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Studying some of the Geotechnical Properties of Stabilized Iraqi Clayey Soils

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ABSTRACT

In many road construction projects, if weak soils exist, stabilization and improvement of their properties is necessary. The stabilization process aims at increasing the soil strength and reducing its permeability and compressibility. An experimental program was undertaken to study the effect of engineering properties of kaolin clayey soils ((the kaolin was supplied by the General Company of Geological Survey and Mining which originally obtains from Al-Dewiekhla near Aukashat district in the west of Iraq)) when blended with lime (L) and Silica Fume (SF). A series of laboratory experiments have been implemented for varieties of samples: 2.5%, 5.0%, 7.5% and 10.0% for (Lime) and 2.0%, 4.0% and 6.0% for(Silica Fume). These experiments are: consistency limits test, specific gravity test, compaction test, unconfined compression test and California bearing ratio test. For each test, the optimal quantity of Lime (L) and the optimal percentage of Lime Silica Fume (LSF) combination were determined. The results revealed that: the optimal percentage of LSF combination was attained at a (2.5%L+6.0%SF), which served as control in this study. This optimal percentage: decrease the liquid limit, plasticity index, specific gravity and maximum dry density; and raise the optimum moisture content, unconfined compressive strength and California bearing ratio. These results showed also, that the combination of LSF stabilization at (2.5% L+6.0% SF) is better than the optimal one which achieved by Lime alone: 2.5%L for plasticity index, 10.0%L for specific gravity, maximum dry density and optimum moisture content, 5.0%L for unconfined compression stress and 7.5%forCaliforniabearingratio. All of these results indicated that the engineering properties of clayey soils can be enhanced, by blending Lime and Silica Fume together.

Keywords: Soil, Soil Stabilization, Lime, Silica Fume.

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دراسة بعض الخواص الجيوتكنيكية لترب طينية عراقية محسنة

الخلاصة

في العديد من مشاريع تشييد الطرق،إذا ما وجدت تربة ضعيفة، فأن تثبيت وتحسين خواصها أمر ضروري. أن عملية التحسين تهدف إلى زيادة متانة التربة وتقليل النفاذية الانضغاطية.

تم اعتماد برنامج تجريبي لدراسة تأثر الخواص الهندسية لتربة طين الكاؤلين ((زود طين الكاؤلين من قبل الشركة العامة للمسح الجيولوجي والتعدين حيث يجلب بالأصل من منطقه الدويخله بالقرب من عكاشات غرب العراق)) عند امتزاجها مع النورة ومادة أل(Silica Fume) وقد تم تنفيذ سلسلة من التجارب المعملية لعينات من التربة بإضافة النسب التالية من النورة:2.5 ٪، 5.0 ٪، 7.5 ٪ و ١٠,٠٪. ونسب أخرى من مادة أل(Silica Fume) : 2.0 ٪،4.0 ٪ و ٦,٠٪ . التجارب هي : حدود قوام الطين، الكثافة النوعية, فحص الرص، فحص مقاومه الانضغاط غير المحصور واختبار نسبة تحمل كاليفورنيا . وتم تحديد الكمية المثلى من ألنورة والنسبة الأمثل للنورة ومادة أل(Silica Fume) معا.

أظهرت النتائج ما يلي :تم تحقيق النسبة الأمثل من مزيج ألنورة ومادة أل(Silica Fume) تلك ألنسبه هي :٢,٥% نوره+٦,٠% مادة أل(Silica Fume) التي كانت بمثابة نسبه سيطرة في هذه الدراسة .هذه النسبة المثلى: قللت من قيم مؤشر اللدونة، الكثافة النوعية والكثافة الجافة القصوى. بينما أدت إلى زيادة محتوى الرطوبة الأمثل، ومقاومه الانضغاط غير المحصور و نسبة تحمل كاليفورنيا . وأظهرت هذه النتائج أيضاأن لمزيج ألنورة ومادة أل (Silica Fume)تأثير أفضل من أضافه ألنورة بمفردها . النسبة المثالية للنورة هي ٢,٥% لمؤشر اللدونة و١٠% للكثافة النوعية وللكثافة الجافة العظمى ومحتوى الرطوبة الأمثل. بينما كانت ٥,٠٪ لتحسين مقاومه الانضغاط غير المحصور و ٧,٥% نسبة تحمل كاليفورنيا.

