Effect of Treating Expansive Soil with Lime

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Abstract

Expansive soil poses significant challenges for civil engineers worldwide since it seriously affects the structures built upon it. This soil has a very active group of minerals called montmorillonite, which is responsible for the significant volume change it exhibits. For a number of years, chemical additives have been utilized to stabilize soil, with various levels of success. Soil stabilization has involved the use of a variety of additives, including cement, lime, polymers, salts, and combinations of these. However, lime is very often used for expansive soil stabilization as it improves the soil's mechanical properties. The effects of adding three percentages of lime (3%, 6%, and 9%) to expansive soil to improve its engineering properties are investigated through several tests. The laboratory tests consist of standard compaction, sieve analysis, Atterberg limits, hydrometer, California bearing ratio, consolidation test, swelling percent, swelling pressure and specific gravity. The test results displayed that the plasticity index, liquid limit, swelling potential, swelling pressure and maximum dry density, specific gravity decreased using (3%, 6%, and 9%) lime. In contrast, the plastic limit, and optimum moisture content increased using (3%, 6%, and 9%) lime. The California bearing ratio is increased from (12.13% to 14.65%) by adding (9% L). The rebound index and compression index are decreased from (0.070 to 0.030) and from (0.581 to 0.193) respectively by adding (9% L). The swelling percent and swelling pressure are reduced from (18.77% to 6.03%) and from (735.75 Kpa to 205.11 Kpa) respectively by adding (9% L).

Keywords: Expansive Soil, Soil Stabilization, Lime, Swelling Characteristics, California Bearing Ratio.

تأثير معالجة التربة المنتفخة بالجير

ساره رعد صالح ، قاسيون سعد الدين محمد شفيق

الخلاصة:

تشكل التربة الانتفاخية تحديات كبيرة للمهندسين المدنيين في جميع أنحاء العالم لأنها تؤثر بشكل خطير على الهياكل المبنية عليها. تحتوي هذه التربة على مجموعة نشطة جدًا من المعادن تسمى المونتموريلونايت، وهي المسؤولة عن التغير الكبير في الحجم الذي تظهره. لعدة سنوات، تم استخدام المضافات الكيميائية لتثبيت التربة، مع مستويات مختلفة من النجاح. وقد شمل تثبيت التربة استخدام مجموعة متنوعة من المواد المضافة، بما في ذلك الأسمنت والجير والبوليمرات والأملاح ومجموعات منها. ومع ذلك، غالبًا ما يستخدم الجير لتثبيت التربة الانتفاخية لأنه يحسن الخواص الميكانيكية للتربة. تم دراسة تأثير إضافة ثلاث نسب من الجير (٣٪، ٦٪، ٩٪) إلى التربة الانتفاخية لتحسين خواصها الهندسية من خلال عدة اختبارات. تتكون الاختبارات المعملية من الرص القياسي، والتحليل المنخلي، وحدود أتربرك، والمكثاف، ونسبة تحمل كاليفورنيا، وفحص الانضمام، وامكانية الانتفاخ، وضغط الانتفاخ، والوزن النوعي. أظهرت نتائج الاختبار أن مؤشر اللدونة وحد السيولة وامكانية الانتفاخ والكثافة الجافة العظمى والوزن النوعي انخفض باستخدام (٣٪، ٦٪، ٩٪) من الجير. وفي المقابل زاد حد اللدونة ومحتوى الرطوبة الأمثل باستخدام (٣٪، ٦٪، ٩٪) من الجير. تمت زيادة نسبة تحمل كاليفورنيا من (١٢,١٣٪ إلى ١٤,٦٥٪) بإضافة (٩%). تم تخفيض معامل الانتفاخ ومعامل الانضغاط من (٠,٠٧٠ إلى ٠,٠٣٠) ومن (٠,٥٨١ إلى ٠,١٩٣) على التوالي بإضافة (٩٪). تم

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تقليل نسبة الانتفاخ وضغط الانتفاخ من (١٨,٧٧٪ إلى ٦,٠٣٪) ومن (735.75 إلى 205.11) على التوالي بإضافة (٩٪).

