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Chemical Stabilization of Gypseous Subgrade Soils for Road Construction in Iraq

Assist. Lec Aamir Mahsen Mahawish
Highway and Transportation Department
College ofEngineerin
Al-Mustansiriya University

ABSTRACT :

This paper describes the soil stabilization process, the process involves stabilize gypseous soil with various percentage of lime and cement, separately, furthermore 1%Phosphorus pentoxide was added with the same percentage of lime and cement to determine the effect of Phosphorus pentoxide when it was mixed with other additive; the soil was brought from Abu Ghraib city. The gypsum content of the soil is found to be 35%. To improve this soil, many soil specimens were prepared by adding different percentage of lime or portland cement. The effects of the additives were studied. Furthermore, Phosphorus pentoxide was added to study its effect when lime or cement is added. It is found that adding 6% of cement and 1% of Phosphorus pentoxide will improve CBR and Absorption characteristics of the gypseous soil while 6% lime with 1% P_2O_5 reduces the swelling of the gypseous soil after soaking in water for four days.

Keywords: *Gypseous soil; Chemical stabilization; Lime; Cement; Phosphorus pentoxide; Swelling; CBR; Absorption test.*

التثبيت الكيميائي للترب الجبسية تحت الطرق في العراق

عامر محسن مهاوش السعيدي

الخلاصة :

هذا البحث يصف عملية تثبيت التربة، العملية تتضمن تثبيت التربة الجبسية بنسب مختلفة من النورة والاسمنت، منفصلا، علاوة على ذلك 1 % خامس اوسيد الفسفور أضيف إلى نفس النسب المئوية من النورة والاسمنت لمعرفة تأثير خامس اوكسيد الفسفور عندما يمزج مع المضافات الأخرى. في هذه الدراسة، التربة جلبت من مدينة أبو غريب. محتوى الجبس في التربة كان 35 %. لتحسين هذه التربة، العديد من النماذج من التربة الجبسية حضرت بإضافة النورة أو الاسمنت البورتلاندي. تم دراسة تأثير المضافات. علاوة على ذلك، خامس اوكسيد الفسفور أضيف لدراسة تأثيره عندما يضاف الى النورة او الاسمنت. وجد بان إضافة 6 % من الاسمنت و 1 % خامس اوكسيد الفسفور سيحسن مقدار التحمل الكليفورني وخصائص الامتصاص للتربة الجبسية بينما 6 % من النورة و1 % خامس اوكسيد الفسفور يقلل الترب الجبسية بعد غمرها لمدة 4 أيام في الماء

1. Introduction :

The developing economics of many countries in the world have resulted in an increase in demand for the transportation of passengers and goods, the highway network plays an important role in the development and economics of the countries, when a site selected for constructing a new pavement or rehabilitating an old pavement, the use of locally available materials will always be a necessary task of highway engineers to minimize the construction cost for road projects. Gypseous soils are mostly found in arid and semi-arid regions, they are considered collapsible soils, therefore, they are usually considered to be problematic and they exhibit unpredictable behavior which could cause significant trouble concerning civil works (**Petrukhin & Boldyrev, 1978**). **Barazanji, (1984**), found that gypseous soil covers approximately (20%) of Iraq area, the amount of gypsum in the Iraqi gypseous soil differs from one area to another. The amount of gypsum is up to (80%) in the upper north and in the middle parts of the Euphrates and Tigris beds, while the gypsum content of Al-Jazirah area ranges from (3-10)% in the upper parts and may exceed (50)% in the lower parts. Chemical soil stabilization has been widely practiced in many countries, Chemical stabilization of a soil eliminates the need to remove an inherently weak soil subgrade and replace it with a quarried, processed granular material. This process is not only cost effective, but it also lessens the demand on non-renewable resources and reduces the environmental footprint of a road construction project (**Christopher, 2010**). Lime stabilization of highway subgrades can provide significantly improved engineering properties, in the high pH environment (**Little, D. N., (1999**).The effect of cement on the properties of soil with increasing cement content strength and bearing capacity increases, durability to wet/dry cycle increases (Akroyd, T. N. E., 1970). Generally, it is preferable to use one additive like lime, cement, or waste lime. However, the using combined additives in some cases may give better results (**Al-Obaydi et.al, 2010)**. Phosphorus pentoxide, another chemical evaluated by Oldham et **al., (1977**) was found to work extremely quickly, too quickly to allow for adequate mixing and compaction according to the authors. Another problem associated with phosphorus pentoxide was the neutralizing effect of trace amounts of calcium carbonate. Phosphorus pentoxide is also extremely toxic.

2. Problem Statement :

The materials required for the construction of the highway pavement usually are not economically available at or near the construction site. At these cases, the regionally available soil may be stabilized by the addition of suitable materials such as cement, lime and P_2O_5, in order to meet the requirements of the engineering specifications and reduce the construction cost.

