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Improving the Characteristics of Subgrade Soil Using Different Chemical Additives: Case Study Al-Nasiriya Soil

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ABSTRACT

The roads in the city of Nasiriya in southern Iraq suffer from problems that occur as a result of repeated vehicle loads or due to weak soil and lead to losing their performance and being out of service despite their construction for a very short period. The use of chemical additives to improve the subgrade widely worldwide and give strength and durability to the weak soil while the possibility of using chemical additives for the substrate in Al-Nasiriya is still practically limited. The study aimed to verify the use of chemical additives (cement, lime, and ferric chloride) and to know their effect on the properties of Al-Nasiriya soil. The results showed a clear improvement in the UCS test when using chemical additives, and then the optimal percentages of additives were determined and were 9%, 10%, and 2% respectively, in addition to knowing the effect of the curing period (1, 7 and 14) days on the results of the test. For the other tests (maximum dry density, CBR, swelling, and optimum moisture content) were verified for the optimal chemical percentages and it was observed that the CBR values increased and the swelling values decreased after treatment and soaking in water for all additives, while the compaction parameters had a different behavior between the materials additive used.

1. INTRODUCTION

The subgrade layer is the basis for the whole pavement structure and it is the dominant layer as it bears the stresses of all the layers from the top, The thickness of this layer is (150 to 300 mm) and this layer must have a bearing capacity at the optimum water content [1].

This layer suffers swell and shrinkage when its clay the reason is due to the fact that it contains the mineral montmorillonite, the process of removing all the layer and replacing it with stronger soil is considered to be of high cost and takes a lot of time. Also, Mechanical soil improvement does not provide a guarantee for the strength and durability of the soil. Therefore, soil properties can be improved by adding chemicals to it such as cement, lime, and other chemicals [2].

In another soil improvement technique, Thamer and Shaia [3] have been used a geotextile material to improve the soil of the city of Al-Nasiriya and the practical results gave an increase in the bearing capacity of the soil with the use of these materials, While the deep mixing method was used by, Ho et al. [4] to increase the bearing capacity of the soil and gave good results.

The additives were added to the subgrade layer of Al-Nasiriya soil by Sarsam et al. [5] and an increase in the bearing capacity and an improvement in the properties of the soil were observed, as the value of CBR increased, also decreased settlement.

Cement and lime were used by Etim et al. [6] to improve clay soil, they noted that the values of UCS and CBR have been increased, as well as an improvement in the properties of that soil.

Ferric chloride was added by Koteswara Rao et al. [7] and mixed with Rice husk ash to improve the subgrade layer, they found an improvement in the value of the UCS and they obtained good results in terms of shrinkage and swelling.

Srinivas and Raju [8] conducted field tests on the subgrade layer and improved it with $CaCl_2$, $FeCl_3$, and KCl, they showed that $FeCl_3$ gave the best performance and more strength and durability than the chemical materials.

While Bharambe and Patil [9] used ferric chloride and fly ash in soil to improve the soil. They noticed an increase in the value of CBR by about 155%. In addition, they found that adding ferric chloride to soil improved with fly ash reduced the swelling of soil.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials used

2.1.1 Soil

A weak subgrade was collected from one of the areas of Al-Nasiriya city, 380 km south of Baghdad, the location was shown in (Figure 1). The soil sample was chosen at a height of (1.5-2.0 m) below natural ground level. The chemical properties of the soil are shown in (Table 1). While the physical properties are shown in (Table 2).

