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Strength, Durability And Hydraulic Properties Of Clayey Soil Stabilized With Lime And Industrial Waste Lime

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Abstract

This research aims to study the effect of utilization of industrial waste/lime (by-product of sugar factory) on some engineering properties of clayey soil selected from Mosul city. These characteristics are unconfined compressive strength, permeability, soil-water characteristic curve and Durability. The tests were performed at different percentages of lime (2, 4 and 6) % and industrial waste/lime (2, 4, 6 and 8) % by dry weight of soil.

Results showed a decrease in the plasticity, swelling pressure and swelling potential of treated soil. The soil became non plastic at optimum lime, waste lime contents of (4, 6) % respectively. Unconfined compressive strength (UCS) increased with increasing of curing time and stabilizer contents and reached a maximum value at optimum stabilizer contents. The (UCS) of soil stabilized with industrial waste lime was more than that stabilized by lime at different curing times. Durability tests (immersion and slaking) showed that the treated soil with lime was more durable than that treated with waste lime. The Permeability of treated soil was found to be more than that of natural soil. On the other hand, the permeability of soil treated with waste lime was more than that of treated by lime at different curing time and it reached a maximum values at (4, 2)% for the soil treated with waste lime and lime respectively. The soil-water characteristic curve showed that the soil ability to hold water increased with increasing lime and industrial waste contents.

Keywords: *clayey soil, lime, industrial waste lime, strength & durability, hydraulic properties.*

المقاومة والديمومة والخصائص الهيدروليكية لتربة طينية مثبتة بالنورة ومخلفات النورة

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الخلاصة

يهتم البحث بدراسة مقارنة تأثير إضافة النورة والمخلفات الصلبة/نورة لمعمل السكر والخميرة على الخواص الهندسية لتربة طينية في مدينة الموصل، وقد اضيفتا بنسب (٢،٤،٦)% نورة و (٢،٤،٦،٨)% مخلفات النورة وزنا من التربة الجافة.

اظهرت النتائج انخفاض في لدونة التربة، نسب وضغط الانتفاخ للتربة المعاملة، حيث اصبحت التربة عديمة اللدونة عند نسب التثبيت المثلى للنورة والمخلفات (٤،٦)%على التوالي. مقاومة الانضغاط غير المحصور تزداد مع زيادة كل من فترة الانضاج،نسبة النورة والمخلفات بحيث تصل الى اعلى قيمة عند نسب التثبيت المثلى للنورة والمخلفات. لوحظ ان مقاومة الانضغاط غير المحصور للتربة المعاملة بالمخلفات اعلى منها للتربة المعاملة بالنورة عند فترات الانضاج المختلفة. نتائج فحص الديمومية اظهرت انخفاض مقاومة الانضغاط للتربة المعاملة وكانت بمقدار اكبر منه للتربة المعاملة بالمخلفات نتيجة الغمر، كما بين فحص التآكل ان الفقدان بالوزن للتربة المعاملة بالمخلفات اكبربكثير منه للتربة المعاملة بالنورة.من جهة اخرى،وجد ان نفاذية التربة المعاملة اعلى منها للتربة الطبيعية، كما وجد ان نفاذية التربة المعاملة بالمخلفات اعلى منها للتربة المعاملة بالنورة عند فترات الانضاج المختلفة، فقد صلت الى اعلى قيمة عند النسب (٤،٢)% للنربة المثبتة بالمخلفات والنورة على التوالي.اخيراً ومن منحنيات خاصية التربة-الماء وجد ان قابلية التربة للاحتفاظ بالرطوبة تزداد مع زيادة النورة والمخلفات، لكن قابلية التربة المعاملة بالمخلفات للاحتفاظ بالرطوبةاقل منها للتربة المعاملة بالنورة.

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1-Introduction

Many research works in Iraq aimed nowadays to utilize some industrial by-products in some engineering applications particularly in geotechnique. These works are directed mainly to find a cheep source of materials to enhance the soil properties. in the same time, to find a way of the disposal of these materials which could be a potential environmental problem. Al-Shalhomi [5], Al-Safar [4] and Al-kiki [2] studied the effect of industrial wastes of many factories on clayey and gypseous soils. They found that the industrial waste improve the engineering properties of these soils.

On the other hand, several problems are commonly encountered when light weight structures such as highway and roads are constructed on some clayey soil (expansive types). This problem was studied extensively by others and lime treatment was the main suggested technique used to improve the engineering properties of clayey soil [12, 14, 15 and 16].

Typically, lime addition to expansive soils initiates four types of reactions between lime and the silicate/aluminate constituents of the expansive clay. These are flocculation, cation exchange, carbonation and pozzolanic reaction [7,14]. These reactions contribute to mineralogical and micro-structural changes in the treated or stabilized soils. Due to this reason, lime treated expansive soil behavior is significantly different from natural or untreated expansive soils. Pozzolanic reaction has significant influence particularly on the expansive soil behavior. This reaction needs a considerable period of time and needs a highly alkaline environment (i.e., $pH \geq 12.4$) which is achieved by the addition of an optimum amount of lime [9,11]. The alkaline environment is responsible for the slow dissolution of the alumina-silicate constituents of clay, which react with lime producing hydrated cementitious products that bond the adjacent soil particles together [8,12,16]

Several research studies were undertaken to better understand lime stabilized expansive soil behaviours [15, 16, 19]. However, studies related to the understanding of hydraulic properties and long-term stability characteristics with respect to the influence of environmental factors (durability) of lime treated expansive soils are limited. Actually, no standard specifications are proposed concerning these properties of lime stabilized soil.

