Stabilization of Expansive Clayey Soil Modified by Lime with an Emulsified Asphalt Addition

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Abstract

This study deals with the possibility of the stabilization of expansive clayey soil pre-treated by lime, with an emulsified asphalt addition.
Soil from the "2nd Kafaat" District in Mosul was chosen it is classified as medium to high expansiveness in naturally.

The pre-treated soil was performed with (0.5, 1.0, and 1.5%) lime addition by weight. After short period, emulsified asphalt was added with different percentages namely (2, 4, 6 and 8) by weight, for optimum percentages of an emulsified asphalt to give the most useful stabilization aspects.
The test result of lime addition alone showed that there was a considerable reduction in soil plasticity, 1.5% of lime addition converted the clayey soil towards non-plastic types. The emulsified asphalt addition to the mixture, caused slight increase in the plasticity but, their values in the whole, remained below the value of the natural soil.
The specific gravity decreased with the emulsified asphalt addition as well as, a general reduction, compatible with the increase in the optimum moisture contents.
The absorption values of the treated soil with the emulsified asphalt showed consequent reduction as compared with the original one.
A significant reduction in swelling pressure and swelling percent were obtained as well as an improvement in some values of the unconfined compressive strength were realized at low percentages of emulsified asphalt addition, compatible with reduction in values of the high percent additions.

تثبيت الترب الانتفاخية المعدلة بالنورة بإضافة المستحلب الإسفلتي

الخلاصة

لغرض الدراسة، تم إضافة نورة بالنسب (٠,٥،١,٠،١,٥ %) إلى تربة طينية معروفة بقابليتها على الانتفاخ، كمعاملة مسبقة. بعد ذلك أضيف إليها مستحلب إسفلتي بمواصفات خاصة وبالنسب (٢،٤،٦،٨ %) لكل نسبة مذكورة آنفا للترب المعاملة، لغرض تعيين نسب التثبيت المثلى لمعالجة الترب الانتفاخية المماثلة لها.
بينت النتائج حصول تغيير ملحوظ في خصائص التربة الهندسية والتي تشمل انخفاض في أقيام اللدونة، الانكماش الخطي، الوزن النوعي، الكثافة الجافة العظمى، الامتصاص، نسب وضغط الانتفاخ، دليل الانضغاط وكذلك دليل الانتفاخ.
أما أقيام معاملات النفاذية فقد وجد بأنها مقاربة أو اقل قليلا من قيمتها في التربة الطبيعية.
كما ظهر تحسن في بعض أقيام مقاومة الانضغاط غير المحصور ولنسب المستحلب الإسفلتي الواطئة مع نقصان في هذه الاقيام عند النسب العالية للمستحلب الإسفلتي المضاف.
استنادا إلى هذه النتائج، يمكن اعتبار إن حدود نسبة التثبيت المثلى هي ١,٥%- نورة كمعاملة مسبقة، مضافا إليها (٢,٠-٤,٠ %) مستحلب إسفلتي، والتي تعطي أفضل النتائج لتثبيت تربة طينية انتفاخية لها خصائص هندسية مقاربة للتربة التي أجريت الدراسة عليها، مع مراعاة الناحية الاقتصادية لنسب الإضافة حسب نوعية المنشأ و أهميته.

Introduction

The stabilization with asphalt is considered as one of the methods used to improve the coarse-grained soils by giving cohesive strength and to improve the waterproofing action, (Kezdi, 1979), (Ingles and Metcaf, 1972) but, the difficulties facing the mixing of this additive with cohesive soils, requires finding out employed methods and types

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of asphalt that are capable of improving such soils.

It has been found by several studies that stabilization with lime reduces soil plasticity, increases strength and durability, decreases water absorption and swelling (Bell , 1996),(Nalbantoglue, 2000).Here the stabilization affect is due to certain chemical processes, so it is not merely a mechanical reinforcement. These chemical processes modify the soil structure whereby larger grain aggregates are formed leading to several advantages in the suitability of the soil for foundations or road construction. Hence, it can be used to affect a partial control sufficient to overcome short term and seasonal moisture changes in the soil that overcomes the disruptive effects of moisture changes in expansive soils.

The emulsified asphalt addition to the pretreated expansive clayey soil by lime, will plug the voids generated between the clay lumps by adsorption effect. Thus, it's acting as water proofing agent, plugging or limiting the flow cannels that occurred and decreasing the water absorption. The stabilization by the emulsified asphalt is due to physical action only, (George, 1997), (Uppal, 1967)

2- Lime Stabilization of Clayey Minerals

Many of the important engineering properties of clay soils are enhanced by the addition of lime.

All the same, the properties of such soil-lime mixture vary and depend upon the character of the clayey soil (Bell, 1996), the type and length of curing and the method and quantity of construction, (Guide Specification, 1997).

When lime is added to clayey soils, calcium ions initially combine with or absorb by clay minerals. These changes continue up to the lime fixation point. This addition of lime contributes towards the improvement of soil workability, but not to strength increase. Lime added in excess of the fixation point is utilized in the cementation process. The effectiveness of lime stabilization is independent on the development of reaction products formed from the attack of lime on the minerals on a deposit of clay. (Bell, 1996).

(Little, 1996) stated that two phases of stabilization occur in a lime-soil system. The first, involved the practically immediate reactions of cation exchange and flocculation-agglomeration. These reactions occur to some extent with all fine-grained soils. Due to textural changes caused by these reactions within the soils are improved. These improvements are reflected in improved workability, immediate strength improvement and reduce swell-susceptibility.

In order to reduce the effect of the carbonation (The lime reaction with the atmospheric CO_2) to the exposed surfaces, it is recommended to conduct the field compaction within a short period after the addition of lime and asphalt. Pozzolanically induced long-term strength gain in more capricious as its success, depends on a cooperative reaction between the lime and the clay as well as the mineralogy of the clay. Many types of clay are reactive and upon lime stabilization, their strength may easily triples or quadruple.