Figure 1. The geographical location of the collected soil

Table 1. Chemical composition of soil

Composition	Value%
Sio_2	9.3
Al_2o_3	0.33
Fe_2o_3	0.21
Cao	49.8
Mgo	0.99
K_2o	0.12
Na_2o	0.017
Cl	0.17
So_3	0.98
Loss On Ignition	37.8

Table 2. Index and engineering properties of weak subgrade

Property	Value
Liquid Limit%	36.5
Plastic Limit%	20.22
Plasticity Index%	16.28
Classification IS	A6
Classification UCSC	CL
Specific Gravity	2.61
MDD	1.804 gm/cm^3
OMC	122.37 Ib/ft^3
CBR (compacted to MDD at OMC)	16.3%
Unconfined compressive strength	6.6
(at OMC & MDD)	344 Kn/m^2
Hydrometer test	Figure 2 & 4

The Hydrometer test for natural soil in Figure 2, and found the Soil finer than the No.200 sieve size was less than 90%, so the modified method of the hydrometer was done by washing remaining on the sieve No. 200 and drying in the oven and crushing as showing in Figure 3, it was obtained good results shown in Figure 4, This method was carried out based on Soil Mechanics Laboratory Manual Book [10].

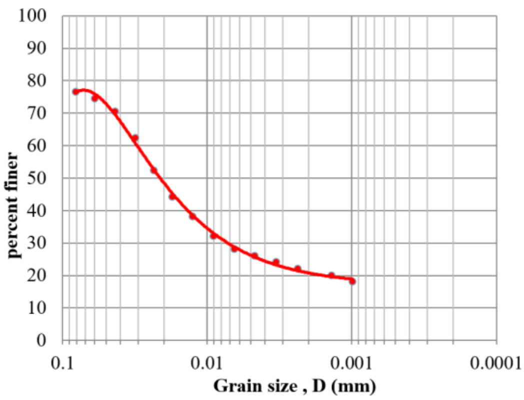

Figure 2. Grain size distribution by hydrometer

Figure 3. Washing remaining and drying it

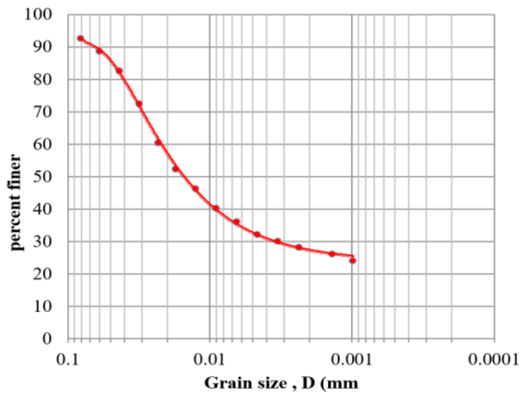

Figure 4. Grain size distribution by modifying the method

2.1.2 Cement

Sulfate-resistant cement (SEM 42.5 N–SR 3.5) made in Al-Samawa/Iraq was used in this study, The amount of cement used was between 1 to 11% by dry weight of soil with an increment of 2%. Table 3 shows its chemical composition.

Table 3. Chemical composition of cement

Composition	Percent
Cao	56.4
Sio_2	21.5
Al_2O_3	5.0
Fe_2O_3	6.0
lime saturation factor	0.7831
Mgo	3.0
So_3	2.15
Burning loss	3.0
Insoluble substances	1.22
C_3A	3.1

2.1.3 Lime

Hydrated lime (calcium hydroxide) in this study, used Iranian-made it was available in the market; It is a white powder whose chemical composition is shown in Table 4.

Table 4. Chemical composition of lime

Composition	Percent
$CaCo_3$	89.4
$MgCo_3$	1.12
Cao	44.3
Mgo	1.37
Sio_2	11.88
Al_2o_3	4.1
Fe_2o_3	3.2
L.O.I	35.5

2.1.4 Ferric chloride

Commercial grade is a clear dark brown liquid with a concentration of 43±2% and made in India by (SUKHA CHEMICAL INDUSTRIES MANUFACTURER). The amount of ferric chloride used in this study was between 0 to 2.5% by dry weight of soil with an increment of 0.5%. The properties of ferric chloride obtained from the importing company in Baghdad, are presented in (Table 5).

