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Long Term Dry and Wet Effects on the Engineering Behavior of Subgrade Soil with High Amount of Soluble Salts using Low Cost Stabilizers

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ABSTRACT: The performance of pavements depends upon the quality of subgrades. A stable subgrade and properly draining pavement help to produce a long-lasting pavement. Subgrade soil provides support to the remainder of the pavement system. This study is performed to evaluate the effect of total soluble salts (T.S.S.) on the strength of subgrade soil brought from Al-Mahmodia city south of Baghdad. Chemical and physical test, carried out on the soil sample, indicate that, the soil is lean clay of (CL) group according to the Unified Soil Classification System (U.S.C.S.). The soil sample contains about (15.685%) by weight of (T.S.S.) content. Different stabilizers are added to the subgrade soil to study the influence of these stabilizers on (T.S.S.) and the strength of subgrade, the stabilizers are (5% lime, 2.5% calcium chloride, 6% kaolin, 6% Rice Husk Ash and 5% saw dust). California Bearing Ratio (CBR) test is determined for the natural soil and different stabilizers with different number of blow per layer (10, 25 and 56) for (4-days) soaking periods under (10 Ibs.) surcharge load. The number of blow per layer and (CBR) value, required to achieve (95%) relative modified proctor compaction are determined from the results of different number of blow (10, 25 and 56) and soaked for (4-days). The (CBR) value of the natural soil at 95% relative modified proctor increases by about (48%, 66.1%, 36.1% and 38%) for the (2.5% $CaCl_2$, 5% lime, 6% RHA, 6% kaolin) respectively. While the CBR value of soil with the (5% saw dust) decreases to (29%). The (T.S.S) is reduced after the addition of the different stabilizers. Durability test (long term soaking) for the subgrade stabilized with (6% RHA) and compacted at 95% relative modified proctor is conducted, the results of soaking showed reduction in both (CBR) value and (T.S.S) with the time.

Keywords: Strength, Rice husk ash, Total soluble salts, Durability, Calcium chloride

INTRODUCTION

The main properties for a road pavement are strength, durability, impermeability, volume stability, wear resistance and workability during construction. In addition to these properties, road structures require non-aggressive soil environments that are, low chloride, low sulphate, pH neutral and low potential for erosion of the material surrounding the structure.

Netterberg and Maton (1975) suggested that, the term "soluble salts" is restricted to those minerals which are sufficiently soluble to cause deleterious physical or chemical effects under the conditions normally encountered in civil engineering practice.

Ahmed (1985), studied the effect of lime stabilization of the soil containing high soluble salts content and laboratory investigation is carried out on three soils with different percentages of soluble salts, (soil A1 with 4.5% , soil A2 with 7.5%, soil A3 with 9.3%). The investigation showed that, the addition of lime to the soils improves considerably their strength. Furthermore, the addition of lime causes a reduction in both plasticity index and soluble salt content.

Subhi (1987) found for compacted soil that, the maximum density decreases with the increases in gypsum content, while the optimum moisture content decrease or increases with the increase in gypsum content depending on the grain size of the added gypsum. Al-Ani (1988) found that, the maximum dry unit weight and optimum water content increase with the increase in gypsum content. Al-Qaissy (1989) dealt with a clayey silty soil with (1, 9, 18 and 38%) gypsum content and he found a reduction of 0.15 in specific gravity when the gypsum content increases from 1% to 38 %.

El-Janabi (1995) 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.

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Al-Doori (1997) studied the influence of soluble salts on the engineering properties of a soil-aggregate material. The influence of soluble salts on maximum dry density, optimum moisture content, shear strength, resilient modulus and CBR value was studied and investigated. Razouki and El-Janabi (1999) studied the effect of long-term soaking on the CBR (California Bearing Ratio) of a granular gypsiferous soil, and they concluded that, the normal soaking period of 4 days can lead to serious overestimation of the CBR values of gypsiferous soils.

Parson (2003) performed durability tests on the four different types of soils (CH, CL, ML and SM) stabilized with lime, cement, fly ash, and enzymes. Durability test includes swelling, freeze and thaw, wet and dry, and leaching test of the stabilized soil samples. Swelling of all soils treated with all stabilizers was almost reduced, except for a soil with small amount of sulfate content (0.41%). The order of soil loss after freeze and thaw was cement < fly ash < lime. However, they found higher strength and lower PI in lime and cement treated soils than in those treated with fly ash after leaching. The result showed that, the clayey soils are vulnerable to wet and dry cycles; however different stabilizers perform differently depending upon the type of the soil.

Texas A and 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).

Rice husk is an agricultural waste obtained from milling of rice. About 10^8 tons of rice husk is generated annually in the world. In Nigeria, about 2.0 million tons of rice are produced annually, while in Niger state, about 96,600 tons of rice grains is produced in (2000). Meanwhile, the ash has been categorized under pozzolana, with about 67-70% silica and about 4.9 and 0.95% aluminum and iron oxides, respectively.

The silica is substantially contained in amorphous form, which can react with the CaOH librated during the hardening of cement to further form cementitious compounds. This will go a long way in actualizing the dreams of the Federal Ministry of works in Nigeria of scouting for readily cheap construction materials. The World Bank too has been spending substantial amount of money on research aimed at harnessing industrial waste products for further usage (Oyetola and Abdullahi 2006).

Koteswara used rice husk ash, lime and gypsum as additives to the expansive soil which resulted in considerable improvement in the strength characteristics of the expansive soil. It was found that, rice husk ash can potentially stabilize the expansive soil mixed with lime and gypsum. The utilization of industrial wastes like RHA, lime and gypsum is an alternative to reduce the construction cost of roads particularly in the rural areas. It was observed that, the liquid limit of the expansive soil has been decreased by 22% with the addition of 20% RHA+5% lime. It was noticed that, the free swell index of the expansive soil has been reduced by 88% with the addition of 20% RHA + 5% lime. The unconfined compressive strength of the expansive soil has been increased by 548% with addition of 20% RHA+5% lime + 3% gypsum after 28 days curing *(Koteswara, 2011)*.