In the pozzolanic reaction, the reasonable amount of lime addition to the clayey soil will increase the pH-value at 25° C to 12.4, the CSH (Calcium Silica Hydrate) and CAH (Calcium Alumina Hydrate)well be formed, binding and flocculating the clayey particles to larger sizes.

In a study conducted by using Electron Microscopy, anther compound CSAH (Calcium Silicate Aluminates Hydrate) was created (Khattab, 2002). These reactions could last for years leading to continuous increase in strength.

The Factors affecting chemical reactions are:-

1- Curing Condition: (Temperature facilitate the chemical reaction)
2-Clay Content with clay minerals: the more specific surface the more effective
3-Biomass Material: (1-2%) is the acceptable value.
4-Sulphate Content: When high percentage is presented, the pozzolanic reaction will create the (Ittringite) which differs from the ordinary pozzolanic reaction in that; larger crystals particles will be formed causing excess pressure to the adjacent particles (Little, 1995).
5-Weathering: When pH-value of the soil is more than 7 it is considered as convenient for lime stabilization.

The effect of lime treatment and the curing periods with temperature variations of on the permeability of clayey was studied by (Al-Daood, 2006). She concluded that the permeability increases with curing temperature and periods, for all amounts of added Lime. Higher permeability was found for samples compacted on a dry side of the compaction curves, while the lowest was obtained on the wet side.

3-Stabilization with Bituminous Materials

Bituminous Stabilized materials have been used for base and sub-base construction to impart the lubricant, sealant, adhesive and stability properties which are desired for a bituminous mix.

In granular soil, the coarser grains may be individually coated and stuck together by a thin film of bituminous material imparting strength due to increased materials plugging the voids between small clay lumps, thus acting as a water proofing agent for compacted soil-bitumen mix.(Al-Khashab and Al-Harbawy-2004).

Hence the types of soil that could be stabilized with bitumen are:

1- Cohesionless sand mixed with bitumen is called sand-bitumen.
2- Fine material that passes through sieve No.4, mixed with bitumen is called soil bitumen.
3- Gravelly-sand with the bitumen is called sand-gravel bitumen. (Sharma and Sharma, 1985).

4-Types of Bitumen material used in stabilization

The following materials do not undergo significant changes during their use, and their main function is to cement the soil particles (Kezdi, 1979), (Sharma and Sharma, 1985) and (Yoder,E.J & Witczak, 1975).

4-1 **Asphalt**: is a natural or synthetic product in which the mineral particles are impregnated or cemented. It can be fully dissolved in (CCL_4) and (CS_2) as well as in Kerosene and Naphtha. It is a black, elastic or semi solid material
That is insoluble in water, diluted acids and alcohols. The greater part of the asphalt used for road construction to day is petroleum distillery products.
Liquid asphalt is produced by mixing asphalt with different hydrocarbon solvent such as Gasoline, Kerosene and Diesel oils.
One of the most famous and important type of the liquid asphalt is "cutback asphalt" which is formed as portion or fraction of the distillate, mixed with residue close to the end of distillation which is termed "Cutback".
It has the advantage, as compared to straight-run asphalt, that it can be used with cold aggregates and with minimum heating requirements.

4-2 **Tar:** is a liquid or semi-solid hydrocarbon produced by the destructive distillation of different types of coal (anthracite, lignite and bituminous coal). For road construction purposes coal tar is mainly used (Kezdi, 1979).

4-3 **Emulsified asphalt:** It is an intimate mixture of water, asphalt and emulsifying agent. It has an advantage over hot asphalt in that it can be used with cold or hot aggregates under their dry, damp or wet conditions. Its use with wet aggregates is an advantage for this material over other types of liquid asphalt (i.e. Cutback). In addition, emulsified asphalt does not need any heat for its application (Hopson and Pohl, 1975).

In the case of lime addition to the clayey soil, there will be a chemical reaction (pozzolanic reaction), that increases the alkalinity of the media. This operation is considered as a positive aspect to avoid the harmful affect of bacterial attack to the bituminous material, as the bacteria can be grown in an acid media.

5-Material and Methods

The clay in Mosul area is generally found as moderate to high expansive. Its swelling potentials varies between 4.7 to 15% for remolded and 2.4 to 9% for undisturbed samples (AL-Layla and Al-Ashou-1985). The previous studies showed that the index properties can used to estimate the expansiveness of these soils (Holtz & Gibbs, 1956).However such estimation is more convenient for remolded rather than undisturbed soil. The swelling potential of the soil can also be estimated with the help of activity of the soil and the percentage of clay size particles, which can be used as a measure for the amount of volume change (Seed et al, 1962).

5-1 **Materials**:

The following materials have been used for this study:

5-1-1 **Soil samples**: disturbed clayey soil was taken from the "2nd Kafaat" district of Mosul city at a depth of (1.5-2.0 m).The index properties of natural soil are presented in table (5-1)

5-1-2 **Asphalt Emulsion:** Cationic type having grading -45, having the physical and chemical properties presented in table (5-2).

5-1-3 **Water:** Distilled water was used for all experimental works

5-1-4 **Lime:** Brought from Al-Mishraq region having purity of 80%.

5-2 **Method of blending and mixing:** Oven dried soil (105±5 C̊) was used, sieved for each specified test, blended with lime by weight as per forenamed percentages. Then, water added as per the specified amounts. The mixing was performed thoroughly by hand trowel. Prior to period of an hour, emulsified asphalt was added and immediately mixed with the aforementioned material.

5-3 **Laboratory Tests:** The following tests have been conducted on natural and treated soils, according to the mentioned standards:

5-3-1 Atterberg limits: W_L& W_P – ASTM (D4318-98), L.S. (B.S.-1377).