3. Objectives :

The main objectives of the present study can be summarized as follows:

1. Study the effect of lime and P_2O_5 as stabilizing agents on California Bearing Ratio test, swelling test and absorption test.
2. Study the effect of cement and P_2O_5 as stabilizing agents on California Bearing Ratio test, swelling test and absorption test.

4. Materials and Experimental Tests:

The materials used in this study selected from the local materials used in roads construction in Iraq.

4.1 Materials : The materials used in this study describe as shown below:

4.1.1 Soil : The soil sample used is obtained from Abu Ghraib city (30 km from Baghdad center) with gypsum content (35%). A summary of the classification tests of the soil used is shown in **Table (1).** The soil used can be classified as (SP-SM) according to (USCS). The gypsum content of soil defines the soil as highly gypseous soil according to (Barazanji, 1973). The chemical composition test and the mineralogical composition of the soil are presented in **Table (2).**

Table (1): The classification tests of the gypseous soil

Index Property	Index Value	Standards
Gypsum content (%)	35	Nashat and Al-Mufty, (000)
Specific gravity (Gs)	2.39	BS 1377: 1975, test No.6B
Max. dry density (KN/m^3)	1.86	ASTM D698-07
Optimum moisture content (%)	10	
Liquid limit (L.L)%	31	BS 1377: 1975, test No.2, ASTM D2216-98
Plastic limit (P.L)%	N.P	BS 1377: 1975, test No.3, ASTM D2216-80
Plasticity index (P.I)%	N.P	
Sand %	90.5	ASTM D422-63
Fines %	9.5	ASTM D422-63
Soil classification(USCS)	SP-SM	ASTM D422-63

Table (2): Chemical tests of the gypseous soil

Index Property	Index Value
Gypsum content (%)	35
Sulphate content ($S0_3$) (%)	22.21
Total soluble salt (T.S.S) (%)	63.7
Chloride content (CL) (%)	0.09
Organic matters (%)	0.2
PH	8.1

(*) Test was conducted by NCCLS, Baghdad

4.1.2 Additives: The additives used in this study include:

4.1.2.1 Phosphorus pentoxide **:** It is one of the chemical additives proposed to be used to improve the properties of the Soil stabilized with lime or cement. This material is obtained from local market.

4.1.2.2 Lime**:** For stabilization purpose, lime is usually employed hydrated, in form of calcium hydroxides. Hydrated lime (Ca $(OH)_2$) from local market (Karbala) is used for the soil stabilization. The chemical analysis of the lime used is given in **Table (3).**

4.1.2.3 Cement **:** Ordinary Portland Cement (OPC) produced by Turaba sibline S.A.L Lebanon cement. **Table (4)** shows the chemical composition of the cement used.

4.1.2.4 Water**:** Ordinary tap water is used throughout this study to prepare the specimens.

Table (3): Chemical Composition of the lime

The composition	Percent by weight
SiO_2	10.25
AL_2O_3	1.68
CaO	72.33
Fe_2O_3	8.13
MgO	6.83

(*) Test was conducted by NCCLS, Baghdad

Table (4): Chemical Composition of cement

The Composition	Percent by Weight
Calcium oxide CaO	62.33
Silicon dioxide Sio_2	22.01
Aluminum oxide Al_2O_3	5.49
Ferric oxide Fe_2O_3	3.93
Magnesium oxide MgO	2.54
Sulphur trioxide So_3	2.38
Loss on Ignition (L.O.I)	0.83
Lime Saturation Factor (L.S.F)	0.86
Insoluble Residue (I.R)	0.34

(*) Test was conducted by NCCLS, Baghdad

4.2 Experimental Work

The California Bearing Ratio test, swelling test and absorption test are carried out to the samples prepared with different percentage of lime or cement then with added 1%Phosphorus pentoxide with the same percentage used previously as shown in **Figure (1)** and the experimental work describe in the following articles.

Fig. (1) Experimental Work

4.2.1 California Bearing Ratio (Strength Test) and Swelling test

In order to investigate the bearing characteristics of the stabilized soil with lime or cement and P205 the California Bearing Ratio is determined. The tests are performed on samples prepared and compacted to various percentages of lime or cement (0%, 2%, 4%, 6%) with the optimum water content from compaction test (ASTM D698-78), the preparation of specimens and testing procedure for CBR tests are generally done in accordance with (ASTM Dl883-99). Three specimens are prepared for each CBR test of the modified compaction test. Compaction in five layers using 4.54 kg hammer dropped from a height of 45.72 cm fifty six blows per layer is used for the compaction of three specimens in order to give equivalent compaction energy to the modified proctor compaction test. Second series of tests is performed on specimens soaked in water for 4 days to give an indication of strength loss due to saturation and to give information expected about soil expansion when the stabilized soil becomes saturated. Then after added 1%P205 with the (2%, 4%, 6%) percentages of lime and cement, another samples were tested for the soil to know the effect of Phosphorus pentoxide with the other additives, it can be observed that the (CBR) values at (0.2) in. (5mm) penetration are greater than those at (0.1) in. (2.5mm) penetration. The swell characteristics of the stabilized soil after soaking for 4 days in water are determined.

