Effect of Calcium Chloride on Highway Subgrade Soil Containing High Soluble Salts

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Abstract

The quality of the subgrade will greatly influence the pavement design and the service life of the pavement. This study is performed to evaluate the effect of Calcium Chloride ($CaCl_2$) on the strength of subgrade soil containing high percentage of soluble salts. The soil sample brought from Al-mahmodia city south of Baghdad, it contains about (15.685%) of soluble salts by weight of soil content. California Bearing Ratio (CBR) value is determined for the natural soil and Calcium Chloride ($CaCl_2$) with different number of blow per layer (10, 25 and 56) for (4-days) soaking periods to achive CBR value at 95% relative modified proctor. Durability tests (effect of long term soaking and drying) for the subgade stabilized with (2.5% $CaCl_2$) and compacted at 95% relative modified proctor is determined, the soaking periods are (4, 7, 14, 28, 60 days), the results of soaking periods are (7.961, 6.446, 4.436, 3.398, 2.427) respectively and the results of soaking and drying periods are (8.258, 6.531, 4.563, 3.511, 2.621). The results of soaking and drying show reduction in both (CBR) value and (T.S.S) with the time.

تاثير كلوريد الكالسيوم على تربة ما تحت الاساس للطرق المحتوية على نسبة عالية من الاملاح الذائبة

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الخلاصة

نوعية تربة ماتحت الاساس تؤثر بشكل كبير على تصميم طبقات التبليط والعمر التصميمي للطبقات . اجريت هذه الدراسة لتقييم تاثير اضافة كلوريد الكالسيوم على قابلية تحمل تربة ما تحت الاساس المحتوية على نسبة عالية من الاملاح الذائبة حيث وجد ان نسبة الاملاح الذائبة هي (15.685 ٪) من وزن التربة. تم تحديد نسبة التحمل الكليفورني (CBR)

للتربة الطبيعية و كلوريد الكالسيوم من المثبتات بعدد ضربات مختلفة (10، 25 ، 56) وتحت تاثير الغمر لمدة (4 ايام) مع وضع احمال اضافية بمقدار (10 باون) ، حيث تم من خلال الفحص تحديد عدد الضربات ونسبة التحمل الكلفورني (CBR) المطلوبة للحصول على (95٪) من كثافة حدل فحص بروكتور المعدل. فحوصات المتانة (Durability Tests) (تاثير الغمر والتجفيف على المدى الط ويل) اجريت لتربة ماتحت الاساس (Subgrade) المثبتة بنسبة (2.5 ٪ كالسيوم كلوريد) والمحدولة بنسبة (95٪) من كثافة حدل بروكتور المعدل مدة الغمر كانت (4، 7، 14، 28 و 60 يوم) ومدة الغمر والتجفيف ((4، 7، 14، 28 و 60 يوم غمر و تجفيف اي 4 يوم غمر و 4 يوم تجفيف لنفس النموذج وهكذا بالنسبة لبقية النماذج) ، نتائج فحص التحمل الكليفورني (CBR) بالنسبة للغمر كانت كالاتي (7.961,6.446، 4.436، 3.398، 2.427) ونتائج فحص التحمل الكليفورني بالنسبة للغمر والتجفيف كانت كالاتي (8.252، 6.531، 4.563، 3.511، 2.621) . النتائج اظهرت ان نسبة التحمل الكليفورني (CBR) ونسبة الاملاح الذائبة (T.S.S) قد انخفضت مع الزمن.

1. Introduction:

Good quality subgrade soils are preferable for durable roads but they are not always available for highway construction. The highway engineer designing a road pavement may be encountered by weak or unsuitable subgrade. In this case the following methods to overcome this problem can be considered. Firstly, improvement in-situ materials by normal compaction methods and designing for the modified properties. Secondly, import suitable materials from the nearest convenient source and replace the site materials. Thirdly, improvement in the properties of the existing materials by incorporating some other materials; this process is known as "soil stabilization (***Ingles and Metcalf***, **1972**)[6].

El − Janabi (**1995**)[4] studied experimentally the effect of long term soaking on the strength of Tikrit granular gypsiferous soil [A- 3(0) soil group with 64% gypsum content].He prepared CBR samples at 95% relative modified AASHTO compaction. After soaking the sample it was found that the reduction in CBR value after four days of soaking is about (32%) of the original unsoaked CBR. However, at the end of days soaking period the loss in CBR value is about (84%) relative to the initial unsoaked CBR value.

Al − Busoda (**1999**)[1], used (2.5%) by weight of calcium chloride as additive to treat the gypseous soil, the treatment causes a decrease in the rate of dissolved gypsum upon leaching. While the shear strength and its parameters were unaffected upon leaching. Moreover, the treated unleached samples showed a decrease in compressibility characteristics.

Texas A&M University found that an addition of calcium chloride ($CaCl_2$) and fly ash (Class C and F) to soils and crushed limestone significantly increases the effectiveness of road base stabilization and base stabilization along with dust control in Full-Depth-Recycling (FDR) of old asphalt roads. It was also shown that, class F fly ash tends to give more durable early higher strength than Class C fly ash (***McDonald*** **2003**; ***Hilbrich*** **2003**)[7].

According to the Virginia Transportation Research Council (VTRC), calcium chloride has been used as a dust suppressant, but it is also referred to as a stabilizer because of its ability to alter material properties such as strength, compressibility and permeability. Essentially, the function of this chemical is to agglomerate fine particles and bind them together (***Bushman et al.* 2004**).[3]

2. Materials

2.1. Soil:

The experimental work is carried out on soil sample obtained from the Al-Mahmudiyah city south of Baghdad, the reason of selection this area because new highway construct in it. This sample is taken from (1-1.5m) depth below the natural ground surface then packed in nylon bags. The soil sample is taken to soil mechanics laboratory, College of Engineering, Al-Mustansiriya University for testing, where it is mixed well by hand before conducting any test to be homogeneous. Standard tests were performed to determine the physical and chemical properties of the soil(***Ibrahim*, 2014**)[5]. Details are given in Table 1.

Grain size distribution of the soils is shown in Figure 1. According to the unified soil classification system (USCS), soil is classified as CL.

Table (1): Physical Properties of the Soil Sample.

