Where the strength of cement treated soils is inversely proportional to the \(w/c\) ratio. Moreover, \(w/c\) ratio affects the hydration kinetics. Where the higher \(w/c\) ratio leads to the higher hydration rate (Rekik and Boutouil, 2009; Yun et al., 2006; Chan, 2016).

**EXPERIMENTAL WORK**

Distilled water was added to the DMS to achieve the consistency of 3.4 \(LL\) for each sample to achieve the same as natural water content of the DMS. Cement was added to the DMS at a dosage of 2.5 – 40 \%, corresponding to the \(w/c\) ratio as shown in Table 1. Those dosages were investigated to determine cemented DMS behavior at different \(w/c\) ratio. DMS and cement was thoroughly mixed by using kitchen mixer at a lower speed. The mixture was then transferred into a rectangular airtight container (see Figure 1) and cured for 1, 168, 336 and 672 hours before a laboratory vane shear (LVS) test were performed.

![Figure 1. Cement-treated DMS specimen](image-url)
Table 1. Specimen list and mix ratio

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Natural Water Content (%)</th>
<th>Wet Soil (g)</th>
<th>Dry Soil (g)</th>
<th>Water, W (g)</th>
<th>Cement, C (g)</th>
<th>Cement Dosage (%)</th>
<th>W/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5C</td>
<td>240.74</td>
<td>2000</td>
<td>586.96</td>
<td>1413.04</td>
<td>14.67</td>
<td>2.5</td>
<td>96.3</td>
</tr>
<tr>
<td>5C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29.35</td>
<td>5</td>
<td>48.1</td>
</tr>
<tr>
<td>10C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58.70</td>
<td>10</td>
<td>24.1</td>
</tr>
<tr>
<td>20C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>117.39</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>40C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>234.78</td>
<td>40</td>
<td>6</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSIONS

Material

The studied materials was dredged from Kuala Perlis, Kedah of Peninsular Malaysia in year 2016. The properties results of the dredged materials are reported in Table 2. The natural water content is about 240.74 % (3.4 LL), dried in an oven at 100 ºC (BS 1377-2:1990:3.2). The particle density value of dredged material is 2.36, measured using a small pyknometer method (BS 1377-2:1990:8.3). The liquid limit value is 71.70 % by using a cone penetrometer method (BS 1377-2:1990:4.3). The plastic limit and plastic index value for dredged material are 40.06 % and 31.64 %, respectively (BS 1377-2:1990:5). The dredged material was classified in high plasticity silt, MH for its soil type (Unified Soil Classification System).

Table 2. Properties of dredged marine soils

<table>
<thead>
<tr>
<th>Soil type</th>
<th>High plasticity silt, MH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural water content, ( w_{nat} ) (%)</td>
<td>240.74</td>
</tr>
<tr>
<td>Specific gravity, ( G_s )</td>
<td>2.36</td>
</tr>
<tr>
<td>Liquid limit, ( LL ) (%)</td>
<td>71.70</td>
</tr>
<tr>
<td>Plastic limit, ( PL ) (%)</td>
<td>40.06</td>
</tr>
<tr>
<td>Plastic index, ( PI ) (%)</td>
<td>31.64</td>
</tr>
</tbody>
</table>

Shear Strength

Undrained shear strength, \( s_u \) was obtained by LVS test. Figure 2 indicates the \( s_u \) values for various cement dosage ranging 2.5 – 40 % at different curing time (hour). It shows the \( s_u \) value of the DMS were proportionated to the curing period. At dosage below 10 %, the rate of \( s_u \) increment did not show a significant changes throughout the curing process. It shows these ratios are insufficient enough to strengthen the DMS due to its high natural water content. While for dosage at 20 and 40 %, the \( s_u \) are increases rapidly up to 168 hours of curing. It was expected that the \( s_u \) will continuously increase beyond the 672 hours of curing. Several studies have revealed that the strength increases as samples undergo longer curing time and maximum value of strength were attained for the 28 days (672 hours) curing time (Yun et al., 2006; Vakili et al., 2016). It is because extended curing time is required to induce cementation of soil (Rahman et al., 2013). Kang et al. (2016) clarifies the pozzolanic reaction will begin upon 28 days (672 hours) of curing where indirectly will producing the cementing products in cement-treated DMS.
The relationship of $s_u$ and $w/c$ for the preliminary study are presented in Figure 3. These two factors describes a good correlation between the $s_u$ and $w/c$ value. It shows the high value of $w/c$ tend to have the lowest $s_u$ and it verifies the $w/c$ factor are strongly affecting the $s_u$ of cement-solidified DMS. Furthermore it shows the prolonged curing of cement-solidified DMS results in continuous increasing of $s_u$. Liu et al. (2008) introduced a simple index of total water-cement ratio ($R$) where defined as (1). Where $m_w$ represents the weight of water on the mixed soil-cement, including the water in original soils and water in slurry cement. And $m_c$ represents the weight of cement in dry state.