4.2.2 Absorption Test

The absorption test is carried out according to the method described by Akroyd, (1970) the preparation of specimens for such test is similar to that described in the compaction test, but the dimensions of the test are 4in. (101.6mm) in diameter and 4.584in. (116.43mm). The compaction in this test is carried out in five layers with 26 blows/layer using a hammer of 101b (4.536Kg)weight, with drop of 18in. (457.2mm) in order to give an equivalent compaction effort to modified proctor compaction test.

After preparation and compaction, the specimens are weighed to check the wet density, and then completely coated with a layer of paraffin wax to maintain the water content at a constant value. The specimens are then a stored for (3) day at room temperature before the paraffin wax is removed from the top and the bottom of each specimen to allow water to be absorbed freely. The specimens are subjected to (7) days air curing, then weighed again and placed in a metal tank that contains sand layer in order to permit the water at level of (6mm) above the bottom of the specimens. The weight of absorbed water is then determined at the intervals of (1, 3, 7 and 14) days by successive weightings at these ages. Various percentage of lime or cement ((0%, 2%, 4%, 6%) added to prepared specimens and tested then another specimens prepared with mix 1%P205 with each of percentage lime and cement (2%, 4%, 6%) for the soil to know the effect of Phosphorus pentoxide with the other additives.

5. Data Analysis and Testing Results

Effect of mix P205 on soil stabilized with lime on CBR value is shown in **figures (2 & 3)** for soaking and unsoaking specimens, it can be seen that the CBR values increase with the increase in the lime percentage up to a certain point, while the CBR values exhibit a decrease when immersed in water for 4 days. Effect of mix P205 on soil stabilized with cement on CBR value is shown in **Figures (4 & 5)** for soaking and unsoaking specimens, it can be seen that the CBR values increase more than the values obtained from soil stabilized using lime with the increase in the cement percentage, while the CBR values exhibit a decrease when immersed in water for 4 days. **Figure (6)** show the swell characteristics of the stabilized soil with lime and cement respectively after soaking for 4 days in water. **Table (5)** shows the results of CBR and Swelling tests.

The effect of mix of P205 on soil stabilized with lime on water absorption percent are shown in **Figures (7 & 8)** it can be seen from these figures that the water absorption percent is decrease with the increase in lime content, and **Figures (9 & 10)** show the effect of P205 on the relationship between water absorption percent and time. In **Figures (11 & 12)** It can be seen that the water absorption percent is decrease more than in case of lime stabilization with the increase in cement content and **Figures (13 & 14**) show the effect of P205 on the relationship between water absorption percent and time. **Table (6)** show results of absorption test.

Table (5): Results of CBR and Swelling tests

Type of additive	Percentage of additive (%)	California Bearing Ratio (%)				Swelling (%)
		Unsoaked		Soaked		
		2.5 mm	5.0 mm	2.5 mm	5.0 mm	
Lime	0	5.90	6.00	3.40	3.91	0.085
	2	20.27	23.53	12.27	14.93	0.0795
	4	28.33	30.00	19.00	20.67	0.0692
	6	33.67	34.44	24.67	26.44	0.0589
Lime and 1%P_2O_5	2	25.67	26.67	14.33	16.44	0.0538
	4	31.00	32.67	22.67	24.44	0.0469
	6	36.67	39.78	26.67	29.33	0.0397
Cement	2	25.53	27.49	17.67	18.71	0.081
	4	33.67	36.00	22.67	24.89	0.0765
	6	41.33	44.44	31.00	32.89	0.0643
Cement and 1%P_2O_5	2	29.67	32.44	19.67	22.44	0.07
	4	37.00	40.67	26.00	29.33	0.063
	6	44.33	47.56	33.33	35.11	0.0521

Table (6): Results of Absorption test

Additive type	lime				lime+ 1%P_2O_5				Cement				Cement +1%P2O5			
Additive percentage	Time (day)															
	1	3	7	14	1	3	7	14	1	3	7	14	1	3	7	14
0%	2.668	2.987	3.442	4.03	2.668	2.987	3.442	4.03	2.668	2.987	3.442	4.03	2.668	2.987	3.442	4.03
2%	1.807	2.031	2.268	2.538	1.7	1.758	1.84	1.929	2.475	2.74	3.145	3.778	1.66	1.871	2.221	2.415
4%	1.569	1.813	2.031	2.288	1.44	1.654	1.74	1.797	2.251	2.542	2.9	3.59	1.261	1.521	1.72	1.831
6%	1.4	1.609	1.84	2.037	1.32	1.554	1.7	1.754	2.03	2.314	2.73	3.42	0.912	1.133	1.414	1.589

