Cement Kiln Dust Chemical Stabilization of Nile Silt Soil Exposed Along Nile Banks at Taramsa Village, Qena Region, Egypt

Hesham A.H. Ismaiel

Abstract- This work dealt with a chemical stabilization of the Nile silt soil exposed at Taramsa village using cement kiln dust (CKD) and cement kiln dust with lime (L) to improve its geotechnical properties. Several specimens of the studied soil were collected from two sections at the studied area. Chemical analysis of the cement kiln dust and the lime was conducted. Microstructural changes were examined using scanning electron microscope (SEM) before and after the chemical stabilization of the Nile silt. Geotechnical properties including plasticity, compaction parameters, unconfined compressive strength (qu), ultrasonic velocities and free swelling of the Nile silt were measured before and after the stabilization. An optimum content of the cement kiln dust was 14 % (CKD). The optimum content of the cement kiln dust with the lime was 12 % (CKD) with 1 % (L) according to pH-test. The results showed that the addition of the cement kiln dust and the cement kiln dust with the lime led to a decrease in a maximum dry density and an increase in an optimum water content. Unconfined compressive strength values were increased using the cement kiln dust and the cement kiln dust with the lime at 7 days curing time. Ultrasonic longitudinal (Vp) and shear (Vs) velocities values were also increased by the addition of the cement kiln dust and the cement kiln dust with the lime at 7 days curing time. Increment of the curing time from 7 to 28 days led to an increase in both the unconfined compressive strength and the ultrasonic velocities values. Free swelling percent of the studied soil was reduced from 50.00 to 0.00 % after the stabilization.

Index Terms- Nile silt, Free swelling, Heave, Unconfined compressive strength, Compaction, Plasticity, Ultrasonic velocities.

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1 INTRODUCTION

As the population growths; road constructions, bridges, tunnels and other engineering projects are constructed on and in the Nile silt soils along the river banks [1]. Study of geotechnical properties of the Nile silt soil plays an important role in its engineering classification, an evaluation of its mechanical behavior, a prediction of its geotechnical problems and a recommendation of a suitable solution. Chemical stabilization of the problematic soils (expansive soils and soft fine-grained soils) is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines to avoid the damage due to the swelling action (heave) of the expansive soils or the settlement of the soft soils [2].

In Egypt, lime was used in-situ chemical stabilization of expansive clay soil at New Valley Governorate. An addition of lime slurry showed an improvement of physical and chemical soils properties with respect to the heave [3].

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Cement kiln dust is a by-product in the production of Portland cement clinker. Disposal of the cement kiln dust is an environmental problem. The utilization of this waste material has received increasing attention because it not only solves a potential solid waste problem but also provides an alternative stabilizing agent using in chemical stabilization of problematic soils and provides an alternative construction material. The use of the cement kiln dust for chemical stabilization applications may be an environmental solution of the problems associated with its disposal process where a very huge amount of the cement kiln dust as by-product are daily produced from the cement factories in Egypt. The composition of the cement kiln dust is similar to raw materials of cement but the amount of alkalis, chlorides and sulfates is usually considerably higher in the cement kiln dust [4]. Cement kiln dust is not a hazardous waste material under united state environmental protection agency guidelines [5]. A roadway section consists of a complete pavement system shown in Figure 1. The sub-grade refers to the *in situ* soils on which the stresses from the overlying roadway will be distributed. The sub-base or sub-base course and the base or base course materials are stress distributing layer overlying sub-grade layer and underlying of the pavement layer. The pavement structure consists of a relatively thin wearing surface constructed over a base course and a sub-base course, which rests upon an *in situ* sub-grade. The wearing surface is primarily asphalt layer [6]. The quality of the sub-grade soils used in pavement application is classified into 5-types (soft, medium, stiff, very stiff and hard sub-grade) depending on unconfined compressive strength values [7]. The sub-grade soils, which are classified as A7-5 and A7-6, have general rating as fair to poor according to American association of state highway and transportation officials (AASHTO). These types are considered as unstable sub-grades and need to be improved and stabilized, especially in terms of pavement applications [8]. Sub-grade soil of the studied area is fine clayey silt (the Nile silt).

