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Volume Change Measurement Of Collapsible Soil Stabilized With Lime And Waste Lime

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Abstract

This paper presents a series of laboratory tests to evaluate the effects of lime and waste lime on the volume change and strength characteristics of moderately collapsible soil selected from Al-Rashidia in Mosul city. The tests are performed at different percentages of lime and waste lime of 0, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 and 8.0% by dry weight of soil. One dimensional compression tests are conducted to clarify the influences of relative compaction, compaction water content, vertical stress level and curing time on the volume change and strength characteristics.

The results of this study indicated a decrease in the plasticity, swelling potential and swelling pressure of treated soil. The soil became non-plastic at (3&6)% of lime and waste lime respectively. Swelling pressure and swelling potential reached to zero at 2% lime and 2&7 days of curing time.

Unconfined compressive strength (UCS) reached to maximum value at optimum stabilizers content. The UCS of lime treated soil is more than that treated by waste lime at different curing time. The collapse index and potential of treated soil are found less than that of natural soil and decrease with increasing stabilizer content until drop to zero at 2% lime. Collapsing increased continuously with applied stresses, but with curing time reached a maximum value at 2 day. On the other hand, collapsing of treated soil with lime is less than that of waste lime treated soil at different curing time and stresses.

Keywords: Collapsible soil, lime, waste lime, swelling, collapsing, shears strength.

قياس التغير ألحجمي لتربة متداعية مثبتة بالنورة ومخلفات النورة

الخلاصة

يهتم البحث بدراسة تأثير إضافة النورة ومخلفات النورة على خصائص التغير ألحجمي والمقاومة لتربة متداعية مختارة من منطقة الرشيدية في مدينة الموصل. أضيفت النورة ومخلفات النورة بنسب مقدارها (0، 0.25، 0.5، 1.0، 2.0، 3.0، 4.0، 6.0، 8.0)% وزنا من التربة الجافة. درست العديد من المتغيرات منها، فترة الإنضاج ووحدة الوزن الجاف الأولية ومحتوى الرطوبة الأولي بالإضافة إلى الاجهادات المسلطة على خصائص التغير ألحجمي والمقاومة.

أظهرت النتائج انخفاضا في لدونة التربة ونسب وضغط الانتفاخ، حيث أصبحت التربة عديمة اللدونة عند نسب التثبيت المثلى 3 و 6% نورة ومخلفات النورة على التوالي. كما اختفت نسب وضغط الانتفاخ عند اضافة 2% نورة ولفترات إنضاج 2 و 7 يوم.

وصلت مقاومة الانضغاط غير المحصور الى اعلى قيمة عند نسب التثبيت المثلى. لوحظ ان مقاومة الانضغاط غير المحصور للتربة المعاملة بالنورة أعلى منها للتربة المعاملة بمخلفات النورة عند فترات الإنضاج المختلفة. بينت النتائج انخفاض قابلية التداعي للتربة عند زيادة نسب النورة والمخلفات وتختفي عند النسبة 2% نورة، بينما تزداد مع فترات الإنضاج وتصل إلى أعلى قيمة عند 2 يوم. من جانب أخر، ان قابلية التداعي للتربة المثبتة بالنورة اقل منها للتربة المثبتة بمخلفات النورة.

الكلمات الدالة: تربة متداعية،نورة، مخلفات النورة، انتفاخ، تداعي، مقاومة القص.

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Introduction

Deformation behavior of unsaturated soil under field conditions depends mainly on existing (initial) conditions and the wetting and loading history of the soil. The soil can experience a complex volume change reaction depending on the intensity of the applied external load. Thus, compacted soils wetted under load can both swell and collapse depending on their conditions and the magnitude of vertical stress. The clayey soils swell when wetted under low applied stresses and compress when wetted under high stresses. Volume decreases due to surplus of water under the same stresses in loose, partly saturated natural soil deposits have been termed collapse [1-5].

Swelling and collapsing cause damage to many civil engineering structures such as: spread footing, buildings, roads, highways, and earth dams leading to high economic losses.

There are many factors affecting collapse behavior of compacted and cohesive soils which are: initial dry unit weight, initial water content, percentage of fines, and the method used in compaction, [4-7].

From the art of review, researchers mentioned that compaction is considered as the best method to reduce or eliminate the severity of collapse [3,4,7,8]. Al-Awaje [9] stated that relative compaction of soil to 95% of the maximum dry unit weight of modified compaction will improve the soil characteristic and reduce the collapse of the soil.

Lime is considered as an effective additive to improve the soil properties and prevent damage of structures. Lime treatment in cohesive soil generally reduces swelling, permeability, and improves soil plasticity, workability, compressibility, and bearing capacity [10-14].

Recently, several researchs are conducted to utilize some industrial by-products in some engineering application. Al-Shalhomi [15], Al-Safar [16], Al-Kiki [17, 18], and Khattab et al. [19] studied the effect of adding industrial waste of many factories on clayey and gypseous soils. They found that the industrial waste improves the engineering properties of these soils.

To understand the effect of lime on physical and mechanical properties of clayey soils, the chemical reactions of soil-lime must be examined: four reactions are responsible for lime stabilization. Cation exchange, flocculation and agglomeration, lime carbonation, and pozzolanic reaction [11].

The first two reactions occur rapidly and result in an improvement in soil plasticity and workability. However, the third and forth reactions are slower or time dependent. According to Ingles and Metcalf [20], lime reacts with clay minerals to form water insoluble gel of calcium silicate. With time, this gel gradually crystallizes into well-defined cementing agents such as calcium silicate hydrates and calcium aluminate hydrates. The high alkalinity in presence of water changes the physico-chemical conditions of the clay mineral surfaces and therefore facilities the development of new minerals through pozzolanic reactions that is responsible for the formation of the cementing agents. The reaction proceeds only in the presence of water.

A review of literature on lime and waste lime stabilization of compacted soils indicated that previous research has not fully provided information on the effect of lime on important soil properties such as collapse index and collapse potential.

Thus, the main objective of this paper is to investigate the effect of lime and waste lime on the swelling, collapsing, and strength characteristics of Al-Rashedia soil as well as to show the ability of utilizing the industrial waste lime to stabilize this type of soil. Laboratory Work and Procedure.