Index property	No. of standard specification	Index values
Liquid limit (L.L.) %	*ASTM* D 4318 (2002)	32.3
Plastic limit (P.L.) %	*ASTM* D 4318 (2002)	19.2
Plasticity index (P.I.) %	*ASTM* D 4318 (2002)	13.1
Specific gravity (Gs)	ASTM D854-02 (2002)	2.54
Gravel (larger than 2mm) %	ASTM D422-63 (2002)	0
Sand (0.075 to 2mm) %	ASTM D422-63 (2002)	7.9
Silt (0.005 to 0.075 mm) %	ASTM D422-63 (2002)	65.3
Clay (less than 0.005mm) %	ASTM D422-63 (2002)	26.8
AASHTO Classification	AASHTO M145-82 (1993)	A-6
Unified Soil Classification System (U.S.C.S.)	(ASTM D 2487-00 (2002)	CL
Maximum dry density (KN/m^3)	ASTM D1557-02, (2002) ASTM D698-12, (2002)	18.7 17.64
Optimum moisture content (%)	ASTM D1557-02, (2002) ASTM D698-12, (2002)	11 13.5

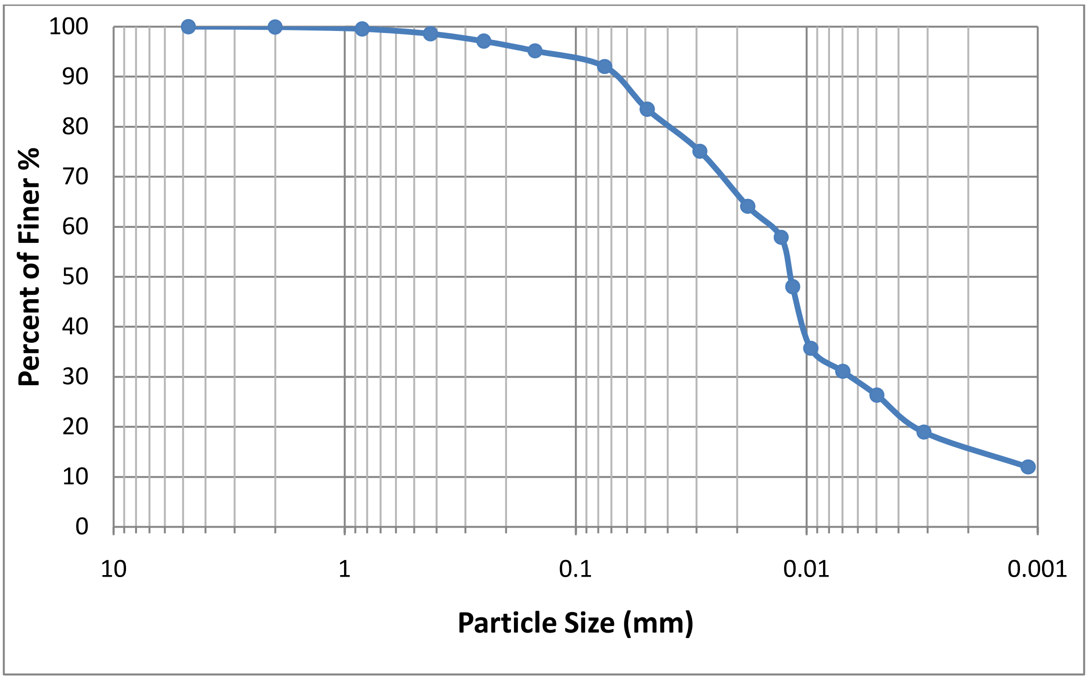

Figure (1): Grain Size Distribution of Soil Sample.

2.2. Calcium Chloride ($CaCl_2$) :

The commercial product of Calcium Chloride ($CaCl_2$), with purity of (98 %), is used in this study to improve the engineering properties of the soil .The Calcium Chloride ($CaCl_2$) is a white color and crystalline solid in the hydrous state.

For this study the amount of the Calcium Chloride ($CaCl_2$) used is (2.5%) by dry weight of soil. Iraq specification detected that for stabilizing highway with calcium chloride use (2-3 %) by weight of soil ($\boldsymbol{SCRB}, \mathbf{2003}$)[8].

3. Laboratory Tests

The testing program conducted on the natural soil containing high soluble salts and Calcium Chloride ($CaCl_2$) to study the effect of Calcium Chloride ($CaCl_2$) on the strength of the subgrade soil.

3.1. Compaction:

The moisture–density relationships for both standard and modified compaction tests are obtained using manual hammer. All the tests for the soil sample are carried out according to [$\boldsymbol{ASTM\ D1557-02, method\ C}$ (2002) & $\boldsymbol{ASTM\ D698-12, method\ C}$ (2002)][2] for modified and standard compaction tests respectively.

Figures (2) & (3) show the moisture-density relations of modified and standard compaction curve for the natural soil respectively, for the soil sample with (0, 5 % and 10%) air void lines. It is apparent from these figures that, the maximum modified dry density of the soil sample is (18.7kn/m^3) at an optimum moisture content of (11 %), while the maximum standard dry density of sample is (17.64kn/m^3) at an optimum moisture content of (13.50%)(***Ibrahim*, 2014**)[5].

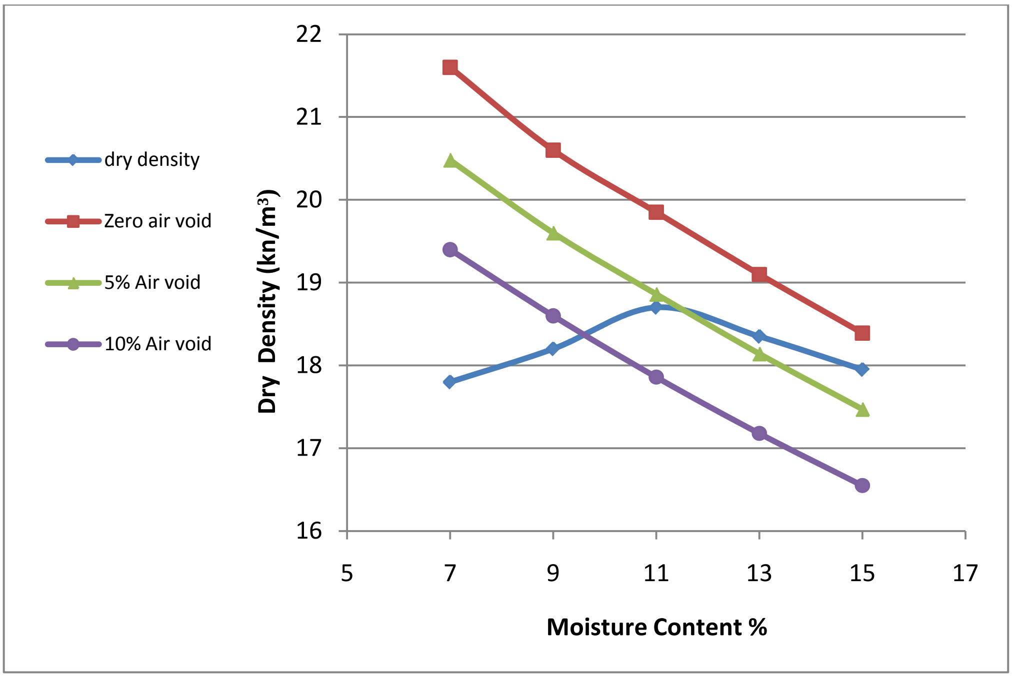

Figure (2): Moisture-Density Relations of The Soil Sample With Different Air Void Lines (Modified Compaction).