It is observed that, the liquid limit, plastic limit, plasticity index and O.M.C of the marine clay have been decreased by (15.43%, 4.08%, 26.47%, 15.37%) respectively, on the addition of (15% Saw Dust) and it is found that the (M.D.D and CBR) of the marine clay increased by (1.96% and 129.76%) respectively,

MATERIAL AND METHODS

Soil Used

The experimental work is carried out on soil sample obtained from the Al-Mahmudiyah city south of Baghdad. This sample is taken from (1-1.5m) depth below the natural ground surface .The soil sample is taken to soil mechanics laboratory, to determine the physical and chemical properties of the soil. Details are given in Table 1. Grain size distribution of the soils is shown in Figure 1.

Table 1. Physical and Chemical Properties of the Soil Sample

Index property	Index values
Liquid limit (L.L.) %	32.3
Plastic limit (P.L.) %	19.2
Plasticity index (P.I.) %	13.1
Specific gravity (Gs)	2.54
Gravel (larger than 2mm) %	0
Sand (0.075 to 2mm) %	7.9
Silt (0.005 to 0.075 mm) %	65.3
Clay (less than 0.005mm) %	26.8
U.S.C.S.	CL
Total Soluble Salts T.S.S%.	15.685
Gypsum Content %.	3.465
Total Sulphate Content (SO3) %.	1.61
Organic Matter Content %.	1.915
PH Value.	7.74

Note: all tests were performed according to the ASTM (2002).

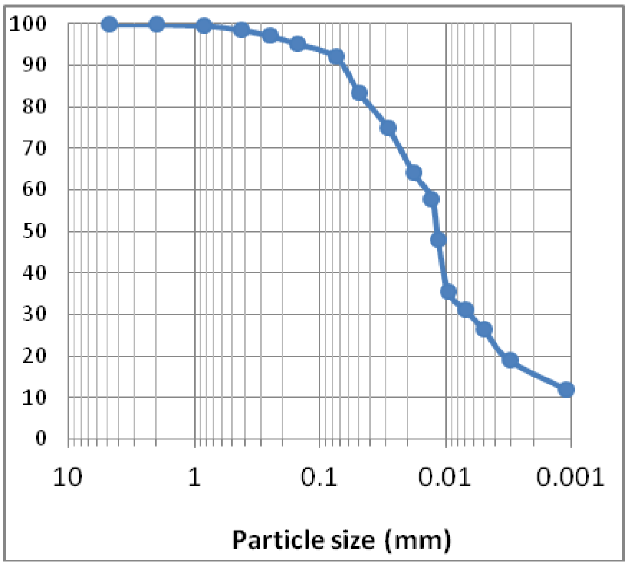

Figure 1. Grain size distribution of the soil

Calcium Chloride ($CaCl_2$)

The commercial product of Calcium Chloride ($CaCl_2$), with purity from (98 %), is used in this study to

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improve the engineering properties of the soil .The Calcium Chloride ($CaCl_2$) is a white color and crystalline solid in the hydrous state. Al-Busoda (1999), used (2.5%) by weight of calcium chloride as additive to treat the gypseous soil. For this study the amount of the Calcium Chloride ($CaCl_2$) used is (2.5%) by dry weight of soil.

Lime

This material is obtained from local market. Pure hydrated lime (Ca $[(OH]]_2$) is used in this study.The percentage of lime used for any project depends on the type of soil being stabilized. The determination of the quantity of lime is usually based on an analysis of the effect that different lime percentages have on the reduction of plasticity and the increase in strength on the soil. The PI is most commonly used for testing the effect on plasticity; whereas, the unconfined compression test, the Hveem Stabilometer test, or the California bearing-ratio (CBR) test can be used to test the effect on strength. However, most fine-grained soil can be effectively stabilized with (3 to 10) percent lime, based on the dry weight of the soil (Garber, 2010).

The amount of the lime used is 5% by dry weight of soil. Physical properties and chemical composition of Hydrated Lime are shown in Table 2.

Table 2. Physical Properties and Chemical Composition of Hydrated Lime

Form	**Fine dry white powder**
Color	white
Specific Gravity	2.28
pH (25ºC)	12.45
CaO	69.4
Al_2O_3	0.5
Fe_2O_3	0.2
SiO_2	2.78
MgO	2.5
Active CaO	53
SO_3	0.27
CO_2	2.21

Kaolin, available in local market, is used in this study. Al-Neami (2000), used (6%) of kaolin by weight as additive to treat gypseous soil. For this study, the amount of the kaolin used is 6% by dry weight of soil. Physical properties and chemical composition of kaolin are shown in Tables 3.

Table 3. Physical Properties and Chemical Composition of Kaolin

Specific gravity	**2.58**
Liquid Limit (L.L%)	57
Plastic Limit (P.L%)	27
Plasticity Index (PI%)	30
Soil Symbols (USCS)	CH
SiO_2	51.6
Al_2O_3	33
CaO	1.5
Fe_2O_3	1.4
MgO	0.6

Note: all tests were performed according to the ASTM (2002).

Rice Husk Ash (RHA)

Rice husk (RH) is a by-product of the rice mill industry, which is brought from Al-Diwaniyah city. The ash is obtained from burning the rice husk.

In this study the amount of the (Rice Husk Ash) used is 6% by dry weight of soil. Gs is (2.03) and color is black. Chemical composition of (Rice Husk Ash) are shown in Table 4.