أشارت كل من هذه النتائج إلى أمكانيه تحسين الخواص الهندسية للتربة الطينية، عن طريق مزج ألنورة ومادة أل(Silica Fume) معا.

SOIL STABILIZATION

[1] defined stabilization as any process by which a soil material is improved and made more stable. Soil stabilization maybe described as the treatment of natural soil to improve its engineering properties. Soil stabilization is one of the oldest techniques which were used to alter soil properties in order to improve the performance in engineering application. In general, volume stability, strength, hydraulic conductivity and durability are of primary concern in soil stabilization [2] general methods of stabilization are mechanical and additive .In mechanical method. In mechanical method of soil stabilization, improvement of soil engineering properties is done by the addition of other soil particles which are missing from its natural grading. In ground improvement projects, this is normally leads to soil composition, both deep and superficial. The soil as a material is densified by mechanical means and is being used as fill in the construction of embankment, earth dams, sub grade of roads, etc **[3]**.

In the additive method of soil stabilization, it refers to a manufactured commercial product that, when added to the soil in the proper quantities, will improve the quality of the soil layer. The type of admixture used to stabilize the soil depends on the type of soil, the desired properties which are required, the environmental condition, and the economic consideration. In general the admixtures are used for the following purposes **[4]**:

1. To fill voids, as in grouting.
2. To bind particles, as with Portland cement or asphalt.
3. To react with soil to improve its physical properties and / or form cementing material as with lime.
4. To interact with soil surfaces to eliminate water sensitivity, as with asphalt or water-proofers. The most types of soil stabilizer are lime, cement and bitumen or waste materials such as Silica Fume.

LIME STABILIZATION

Lime meets the construction challenge: Lime is an unparallel aid in the stabilization of soil beneath road and similar construction projects. Lime reacts with medium, moderately fine and fine-grained soils to decrease plasticity, increase workability, reduce swelling, and increase strength **[5].** The major soil properties and characteristics that influence the soils ability to react with lime to produce cementitious materials are pH, organic content, natural drainage, and clay mineralogy. As a general guide, treated soils should increase in particle size with cementation, reduction in plasticity, increased in internal friction among the agglomerates, increased shear strength, and increased workability due to the textural change from plastic clay to friable, sand like material **[6].**

Soil stabilization with lime occurs when lime is added to a reactive soil to generate long –term strength gain through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminates hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. The primary effect of small lime additions is to reduce significantly the liquid limit, plasticity index, optimum dry density, swell, and to increase the optimum moisture content and strength of expansive clay. **[7]** stated that lime can be added and the soils mixed and compacted, initially drying the soil and then flocculating it. Several days to week later, the soil can be remixed and compacted to form a dense stabilized layer that will continue to gain strength for many years.

SILICA FUME STABILIZATION

Silica fume, also known as micro silica, is a fine –grain, thin and very high surface area silica. It’s sometimes confused with fumed silica (also known as pyrogenic silica) and colloidal silica. These materials have different derivations, technical characteristics, and applications **[8].**

History: the history of silica fume is relatively short, the first recorded testing of silica fume in Portland cement based concretes was in 1952 and it wasn’t until the early 1970 that concretes containing silica fume came into even limited use. The biggest drawback to discovering the unique properties of silica fume and its potential was a lack of silica fume to experiment with. Early research used expensive additive called Fumed silica, a colloidal form of silica made by combustion of silicon tetrachloride in hydrogen-oxygen furnaces. Silica fume on the other hand, is a by – product or a very fine pozzolanic material, composed of mostly amorphous silica produced by electric arc furnaces during the production of elemental silicon or Ferro silicon alloys. Before the late 1960s in Europe and the mid 1970 s in the United States, silica fume simply went up the stack as smoke vented into the atmosphere **[9].**

[10] have found that the addition of silica fume plays a very important role for the improvement of chemical properties of lime treated soils. The fact that the addition of silica fume improves the reactivity of the mixtures of lime and soil and the fact that the concentration of aluminum in the aqueous phase is much reduced when the silica fume is added to the mixture, indicates that the addition of silica fume is a very effective way for the control of formation of deleterious products such as ettringite in sulphate bearing soils stabilized with lime or other calcium based stabilizers such as Portland cement.

