Long Term Strength and Durability of Clayey Soil Stabilized With Lime

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Abstract

This study deals with durability characteristics and unconfined compressive strength of clayey soil stabilized with lime. The tests comprises of unconfined compressive strength for samples stabilized with the optimum lime percent (4%), and subjected to cycles of the wet-dry, dry-wet and freeze-thaw durability tests as well as, long-term soaking and slake tests.

The results indicated that, the efficiency of the lime in the improvement of unconfined compressive strength of clayey soil is of negative effect in the long term durability periods The wetting-drying cycles showed greater reduction in unconfined compressive strength than drying-wetting cycles, while the volume change of samples which subjected to drying at first, was greater than those conducted with wetting. On the other hand, freezing-thawing cycles causes a decreasing in the unconfined compressive strength values, and the reduction ratio was greater than wetting and drying cases. But, during soaking tests it was found that at early soaking periods, the lime stabilized samples continuously gaining strength, but beyond this the strength decreased with increasing soaking period. Finally, the stabilized samples with (4 and 6%) lime becomes more durable against the cycles of wetting and drying.

Keywords: lime stabilization, Durability, Wetting and drying cycles, Freezing-thawing cycles, Slake durability, Volume change.

المقاومة طويلة الأمد والديمومة للتربة الطينية المثبتة بالنورة

الخلاصة

يهدف هذا البحث إلى دراسة تأثير الظروف المناخية المختلفة والمتمثلة, بكل من دورات الترطيب-التجفيف, التجفيف-الترطيب وكذلك الانجماد-الذوبان على مقاومة الانضغاط غير المحصور لتربة طينية مثبتة بنسبة (4%) نورة من الوزن الجاف. كذلك تمت دراسة تأثير الغمر الطويل والتآكل على هذه الأقيام.

أظهرت النتائج حصول تحسن في مقاومة الانضغاط للتربة المثبتة مقارنةً مع التربة الطبيعية. كما أظهرت نتائج دورات الترطيب -التجفيف نقصان كبير في قوة الانضغاط غير المحصور مقارنةً مع دورات التجفيف-الترطيب, في حين كان مقدار التغير الحجمي في حالة الدورات التي بدأت بالتجفيف أكبر منه في حالة الدورات التي بدأت بالترطيب. من جانب أخر سببت دورات الانجماد-الذوبان نقصان في قوة الانضغاط غير المحصور, وكانت نسبة النقصان عالية مقارنةً مع حالة الترطيب والتجفيف. بالنسبة للغمر, حصلت زيادة في قوة الانضغاط في فترات الغمر الأولية, بعدها قلت المقاومة مع زيادة فترات الغمر. أخيراً أعطت نماذج التربة المثبتة بنسبة (4 و 6%) نورة مقاومة جيدة ضد دورات الترطيب-التجفيف خلال فحص التآكل لنسب الإضافة.

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1. Introduction

The construction material used in different civil engineering applications, should have sufficient durability within time against alternate wetting and drying conditions, frost susceptibility and alternate freezing and thawing periods. Strength and durability of soil are very important factors to be considered for use as construction material [1]. Durability, that is defined as the ability of material to retain stability and integrity over years of exposure to the destructive forces of weathering, is one of most important factors [2]. Soil in nature did not sustain the effects of environmental factors, such as wetting-drying cycles [3].

The strength and durability properties of natural soil can be improved by both mechanical and chemical stabilization [4]. Chemical stabilization of soils involves additives such as cement, lime and other chemical additives [5].. Lime stabilization is one of the most economical techniques to improve the engineering behavior of clayey soils [5,6]. The addition of lime to a soil causes two basic sets of reactions, one being a short-term reaction while the second is long-term reaction (pozzolanic reaction) [6]. The immediate effect of lime addition to

the soil is to cause flocculation and agglomeration of the clay particles caused by cation exchange at the surface of the soil particles. The result of this short-term reaction is to enhance workability and plasticity [6,7]. The long-term reactions that are accomplished over period of time may require weeks, months or even years for completion of these reactions depending on the rate of chemical break down and hydration of the silicates and aluminates. This results in the formation of cementations material, which binds the soil particles together [5,6].