Table 4. Chemical Composition of Rice Husk Ash (RHA) (after Oyetola and Abdullahi, 2006)

Constituents	**Percents %**
SiO_2	86
Al_2O_3	2.6
Fe_2O_3	1.8
CaO	3.6
MgO	0.27
Loss on ignition	4.2

Sawdust

Saw dust is by-product material obtained from the wood cuttings in wood working plant. The saw dust passing sieve No.60 is used in this study. The amount of the (Saw dust) used is 5% by dry weight of soil. Specific gravity of saw dust is (2.11).

Laboratory Studies

The testing program conducted on the natural soil containing high soluble salts and different stabilizers and study the effect of these stabilizers on the strength of the subgrade soil.

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 [ASTM D1557-02, method C (2002) & ASTM D698-12, method C (2002)] for modified and standard compaction tests respectively.

Figures 2 and 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%).

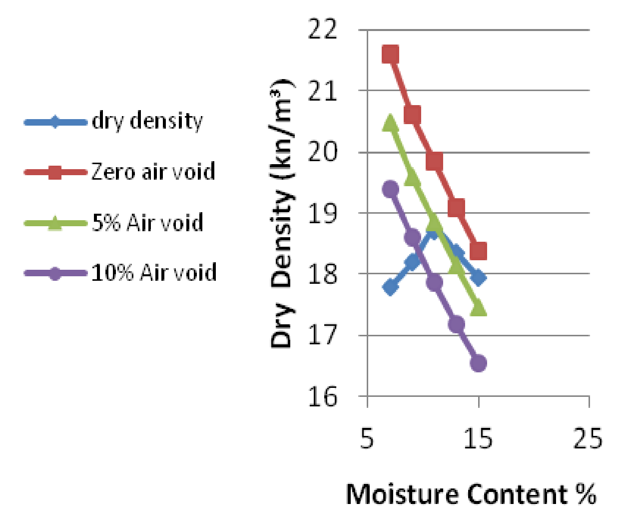

Figure 2. Moisture-Density Relations of the Soil Sample With Different Air Void Lines (Modified Compaction).

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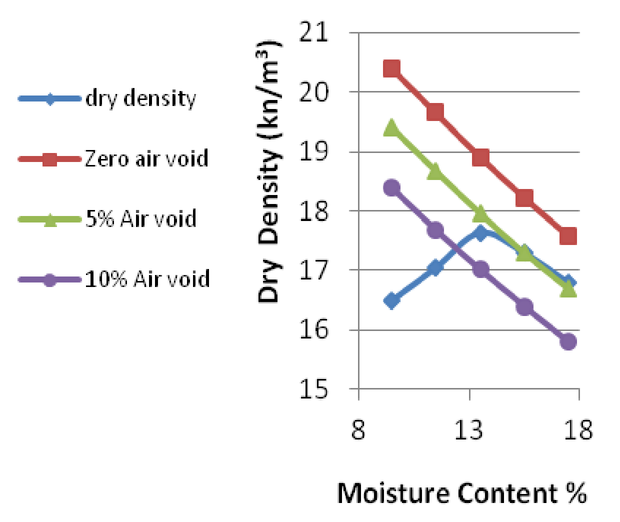

Figure 3. Moisture-Density Relations of the Soil Sample With Different Air Void Lines (Standerd Compaction).

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).

To study the effect of long-term soaking on the CBR value and (T.S.S) of the soil stabilized with (6%RHA) various samples compacted at 95% relative modified proctor with optimum moisture content of (6% RHA).These samples are soaked for (4, 7, 14 and28) days. The CBR value and (T.S.S) are computed for each soaking period.

RESULTS

The Effect of CBR Value

Figures (4 to 9) show the results of the stress-penetration curve of natural soil and different stabilizers. Figures (10 to 15) show the CBR value with different dry density for natural soil and stabilizers and Figures (16 to 21) show the CBR value with different number of blow. From these Figures, it is obvious that the final CBR is (3.37, 7.5, 11.5, 6.26, 6.3, 2.8) and the corresponding number of blows per layer is (32, 27, 28, 30, 27, 29), for (natural soil, $2.5\%\ CaCl_2$, 5% lime,6%kaolin,6%RHA, 5%saw dust) respectively.

From figure (4) of the (natural soil),the soaked CBR values for sample decrease 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.

From 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.

From Figure 6 of the (5% lime), the CBR value is increases. The improvement of the soil by lime is due to the replacement of exchangeable cations percent in clay soil such as sodium and potassium by calcium cations of lime. Also, the pozzolanic reaction which is reaction of calcium with silicates and aluminates of the soil to produce the cementitious material.

From Figure 7 of the (6% kaolin), the CBR value increases. The improvement of the CBR value is due to the decrease in soluble salts with the addition of kaolin.

From Figure 8 of the (6% RHA), the CBR value increases. The improvement in the CBR of RHA can be attributed to the gradual formation of cementitious compounds between the RHA and CaOH contained in the soil (Alhassan, 2008).

From Figure 9 of the (5% saw dust), the CBR value decreases. This decrease in CBR value is because there is no cementitious agent between saw dust soil particles.

