Diyala Journal of Engineering Sciences

Journal homepage: https://en.enginmag.uodiyala.edu.iq/

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Improving California Bearing Ratio (CBR) Using Chemical and Physical Treatments for Diyala Soils

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ARTICLE INFO

Article history:
Received 9 March 2021
Accepted 21 May 2021
Keywords:

CBR; Soft soils; Quicklime; Class F fly ash activated by cement; Rock powder; Crushed waste concrete; Crumb rubber of tires.

ABSTRACT

Gets in the world at this time continued growth and rapid development in the whole aspects of life. The urgent needing accomplished that is in civil engineering demands like the construction of houses, schools, hospitals, roads, and other structures. Because of that and for economic and security reasons; classifying soil and knowing its bearing capacity appeared to be very necessary conditions that offer a large domain of benefits that could not be counted. This study focused on classifying and determining the bearing capacity of some samples of soil that classified as soft soils of Baquba city the center of Diyala governorate in Iraq. Then trying to increase their bearing capacity. The California Bearing Ratio (CBR) was used in the paper to define soil strength because it is considered a force measuring parameter. Five elected physical and chemical treatments were used in predetermined percents taken from the literature and suited the kind of soil. They were quicklime, class F fly ash activated by cement, rock powder, crushed waste concrete, and crumb rubber of tires. The treatment that was the best among the five used methods was by the rock powder that improved CBR value by 570% in soil samples A used.

1. Introduction

Soil improvement technique is a method of increasing the load-bearing capacity and strength of the soil [1]. A geotechnical project feasibility study is most beneficial before a project can start. A site survey is usually carried out before the design process begins, to understand the characteristics of the subsurface on which the decision on the site of the project can be made. The geotechnical design criteria that must be taken into account when selecting the location are the design load and the function of the structure, the type of foundation to be used, and the load-bearing capacity of the subsoil. In the past, the bearing capacity of the soil was the key factor in the decision. Once the bearing capacity of the soil was poor, the old option was to adapt the design to the condition of the site, remove and replace the in-situ soil, and the final decision was to leave the site. Nowadays soils such as soft clays and organic soils can be upgraded to meet the demands of civil engineering. This form of art review focuses on the soil stabilization method, which is one of the various methods of soil improvement. This view was laid by Nicholson [2]. Soil stabilization is a general term for any physical, chemical, mechanical, biological, or combined method of modifying a natural soil to serve a technical purpose. Improvements increase the load-bearing capacity, tensile strength, and overall performance of on-site sub-soils and sands and waste materials to reinforce road surfaces as an example. Stabilization can be divided into two groups:

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DOI: 10.24237/djes.2021.14204

mechanical stabilization and admixture stabilization. Mechanical stabilization by mixing the gradation component into the soil on-site or in a quarry to change the gradation and achieve good results of the soil specifications. The spreading, mixing, and compacting is done to achieve the required density. According to what was stated by Balkis and Macid [3]. The continued demand for aggregates in highly developed countries has now resulted in a shortage of stone and gravel in many places, e.g. In large urban areas where the availability of aggregates has traditionally been low and the production of aggregates is prohibited for environmental reasons. In many developing countries, the availability of good, cheap supplies of aggregates is limited and cannot meet the needs of their emerging economies. As a result, more attention is now being paid to use locally available substitute materials such as stabilized soil and waste materials to meet construction requirements. With the concept of O'Flaherty AM & Hughes [4].

The effects of lime, cement, and fly ash on the geotechnical properties of the soil can be summarized as follows. These additives improve the particle size distribution of soils and convert clayey soils into force silt like, sandy and gravelly soils, thereby better classifying the soil. They also decrease the maximum dry density and increase the optimal moisture content of the soils when added to them. They also decrease the liquid limit and increase the plastic limit. The liquid limit is not always decreased as discovered, but the plastic limit is always increased with these additives. In any case, the plasticity index of the soils is decreased, which leads to a decrease in the plasticity of these soils. These additives increased the specific gravity, the unconfined compressive strength (UCS), the cohesion (C) of the soils, and the angle of the internal friction (φ) of the soil. And finally, these additives reduce the swelling potential of the soil and its compressibility [5-7].