The long-term stability characteristics referred to, as durability in this paper can be better interpreted if the influence of environmental factor as wetting-drying cycles on engineering properties is studied. There are several questions that are not well understood with respect to the durability characteristics of lime and waste lime treated expansive soils in spite of being used as a conventional technique to improve the properties of expansive soils. For this reason, an attempt is made to study the hydraulic properties, (i.e permeability and water retention) durability characteristics using effect of water immersion on UCS and slake durability test (to simulate wetting/drying cycles) as well as strength of untreated and lime/waste lime treated expansive soil. In the study presented in the paper, untreated and lime waste treated expansive compacted soil specimens were studied through the aforementioned tests and compared with some results of lime stabilized soil.

2-Labrotory work and test procedure

2-1 Materials:

2-1-1 The soil: Disturbed clayey soil (CL-CH) samples was obtained from Al-Hadbaa part of Mosul city at depth (1.5 m) below the ground surface. The index properties and chemical tests were listed in Table (1). X ray diffraction (XRD) analysis shows that the clay part of soil contains mainly mixed layers of Montmorillonite / Chlorite with small quantities of Kaolinite and illite. The non-clay minerals are Quartz, calcite and Feldspar. The soil was air dried for several days then passed through a sieve (#4).

The standard and modified compaction test indicated that the soil has a maximum dry unit weight of (16.85, 17.9) kN/m^3, which corresponded to an optimum moisture contents of (18, 15.4) % respectively as shown in Fig.(1).

2-1-2 Lime and industrial waste/lime: In this study, high-calcium hydrated lime ($Ca(OH)_2$) brought from Al-Mishrac sulphate factory 71% activity was used. The chemical composition of lime was listed in Table (2).

Industrial waste lime (by-product production 500-1000 tons/year) was obtained from sugar factory in Mosul city. This waste is a mixture of many Impurities (with small pieces of limestone rocks), organics and inorganic, Soluble and Insoluble. The main constituents of lime used in the purification of sugar slurry production contains $Ca(OH)_2$ and many materials with small quantities of sugar substance. It includes also a by-products obtained from the lime industry unit, rejected and contains; over-burned (CaO but with different physical properties) and under-burned lime (CaCO3 + CaO). The chemical properties of industrial waste lime are listed in table (2).

2-2 Specimen preparation:

An experimental program was performed on Al-hadbaa soil specimens which stabilized by adding varying percentage of lime (2, 4, 6) % and industrial waste lime (2, 4, 6, 8) % by dry weight of soil.

The soil was oven-dried for two days at 60^{o}C, then mixed with a calculated amount of stabilizers and distilled water, which sprayed and remixed thoroughly. The mixture was then placed in plastic bags and kept in a humidity-controlled room for mellowing time (24 hours for untreated soil and one hour for treated). Then the mixtures were statically compacted to the required maximum dry unit weight (16.85 kN/m^3) and optimum moisture content (18%) at a rate of 1.0 mm/min. The treated soils were then sealed with aluminum foil, plastic bags and finally by paraffin to cure for different curing time (2, 7, 28 and 90) day at temperature 25^{o}C.

Testing program was performed to study the suitability of the waste lime as a stabilizer. Many ways of assessment were followed; swelling, strength, durability and hydraulic properties (i.e. permeability and water retention capacity).

Table (1) Chemical & Physical Properties of natural soil

Properties	**Values**
Liquid Limit (%)	50
Plastic Limit (%)	27
Plasticity Index (%)	23
Activity	0.57
Total Soluble salts (%)	1.02
Gypsum content (%)	1.5
Organic content (%)	2.3
Specific Gravity	2.7
Sand (%)	10
Silt (%)	50
Clay (%)	40
Soil Classification	CL-CH
Soil Classification for Permeability [20]	Low permeability

Table (2) Chemical Composition of Lime, Waste Lime

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	AL_2O_3	Fe_2O_3	SiO_2	MgO	H_2O
Lime	71.3	6.1	6.1	0.17	0.04	11.	4.01	0.09

						1	9	
Waste lime	43.6	8.1 9	12.74	14.9	0.42	16. 9	3.13	0.1

Table (3) Laboratory Tests of Natural and Treated Soil

Test	**Test method**	**Dimensions (mm)**	**Curing condition**	**Note**
Swelling pressure	Constant volume & Free swell	D=63.5 H=19.5	2 day @ 49^{o}C	
Unconfined compressive strength	---------	D=51 H=102	2,7,28 day @ 25^{o}C	Sample compacted in 3 layers
Permeability	Variable head method	D=38.5 H=97	2,7,28,90 day @ 25^{o}C	
Soil suction	Osmotic membrane & Saturated salt solutions [13]	D=30 H=12	7 day @ 25^{o}C	
Durability	Immersion	D=51 H=102	7 day @ 25^{o}C	

	Slaking ASTM D 4644-87	---------	7 day @ 25^{o}C	6 @100 gm for each ball

2-3 Laboratory tests:

According to the purpose of this research, specifications, curing time and sample dimensions are shown in Table (3).

It should be noted that the soil water characteristics curve (SWCC) was conducted to cover the entire suction range of 0 – 10^6 kPa. The suction application was performed using two methods; the saturated salt solution method and the Osmotic solution method using an osmotic membrane submerged in different concentrations of a Poly ethylene Glycols (PEG) solutions in order to cover a suction range between 0 to 2700 kPa [13].