1. Introduction

Swelling soils are located in semi-arid and arid areas worldwide. These soils pose challenges to structural engineering due to their capability to shrink during the dry season and expand during the wet season [1], [2], [3], [4], [5]. Swelling soils are an issue that presents challenges worldwide to civil engineers. They are seen as a possible natural risk that can do a lot of damage to buildings if they are not treated properly [6]. More damage is caused to structures by expansive soils than by any other natural hazard, such as earthquakes and floods, especially to light buildings and pavements [7]. In semi-arid areas, damage from swelling has been seen clearly over the last few decades in the form of cracking of building foundations, pavements, roadways, slab-on-grade members, channel and reservoir linings, irrigation systems, underground pipes, and water lines [8]. Adding small quantities of lime enhances the properties of clayey soils, leading to better construction materials [9]. Farooq et al. [10] investigated the impact of the curing time and lime on the unconfined compressive strength (UCS) of clayey soil and showed that a 4% addition of lime with clayey soil rose 4 to 6 times the UCS of the soil at various curing periods. Abass [11] concluded that the expansive soil's swelling behavior had enhanced with the addition of lime. The best enhancement occurs at 15% lime for free swell and 9% lime for swell pressure. Therefore, it was found that lime was a very good option for stabilizing the expansive soil characteristics. Malhotra and Naval [12] conducted tests in the lab on expansive soils that had been treated with inexpensive additives like fly ash and lime. In this paper, the tests include the Atterberg limits, the standard compaction, and the differential free swelling test. The study showed that the stabilized expansive soil has a lower swelling potential and an increase in optimum moisture content. Al Hassany [13] examined the impact of adding lime and silica fume into the expansive soil. The study showed that adding a silica fume-lime mixture decreases the plasticity index, liquid limit, maximum dry density, and free swell but it increases plastic limit, California Bearing Ratio, optimum moisture content, and unconfined Compression Strength which was enhanced with the increasing the curing period. The maximum reduction in swelling percentage occurs at 92.93% when 4% lime and 8% silica fume are added. The results display that swell percentage decreases as the number of cycles increases. Barasa et al. [14] studied the properties of the California Bearing Ratio and the plasticity index of lime-stabilized expansive clay soil. The lime percentages used to stabilize clay soil were (4%, 5%, and 6%). Soil shrinkage and swelling behavior, and therefore plasticity, can be reduced by adding lime. The California bearing ratio increased as lime quantity was increased. Mohammed Shafiqu and Abass [15] focused on the enhancement of properties of expansive soil through the combination of lime (L) and cement kiln dust (CKD). The study aimed to decrease the swelling percentage of the soil whereas it enhances the geotechnical properties of it. The study indicated that the addition of (6% L+16% CKD) decreased the swelling potential from 19% to 2%. Furthermore, the highest California Bearing Ratio (CBR) value was achieved by adding (9% L + 16% CKD), which improved the CBR from 5.45 to 35.95. Mohammed Shafiqu [16] found that the addition of polyacrylamide polymer (PAM) with lime (L) and cement kiln dust (CKD) improved the properties of the clayey soil more than adding lime and CKD only. The optimum percentage of (LCKD and PAM) that achieved the best results was determined to be 3% lime, 8% CKD, and 5% PAM. This combination resulted in a significant reduction in free swell value by 94.5%, an increase in unconfined compression strength by 262% for curing periods of 7 days and 400% for curing 28 days. Also, the study showed an improvement in the California Bearing Ratio value (from 5.45 to 27). Boobalan and Devi [17] studied the influence of lime and coir fiber on UCS, where the results showed that UCS reaches a maximum value when adding 1% fiber and 5% lime.

2. Main Objective of this study

This study aims to investigate how adding lime affects the properties of prepared expansive soil (40% bentonite + 60% natural soil), including swelling characteristics, CBR, and Maximum dry density.

3. Materials

3.1. Natural Soil

Soil samples for this research were obtained from Al-Zafaraniya, located southeast of Baghdad, at a depth ranging from 2 to 2.5 meters below the soil surface as shown in Fig. (1). This was lean clay soil (which consists of 50% clay, 44% silt, and 6% sand).