Table 5. Chemical composition of ferric chloride

Test	Specification	Result
Appearance	Clear Dark Brown	Complies
Assay (as $FeCl_3$)	Liquid	42.28%
Specific Gravity	43+2%	1.435
Insoluble Matter	1.42-1.46 min	0.025%
Free Acid (as HCL)	0.05% max	0.0177%
Free Chlorine (as CL)	0.02% max	0.0051%
Ferrous Salts (as $Fecl_3$)	0.01% max	Within
Sulphates (as So_4)	0.10% max	Limits
Nitrates (as No_3)	0.30% max	0.223%
Copper (as Cu)	0.05% max	0.0083%
Zinc (as Zn)	0.015% max	0.0020%
Arsenic (as As_2O_3)	0.01% max	0.0062%
Alkalies & Alkaline	0.0002% max	0.00013%
earths	0.20% max	0.142%

2.2 Methodology for determining optimum percentage

There are several recommendations and parameters suggested to determine the optimum percentage of chemical improvement and will be taken into account and laboratory verification of UCS values and PH test.

2.2.1 Cement

Depending on the Soil Cement Laboratory Handbook [11] obtaining the Group Index, the average percentage of cement in the soil was obtained from the table average cement requirement, and the value was 9% weight percentage of dry soil. Also from the other table was Cement Requirements of AASHTO Soil Groups also was 9% weight percentage of dry soil, while UCS at 7 days generally between 300psi (2068.4 kpa) and 800psi (5515.8 kpa).

Soil Stabilization with Portland Cement [12], this book reported the range for UCS at 7 days was from200psi (1378.9 kpa) to 400psi (2757.9 kpa).

Soil Stabilization for Pavement [13] referred to the minimum UCS for cement stabilized soils as 250psi (1723.68 kpa).

Also, An Introduction to Soil Stabilization with Portland Cement [14] recommended the Cement requirement for various soils, and the value for this soil was 9% of the dry weight.

2.2.2 Lime

The PH measurement method (Eades and Grim in 1963 method) [15] was used to determine the optimum percentage of Lime, many researchers [15-18] referred to using this method by mixing lime and soil with distilled water and placing in a temperature bath to obtain a constant temperature of (25°C). The optimum ratio at which a mixture obtains PH is 12.4 or more at a temperature (25°C±2).

According to UCS determined by Standard specification for road works at 7 days is not less than 1.0 N/mm² (1000 kpa), This value will be checked in order to conform to this specification [19].

2.2.3 $Fecl_3$

Many researcher works have been done to improve soils by Ferric chloride [7, 9, 20-24]. During their review, it was found that the UCS test is appropriate to determine the optimum percentage, and after that percentage, the UCS value will decrease.

3. LABORATORY TESTS

The soil sample was passed through Sieve No. 4 after it was crushed with a hand hammer. All series of tests conducted on the collected samples (treated and untreated) were carried out based on the American Standards for Materials and Testing (ASTM) specifications as follows:

3.1 The hydrometer test

One of the most important engineering properties to classify the clay soil, its importance comes in knowing the type of soil you are working with, and the test was conducted in compliance with ASTM D 422-63 [25].

3.2 Initial water content

This test was carried out by ASTM D 4643-00 [26] for the natural soil.

3.3 Specific gravity of soil

The Specific Gravity test was carried out as per ASTM D 854-14 specification [27].

3.4 Atterberg limits

Atterberg limits are describing the state of the soil based on the amount of water in it. The samples passing through Sieve No. 4 were collected and the tests (liquid limit and plastic limit) were conducted on the natural soil by ASTM D 4318-00 [28].

3.5 Modify proctor test

Following ASTM D 1557-12 [29], the modify proctor was used to measuring the dry density of each sample and to obtain the moisture content as well.

This test is conducted for both the natural as well as the treated soil samples with optimum percentage for Cement, Lime, and Ferric chloride.

3.6 Unconfined compression strength of soil (UCS)

Depending on ASTM D2166-00 [30], the test was carried out on natural soil by molded with a diameter of 30.5 mm and a height of 71 mm to the maximum dry density and moisture content of the natural soil, and then it was extruded from the mold and placed in the unconfined compressive testing device, for curing purposes, the Cement, Lime, and Ferric chloride treated soil, samples were prepared as previously mentioned and wrapped in plastic bags and kept to be tested after1, 7, and 14 days.