However, recent studies related to understanding of the durability of natural or stabilized soils with respect to the influence of environmental factors such as wetting-drying, freezing-thawing cycles and immersion on some engineering properties have been carried out relating to the following tests, unconfined compressive stress, direct shear tests and flexural tensile tests [1,3,8,9,10,11].

Hence, the objective of this study is to determine the effects of environmental factors such as wetting-drying, drying-wetting and freezing-thawing cycles on the unconfined compressive strength and volume change of clayey soil stabilized with optimum lime percent (4%). As well as, soaking test to indicate the variations of the unconfined compressive strength, during soaking durations that extends from (2 – 60) days. Finally, slake durability test was investigated for the aforementioned conditions.

Materials Used.

Soil.

The soil used in this study is a clayey soil obtained from Al-Hadbaa district, in Mosul city at depth (1.0 m). The soil was oven dried for (2 days at 60^0 C), disaggregated gently using hammer to pass through as ASTM # 4 sieve (Annual 1993). The sieved soil was then homogenized thoroughly and kept in plastic bags until testing. Some of the index properties and chemical tests of soil were presented in Table (1), using the relevant tests according to the ASTM standards or B.S. (British Standard).

- Lime.

High calcium hydrated lime brought from Al-Meshrag Sulphate factory (73 %) activity was used. The chemical analysis results of the lime are shown in Table (2).

Water

Tap water was used in the preparation of samples as well as in all the tests.

Samples Preparation.

Oven – dried representative clayey soil samples were thoroughly hand mixed with the required amount of water and allowed to equilibrium for (24 hours) in sealed plastic bags. The soil was stabilized by different percentages of lime (1,2,4, and 6%) by weight of oven dry soil. The soil-lime mixtures were prepared first by thorough mixing of dry predetermined quantities of soil and lime to obtain uniform color.

Then, the required amount of water was added and again mixed to get a uniform moisture distribution. The mixture was then placed in plastic bags for mellowing time (1 hour) [6]. Mixtures of untreated and lime treated soil were then compacted in a specific mold corresponding to the required tests using a modified Proctor compaction (ASTM D-1557).

Unconfined Compression Test.

It is common practice to determine the strength of soil from Unconfined Compression Test, which is conducted using cylindrical samples of (50 mm diameter * 100 mm height) following (ASTM D-2166) standard.

All prepared samples with lime, were sealed with aluminum foil, coated with paraffin wax to cure for (2 days at temperature of 49^0 C).

- Experimental Program and Test Procedures.

To study the effect of the environmental factors on the unconfined compressive strength and volume changes of stabilized clayey samples with 4% lime (optimum lime content according to the Illinois procedure, which depend on the unconfined compression strength values [6]), the experimental program was scheduled in the following approaches: firstly involved with the effect of wetting-drying and drying-wetting cycles on the aforementioned properties, while the second consists of the freezing-thawing cycles. The third and forth approaches comprises the effect of soaking and slaking tests.

Wetting-Drying and Drying-Wetting Test Procedures.

Long-term strength of soil-lime mixture has usually been examined by the wetting –drying cycles test or by drying-wetting cycle test. This procedure was adopted in this study to evaluate the long-term strength of lime stabilized clayey soil. Two identical sets of samples were prepared with the maximum dry unit weight (γ_{max}) and the optimum moisture content (OMC) of the modified compaction curve.

The first set of samples was subjected to (12 cycles) of wetting and drying (2 days wetting and 2 days drying at 60^0 C). At the end of each cycle, the volume change was carefully measured (averaged of four reading of measurements were taken). The unconfined compressive strength (σ_c) estimated at the end of (2^{nd}, 4^{th}, 6^{th}, 8^{th}, 10^{th} and 12^{th}) cycle.

The second set of samples was subjected to the same as indicated above conditions and with the same test procedure, except that, the cycles started with drying instate of wetting.

- **Freezing-Thawing Test**
- **Procedure.**

To simulate the effect of winter seasonal conditions on the unconfined compressive strength, duplicate sets of lime stabilized samples were prepared. After 2 days curing at 49^0 C, the samples were placed in water-saturated felt pads and kept in a freezer box at a temperature not less than (-5^0 C) for two days. After that, the samples were removed from freezer and kept in a laboratory temperature room for (2 days), care being taken that the felt pads are kept moist. This procedure is repeated until the samples have been through 12 cycles of freezing and thawing.

