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Effect of Static Soaking Under Different Temperatures on the Lime Stabilized Gypseous Soil

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Abstract

This study concerns with the effect of long-term soaking on the unconfined compressive strength, loss in weight and gypsum dissolution of gypseous soil stabilized with (4%) lime, take into account the following variables: initial water content, water temperature, soaking duration.

The results reveals that, the unconfined compressive strength was dropped, and the reduction in values was different according to the initial water content and water temperature, so that the reduction of the unconfined compressive strength of samples soaked in water at low temperatures (5^0 and 25^0 C) was greater than those soaked in water temperatures at (49^0 and 60^0 C). The results obtained shows that the increase in soaking period decreases the percentage amount of gypsum and loss in weight for all water temperatures and soaking durations.

Key Words: Gypseous soil, Lime stabilization, Strength, Loss in weight.

تأثير الغمر الساكن تحت درجات حرارة مختلفة على التربة الجبسية المثبتة بالنورة

الخلاصة

يهدف البحث إلى دراسة تأثير الغمر الساكن على مقاومة الانضغاط غير المحصور، الفقدان بالوزن والفقدان في المحتوى الجبسي، لتربة جبسية مثبتة بنسبة (4% وزناً) نورة، أخذين بنظر الاعتبار المتغيرات الآتية: المحتوى الرطوبي الابتدائي، درجة حرارة ماء الغمر، فترة الغمر. أشارت النتائج إلى حصول نقصان في مقاومة الانضغاط للنماذج المغمورة بالماء عند درجات الحرارة الواطئة (5^0,25^0) درجة مئوية. في حين ازدادت هذه المقاومة عند درجات حرارة الماء العالية (49^0,60^0) درجة مئوية والى حد معين بعدها قلت المقاومة. صاحب هذه التغيرات نقصان مستمر في كل من وزن التربة والمحتوى الجبسي. اعتمد مقدار النقصان في المقاومة والفقدان بالوزن على قيم المتغيرات المؤثرة (درجة حرارة الماء وفترة الغمر).

الكلمات الدالة: التربة الجبسية، التثبيت بالنورة، المقاومة، الفقدان بالوزن

Introduction

About one - third of the World 's land surface lies within the arid climatic zone. In most regions, natural soil and aggregates contain varying quantities of soluble salts [1,2,3]. Gypsum is one of these salts, which has a detrimental effect on pavement, foundation and earth structures[4]. Gypseous soils occupy about 20% of the total area in Iraq, which is equivalent to about 8.7% of the total area of gypsiferous soils in the world[3]. In dry soil, the gypsum acts as a cementing material. However, the intrusion of water through rain fall, a rise in the ground water table or leakage through canal linings may result in dissolution of gypsum and softening of soils that can lead to serious damages and even collapse of structures founded on such soils[5,6,7], Moreover, gypseous soils are very sensitive to moisture, complete collapse and reduction in the bearing capacity are anticipated when ever they get into contact with water. There are many situations where the ground water table is very high or the subgrade soil is subjected to long-term flood or soaking. In situations where ground water flow is near the ground surface, the dissolution of the total soluble salt in the subgrade can lead to serious volume changes leading to loss of strength[8,9,10,11]. The rate of dissolution of gypsum is very sensitive to many parameters such as temperature, salinity, water volume and velocity of water flow[12,13,14]. James and Kirkpatrik [15] pointed out that the solubility of gypsum in pure water at (10 ^{0}C) is 2.5 kg/m^3. According to James and Lupton [16], the solution rate of gypsum depends on the concentration of salts in solution, flow rate and temperature. This rate increase linearly as the flow velocity increases and as the concentration of sodium chloride increases. To improve the strength of gypseous soils and reduce the problems related to gypsum dissolution, lime treatment has been used [17]. Moreover, lime treatment is one of the most economical techniques to improve the engineering properties of gypseous soils [17].

This research aims at studying the effect of static soaking under different temperatures on the unconfined compressive strength, loss in weight and gypsum dissolution of gypseous soil stabilized with optimum lime percent.

Experimental Program

Materials

Soil

The soil used in this study is a gypseous soil having (20 %) gypsum content, obtained from a region near Al – Hader district about (80 km) south of Mosul city, at (2.0 m) below the ground surface. Table (1) shows some of the index properties and chemical tests of the soil, using the relevant tests according to the ASTM standards.