3.7 California bearing ratio test (CBR)

Using a standard CBR mold with a diameter of 6 inches

(152.4 mm) and a height of 7 inches 177.8 mm (177.8 mm) and compacted to MDD at OMC determined from the modify proctor of the natural soil for testing according to ASTM D 1883-07 [31] for untreated soil and treated with the optimum percentages of Cement, Lime, and Ferric chloride.

With treatment for 7 days in a plastic bag, and then soaking it with water for 4 days and conducting the test in a CBR device.

3.8 PH test method

According to the ASTM D 6276 method (2006) [32], determining the optimum lime requirements of soil are determined at a pH value of 12.4 at a temperature of 25℃.

4. RESULTS AND DISCUSSION

4.1 UCS and PH tests

UCS tests were conducted by adding percentages of improvers to determine the optimum percentage that is suitable in the city of Al-Nasiriya.

Where an increase in UCS was observed with an increase in the percentage of improvement for Cement and Lime, while it was the opposite for $Fecl_3$ where after the optimum value the UCS decreases.

The curing periods give an increase in the value of UCS at 1, 7, 14 days for all material additives, all these results are shown in Table 6, and also for Figures 5 to 8, Figures 9 to 12, and Figures 13 to 16 shows the effect on UCS with adding Cement, Lime, and $Fecl_3$ respectively.

After obtaining the values of UCS, the percentage of Cement was determined 9% as the optimum percentage that is suitable for the soil of the city of Al-Nasiriya.

For Lime, a PH test was conducted and a value of 10% was obtained as an optimum percentage after getting the PH=12.4 at 25℃ was obtained as shown in Figure 17 and results in Table 7, While the UCS value was checked.

Also according to $Fecl_3$ the highest value of UCS was reached at 2% of the $Fecl_3$ adding, and then this value decreased. Accordingly, 2% of the dry soil weight was named as the optimum percentage.

Figure 18 shows a comparison in the value of UCS at the optimum percentages of Cement, Lime, and $Fecl_3$ as well as knowing the curing influence on the UCS for those values. And found that the curing period had the greatest effect on cement, which gave a high increase between 1 to 14 days.

The effects in Lime and Ferric chloride were less than in Cement and almost similar.

Table 6. Effect of cement, lime, and $fecl_3$ with curing periods

Improver materials	Percentage%	Curing 1 day	UCS (KN/m^2) Curing 7 day	Curing 14 day
Cement	0	344	344	344
	1	667	802	912
	3	855	1069	1756
	5	931	1218	1958
	7	1030	1578	2373
	9	1171	2194	2514
	11	1715	2443	3604
lime	0	344	344	344
	4	482	572	805
	7	653	709	1015
	10	701	1013	1203
	12	741	1147	1335
	0	344	344	344
$Fecl_3$	0.5	385	478	548
	1	495	620	737
	1.5	687	923	1116
	2	901	1249	1510
	2.5	612	881	1102