[11] stated the reaction mechanism of pozzolanic materials: Lime reacts with any other fine pozzolanic component (such as Silica Fume) to form calcium-silicate cement with soil particles .This reaction is also water insoluble. The cementing agent is exactly the same for ordinary Portland cement. The difference is that the calcium silicate gel is formed from the hydration of anhydrous calcium silicate(cement), whereas with the lime, the gel is formed only by the removal of silica from the clay minerals of the soil. The pozzolanic process may be written as:

$$Ca\,(OH)\,2+SiO2\quad C\text{-}S\text{-}H1 \qquad \ldots\ \mathbf{(1)}$$

$$Ca\,(OH)\,2+Al2O3\quad C\text{-}S\text{-}H \qquad \mathbf{\ldots\ (2)}$$

(Note: Calcium Silicate Hydrate, C-S-H, is cemented materials).

The silicate gel proceeds immediately to coat and bind clay lump in the soil and to block off the soil voids. In time, this gel gradually crystallizes into well-defined calcium silicate hydrates such as tobermorite and hillebrandite. The micro-crystals can also mechanically interlock. The reaction ceases on drying, and very dry soils will not react with lime or cement. The mechanism of the reaction can be represented as:

$$\begin{tikzcd} NAS4H + CH \arrow[r, Rightarrow] & NH + CAS4H \arrow[dl, "(2CH)"] & NS \arrow[r, Rightarrow] & \text{degradation product*} \\ NH + C2SH** \arrow[u] & & & \mathbf{..(3)} \end{tikzcd}$$

Where: S = SiO2, H = H2O, A = AL2O3, C= CaO, N = Na2O.

*As silica is progressively removed, calcium aluminates and alumina are formed residually

** *Or CSH.*

MATERIALS USED

The materials used in this study are:

1. Kaolin as untreated clayey soil;
2. * Hydrated Lime as stabilizing agent; and
3. ** Silica Fume as stabilizing agent.

Kaolin: The kaolin clay is used as untreated soil. It is widely used in the industrial domain "ceramic, tooth paste and industry, mixing in fodder, paper industry and in dye" its properties like slow moisture losses and easily formality give the variety in use.

Kaolin consists of repeating layers of elemental silica-gibbsite sheets. Each layer is about 7.2 A^o thick. The layers are held together by hydrogen bond and secondary valence forces **[3].**

The kaolin group, A hydrous alumina-silicate, has the general chemical composition of formula $Al_2 (Si_2O_5)(OH)_4$**.**

Table (1) and Table (2) give the physical properties results and the chemical composition of kaolin clay soil used in this study, respectively.

Lime: hydrated high calcium lime, $Ca(OH)_2$, has been used as a stabilizer agent, and is available in the local market; Hydrated lime has a higher effect on soil stabilization (among the other kinds of limes) and is really easy to use and mix with soil due to its fine particle size**[6] and [7].** Further more, working with hydrated lime is safer and using of it, is more usual in industry

Silica fume: The American Concrete Institute **ACI 116R(1996**)defines silica fume as “very fine non-Crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon”**[8].**

*****: In the firstmanner, (lime) was used only; and**: In the second manner, (lime + silica fume) mixture, were blended together It is produced by Wackier Silicones Company in Germany and it is obtained from the local market with 10 kg in one sack. Chemical compositions {as shown in Table (3)} were tested in the laboratory of the General Company of Geological Survey and Mining. The physical properties are given in Table (4).

Because of its high silica content as given in Table (3), {this high amount provides good pozzolanic action} and its extreme fineness {high specific area as given in Table (4)}, Silica Fume is therefore, a very effective pozzolanic material.

Water: Distilled water was used in conducting all the tests mentioned in this study.

TESTS AND RESULTS

Preparation of specimens: Kaolin soil was mixed with 2.5%, 5.0%, 7.5% and 10.0% lime. An amount of 2.0%, 4.0% and 6.0%(by dry weight of soil) Silica Fume was added to mixture and blended about 5 minutes, and then the mixture was allowed to stand for 1 hour in covered container.