The results of a study on the stabilization of dispersive soil by lime showed that the CBR of the stabilized subsoil increased by 86.55%. The CBR value of the treated soil lime was significantly increased with 9% lime content in 7 days and 14 days of curing time. The study showed that 7% to 9% of the lime content for 7 and 14-day curing periods was optimal lime content. Devoted to studying conducting by Gidday & Mittal [8].

The CBR values in a study [9] for cement-soil mixtures were remarkably higher than the values for untreated samples. The CBR increased by 87.65% for 9% cement based on the dry weight of the soil.

Umar et al. [10] conducted a study using class C fly ash to stabilize the soil at 3%, 6%, 9%, 12%, 15%, and 18% of the dry weight of the soil. It was observed that the CBR values decreased at all a soil fly ash content, above which it remained constant and then gradually decreased between 15 and 18% fly ash content.

The results of a study by Pavani et al. [11] of the un-soaked CBR test of black cotton soil when mixed with rock dust of 10%, 15%, up to 75% with 5% increments showed that there is an increment of 14.79% to 18.86%, to 15.26% to gives 28.99%.

The CBR values were improved by 3.45% at 40% waste concrete fines added to the soils above its initial value that is 6.56%, [12].

A.Nilesh et al. studied the behavior of soil mixed with tire shreds indicated that un-soaked CBR values improved by 21% above their original value which is 10.94%. This improvement occurred at 2% weight of soil of tire shreds [13].

This research tries to investigate the bearing capacity of Iraqi soils, especially in the Diyala governorate, and the possibility of treating them when their weakness appears. This treatment is done by improving the value of the California bearing ratio (CBR) by using five stabilizers. The five stabilizers used in the study were quicklime, class F fly ash activated by cement, rock powder, crushed waste concrete, and crumb rubber of tires].

2. Methodology

2.1. Materials Used

2.1.1. Soil

Three soil samples used in this study were each coded with letters (A, B, and C). The three samples were brought from three different locations in the city of Baquba, the provincial center of Diyala in central East Iraq, about 70 km from the capital Baghdad. The research purpose of the study was the reason for bringing soil out of this city. The three soil samples were brought from locations with coordinates represented by (Latitude 330 48` N, Longitude 440 34` E) for sample (A) and (Latitude 330 46 `N, Longitude 440 37`E) for sample (B) and finally (Latitude 330 39` N, Longitude 440 35` E) for sample (C) knowing that all of these coordinates are within the city limits mentioned above. Soil samples were obtained in the form of disturbed samples from a depth of 0.5 to 1.5 m. In the meantime, a small cylindrical metal sampler was used to extract undisturbed samples in their natural state for experiments on natural water content and the limits of Atterberg and the specific gravity of the soil.

2.1.2. Water

Tap water was used in the experimental work of this study. The standards required that distilled water and tap water may be used and the seawater can be permitted for use in some cases if it is proved not to be unsuitable.

2.1.3. Quicklime

The type of lime used in this study was the quicklime (un-hydrated) which is called locally (Noora) that made artificially from limestone. It was brought from local Iraqi markets and it was made in Iran. The particles of this additive were from passing 0.85 mm sieve.

2.1.4. Cement

The cement used in this study is the sulfate resistance Portland cement (type V) which was made by (Al-Jessir) company in Iraq. In this study, cement was not used as an alone stabilizer but it was used as a pozzolanic and cementitious activator to the class F fly ash stabilizer. The specific gravity of used cement is 3.15.

2.1.5. Fly ash

The fly ash used for this study was obtained from local Iraqi markets and its origin was from India. This fly ash is proven by checking in the National Center for Construction Laboratories and Research (NCCLR) in Baghdad that this fly ash was class F. Class F fly ash is considered just a primary fixator to the soil and it lacked naturally cementitious properties that made it need to be activated by a pozzolanic and cementitious material like cement and lime. Conversely there is a type of fly ash which is class C that considered as a stabilizer that can be used to treat the soil alone and need no activator.

2.1.6. Rock powder

This substance derived from quarrying works occurred in crushers at most local quarries. This waste product additive as it is locally called rock powder (quarry dust or stone powder) was collected from locally available quarries in Baquba city. Its particles were from the passing (0.075 mm) diameter of the sieve. The measured specific gravity of this used material is 2.7.