3-Results and Discussion

3-1 Estimation of optimum stabilizer content:

Two methods were performed for this purpose, first was proposed by Eades and Grim (1966) [9] and the second is Illinois procedure [16]. In the first method, a minimum pH value of 12.4 is necessary to activate pozzolanic reaction between the lime and the soil. The alkalinity of the soil increases with the addition of lime. Major transformations take place with respect to the soil structure in the expansive clay when lime is mixed with clay. Flocculation and agglomeration contribute to bring several expansive soil particles together and form into larger sized aggregates [13]. The change in the soil structure is a consequence of cation exchange caused by dissociated bivalent calcium ions in the pore water replacing such univalent ions that are normally attached to the negatively charged individual expansive soil particles.

The *pH* values measured in the soil specimens for various lime percentages are shown in Table (4). *pH* of a soil-water mixture containing various amounts of lime and waste lime (by mass) was measured. According to this method, a minimum of 4% and 6% of lime and waste lime respectively is necessary to achieve *pH* value of 12.4.

The second procedure depends on the maximum UCS of treated soil, Fig.(2) confirms that (4, 6)% gave maximum UCS at different curing time of lime and waste lime respectively.

Based on both methods, optimum percentage of stabilizer is approximately 4% lime and 6% waste lime. Additional tests with stabilizer percentages of 2, 4, 6 and 8%, were also tried to perform some tests as indicated in the results and discussion section.

3-2 Effect of waste lime on the engineering properties of stabilized soil :

3-2-1 Index properties: lime and waste lime addition affected highly the Atterberge limits and linear shrinkage of treated soil Table (5). It is shown that the soil becomes non plastic when treated with (4, 6) % lime and waste lime respectively. These results were obtained by the reduction of L.L and the increase of PL and hence reduction of PI. This could be attributed to the immediate reactions between clay constituents and lime (cation exchange, flocculation and agglomeration) which reduce the thickness of the double diffuse layer.

3-2-2 Compaction characteristic: the obtained results of compaction curves, Fig.(3) showed that the maximum unit weight of clayey soil decreased and the OMC increased with increasing both stabilizer contents. In general, the effect of stabilizer was found to be more in the case of lime addition, i.e more considerable reduction was obtained when using lime as a stabilizer. This reduction results from the immediate reactions between stabilizer and soil particles (flocculation and agglomeration) which form further voids and made more open structure and hence, reduce the maximum dry density. The increase in OMC with increasing both stabilizers is due to the consumption of water during lime/waste lime–clay reaction and/or the increase in water necessary to lubricate the new established particle skeleton of lime/clay system and finally due to evaporation of water as a result of the borne high temperature during reactions [18].

3-2-3 Swelling potential and swelling pressure: the effect of lime and industrial waste lime on swelling potential and swelling pressure of natural and treated soils is shown in Fig.4 (A & B). It is indicated that lime and waste lime are efficient in reducing the swell potential and swelling pressure of the treated soils. A continuous decrease in the swell potential and swelling pressure was obtained with an increase of stabilizer percentage. Soil treated with lime showed a swell potential and swelling pressure less than that of soil treated with waste lime. Finally, no swelling could be noticed at optimum stabilizer content.

3-2-4 Unconfined compressive strength: the effect of stabilizer content and curing time were studied through samples prepared and statically compacted at OMC and corresponding to maximum dry unit weight of natural soil. Compaction was conducted in three layers to prepare samples following the procedure proposed by many authors [1], [14] and [15]. The samples were tested using a compression machine with uniform deformation rate of 1 mm/min. The effect of stabilizer content on the unconfined compressive strength (UCS) was presented in Fig.(2). It is clear that generally, a maximum UCS reached using 4% lime and 6% waste lime. The curing time effect could be discussed through Fig.(5). It is clear that there is a continuous strength progress with respect to time due to pozzolanic reaction between clay constituents and lime constituents of stabilizers as well as any complicated reactions causing cementation of soil particles. The rate of increase in UCS is increased up to 7 days curing time then, decreased with additional curing time for both stabilizers. On the other hand, it could be noted that the rate of increase in UCS increased with increasing the amount of both stabilizers. It is worth mentioning here that there is nearly identical rate of increase in UCS using the two stabilizers but with a more significant increase in UCS the case of lime.

Finally, it should be noted that the gain in UCS of the stabilized soil is more using waste lime, which seems to be illogical. Therefore, a preliminary idea about the durability of these results should be obtained.

Table (4) Hydrogen Number of Natural and Treated Soil [9]

Type of treated material	% Adding			
	0	2	4	6
Lime	٧.٩١	١٢.١٦	12.54	12.56
Industrial waste lime	7.91	١٢.١٦	12.35	12.58

Table (5) Index Properties of Natural and Treated Soil

Type of treated material	Property		%Adding			
			0	2	4	٦
Lime	Atterberge limit (%)	w_L	50	44	-	-
		w_P	27	37	NP	NP
		I_p	23	7	-	-
	Linear shrinkage		14.5	6.8	-	-
	Classification		CL-CH	ML	-	-
Industrial Waste lime	Atterberge limit (%)	w_L	50	45	38	-
		w_P	27	32	35	NP
		I_p	23	13	3	-
	Linear shrinkage		14.5	8.93	5.15	-
	Classification		CL-CH	ML	ML	-

Table (6) Reduction in UCS (%) of stabilized Soil during wetting

Table (7) Parameters for SWCC

Mate	% addin	ψa (kPa)	w/c a (%)	ψr (kPa)	w/c r (%)	a	n	m	SSR	R^2
Lime	2	٢٠٠٠	٢٢.٦	٩٠٠٠٠	٤.٢	1909	٣.٩٥	٠.٢٩٩	٩٤.٨٦	٠.٩٦٩
	4	٣٤٠٠	٢١.١	٩٥٠٠٠	٤.١	٣٣٩٩	٥.٠٠	٠.٣٠٠	١٦٦.٣٢	٠.٩٦٩