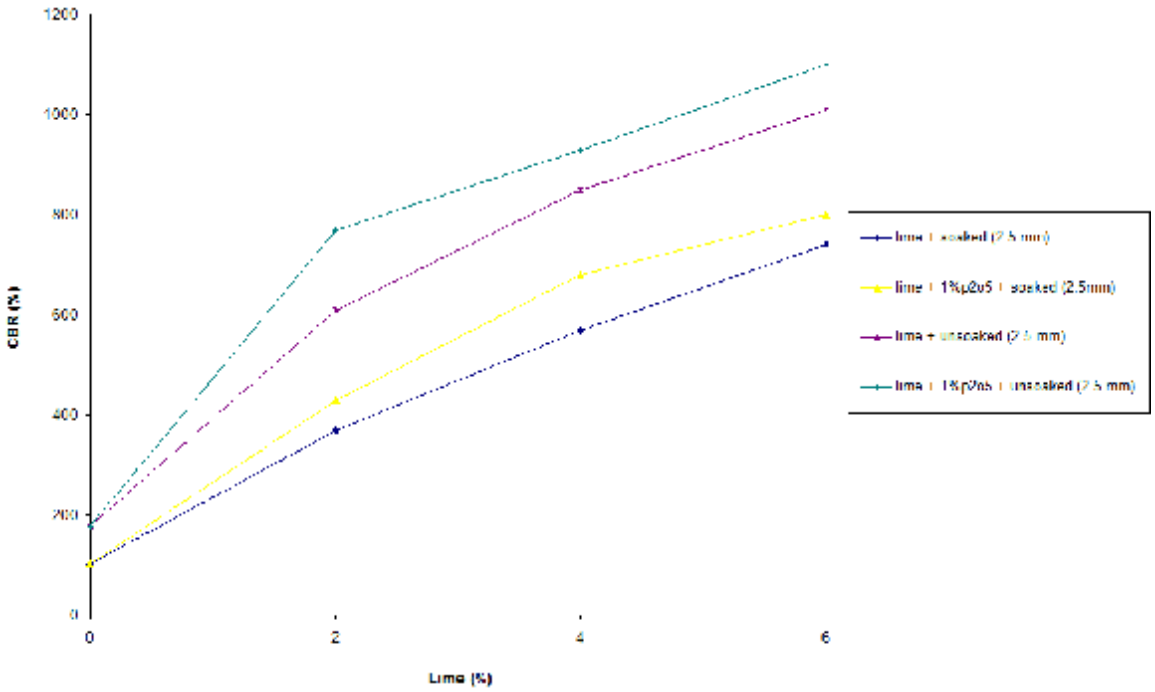

Fig. (2) Effect of Mix 1% P_2O_5 and Lime on the CBR (2.5mm) for Soaking and Unsoaking Specimens

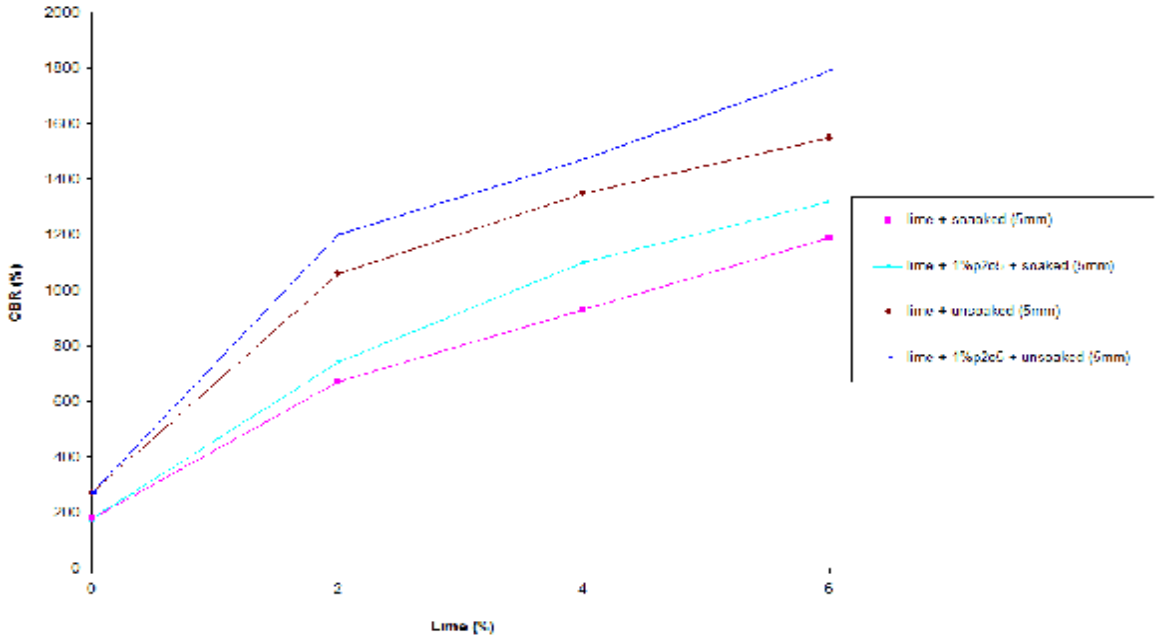

Fig. (3) Effect of Mix 1% P_2O_5 and Lime on the CBR (5mm) for Soaking and Unsoaking Specimens