A seven-day curing period was selected, to all specimens (whether treated or untreated), as a reasonable delay to allow reactions between the stabilizer and the soil prior to conducting the evaluation tests. Laboratory assessments of soil stabilizers often include a 28-day cure following treatment; the additional three weeks may, depending on the stabilizer, yield additional changes in the soil properties. However, it is expected that significant changes due to an effective soil treatment should be measurable at seven days**.** All the tests mentioned in this research were conducted according to the procedure described by **[12]** and **[13].**

Knowing that, these specimens were compacted at maximum dry density and optimum moisture content.

CONSISTENCY LIMITS TEST

The results of LSF stabilization on LL; PL; and PI of the soil samples are shown in Figures (1), (2); and (3) respectively. These results indicated that: The addition of lime only and at (2.5%) reduced the PI from (31-18%), indicating the optimal mixture of the lime. The PI however increased further with the addition of (7.5%) lime then decreased to (25%) at (10%) lime. This is due to the extra water required by the excess lime which makes the soil to swell**[1].**

The addition of combination LSF mixture, the optimal mixture was achieved at (2.5% L + 6.0 % SF) combination, resulted in lowering PI from (31-14.8%), a value which is lower than that of (18%) obtained from lime optimal mixture. The PI values, increased at (5.0%L +6.0%SF) then drops with subsequent increment of LSF mixture, indicating that the addition of LSF has a positive effect on the PI when compared with that of sample 2.5% Lime and 0.0% Silica Fume. This a good agreement with the results obtained by**[11].**

SPECIFIC GRAVITY TEST

The results of the specific gravity test are summarized in Figure (4). The Gs of the untreated soil (2.58) was decreased as the lime content increased, the lowest value was (2.50) at (10.0%) Lime. The same influence on the Gs was shown for the LSF mixture, the lowest value was observed at (2.5% L+ 6.0% SF) which decreased Gs to (2.44).

It can be seen that rate of decrease in specific gravity due to LSF is high as compared to Lime only. This indicates that the soil is lighter than that of its natural condition.

COMPACTION TEST

Figures (5) and (6) show effect of LSF on MDD and OMC respectively. For MDD of (15.7kN/m³) and OMC of (21.8%) of the untreated soil, the followings were observed:

For Lime soil mixture; the addition of lime causes a decrease in MDD and an increase in OMC. The best enhancement was at 10% lime; which decreased the MDD to (15.0 kN/m³), and increased the OMC to (23.1%).

For Lime Silica Fume mixture: The addition of (2.5% L +6.0% SF) results in decreasing the MDD to the lowest value of (14.3 kN/m³) and increasing the OMC to (25.13%). Generally, Lime and Silica Fume mixture, make MDD drops and OMC rises so that the soil moves into a humidity range, therefore, blended LSF has a place in construction work where a soils moisture content is very high, the same results were obtained by **[11]**; and this effect is important when used with soil of a high water content which is common in our area.

UNCONFINED COMPRESSION TEST

To ASTM D 2166-66. Samples for the unconfined compression tests were

The test was conducted according prepared after allowing the soil Lime Silica Fume mixture to cure at room temperature for 7 days (as mentioned before). The

35.5 mm-diameter, 71 mm-long samples were statically compacted to the MDD and OMC. The effect of LSF on UCS for a curing period of 7 days of the soil is presented in Figure (7). When the Lime content was increased from (0.0 to 5.0%)UCS increased from (24 to 42.24 kPa). Further increase in lime decreased the UCS, indicating that 5.0% is the optimum value for Lime. (0.0%L +2.0%SF) has a slight effect on compressive strength. The addition of (2.5%L + 6.0%SF) raised the value of the UCS from (24 to 69.5 kPa).The following mechanism explains the obtained improvements:

The chemical reactions that occur when lime silica fume is mixed with clay include pozzolanic reactions, cation exchange, and cementation, i.e., the extra strength displayed by the lime silica fume mixture is due to the binding action that lime silica fume has with fine soil particles. These result in agglomeration in large size particles; This causes the increase in compressive strength**[10].**

CALIFORNIA BEARING RATIO TEST

The California Bearing Ratio (CBR) of a soil: is an indefinable index of its strength, which for a given soil, is dependent upon the conditions of the materials at the time of testing. This means that the soil needs to be tested in a condition that is critical to its design **[13].** The pavement design is usually based on the CBR value of subgrade soil. In the present study soaked CBR tests were conducted on the raw and stabilized soils.