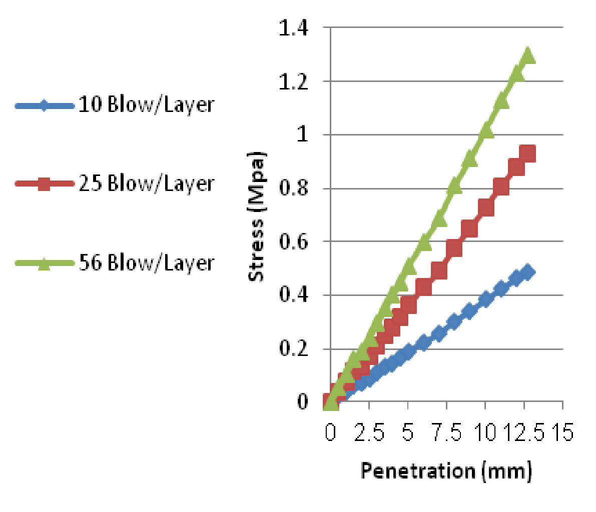

Figure 4. Stress-Penetration Curves of Natural Soil with Different Number of Blow per Layer

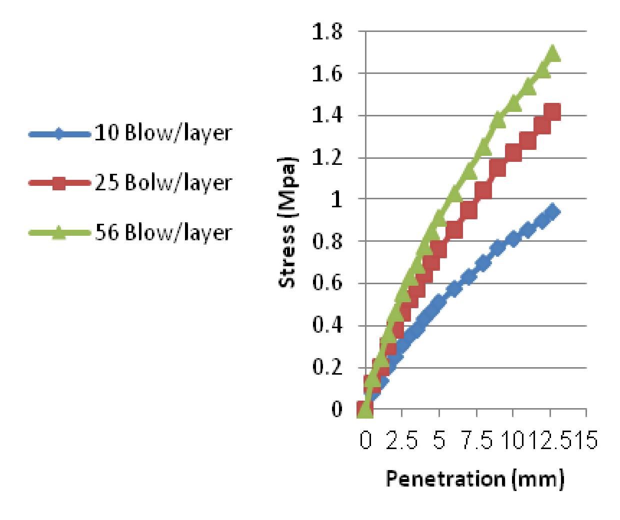

Figure 5. Stress-Penetration Curves of $(2.5\%CaCl_2)$ With Different Number of Blow per Laye

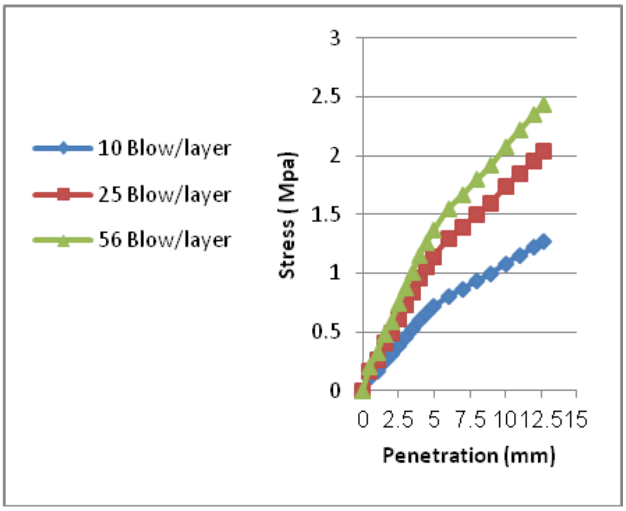

Figure 6. Stress-Penetration Curves of (5%Lime) With Different Number of Blow per Layer.

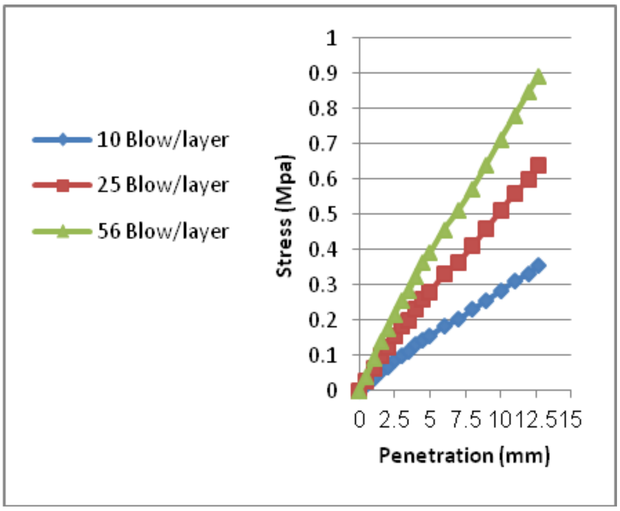

Figure 9. Stress-Penetration Curves of (5%Saw Dust) With Different Number of Blow per Layer.

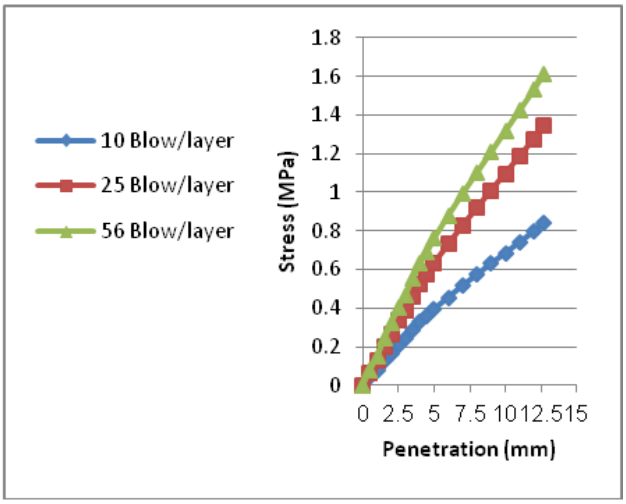

Figure 7. Stress-Penetration Curves of (6%Kaolin) With Different Number of Blow per Layer.

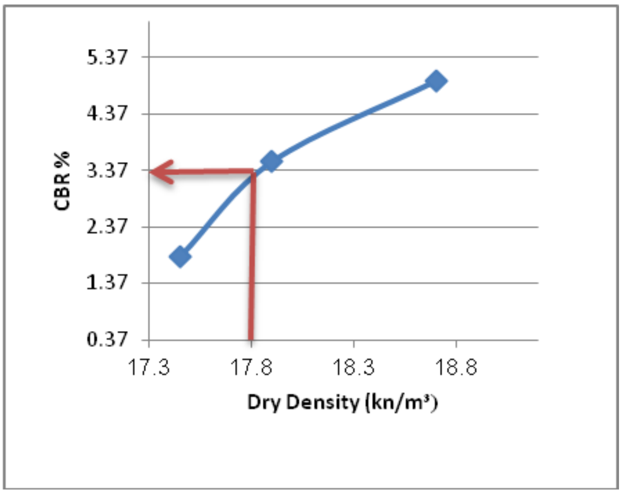

Figure 10. CBR versus Dry Density of the (Natural Soil).

