Improvement of Soft Clay Soil Using Different Types of Additives

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Abstract. This study deals with the evaluation of the stabilization of several samples of soft soil with some chemical and physical additives. The intention is to amend the weak properties of these soils summarized in low bearing capacity and high settlement. The used stabilizers are quicklime, class F fly ash activated by cement, rock powder, crushed waste concrete, and tire crumb rubber. The paper investigated the effects of these stabilizers by unconfined compression test that considers very effective geotechnical test for measuring the ability of soils to bear structures constructed on them especially when used additives. This test was carried out on three samples of soils. They were classified by (UCSC) as (CL) soft soils. They were also classified by (AASHTO) as (A-7-6), (A-6), and (A-6) are rated as fair to poor subgrades in (AASHTO). The results of (UCS) test for each of the five additives used were compared according to the responding of each soil samples used. The (UCS) test was conducted in this study on sixty samples of soils before and after treatment and under the basics of the Proctor compaction test at optimum moisture content and maximum dry density. The results showed that the rock powder was the most suitable stabilizer that gave best results of improvement reached to 900% at 25% percent by dry weight of soil, crushed waste concrete came after it that gave treatment 683% at 15%, class F fly ash activated by cement followed the two formers which increased strength 533% at 15%, quicklime after that in an amendment 517% at 9% and finally tire crumb rubber that stabilized the soil 500% at 4%. In the literature, these materials founded to be very efficient in the stabilization of soils in their physical and chemical properties like increasing bearing capacity and reducing settlement of soil.

Keywords: Soft clay, improvement, quicklime, fly ash activated by cement, rock powder, crushed waste concrete, tire crumb rubber.

1. Introduction

The objective of this study is for checking the effect of soil improvement or soil stabilization (as the two terms indicated to the same meaning in the literature) on some samples of soft Iraqi clayey soils by using five different physical and chemical admixtures. The admixtures used are quicklime, class F fly ash activated by cement, rock powder, crushed waste concrete, and tire crumb rubber. The measured engineering instrument used in this study is the unconfined compression strength (UCS) test as it gives usually good geotechnical information about the expected bearing capacity of the soil and the stiffness of it. In the results of the search, it was evaluated that rock powder was the best-used stabilizer because it gave proportional increments reached 900% at 25% by dry weight of soil in (UCS) test to the first sample of soil.
In every engineering structure when the consultant engineer faced arduous (challenging or problematic) soil, he/she orders leave the site, digging the soil and replacing it by strong type, and finally go to soil improvement. The soil improvement concept has many methods and a lot of benefits like increasing the bearing capacity of the soil and reducing its settlement and also to resemble very economic choice. Soil improvement concept is still from the ancient and the renaissance in developing of current methods and invention of new ones for this aim; especially in developing countries suffering from increased population and problems in economic sources [1].

Soil stabilization is a general term for any physical, chemical, mechanical, biological, or combined method of changing a natural soil to meet an engineering purpose. There are a lot of stabilizers that can be used to improve the soil. The name that is termed to the weak soil is “problematic soils”. The moisture when touching these soils act as an enemy to them that making them very harmful to the structures built above them like foundations and light structures. Soft clay is one of these challenge soils. In Iraq, soft clay covered large areas of its geographic map especially in the middle and southern parts of it [2].

The reactions of chemical stabilization can be divided into two processes the first is the cation exchange that is chemical reactions inside the particles of the soil themselves and these reactions continued immediate flocculation and agglomeration of soil particles that restructured the soil and made it more friable transforming the contact of particles from the surface-to-surface parallel arrangement to surface to edge arrangement that reduced plasticity. The second part of these reactions is the pozzolanic reactions outside the structure of the soil atoms and between them which these reactions called cementitious reactions that lasting for a very long time and continuing also flocculation and agglomeration of soil particles but for a long time and affected permeability of soil in positive benefit.

The chemical stabilization becomes more successful when the minerals of soil are weaker especially montmorillonite. In the cation exchange reactions, the defused double layer of water omitted, and the single equivalent weak ions like sodium replaced by stronger multiple equivalent ions like calcium and in the pozzolanic reactions, the calcium from the stabilizer reacts with the Silica and alumina exist in the soil to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) that these compounds are cementitious and the information about them is limited [3].