% Adding (lime, waste)	Effect of immersion on unconfined compressive strength % (7 days curing + 2days immersion)	
	Lime	**Waste**
2	-30	-81
4	-13	-72
6	-6	-27
8	----	-9

	6	٣٥٠٠	٢٠.٨	١٠٠٠٠٠	٤	٣٤٩٩	٢.٩١	٠.٣٧٩	٤٩.٧٥	٠.٩٧٦
Waste Lime	2	٣٧٠٠	١٦.٤	٩٠٠٠٠	٤	٣٦٩٩	٢.٥٠	٠.٤٣٨	٢٩.٠٨	٠.٩٨
	4	٣٧٥٠	١٧.٤	١٠٠٠٠٠	٣.٨	٣٧٤٩	٢.٤٠	٠.٤٥٢	٣١.١٣٩	٠.٩٨١
	6	٣٨٠٠	١٧.٨	١٢٠٠٠٠	٣.٦	٣٧٩٩	٢.١٨	٠.٤٥٥	٣٢.٣٩٦	٠.٩٨٢
	8	٤٢٠٠	٢٠.٣	١٤٠٠٠٠	٣.٥	٤١٩٩	٤.٥	٠.٣٠	٧٣.٣٢	٠.٩٦٨

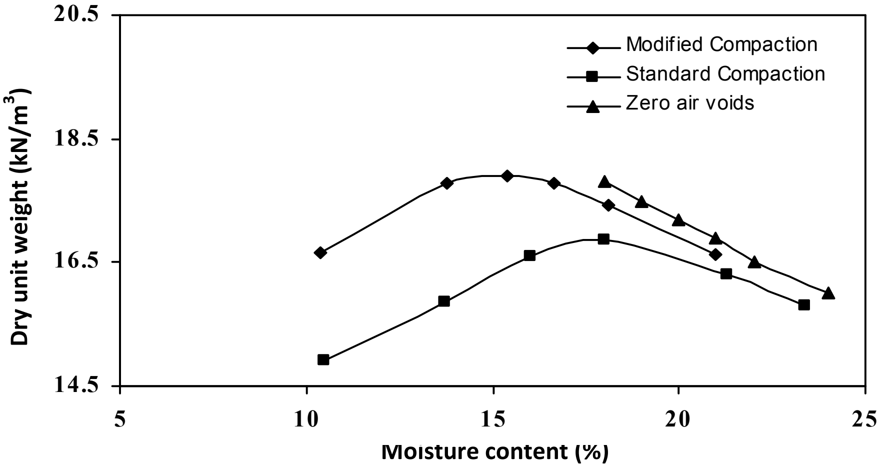