1.1 Location of Study Area

The study area (Taramsa village, west Qena city and along the Nile river banks) lies between latitudes 25º 55′ 00″ to 26º 15′ 00″ N and longitudes 32º 30′ 00″ to 32º 55′ 00″ E (Figure 2).

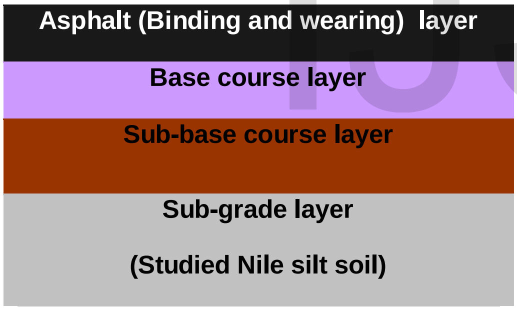

Fig. 1. A typical flexible pavement structure.

1.2 Previous Studies

Many geological investigations were carried out on the study area like [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26] and others. Few geotechnical investigations for lime chemical stabilization in the studied area and in Egypt were achieved like [1] (at taramas village), [3] (at Idku city), [27] (at Toshka area), [28] (at New Valley Governorate) and [29] (at El-Kawther area).

1.3 Scope of Present Study

This work dealt with an investigation of the geotechnical properties of the Nile clayey silt soil at Taramsa village (along the Nile banks, west Qena city, as shown in Figure 3). The studied soil (the Nile silt) occurred as sub-grade of Qena–Sohag road. The

Fig. 2. Location map of the studied area.

main goal of this study was a chemical stabilization program of the studied sub-grade soil using the cement kiln dust and the cement kiln dust with the hydrated lime to improve its geotechnical properties. One of the most important aims of this study was to evaluate the improvement of the geotechnical properties of the stabilized soil using both destructive (measuring unconfined compressive strength) and nondestructive (measuring ultrasonic velocities) methods. Finally, the increasing trend towards cement production, in Egypt, through limestone/shale and/or marl combustion has aggravated the problems associated with the disposal of the cement kiln dust (by-product), so that the use of the cement kiln dust as a stabilizing agent plays an important environmental and economical role. Economically, use of the cement kiln dust as a chemical additive in chemical soil stabilization and for geotechnical applications is cheaper than Portland cement and other (expansive) chemical stabilization. Environmentally, reuse of the cement kiln dust for soil chemical stabilization may be a solution of the environmental problems associated with its disposal process where a very huge amount of the cement kiln dust as by-product are daily produced from the cement factories in Egypt.

2 GEOLOGICAL SETTING OF STUDY AREA

The modern flood plain is represented by the fertile silt layers of agricultural land which lies on the eastern and western banks of the Nile. Its elevation ranges from about 3 to 5.5 meters above the modern water level of the Nile [24]. The mineral and chemical compositions of the banks sediments indicated that the basaltic and andesitic rocks of the

Ethiopian plateau are the main source whereas plutonic igneous and metamorphic rocks and recycled sediments are the main source of Prenile sediments [25]. The studied soil belongs to Quaternary age. The distribution of the sediments is mapped in some details in a geological map as shown in Figure 4.

Fig. 3. Nile silt soil at Taramsa Village.

3 MATERIALS AND METHODS

3.1 Materials

Sixty eight specimens of the studied soil were collected from two sections along the Nile banks, west of Qena city. The studied soil represented the sub-grade of Qena-Sohag road at Taramsa village. The studied Quaternary Nile silt soil was composed of fine sand (61.00%), silt (37.00%) and clay (2.00%). Its organic matter was 5.90%. It was low plastic organic clayey silt and was classified as (OL) according to unified soil classification system (USCS) and as A-7-5 according to AASHTO. The studied Nile silt soil was poor to fair as sub-grade. The studied soil is mainly composed of silica, aluminum and iron. The mineralogical composition of the studied soil is quartz, albite, orthoclase, calcite and montmorillonite. The soluble salts of the studied soil including sulfates and chlorides are 0.03 and 0.09 % respectively [1]. In the present study, the cement kiln dust and the cement kiln dust with the hydrated lime were used for chemical stabilizing of the studied Nile silt. The chemical composition of the cement kiln dust and the hydrated lime was illustrated in Table 1. Cement kiln dust is by-product from Qena cement plant which lies at industrial Qift city. Huge amount of the cement kiln dust (180 Tons) is daily produced. The cement kiln dust is non-plastic fine grained materials having silt size grains. The chemical analysis showed that it was mainly composed of the oxides of calcium, aluminium, iron and silica. The hydrated lime is calcium hydroxide, Ca $(OH)_2$. It is produced by reacting quicklime (CaO) with sufficient water to form a white powder.