The tests were conducted according to ASTM D 2188. Figure (8), shows the effect of LSF mixture on CBR. The addition of lime up to (7.5%) led to increase in CBR. Further increase in lime decreased CBR, indicating that (7.5%) is the optimum value of lime, which raised the CBR value from (7.9 to 20.0%).While LSF mixture, improved CBR from (7.9 to 22.9%) at (2.5% L + 6.0% SF).It could be seen that the addition of (2.5% L + 6.0%SF) still gave the best overall result. These results in a good agreement with the results obtained by **[8].** This increment shows that the soil samples were effectively stabilized, which in turn improved the ENGINEERING properties of the soil by making them a good non-plastic subbase material. This will considerably reduce the subbase and surfacing materials required for road construction works.

CONCLUSIONS

Generally, Lime-Silica Fume is found to be most effective in stabilizing clayey soils than lime can do; the following conclusions may obtain:

1- The addition of combination LSF mixture resulted in lowering the liquid limit and plasticity index by about 41.6% and 52.2% respectively. The optimal mixture was achieved at (2.5%L + 6.0%SF).Where Lime alone, decreases the liquid limit and plasticity index by about 33.3% and 42%respectively. The optimum advantage occurs at (2.5%L+0.0%SF).

2- Lime-Silica Fume decreases the specific gravity by about 5.5% at (2.5%L+ 6.0%SF). While lime alone decreases the specific gravity by about 3.1%at (10.0%L+0.0SF).

3- Lime-Silica Fume mixture decreases the maximum dry density and increases the optimum moisture content. The best enhancement was at (2.5%L+ 6.0%SF) which decreases the maximum dry density by about

9% and increases the optimum moisture content by about 15.3%.The addition of 10.0% Lime decreases the maximum dry density by about 4.5%, and increases the optimum moisture content by about 6%.

4- The addition of LSF raised the value of the UCS. The addition of (2.5% L+6.0% SF) increased the UCS from (24.0–69.5 kPa). While the addition of 5.0%L + 0.0%SF) raised the UCS to (42.24 kPa). Indicating that LSF mixture gives better results than that which lime can do alone.

5- Lime-Silica Fume mixture, improved CBR from (7.9-22.9%) at (2.5% L + 6.0% SF). At (7.5%L + 0.0%SF), the CBR rose from (7.9- 20.0%).It could be seen that the addition of (2.5% L + 6.0%SF) still gave the best overall result.

Based on the summary of results discussed above, it was concluded that Lime-Silica Fume mixture was an effective stabilizer for improving the geotechnical properties of clayey soil samples.

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Table (1) Physical Properties Results of Kaolin.

Test	Value	Specification
Consistency Limits:		
Liquid limit, L.L, %	٦٠	BS 1377:1975, Test 2 (A)
Plastic limit, P.L, %	٢٩	BS 1377:1975 Test 3.
Plasticity index, P.I, %	٣١	
Specific gravity	2.58	BS 1377:1975, Test 6 (B)
Grain Size Distribution:		ASTM D421-72 & D422-72
Clay, %	90.5	
Silt, %	9.5	
Soil Compaction:		BS 1377:1975, Test 12
OMC (Optimum Moisture Content), %	21.8	
MDD (Maximum Dry Density), kN/m^3	١٥,٧	
Classification According to Unified Classification System.	CH	

Table (2) Chemical Compositions of Kaolin (Provided by the General Company of Geological Survey and Mining).

Fe_2O_3%	SiO_2%	Al_2O_3%
1.4 Max	50 Max	32 Min

Oxide	Percent
SiO_2	99.1
Fe_2O_3	35.0 p.p.m
AL_2O_3	< 0.035
TiO_2	<0.006
CaO	0.03
MgO	52.0 p.p.m
SO_3	<0.07
L.O.I	0.7

Table (3): Chemical Component of Silica Fume (Laboratory ofthe General Company of Geological Survey and Mining).

Table (4) Physical Properties of Silica Fume as Supplied by the Manufacturing Company.