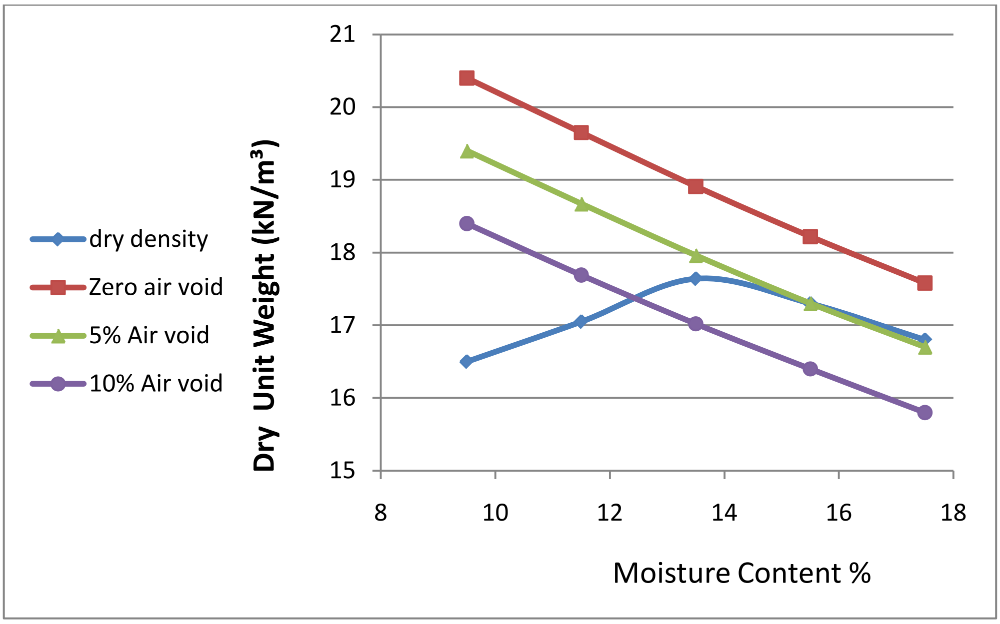

Figure (3): Moisture-Density Relations of the Soil Sample With Different Air Void Lines (Standard Compaction).

3.2. California Bearing Ratio (CBR) Test:

CBR values conducted according to **(ASTM D1883)** specification**.** Where the CBR is desired at optimum water content and some percentage of maximum dry unit weight, three specimens are compacted from soil prepared to within (±0.5) percentage point of optimum water content and using the specified compaction at different number of blows per layer for each specimen. The number of blows per layer should be varied as necessary to prepare specimens having unit weights above and below the desired value. Typically, if the CBR for soil at 95 % of maximum dry unit weight is desired, specimens compacted using 56, 25, and 10 blows per layer is satisfactory. Penetration should be performed on each of these specimens **(ASTM D 1883).**

3.3. Soil Samples Preparation for the Effect of Long Term Soaking and Drying on CBR Value and Total Soluble Salts (T.S.S) of Soil Stabilized with ($CaCl_2$).

To study the effect of long-term soaking on the CBR value and (T.S.S) of the soil, (20 CBR samples 10 samples for soaking and 10 for soaking and drying for each period use two sample and take the CBR value of minimum one) samples compacted at 95% relative modified proctor with optimum moisture content of (2.5% $CaCl_2$). These samples are soaked for (4, 7, 14, 28, and 60) and other samples are soaked and dried for (4 days soaked and 4 days dried, 7 days soaked and 7days dried, 14 days soaked and 14 days dried, 28days soaked and 28 days dried and 60 days soaked and 60 days dried) at the room temperature under the effect of a (10lb) surcharge load. The total period of soaking and drying is (120) days.



4. Results

4.1. The Effect of CBR Value:

Figures (4 and 5) show the results of the stress-penetration curve of natural soil and Calcium Chloride ($CaCl_2$). Figures (6 and 7) show the CBR value with different dry density for natural soil and Calcium Chloride ($CaCl_2$) and Figures (8 and 9) show the CBR value with different number of blow. From these Figures, it is obvious that the final CBR is (3.37 and 7.5) and the corresponding number of blows per layer is (32 and27), for (natural soil and 2.5% $CaCl_2$) respectively, minimum CBR value for road construction is not less than (4%) at 95% relative modified proctor according to (SCRB) specification , so the CBR value of soil stabilizing with calcium chloride is relatively good comparing with the minimum value.

Figure (4) of the (natural soil), the soaked CBR values for sample reduces after 4-days soaking due to dissolution of T.S.S. in the presence of water although this dissolution of T.S.S. is very little during soaking.

Figure (5) of the (2.5%$CaCl_2$) the CBR value increases. This improvement in CBR value may be attributed to the change in soil structure from dispersed to flocculate. Also, the increase in the strength with addition of (2.5%$CaCl_2$), may be attributed to the cation exchange between stabilizer and mineral layers and due to the formation of silicate gel.

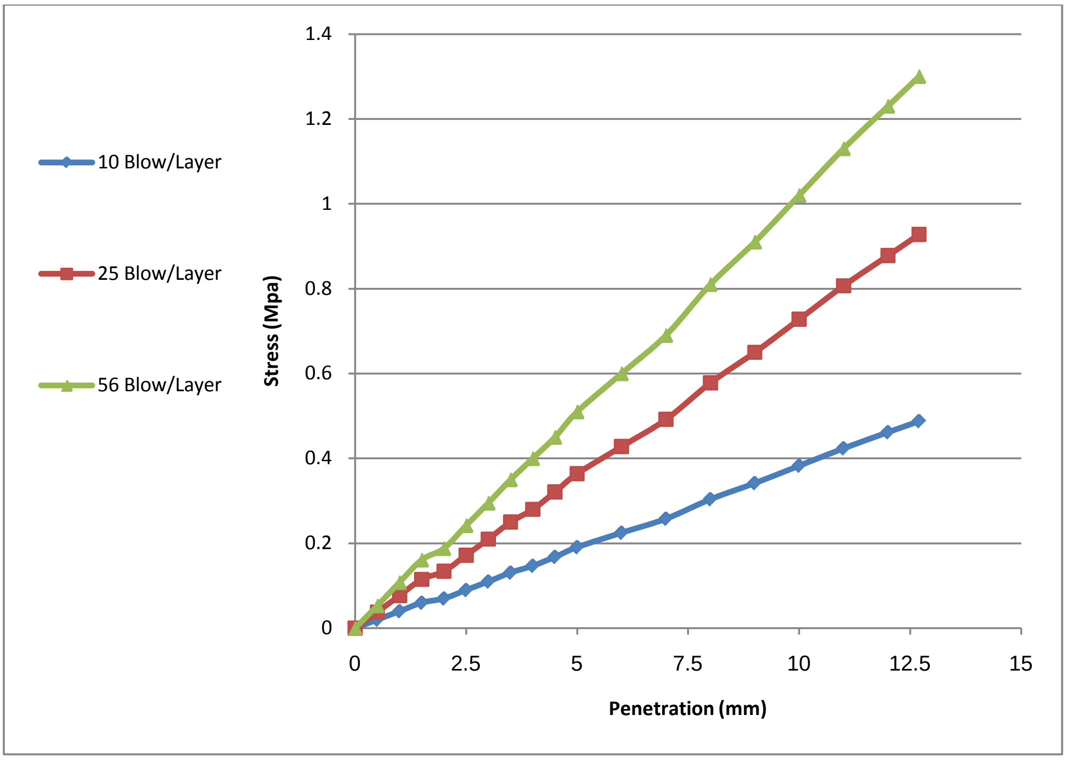

Figure (4): Stress-Penetration Curves of Natural Soil with Different Number of Blow per Layer.