Fig.(1) Compaction Curves for Natural Soil

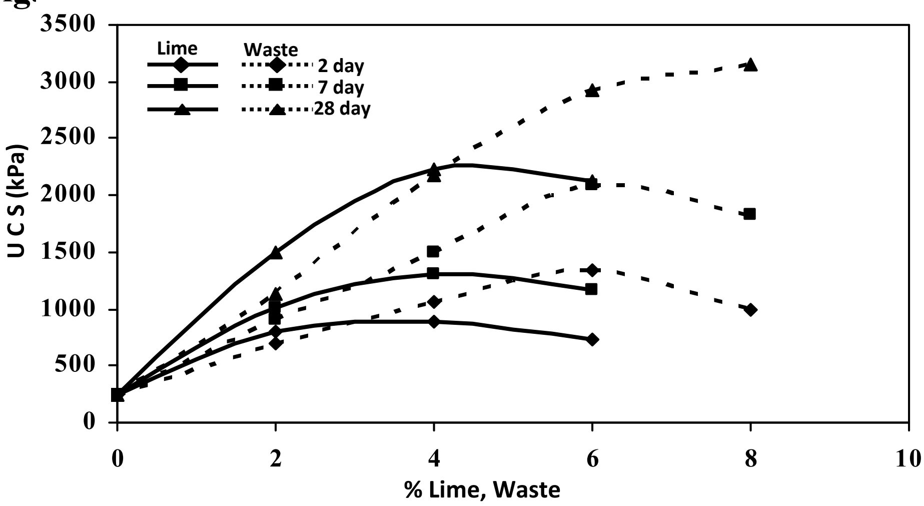


Fig.(2) Correlation Between UCS with Lime.Waste under Different Curin

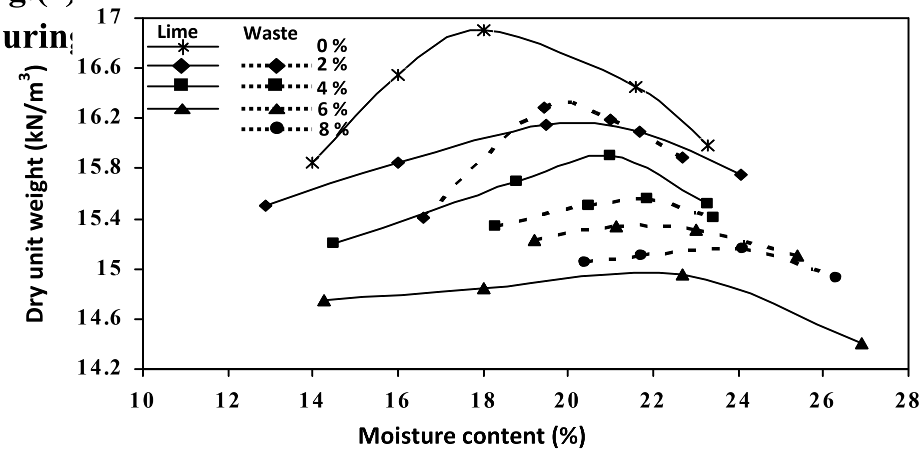


Fig.(3) Effect of lime and Industrial Waste on Standard Compaction Curve

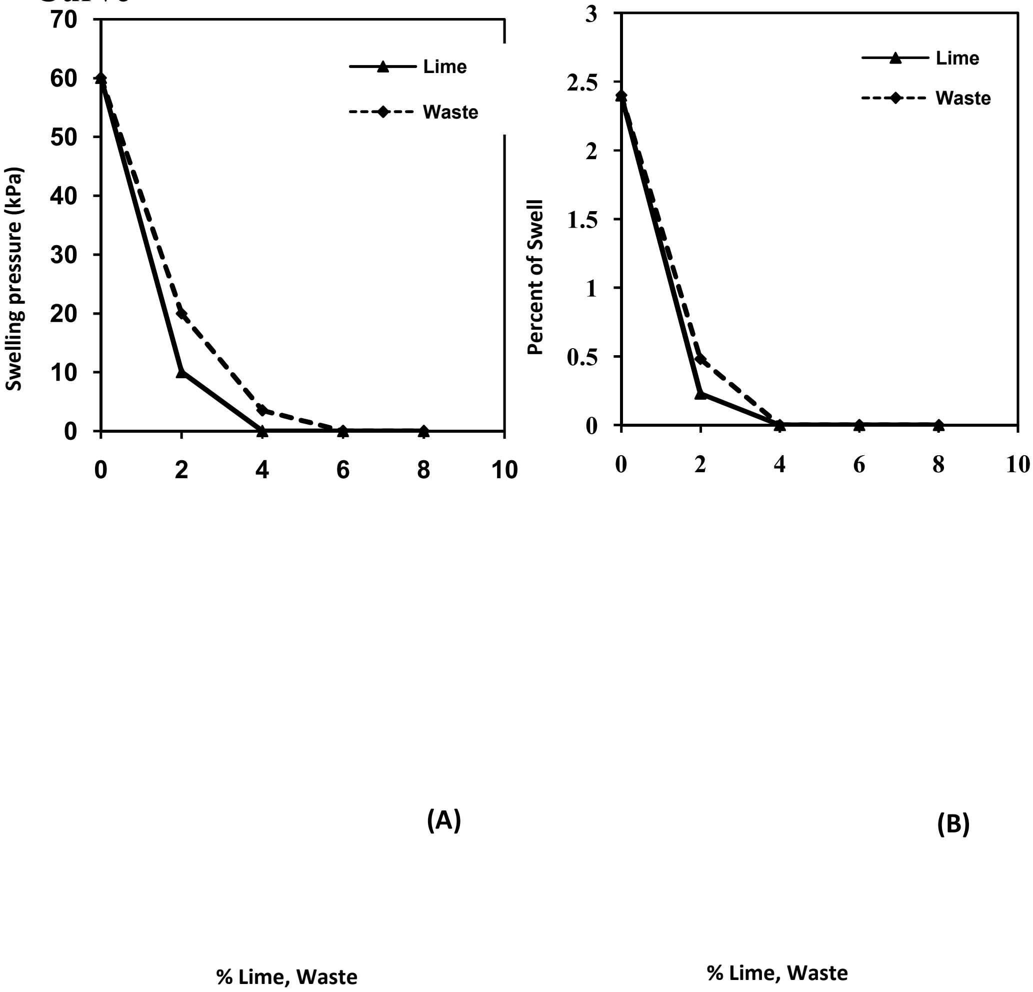


Fig.(4-A, B)Correlation Between Swelling pressure & percent with Lime,

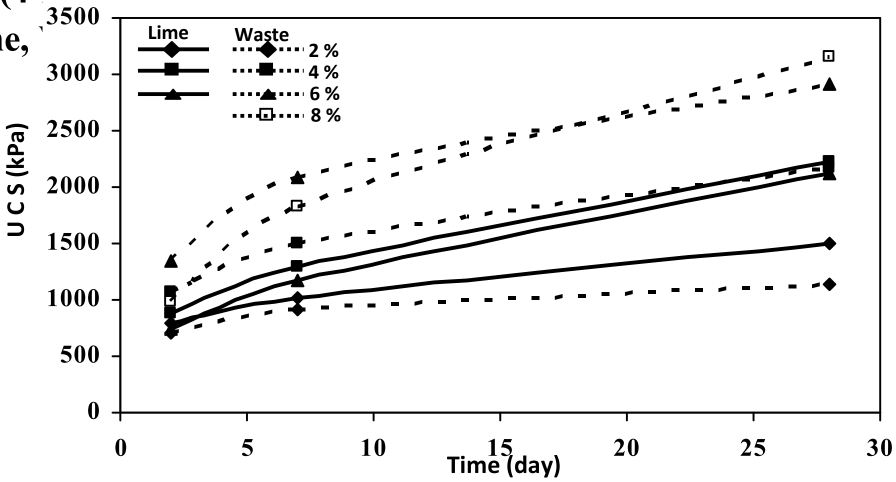


Fig.(5)Correlation Between UCS with Curing Time under Different Lime,Waste lime content