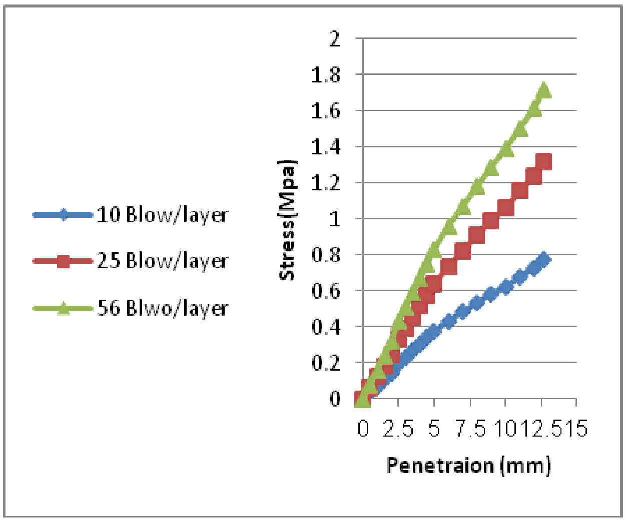

Figure 8. Stress-Penetration Curves of (6%RHA) With Different Number of Blow per Layer.

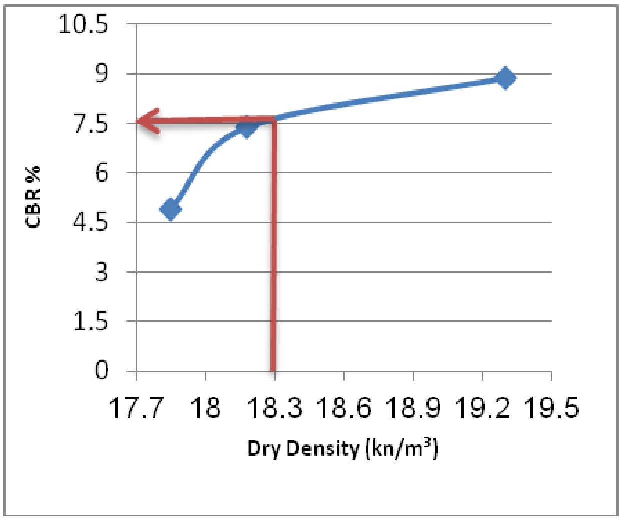

Figure 11. CBR versus Dry Density of the $[(2.5\%CaCl]_2)$.

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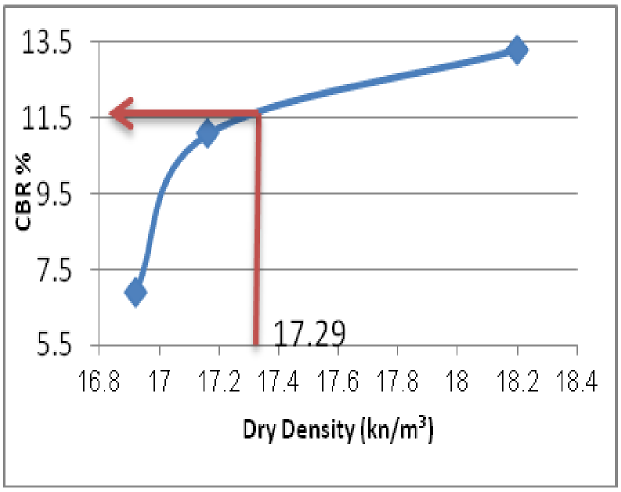

Figure 12. CBR versus Dry Density of the (5% Lime).

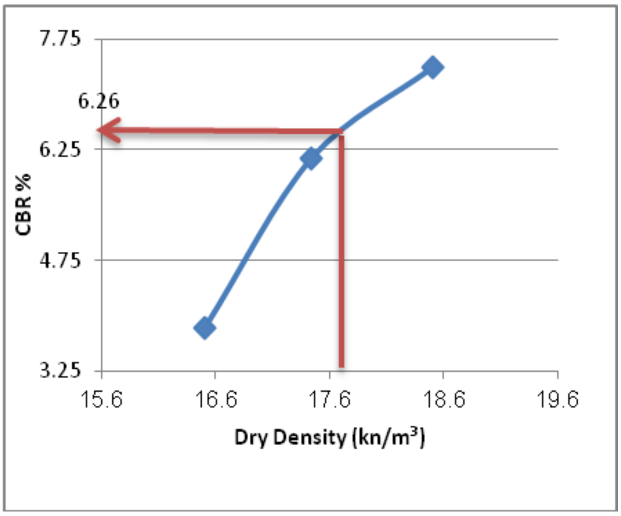

Figure 13. CBR versus Dry Density of the (6% Kaolin).

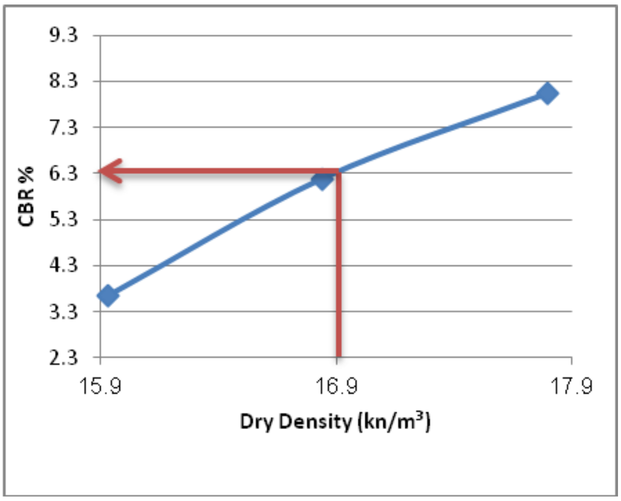

Figure 14. CBR versus Dry Density of the (6% RHA).