Lime

The lime used in this study is high – calcium hydrated lime (76 % activity), was obtained from Meshrag Sulphur factory. The chemical analysis of the lime is shown in Table (2).

Water

Tap water was used in the preparation of samples and in testing.

Tests Procedures

Samples Preparation.

An experimental program was performed on gypseous soil samples, which treated by adding varying percentages of lime (2, 4, and 6%) by dry weight of soil. Firstly the soil was oven dried for (2) days at 60 ^{0}C, then mixed with required amount of lime and water, which sprayed and remixed thoroughly. The mixing continued until the final mixture gets uniform moisture distribution. The mixture was then placed in plastic bags and kept in a humidity controlled room for mellowing time of (24) hour for untreated, and (1) hour for treated soil [18]. Thereafter, the mixture was compacted in a specific mold of each types of testing required. A modified compactive effort was considered.

Unconfined Compression Test

Unconfined compression tests were performed on compacted samples treated with (0,2,4, and 6%) lime. All the treated samples were cured for two days at (49 ^{0}C). The samples tested at rate of

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(1.27 mm/min.) following the procedure of ASTM.

Static Soaking Test.

Soaking test is one of the durability tests, which used to examine the ability of stabilized soils to resist the climatic and environmental conditions. The effect of soaking on unconfined compressive strength (q_u), loss in weight and loss in gypsum content in soil samples under different values of molding water content, i.e, OMC and OMC ± 3.0 % (which denoted to dry side (D.S) and wet side (W.S)) has been examined. The static soaking which represents the long – term soaking (immersion in static water) will be done under different water temperature (5^0, 25^0, 49^0 and 60^0 C). In this test, cylindrical samples (50 mm dia. x 100 mm height) were immersed in large glass water container with referee cover for (2, 7, 14, 28, 56 and 90) days. After the end of soaking period, the samples were tested to find unconfined compressive strength. The failed samples were dried for two days, then tested to find the loss in gypsum content. The dropped soil in container bottom at each soaking period was collected, to find the percent of loss in weight. It is necessary to avoid the concentration of gypsum in the soaking water to reach saturation level. If the concentration of gypsum is allowed to approach the saturated level, no further dissolution of gypsum will take place, leading to misleading results. For this reason, the soaking water changed continuously at a certain rate depending on the volume of water in soaking container, soaking period and number of samples.

Results and Discussion

Compaction Characteristics.

Figure (1) presents the results of the compaction test on the untreated and treated gypseous soil with different percentage of lime (0,2,4 and 6 %). The maximum dry unit weight ($\gamma_{d\ max}$) decrease with the addition of lime, and the optimum moisture content (OMC) increases. The reduction results (i.e maximum dry unit weigth) due to the immediate reactions between lime and clay particles, which represented by flocculation and agglomeration. The increase of (OMC) with increasing lime percent may be due to more fine material added and the affinity of the lime to water to complete the hydration. This behavior have been reported by (Al – Obydi)[17].

Unconfined Compressive Strength

The unconfined compressive strength (q_u) results are presented in Fig. (2) for natural (untreated) and lime treated soil. This figure indicates that the maximum value of (q_u) for natural soil was (1054 kN/m^2), and this value occurred at a moisture content lower than the optimum one (i.e dry side). It is observed that the addition of lime has increased the strength of lime stabilized gypseous samples, which may be due to increase in availability of lime for pozzolanic reaction. The maximum (q_u) values were (2808, 3573 and 2921 kN/m^2) for (2, 4 and 6 % lime) respectively with an improvement ratio being (2.66,3.38 and 2.77) times that of the untreated samples. The water content (w/c) for lime stabilized samples, corresponding to the max. value of (q_u) was on wet side. Through the previous Figure, we indicate vividly that lime has succeeded to increase the unconfined compressive strength (q_u). Similar behavior have been reported by (Al – Obydi)[17] .

Effect of Soaking in Static Water

The soaking in static water aims to study the unconfined compressive strength (q_u), loss in gypsum content and loss in weight of lime stabilized gypseous soil under the following

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variables: water temperature (5^0, 25^0, 49^0 and 60^0 C), soaking duration (2, 7, 14, 28, 56 and 90 days) and initial moisture content (OMC (14 %) and OMC ± 3.0 %). During performing the experiments related to this test, we discovered that, the effect of soaking in static water on the: **(A)** unconfined compressive strength and **(B)** loss in gypsum content of soil was much higher than the loss in weight as shown in Table (3).