2.1.7. Crushed waste concrete

This waste additive was from passing the (0.075) sieve diameter. It was gotten on as milled material from the milling of failed tested concrete blocks from a structural laboratory in the college of engineering (University of Diyala). These blocks were crushed in a special mill for marble and other liked substances in the third industrial zone in Baquba city.

2.1.8. Crumb rubber of tyres

The Crumb rubber of tires used in this paper was produced from waste used tires after removed the metal part and after that, the rubber was cut to very small pieces passing the (0.45mm) sieve by a special cutting machine in Baghdad.

2.2. Experimental work

The experimental work of this study consisted of two parts: the first is of controlled soil tests and the second is of California Bearing Ratio (CBR) test.

2.2.1. Controlled soil tests

This part included conducting the mechanical laboratory tests that considered the parameters of physical properties for knowing the nature and behavior of soil. The tests were natural moisture content test, plasticity (liquid limit and plastic limit) test, specific gravity (Gs) test, particle size distribution tests (including sieve analysis and hydrometer analysis test) of soils, and standard Proctor test. The whole sum of these tests was conducted every separately on each of the three soil samples (A, B, and C) respectively. By the aid of the results of these tests it was classified the three soil samples according to the Unified Classification System of Soil (UCSC) that help on recognition on soil geotechnically and also the soil samples were classified according to the system American Association of State Highways and Transportation Officials (AASHTO) that define the quality of the soils to be a part of layers of constructed roads and highways.

2.2.2. California Bearing Ratio (CBR) test

The design of the various pavement layers depends heavily on the strength of the subsoil over which they are to be laid. The subsurface strength is mainly expressed in CBR (California Bearing Ratio). Essentially thicker layers are required for a weaker sub-base, while thicker sub-soils are required, go well with thinner pavement layers. The roadway and the ground must mutually maintain the volume of traffic. The unsoaked CBR tests were performed on each soil using the methods described in ASTM D 1883. All samples were prepared at OMC and 95% MDD for natural compacted soils using the modified Proctor compaction test. Figures (1) and (2) represent example pictures of the CBR apparatus and its conduct in the laboratory which did the experimental work of this study.

Figure 1. CBR test mould and its accessories

Figure 2. CBR test loading frame

CBR experiments were carried out on all soils (A, B, and C) naturally without treatment, then they were repeated on these soils using five physical and chemical treatments.

The first stabilizer used in laboratory work was quicklime in four proportions, namely 3%, 5%, 7%, and 9% of the dry soil weight. These four ratios were used in the CBR test on the three soil samples collected. The second fixer in use is class F fly ash, which is activated by cement. This fixer was used in four percentages, 5%, 10%, 15%, and 20%, and each of these percentages is combined with a fixed percentage of Portland cement (as a pozzolan activated substance to stabilize the soil by fly ash) is 5%. Third, residual rock powder material was used in four proportions which are 10%, 15%, 20%, and 25%. The fourth fixer used in the laboratory work of this study is concrete powder residue with only three percentages, namely 5%, 10%, and 15%. Fifth and finally, crumb rubber was used from tires and added as a physical stabilizer and fill material additive at four percentages which are 2%, 4%, 6%, and 8%. It must be pointed that each percentage of the five stabilizers added was calculated as a live weight to the dry soil weight, and also, the effect of each ratio and stabilizer was measured by performing the CBR experiment independently and on each of the three soils A, B and C respectively.

The mixing process worked by mixing the soil and a percent of the stabilizer by dry weight of soil and the mixing process was manually conducted in a bowl and by adding the optimum moisture content of the natural soil to the mixture. During mixing, it was taken care that the mix is not stopped until the color of the mixture of soil and stabilizer became uniform and not linearly appeared with different colors.

3. Results

3.1. Results of controlled soil tests

The results of the laboratory experiments conducted on the three soil samples A, B, and C showed that all these soils are of the type of soft clay with low resistance and the possibility of settlement and compressibility when building on it, which made it classified as problematic soils in need of treatment. Table (1) explains the physical properties (of the three natural soil samples) extracted from the laboratory-approved experiments.