3.2. Bentonite

Bentonite utilized in this investigation was collected from Wadi Hauran, Anbar governorate, western Iraq as shown in Fig. (1). It was used to prepare the expansive soil.

3.3. Prepared Soil

In the lab, 60% of natural soil was mixed with 40% of bentonite to prepare the highly expansive soil. Using an odometer test, the prepared soil's swell was (18.77%), and the prepared soil was classified according to ASTM D2487 [18] as (CH). A chemical analysis was conducted on the prepared soil to determine the SO_3 %, total soluble salt %, gypsum %, pH, and organic materials % as displayed in Table (1). Table (2) includes the physical characteristics of natural and prepared soil.

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Table (1): Chemical analysis of prepared soil.

Tests	Results
SO_3%	*0.823*
T.S.S%	*3.190*
Gypsum%	*1.598*
pH	*8.03*
Organic materials %	*0.664*

Table (2): Illustration of the physical characteristics of natural and prepared soil.

The property	Natural soil	Prepared soil	standard
Gs	*2.66*	*2.60*	*ASTM D854*
LL %	*37*	*85*	*ASTM D4318*
PL %	*19*	*29*	*ASTM D4318*
PI %	*18*	*56*	*ASTM D4318*
Sand %	*6*	*0*	*ASTM D422*
Silt %	*44*	*41*	*ASTM D422*
Clay %	*50*	*59*	*ASTM D422*
MDD (g/cm³)	*1.730*	*1.473*	*ASTM D698*
OMC %	*16*	*22*	*ASTM D698*
Swelling %	*1*	*18.77*	*ASTM D4546-96*
Classification according to the Unified Classification System UCS)	*CL*	*CH*	*ASTM D2487*

3.4. Lime

In this study, the lime used was the hydrated lime manufactured in Iran as shown in Fig. (1).

Figure (1): Materials used in this study.

4. Preparation of Sample

In the lab, bentonite was mixed with natural soil to prepare artificial expansive soil. The natural soil and bentonite were dried in an oven at a temperature of (105 °C) for a duration of 24 hours. Subsequently, the natural soil was ground by the Los Angeles machine. By dry mass, 40% bentonite was mixed with 60% natural soil. These percentages were chosen in order to get an appropriate swell percentage for the research.

Lime was mixed by hand with the untreated soil in percentages (3%, 6%, and 9%) until the mixture became homogeneous and then put into nylon bags as shown in Fig. (2). The percentages added to the soil were chosen based on many research papers such as [11], [19], and [20].

Figure (2): Nylon bags containing the mixture.

5. Testing Program

5.1. Grain Size Distribution Test

Grain size distribution tests (hydrometer and sieve analysis) are performed on bentonite, prepared soil, and natural soil. Sieving is typically used to determine the coarse-grained soil's grain size distribution. On the other hand, if there are large amounts of soil fines (silt and clay) passing through a No. 200 sieve, the soil is washed through a No. 200 sieve.

The hydrometer test, as shown in Fig. (3), can be used to determine the fine-grained soil. This test uses 50 g of dry, pulverized soil and is dependent on the sedimentation particles of soil in water. The results of the grain size distribution tests followed ASTM D421 [21] and ASTM D422 [22].

Figure (3): The hydrometer test.

5.2. Consistency Limits Tests

According to ASTM D4318 [23], liquid and plastic limits are determined on prepared soil, natural soil, and prepared soil mixed with various addition percentages. The soil utilized for these tests was sieved using a No. 40 sieve or 0.425 mm. The Casagrande device is used to measure the liquid limit.

5.3. Specific Gravity Test

The specific gravity of soil is calculated in accordance with ASTM D854 [24]. These procedures include using a water pycnometer to determine the soil solids that are passing through a No.4 sieve (4.75 mm).

5.4. Compaction Test

This test is done according to the ASTM D698 [25] laboratory standard compaction test. In order to determine the moisture-density relationship for the untreated and treated soil, the specimens that passed through the No. 4 sieve were then compacted using a 2.5 kg manual hammer, 25 blows per layer.