(A) Unconfined Compressive Strength.

Figures (3 and 4) and Table (4) show the effect of water temperature and soaking duration on the (q_u). A decrease is observed in the (q_u) for samples soaked in water of low temperature (5^0 and 25^0 C), further decrease in strength with increasing soaking duration. The (q_u) decreased when samples soaked for (90) days in water with temperature of (5^0 C) by almost (80, 77 and 71 %) of samples compacted at initial modeling water content represented by (D.S, OMC and W.S) respectively. The water with temperature of (25^0 C) caused decreasing ratios of (46, 52 and 63 %) relative to the unsoaked samples for the same condition above. This behavior may be due to uncompleted pozzolanic reaction which lead to uncompleted crystallization of the gel that formed from the reactions between lime and clay particles, or dissolution of gypsum which occurred by replacement process of water. The higher water temperature (49^0 and 60^0 C) showed increasing in the (q_u), where (q_u) increased from (3573, 2800 and 2000 kN/m^2) to (4620, 3850 and 2750 kN/m^2) for 49^0 C water temperature at 28 days soaking for the initial moisture content (D.S, OMC and W.S) respectively. These values gave an improvement ratios (1.3, 1.38 and 1.38) times of unsoaked samples.

The (q_u) of soaked samples increased to (5210, 4130 and 3000 kN/m^2) for the same condition above but for water temperature equal to (60^0 C), and the improvement ratios were (1.46, 1.48 and 1.5) times of unsoaked samples. However, after (90) days soaking in water at (49^0 and 60^0 C), the values of (q_u) were (3887, 3447 and 2489 kN/m^2) and (4896, 3800 and 2666 kN/m^2) respectively. But these values remains higher than that values of unsoaked samples. The reason of the increasing in the strength may be attributed to continuity of pozzolanic reaction with the higher water temperature and available lime which assisted to complete this reaction. On the other hand, the effect of initial modeling water content on the (q_u) have been illustrated in Table (4). It is observed that the samples which compacted at the dry side of the optimum water content (11.0 %) have higher values of (q_u) under all soaking conditions.

(B) Loss in Gypsum Content.

After the unconfined compression test was conducted, each sample was tested for loss in gypsum content. The percent of gypsum in natural soil was decreased when (4%) lime added to soil and curried for (2) days at (49^0 C). This percent decreased from (20 %) for natural soil to (17.5, 17.5 and 18.0 %) for lime stabilized samples compacted in dry side, optimum moisture content and wet side of the modified compaction curve respectively. These reductions may be due to some part of gypsum sharing in pozzolanic reaction. Table (5) shows the variation of gypsum content with soaking duration for different water temperature and initial water content. The dissolved gypsum shows a gradual decrease with the soaking duration up to a certain period (i.e. 28 days), after that shows insignificant changes. The temperature has significant effect on amount of gypsum solubility at the beginning of soaking, which reduces with the time. The loss in gypsum content values for (90) days soaking were (6.61, 8.83, 10.72 and 11.29 %) : (7.0, 9.38, 11.4 and 11.72 %) : (8.0, 10.24, 12.4 and 13.26 %) for (5^0, 25^0, 49^0 and 60^0 C) and initial water content represented (D.S, OMC and W.S) respectively. This behavior may be attributed to that, the high water temperature increases both the reaction between mixture of soil – lime and gypsum, and increases the dissolution of the gypsum. The samples which compacted at W.S have residual gypsum content less than samples prepared at OMC and D.S.

Finally, it is worth mentioning here that, the loss in weight of lime stabilized samples was almost small as given in Table (3). The maximum values of the loss in weight were occurred at long soaking duration, higher water temperature and the water content represented the dry side (D.S). The maximum values of the loss in weight of samples which compacted at D.S, OMC and W.S were (3.1, 3.36, 3.73 and 4.65 %) : (1.43, 1.67, 2.0 and 2.77 %) : (1.21, 1.32, 1.61 and 2.0 %) for (90) days soaking and water temperature (5^0, 25^0, 49^0 and 60^0 C) respectively.

Conclusions

1- Natural soil exhibit no strength resistance against soaking and failed rapidly during soaking.
2- Static water causes a decrease in the (q_u) for treated samples soaked in water of low temperature (5^0 and 25^0 C), while the higher water temperature (49^0 and 60^0 C) caused an increase in the (q_u).
3- The soluble of gypsum shows a gradual decreases with the soaking duration up to a certain period, which after that shows insignificant changes.
4- The effect of soaking in static water on the (q_u) and loss in gypsum content of soil was much higher than the loss in weight
5- Lime stabilization enhanced the strength properties of gypseous soil against soaking.