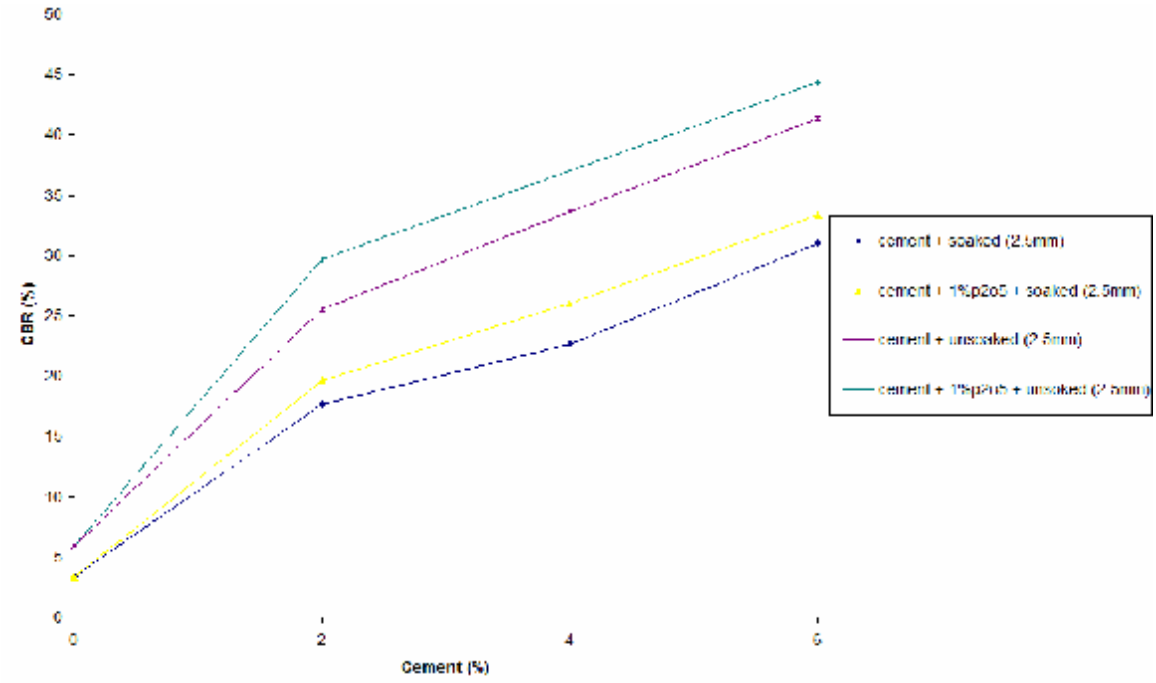

Fig. (4) Effect of Mix 1% P_2O_5 and Cement on the CBR (2.5mm) for Soaking and Unsoaking Specimens