5.5. Swelling Test

Using an odometer test apparatus, the test was done on both treated and untreated soil in accordance with ASTM D4546-96 [26] specifications. Using a manual hammer, the samples were compacted to their maximum dry density (MDD) and optimum moisture content (OMC) from a standard compaction test inside the consolidation ring. The compacted sample's final height is 16 mm less 4 mm than the consolidation ring's height to make sure that the sample will remain confined throughout swelling, and its diameter is the same as the ring's, at 75 mm. following compaction, two filter papers, and two porous stones were positioned at the bottom and top of the sample. After that, the sample is put into the odometer device and given a 1 kpa seating pressure. The dial gauge is then set to zero, and the sample is submerged in distilled water. The sample is eventually permitted to swell freely at a seating pressure of 1 kpa. By a dial gauge of 0.002 mm/division, the increase in specimen height was recorded until the swelling was complete. The swell percent is the final swell achieved by the sample before adding load, whereas the swell pressure refers to the pressure needed to restore the sample to its initial height.

5.6. Consolidation Test

The test was conducted in accordance with ASTM D2435-96 [27]. This test's objective is to determine the magnitude and rate of decrease in volume that occurs when a soil specimen that is laterally confined is exposed to various vertical pressures. The odometer apparatus was used to prepare the samples in accordance with the same procedure as the free swell test. Weights are added to the hanger to begin the consolidation test. Loads were applied at increments of 50, 100, 200, 400, 800, and 1600 kpa, and were removed at 800, 400, and 200 kpa. The load occurred throughout a period of 24 hours. Changes in specimen height are measured for the consolidation process, and these data are utilized to draw the relationship between void ratio and the effective stress and to determine the rebound index (Cr), and compression index (Cc).

5.7. California Bearing Ratio (CBR) Test

The CBR test was performed by ASTM D 1883-87 [28] to define the potential strength of untreated and treated soil specimens. Both in-lab and on-site execution of the CBR test are possible. The specimens were compacted in three layers, each with 56 blows at their optimum moisture content and maximum dry density, corresponding to the values achieved in the 6" standard proctor mold.

Each specimen was put into the CBR testing device, and then the estimated surcharge load was applied. The specimen was then penetrated by a piston with a 50 mm end diameter at a rate of 1.27 mm/min. The load reading was recorded every 0.5 mm penetration. The load against the penetration curve is then drawn.

6. Results and Discussion

6.1. Specific Gravity Test

Fig. (4) displays how the specific gravity of untreated soil decreases as the lime content increases. This means that prepared soil-lime mixtures are lighter than prepared soil [29].

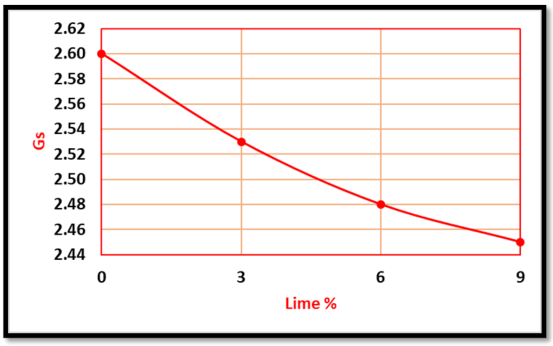

Figure (4): Impact of lime on the specific gravity of expansive soil.

6.2. Consistency Limit Test

The results of the impact of three percentages of lime (3%, 6%, and 9%) on the consistency limits of untreated soil are plotted in Fig. (5), (6), and (7). The results show that while plastic limits (PL) increase with increasing lime content, liquid limit (LL) and plasticity index (PI) values are reduced. A maximum reduction in both the plasticity index and the liquid limit is observed when 9% L is added. This addition reduced the plasticity index (from 56% to 23%) and the liquid limit (from 85% to 82%). The addition of (9% L) results in the maximum increase in the plastic limit (from 29% to 59%). Flocculation and agglomeration have an influence on the texture of expansive clay soils by making clay particles clump together to form bigger ones. These reactions tend to reduce the LL and PI and increase the PL [30].