3.2 Methods

Chemical analysis, X-ray fluorescence (XRF), of the cement kiln dust and the hydrated lime was carried out. Chemical stabilization program (Laboratory) using the cement kiln dust and the cement kiln dust with the lime was conducted including three main steps. The first step was a preparation of the soil sample; soil sample was dried in the air and then it was put into the oven at 50 °C for 24 hours. The dried soil was crushed in crushing-machine. The second step was a determination of an optimum cement kiln dust and an optimum cement kiln dust with lime contents to stabilize the Nile silt soil using pH-test [30]. The third step was a preparation of the cement kiln dust-stabilized samples compacted at a maximum dry density and an optimum water content and a preparation of stabilized samples, using the cement kiln dust with the lime, compacted at a maximum dry density and an optimum water content. There are two methods to evaluate the geotechnical properties of the stabilized soils. The first method is destructive including a measurement of several geotechnical parameters like unconfined compressive strength. The second method is nondestructive including a measurement of ultrasonic velocities of the studied soil before and after the chemical stabilization. Geotechnical properties including plasticity [31], compaction parameters [32], unconfined compressive strength (qu) [33], ultrasonic velocities including both longitudinal [34] and shear velocities using JAMES instrument (V-METER MK IV), free swelling percent [35] of the studied soil were measured before and after the treatment. Microstructural changes of the studied soil were examined using scanning electron microscope (SEM) before and after the treatment, where the changes of the microstructure and the microstructural development of the soils due to chemical stabilization play a significant role in the geotechnical properties and the mechanical behavior of the stabilized soils [2].

4 RESULTS

4.1 Chemical Analysis Results

Table 2 illustrated the relation between pH-values and chemical additives according to pH-test [30]. The results showed that the optimum content of the cement kiln dust was 14 % (CKD) and the optimum

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content of the cement kiln dust with the lime, to stabilize the Nile silt, was 12 % (CKD) with 1 % (L).

4.2 Geotechnical Results

4.2.1 Plasticity Test Results

Table 3 showed the values of Atterberg limits including liquid limit (LL), plastic limit (PL) and plasticity index (PI) of the studied soil before and after the addition of the chemical additives. The addition of the cement kiln dust led to a reduction of the Atterberg limits from 34.60, 22.60 and 12.00 % to 24.00, 16.50 and 7.50 % respectively. The addition of the cement kiln dust with the lime resulted also in a reduction of these values to 22.40, 18.00 and 4.40 % respectively.

4.2.2 Compaction Test Results

Figure 5 illustrated the moisture-density curves (compaction or Proctor curves). The results showed that the maximum dry density (Proctor density) and the optimum water content of the studied natural soil were 1.65 g/cm^3 and 16.00 % respectively. In general, the addition of the cement kiln dust resulted in an increase in the optimum moisture content from 16.00 to 25.00 % and a decrease in the maximum dry density from 1.65 to 1.45 g/cm^3. The addition of the cement kiln dust with the lime led also to an increase in the optimum moisture content to 27.00 % and a decrease in the maximum dry density to 1.40 g/cm^3 (Table 3). The bell-shaped compaction curve of the Nile silt soil was converted to flattened-shaped curve.