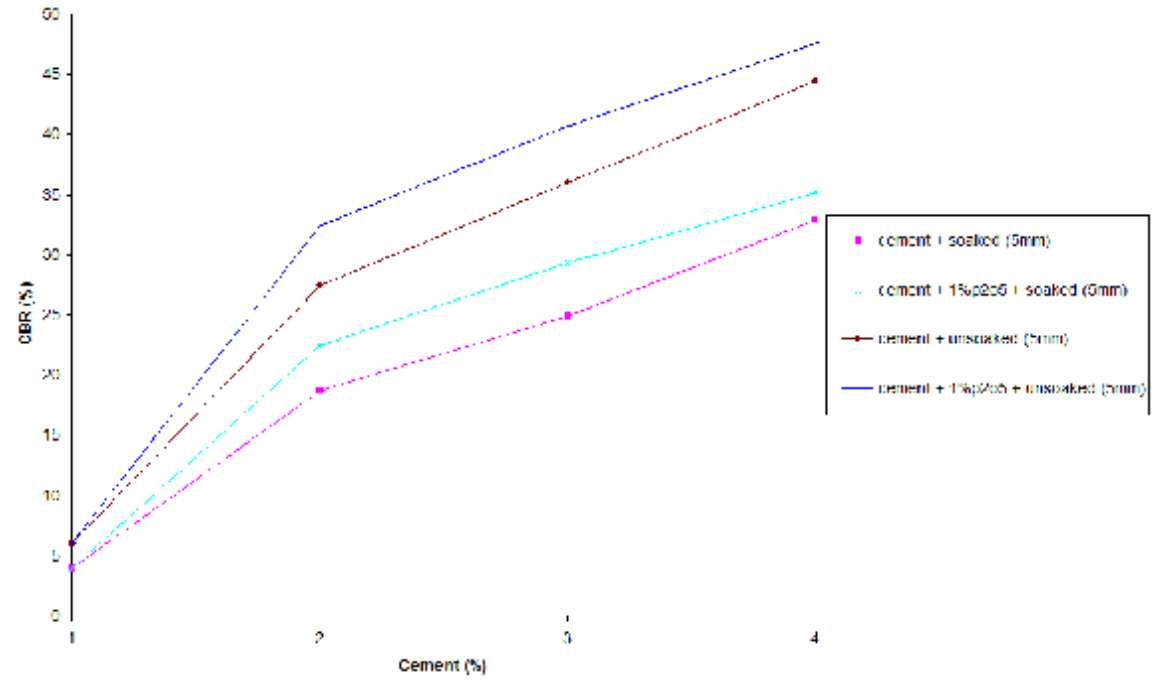

Fig. (5) Effect of Mix 1% P_2O_5 and Cement on the CBR (5mm) for Soaking and Unsoaking Specimens

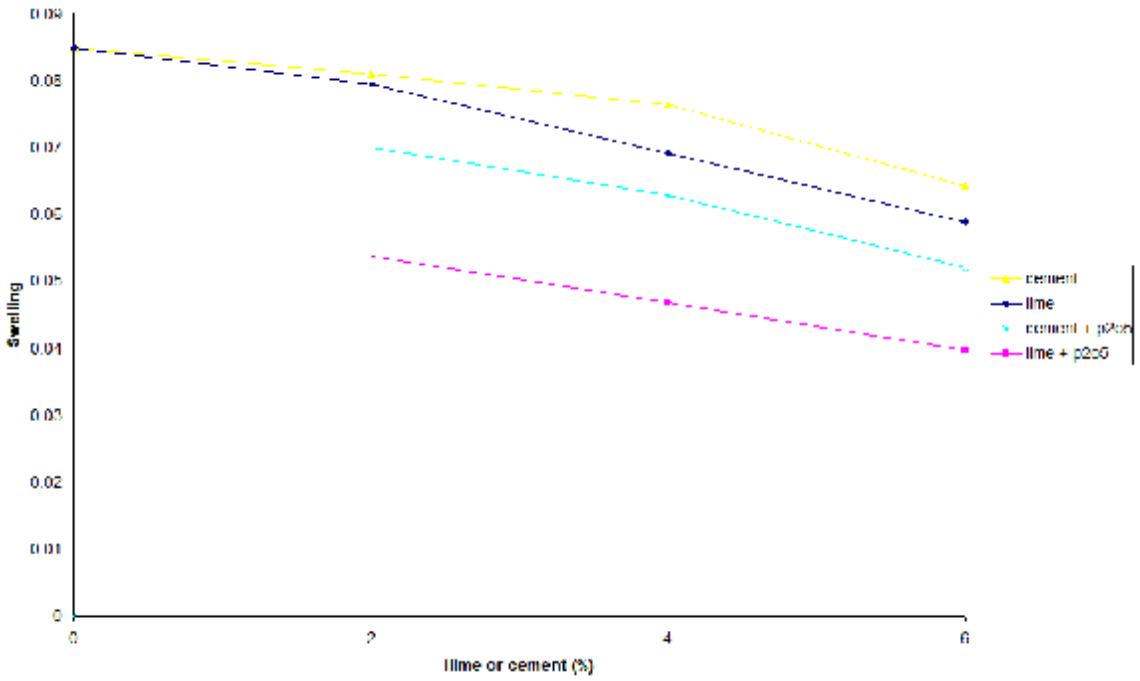

Fig. (6) Effect of Lime & Cement Content on the Swelling of Soil after 4 Days Soaking in Water.

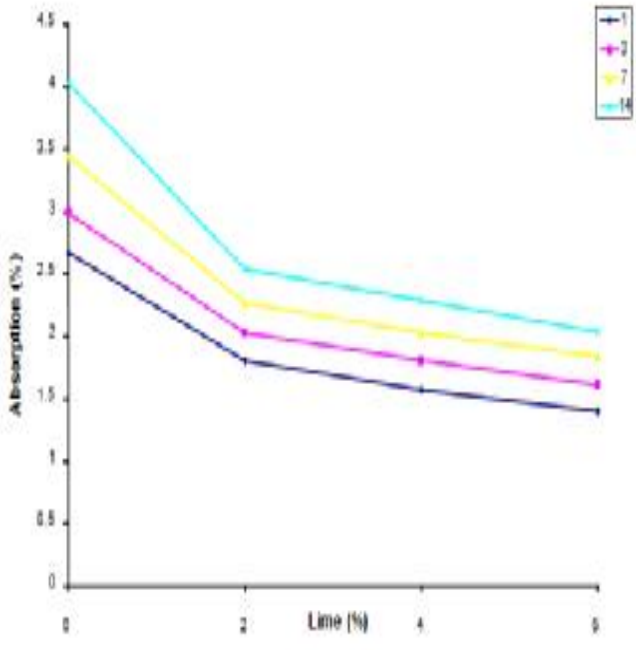

Fig. (7) Relation between the Percentage of the Absorption and the Content of Lime (%)