Portland cement, fly ash, and lime are all used in special percents to stabilize soils, all by reducing their maximum dry density and increasing optimum moisture contents that lessen compaction effort and solving problems of soils. They are also reducing liquid limit and that not happened in all cases but they increasing the plastic limit in all cases, as a result, the plasticity index of soil is decreased. These stabilizers were also proved by those to reduce settlement and consolidation of weak soils and increasing their bearing capacity [4-7]. It was found that rock powder when added to soils the plasticity index (PI) of them decreased, optimum moisture content (OMC) decreased, and maximum dry density (MDD) increased, swell potential of soil decreased, and the unconfined compression strength increased. It concluded that rock powder can be considered a very effective stabilizing admixture to the expansive problematic soils and especially in cement applications [8]. The organic soil showed a response to stabilization perfectly by adding 10, 20, 30, 40, and 50% of crushed concrete. The Atterberg limits were reduced proportionally according to these percents. The maximum dry density was increased and optimum moisture content decreased because of the heavyweight nature of this substance and its capability to absorb water. The strength characteristics of soil were increased and that was proven by increased unconfined compression strength and undrained shear strength values and the swelling, compressibility, and settlement of soil were reduced to an extent very largely. It was discovered that the un-hydrated cement that remained in this substance plays a very important role in improvement [9-11].

Scrap tires rolled invented semi-new methods of stabilizing the soil that they continued substances strengthening the soil and use tires in soil improvement is cheaper than an iteration of them to original made as new tires. Also, they resemble dirt to the environment and home to mosquito at their disposing areas and they occupied large space and they are very economic and cheap ignored materials [12]. Tire rubbers can reduce both the maximum dry density and the optimum moisture content of the soils added to them because the lightweight nature of the reduced density and the ability of them to absorb water reduce the moisture content of the soil. The physical properties of soil like plasticity index decreased,
unconfined compression strength, and California Bearing Ratio (CBR) values can be increased with aid of tire rubber [13, 14].

2. Materials used

2.1 Soil
The soils used in this study were brought from three different locations at Baquba city. Baquba city is the center of the Diyala governorate in Iraq. The samples were taken as disturbed and undisturbed samples from a depth lied in between (0.5-1.5) m. The metalcore was used to extract undisturbed samples for soil preliminary tests.

2.2 Quick lime
The quicklime used in this study was brought from Iraqi markets in Sharjah the main market of Iraq in Baghdad and this quicklime was made in Iran.

2.3 Fly ash
The fly ash used in this study was non-self-cementing class F fly ash that contains low content of calcium compounds and resulted from the combustion of bituminous coals in opposite to the usual category of fly ash that called self-cementing class C fly ash that resulted from the combustion of sub-bituminous coals and contains high Calcium compounds like CaCO$_3$. The class F fly ash usually needs to be activated by a pozzolanic activator-like cement or lime and in this study, it was activated by using cement. The chemical composition of this type of fly ash was also checked in (NCCLR) that proves this type is (F).

2.4 Portland cement
The cement used to activate fly ash was Sulfate resistant Portland cement. It was made in Iraq by the Al-Jisr company.

2.5 Rock powder
This substance as it is called with this name or is as quarry dust (stone powder) was brought from local Iraqi markets by economic price. The rock powder is about the power of rock that is usually used as a replacement substitution material in cement applications. The sieve analysis did for this material had proved it passed the (0.075) mm diameter sieve.

2.6 Crushed waste concrete
This substance was gotten on it as failed concrete blocks from the civil engineering structural laboratory in the college of engineering at the University of Diyala and crushed to the smallest possible size in a special big mill for milling marble and other liked substances in the third industrial zone in Baquba city. This material was from the passed (0.075) mm diameter sieve.

2.7 Tire crumb rubber
It was gotten on it by cutting the rubber of car tires in special local mills after removed the metal part of the tires. The rubber was crushed to a size like ash with a 0.5mm diameter approximately and about 2mm in length.