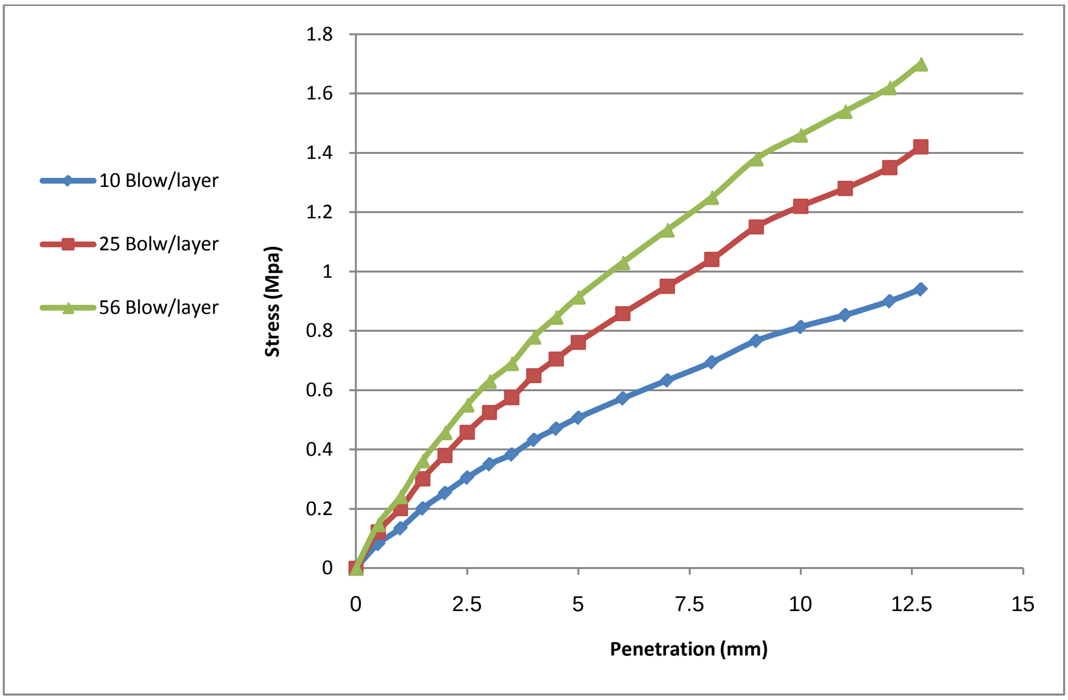

Figure (5): Stress-Penetration Curves of $(2.5\%CaCl_2)$ with Different Number of Blow per Layer.

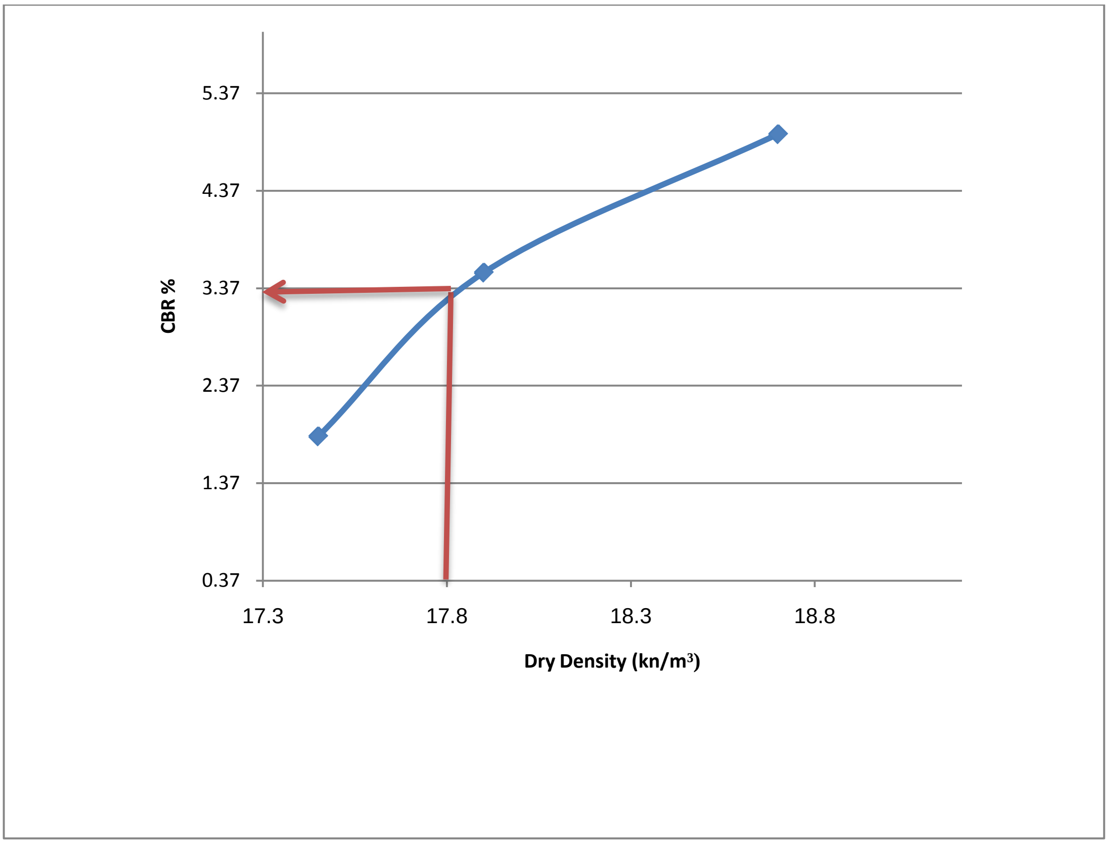

Figure (6): CBR versus Dry Density of the Natural Soil without $CaCl_2$.