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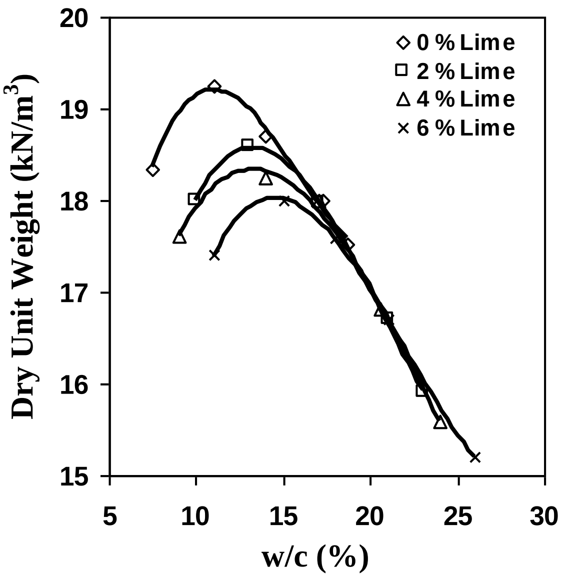

Figure (1) Compaction Characteristics Curves for Natural and Lime Treated Soils

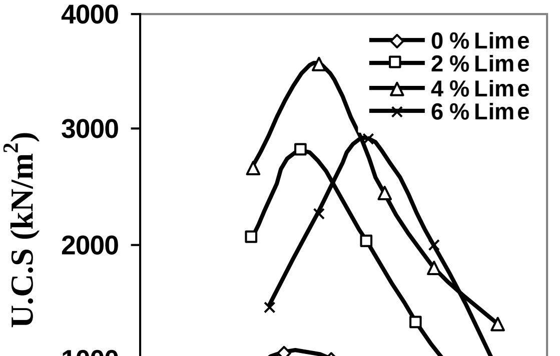

Figure (2) Unconfined Compressive Strength Curves for Natural and Lime Treated Soils

