Study on the Geotechnical Properties of Cement based Composite Fine-grained Soil

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Abstract: This study investigates the effect of cement on the performance of soil, collected from Khanjahan Ali Hall at Khulna University of Engineering & Technology (KUET) in Khulna, Bangladesh. The addition of cement was found to improve the engineering properties of available soil in stabilized forms specifically strength, workability, and compaction and compressibility characteristics. Therefore, laboratory tests such as compaction, Atterberg limits, unconfined compressive strength, direct shear and consolidation tests for different percentages of cement content and original soil samples were performed. These test results show that the soil can be made lighter which leads to decrease in dry density and increase in moisture content and reduced compressibility due to the addition of cement with the soil. Besides that the unconfined compressive strength and shear strength of soil can be optimized with the addition of 7.5% of cement content.

Keywords: Cement, Index Properties, composite fine grained-soil, strength properties and compressibility

Introduction
Generally, partially saturated clayey soils having high plasticity are very sensitive to variations in water content and show excessive volume changes. Such soils, when they increase in volume because of an increase in their water contents, are classified as expansive soils. This highly plastic soil may create cracks and damage on the pavements, railways, highway embankments, roads, building foundations, channel and reservoir linings, irrigation systems, water lines, sewer lines etc (Gromko, 1974, Mowafy, 1985 and Kehew, 1995). Therefore, highly plastic soil exhibits undesirable engineering properties under load. They have low shear strengths and tendency to lose shear strength further upon wetting or other physical disturbances (Mitchell, 1986). Therefore, this plastic soil are very prone to shear failure due to the constant load over time and considered poor material for foundations(Liu, et. al., 2008). soil-cement is widely used to improve foundations of structures, in basement improvement, in rigid and flexible highway, airfield pavements ,in embankment slope protection, stream bank protection, waterproofing, grade control structures, and reservoir and channel linings (Ingles et al., 1972; Williams,1986; Teng et al.,1973). According to The American Concrete Institute, soil cement as a mixture of pulverized soil and measured amounts of Portland cement which is water compacted to a desired high density. Soil cement can be further defined as a material produced by blending, compacting, and curing a mixture of soil/aggregate, portland cement, possibly admixtures including pozzolans and water to form a hardened material with specific engineering properties. Extensive studies have been carried out on the stabilization of expansive soils using various additives such as cement, lime, fly ash, industrial waste products, lime-cement-fly ash admixture, cement kiln dust, emulsified asphalt, geofiber and polymer stabilizers which improve engineering properties of soil having high water content and low workability that poses difficulties for construction projects (Croft, 1967; Basma and Tuncer, 1991; Nelson and Miller, 1992; Al-Zoubi, 1993; Abdullah et al., 1999; Feng, 2002). The choice and effectiveness of an additive depends on the type of soil and its field conditions.

The role of hydraulic cement such as portland or slag cement is to bind soil particles together, improve compaction, and decrease void spacing, improve the engineering properties of available soil such as, unconfined compressive strength, modulus of elasticity, compressibility, permeability, the drying rate, workability, swelling potential, frost susceptibility and sensitivity to changes in moisture content (Leonards, 1962; Woods, 1960; Robert et al., 1971). Cement can be used to stabilize any type of soil, without those having organic content greater than 2% or having pH lower than 5.3 (ACI 230.1R-90 1990). The overall objective of this research is to study the compaction, strength and deformation characteristics of cement treated soils. The specific objectives of the study are investigation of the solidification, workability, and compaction characteristics of Portland cement treated soils; investigation of the mechanical properties of cement treated soils; interpretation of mechanical behavior of cement treated soil using different failure criteria.
Many projects have shown that granular soils and clayey materials with low plasticity index are better suited to be stabilized with cement treatment (Currin et al. 1976; Engineering manual 1110-3-137 1984). Significant reduction in plasticity index and significant increase in strength, modulus of elasticity and resistance against the effects of moisture and freeze-thaw can be achieved by cement treatment. It is noted that reduction in plasticity index is due to an increasing of plastic limit, which is highly affected by cement content and curing time (Bergado et al. 1996). A reduction in plasticity index causes a significant decrease in swell potential and removal of some water that can be absorbed by clay minerals. Cement treatment reduces maximum dry density and increase optimum water content (Mallela et al. 2004; Thompson 1966) which facilitates compaction of soils that are wet of optimum in their natural condition. However report by ACI committee 230 (1990) also states that cement treatment leads to changes in maximum dry density and optimum water content, but the direction of changes is unpredictable. Cement treated materials behave in a more brittle manner than non-treated

Materials and Methods
Specification of Soil
Nearly greyish silty clayey soil was used in this study, collected from Khanjahan Ali Hall at Khulna University of Engineering & Technology(KUET) in Khulna, Bangladesh. The collected soils was hard and it was pulverized manually by hammer. Then the soils were screened through the sieve of 4.75 mm aperture before preparing the specimens for testing. According to the AASHTO classification systems, the soil is classified as A-7-6 and according to the Unified soil classification systems, soil is CL(Clay with low plasticity). The particle size distribution of the original soil is shown in the Figure 1.