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

Index Property	Soil Sample A	Soil Sample B	Soil Sample C
Depth	0.5-1.5m	0.5-1.5m	0.5-1.5m
Natural Moisture Content (%)	40	32	28
Liquid Limit (LL) (%)	48	35	34.3
Plastic Limit (PL) (%)	14.78	15.33	19.94
Plasticity Index (PI) (%)	33.22	19.67	14.36
Specific Gravity (Gs)	2.67	2.71	2.75
Gravel (>4.75mm) (%)	0	0	0
Sand (0.075-4.75mm) (%)	0.7	5	15
Silt (0.005-0.075mm) (%)	38.3	36	40
Clay(< 0.005mm) (%)	61	59	45
The activity of Clay (At)*	0.6	0.5	0.4
(UCSC) Classification	CL	CL	CL
(AASHTO) Classification	A-7-6 (35)	A-6(18)	A-6(12)
MDD (kN/m^3)	17.5	18.6	19.1
OMC (%)	17.7	16.5	16

Note: According to Skempton Formula:
* At =PI/$\{percent\ of\ clay < 0.002mm\}$

3.2. Results of California Bearing Ratio (CBR) test

All soil stability improvement results measured by CBR values were very blooming for all five additives mentioned, and we will cite them all in this statement.

Figure (3) shows the results of the improvement of the CBR by quicklime and for the three soils. From this figure, it can be seen that the improvement ratios were directly proportional to each increase in the quicklime percentage. This included all three mentioned soil samples. but with a relative difference in each soil sample. For soil (A) the CBR values increased by 153%, 216%, 289%, and 353% above the CBR level for natural soil, in line with the increase in the quicklime rates, which are 3%, 5%, 7%, and 9%, respectively. As for soil B, the CBR values increased by the same previous order, but by 110%, 181%, 238%, and 290% above the CBR level of the soils in their pure state. Finally, for soil C, the rates of improvement were 72%, 132%, 180%, and 224%, incrementally increasing the percentage of quicklime used mentioned above. It turns out that 7% and 9% of quicklime represent the optimum ratios of it for stabilizing soil and improving its CBR value, especially 9%.