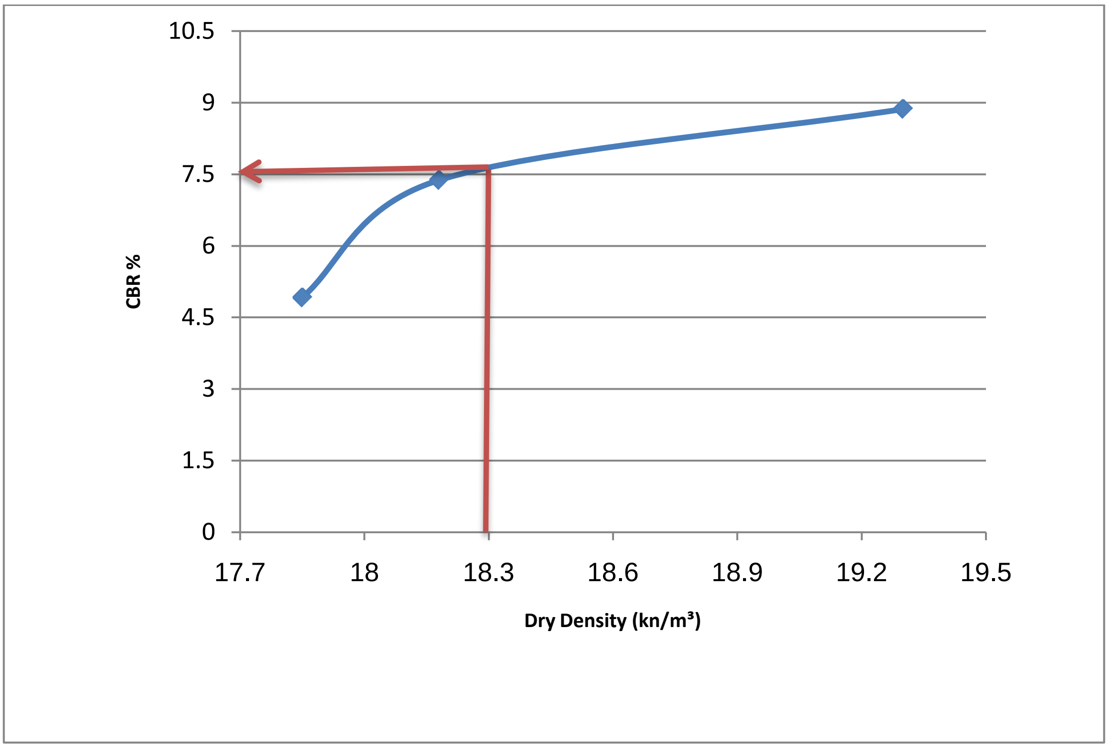

Figure (7): CBR versus Dry Density of the $2.5\%CaCl_2$.

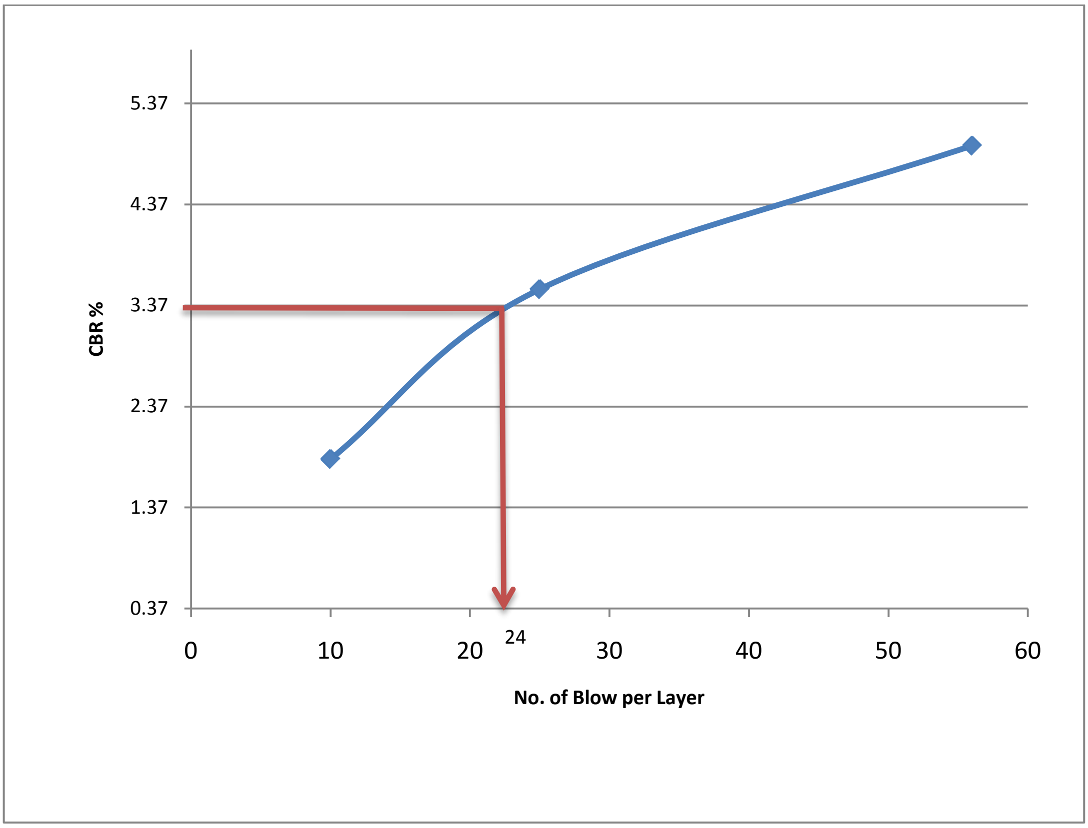

Figure (8): CBR versus Number of Blow per Layer of the (Natural Soil).

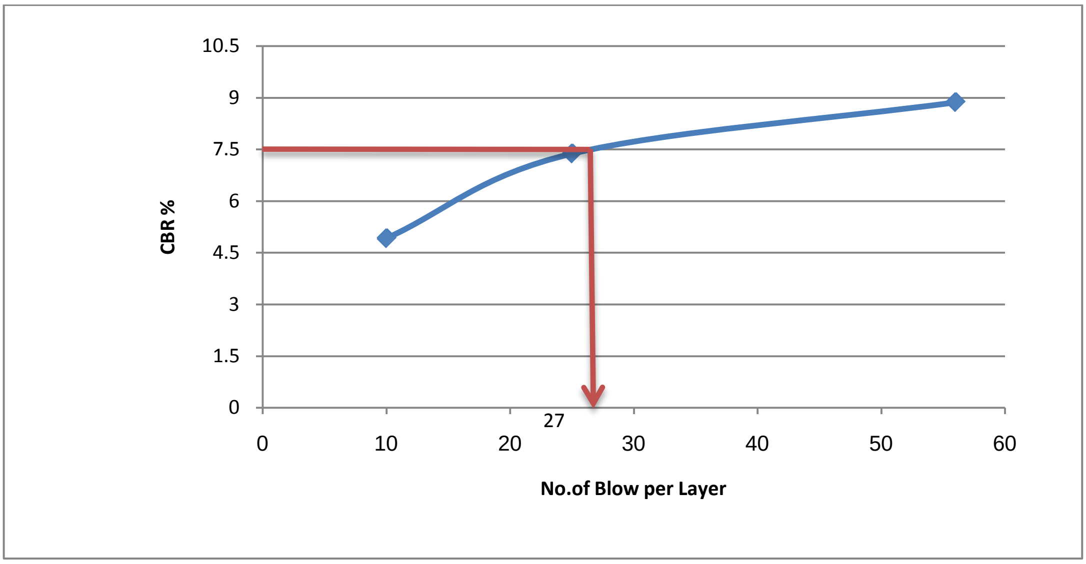

Figure (9): CBR versus Number of Blow per Layer of the $(2.5\%CaCl_2)$.