3. Experimental work
The experimental work of this study consists of two parts and as follows:

3.1 Controlled soil tests
The first section of this search was to conduct approximately the whole available soil mechanic laboratory tests on the three free soil samples. These tests included initial water content, plasticity index test, specific gravity test, sieve analysis, hydrometer analysis, and compaction test. One of the most advantageous characteristics of using these laboratory soil mechanic tests that they could be used with the soil freely without additives and then with additives under the same circumstances.
3.2 Unconfined compression strength (UCS) test
The second part of this search was to conduct the unconfined compression strength (UCS) test on the three soft soil samples freely and then repeated it with five physical and chemical different additives to the three soil samples and the whole of these additives consisted firstly of quicklime in percent's of 3, 5, 7, and 9%; secondly of Class F fly ash in percent's of 5, 10, 15, and 20% all activated by 5% by with Portland cement; thirdly rock powder in percent's of 10, 15, and 25%; fourthly crushed waste concrete in percent's of 5, 10, and 15%; and fifthly and finally the last stabilizer used is tire crumb rubber in percent of 2, 4, 6, and 8%. The used percents of each additive were all by weight soil. All of these percents of additives were selected from the literature according to the type of soil which was soft clay. All UCS samples were compacted to their maximum dry density (MDD) at the corresponding optimum moisture content (OMC) predetermined to each soil sample by standard Proctor test. The UCS test was conducted according to ASTM D2166 by a standard mold of 10 cm length and 4 cm diameter. The whole number of (UCS) test samples was sixty (60) samples. The curing is not used in this research but the samples may be left for 24 hours approximately before checking to get catching.

4. Results and discussion

4.1 Results of controlled soil tests
The results of the controlled soil tests that conducted on the soil without any stabilizer indicated that the three soil samples were soft clayey soils and the results of these tests summarized in Table 1.

4.2 Results of unconfined compression strength (UCS) test
With the quicklime, an additive used the increase in the (UCS) value was proportional with all percents used of this stabilizer and to all three soil samples. The results are given in Figure 1. It is evident from the figure that at 3% lime the improvements are 167, 103, and 54% for samples 1, 2, and 3 respectively. For 5% lime, the improvements are 308, 197, and 131% for samples 1, 2, and 3 respectively. For 7% lime the increases are 367, 248, and 167% for soils 1, 2, and 3 respectively and finally for 9% lime the percents of increases are 517, 377, and 278% for the three samples from one to three respectively.

Table 1. Physical properties of natural soils used in this study.

| Index Property                  | Test Standard | Soil sample No.1 | Soil sample No.2 | Soil sample No.3 |
|---------------------------------|---------------|------------------|------------------|------------------|
| Depth (m)                       | -             | 0.5-1.5 m        | 0.5-1.5 m        | 0.5-1.5 m        |
| Natural moisture content (%)    | ASTM D 2216   | 40               | 32               | 28               |
| Liquid limit (LL) (%)           | ASTM D 4318   | 48               | 35               | 34               |
| Plastic limit (PL) (%)          |               | 15               | 15               | 20               |
| Plasticity Index (PI) (%)       |               | 33               | 20               | 14               |
| Specific gravity (Gs)           | ASTM D 854    | 2.67             | 2.71             | 2.75             |
| Gravel (> 4.75 mm) (G) (%)      |               | 0                | 0                | 0                |
| Sand (0.075 to 4.75 mm) (S) (%) | ASTM D 422    | 0.7              | 5                | 15               |
| Silt (0.005 to 0.075 mm) (%)    |               | 38.3             | 36               | 40               |
| Clay (<0.005 mm) (C) (%)        |               | 61               | 59               | 45               |
| The activity of clay (At)       | Skempton formula* | 0.6               | 0.5              | 0.4               |
| Classification of soil (USCS)   | ASTM D 2487   | CL               | CL               | CL               |
| Classification of soil (AASHTO) | ASTM D 3282   | A-7-6 (35)       | A-6 (29)         | A-6 (11)         |
| Maximum dry density (kN/m³)     |               | 17.5             | 18.6             | 19.1             |
| Optimum moisture content (%)    | ASTM D 698    | 17.7             | 16.5             | 16               |

Skempton formula*: At = PI/Percent of clay < 0.002 mm
Figure 1. Effect of quicklime in treatment of three soil samples.

Figure 2 shows the results of the (UCS) test for the three soil samples after added class F fly ash activated by cement. From this figure we can know that the first soil sample at 5% fly ash activated by 5% cement the increase in UCS is 375% then at 10% is reduced to 208% and after that, at 15% it raised too as in 5% but with the higher level reached to 533%, then at 20% the (UCS) lowered to a level somehow liked in 10% but higher approximately which is 292% at final. The same mentioned trend of improvement was for the remaining two samples of soil but for soil sample, no.2 was 268, 139, 390, and 203% and for soil sample no.3 the improvement was 187, 64, 279, and 136%. Every percent of improvement to samples no.2 and 3 is corresponding to 5, 10, 15, and 20% of class F fly ash activated by 5% cement. It can be noticed from the figure that the peak (UCS) values are noticed at 5 and 15% fly ash. The improvement that occurred at these two percent and especially at 15% is devoted to the cation exchange reactions and cementitious reactions that change the soil structure from dispersed to flocculated.