Preparation of Testing Samples
The collected soils and cement contents were oven-dried at 105°C overnight to remove moisture and repress microbial activity. Then the oven dried samples were mixed throughly by hand in a large tray in a dry state as per shown in Table 1.

Figure 1: Particle size distribution of original soil

Khulna is the southwest part of Bangladesh having high clayey and silt content of very soft to soft consistency up to 20 ft. from the ground surface level on the basis of several soil report collected from CRTS of Khulna University of Engineering & Technology. High water content, high compressibility and low workability of these soils often caused difficulties in the civil engineering construction projects. The soil which is used for the construction pavement or sub-base should have some specification of geotechnical properties for obtaining required strength against tensile stresses and strains variety. In this study, cement was used for the improvement of workability, compressibility and compaction characteristics as well as the physical properties of highly plastic clayey soil.
Table 1: Combination scheme of soil samples

<table>
<thead>
<tr>
<th>Samples ID</th>
<th>Samples Description</th>
<th>Soil (gm)</th>
<th>Cement (gm)</th>
<th>% Ash content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original soil</td>
<td></td>
<td>6000</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>C1</td>
<td></td>
<td>6000</td>
<td>300</td>
<td>5</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td>6000</td>
<td>450</td>
<td>7.5</td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>6000</td>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>C4</td>
<td></td>
<td>6000</td>
<td>750</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Testing Procedure

A series of laboratory tests were conducted to observe the Atterberg limits, maximum dry density, optimum moisture content, unconfined compressive strength, shear strength parameters and consolidation parameters on non-treated, as well as, cement treated soils.

Before conducting the compaction test, the non-treated and cement treated soils (5, 7.5, 10% and 12.5% cement content) were mixed with water for about ten minutes by hand. After that, the mixtures were put into polyethylene bags and mixing was continued by shaking, overturning and pressing the bag to squeeze out the air from the soil voids. In the similar way, different amount of water contents were added to the different soil samples and mixing were done as described before to obtain the optimum moisture content and maximum dry density. A series of standard proctor tests on non-treated and cement treated soils were conducted according to ASTM D 698. Three sets of specimens were prepared. One set was tested half an hour after addition of cement and the other two set were wrapped in a gunny bag in an air tight incubator for seven and twenty eight days soaking. Specific gravity of original and cement treated soil samples were determined according to ASTM D854. Consistency of the original and treated soil samples were determined by Atterberg limit test (ASTM D-4318).

All the test specimens for strength and consolidation tests were prepared by compacting the soils mixed with cement (0, 5, 7.5, 10% and 12.5%) in the standard compaction molds at the corresponding optimum moisture content which has been determined already. The specimens were demolded after completion of compaction and samples of different size were prepared as per requirement for performing the selected test in uncured condition.

The uncured unconfined compressive strength of the cylindrical specimens (36 mm diameter and 71 mm length) was determined according to ASTM D-2166. Drained shear strength parameters ($c$ & $\phi$) were determined by direct shear test (ASTM D 3080) of the compacted uncured soil specimens (60mm diameter and 25 mm height). Settlement characteristics of soils were determined by performing consolidation test (ASTM D-2435) on the samples of 63.5 mm diameter and 25 mm height.

Results and Discussions

Index Properties

Soil index properties are used extensively by engineers to discriminate between the different kinds of soil within a broad category. The index properties of soil is obtained from Atterberg limit test results. The Atterberg limits are a basic measure of the nature of a fine-grained soil. The results of Atterberg limits test using Casagrande method is as shown in Table 2.

Table 2: Atterberg limit test result

<table>
<thead>
<tr>
<th>Cement(%)</th>
<th>Liquid Limit(%)</th>
<th>Plastic Limit(%)</th>
<th>Plasticity Index(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>46</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>7.5</td>
<td>51</td>
<td>33</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>52</td>
<td>35</td>
<td>17</td>
</tr>
<tr>
<td>12.5</td>
<td>53</td>
<td>37</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 2 shows that liquid limit and plastic limit of soil increases gradually with the increases in percentage of cement content. This improvement of liquid limit attributed that more water is required for the cement treated soil to make it fluid and the increase of plastic limit implies that cement treated soil required more water to change it plastic state to semisolid state. This change of atterberg limit is due to the cation exchange reaction and flocculation-aggregation for presence of more amount of cement, which reduces plasticity index of soil. A reduction in plasticity index causes a significant decrease in swell potential and removal of some water that can be absorbed by clay minerals.
From the test result of Atterberg limit, changing of soil grain size due to the addition of cement can be illustrated by plasticity chart. The effect of cement on the particle size of soil is shown in Figure 3. This figure illustrate that initially the soil was clay with medium plasticity. For the increasing amount cement content, the soil class shifts to silt (due to the increase in particle sizes for the agglomeration of caly particles with cement) and high plasticity zone.