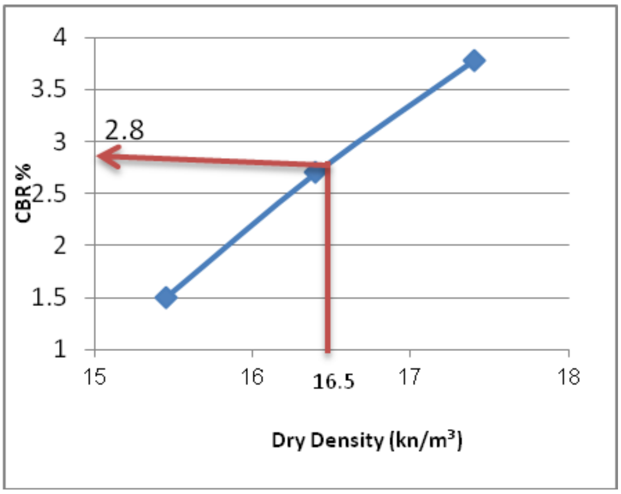

Figure 15. CBR versus Dry Density of the (5% Saw Dust).

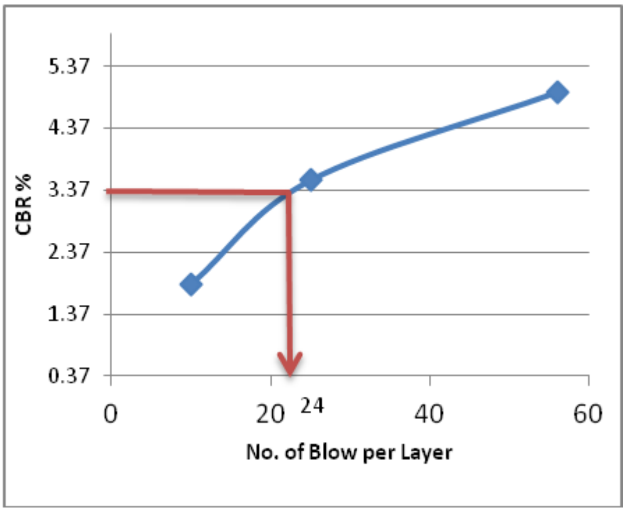

Figure 16. CBR versus Number of Blow per Layer of the (Natural Soil).

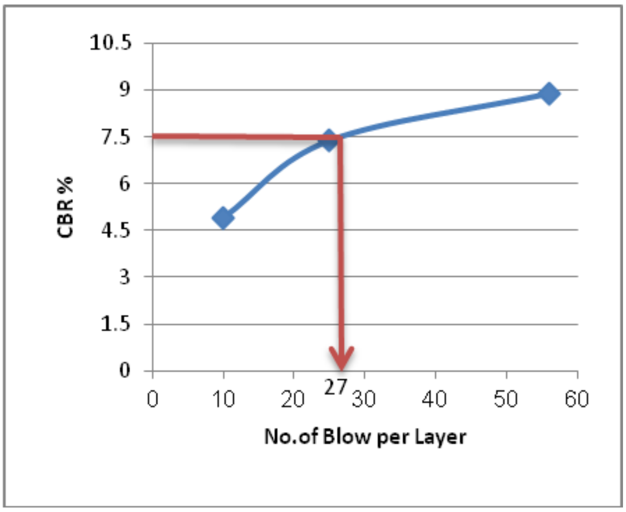

Figure 17. CBR versus Number of Blow per Layer of the $(2.5\%CaCl_2)$.

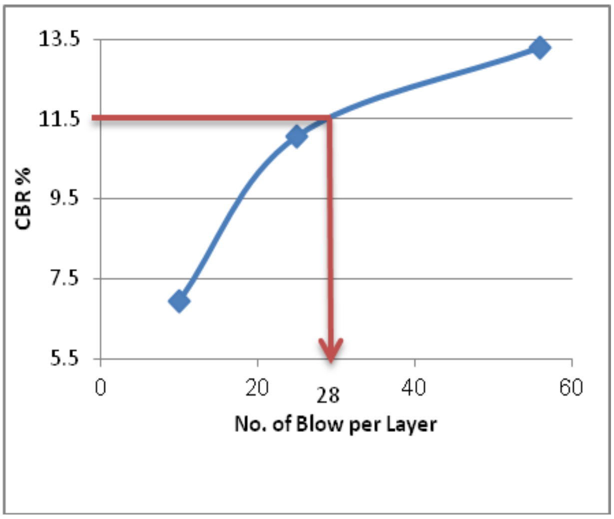

Figure 18. CBR versus Number of Blow per Layer of the (5% lime).

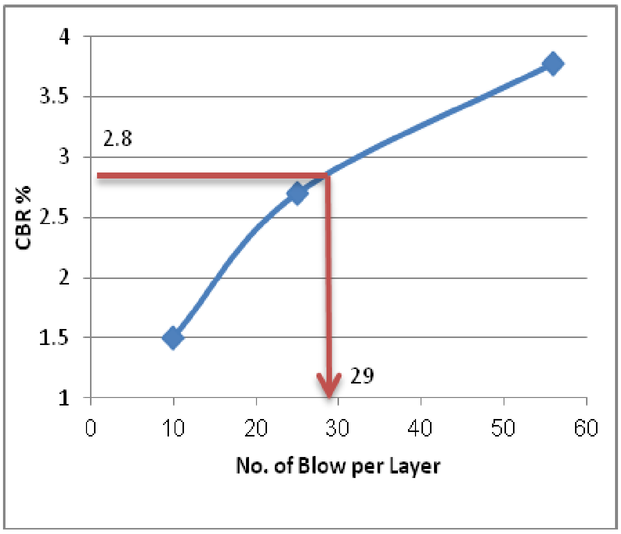

Figure 21. CBR versus Number of Blow per Layer of the (5% Saw Dust).