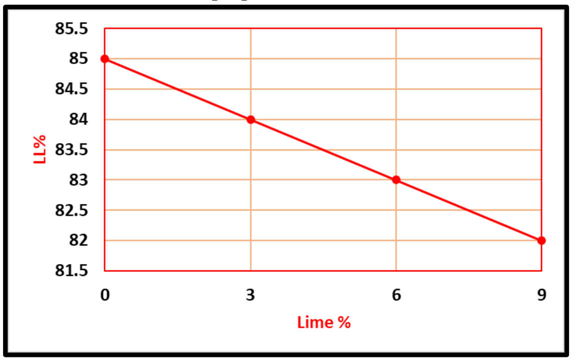

Figure (5): Impact of lime on the liquid limit of expansive soil.

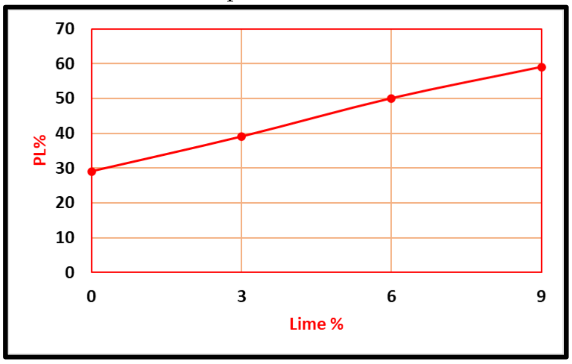

Figure (6): Impact of lime on the plastic limit of expansive soil.

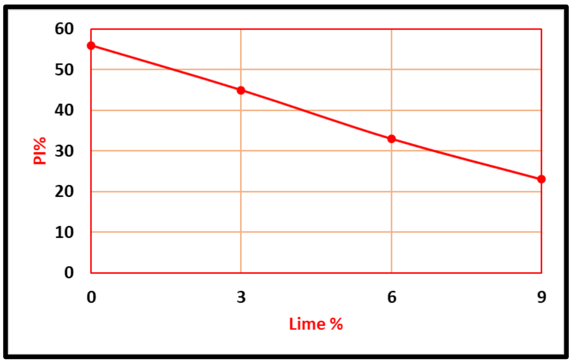

Figure (7): Impact of lime on the plasticity index of expansive soil.

6.3. Compaction Test

The relationship between optimum moisture content and percentages of lime addition to expansive clay soil is shown in Fig. (8). Fig. (9) displays the relationship between maximum dry density and percentages of lime addition to expansive clay soil, whereas Fig. (10) illustrates the impact of adding (3%, 6%, and 9%) of lime on dry density-water content relationships of expansive soil. The maximum dry density of prepared soil decreases with rising lime content, while the optimum moisture content increases with rising lime content. A flocculated structure resists compaction effort and also occupies more space in the soil matrix, resulting in a decrease in maximum dry density (MDD). On the contrary, the impact of lime in the mixture increases the necessary amount of water as a result of its dissociation process. Consequently, the Optimum Moisture Content (OMC) encounters an increment, as stated by [9] and [31].

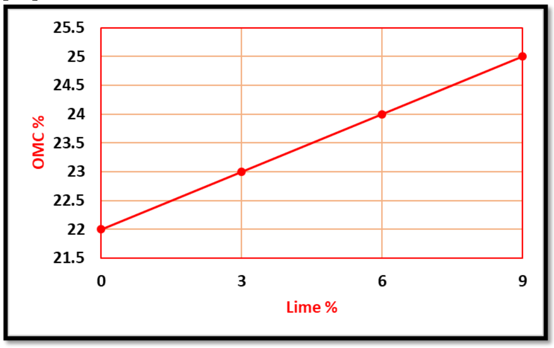

Figure (8): Impact of lime on the optimum moisture content of expansive soil.