$$R = \frac{m_w}{m_c}$$

(1)
According to Kang et al. (2016), the estimation of strength development at early stages is important for construction project. Figure 6 illustrates the strength development with curing time at log-log scale and strength increment coefficient \( b_1 \) with cement content at early stages of curing time (within 3 days), respectively. The strength development can be expressed as shown in (2) and (3). Where \( t \) is curing time, \( a_1 \) is strength at 1 hr of curing, and \( b_1 \) is the rate of strength increment within 3 days. Kang et al. has mentioned that in order to find the coefficient of \( b_1 \), a log-log scale graph must be drawn (see Figure 4).

\[
\begin{align*}
\ln (q_u \text{ or } 2s_u) &= \ln (a_1) + b_1 \ln (t) \\
q_u \text{ or } 2s_u &= a_1 t^{b_1}
\end{align*}
\]  

(2) \hspace{1cm} (3)

Figure 4. Strength development with curing time (log-log scale)

Figure 5 shows the strength increment coefficient within 3 days \( (b_1) \) close to zero when the cement content is small. Kuala Perlis DMS shows the \( b_1 \) sharply increases with cement content up to 20%. While \( b_1 \) are slightly increases at dosage below 20%. The level of \( b_1 \) by hydration reaction generated during early curing time are small at dosage below 20% (Kang et al., 2016). Thus, \( b_1 \) can be expressed as in (4). Where \( e_1 \) and \( e_3 \) are strength increment parameters with cement content within 3 days of curing. And \( e_2 \) represents the threshold of cement content for strength gain of treated clay.

\[
b_1 = e_1 \ln (c^* - e_2) + e_3
\]  

(4)
Figure 5. Strength increment coefficient $b_1$ with cement content at early stages of curing time (within 3 days)

Figure 6 represents the normalized initial water content of sample will change with variation in water content (see Equation 2). The weight of water, clay and cement will change depending on the cement content. Where soil and cement were considered as solid particles in determining the water content. The normalized water content at liquid limit were determined as mentioned in (5) and (6). Where $w_w$ is weight of water, $w_s$ is weight of soils and $w_c$ is weight of cement. There are no significant changes in value of $\ln s_u$ for cement dosage at 2.5, 5, 10 and 20 % (normalized water content: -0.024, -0.048, -0.095, -0.183). The difference in $\ln s_u$ can be seen significantly in the 40 % of cement dosage (normalized water content: -0.335). Henceforth, it shows higher $w_c$ value and prolonged curing are the factor of $\ln s_u$ to increase.

$$w' = \frac{w_w}{w_s + w_c}$$

(5)

$$w_{LL} = \frac{w_w}{w_s}$$

(6)
CONCLUSION

The most obvious finding to emerge from this study is that the $s_u$ value of cement-treated DMS were induced by the lower w/c and prolonged curing time. For $s_u$ at dosage 20 and 40 %, it shows an increment up to 168 hours of curing time. The prolonged curing showing an increment value of $s_u$. The changes of w for dosage 2.5 and 5 % were neglected. It is regarding w values at dosage 2.5, 5 and 10 %, where it seems did not shows a major changes throughout curing process. It was evidently supported by previous study where the pozzolanic activity will begin upon 28 days (672 hours) of curing in producing the cementing products of DMS. The w/c ratio is a prime parameter in analysis the properties of DMS. The higher strength of DMS will be induced by the lower value of w/c or R, with the enhancement of the cementation bond strength. A study towards the variety of w/c ratio will assist in future studies in the appropriate cement dosage selection for high natural water content marine soils.

REFERENCES