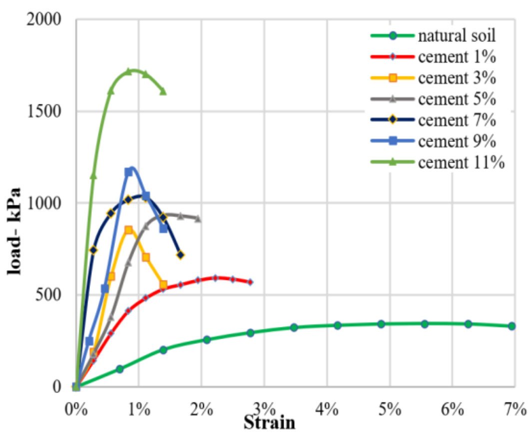

Figure 5. Effect of the cement added on the UCS at 1 day

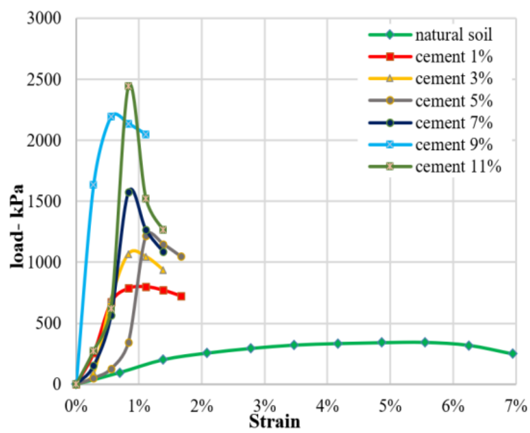

Figure 6. Effect of the cement added on the UCS at 7 day

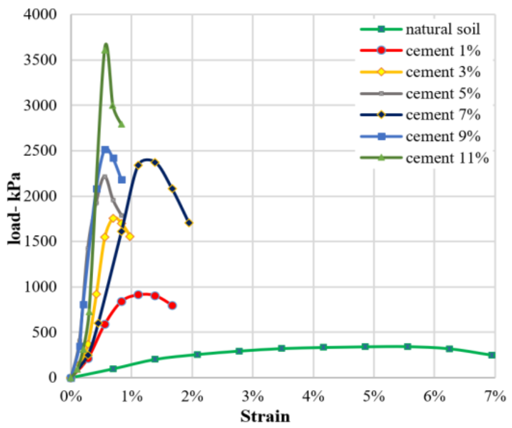

Figure 7. Effect of the cement added on the UCS at 14 day

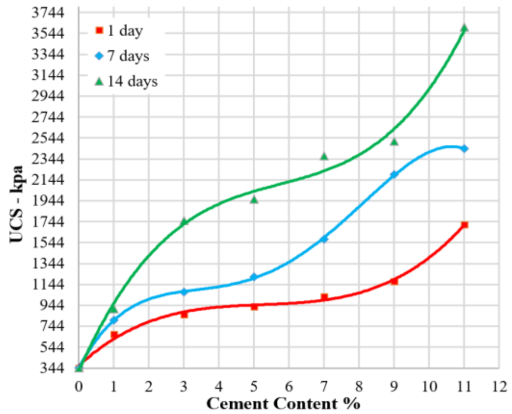

Figure 8. Effect of the cement added with curing periods

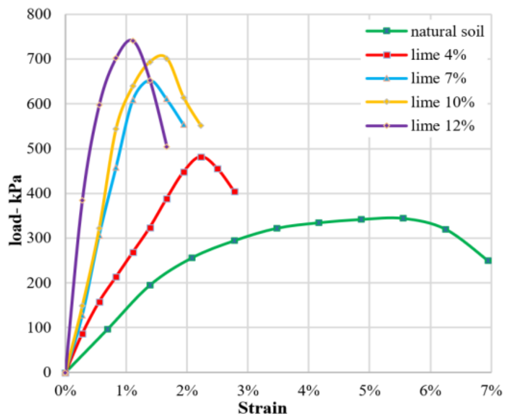

Figure 9. Effect of the lime added on the UCS at 1 day

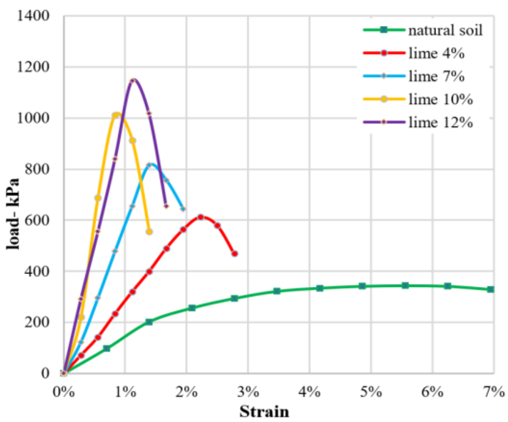

Figure 10. Effect of the lime added on the UCS at 7 day

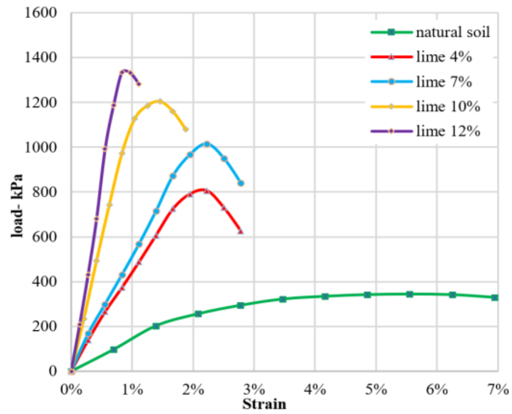

Figure 11. Effect of the lime added on the UCS at 14 day