The same procedure in wetting and drying test was adopted to estimate the unconfined compressive strength.

- Soaking Test Procedure.

There are many situations where the ground water table is very high (fluctuated) or the subgrade soil is subjected to long-term soaking. In this approach, two sets of stabilized samples were prepared and cured for (2 days at 49^0 C), at the end of curing period, the first set of samples was immersed in water for (2,5,15,30 and 60 days), after the end of soaking period, the samples were tested to find the unconfined compressive strength. The second set of samples (controlled samples) was subjected to different curing periods (at room temperature ($25^0 \pm 3^0$) where these curing periods are equivalent to the soaking period. It is worth mentioning that, the controlled samples were immersed in water for two days before testing.

Also, the resistance to loss in strength was determined as the ratio of the unconfined compressive strength of soaked samples to the unconfined compressive strength of control samples.

Slake Durability Test Procedure

The lime stabilized soil samples may not be susceptible to frost action, but the resistance of these stabilized samples against wetting and drying needs to be checked. Because of the high strength of the lime stabilized soil, it was decided to assess its resistance against wetting and drying through the slake durability test following the test procedure of International Society for Rock Mechanics (ISRM, 1981) [12]. Russell [13] reported that, the slake durability test can quantify the properties of materials spanning the range between soil and rock.

The slake durability index (I_d) is defined as:

$$I_d = \frac{Y}{X} \times 100 \quad \text{…. (1)}$$

where X= weight of oven dried sample before first cycle started, Y= weight of oven dried sample retained in mesh drum after 10 minutes of drum rotation (one cycle).

Cured cylindrical samples of the lime stabilized mixes (1,2,4 and 6% lime) of the type used in the unconfined compression test, were broken into lumps of spherical shape (ball shaped) having oven dried weight between (90 – 100 gm) for each lump. Six lumps (balls) have been taken with total weight between (550 – 600 gm) [3,14]. The test procedure followed International Society for Rock Mechanics (standards ISRM, 1981) for slake durability test.

- Results and Discussions.

- Compaction haracteristics.

The compaction characteristics of natural (untreated) and treated soil with different percentages of lime (1,2,4 and 6%) are shown in Fig. (1). The maximum dry unit weight (γ_{max}) decreases with the addition of lime, while the optimum moisture content (OMC) increases. This reduction is due to the immediate reactions between lime and soil, which is represented by the flocculation and agglomeration [6]. The increases of (OMC) with increasing lime may be due to increase of fine material and due to the hydration of lime.

-Unconfined Compressive Strength.

Figure (2) shows the unconfined compressive strength (σ_c) curves of untreated and treated soil. It is observed that, the (σ_c) increased upon the addition of lime. This is due to the reaction that occurs between the soil constituents and the lime. The (σ_c) of soil increase up to (4%) lime, then decreases. The reduction in strength when soil is stabilized with (6%) lime is due to the extra lime, which acts as a fill material due to uncompleted reaction with the short curing period (i.e. 2 days). The (σ_c) of natural soil was (800 kN/m^2), while the soil treated with (1,2,4 and 6% lime) attains after two days curing maximum values of (σ_c) of order (2000, 2550, 3200 and 2600 kN/m^2) respectively, which gave an improvement ratio (2.5, 3.18, 4.0 and 3.25) times of the (σ_c) of the untreated soil.

Effects of Wetting –Drying and Drying-Wetting on the Stabilized Soil.

This section provides the results of behavior of the lime stabilized samples when subjected to wetting-drying and drying-wetting cycles, to study the effect of these cycles on the unconfined compressive strength (σ_c) and volume change.

- Unconfined Compressive Strength.

Figure (3) and Table (3) show the effect of wet-dry and dry-wet tests on the (σ_c) of stabilized samples. The results represented an average increasing in the (σ_c) during the first four cycles, this increasing ranging between (4.7 to 9.4 %) : (10.6 to 18.1 %) for the samples subjected to the cycles started with wetting and those cycles started with drying respectively. The initial increasing in strength may be justified by the continuing reactions between soil and lime, and the rate of strength gain being higher than the rate of deterioration caused by these cycles. Similar behavior have been reported by (Al-Zubydi, 2007) [9].