5-3-2 Specific gravity: [ASTM-(D854-98)]

5-3-3 Grain size analysis: [ASTM-(D422-98)]

5-3-4 Modified Compaction test: [ASTM-(D1557-98)]

5-3-5 Consolidation test: [ASTM-(D2435-96)]

The samples were prepared by static compaction method Fig. (1), using dry soil passing sieve No.4 having max. γ_d and O.M.C with the calculated additive amounts.

5-3-6 Swelling percent and swelling pressure test: [ASTM-(D3877-96)].the tested samples were prepared as per sec (5-3-5)

5-3-7 Shear strength tests:

5-3-7-1 Direct shear test: [ASTM-(D3080-98)].

The samples were prepared as per sec (5-3-5)

In a direct shear box of (60*60*60) mm. The adjusted velocity for the test was (0.02mm/min.)

5-3-7-2 Unconfined compression test: [ASTM-(D2166-98a)].

The samples prepared in a compaction tool, locally manufactured for this purpose, (resembling the Harvard miniature compaction instrument) of 51mm diameter and 102mm height using the equivalent modified compaction efforts.

5-3-8 Absorption test:

The samples were prepared as per sec. (5-3-4). Their weights (Ws) were recorded. They subject to dryness in an oven adjusted to (18-27̊c), till the humidity loss became 90 %. Their weights (W_1) were taken. They maintained vertically in dishes inundate 1.0 inch of the samples with distilled water for seven days. By applying quick blotting, their weights (W_2) were recorded.

The water absorption (W.A) was calculated as:

$$W.A. = \frac{W_2 - W_1}{W_d} \times 100 \qquad \text{Where:}$$

W_d- the calculated dry sample weight from:

$$W.A. = \frac{100\,Ws}{100 + w/c + (E.A\%)} \times 100$$

w/c- water content of compacted samples.

Ws- Sample weight after compaction

(E.A)- Percentage of added (E.A)

6- Results and Discussion

The followings were analyzed according to the tests results:

6-1 **Atterberg limits and linear shrinkage of treated soil**:

Table (5-1) demonstrates the engineering soil properties of the natural soil, while table (6-1-a) presents the Atterberg limits with lime and emulsified asphalt.

It can be realized that the liquid (W_L) and plasticity index (P.I) were reduced considerably due to the increase percentages of both lime and emulsified asphalt (E.A) additions.

The decreasing of (W_L) and (P.I) of lime addition alone, is due to the Cation exchange effect. While the emulsified asphalt (E.A) action is lubricates the Soil particles and consequently increasing (W_L) and (P.I). But, it can be realized that their combined effect decrease (W_L) and (P.I) considerably due to increase percentages of both lime and (E.A) addition, and gave values less that of original soil. The long term reactions (Pozzolanic Reaction) of the lime will create a decrease in (W_L) and (P.I) within time.

The aforementioned reasons can be justified for the linear shrinkage results presented in Table (6-1-b) as well.

6-2 Specific gravity of Treated soil

It can seen that there is a considerable reduction in specific gravity (Gs) shown in table (6-2) due to increasing percentages of both lime and (E.A) addition. These reductions were due to the low (Gs) of the added materials.

6-3 Compaction properties of Treated soil

Table (6-3) and Figs. (6-1), (6-2) presents the above mentioned results. It can be realized that as the increase of (E.A) addition to the treated soil, the maximum dry density (γ_d) generally decreases accordingly, accompanied by increases in the optimum moisture contents (O.M.C).

In general, as the lime addition causing agglomeration to the soil particles, consequently decreasing their max. (γ_d), also increasing the soil voids, that can be filled with (E.A) which cause further decrease in (γ_d) as well, using the same compaction energy effort for all tested samples.

6-4 Consolidation Properties of Treated Soil:

The tests results demonstrated in Table (6-4) clearly show that the void ratios generally increase considerably due to the increase of the additives. The reason of that are the reduction in (γ_d) and an increase in (O.M.C) due to this treatment. The Cc "compression index" and Cv "coefficient of consolidation" increase as well, due to a reduction in (γ_d) and cohesion. While Cs "the swelling index" decreases due to the reduction in soil rebound.

The values of K "the coefficient of permeability" obtained, were nearly equal or slightly less than of that of the natural soil. As the lime addition increases the permeability (Al-Daood, 2006), but the presence of (E.A) will plug the voids and minimizing the effect of water flow channels, consequently tend to decrease or maintain the values of K.

6-5 Swelling Percent and Swelling Pressure of Treated soil

Table (6-5) and Fig (6-3) describe those values due to the lime treatment, as well as with different percentages of (E.A) additions, for the prepared samples having max. (γ_d) and (O.M.C).

It can be realized that the values of swelling pressures and swelling percentages decreasing considerably due to the increasing of the used additives. This phenomenon can be described as follows:

a- The decrement of (γ_d) in general duo to the additives addition.

b- The increment of the (O.M.C) accompanied by the decrement of the max. (γ_d).

c- The (E.A) coating the clay particles. As well as plugging the voids, and causing decrement in the absorption ability of the treated soil, consequently decreasing the swelling properties of treated soil

6-6 Shear Strength Properties of Treated Soil

6-6-1 Unconfined Compression Stress (U.C.S) of treated soil

Table (6-6) (A, B, C) &Fig. (6-4) clearly demonstrates the results of the tested samples prepared at the max. (γ_d) and (O.M.C).

It can be realized that the values of (U.C.S) containing law percentage of (E.A) acquiring (U.C.S) more than that of the original soil, while the samples of higher percentages of (E.A) creating decrements in (U.C.S). These aspects can be described as:

a- The increasing of (E.A) addition accompanied with decrement of (γ_d) and causing increment of (O.M.C).

b- The (E.A) addition lubricating the soil grains, causing weakness to the interlock between the particles, consequently decreasing the frictional forces between them.

It can be noticed from Table (6-6-c) that the curing time which exceeds 14 days, for the samples treated with 1.5% lime, acquires higher values of (U.C.S). Hence this percentage of lime addition can be considered as an optimum modification percentage.