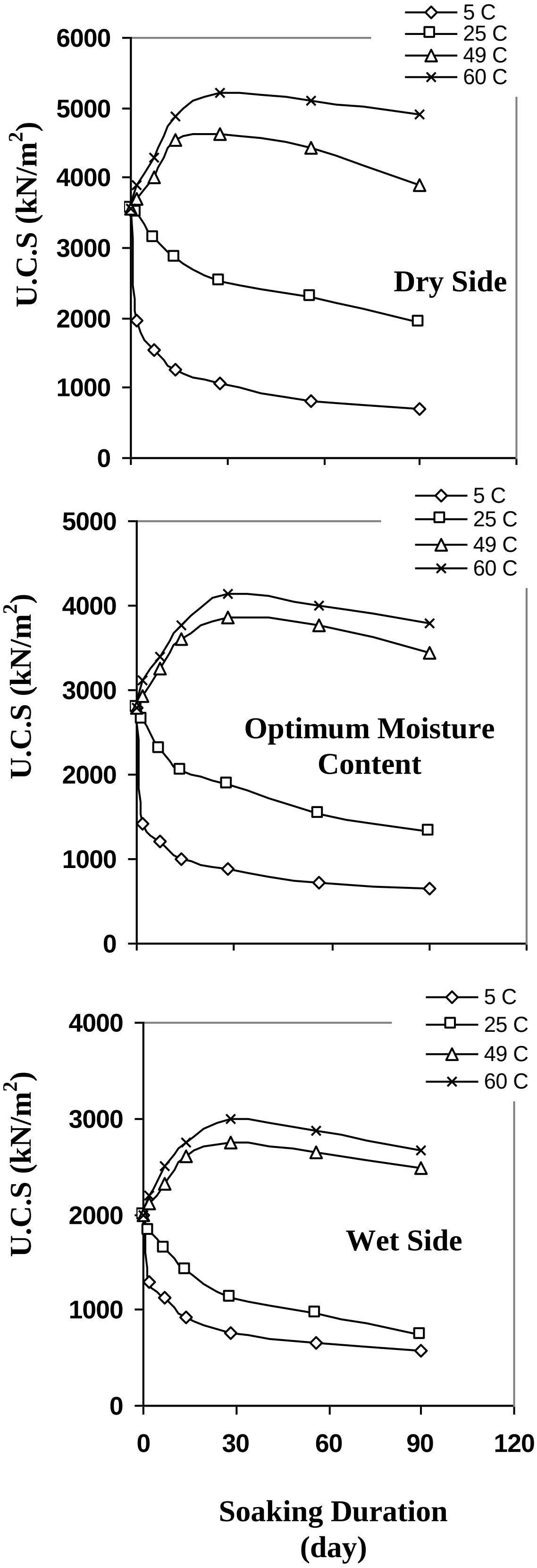

Figure (3) Correlation Between UCS and Soaking Duration

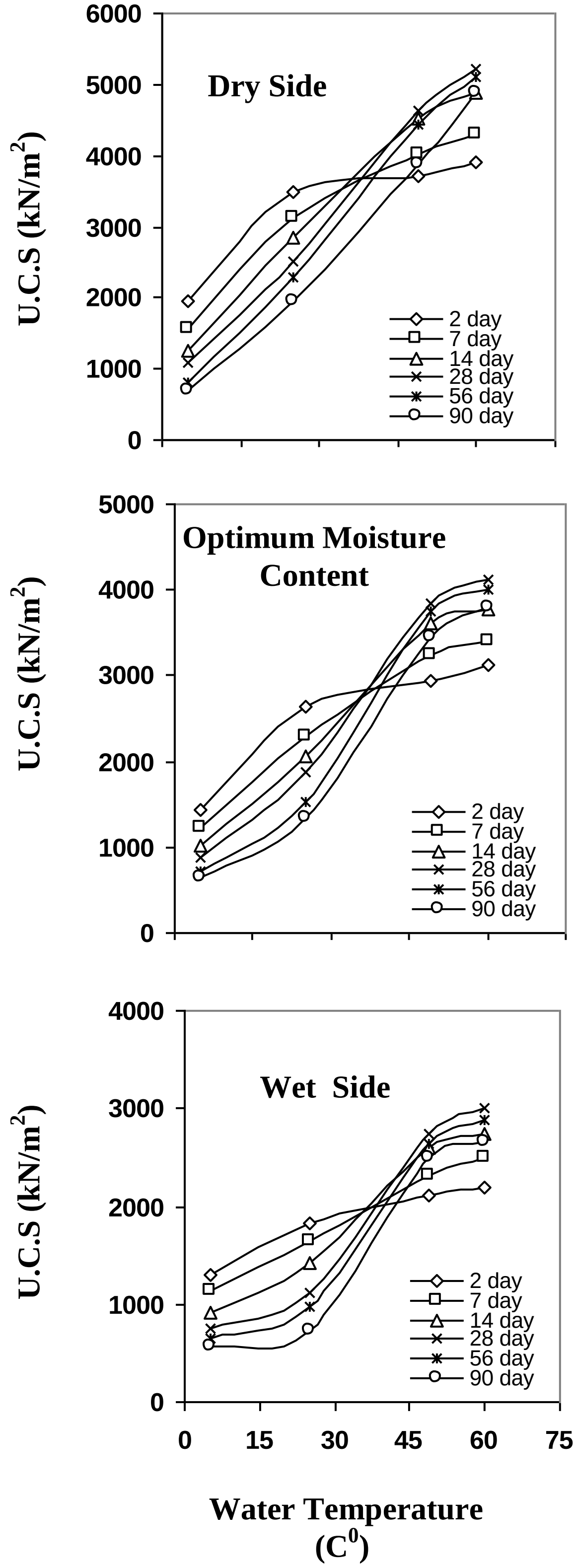

Figure (4) Correlation Between UCS and Water Temperature

Table (1) Chemical & Physical Properties of Natural Soil

Properties	Values
Liquid Limit (%)	46
Plastic Limit (%)	22
Plasticity Index (%)	24
Gypsum content (%)	20.0
Organic content (%)	1.02
Specific Gravity	2.58
Gravel (%)	3
Sand (%)	8
Silt (%)	42
Clay (%)	47
Soil Classification According to USCS	CL

Table (2) Chemical Composition of Lime

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	AL_2O_3	Fe_2O_3	SiO_2	MgO	H_2O	L.O.S
lime	73.0	6.1	5.2	0.17	0.04	10.1	4.19	0.09	-----