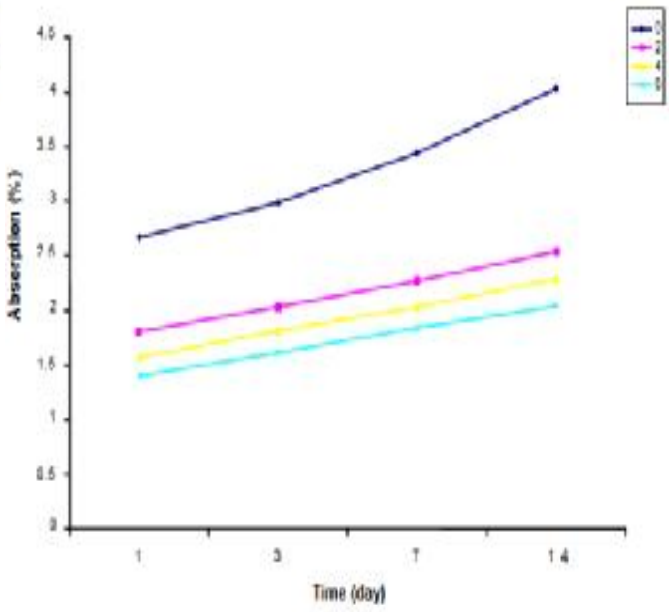

Fig.(8) Relation between the Percentage of the Absorption and Time (day) for Lime

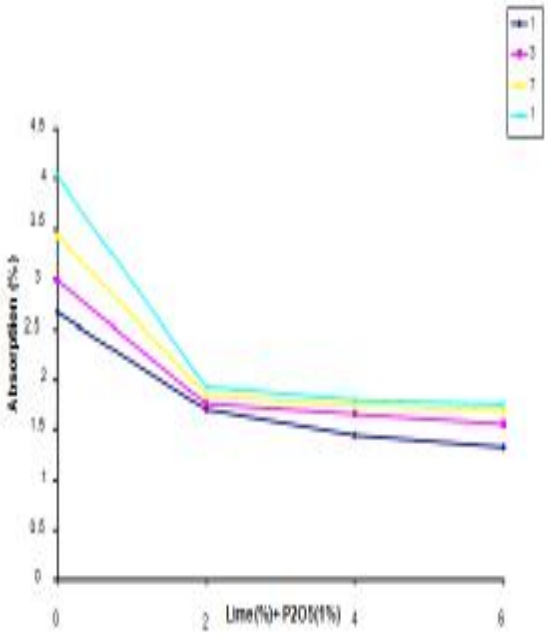

Fig. (9) Relation between the Percentage of the Absorption and the Content of Lime (%) and P_2O_2

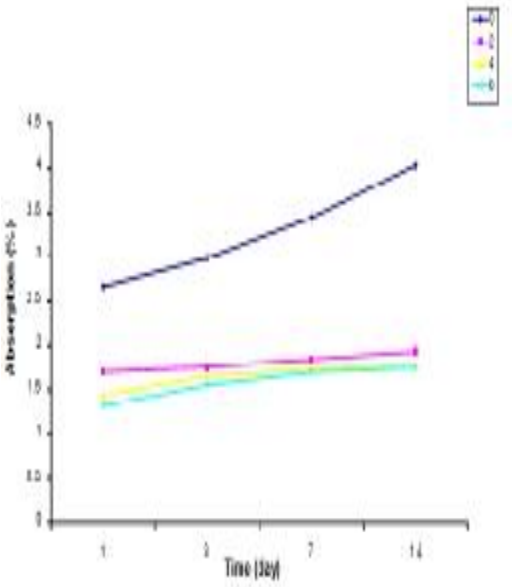

Fig.(10) Relation between the Percentage of the Absorption and the Time (day) for Lime and P_2O_2

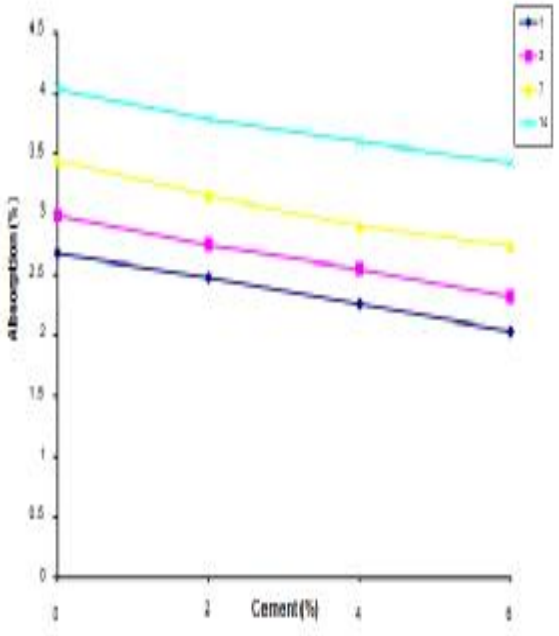

Fig. (11) Relation between the Percentage of the Absorption and the Content of Cement (%)