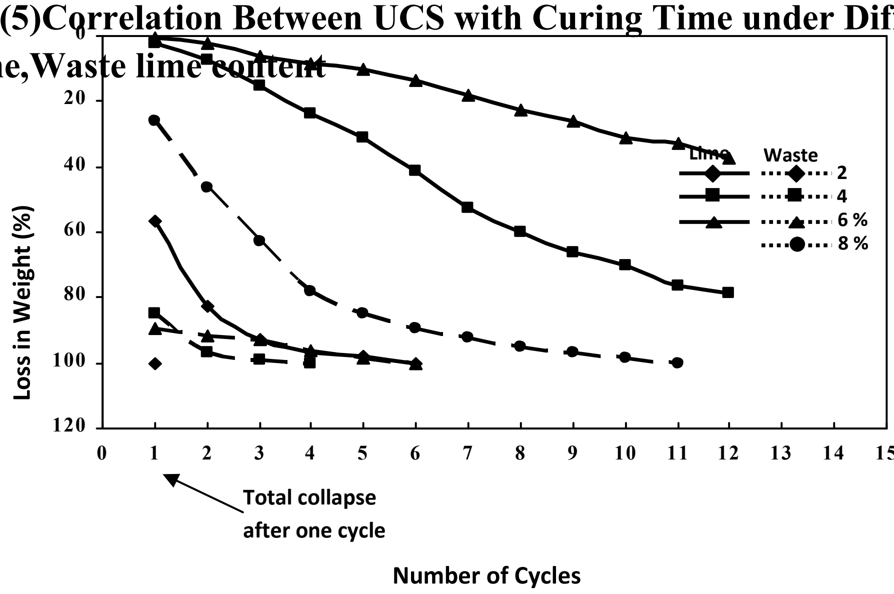


Fig.(6) Correlation Between Loss in Weight (%) with Number of Cycle under Different Lime,Waste Lime Content

3-2-5 Durability of stabilized soil: the durability of the stabilized soil was studied through two approaches; effect of immersion on UCS and of slaking during wetting and drying.

Effect of water immersion on the UCS samples was studied. 2 sets of samples were prepared at OMC and stabilized with 2, 4, 6 and 8 % of each stabilizer. One set was tested after 9 days curing at molding moisture content, the samples of the other set were immersed in water for 2 days after 7 days of identical curing corresponding to the first set.

Results demonstrated that the variations in UCS due to immersion (corresponding to the UCS of cured samples at molding moisture content) are presented in Table (6). It could be noted that there is a limited reduction in UCS during immersion ranging from (6 to 30) % for the lime-stabilized soil. While more reductions were obtained with waste lime treatment of the soil (ranged from 9% to 81%). It seems that the high reduction was obtained when stabilizers were lower than the optimum lime stabilization (OLS). The high reduction in UCS when using waste lime, which is in the contrary of the good indication obtained from the UCS results discussed in sec. 3-2-4. This behavior could be attributed to the dissolution and/or the break-down, disintegration and degradation of some of the linkage system (cementing) initiating when adding waste lime. On the other hand, the reduction was diminished with the increase of the waste lime content, i.e a more durable mixture could be obtained when greater percentage of waste lime is added.

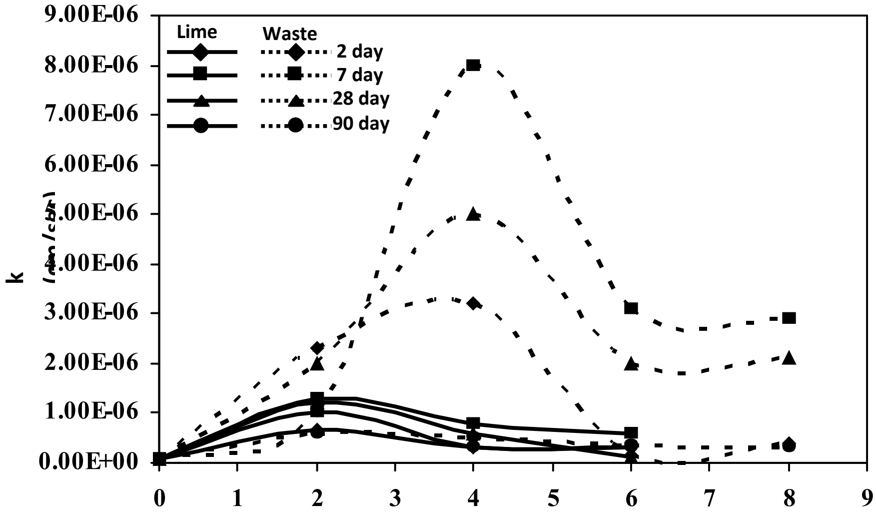
The second durability test (slaking) was conducted to show the resistance of the stabilized soil to weathering during wetting and drying processes. Hence, a slaking test (ASTM D 4644-87 (1998)) (specified for rocks) suggested to be used in the evaluation of the lime stabilized soil [23]. That is conducted on lime and waste lime treated soils. Six ball samples were compacted for each test at optimum moisture content and maximum dry unit weight of standard compaction test. The results shown in Fig. (6) pointed out that the obtained loss in weight of samples treated with the waste lime was more than that the lime treated soil. Samples treated with 2 to 6% waste lime were totally demolished after the first cycle and after the 5th cycle when treated with 8% waste lime. While samples treated with 4% and 6% lime resists well the slaking effects. These results confirm the results of the immersion test.

However, the results proved that the durability of treated soil gives a good indication of the performance of the stabilized soil. Consequently, the mixture design of stabilized soil should not depend only on optimum stabilizer content based on the UCS only but the durability of stabilized soil should be considered.