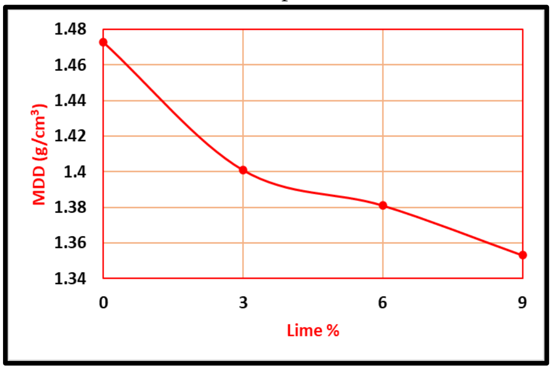

Figure (9): Impact of lime on the maximum dry density of expansive soil.

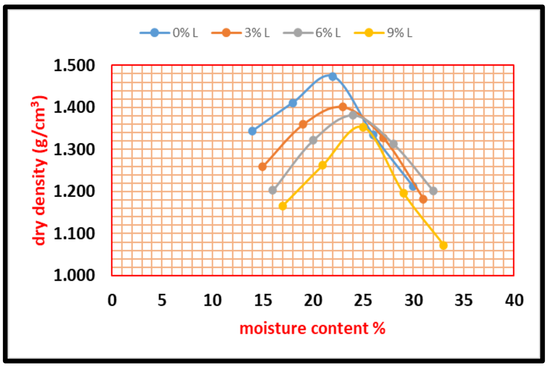

Figure (10): Impact of lime on the water content-dry density relationship of expansive soil.

6.4. Swelling Test

The impact of adding (3%, 6%, and 9%) lime on the swell % and swell pressure values of the prepared soil are studied. The decrease in the free swell and swell pressure of prepared soil with increasing lime content is shown in Fig. (11) and (12) respectively. The decrease in free swelling may be caused by chemical reactions and the replacement of some components of expansive material with non-expansive material. The decrease in swell percentage was affected by having a high calcium content [32]. Fig. (13) shows the increase in swell % of soil with time in days.

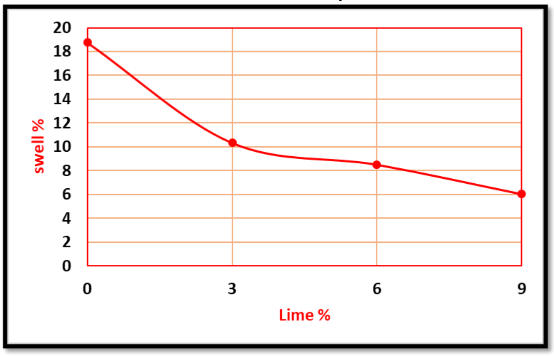

Figure (11): Impact of lime on the free swell of expansive soil.

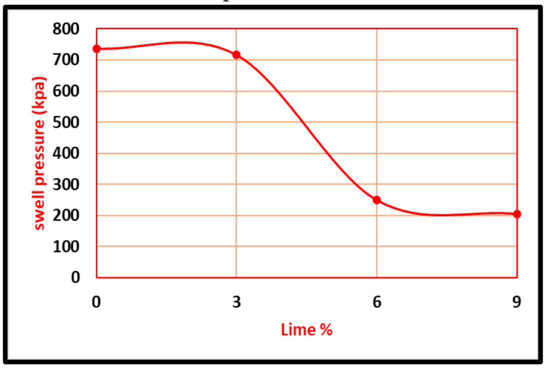

Figure (12): Impact of lime on the swell pressure of expansive soil.

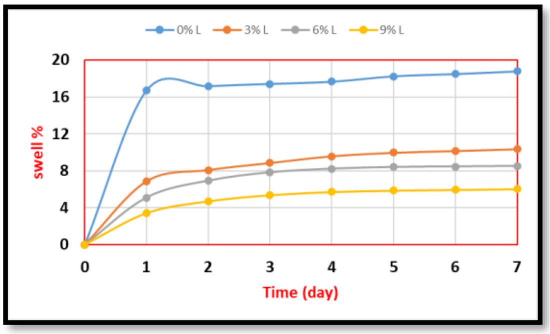

Figure (13): Impact of lime on the relationship between swell % and time (days).