Laboratory Work and Procedure

The Materials

<u>The Soil</u>

Disturbed and undisturbed soil samples are obtained from a depth of 1.0 m below the ground surface from Al-Rashedia district, located at the left bank of Tigris river in Mosul city. Undisturbed samples are taken directly by pushing the consolidation rings perpendicular on the top of perfectly leveled natural soil. They are placed on small glass plate to prevent disturbance, sealed and kept in a dessicator to insure that there is no loss in their natural water contents prior to use. The standard and modified compaction tests indicated that Al-Rashedia soil has a maximum dry unit weight of 16.4 and 18.34 kN/m^3 with optimum moisture content of 20.3 and 13.5% respectively as shown in Fig. (1). The engineering properties and grain size distribution curve of Al-Rashedia soil are listed in Table (1) and graphed on Fig. (2). The clay percentage of the soil is 28%. Therefore, according to the criteria proposed by Handy [21], Al-Rashedia soil is classified as a collapsible soil. The X-Ray diffraction analysis showed that the clay portion of soil contains (Smectite & Vermoclit, Illite & Kaolinite) as its major and minor clay respectively, whereas, (Quartz, Calcite & Feldisbar) minerals compose the non clay mineral fraction.

<u>Lime And Industrial Waste/ Lime</u>

In this study, high-calcium hydrated lime $Ca(OH)_2$ brought from Al-Mishrac sulphate factory 76% activity is used. Chemical composition of lime was listed in Table (2). Industrial waste lime is obtained from sugar factory in Mosul city. The production reached to 500-1000 tons/year. The chemical properties of industrial waste lime are listed in Table (2). The waste consist of many Impurities (with small pieces of limestone rocks), organic and inorganic, Soluble and Insoluble.

Specimen Preparation

An experimental program is performed on Al-Rashedia soil specimens which is stabilized by adding varying percentage of lime and industrial waste lime of 0.25, 0.5, 1, 2, 3, 4, 6 & 8) % by dry weight of soil.

The soil is air dried, passed through sieve (#4), oven-dried for 24 hour under 110^{o}C, then mixed with calculated amount of stabilizers and distilled water, which is sprayed and remixed thoroughly. The mixture is then placed in plastic bags and kept in a humidity-controlled room for a mellowing time of 24 hour for untreated soil and one hour for treated. The mixtures are statically compacted at a rate of 1.0 mm/min to the required dry unit weight (γ_d), which consist of three different values of γ_d (corresponding to three different values of relative compaction ($Rc= \gamma_d/ \gamma_d$ (max.)) (95% of maximum dry unit weight of standard and modified compaction of Al-Rashedia soil is 15.58 and 17.42 kN/m^3 respectively. Many researchers stated that the use of lime and waste lime reduces the maximum dry unit weight of treated soil[10,17, 19]. Therefore, 90% for a maximum dry unit weight of standard compaction (14.52 kN/m^3) is also used. The molding water content is also made corresponding to dry unit weight used at dry and wet side from compaction curves. The treated soils are sealed with aluminum foil, plastic bags and finally by paraffin to be cured under different curing time of0,2 and 7 days under temperature of 25°C.

Laboratory Tests

According to the purpose of this research, specifications, curing time, and sample dimensions are shown in Table (3).

Single oedometer test is selected for the collapse test for disturbed and undisturbed samples. This test is carried out according to the procedure recommended by ASTM (D5333-92) (2003).

Results and Discussion

Collapse Index And Collapse Potential

For undisturbed soil samples with dry unit weight of 14.91 kN/m^3 and in-situ water content of 16 %, a typical stress strain curve is plotted on Fig. (3). Collapse index is found to be 4.52%. Collapse potential is also estimated to be 3.8 & 5.6% at stress level of 100 & 400 kN/m^2 respectively. Thus, according to ASTM (D 5333-92) (2003), Al-Rashedia soil is classified as moderate - moderate severe according to collapse potential respectively.

The collapse index of remoulded samples compacted at dry unit weight of 14.78 & 15.58 kN/m^3 with initial water content of9.6 and 14.4% are 6.93 and 4.4% respectively. Consequently, the compacted soil is classified as moderate, sever-moderate according to collapse potential respectively. While the collapse index of another set of remoulded samples with the same dry unit weight but the initial water content of 28 & 25% are found to be 0.2 & 0.82% respectively.

Attempts are made to reduce collapsing of the soil by compacting to relative compaction of 95% from the maximum dry unit weight of modified compaction (17.42 kN/m^3). Here, swelling pressure and swelling potential increased and reached to 300 & 140 kN/m^2 and 10.5 & 5% at compaction water content of 9.6 and 17.6% respectively.

According to the above results, mechanical stabilization becomes unsuitable method to improve this type of soil. Therefore, chemical stabilization is suggested to overcome the collapsing and swelling characteristics of the compacted soil.

Estimation of Optimum Stabilizer Content

Two methods are considered for this purpose. The first is proposed by Eades and Grim [22], while the second is Illionois procedure [10].

Following the first procedure, the pH values measured in the soil specimens for various lime percentages are shown in Table (4). pH of soil-water mixture containing various amounts of lime and waste lime (by mass) are measured. According to this method, a minimum of 3% and 6% of lime and waste lime respectively is necessary to achieve pH value of 12.4.

The second procedure depends on the maximum UCS of treated soil. Fig.(4) confirms that 3 & 6% gave maximum UCS under different curing time of lime and waste lime respectively.

Based on both methods, the optimum percentage of stabilizer is approximately 3% lime and 6% waste lime.

Effect Of Lime And Waste Lime On the Stabilized Soil Properties

Index Properties

Table(5) shows that the treated soil with lime and waste lime becomes non plastic when treated with 3 & 6% lime and waste lime respectively. Lime addition leads to a reduction in liquid limit and increase in plastic limit and hence a reduction of plasticity index is observed. This could be attributed to the immediate reactions between clay constituents and lime (cation exchange, flocculation and agglomeration) which reduce the thickness of the double diffuse layer.

The Effect Of Stabilizers Content And Curing Time On The Strength Of The Soil (UCS)

The effect of stabilizers content on the UCS of samples prepared at maximum dry unit weight and optimum moisture content of modified compaction are shown on Fig.(4). It is clear that generally, the UCS increased with increasing stabilizers content till optimum values of 3% lime and 6% waste lime for 2 & 7 day of curing time. However, there is continuous increase in UCS for (1) hour curing time. The curing time effect could be discussed through Fig.(5). It is clear that there is a continuous strength with curing time due to pozzolanic reaction between clay and lime constituents of stabilizers that is due to the development of cemented material among the soil particles. The rate of increase in UCS is increased within the first 2 days of curing time, then decreased for the remaining curing time for both stabilizers. On the other hand, it could be noted that the rate of increase in UCS increased with increasing the amount of both stabilizers. It is worth mentioning here that there is nearly identical rate of increase in UCS when using both stabilizers but with a more significant increase in UCS in the case of lime.