Physical Properties	Test Result
Specific surface area	170000-230000
Density kg/ m^3	202
Loss of weight % when drying at 1000° c for 2 hrs.	<2
Loss of weight % when drying at 105° c for 2 .hrs.	<1.5
PH	3.9-4.3
%Retained on 40 µm sieve	<0.04
Moisture%	0.82

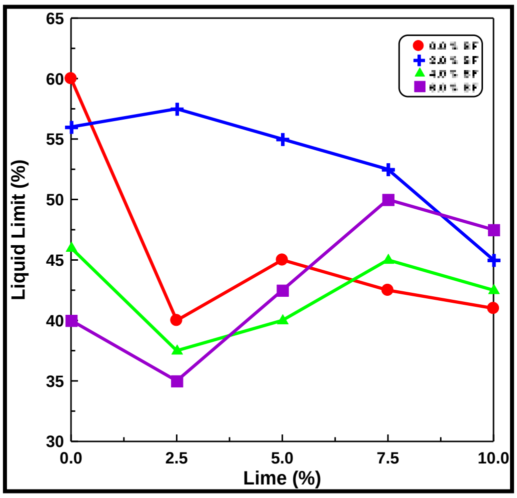

Figure (1) Effect of LSF on Liquid Limit.

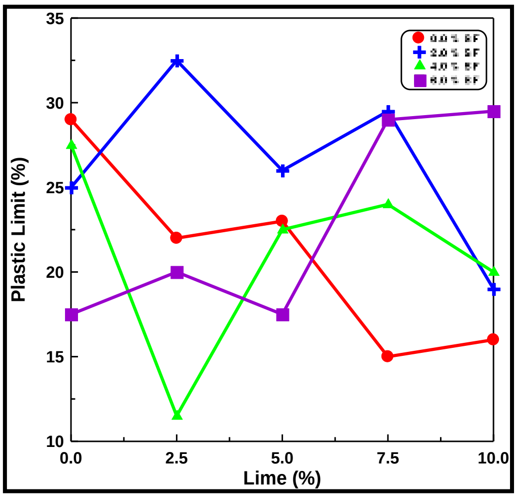

Figure (2) Effect of LSF on Plastic Limit.

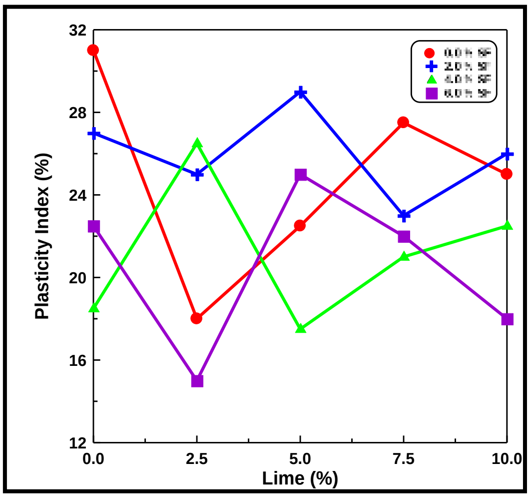

Figure (3) Effect of LSF on Plasticity Index.

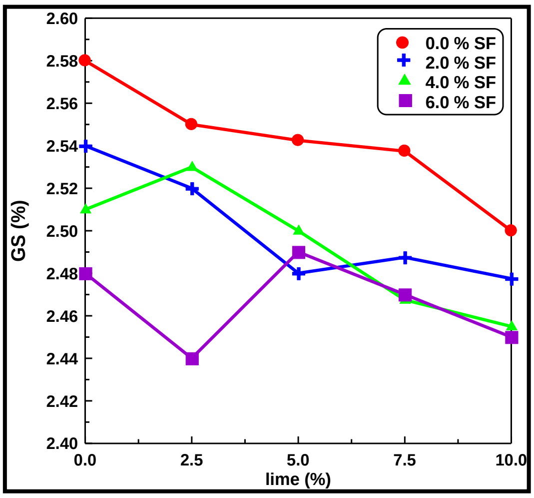

Figure (4) Effect of LSF on Specific Gravity

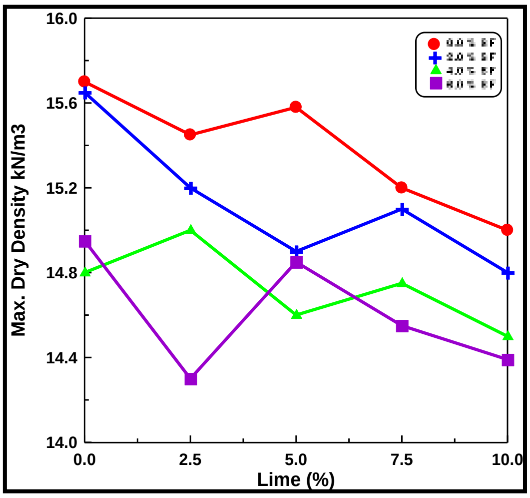

Figure (5) Effect of LSF on Maximum Dry Density.

