Swelling Control of Expansive Soils Using Cement Dust

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Abstract. Expansive soils exist in many regions over the world including Iraq. Expansive or swelling soil contains minerals that are capable to absorb water easily causing an increase in its volume. In this research, an expansive soil that exists in some locations in the province of Karbala in Iraq was used. Limited data is available to investigate the effect of cement dust on engineering properties of expansive soils. For this purpose, samples have been prepared by mixing the expansive soil with different percentages of cement dust. The samples have been subjected to cycles of wetting and drying to investigate the swelling behaviour. Soil samples that are used were compacted at the optimum moisture content. Five different percentages of cement dust content are used in this study include: 4, 8, 12, 16 and 20%. Fundamental tests for all soil samples. It is concluded that the addition of cement dust to the expansive soils is successful method to improve their properties such as decreasing the consistency limits, increasing the maximum dry density corresponding to lower optimum water content, decreasing the swelling pressure and swelling potential.

1. Introduction

Expansive soils are soils that experience significant volumetric changes (swell or shrink) associated with changes in moisture content. Such soil usually contains excessive amount of swelling clay minerals that have high ability to absorb water such as smectite or vermiculite. As a result, soil swells (increase in volume) as it gets wet and shrinks (decrease in volume) as it gets dry [1], [2].

Expansive soil causes considerable damages to civil engineering structures because of the pressures that are associated with heaving and/or differential settlement. Pressures are strong enough to crack foundations, floors, walls, roads, and pipelines. Many factors govern the expansion behavior of such soils like changes in water content, amount and type of clay size particles, type of soil (natural or fill), dry density, moisture content, magnitude of the surcharge pressure, and amount of non-expansive material such as gravel or cobble size particles [2].

Civil engineering projects that are constructed in areas with problematic soils are one of the most common problems over the world. This soil can be removed before construction and replaced by soil with good properties. This technique would be expensive and not economic when the soil depth is high. Therefore; researchers look for alternative methods to improve soil properties before construction. Soil stabilization is one of the most common methods that has been used to enhance the physical and mechanical properties of soils to meet the engineering requirements of specific projects [3], [4].
Kallan and Akbulut, (2004) [5], studied the effect of adding silica fume to clay soil. Permeability, swelling pressure, and compressive strength were determined for all testing samples. Silica fume-added samples were characterized with low permeability and swelling pressure and significantly high compressive strength. Silica fume was also used to investigate its effect on desiccation cracks that are developed on the surface of expansive soils. Kallan (2009) [6], concluded that silica fume is well suited for use in construction of liners in landfills.

Kolias et al., (2005) [7], investigated the effectiveness of using high calcium fly ash and cement in stabilizing high plastic (CH) and low plastic (CL) clays. Testing samples were prepared by adding various percentages of fly ash and cement to the clay soils. Uniaxial compression and indirect tension tests were carried out to determine the elasticity modulus and CBR values at 90 days. In addition, field tests were done on subgrades that have been stabilized by fly ash and cement. The results show clear improvement of mechanical properties of clay soils.

Basha, et al., (2005) [8], used rice husk ash and cement to stabilize soils and evaluate some soil properties such as plasticity, compaction, and strength and X-ray diffraction. It was found the plasticity of the treated soils was reduced. Compaction test results showed that soil samples with any percentage of rice husk and cement have lower maximum dry density associated with higher optimum moisture content compared with untreated soil samples.

2. Experimental Study

2.1. Properties of Raw Soil

Soil was collected from Karbala city Figure 1 [9] at a depth of (0.5-1m) below the ground surface. The site location and coordinates are shown on the map in Figure 1. The soil was primarily allowed to dry for 2 days and then thoroughly ground. It was then tested to find some of the important properties that are relevant to this study as given in Table1. Sieve analysis was also conducted on the collected soil in order to determine its grain size distribution as presented in Figure 2.
Table 1. Engineering and index properties of the selected soil.

| Properties                          | Results | Standards             |
|-------------------------------------|---------|-----------------------|
| Liquid Limit, LL (%)                | 88      | ASTM 423-66[10]       |
| Plastic Limit, PL (%)               | 33      | ASTM D424-59[10]      |
| Plasticity Index, PI (%)            | 55      |                       |
| Specific gravity, Gs                | 2.61    | ASTM D854-00[11]      |
| Sand, S (%)                         | 11      |                       |
| Silt, M (%)                         | 24      |                       |
| Clay, C (%)                         | 65      | ASTM D 422-63[10]     |
| Activity, A (%)                     | 0.81    |                       |
| Soil type (USCS classification)     | CH      |                       |
| Maximum Dry Unit Weight, γmax (kN/m³) | 14  | ASTM D698-78[12]     |
| Optimum moisture content, wopt (%)  | 27      |                       |

Figure 2. Grain size distribution of the selected soil.

2.2. Properties of Cement Dust
Cement dust is a kiln waste product that is accumulated during the production of Portland cement. On average approximately 1500 to 2000 ton is produced daily in Iraq [13]. It has a bad effect on the environment and needs a lot of money and effort for recycling or disposal. Cement kiln dust that was obtained from Al-Kufa Cement Factory was used in this study as a stabilizer material. Its physical properties and chemical composition are presented in Table 2.
Table 2. Physical and chemical properties of cement dust

| Properties                  | Results          |
|-----------------------------|------------------|
| **Physical Properties**     |                  |
| Color                       | Light brown      |
| Texture                     | Fine             |
| Particle shape              | Semi-circle      |
| Specific gravity, Gs        | 2.85             |
| **Chemical Composition by weight (%)** |         |
| Silicon dioxide (silica), SiO₂ | 14.1             |
| Aluminum oxide (alumina), Al₂O₃ | 4.7              |
| Iron Oxide, Fe₂O₃           | 1.97             |
| Calcium Oxide (Lime), CaO   | 40.17            |
| Magnesia, MgO               | 2.79             |
| Sulfate, SO₃                | 5.85             |
| Potassium oxide, K₂O        | 3.13             |
| Sodium oxide, Na₂O          | 1.55             |
| Cl                          | 1.83             |
| Loss of ignition (L.O.I)    | 24.25            |