4.2.3 Unconfined Compressive Strength Test Results

Table 3 showed the results of the unconfined compressive strength tests of both the natural compacted and the stabilized samples. The addition of the optimum cement kiln dust content to the study soil led to an increment of the strength value from 625.00 to 1477.70 KN/m^2 after 7 day curing. Increasing curing time from 7 to 28 days led to an increase in the qu-value to 1783.44 KN/m^2. The addition of the optimum cement kiln dust with the lime content resulted in an increment of the strength value to 1401.28 KN/m^2 after 7 day curing. Increment of the curing time from 7 to 28 days led to an increase in the qu-value to 2038.24 KN/m^2. Figure 6 illustrated the stabilized samples after the unconfined compressive strength tests.

4.2.4 Ultrasonic Velocities Test Results

Table 3 illustrated the ultrasonic velocity values including both longitudinal (Vp) and shear (Vs) wave velocities of both the natural and the stabilized samples. The addition of the optimum cement kiln dust content to the soil resulted in an increase in both Vp- and Vs-values from 648.61 to 1199.99 m/sec and from 1155.20 to 1853.18 m/sec after 7 day curing. Increment of the curing time from 7 to 28 days led to an increment of both Vp- and Vs-values to 2018.70 and 3574.39 m/sec respectively. The addition of the optimum cement kiln dust with the lime content to the soil led also to an increment of both Vp- and Vs-values from 648.61 to 1042.11 m/sec and from 1155.20 to 1773.94 m/sec after 7 day curing. With increasing curing time from 7 to 28 days, both Vp- and Vs-values were increased to 1724.40 and 3062.33 m/sec respectively.

4.2.5 Free Swelling Test Results

Table 3 showed the free swelling percent values of the studied Nile silt before and after the treatment. The results showed that the free swelling percent of the natural studied soil was 50.00 %. After 7 and 28 days curing, the addition of the cement kiln dust and the cement kiln dust with the lime led to a reduction of the free swelling percent from 50.00 to 0.00 %.

TABLE 1

CHMECAL COMPOSITION OF THE CEMENT KILN DUST AND THE HYDRATED LIME

Chemical oxides (%) / Type of additive	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	P_2O_5	Na_2O	SO_3	Cl	LOI
Cement kiln dust (CKD)	0.78	5.13	16.96	1.18	57.39	-	3.28	-	-	4.43	0.82	10.03
Hydrated lime (L)	1.90	0.10	1.16	0.27	62.60	0.01	1.40	0.01	0.55	-	-	32.0

LOI= Los of ignition

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TABLE 2

RELATION BETWEEN THE pH-VALUES AND THE OPTIMUM CONTENTS OF THE CHEMICAL ADDITIVES

Type of chemical additive	Percent (%)	pH-value	Temperature
Without additive	0	10.2	25
Cement kiln dust (CKD)	8 CKD	12.37	25
	10 CKD	12.38	25
	12 CKD	12.39	25
	14 CKD*	12.40	25
	16 CKD	12.59	25
	18 CKD	12.64	25
	20 CKD	12.66	25
	22 CKD	12.67	25
	24 CKD	12.68	25
Cement kiln dust with lime (CKD/L)	8 CKD + 1 L	12.30	25
	10 CKD + 1 L	12.31	25
	12 CKD +1 L*	12.40	25
	14 CKD + 1 L	12.42	25
	16 CKD + 1 L	12.42	25
	18 CKD + 1 L	12.43	25
	20 CKD + 1 L	12.44	25
	22 CKD + 1L	12.45	25
	24 CKD + 1 L	12.47	25

* = Optimum content

TABLE 3

GEOTECHNICAL PROPERTIES OF THE NILE SILT SOIL

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Geotechnical properties / Sample type	MDD (g/cm^3)	OWC (%)	Vp (m/sec)	Vp-gain	Vs (m/sec)	Vs-gain	qu-value (KN/m^2)	qu-gain	Consistency limits			Free swelling (%)
									LL (%)	PL (%)	PI (%)	
Untreated compacted soil	1.65	16.00	648.61	0.00	1155.20	0.00	625.00	0.00	34.60	22.60	12.00	50.00
Cement kiln dust-treated soil (7 days curing)	1.45	25.00	1199.99	1.85	1853.18	1.60	1477.70	2.36	24.00	16.50	7.50	0.00
Cement kiln dust-treated soil (28 days curing)			2018.70	3.11	3574.39	3.10	1783.44	2.85				0.00
Cement kiln dust with lime-treated soil (7 days curing)	1.40	27.00	1042.11	1.61	1773.94	1.54	1401.28	2.24	22.40	18.00	4.40	0.00
Cement kiln dust with lime-treated soil (28 days curing)			1724.40	2.66	3062.33	2.65	2038.24	3.26				0.00