At the end of the 4^{th} cycle, it has been seen that, there is a reduction in the (σ_c) in stabilized samples. The (σ_c) of the samples subjected to wetting-drying cycles decreased from (3500 kN/m^2 to 1850 kN/m^2) at the end of the 12^{th} cycle, with a reduction ratio (42.2 %), while (σ_c) decreased from (3780 kN/m^2 to 2100 kN/m^2), with a reduction ratio (34.4%) for the sample subjected to drying-wetting. This behavior may be referred to reactions that were almost complete and the damaging effects becomes more pronounced.

- Volume Change.

Figures (4 and 5) show the effect of wetting-drying and drying-wetting cycles on the volume change of the stabilized samples. Figure (4) clarified that, the volume change of stabilized samples, in general, increase up to the 4^{th} cycle, then decrease during the wetting process, while the volume decreases gradually, after the rate of decrease drops to almost a linear rate during the drying. The decreasing in volume may be due to the formation and propagation of cracks in soil samples during these cycles, which lead to drop the soil from the weakest surfaces of samples.

Similar behavior is expected for drying-wetting cycles, Figure (5). This Figure also shows similar trends for dry-wet test, however, soil samples exhibited higher volume change than those subjected to wet-dry test.

- Effect of Freezing-Thawing on the Unconfined Compressive Strength

The values of (σ_c) of stabilized samples subjected to the freezing-thawing cycles are presented in Figure (3) and Table (3). This Figure indicates that, the freezing and thawing causes larger drop in (σ_c), when reduction ratio was (52.8%) where the (σ_c) decreased from (3200 kN/m^2 to 1510 kN/m^2) at the end of the 12^{th} cycle.

Finally, it is interesting to note that although the wet-dry and freeze-thaw durability tests are two different tests, they showed a close correlation between the (σ_c) obtained from each tests (i.e. wet-dry, dry-wet and freeze-thaw). Figures (6 and 7) show that the relationships exist between the (σ_c) of the wet-dry and freeze-thaw : and between dry-wet and freeze-thaw, respectively. These relations were linear with a good coefficient of determination : R^2 = 0.8091 and 0.7063 respectively. The relatively large magnitude of the intercept may indicate that, there is a missing variables that should be taken into consideration.

Effect of Soaking on the Unconfined Compressive Strength

Figure (8) shows the effect of soaking on the (σ_c). An increase in the (σ_c) was obtained at the first soaking periods (2 and 5 days). The (σ_c) increases from (3200 kN/m^2) for unsoaked samples to (3370 and 3560 kN/m^2) for soaked samples (2 and 5 days) respectively, which gave improvement ratio (1.05 and 1.11) times of the (σ_c) of unsoaked samples. This increasing may be due to more lime hydration and more reactions between soil and lime, that give more cementing materials. Similar behavior was reported by(Mohammed, 2008) [10]. After soaking of 5 days, (σ_c) showed slight decreasing in its values and further decrease in strength with increasing soaking periods that extended to (60 days). The (σ_c) decreased from (3200 kN/m^2) of unsoaked samples to (2000 kN/m^2) when samples were soaked for (60 days), and the reduction ratio was (37.5 %). Figure (9) shows the variation of loss of resistance, which represented the (σ_c) of soaked samples to the (σ_c) of control samples. It is observed that the resistance to the loss in strength was started after the end of the (5 day) soaking, further decrease in this resistance with increasing soaking periods.

Slake Durability Index.

Slake durability index (I_d) of the stabilized samples cured for 2 days at 49°C are presented in Fig. (10). While performing the test, it was observed that the untreated soil samples and samples treated with (1%) lime did not sustain even the third cycle. Also the samples with (2%) lime are collapsed before the 12th cycle. The samples treated with other percents of lime (4 and 6%) exhibit medium to high durability against wetting and drying cycles (Goodman, 1989) [15]. This is a good indication of the composition of the cementing bond between soil particles upon the addition of lime.

Conclusions.