3-2-6 Permeability: the permeability test was conducted on natural and waste lime stabilized soil samples cured form 0 to 90 days. The results were compared with the results obtained from Al-Daood, A, 2006 [1] using the same soil. Attempts were made to assure nearly 100% saturation through application of suction of about 2 bars for 30 minute in the top and leaving water to enter the samples from bottom side to enhance the evacuation of the entrapped air bubble [1]. The results Fig.(7) showed that the permeability of industrial waste lime treated soil has similar behavior of lime treated soil. It is also shown that the permeability of treated soil was more than that of natural soil for different curing time. This could be explained by the flocculation action, which leads to a more open structure. With curing time (more than 7 days), the stabilized soil permeability was decreased with curing time. A more significant rate of reduction was shown with waste lime treated soil. It could be noted also that, in general, the soil treated with industrial waste lime has more permeability than that of lime treated soil. Also, the permeability reaches maximum values at 2% lime then started to decrease, while it reaches maximum values at 4% for waste lime treated soil. This could be confirmed by the optical microscopic photos Fig. (8 A&B). On the other hand, the permeability reached maximum values at 7 days curing time Fig. (9) for both stabilizers. While, permeability started to decrease with curing time more than 7 days. This could be attributed to the formation of gel around the soil particles, which grew in size with time and hence, decrease the voids size. These results agree with that obtained by others [10 and 17].

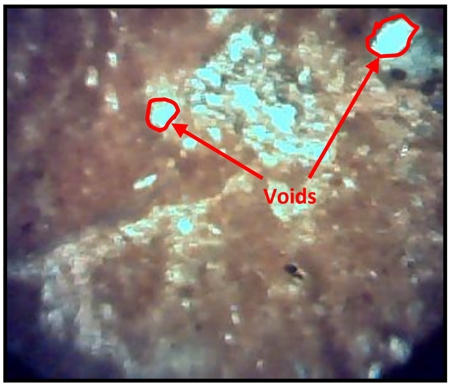
3-2-7 Soil- water characteristic curve: samples were prepared at optimum moisture content and maximum dry unit weight by static compaction method, lime and industrial waste lime were added (2, 4, 6) % and (2, 4, 6, 8) % respectively by dry weight of soil. All compacted samples were placed in vacuum desiccators for equilibrium time 45 days [6]. A computer program [6] was used to fit the experimental data using the three selected modeling equations Gardener, VenGenchten and Fredlund & Xing depending on the least value of sum of the square residuals (SSR) and the highest value of correlation factor (R^2) [6] for details. Results have shown that Fredlund & Xing equation is the best representing the experimental data. Table (7) shows the equation parameters (*a, m, n*) with statistical indices calculated by the program for the studied conditions. Lime and waste lime effects on soil- water characteristic curve are shown in Figs. (10 &11). It could be noted that the SWCC of lime and waste lime treated soils lay in consecutive order (with respect to added quantity) in the direction of the ordinate. i.e the water holding capacity increase with stabilizer addition. This could be attributed to the higher presence of additives which produced gel materials that close some voids between particles, and/or to the non reacted quantity of additives that act as a fill material. At a higher suction, it is noted that there is no visible difference between the SWCC curves due to the very little water content at this suction range, which limit the reaction.

Fig (12) indicates that the soil suction of industrial waste lime was less than that of lime treated soil for all percentage. This is related to the higher lime content which reveals more reaction and/or due to presence of small voids in lime treated soil system with comparison of that of waste lime. The curves in Fig.(12) showed an interaction between them at high values of suction that is related to low quantity of water which is necessary to complete pozzolinic reaction during equilibrium time that is reflect on effectiveness of the additives and appears with no effect on these curves.



% Lime, Waste

Fig.(7) Correlation Between k with Lime,Waste under Different Curing Time



A-Soil treated with lime (4%)

B-Soil treated with waste lime (4%)

Fig.(8) Optical Microscopic Photos For Treated Soil

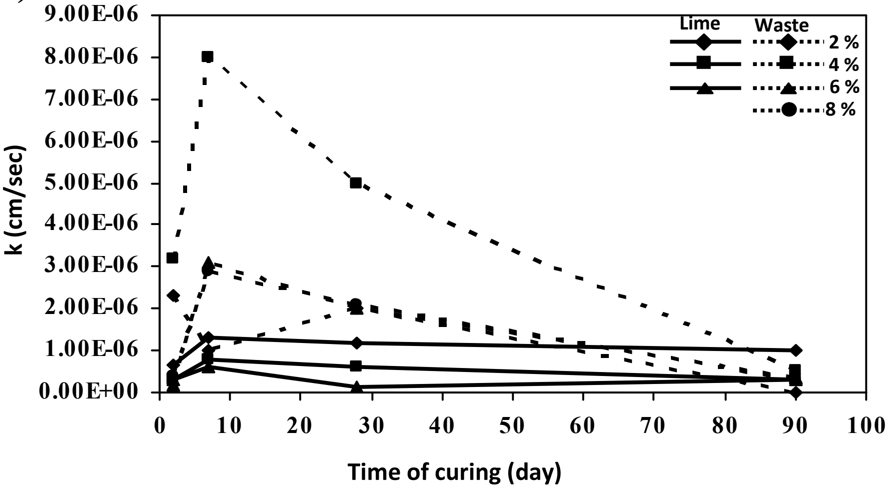


Fig.(9) Correlation Between k with Curing Time under Different Lime,Waste Lime Content