- **L.O.S = Loss of Ignition.**

Table (3) (%) Loss in Weight of Lime Stabilized Gypseous Soil

Temp. (C^0)	Initial water content (%)	Soaking Duration (day)					
		2	7	14	28	56	90
5^0	D.S	0.07	0.12	0.87	1.63	2.13	3.1
	O.M.C	0.04	0.087	0.113	0.76	1.0	1.43
	W.S	0.04	0.073	0.096	0.54	0.89	1.21
25^0	D.S	0.09	0.23	0.91	1.78	2.32	3.36
	O.M.C	0.063	0.091	0.16	0.88	1.2	1.67
	W.S	0.051	0.085	0.131	0.73	1.0	1.32
49^0	D.S	0.1	0.32	1.12	1.86	2.47	3.73
	O.M.C	0.094	0.15	0.89	1.33	1.77	2.0
	W.S	0.09	0.13	0.66	0.92	1.23	1.85
60^0	D.S	0.12	0.41	1.23	2.0	2.88	4.65
	O.M.C	0.11	0.2	1.13	1.84	2.21	2.77
	W.S	0.097	0.178	1.0	1.41	1.85	2.0

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Table (4) Change in U.C.S Values with Soaking Durations

Soaking Temp. (C^0)	Soaking Duration (day)	Dry Side (D.S)		Optimum Moisture Content (O.M.C)		Wet Side (W.S)	
		U.C.S (kN/m^2)	Change (%)	U.C.S (kN/m^2)	Change (%)	U.C.S (kN/m^2)	Change (%)
*	*	3573 *	-----	2800 *	-----	2000 *	-----
5^0	2	1956	- 45	1430	- 50	1300	- 35
	7	1550	- 57	1220	- 56	1130	- 44
	14	1248	- 65	1010	- 64	915	- 54
	28	1078	- 70	875	- 69	760	- 62
	56	810	- 77	710	- 75	647	- 68
	90	700	- 80	643	- 77	573	- 71
25^0	2	3500	- 2	2650	- 5	1820	- 9
	7	3130	- 12	2300	- 18	1650	- 18
	14	2850	- 20	2050	- 27	1420	- 29
	28	2520	- 29	1875	- 33	1120	- 44
	56	2300	- 36	1530	- 45	965	- 52
	90	1943	- 46	1334	- 52	731	- 63
49^0	2	3710	+ 4	2940	+ 5	2120	+ 6
	7	4010	+ 12	3250	+ 16	2315	+ 16
	14	4530	+ 27	3600	+ 29	2600	+ 30
	28	4620	+ 29	3850	+ 38	2750	+ 38
	56	4430	+ 24	3760	+ 34	2640	+ 32
	90	3887	+ 9	3447	+ 23	2489	+ 24
60^0	2	3900	+ 9	3120	+ 11	2200	+ 10
	7	4300	+ 20	3400	+ 21	2500	+ 25
	14	4870	+ 36	3770	+ 35	2750	+ 38
	28	5210	+ 46	4130	+ 48	3000	+ 50
	56	5100	+ 43	4000	+ 43	2877	+ 44
	90	4896	+ 37	3800	+ 36	2666	+ 33

* control sample cured for (2) days at (49^0 C).
- means reduction in the strength of the soil samples.
+ means increase in the strength of the soil samples.

Table (5) (%) Residual Gypsum Content of Lime Stabilized Gypseous Soil

Soaking Temp. (C^0)	Initial water content (%)	Soaking Duration (day)					
		2	7	14	28	56	90
5^0	D.S	17.16	16.5	14.35	12.1	11.4	10.87
	O.M.C	17.0	16.23	13.92	11.86	11.0	10.5
	W.S	17.0	16.0	13.63	11.2	10.78	10.0
25^0	D.S	16.87	15.34	13.2	11.12	10.0	8.67
	O.M.C	16.2	15.1	13.0	11.0	9.24	8.12
	W.S	16.1	14.9	12.71	10.85	9.0	7.76
49^0	D.S	16.21	14.76	12.23	10.1	8.21	6.78
	O.M.C	15.93	14.22	12.01	9.93	8.0	6.1
	W.S	15.8	13.8	11.9	9.0	7.5	5.6
60^0	D.S	15.86	14.0	11.75	9.45	7.85	6.21
	O.M.C	15.5	14.0	11.52	8.96	7.2	5.78
	W.S	15.3	13.5	10.9	8.0	6.63	4.74