6-6-2 Direct Shear Test for Treated Soil

It can noticed form Table (6-7) &Fig. (6-5), that for all percentages of lime treatments, the cohesion (C') increases considerably up to 4% of (E.A) addition then tend to decrease beneath this value. As the lime addition tends to agglomerate the clay particles to coarser sizes, causing a cohesion decrease. But, the (E.A) addition coats these particles and becomes more effectives to the coarser grains and tends to increase the cohesion up to certain limit of (E.A) addition, which is 4%.

Beyond this, the cohesion will decrease. The fluctuation of Ǿ (the effective angle of internal friction) was obtained, to be less than that of the original soil, because of the effect of both, the lime that creates clustering of the particles and the (E.A) which lubricate them facilitate their sliding on each other.

6-7 Absorption Test:

From Table (6-8), it can be realized that for the soil, treated with 1.5% Lime (The obtained optimum percentage) that the absorption percent decrease with the increase of (E.A) addition, as it plug the voids generated between the clay lumps and minimizing the effect of flow channel within the soil.

7- Conclusions

The test results of this work lead to the following conclusions:

1- The optimum value of the lime addition alone that tends to convert the clayey soil to non-plastic is 1.5%.

2- The effects of the (E.A) to the pre-treated clayey soil with lime are as follows:

a- reduction in its liquid limit (W_L), Specific Gravity (Gs), max.dry density (γ_d), and considerable reduction in swelling pressure and swelling percent as well as in the absorption phenomena values.

b- An improvement occurs in the (U.C.S) values for samples with low percentages of (E.A).

c- An increment of effective cohesion (C') up to 4% (E.A) addition. While the effective angle of internal friction (Ǿ) decreased and generally remained below the natural soil value.

The minimum value of (Ǿ) obtained is at 4% of (E.A) addition.

d- The obtained compression indices (Cc) are generally below the value of natural soil. It increases with the increase of (E.A) addition. While the coefficient of consolidation (Cv) increase with the increase of lime addition.

The swelling indices (Cs) in general are below the value of the natural soil. It increases with the increase of (E.A) and decreases with increase of lime.

e- The coefficients of permeability (K) are nearly equal, or slightly beneath the value of the natural soil.

3- It can be concluded from this study that the optimum values of stabilization of this type of clay are (1.5%) lime addition with (2-4%) of (E.A) that can be used in road embankments, water storage reservoir lining ….considering the economical aspects based on the project type.

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Table (5-1) Engineering properties of natural soil

Atterberg Limits	**Liquid Limit (W_L) =49%**
	Plastic Limit (W_P) =23%
	Plasticity Index (PI) =26%
	Linear shrinkage (L.S) =13%
Specific Gravity	**G.s=2.74**
Grain Size Analysis	**Sand=14% (S)**
	Silt=46% (M)
	Clay=40% (C)
Classification	**Classification According to AASHTO is (A-7-6)**
	Classification According to Unified system is (CL)
Activity	**P.I/C=0.65**
Swell Parameter	**Swelling Percentage prepared by: (Dynamic method) 5.5 %, (Static method) 4.8 %**
	Swelling Potential According to (seed, 1962) =4.08%
	Swelling Pressure: 175 kN/m^2 (dynamic),200 kN/m^2(static)
Modified Compaction Properties	**Dry Unit Weight =17.4 (kN/ m^3) at O.M.C=16%**
Strength of Soil	**U.C.S=63.3kN/m^2 at O.M.C=15.8%**
	c` (cohesion)=25kN/m^2 Ø'(eff.Angel of friction=29 Direct Shear test
Consolidation of Soil	**c_c (Comp.Index)=0.251 c_s (Swelling Index)=0.055 c_v (Coff.of Comp)=4.46*10^{-3}cm^2/sec**
Permeability Coff.	**k=3.82*10^{-5}cm/sec (Form Consolidation Test)**
Chemical Test	**Gypsum content=1.72%**
	SO_3=0.05%
	pH=8.16
	Total Soluble Salts (T.S.S) =2.72%
	Organic matters content=3%

Table (5-2) Physical and Chemical Properties of Emulsified Asphalt used in this Study

Properties	*Value*
Viscosity at 25^0 C (C.Stoke)	45
Settlement (5 – day) (%)	3.2
Storage stability test, 24-hr (%)	20
Coating ability and water resistance	Good
Coating , day aggregate	Fair
Coating , wet aggregate	Fair
Coating mixing test (%)	1.2
Particle charge test	Positive
Setting time (hr)	19

Table (6-1-a) Consistency Limits of Treated Soil with Lime and Emulsified Asphalt

%Emulsion Asphalt	% of Added Lime								
	0.5%Lime			1%lime			1.5%Lime		
	W_L	W_P	P.I	W_L	W_P	P.I	W_L	W_P	P.I
0%	48	30	18	44	34	10	-	-	N.P
2%	46	40.85	5.15	46.6	37.625	8.975	47.3	40.92	6.38
4%	47	37.84	9.16	48.2	39	9.2	48	40.54	7.46
6%	47.7	39.87	9.83	48.5	37.315	11.85	46	37.3	٧,٧
8%	54	41.52	12.48	49	37.55	11.45	45	35.405	9.595

Table (6-1-b) Linear Shrinkage of Treated Soil with Lime and Emulsified Asphalt

Emulsion (%)	0.5%Lime	1%Lime	1.5%Lime
2%	12.859	11.0705	9.125
4%	13.563	11.1896	8.5075
6%	13.2	10.9445	9.345
8%	12.882	10.9095	9.545

Table (6-2) Specific Gravity of Treated Soil with Lime and Emulsified Asphalt

Emulsion	0.5%Lime	1%Lime	1.5%Lime
2%	2.618	2.617	2.659
4%	2.631	2.591	2.631
6%	2.59	٢,٥٨	2.624
8%	2.475	2.577	2.551