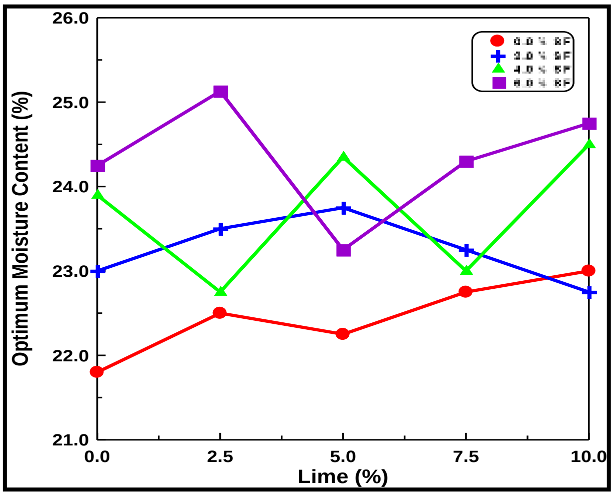

Figure (6) Effect of LSF on Optimum Moisture Content.

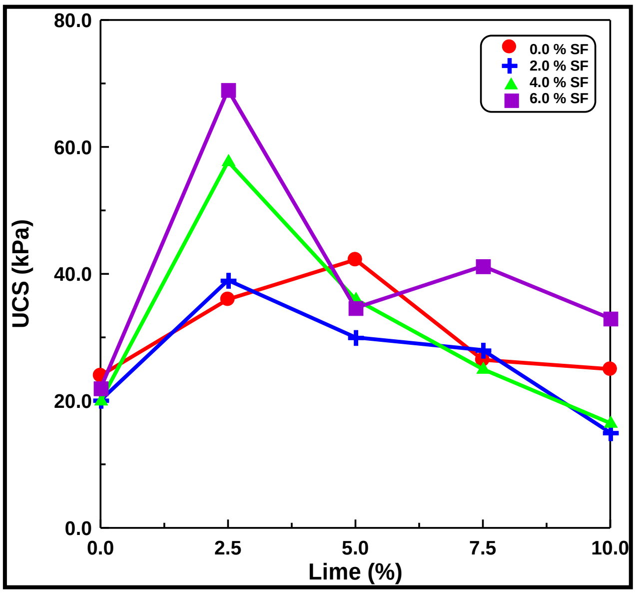

Figure (7) Effect of LSF on Unconfined Compressive Strength.

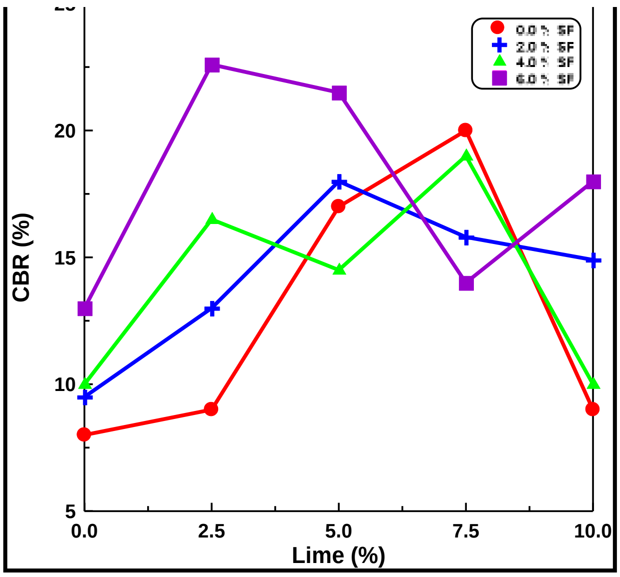

Figure (8) Effect of LSF on California Bearing Ratio.