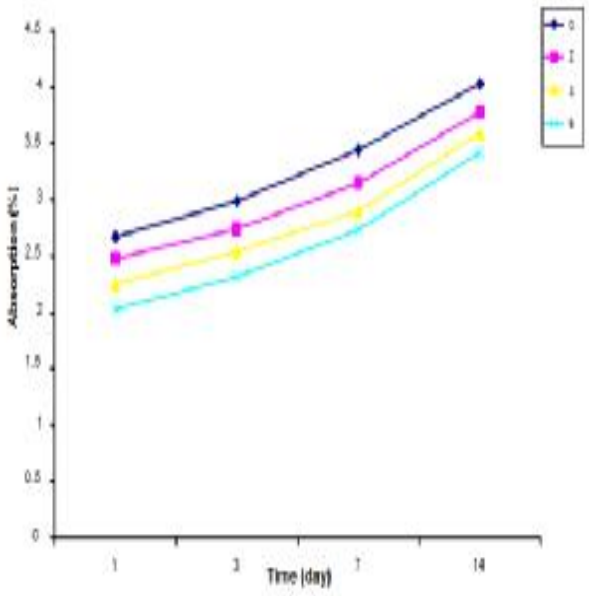

Fig.(12) Relation between the Percentage of the Absorption and Time (day) for Cement

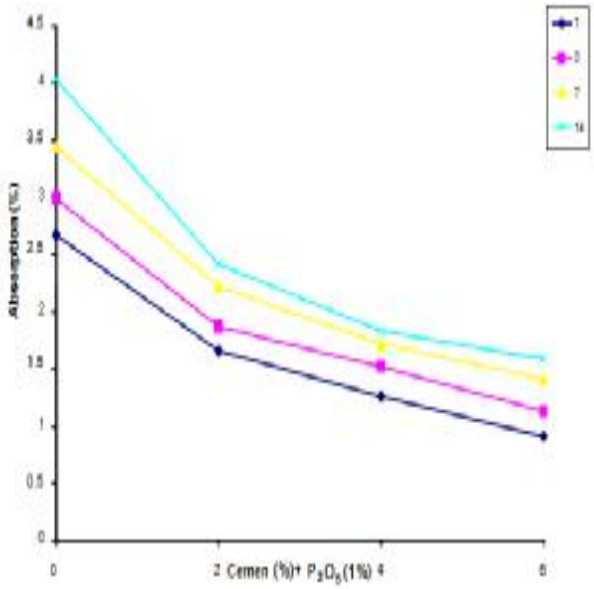

Fig.(13): Relation between the Percentage of the Absorption and the Content of Cement (%) and

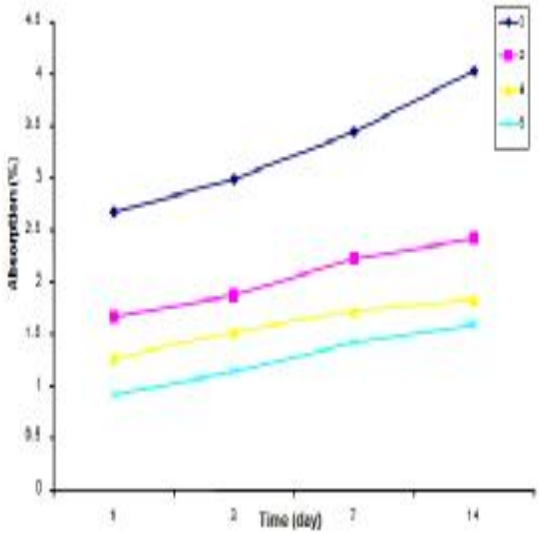

Fig.(14) Relation between the Percentage of the Absorption and the Time (day) for Cement and

6. Conclusions :

According to the results of the tests performed, it can be seen using combined additives give better results than when use one additive in chemical soil stabilization of the gypseous soils. The main conclusions obtained from all tests are:

- It can be seen that 6% cement with 1%P2O5 is the best percentage for improving the bearing characteristics (California Bearing Ratio) of the stabilized soil.
- For Swelling test the best percentage is 6% lime with 1%P2O5 that it reduce swelling of the gypsum soil after soaking in water for four days and
- For Absorption test 6% cement and 1%P2O5 is the best percentage.

7. Recommendations :

The main recommendations that can be drawn from this work are summarized, as follows:

1. It is recommended to study the effect of other percentage of additives such as 8% lime or cement on the California Bearing Ratio test, swelling test and absorption test.
2. It is recommended to carry out unconfined compression test to investigating the influence of these additives on this test.

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