MDD= Maximum Dry Density OWC= Optimum Water Content Vp= Longitudinal Velocity Vs= Shear Velocity qu= Unconfined Compressive Strength

Fig. 4. Geological map of the study area modified after [1].

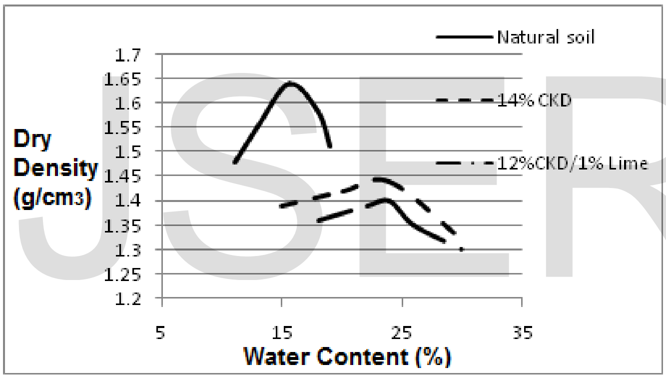

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Fig. 5. Compaction curves of the natural and the treated soil.

4.3 Microstructural Changes

Figure 7 (a) illustrated the micrograph of the natural Nile silt which showed flaky arrangements of clay particles as matrix between detrital fine grains (silt and fine sand) [1]. Figure 7 (b) showed the micrograph of the stabilized soil with 14 % CKD cured for 7 days. The micrograph showed crumbs of floccules with a porous nature and cementitous compounds coating the relics of the silt particles and the flocs. The edges of the relics of the particles were attacked by cement kiln dust and their boundaries had a ragged-form. Additionally, the reaction of the cement kiln dust with the clay led to a formation of an aggregate of various sizes and that was responsible for the increase in porosity of the soil system. Similar microfabric structure was observed by [1], [2], [36], [37], [38], [39] and [40]. Figure 7 (c) illustrated the micrograph of the treated soil with 12 % CKD with 1 % L cured for 7 days. The microstructure showed hydration reaction products coating both the cement kiln dust and the soil-particles and filling the voids partially between the particles. The microstructure is porous due to the flocculation and the increase in the diameter of the flocs by production of the cementitous compounds surrounded these flocs. Figure 7 (d) illustrated the micrograph of the stabilized soil with 14 % CKD cured for 28 days. The micrograph showed cementitious compounds (due to pozzolanic reaction) coated and joined the soil and the cement kiln dust particles. The pores were partially filled with the cementitious compound and were relatively reduced. Figure 7 (e) showed the micrograph of the treated soil with 12 % CKD with 1 % L cured for 28 days. The microstructure had relatively small pores due to a formation of the cementitious compound resulted from the reaction between the cement kiln dust and the lime together with the soil particles.

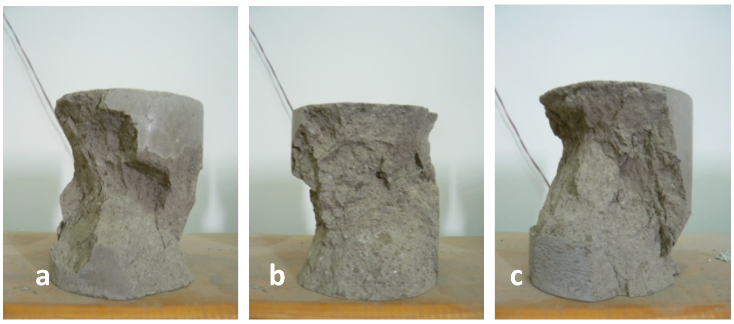

Fig. 6. Stabilized samples after qu-tests; a) stabilized sample after 7 days curing (CKD), b) stabilized sample after 7 days curing (CKD with L), and c) stabilized sample after 28 days curing (CKD with L).