2.3. Preparation of Testing Samples
In order to investigate the effect of cement dust, some of the parametric variables of soil should be considered as constants such as initial water content and dry density. The raw soil was mixed with different percentages of cement dust (4, 8, 12, 16, and 20%) by adding the required amount of water to prepare many samples with different cement dust content. The soil mixtures (7, 14, 21 and 28 days) were used then to prepare testing samples. Samples were compacted in molds according to Standard Proctor Compaction in order to obtain undisturbed samples. The samples were extracted from molds by pushing a Shelby tube that is 50 mm in diameter. The obtained samples were cut in to 100 mm long and used to determine the swelling, shear strength and consolidation properties.

3. Results and Discussion

3.1. Consistency
Liquid limit, plastic limit, and plasticity index were determined for samples with different cement dust content and presented in Figure 3. It can be noticed that there is a significant decrease in all indices as cement dust content increases. This can be explained by the fact that cement dust is a soft and very fine matter which can occupy the voids between soil particles instead of water. This will reduce the water content
of the treated soils. Soil with low consistency limits is considered to be good soil that can be used as a base layer in construction of roads and airports because of its high shear resistance [14].

![Figure 3. Effect of cement dust content on consistency limits.](image)

The effect of curing time on plasticity index of soils with different cement dust content was studied and presented in Figure 4. It can be noticed that there is a considerable decrease in the plasticity index as samples were cured for longer time. The Figure shows that the plasticity index is decreasing at small rate when cement dust content is about 4% to 8%. Significant decrease of plasticity index can be noticed at cement dust content range of 12% to 20% for all curing periods.

![Figure 4. Variation of plasticity index with cement dust content and curing time.](image)
3.2. Compaction Test
Compaction curves for samples with different cement dust content were determined using Standard Proctor Test as demonstrated in Figure 5. The maximum dry unit weight and the optimum moisture content were determined for each curve. It can be noticed that soil sample with higher cement dust content has the higher maximum dry unit weight with an increase of its moisture content. The increase in the optimum water content can be related to the increase in surface area of soil particles mixed with cement dust. Moreover, the increase in optimum moisture content is thought to result from the increasing desire for water, as more water is required for the dissociation of cement dust.

![Figure 5. Compaction curve for soils with different cement dust content](image)

3.3. Free Swelling Index
The soil-cement dust mixtures were prepared and cured for different periods. The cured samples were soaked in distilled water and kerosene for 24 hours. The height of sediment columns in water (Vw) and in kerosene (Vk) were recorded. The deferential Free Swelling Index (FSI) [15] was calculated as:

\[
\text{FSI} = \frac{(V_w - V_k)}{V_k} 
\]  

(1)

The Swelling Index was presented versus cement dust content for different curing periods as shown in Figure 6. It can be noticed that the Swelling Index decreases by 70% to 75% to for soils that are mixed with 20% of cement dust. In terms of curing period, there is a noticeable decrease in the swelling index with increasing curing days for samples that contain 4% of cement dust. There is a negligible or no effect of the curing period on the swelling index at a cement dust content of 8%.

Swelling pressure is also measured for the raw soil samples and other samples with some percentages of cement dust. The results are presented in Figure 7. A considerable reduction of 43% in the swelling pressure can be noticed for samples that contain 20% of cement dust.
3.4. Consolidation Test

Results of consolidation test represented by consolidation curves \((e \log \sigma_{v}-)\) for six samples with different percentages of cement dust content are shown in Figure 8. When the swelling pressure of samples assessed the dead load was applied on specimens by double increment to allow specimens to consolidate. It was noticed that as the cement dust content decreases, the initial void ratio and hence the compressibility decreases. Low compressibility values were yielded in the composite samples with 4%, 8%, 12%, and 16% cement dust content as compared with raw soil samples. When an effective stress of 25 kPa and 1000 kPa was applied, it was observed that the void ratio and compressibility gradually decrease with increasing cement dust content. While the void ratio of natural clayey soil samples decreases. This reduction in the compression and swelling can be related to the addition of low-plastic material and the interaction between clay minerals and cement dust particles.
3.5. Shear Strength

Results from Unconfined Compressive Tests (UC) for stabilized clayey soil samples with cement dust are shown in Figure 9. The unconfined compressive strength of samples increased by 8% with increasing cement dust content from 0% to 16%. A drop down of soil strength can be noticed after increasing the cement dust to 20%. The maximum unconfined compressive strength was achieved at 16% of cement dust content, so it can be considered as the optimum cement dust content for this study. This is attributed to soil cement dust reaction, which results in the formation of cementitious materials compounds that bind soil aggregates and may be attributed to the internal friction of cement dust particles and pozzolanic reaction between cement dust and clayey soil.

4. Conclusions

The present research investigated the effect of cement dust on the engineering characteristics of local expansive clayey soil. The following conclusion may be drawn:
1. The addition of cement dust up to 16% decreased the Consistency limits (liquid limits, plastic limits and the plasticity index).

2. The swelling pressure and swelling potential values steadily decreased with increasing cement dust content and the lowest values were finally reached in the stabilized samples with 16% cement dust contents. With the addition of cement dust,

3. The effect of cement dust is decreased the compressibility of clayey soil.

4. The addition of cement dust improved the unconfined compressive strength by 8% with increasing cement dust content to 16%.

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