Table (6-3) Compaction Properties for Treated Soil with Lime and Emulsified Asphalt

Emulsion Addition (%)	Lime 0.5%		Lime ١,٠%		Lime ١,5%	
	W/c Opt	γ_d max kN/m^3	W/c Opt	γ_d max kN/m^3	W/c Opt	γ_d max kN/m^3
0%	**18**	**1.68**	**18.7**	**1.674**	**19.2**	**1.658**
%2	20	1.63	20.8	1.668	16.5	1.65
%4	**22**	1.645	20	1.66	19.5	1.607
%6	23	1.625	21	1.65	22.4	1.593
%8	22	1.63	21.5	1.645	22	1.581

Table (6-5) Swell Percent &Swell Pressure for Treated Soil with Lime and Emulsified Asphalt

Natural soil	**Free=5.5% Swell Pressure=175 kN/m^2**	**Free=4.7% onstant=200kN/m^2 static**	
(E.A) %	**0.5%Lime**	**1%Lime**	**1.5%lime**
2%	**Free=1.81% Swell Pressure=51.4 KN/m^2**	**Free=0.1358% Swell Pressure =21.42 kN/m^2**	**Free=0.3803% Swell Pressure =28 kN/m^2**
4%	**Free=0.6% Swell Pressure =21.42 kN/m^2**	**Free=0.2721% Swell Pressure =21.42 kN/m^2**	**Free=0.116 Swell Pressure =21.42 kN/m^2**
6%	**Free=0.3667% Swell Pressure =21.4 kN/m^2**	**Free=0.3124% Swell Pressure =35 kN/m^2**	**Free = nil Swell Pressure =10.71 kN/m^2**
8%	**Free=0.4605% Swell Pressure =21.42 kN/m^2**	**Free = nil Swell Pressure =28 kN/m^2**	**Free=0.0549% Swell Pressure =10.71 kN/m^2**

Table (6-7) Effective Direct Shear Parameters for Treated Soil with Lime and Emulsified Asphalt

Emulation Addition	0.5%Lime	1% Lime	1.5%Lime
2%	C'=27.5 Ø=23.96	C'=45 Ø'=26.56	C'=87 Ø'=14
4%	C'=32.5 Ø'=21.8	C'=55 Ø'=15.94	C'=97 Ø'=14
6%	C'=30 Ø'=24.22	C'=52 Ø'=17.1	C'=72 Ø'=19.24
8%	C'=29 Ø'=17.52	C'=50 Ø'=17.35	C'=92 Ø'=14

Table (6-8) Absorption Ability of the Soil Treated 1.5% Lime and the Mentioned (E.A)

Emulsified Asphalt	2%	4%	6%	8%	Natural soil	
					Unit weight kN/m	
Absorptior (%)	22.635	21.834	17.199	17.1	15,68	15,84
					28.49	29.284