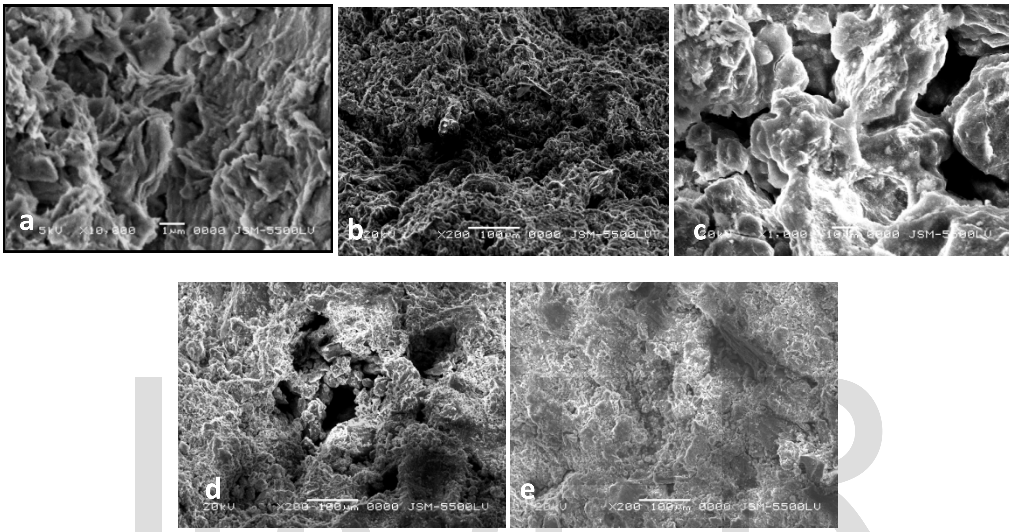

Fig. 7. Micrographs of the natural and the stabilized soil using scanning electron microscope (SEM).

5 DISCUSSIONS AND CONCLUSIONS

The optimum content of the cement kiln dust to stabilize the Nile silt was 14% and the optimum content of the cement kiln dust with the lime was 12 % (CKD) with 1 % (L), using pH-test [30]. The addition of the optimum cement kiln dust to the soil resulted in a reduction of the liquid limit (LL), the plastic limit (PL) and the plasticity index (PI) values from 34.60, 22.60 and 12.00 % to 24.00, 16.50 and 7.50 % respectively. The addition of the cement kiln dust with the lime led also to a reduction of these values to 22.40, 18.00 and 4.40 % respectively. This reduction was due to a decrease in the thickness of the double layer of the clay particles. That is as a result of cation exchange reaction, which causes an increase in the attraction force leading to a flocculation of the particles [41]. The maximum dry density (Proctor density) and the optimum water content of the natural Nile silt were 1.65 g/cm^3 and 16.00 % respectively. Generally, the addition of the cement kiln dust to the Nile silt led to an increment of the optimum moisture content from 16.00 to 25.00 % and a decrement of the maximum dry density from 1.65 to 1.45 g/cm^3. Similar results recorded by the addition of the cement kiln dust with the lime where the optimum moisture content was increased to 27.00 % and the maximum dry density was reduced to 1.40 g/cm^3. The bell-shaped compaction curve of the Nile silt was converted to flattened-shaped curve. The typical flattening of the compaction curve of the studied stabilized soil makes it easier to achieve the required density over a wider range of possible moisture contents [2]. The change in the shape and characteristics of the peak of the compaction curves can allow for significant savings in time, effort and energy [42]. The addition of the cement kiln dust resulted in an increase in the strength value from 625.00 to 1477.70 KN/m^2 after 7 day curing. Increasing curing time from 7 to 28 days resulted in an increase in the strength value to 1783.44 KN/m^2. The strength gain (strength of stabilized soil/ strength of natural compacted soil) was also increased from 2.36 to. 2.85. The addition of the cement kiln dust with the lime led to an increment of the strength value to 1401.28