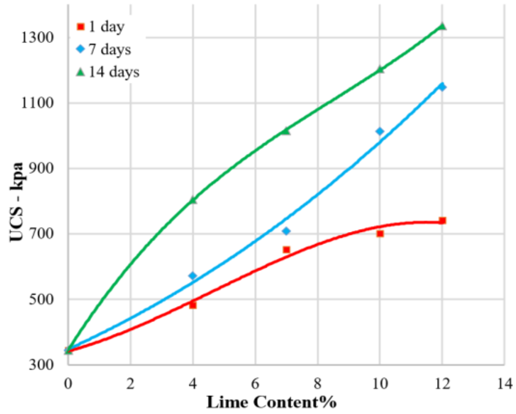

Figure 12. Effect of the lime added with curing periods

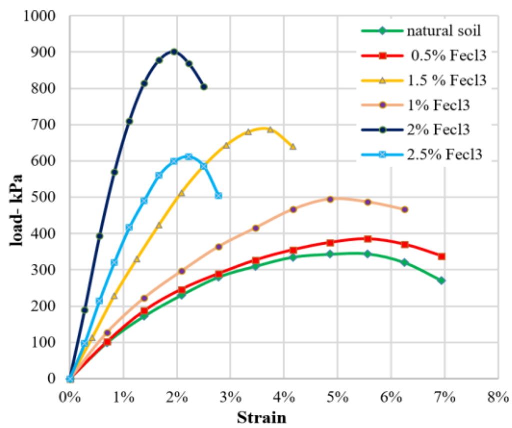

Figure 13. Effect of the $Fecl_3$ added on the UCS at 1 day

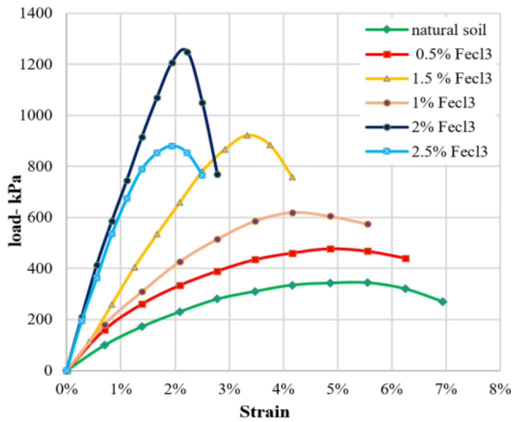

Figure 14. Effect of the $Fecl_3$ added on the UCS at 7 day

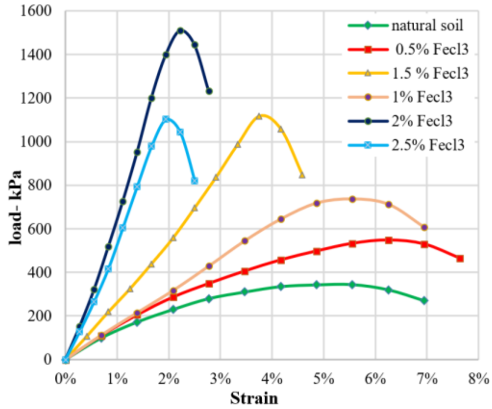

Figure 15. Effect of the $Fecl_3$ added on the UCS at 14 day

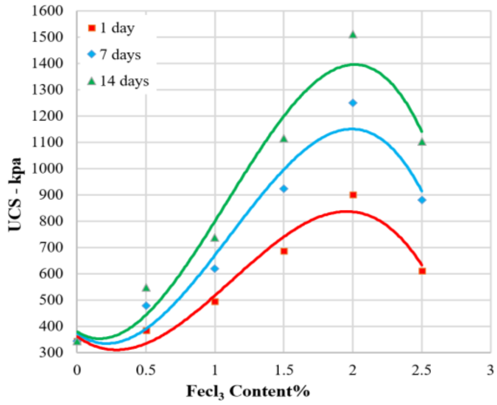

Figure 16. Effect of the $Fecl_3$ added with curing periods

Figure 17. Measure the pH to determine the optimum percentage of Lime

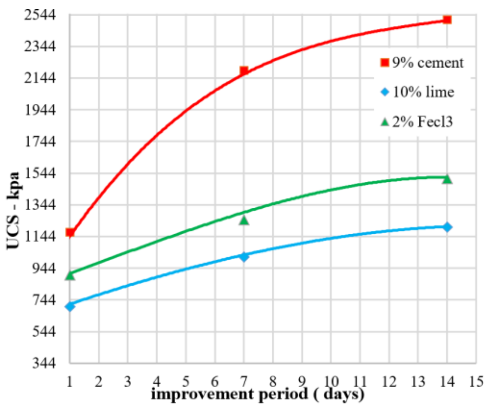

Figure 18. Curing influence on the UCS for optimum additives

Table 7. Measurement of the PH values of the samples

Lime percentage%	PH reading	Temperature ℃
0%, (Natural soil)	8.0	25.1
6%	12.1	23.6
8%	12.3	24.8
10%	12.4	25.1

4.2 California bearing ratio test and swelling

After determining the optimum percentages of the additives used in soil improvement. Where the CBR test was conducted for those ratios of Cement, Lime, and Ferric chloride, as shown in Figures 19 and 20, The results after curing for 7 days and soaking for 4 days showed that Cement gave the highest value among those materials, followed by Ferric chloride and the last was Lime, which gave good results compared to the value of natural soil.