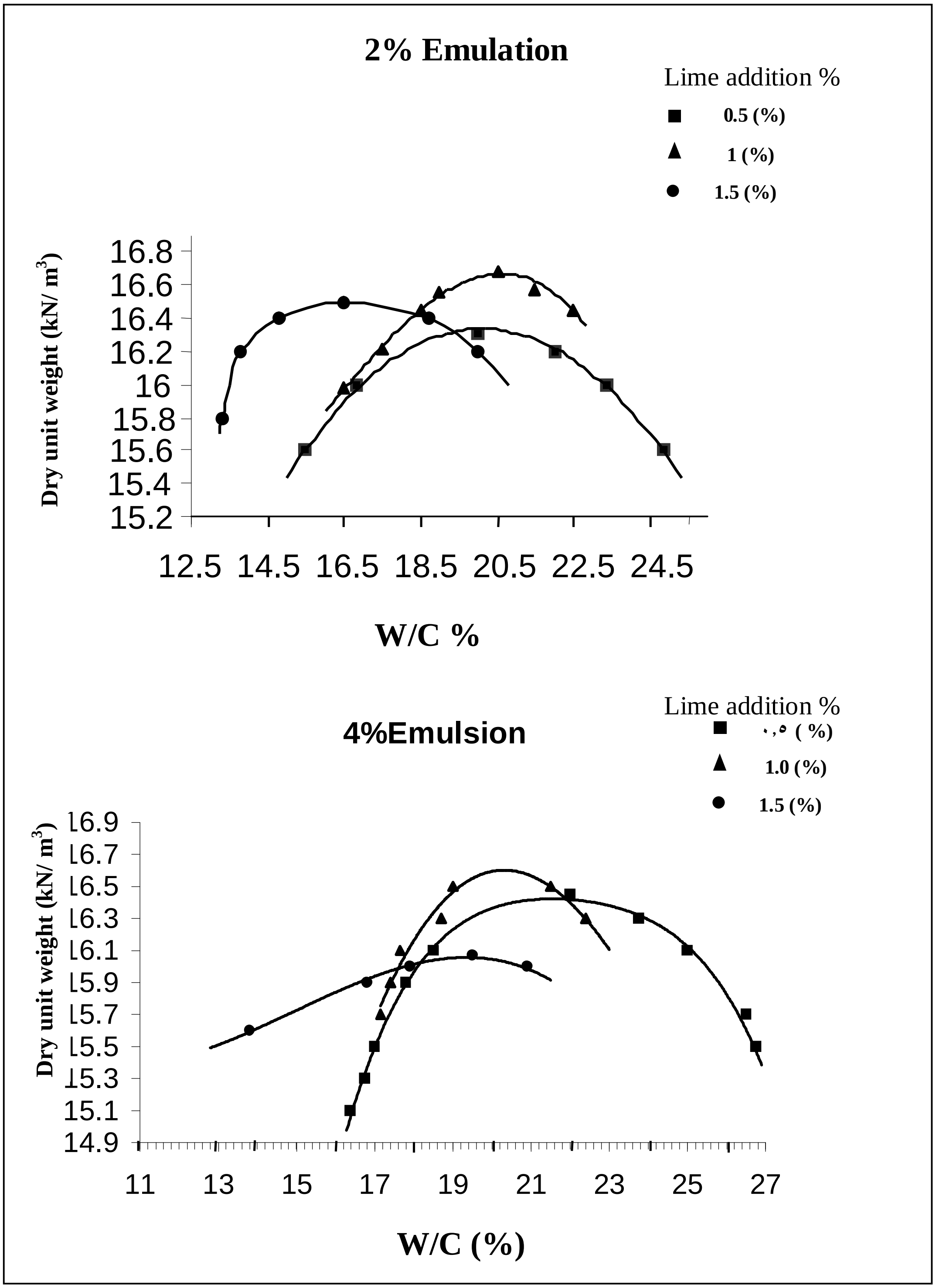


Fig. (6-1) Compaction properties of Treated soil

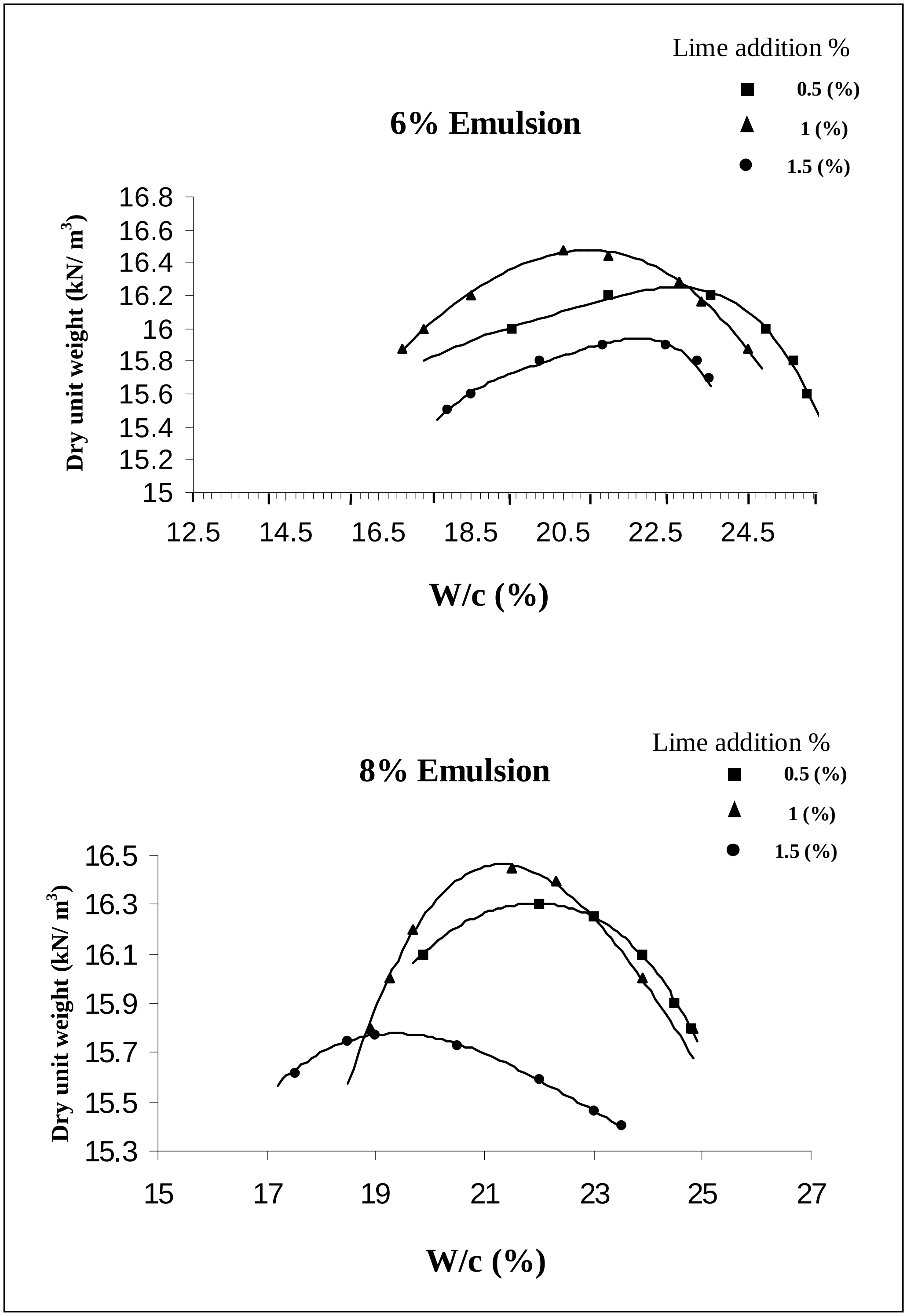


Fig. (6-2) Compaction properties of Treated soil