The following conclusions can be drawn from this study:

1. Natural soil exhibit no strength resistance against environmental factors and failed rapidly during soaking.
2. Stabilization of the clayey soil with lime is effective to enhance the strength against environmental factors.
3. Wetting and drying cycles causes decreasing in the (σ_c), more loss in strength for freezing-thawing cycles.
4. Cyclic wetting and drying increases the variations in the volume change, and more volume change occurs during drying-wetting cycles.
5. Soaking has significant effect on the (σ_c) of stabilized samples. The strength initially increased, then decreased with increasing soaking periods.
6. The amounts of (4 and 6%) lime addition only succeeded in improving the strength of soil against slake durability test.

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Table (1) Physical and chemical properties of natural soil.

Properties	**Values**
Liquid Limit (%)	52
Plastic Limit (%)	25
Plasticity Index (%)	27
Linear shrinkage (%)	14
Total Soluble salts (%)	1.9
Organic matter (%)	1.3
Specific gravity	2.72
Sand (%)	14
Silt (%)	40
Clay (%)	46
Soil Classification (USCS)	CH

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	1.11

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

Table (3) Results of the unconfined compressive strength with respect to durability cycles

No. of Cycles	Wetting - Drying		Drying-Wetting		Freezing-Thawing	
	(σ_c) (kN/m^3)	(%) Change	(σ_c) (kN/m^3)	(%) Change	(σ_c) (kN/m^3)	(%) Change
0	3200	--------	3200	--------	3200	--------
2	3350	+ 4.7	3540	+ 10.6	3050	- 4.7
4	3500	+ 9.4	3780	+ 18.1	2820	- 11.9
6	3290	+ 2.8	3420	+ 6.9	2430	- 24.1
8	2700	- 15.6	3000	- 6.2	2180	- 31.9
10	2360	- 26.3	2640	- 17.5	1820	- 43.1
12	1850	- 42.2	2100	- 34.4	1510	- 52.8

- **(+) means increasing in the unconfined compressive strength.**
- **(-) means decreasing in the unconfined compressive strength.**

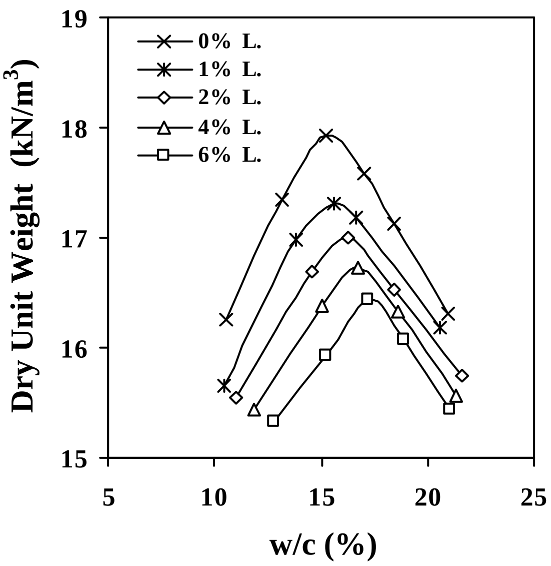

Figure (1) Compaction curves of natural and lime treated soil

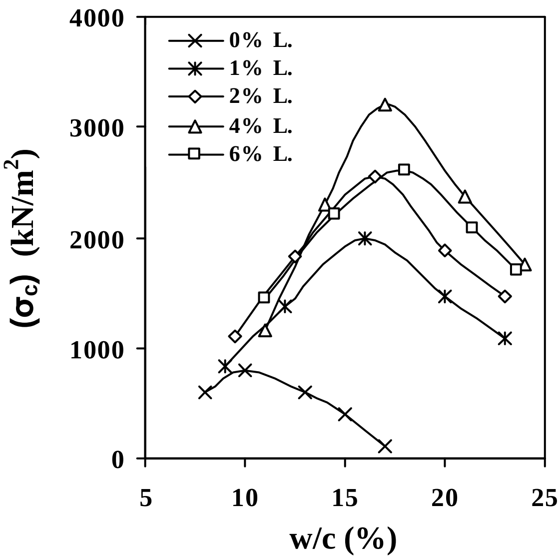

Figure (2) Unconfined compressive strength curves of natural and lime treated soil