6.5. Consolidation test

The compression index (Cc) and rebound index (Cr) values of prepared soil treated with (3%, 6%, and 9%) lime are studied. The value of the compression index of prepared soil decreases with rising lime content as shown in Fig. (14). The value of the rebound index of prepared soil decreases with increasing lime content as shown in Fig. (15). The reduction in the compression index and rebound index of specimens can be attributed to the addition of low plastic material and the interplay between clay minerals and additive particles [33].

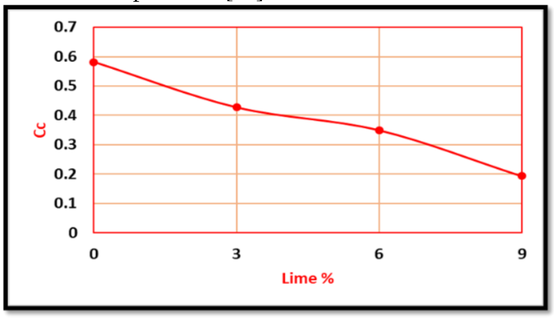

Figure (14): Impact of lime on the compression index of expansive soil.

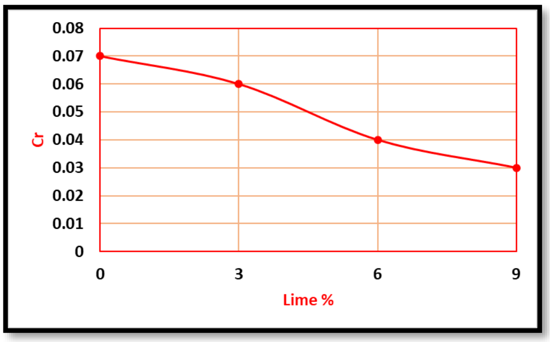

Figure (15): Impact of lime on the rebound index of expansive soil.

6.6. California Bearing Ratio Test

Fig. (16) displays the impact of adding (3%,6%, and 9%) of lime on California bearing ratio values of prepared soil. In general, the California bearing ratio increases with rising lime content. The formation of cementitious compounds, (CSH) and (CAH), resulting from calcium obtained from lime and silica or alumina obtained from the soil, resulted in this increase. CSH and CAH are cementitious compounds that share similarities with the products formed in Portland cement. They create a matrix that strengthens the soil layers that have been stabilized [34].

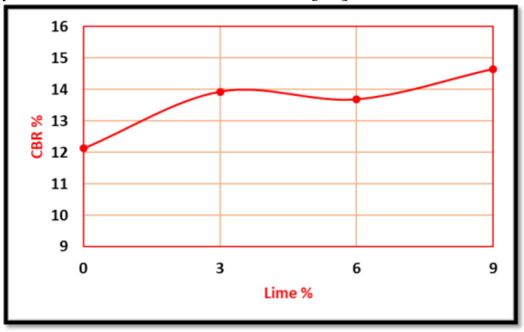

Figure (17): Impact of lime on California bearing ratio of expansive soil.

7. Conclusion

1- With rising lime content, the specific gravity of prepared soil decreases.

2 – Adding 9% lime resulted in the maximum decrease in the plasticity index (from 56% to 23%) and reduced the liquid limit of prepared soil (from 85% to 82%). Additionally, adding 9% of lime increases the plastic limit (from 29% to 59%).

3- The optimum moisture content of prepared soil increases from 22% to 25% with rising lime content, while maximum dry density decreases from 1.473 g/cm³ to 1.353 g/cm³ with rising lime content.

4- The CBR value of prepared soil increases with the increase in lime content. The maximum increase is found with the addition of (9% L) which increases the CBR value from 12.13 % to 14.65 %.

5- By raising the lime content, the swelling potential and swelling pressure of prepared soil decrease. The addition of (9% L) reduce the swelling potential and swelling pressure from 18.77 % to 6.03% and from 735.75 Kpa to 205.11 Kpa respectively, which is the maximum decrease.

6- The rebound index and the compression index for the consolidation test of prepared soil decrease with the increase in the lime content. The greatest reduction is observed, when (9% L) is added which decreases the compression index (from 0.581 to 0.193) and swelling index (from 0.070 to 0.030).

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