4.2. The Effect of Long Term Soaking and Drying on CBR Value and Total Soluble Salts (T.S.S) of Soil Stabilized with $(2.5\%\ CaCl_2)$ Compacted at Optimum Moisture Content and 95 % Relative Modified Compaction.

4.2.1. Soaking Condition

Figure (10) shows the stress-penetration curve of CBR test of $(2.5\%\ CaCl_2)$ for periods (4, 7, 14, 28, 60) respectively. The results of CBR values of periods (4, 7, 14, 28, 60) are (7.961%, 6.446%, 4.436%, 3.398%, 2.427%) respectively.

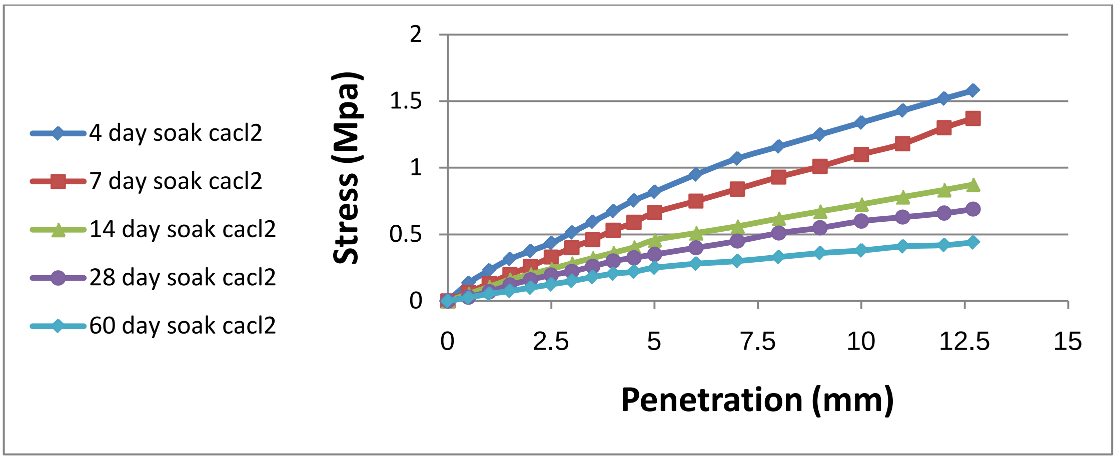

Figure (10): Stress-Penetration Curves of Long Term Soaking Soil Stabilized With$(2.5\%\ CaCl_2)$.

Figure (11) shows the decrease in CBR with the increase in soaking period and show the min. CBR value required according to $(\boldsymbol{SCRB}, \mathbf{2003})$[8] specification. It is quite obvious from this figure that, the soaking period has a significant effect on the CBR indicating that the four days soaking period for stabilized soil are not enough period for predicting CBR value. The significant drop in CBR due to long –term soaking is associated with the dissolution of soluble salts in water and the stabilizer ($CaCl_2$) losses the ability to stabilize due to water effect.

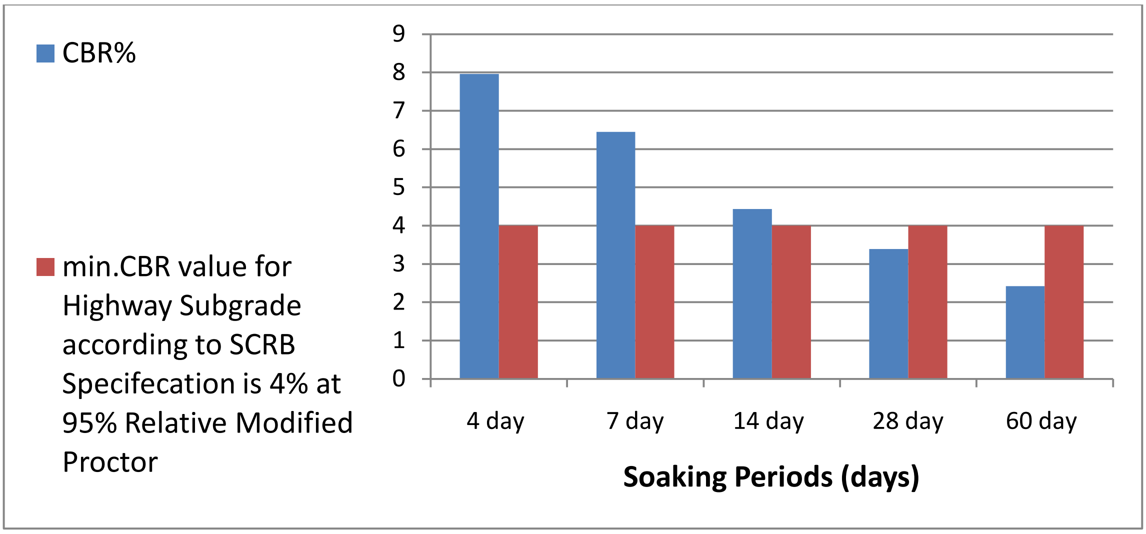

Figure (11): Effect of Long Term Soaking Periods on CBR Values of Stabilized Soil with $(\mathbf{2.5\%\ CaCl_2})$.

It is necessary to avoid full saturation of the water in soaking tank with soluble salts. If the concentration of soluble salts is allowed to approach the saturated concentration, no further dissolution of soluble salts will take place leading to misleading results. For this reason, water in soaking tank of this work is changed continuously at a certain rate depending on the volume of water in soaking tank, soaking period and number of samples in the tank.

After the CBR test is finished, each CBR sample is tested for (T.S.S), Figure (12) shows the variation of (T.S.S) with soaking period for the top 1 inch (25.4 mm) of the CBR sample. It is quite obvious from this figure that, there is a continuous dissolution of soluble salt of the sample in the fresh water of the soaking tank.

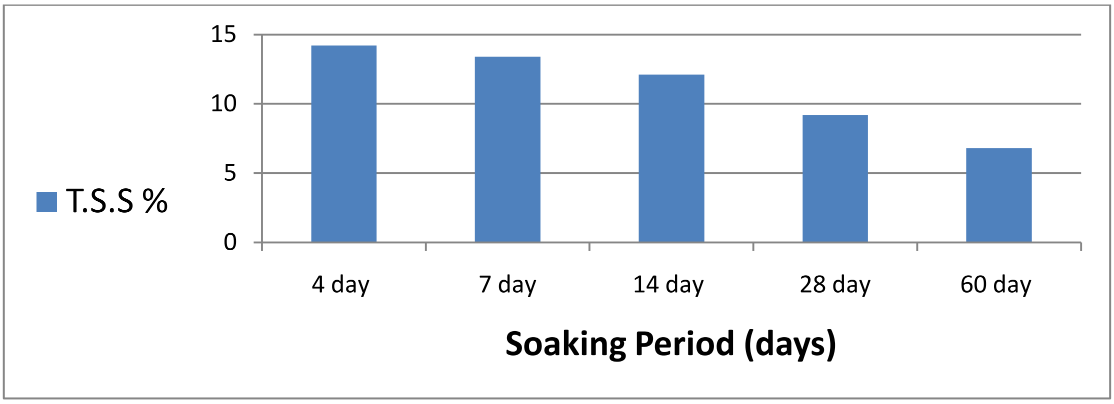

Figure (12): Effect of Long Term Soaking Periods on (T.S.S) Values of Stabilized Soil with $(2.5\%\ CaCl_2)$.