Finally, it should be noted that the gain in UCS of stabilized soil is more when using lime. This is due to the activity of lime comparing with waste lime. Also, the UCS at optimum lime, waste lime stabilization 3 and 6% is approximately equal.

Effect Of Stabilizers On The Volume Change Of The Soil

<u>Swelling Potential and Swelling Pressure</u>

Samples are statically compacted at 95% of maximum dry unit weight at dry and wet side of modified compaction curve. The effect of lime and waste lime under different curing time on swelling pressure and swelling potential of natural and treated soil is shown on Fig.(6). It is indicated that lime and waste lime are efficient in reducing the swelling potential and swelling pressure of the treated soils. Generally, a continuous decrease in the swelling potential and swelling pressure is obtained with an increase of stabilizers content. At 2 & 7 day of curing time, the large decrease is obtained at 1 & 2% lime and waste lime respectively. Thus, using 2% lime is noted to reduce the swelling potential and swelling pressure to zero. But, approached to zero for soil samples treated with 2% waste lime and prepared at wet side. The rate of decrease of swelling potential and swelling pressure is decreased with stabilizer contents at different curing time. Similar tendency is noted for waste lime treated soil. But, the rate of decrease of swelling potential of waste lime treated soil at dry side nearly remain constant. It should be noted that the soil treated with lime has a swelling potential and swelling pressure less than that of waste lime treated soil. The decrease in swelling potential and swelling pressure of 3% waste lime treated soil at dry side and 7 days curing time reached to 60 and62% respectively. The swelling pressure of samples prepared at water content of 9.6% and cured for 1 hour increased with increasing stabilizers content, which is probably related to the action of stabilizers as a fill material. Therefore, the voids between the soil particles are reduced and resulted in increasing the

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swelling pressure, also flocculated structure of treated soil increased swelling [23].

The effect of curing time on swelling potential and swelling pressure of treated soil can be discussed through Fig.(6). It shows that time is very effective in reducing swelling potential and swelling pressure. At dry side and 7 days curing time, only 1% lime is sufficient to reduce swelling potential and swelling pressure from 10.25 to 1.6% and from 300 to 146.4 kN/m^2. The swelling potential and swelling pressure at 2 & 3% lime treated soil becomes zero. In the case of waste lime treated soil with different percentage, there is low rate of decrease in swelling with curing time. At 3% waste lime and curing time ranged between 1 hour to 7 days. The decrease in swelling potential is 31.5%. The best results are obtained in the case of samples prepared at wet side of compaction curves. At 3% lime and waste lime and curing time ranged between 1 hour to 7 days, the decrease in swelling potential is 100 & 91.9% respectively. The reduced water absorption tendency due to the cation exchange decrease the swelling pressure and swelling potential of the treated soil.

In order to study the effect of the initial water content on the swelling potential and swelling pressure, remoulded specimens are prepared from the natural and treated soil at dry and wet side from the modified compaction curve 9.6 & 17.6% respectively at the same dry unit weight of 17.42 kN/m^3.

The effect of initial water content on the swelling potential and swelling pressure is shown on Fig. (6). It is evident that the initial water content has a considerable influence on the swelling potential and swelling pressure of the remoulded samples. These results may be expected, since as the initial water content increases, the degree of saturation will also increased. Thus the amount of absorbed water to complete saturation will become smaller. Therefore, swelling pressure and potential will decreased. For natural soil, a reduction in swelling potential for remoulded samples in dry and wet side is 51.2%, then increased with the stabilizers content and curing time. This sufficient amount of stabilizers and water necessary for the lime/clay instantaneous reactions, and producing better conditions for the reactions.

Collapse Index And Collapse Potential

This study investigates the effect of lime and waste lime on the collapse characteristics of natural and treated soil under different curing time, applied stresses, and dry unit weights. Prepared samples with 0.25, 0.5, 1.0 and 2.0% lime and waste lime are used. Figure (7 A&B) give the collapse percent versus percent of lime and waste lime, diagrams obtained from one dimensional consolidation. It is clear that there is a considerable decrease in collapse with increasing stabilizers content. Lime is very effective in reducing the collapse potential of the soil. At stress level of 100 kN/m^2 and one hour curing time, only one percent lime is sufficient to reduce the collapse potential from 4.40 to 0.484% due to cation exchange reaction. An increase in the flocculation and aggregation causes chemical effects and reduces the collapse characteristics.

The calcium ion is considered as flocculating agent in soil [11]. Since some cation exchange occurs when adding stabilizers, this causes the replacement of the exchangeable sodium, magnesium, or other cations previously held by the clay soil by calcium cation, Abduljauwad [24]. This is believed to produce a soil with a more flocculated fabric and result in a reduction in collapse characteristics.

The difference in collapse potential between 1 and 2 percent lime becomes very little. This means that any additional amount of lime does not improve considerably the control of collapse. Similar result is obtained for 2 and 7 days curing time. On the other hand, the results obtained from waste lime treated soil has similar tendency of lime treated soil, but with collapse potential values more than that obtained from lime treated soil.

It should be noted that the rate of decrease in collapsing with respect to lime and waste lime content is increased with increasing stress level from 200 to 400 kN/m^2. Moreover, the rate of decrease is increased with increasing curing time. This behavior seems to be more clear in the case of lime as compared with waste lime treated soil. Therefor, at 2 percent lime, collapse is decreased with increasing curing time.

The effects of dry unit weight on collapse index and potential of natural and treated soil under different stress levels and curing time is also studied by preparing another sets of samples with γ_d=15.58 kN/m^3. Fig. (7 B) shows the effect of stabilizers content on collapse potential and collapse index. Comparing Fig.7A and Fig.7B indicated that collapse index and potential for natural and treated soil prepared at dry unit weight of15.58 kN/m^3 is less than that prepared at dry unit weight of 14.78 kN/m^3. With 2 and 7 days curing time, the collapse potential of lime treated soil becomes zero at 1 and 2% lime, but for waste lime treated soil, collapse potential approaches zero at 1% waste lime, then become zero at 2% waste lime. Under stress level of 200 and 400 kN/m^2, the slope of the curves is increased also with stabilizer content and curing time. Therefore, collapse index and potential drop to zero at 2% lime. However, collapse index of treated soil with 2% waste lime approaches zero under stress level of200 kN/m^2.