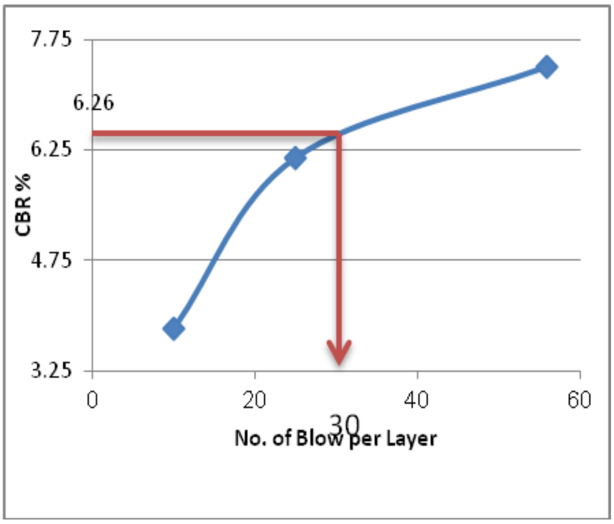

Figure 19. CBR versus Number of Blow per Layer of the (6% Kaolin).

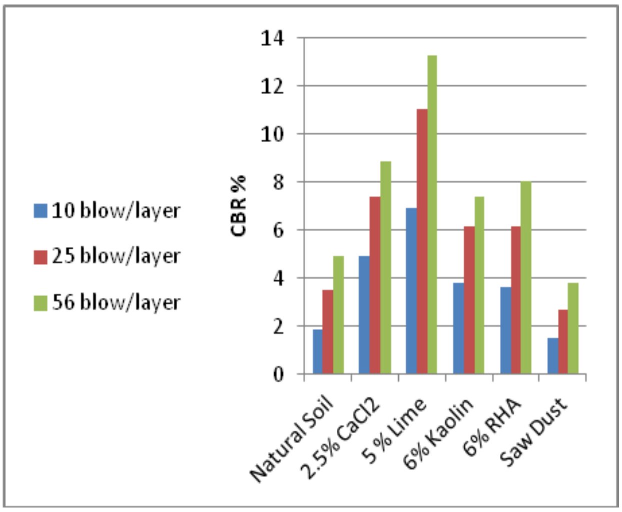

Figure 22. Effect of Number of Blow per Layer on CBR Value of natural Soil and Stabilizers.

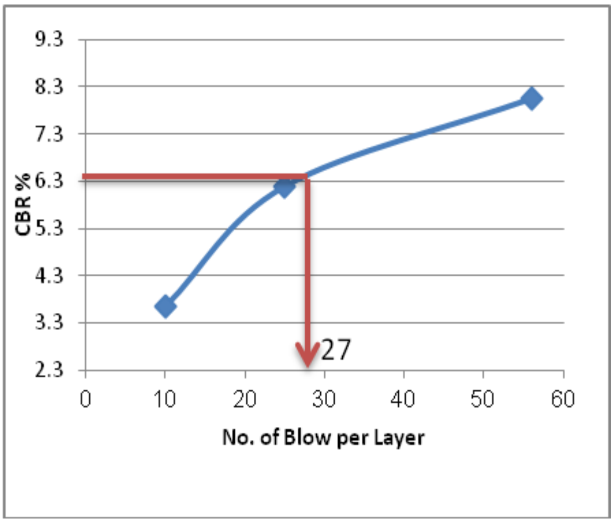

Figure 20. CBR versus Number of Blow per Layer of the (6% RHA).

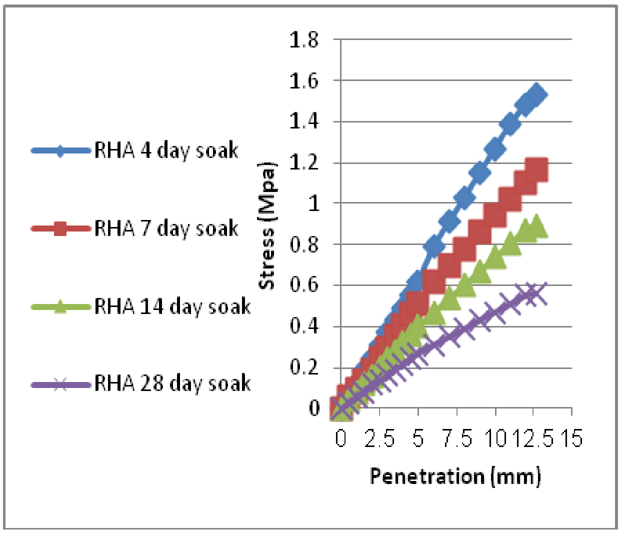

Figure 23. Stress-Penetration Curves of Long Term Soaking Soil Stabilized with (6% RHA).

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Figure 22 below, explains the CBR value in different number of blow per layer of the natural soil and stabilizers. It is obvious from this figure that CBR value increases with the increase in number of blows.

To determine the effect of long-term soaking on the (CBR value) and the (T.S.S) of stabilized soil with (6% RHA) Compacted at Optimum Moisture Content and 95 % Relative Modified Compaction. Four soaking periods are chosen namely (4, 7, 14, 28) days.