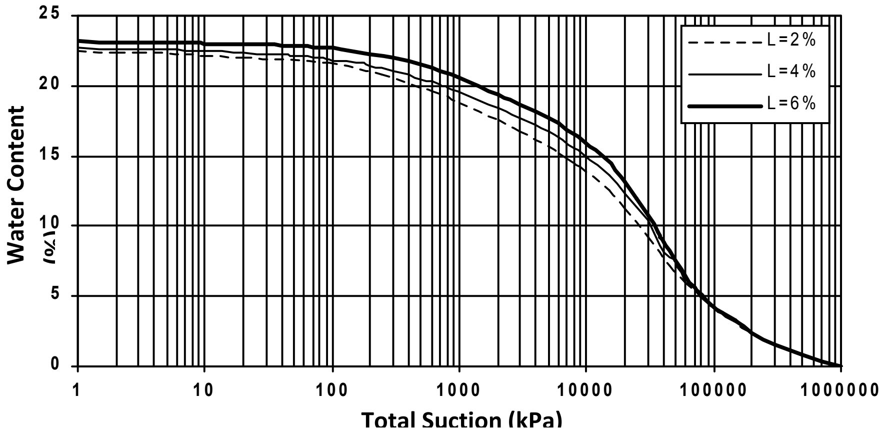


Fig.(10) Correlation between water content (%) with total Suction under Different Lime content.

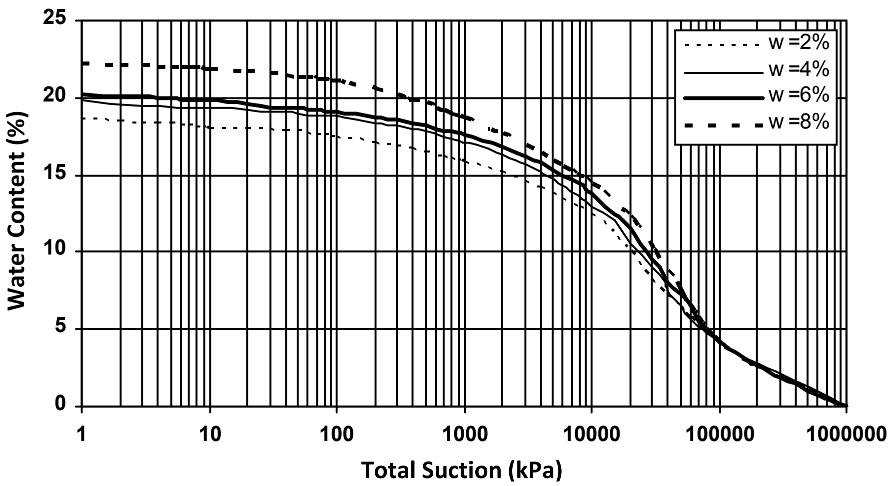


Fig.(11) Correlation between water content (%) with total Suction under Different Waste Lime content

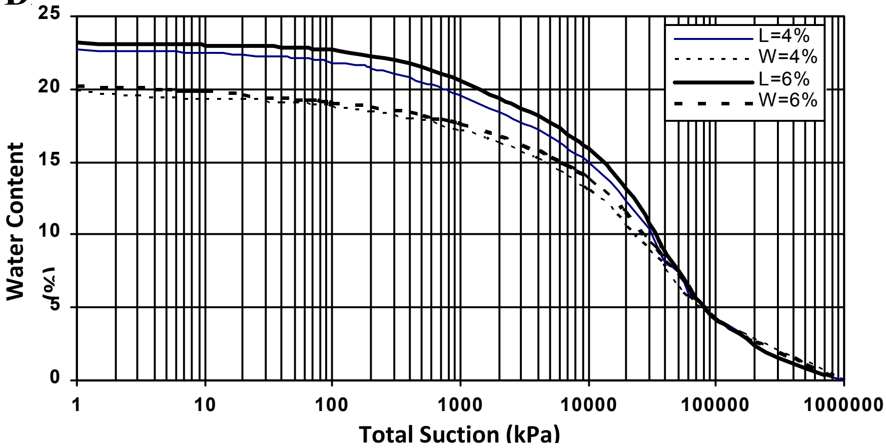


Fig.(12) Correlation between water content (%) with total Suction under Different Waste, Lime content.

4-Concolusions

1- Plasticity of treated soil decreases and turn into non-plastic at optimum lime, industrial waste lime stabilization (4, 6) % respectively.

2- The maximum dry density of lime is less than that of industrial waste lime treated soil while the optimum moisture content of lime is more than that industrial waste lime treated soil.

3- Swelling pressure and potential of lime was less than that soil treated with waste lime.

4- UCS reaches maximum values at optimum lime, waste lime stabilization
(4, 6) %. UCS of waste lime treated soil was more than that of lime-stabilized soil.

5- The durability measured by immersion and slack durability tests of treated soils was found to have negative effects on these soils (i.e decrease in wetted UCS of treated soils and loss in weight during slacking). Appreciable effects were noted when using waste lime.

6- Permeability of industrial waste lime was more than lime stabilized soil and reach maximum values at (4, 2) % respectively. Permeability increased up to 7 days then decreased with curing time.

7- Soil treated with industrial waste lime has less ability to hold water than lime stabilized soil.

Generally, it could be concluded that the industrial waste lime has a positive effect on the engineering properties of clayey soil. This positive result is highly affected by water, and then more waste lime (the double quantity) should be used to surmount this effect. So, waste lime could be used in the earth work for roads, especially, low cost roads, temporary roads and earth fills but when protecting the stabilized layers from water.

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