Among the different variables affecting the collapse index and collapse potential of lime-stabilized soil, curing time is of major importance. Its effect on collapse percent is a function of time. For all cured specimens prepared at various stabilizers content with different stress level and two relative densities, collapse index and collapse potential increased rapidly at first, generally during the first 2 days of curing, then decreased with further increase of curing time up to 7 days (Fig. 8 A&B). This behavior is more clear in samples prepared at γ_d =15.58 kN/m^3. This could be attributed to the complexity of the lime-soil reaction mechanism. After 2 days, the chemical reaction has not yet completed and creating more voids around the flocculated soil structure.

The decrease in collapse after 2 days' curing period for all the lime-treated specimens could be due to the precipitation of calcium carbonate in the voids as the ionized calcium reacted with the dissolved carbon dioxide in water. The cementing material gained more strength and hence the collapse ability decreased [21]. This could be confirmed by the optical microscopic photos Fig. (9 A,B&C).

For samples prepared at γ_d=14.3 kN/m^3, collapse percent increased at 2 days then remains constant for samples treated with low percentage of lime and waste lime (0.25&0.5)%. This could be attributed to the slow reactions between lime/clay constituents. While collapse percent increased continuously with 1% lime and 1& 2% waste lime under stress level of 200&400 kPa, it is decreased continuously at 2% lime with different stress level. This is due to the formation of adequate amount of cemented material, which bond the soil particles.

The results of collapse tests on natural and treated soils under different applied pressure of100, 200 and 400 kPa are presented in Fig.(10 A&B). It is noted that the collapse potential and collapse index increased with pressure for one hour curing time, up to certain stress (200 kPa) beyond which no appreciable increase is observed at low percentage of stabilizers content (0.25& 0.5)%. But, further increase in pressure beyond this level will subsequently, cause little change in collapse potential at 1 and 2% lime. This phenomenon is explained by the flocculated soil structure of the treated soil as a result of the cation exchange. It is expected that the flocculated structure probably starts to change towards more dispersed structure under stress of 100 kPa, then followed by a much more general structure failure under 200 kPa. Under 400 kPa, collapse remains constant. However, at 2 and7 days curing time, the rate of collapse is increased continuously with the applied pressure. It should be noted that the behavior of waste lime treated soil is somewhat similar to that noted for lime treated soil, but with more values of collapse of lime treated soil.

The rate of collapse is decreased with stabilizers content due to the stronger bonds that reduce the magnitude of collapsing caused by general bond failure. On the other hand, the treated soil with 1 and 2% lime and waste lime has the ability to resist low applied stresses below 100 kPa. With further increase of applied stresses more than 100 to 400 kPa, 2% lime used to overcome the collapse problems.

Conclusions

1- Mechanical stabilization is failed to stabilize low plasticity clayey soil. So, chemical stabilization is used.
2- Plasticity of treated soil decreases and become non-plastic at optimum lime and industrial waste lime stabilization ,3 and 6% respectively.
3- UCS reaches maximum values at optimum lime and industrial waste lime stabilization of 3 and 6% respectively. UCS of lime treated soil is more than that of industrial waste lime treated soil.
4- Swelling pressure and swelling potential reached to zero at 2% lime. Swelling obtained for lime treated soil is less than that of waste lime treated soils. The reduction in swelling potential of 3% lime, waste lime treated soil at 7 days curing time is 100 and 91.9%.
5- Collapse potential and collapse index decreased with stabilizers content and drop to zero at 2% lime. Collapse potential and collapse index of lime treated soil is less than that of industrial waste lime treated soil.
6- Collapse is increased with curing time up to 2 days then decreased.
7- Collapse is increased continuously with selected pressure. 1 and 2% lime and waste lime is able to resist low applied stresses, but 2% lime has higher ability to resist higher values of applied stresses of400 kPa.

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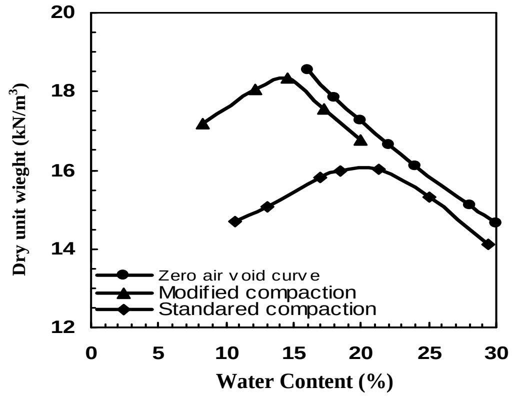