KN/m^2 after 7 day curing. Increment of the curing time from 7 to 28 days resulted in an increase in the strength value to 2038.24 KN/m^2. The strength gain was also increased from 2.24 to 3.26. The mechanical behavior of the stabilized soil had a brittle behavior due to a formation of cementitous compounds. The formed cementitious compounds (as a result of the chemical reactions between the silica and the alumina and the additives) reduced the volume of the void spaces and joined the soil particles [2].

$$Ca^{++} + 2\,(OH) + \underset{\text{(Silica)}}{SiO_2} \longrightarrow \underset{\text{(Gel)}}{CSH}$$

$$Ca^{++} + 2\,(OH) + \underset{\text{(Alumina)}}{Al_2O_3} \longrightarrow \underset{\text{(Fibrous)}}{CAH}$$

The addition of the cement kiln dust to the Nile silt resulted in an increase in both Vp- and Vs-values from 648.61 to 1199.99 m/sec and from 1155.20 to 1853.18 m/sec after 7 day curing. Increment of the curing time from 7 to 28 days led to an increment of both Vp- and Vs-values to 2018.70 and 3574.39 m/sec respectively. The addition of the cement kiln dust with lime to the Nile silt led to an increment of both Vp- and Vs-values from 648.61 to 1042.11 m/sec and from 1155.20 to 1773.94 m/sec after 7 day curing. With increasing curing time from 7 to 28 days, both Vp- and Vs-values were increased to 1724.40 and 3062.33 m/sec respectively. The increase of the ultrasonic velocity was due to the formation of new cementitous compounds and mineral crystals as a pozzolanic reaction produced through the curing time [2]. The addition of the cement kiln dust and the cement kiln dust with the lime led to a decrease in the free swelling value from 50.00 to 00.00 % at curing times 7 and 28 days. The reduction of the free swelling due to consumption of the clay minerals during the hydration reaction formed the cementitious compounds. Additionally, the reaction of chemical additives with the clay occurred in the Nile silt led to a formation of an aggregate of various sizes with low ability for swelling. The improvements of the engineering properties of the Nile silt due to use of the chemical additives can be explained by two basic reactions; short-term reactions consisting cation exchange and flocculation and the long-term reaction named pozzolanic activity. During the first stage of the reaction between the chemical additives and the clay, excess of calcium ions in the lime or in the cement kiln dust replace all other monovalent cations in the clay and change the electrical charge density around the clay particles. This results in an increase in the interparticle attraction causing flocculation and aggregation and a consequent decrease in the plasticity of the soil [43]. The pozzolanic reaction is time-bound and tempreture dependent. During this process, the high pH causes silics and alumina to be dissolved out of the structure of the clay minerals and to combine with the calcium (occurred in the cement kiln dust or the lime) to produce the new cementitious compounds calcium silicate hydrates (CSH), calcium aluminate hydrates (CAH) and calcium alumino-silicate hydrates (CASH) [43] and others. Examination of the stabilized Nile silt using scanning electron microscope (SEM) indicated that the microstructures of the studied Nile silt were changed due to the cement kiln dust and the cement kiln dust with the lime. The stabilization process caused a formation of a silt-fine sand like structure (open fabric) characterized by a highly porous system. The SEM-micrographs of the natural and the stabilized soil indicated the formation of new cementitous compounds and mineral crystals as a pozzolanic reaction product through the curing. These cementitous compounds improved the geotechnical properties of the studied soil and reduced the swelling. In case of the rich clay soil, the influence of the cement kiln dust with the lime on the soil was greater than the influence of the cement kiln dust alone. In case of the poor clay soil like the Nile silt, the use of the cement kiln dust alone had relatively the same influence compared to the use of the cement kiln dust with the lime. That may be due to an occurrence of a small amount of the clay which could be reacted with the lime. Finally, the cement kiln dust (as by product of Qena cement plant, at Qift industrial city) contains relatively small percent of sulfates (4.43%) and can be utilized to treat and stabilize the Nile silt soil as economical (cheaper) alternative to Portland cement and other (expansive) chemical stabilizers. The use of cement kiln dust for chemical stabilization applications is an environmental solution of the problems associated with its disposal process.

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