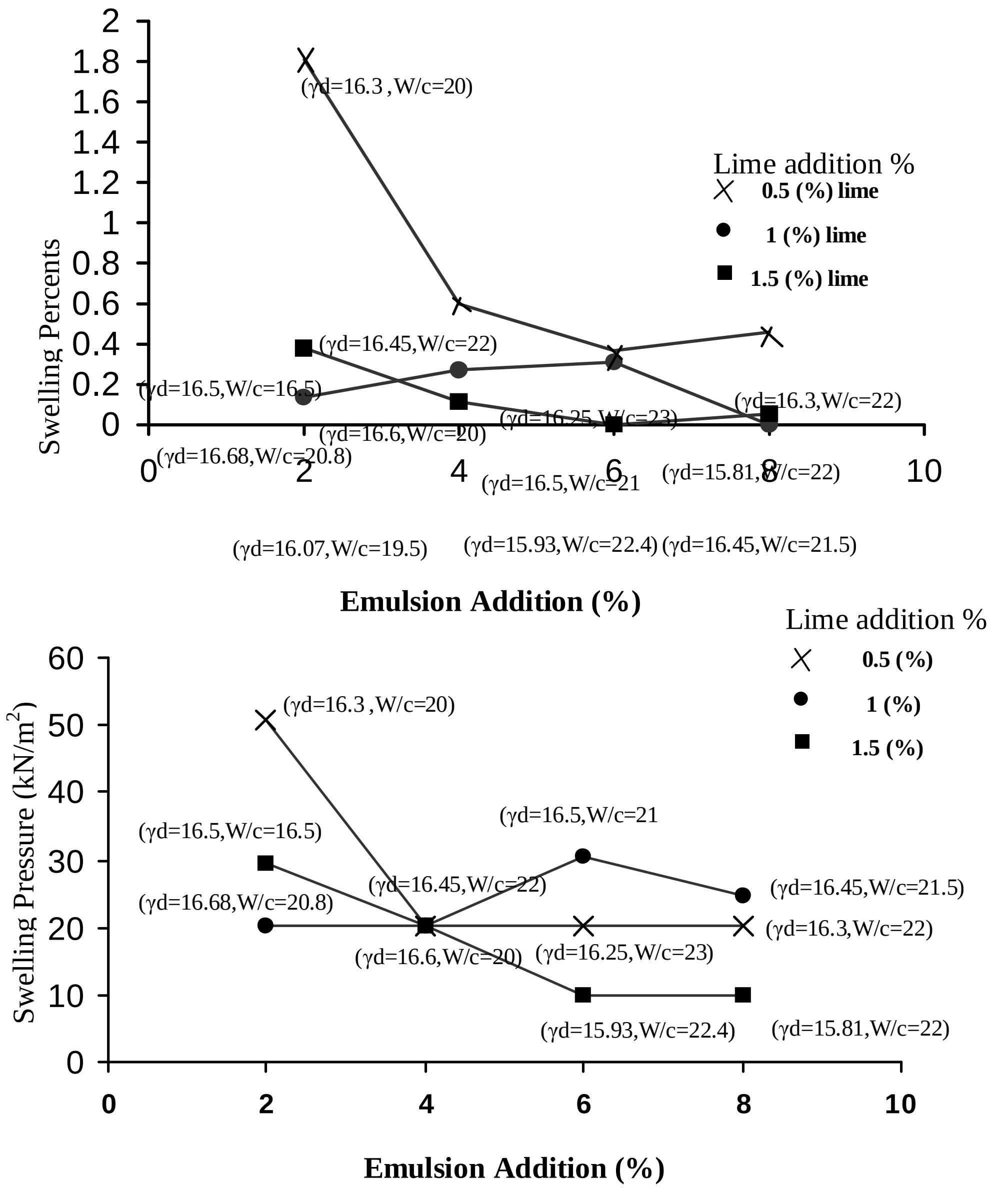


Fig. (6-3) Swelling Percent and Swelling Pressure of Treated Soil

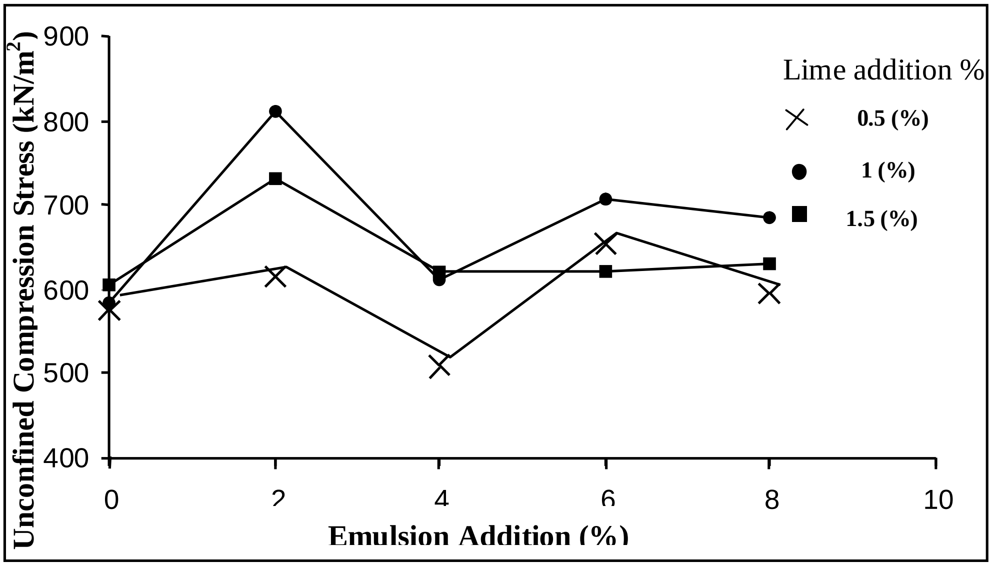
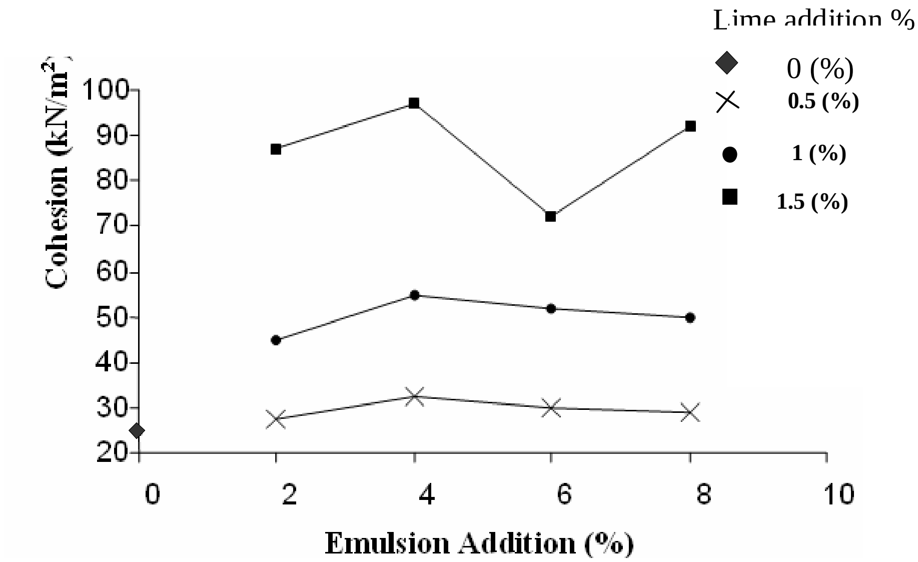