Fig. (1) Compaction Curve for Al-Rashedia Soil

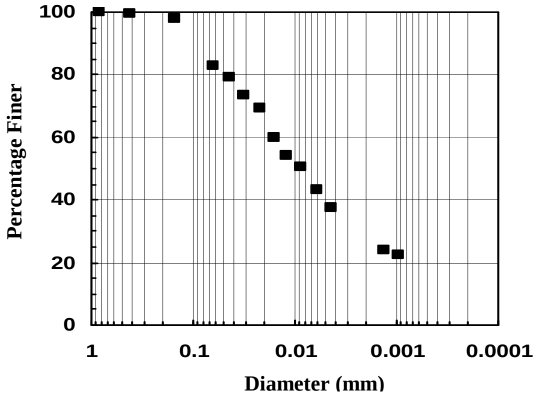

Fig. (2) Grain Size Distribution for Al-Rashedia Soil

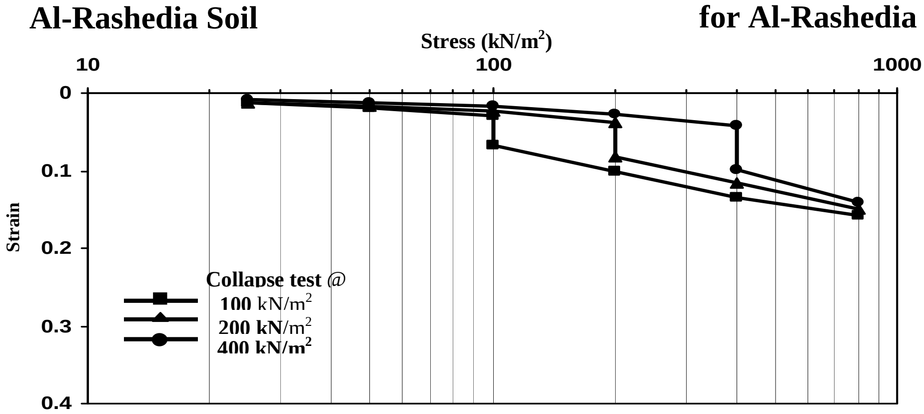

Fig. (3) Collapse Index and Potential Test for Undisturbed Samples

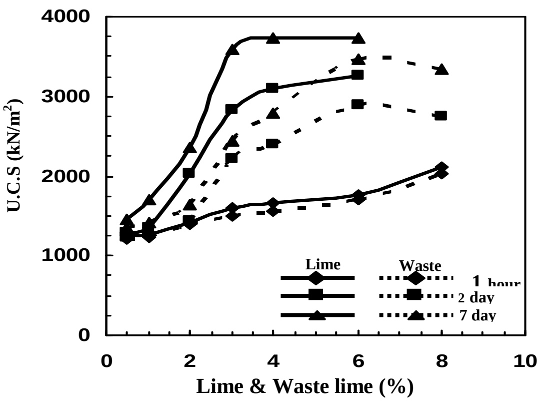

Fig. (4) U.C.S for Treated Soil at Different Curing Time

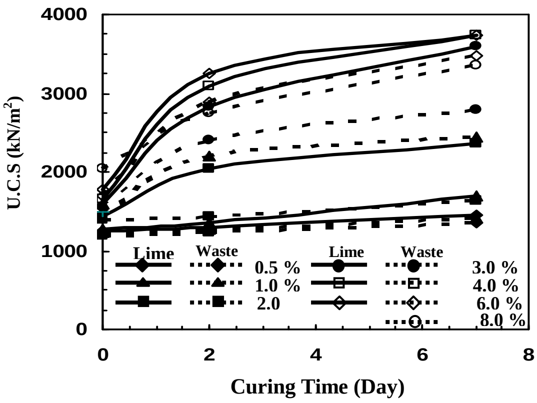

Fig. (5) Effect of Curing Time on U.C.S

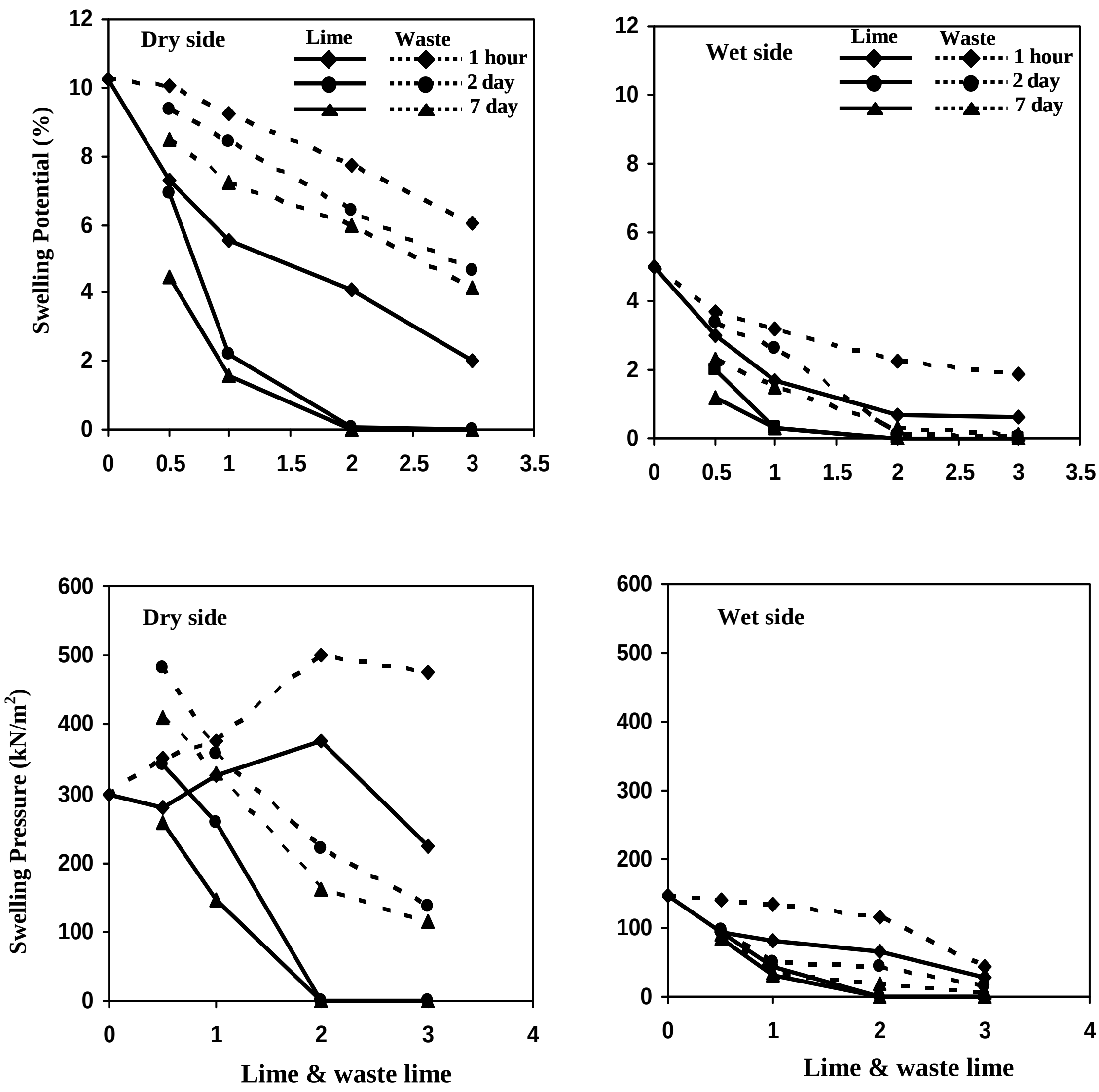

Fig. (6) Effect of Lime & Waste Lime on Swelling Pressure and Potential for Al-Rashedia Soil at Different Curing Time