Figures (13 and 14) show correlation between soaking periods with (CBR) value and (T.S.S) by using the principle of least square method.

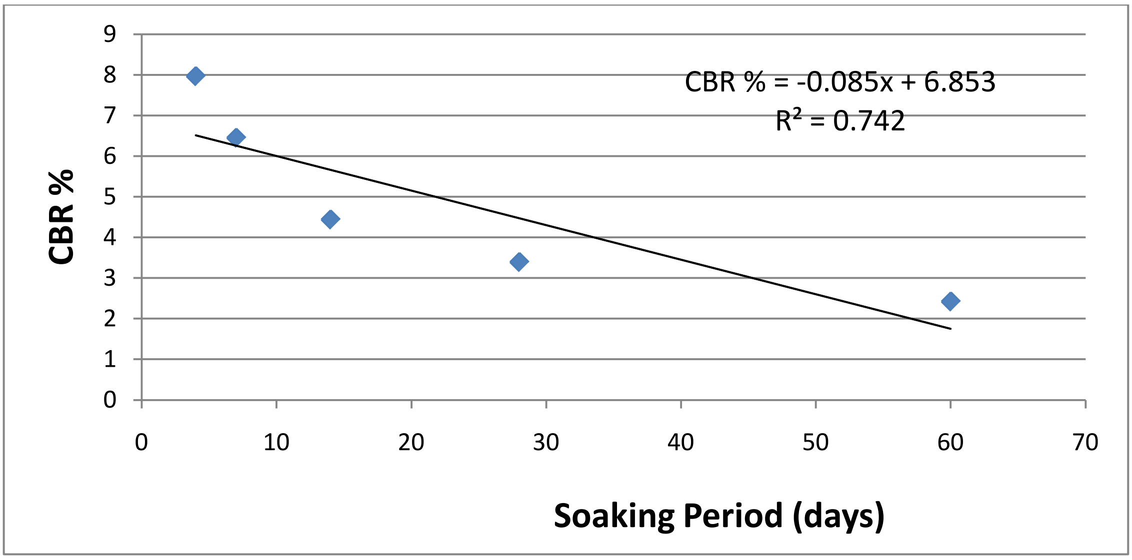

Figure (13): Correlation Between CBR Value and Soaking Periods for Stabilized Soil with $(2.5\%\ CaCl_2)$.

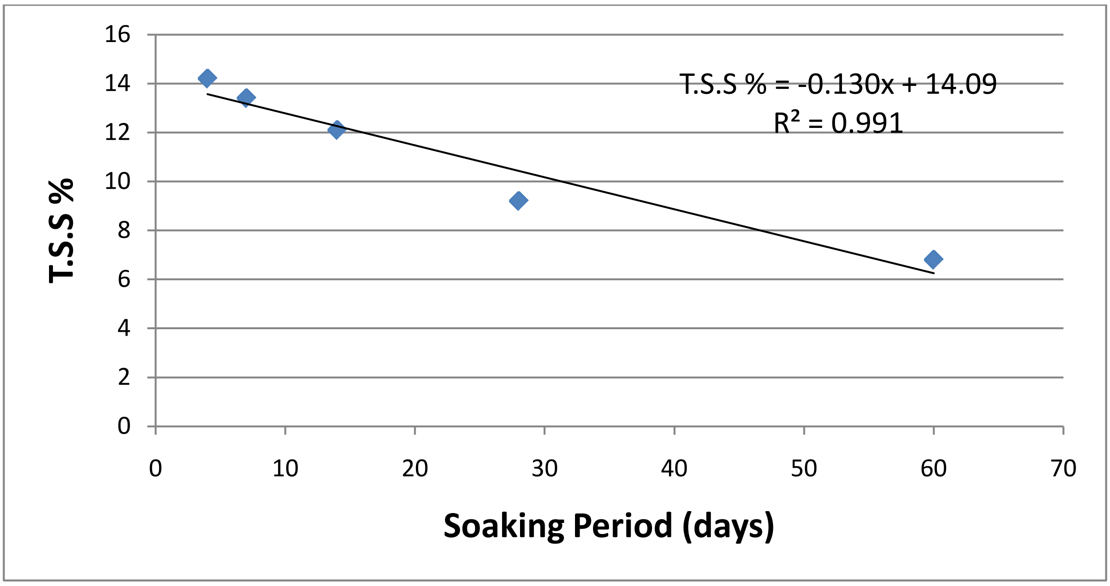

Figure (14): Correlation Between (T.S.S.) and Soaking Periods for Stabilized Soil with $(2.5\%\ CaCl_2)$.

From these figures, the following equations can be obtained:

CBR % = -0.085 X+ 6.853 ……. (4.15)

T.S.S% = -0.130 X + 14.09 ……. (4.16)

where:

X= soaking period (days) , $X \geq 4$ day and $X \leq 60$ day

4.2.2. Soaking and Drying Condition.

To determine the effect of long-term soaking and drying, five soaking and drying periods are chosen namely (4 day soak and 4 day dry, 7 day soak and 7 day dry, 14 day soak and 14 day dry, 28 day soak and 28 day dry, 60 day soak and 60 day dry). The total period of soaking and drying is (120) day.

Figure (15) shows stress-pentration curve of long term soaking and drying of (CBR%) for stabilized soil with (2.5% $CaCl_2$). The results of CBR values of periods(4 day soak and 4 day dry, 7 day soak and 7 day dry, 14 day soak and 14 day dry, 28 day soak and 28 day dry, 60 day soak and 60 day dry) are (8.252%, 6.531%, 4.563%, 3.511%, 2.621%).

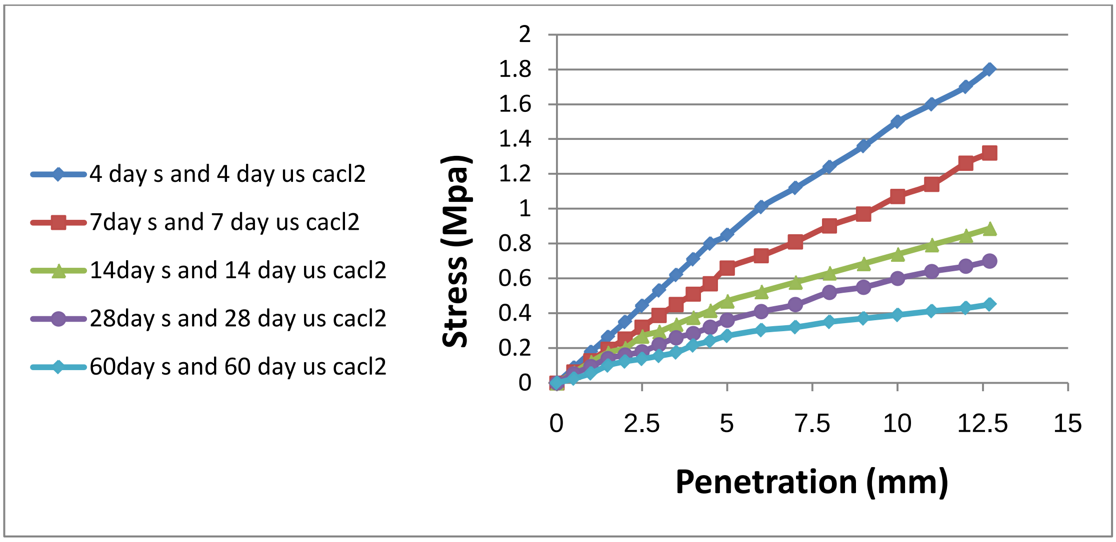

Figure (15): Stress-Penetration Curves of Long Term Soaking and Drying Soil Stabilized with $(2.5\%\ \mathbf{CaCl_2})$.