Fig. (6-4) Unconfined Compression Stress of Treated Soil



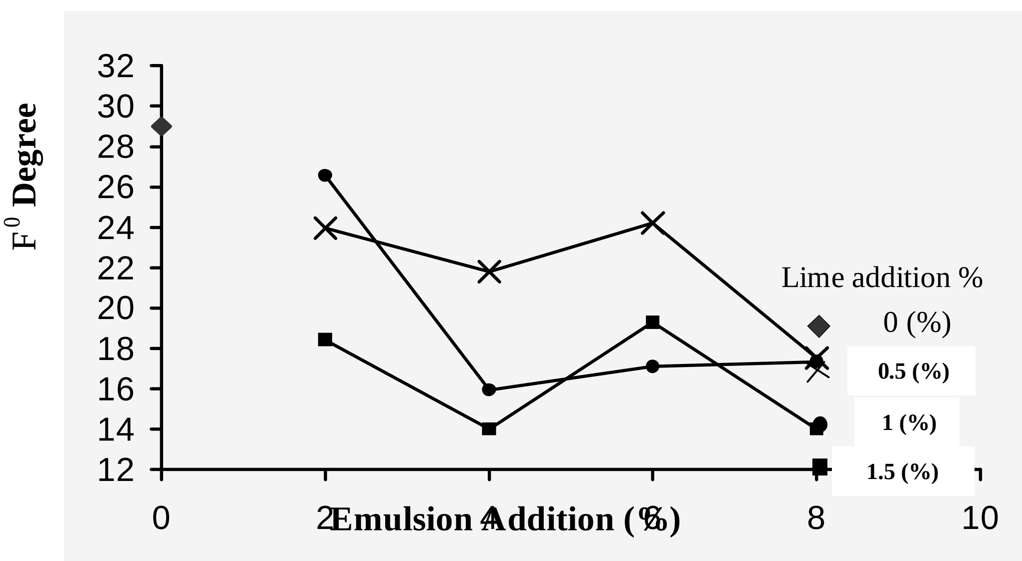


Fig (6-5) The Effect of Lime and (E.A) on Shear Parameters

Table (6-4) Consolidation Parameter for treated Soil with Lime and Emulsified Asphalt

Lime (%)	0.5 % Lime				1 % Lime				1.5 % Lime			
Emulsion Addition (%)	c_c	c_s	c_v*10^{-3}	$k*10^{-5}$	c_c	c_s	c_v*10^{-3}	$k*10^{-5}$	c_c	c_s	c_v*10^{-3}	$k*10^{-5}$
2	0.1786	0.017	6.358	2.408	0.126	0.0249	6.454	2.074	0.096	0.0166	9.398	2.339
	e = 0.6681				e = 0.7734				e = 0.578			
4	0.1827	0.033	4.568	3.594	0.1603	0.0315	8.6116	3.267	0.094	0.0149	6.99	2.667
	e = 0.7804				e = 0.7665				e = 0.5582			
6	0.249	0.047	4.0866	3.218	0.168	0.035	7.616	3.162	0.119	0.019	9.935	2.438
	e = 0.8167				e = 0.861				e = 0.727			
8	0.2823	0.049	4.3916	3.112	0.1853	0.0365	4.869	1.971	0.124	0.02	10.896	1.946
	e = 0.857				e = 0.7744				e = 0.7508			

Table (6-6) Unconfined compression Stress for Treated soil with Lime and Emulsified Asphalt A (Curing 1 day)

%Lime			1%Lime				1.5%Lime			
d x 3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2
3	17.25	547	18.7	1.647	17.9	585	19.2	1.658	17.9	605
3	14	580	20.8	1.668	17	810	16.5	16.5	18	730
5	20	475	20	1.66	18	612.5	19.5	16.07	17	620
5	16.5	620	21	1.65	18	706.8	22.4	15.93	17.7	620
3	18	560	21.5	1.645	20.7	705	22	15.81	18	630

B (Curing 7 day)

(E.A) Addition (%)	0.5%Lime				1.0%Lime				1.5%Lime			
	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2
2%	19.01	16.21	18.1	542.8	18.2	16.2	19.0	613.1	15.3	15.61	14.8	674.6
4%	19.75	16.42	19.65	316.2	17.8	16.02	17.5	503.9	18.4	15.74	17.9	835.5
6%	19.9	16.15	20.37	210.8	15.8	16.14	18.3	397.8	21.7	15.91	20.9	611.4
8%	19.55	15.85	18.85	200.2	17.7	15.87	18.9	316.2	20.3	15.73	20.3	579.7

C (Curing 14 day)

(E.A) Addition (%)	0.5%Lime				1%Lime				1.5%Lime			
	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	U.C.S kN/m^2	W/c Opt.	γ_d max kN/m^3	W/c	.C.S kN/m2
2%	16.23	16.24	16.9	552.3	18.3	16.04	18.8	689.6	15.6	15.9	15.6	988.8
4%	19.77	16.3	19.7	322.5	17.2	15.98	17.7	477.4	17.8	15.93	17.9	790.6
6%	19.94	16.13	20.9	263.5	16.6	16.1	18.3	381.9	20.9	15.94	20.6	542.8
8%	19.02	158.5	19.2	200.2	15.8	16.09	19.0	323.6	19.8	15.78	19.0	634.5