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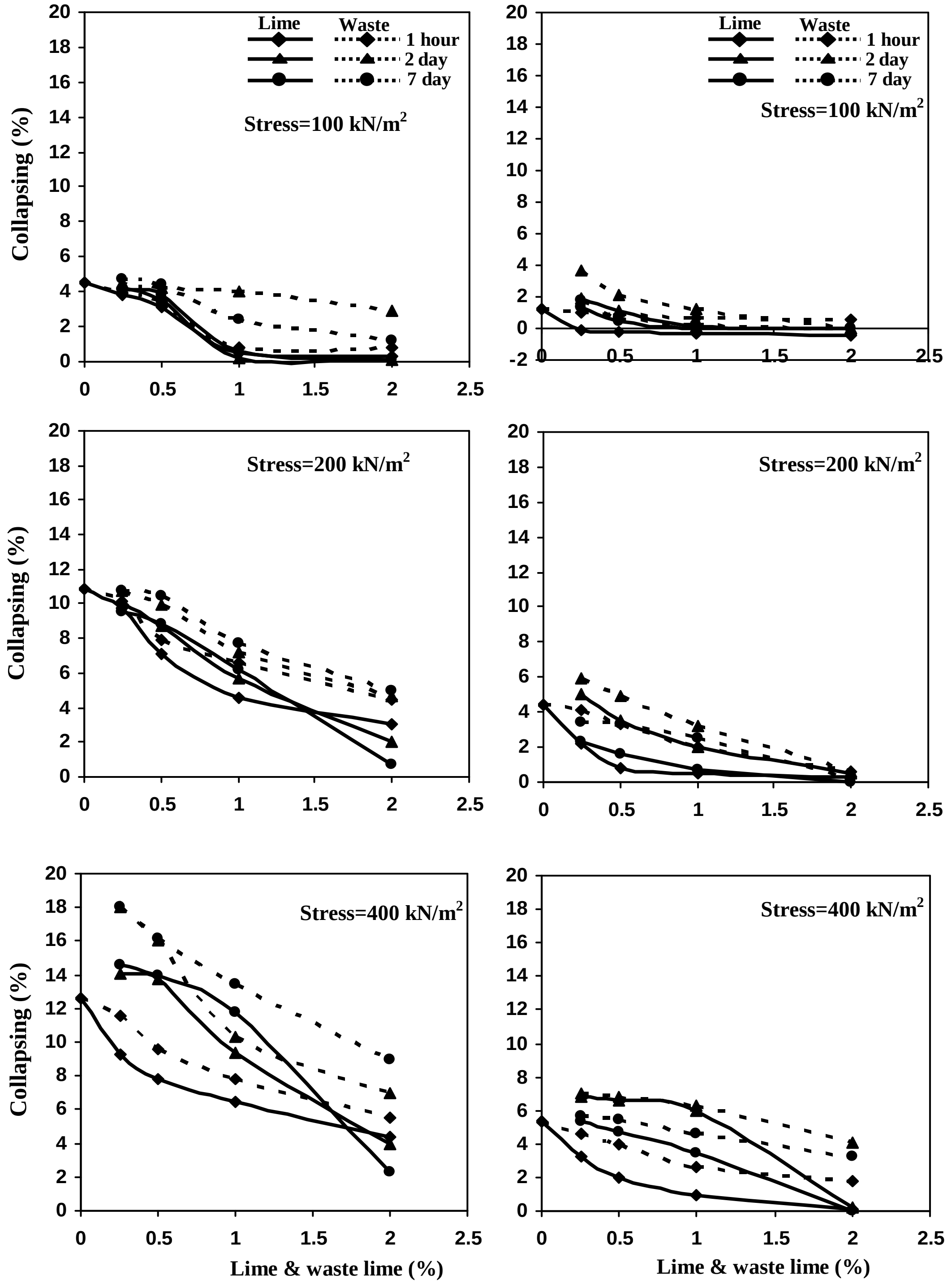

[A] [B]

Fig. (7) Effect of lime & waste lime on Collapse potential for Al-Rashedia Soil under different curing time.

A- Samples prepared at γ_d=14.78 kN/m^3, w/c =9.6%.

B- Samples prepared at γ_d=15.58 kN/m^3, w/c =14.4%.