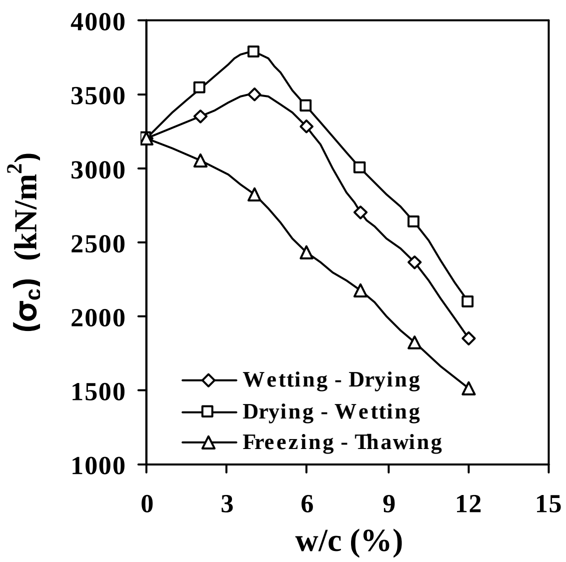

Figure (3) Effect of wet, dry, freeze and thaw cycles on the unconfined compressive strength

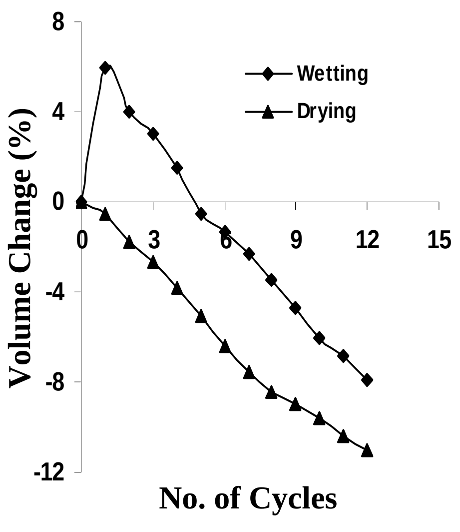

Figure (4) Effect of wetting-drying cycles on the volume change

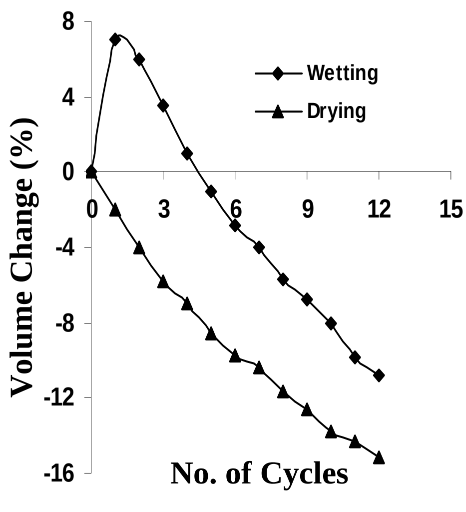

Figure (5) Effect of drying-wetting cycles on the volume change

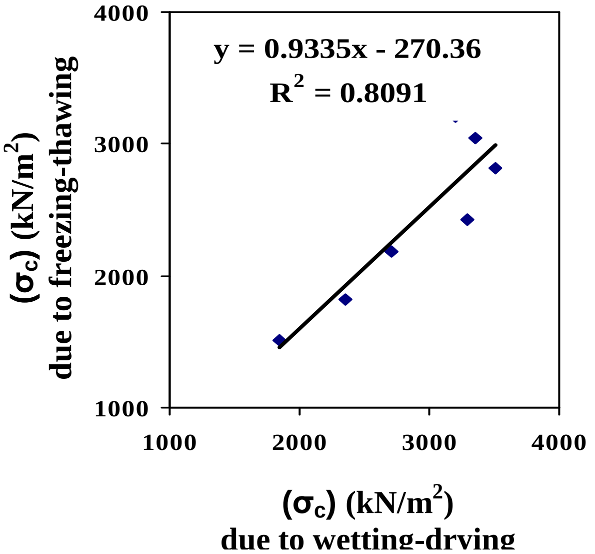

Figure (6) Relation between compressive strength for freeze-thaw and wet-dry test