Figure 2. Effect of class F fly ash activated by cement in the treatment of three soil samples.
The improvement with the rock powder was proportional for all percent of it and all three soil samples. At 10% the improvements were 208, 139, and 90% for samples 1, 2, and 3 respectively. At 15% the improvements were 317, 223, and 151% to the same numbering of samples. At 20% the resulted percent increments were 471, 339, and 228% for samples 1, 2, and 3 increasingly. At 25% the treatment resulted in 904, 658, and 503% increments in unconfined compression strength to the 1 to 3 tested soil samples. These implications of results are shown in Figure 3.

![Figure 3](image-url)

**Figure 3.** Effect of rock powder in the treatment of three soil samples.

The improvement results for the crushed waste concrete were proportional too for the three percent used. The increases were 308, 210, and 141% for samples no.1, 2, and 3 respectively at 5% percent crushed waste concrete. For 10% of this additive, the increments were 417, 294, and 208% for the first to third samples. For 15% of this substance, the increments were 683, 494, and 364% for 1 to 3 samples too. Figure 4 shows all results of treatment that are explained in this manner in this paragraph.

![Figure 4](image-url)

**Figure 4.** Effect of crushed waste concrete in treatment of three soil samples.
The results of the physical additive (tire crumb rubber) were in the last level of improvement results to the soils. From Figure 5, it can be noticed that for 2% of this material the results for increasing in the (UCS) values for the three soils are 146, 75, and 26% respectively. Then at 4% of tire crumb rubber, the (UCS) values are raised for the three soil samples respectively to 500, 352, and 259%. After that and at 6% of this material the results of improvement declined below the used 4% of this substance to 333, 235, and 166% for the three samples respectively. At 8% percent, the results of (UCS) values are the lowest in the arrangement of improvement but higher than 2% of this material. The results of 8% percent tire crumb rubber for the three soils are 208, 139, and 64%. The decrease in the (UCS) values is due to the existence of a high percent of crumb rubber that resulted in more compressibility in the soil and also the elasticity of rubber is so high compared to the soil.

![Figure 5. Effect of tire crumb rubber in treatment of three soil samples.](image)

The 9% quicklime is considered the optimum percent for this substance in the treatment of the three samples. The optimum percent of class F fly ash activated by 5% cement was 15% followed by 5% for all three samples. The optimum percent of rock powder was (25%) for all three stabilized soil samples. The 15% crushed waste concrete is optimum for the three soil samples. The 4% tire crumb rubber is considered the optimum for the soft clay samples used in the study. From the results, it is evident that rock powder is the best additive used in the study that doubled the strength of soils (7) times above its initial strength, followed by crushed waste concrete that doubled the strength (5) times. The class F fly ash activated by cement came in the third rank of improvement that increased the strength (4) times. The additive that occupied the fourth level in treatment is the quicklime that gave little below (4) increments approximately to the initial strength of the soil. The fifth stabilizer in strength is tire crumb rubber which gave the smallest results of improvement but it did and gave strength to the soil higher (3) times above its initial strength.

5. Conclusions
Based on the previously given hypotheses, data, and results presented in this study it can be concluded the following points:

- The first treated sample showed more response to stabilization than the remained samples and that could be because of the expected weakness of it defined by the AASHTO classification of this sample which laid it as A-7-6 (35).
- The second and third samples take the followed levels respectively according to the domain of amendment and that may be also devoted to the AASHTO classification of them which is A-6(29)
to the second sample and A-6 (11) to the third sample. All the used stabilizers gave bright results to the used soils.

- All stabilizers that were used in this study had been ensured to increase (UCS) values at their concluded optimum percent which is special and different from each stabilizer used. The best stabilizer used was the rock powder.
- The results of the additives can be translated to economic findings in the work fields. The success of using waste byproducts additives (fly ash, rock powder, crushed waste concrete and tire crumb rubber) in the treatment of weak soils can prove their economic and environment-friendly useful purposes.

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