![Figure 3: Plasticity chart showing the original and cement-treated soil](image1)

**Compaction Characteristics**

The variation of optimum moisture content and maximum dry density of cement treated and untreated soil is shown in figure 4. This figure represents the maximum dry density of soil decreases gradually with an increase of cement content. The reduction in dry density is a result of flocculation and agglomeration of fine grained soil particles which occupies larger space leading to a corresponding drop in maximum dry density. It is also the result of initial coating of soils by cement to form larger aggregate, which consequently occupy larger spaces.

On the other hand, the optimum moisture content of soil increases with an increase cement content, because cement is finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication. The cement content also decrease the quantity of free silt and clay fraction, forming coarser materials, which occupy larger spaces for retaining water. The increase of water content was also attributed by the pozzalanic reaction of cement with the soil.

![Figure 4: Variation of maximum dry density and optimum moisture content with cement content](image2)

**Strength Characteristics**

**Unconfined Compressive Strength (UCS)**

The test result of unconfined compressive strength is shown in Figure 5. This figure illustrates the stress-strain behavior of original and cement treated soil under vertical load. Initially the stress is rapidly increases with the increase of strain but in case of soaking untreated soil sample, stress increases gradually with the increase of strain. After attaining the peak stress, it decreases with the increase of strain for all the combination of cement and soil. Approximately all the specimen shows shear failure after observing the failure plane of specimens.

![Figure 5: Stress-strain behavior of original and cement treated soil](image3)
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The variation of unconfined compressive strength for soil at different percentages of cement at 0 days, 7 days and 28 days soaking is shown in Figure 6. There is a rapid increase of unconfined compressive strength with the addition of 7.5% cement. After that, the value of unconfined compressive strength gradually increased for both unsoaked and soaked sample. It is also observed that the value of compressive strength increases with the increases of soaking days for cement treated soil, whereas the untreated soil shows that the compressive strength decreases with the increasing of soaking days. So it can be accomplished that the7.5 % cement treated shows better performance than other combinations and the strength can be maximized by soaking the samples. The reason for this improvement is due to the pozzolanic reactions of cement with soil. This results in agglomeration in large size particles and causes the increase in compressive strength.

Mohr-Coulomb’s shear strength parameters

The Mohr-Coulomb shear strength envelops of the cement based composite soils are shown in the Fig. 7. Fig. 8 shows the variation of the intercept or cohesion (c) and angle or frictional angle (φ) corresponding lines. This Figure illustrates that the slope of the of curve increases with the increases of cement.
It is observed that the value of cohesion gradually increases with the addition of 5% cement content and it increases rapidly up to 7.5% of cement content for 7 days and 28 days soaking. After that, the value increases gradually for the further amount of cement content. Besides that, there is no significant improvement in cohesion for unsoaked samples. The value of angle of internal friction increases rapidly for the 5% of cement content and this value increases gradually for the further amount of cement content.

**Consolidation Characteristics**

In this study one dimensional consolidation test were performed to determine the consolidation characteristics of untreated and cement treated soil and the corresponding consolidation curves are shown in Figure 9. The variation of compression index and initial void ratio with cement content are shown in Figure 10. Firstly, this plot shows that the compression index (Cc) is decreasing gradually for the 5% of cement treated soil and there is a sudden drop for the addition of 7.5% of cement. This decrease in compression index implies that there could be a result of increased formation of pozzolanic products within the pore spaces of soil from physicochemical changes (Osinubi et al. 2006) which leads to a reduction in compression index. When the cement content exceeds the quantity required for the soil-cement reaction, they will be filled between the voids of the soil. A more compact state of the soil is probably attained. On the
other hand the value of initial void ratio \((e_o)\) increased with increasing cement content.

\[\text{Figure 9: Plot of void ratio, } e \text{ versus effective stress, } \sigma\]

\[\text{Figure 10: Variation of Initial void ratio}(e_o) \text{ and Compression index}(c_c) \text{ with RHA}\]

\[\text{Conclusions:}\]

A study has been conducted to investigate the fundamental properties such as consistency, compaction, compressive strength, shear strength and settlement characteristics of untreated and cement treated soil. It can be concluded that there is an improvement of all the geotechnical properties of cement treated soil. The following conclusions, based on the test results in this study, are drawn.

- The maximum dry density of soil decreased with the addition of cement and value of optimum moisture content of cement treated soil increased because of the pozzalonic action of cement and soil, which needs more water.

- A series of liquid and plastic limit tests were performed on the untreated and cement treated soil samples. It is observed that the value of liquid limit and plastic limit increased with the increasing percentage of cement content, whereas the value of plasticity index shows different characteristics.

- The pozzalonic behavior of cement makes the treated soil coarser than original soil samples due to the agglomerations of cement and soil particles. This improvement changes the naming of soil from clay to silt.

- The optimum unconfined compressive strength was obtained for 7.5% of cement content. The cohesion and the angle of internal friction of soil shows an increasing order for the cement treated soaking samples.

- From the consolidation test result, it can be concluded that the values of compression index decreased with the increases of cement content and the initial void ratio increases for the cement treated soil.

\[\text{References:}\]


construction, Department of the Army, Corps of engineers office of the chief of engineers.