As shown in Figure (16), the CBR value decreases with the increase in soaking and drying period and show the min. CBR value required according to $(\boldsymbol{SCRB}, \mathbf{2003})$[8]specification.

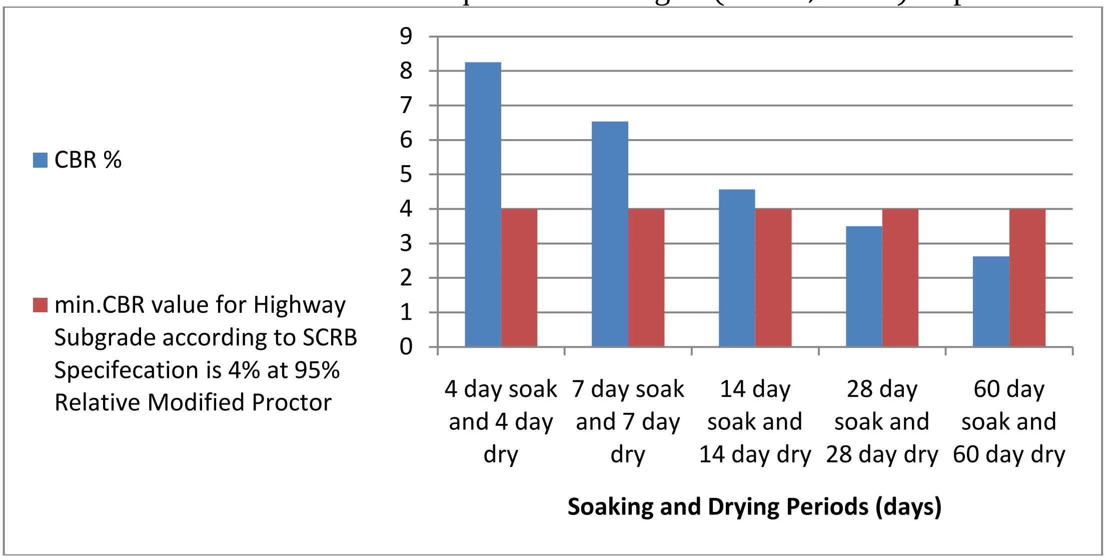

Figure (16): Effect of Long Term Soaking and Drying Periods on CBR Values of Stabilized Soil with $(2.5\%\ \mathbf{CaCl_2})$.

As shown in Figure (17), the total soluble salts (T.S.S) decrease with the increase in soaking and drying periods.

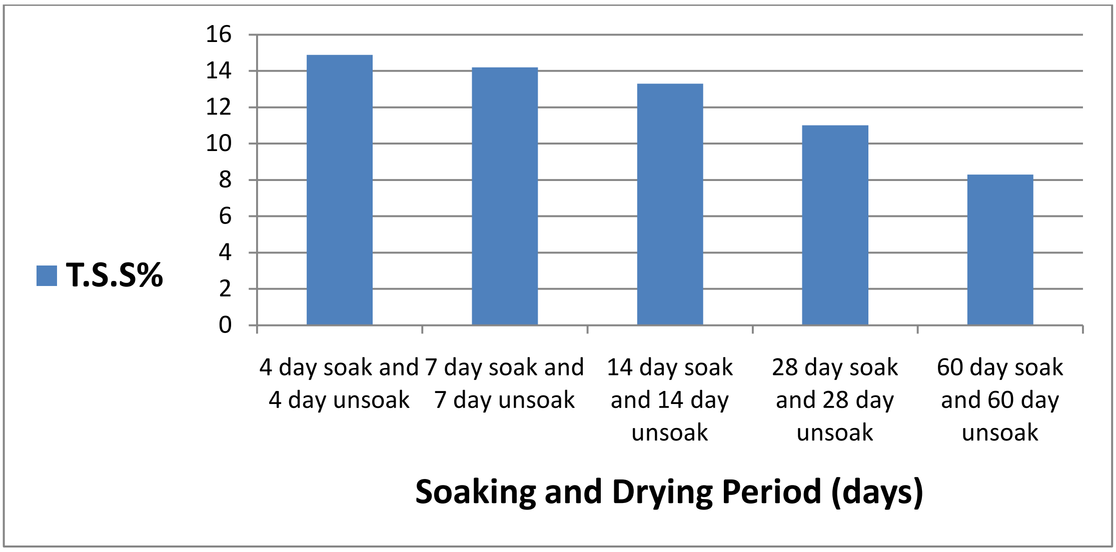

Figure (17): Effect of Long Term Soaking and Drying Periods on (T.S.S) of Stabilized Soil with $(2.5\%\ CaCl_2)$.

Table (4.5) shows the results of CBR value and (T.S.S) of long term soaking and long term soaking and drying of stabilized soil with (2.5% $CaCl_2$).

Table (4.5): (CBR value) and (T.S.S) of Long Term Soaking and Long Term Soaking and Drying of Stabilized Soil With (2.5% $CaCl_2$).

Soaking periods (day)	CBR %	T.S.S %	Soaking and drying period (day)	CBR %	T.S.S %
4	7.961	14.2	4 S & 4US	8.252	14.88
7	6.446	13.4	7 S & 7US	6.531	14.2
14	4.436	12.1	14 S & 14US	4.563	13.3
28	3.398	9.2	28 S & 28US	3.511	11
60	2.427	6.8	60 S & 60US	2.621	8.3

S= soaked and US= unsoaked

5. Conclusions:

1. The CBR value of the tested soil decreases after 4-day soaking, and this is due to dissolution of (T.S.S) content of the soil sample.
2. The CBR value of the tested soil at 95% relative modified proctor increases after the addition of the (2.5% $CaCl_2$), the increase in CBR value are (48%) for the (2.5% $CaCl_2$).
3. The (T.S.S) decreases after addition of different stabilizers.
4. From durability test (long term soaking and drying) of stabilized soil with(2.5% $CaCl_2$), the CBR value reduces with the increase of soaking period, the percents of reduces are (19%, 44%, 50%, 67.3%) fo
    a. r (7,14, 28, 60 days of soaking) respectively. For the soaking and drying condition, the CBR value increases slightly after drying but the increase is at the same period.

6. References:

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