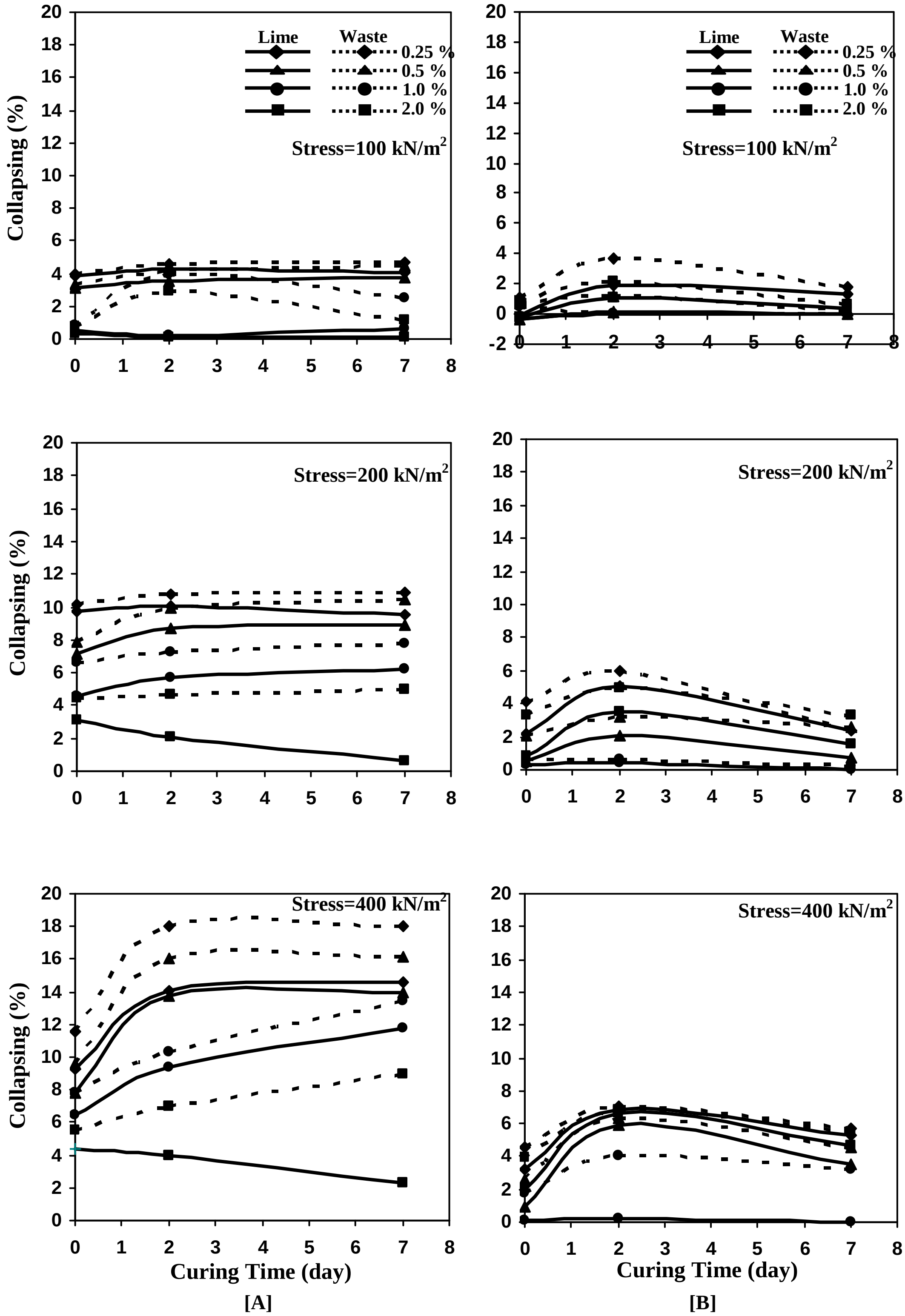

Fig. (8) Effect of Curing Time on Collapse Potential of Treated Soil at Different Stresses.

A- Samples prepared at γ_d=14.78 kN/m^3, w/c =9.6%.

B-Samples prepared at γ_d=15.58 kN/m^3, w/c =14.4%.