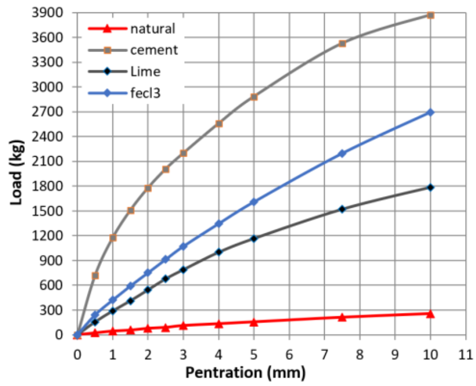

Figure 19. CBR test for optimum chemical additives

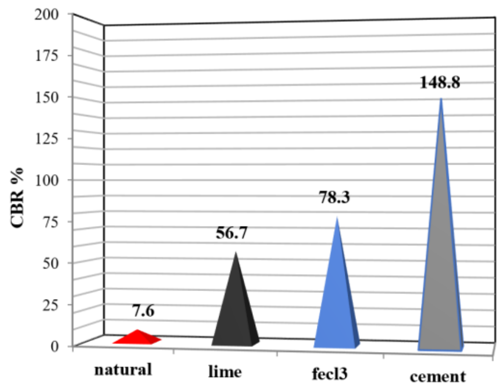

Figure 20. CBR values for optimum chemical additives

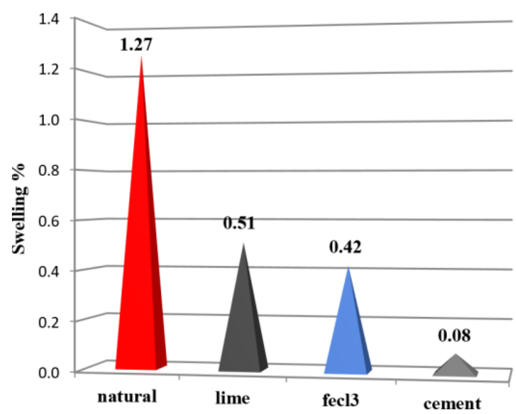

Figure 21. Swelling values for optimum chemical additives

Also, the percentage of swelling was measured during the period of soaking the mold with water. The test was carried out on natural soil (it was 1.27), then the optimum proportions of additives were added, and a reduction in the swelling percentage was observed.

The highest improvement rate was for Cement (it was 0.08%), followed by Ferric chloride (it was 0.42%), then Lime (it was 0.51%). All these results are shown in Figure 21.

4.3 Modify proctor test

The compaction tests of the samples were conducted after adding the improver materials and the results shown in Table 8 and Figure 22 were obtained.

The results of Cement and Ferric Chloride were similar (with different values) where it was observed increase in (MDD and a decrease in OMC).

Which increased MDD from 1.804 to 1.92 and 1.85 and decreased OMC% from 16.3 to 13.9 and 128 respectively), in contrast to the behavior of the material Lime where the MDD decreased and the OMC% increased) which decreased MDD from 1.804 to 1.72 and the OMC% increased from 16.3 to 19.1).

Table 8. The MDD and OMC of natural soil and with optimum chemical additives

Additives	OMC%	MDD (g/cm^3)
Natural soil	16.3	1.80
Cement	13.9	1.92
Lime	19.1	1.72
Fecl$_3$	12.8	1.85

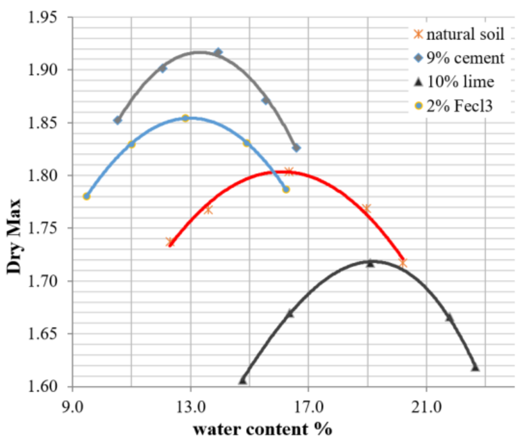

Figure 22. Compaction for optimum chemical additives

5. CONCLUSIONS

Depending on the test results obtained from the addition of cement, lime, and Fecl$_3$, the following was concluded.

(1) According to the UCS test and after obtaining the optimum and economical percentages of Cement, Lime, and Fecl$_3$ and which are suitable for the soil of Al-Nasiriya soil. An increase in UCS values was observed by about (340%, 638% and 731%), (204%, 294% and 350%) and (262%, 363 and 439%) at curing periods (1, 7, and 14), respectively. These results are consistent with the findings of the researchers Etim et al. [6] and Koteswara Rao et al. [7].

(2) CBR tests increased by about) 1968%, 750%, and 1036% (with the addition of optimum percentages of (Cement, Lime, and Fecl$_3$), respectively, these results are consistent with the findings of the researchers Sarsam et al. [5], Bharambe and Patil [9].

(3) The percentages of swelling that occurred in the natural soil decreased by about (1588%, 249%, and 302%) When adding the optimum percentages of (Cement, Lime, and Fecl$_3$), respectively, the results of this research paper are consistent with previous findings by Koteswara Rao et al. [7], and Etim et al. [6].

(4) The compaction tests give an impression of the behavior of materials by changing MMD and OMC as observed when adding Cement and Ferric chloride in optimum percentages leads to an increase in the MDD with a decrease in OMC, while the opposite happens when you add Lime to the soil.

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