Figure 23 shows the stress-penetration curve of CBR test of (6% RHA) for periods (4, 7, 14, 28). The results of (CBR value) of periods (4, 7, 14, 28) are (6.019%, 4.951%, 3.912%, 2.601%).

Figure 24 shows the decrease in CBR with the increase in soaking period. The significant drop in CBR due to long –term soaking is associated with the dissolution of soluble salts also water decreases the pozzolanic reaction between soil and (RHA).

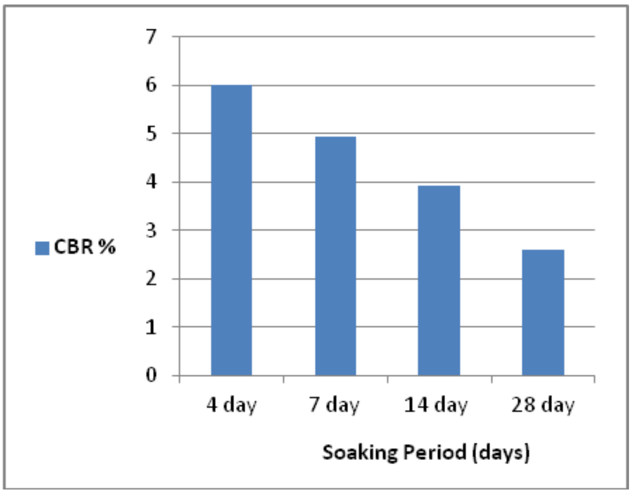

Figure 24. Effect of Long Term Soaking Periods on CBR Values of Stabilized Soil with (6% RHA).

After the CBR test is finished, each CBR sample is tested for (T.S.S). Figure 25 shows the variation of (T.S.S) with soaking period for the top (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 in soaking tank.

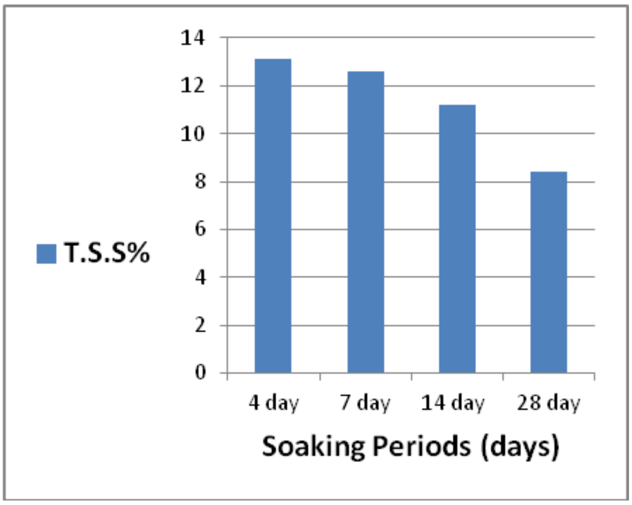

Figure 25. Effect of Long Term Soaking Periods on (T.S.S) of Stabilized Soil with (6% RHA).

Figures 26 & 27 show correlation between soaking periods with (CBR) value and (T.S.S) by using the principle of least square method.

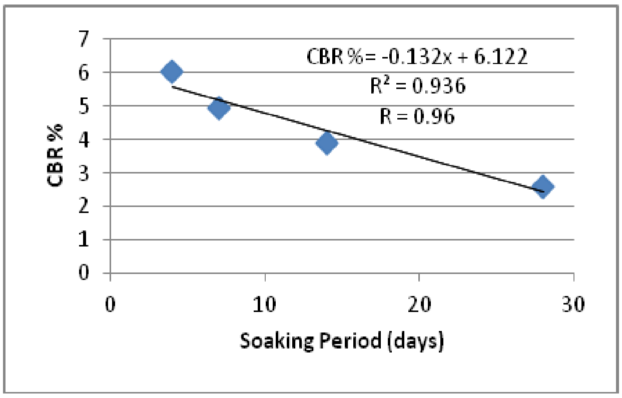

Figure 26. Correlation Between (CBR %) and Soaking Periods for Stabilized Soil with (6% RHA).

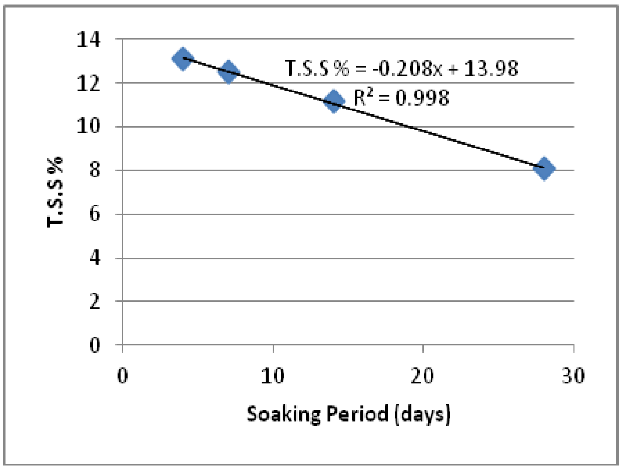

Figure 27. Correlation Between (T.S.S %) and Soaking Periods for Stabilized Soil with (6% RHA).

CONCLUSION

From the results of the investigation carried out within the limited of the study, the following conclusions can be drawn:

1. The CBR value of the tested soil reduces 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 different stabilizers, the increase in CBR value are (48%, 66.1%, 36.1% and 38%) for the (2.5% $CaCl_2$), 5% lime, 6% RHA, 6% kaolin) respectively. While the CBR value of soil with the (5% saw dust) decreases to (29%).
3. The (T.S.S) decreases after addition of different stabilizers.
4. The CBR value of the long soaking of soil stabilized with 6% RHA decreases with the increase in soaking periods the decreased percents are (24%, 40%, 60%) for (7, 14, 28 days of soaking) respectively.

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