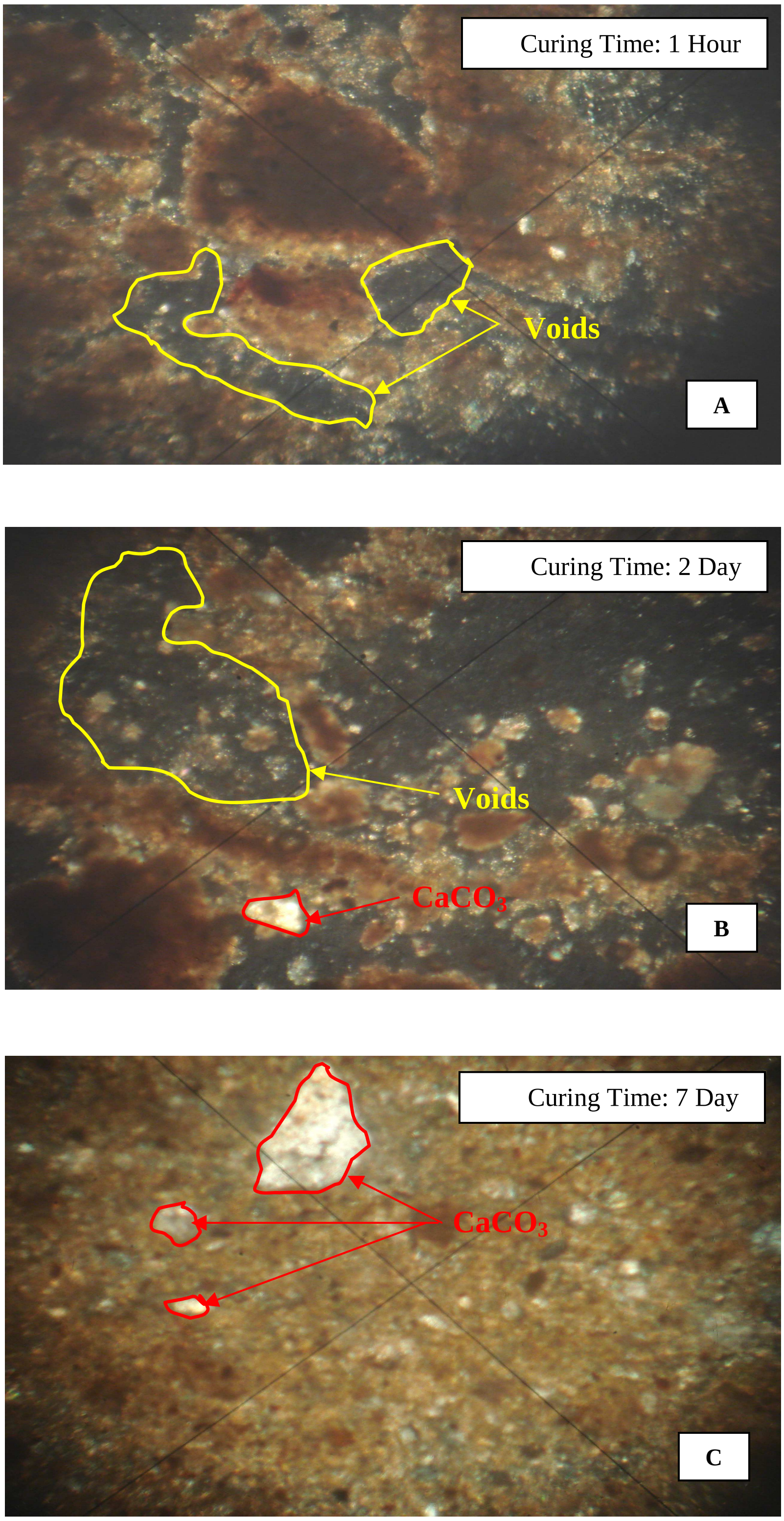

Fig.(9) Optical Microscopic Photos For (1%) Lime Treated Soil

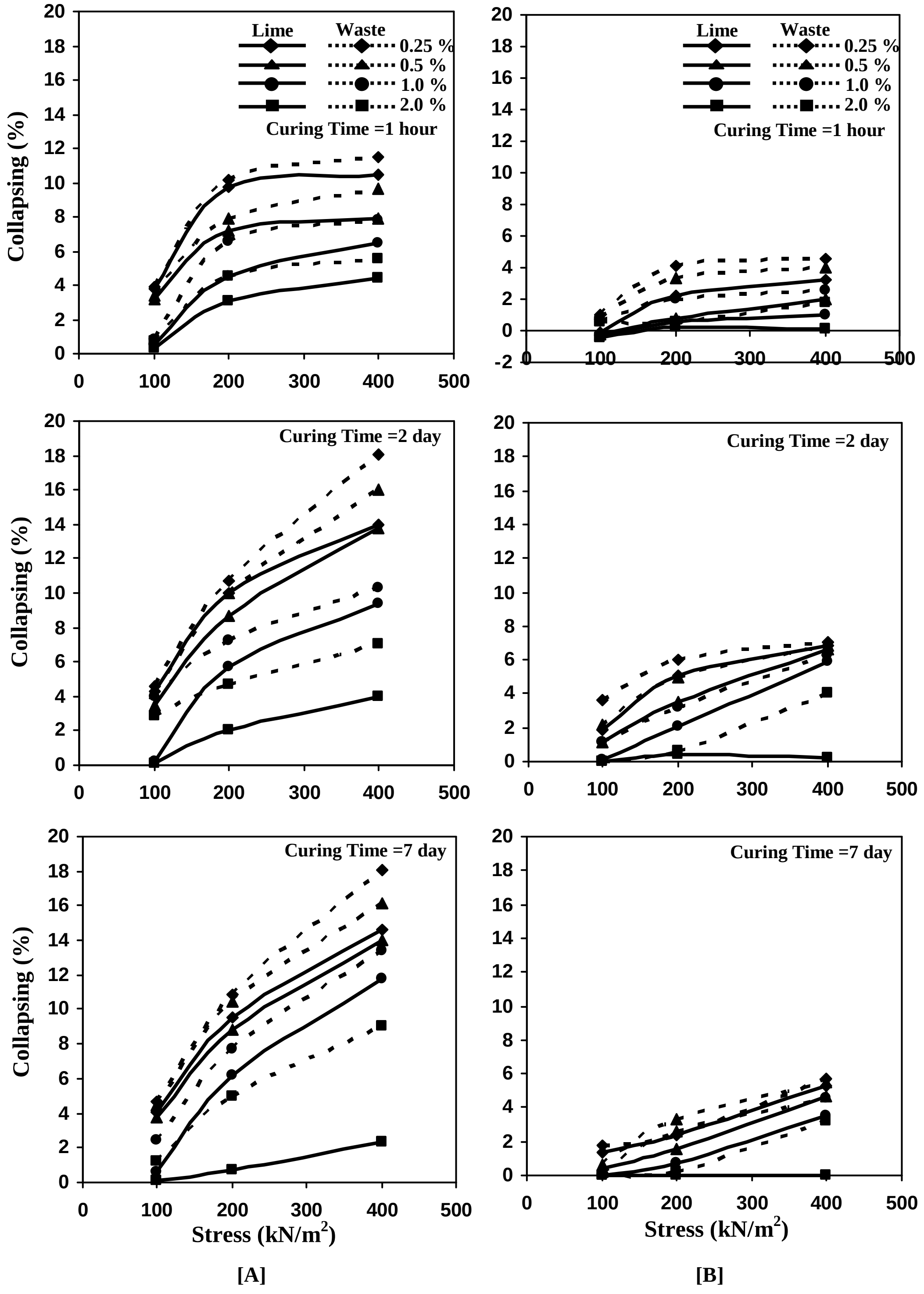

Fig. (10) Effect of stresses on Collapse potential of treated Soil at different curing time.

A- Samples prepared at γ_d=14.78 kN/m^3, w/c =9.6%.

B-Samples prepared at γ_d=15.58 kN/m^3, w/c =14.4%.

Table (1) Chemical & Physical Properties of natural soil

Test Type		Value
Organic Matter (%)		5.12
SO_3 (%)		0.096
Total soluble salts (%)		1.16
Specific gravity		2.71
Liquid Limits (%)		42
Plastic Limit (%)		22
Plasticity Index (%)		20
Soil classification		CL
Clay (%)		28
Silt (%)		55
Sand (%)		17
Natural Dry unit weight (kN/m^3)		14.91
Initial water content (%)		16
Standard compaction	Max. Dry unit weight (kN/m^3)	16.4
	Optimum moisture content (%)	20.3
Modified compaction	Max. Dry unit weight (kN/m^3)	18.34
	Optimum moisture content (%)	13.5

Table (2) Chemical Composition of Lime, Waste Lime

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	AL_2O_3	Fe_2O_3	SiO_2	MgO	H_2O
Lime %	76.0	4.1	4.1	0.17	0.04	11.1	4.019	0.09
Waste lime%	43.6	8.19	12.74	14.9	0.42	16.9	3.13	0.1

Table (3) Laboratory Test of Natural and Treated Soil

Test	Test method	Dimensions (mm)	Curing condition	Note
Swelling pressure	Constant volume	D=63.5 H=19.0	0,2,7 day @ 25^oC	Samples compacted at dry & wet side(w/c=9.6, 17.6) %
Swelling potential	Free swell	D=63.5 H=19.0	0,2,7 day @ 25^oC	
Unconfined compressive strength	---------	D=51 H=102	0,2,7 day @ 25^oC	Sample compacted in 5 layers (γ_d=18.34 kN/m^3,w/c=13.5%)
Collapse index & collapse potential	ASTM 2003	D=63.5 H=19.0	0,2,7 day @ 25^oC	Samples compacted at (w/c=9.6, 14.4)%

Table (4) Hydrogen Number of Natural and Treated Soil [22]

Type of treated material	% Stabilizers						
	0	1	2	3	4	6	8
Lime	7.85	11.85	11.93	12.74	12.72	12.70	-
Industrial waste lime	7.85	10.55	11.66	12.11	12.26	12.33	12.3

Table (5) Index Properties of Natural and Treated Soil

Type of treated material	Property		% Stabilizers			
			0	**2**	**3**	**6**
Lime	Atterberge limit (%)	w_L	42.0	40.0	-	-
		w_P	22.0	32.0	NP	NP
		I_p	20.0	8.0	-	-
	Classification		CL	ML	-	-
Industrial Waste lime	Atterberge limit (%)	w_L	42.0	41.0	39.0	-
		w_P	22.0	25.0	30.0	NP
		I_p	20.0	16.0	9.0	-
	Classification		CL	CL	ML	-