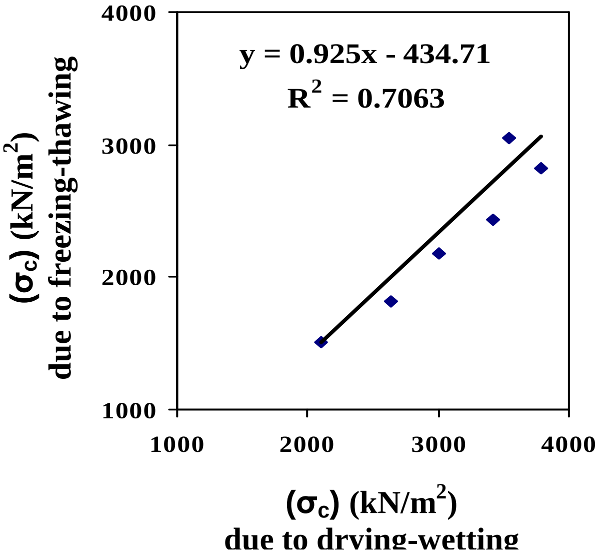

Figure (7) Relation between compressive strength for freeze-thaw and dry-wet test

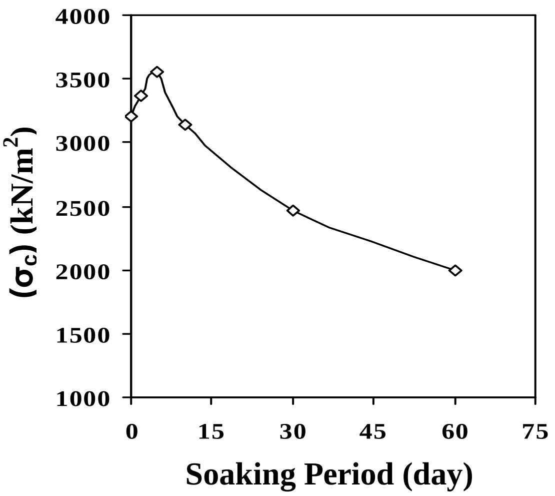

Figure (8) Effect of soaking on the unconfined compressive strength

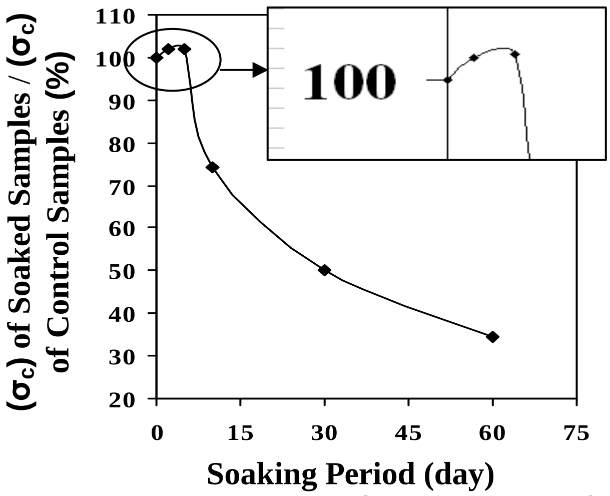

Figure (9) Variation of loss in the unconfined compressive strength with soaking period

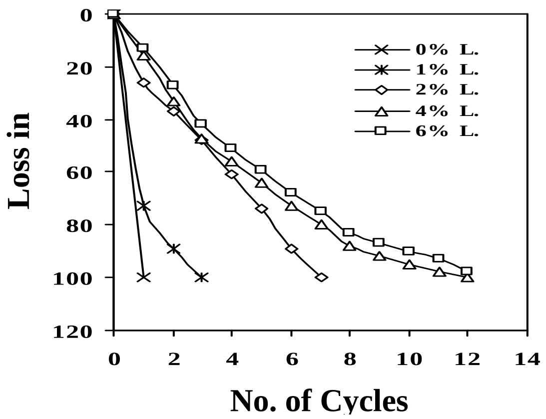

Figure (10) Loss in weight (%) with wetting and drying cycles