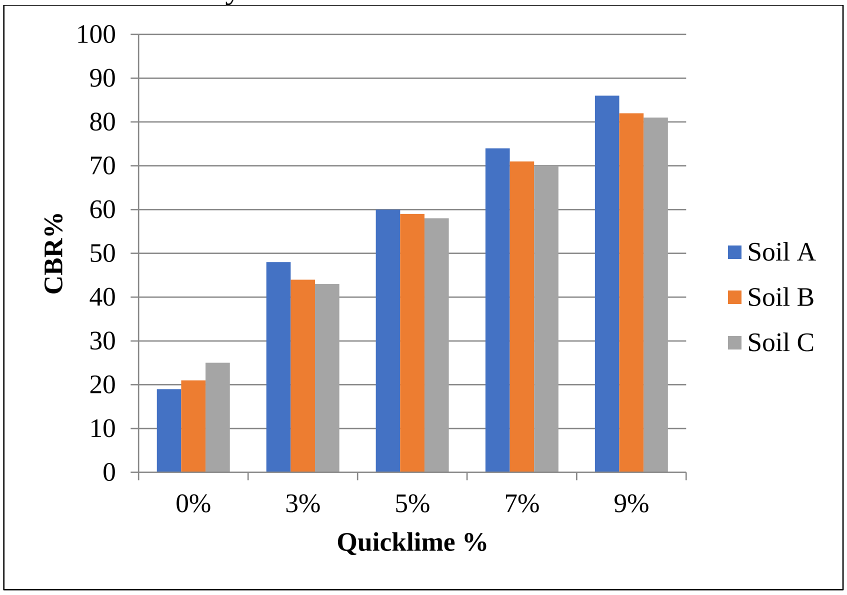

Figure 3. Effect of quicklime on CBR

Regarding the results of the second stabilizer used in this paper (which is class F fly ash activated with all percentages of 5% Portland cement), these results were presented in Figure (4). Here, the results were not positive with the increase in the stabilizer ratios, but they were differentiated differently with the emergence of one optimal ratio for this stabilizer in fixing the three soil samples symmetrically. It is evident from the display of the figure that at 5% fly ash (class F) the CBR values increased by 305% for soil A, 252% for soil B, and 196% for soil C. Then at 10% of fly ash the rates of improvement were 168%, 133% and 96% for A to C soils, respectively. We can notice that the improvement decreased at this percentage of stabilizer. Then, at 15% fly ash, the improvement rates for the CBR values of the three soil models increased to 384%, 314%, and 244%, respectively, corresponding to an increase of 5% of this stabilizer and higher compared to it as well. Through the last percentage of this additive, 20%, the improvement rates for CBR values decreased, maintaining an increase over those raw values by 332%, 190%, and 140% for the three soils, respectively. The decrease in soil treatment represented by CBR values at the ratio of this stabilizer may be due to an increase in the proportion of non-pozzolanic substance from fly ash and a decrease in the percentage of activated binder represented by cement. We conclude from the aforementioned results of soil improvement with this stabilizer that 5% and 15% and especially 15% of this stabilizer are the optimum harmonic ratios for fixing the specific types of research soil. In Figure (4) we can interpret that the manner of appearing the results has happened because the class F fly ash needs an activator to succeed in soil stabilization and when the balance happened between the percents of the two combined stabilizers with the treated soil the optimum percents of the stabilizers are appeared and being underestimated and since class F fly ash has little CaO, so its cementitious work had been compensated by cement. Also, it means that the development of CBR values at these two ratios is due to the change of soil composition from dispersed and inconsistent to flocculated and agglomerated.

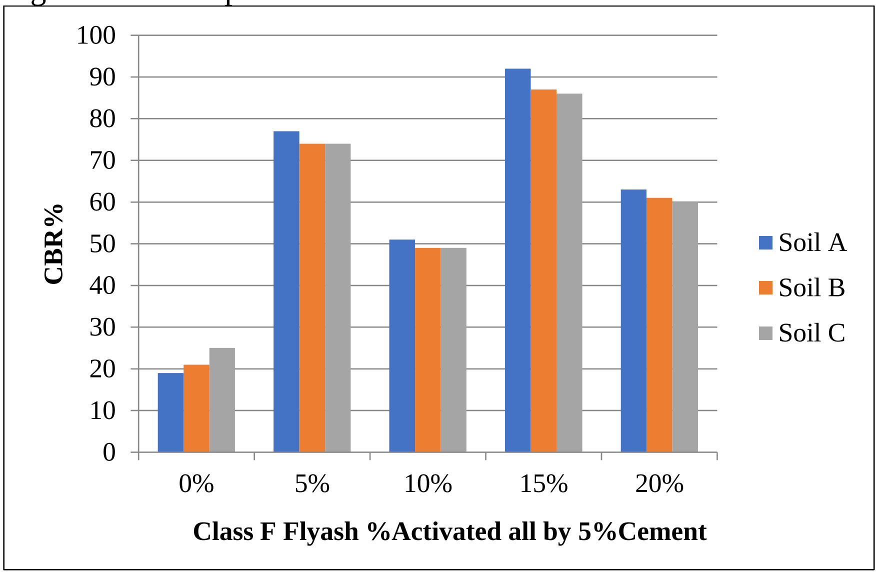

Figure 4. Effect of class F fly ash activated by cement on CBR

The results of soil stabilization with rock powder (the third stabilizer used in the laboratory work of this study) were directly proportional to the increase in its percentage, as is noticed and evident from Figure (5), which illustrates this behavior of the three samples taken. We can see from this figure that the percentage of improvement in the CBR value at 10% of the stabilizer is 174%, 148%, and 104% for A, B, and C soils, correspondingly. Crossing over to 15% rock powder, the improvement rate for the three soils increased to 253% for soil A, 214% for soil B, and 164% for soil C. Then, after this increase and at 20% rock powder, the increase in CBR values continued, reaching 311%, 271%, and 208% for the three soils. When the last percentage (25%) of this additive of soil weight dry was used the improvement, rates were the highest and this percentage is considered as the optimum of this additive for all three soils, which led to an increase of 570%, 456%, and 344% for A, B and C soils, respectively.

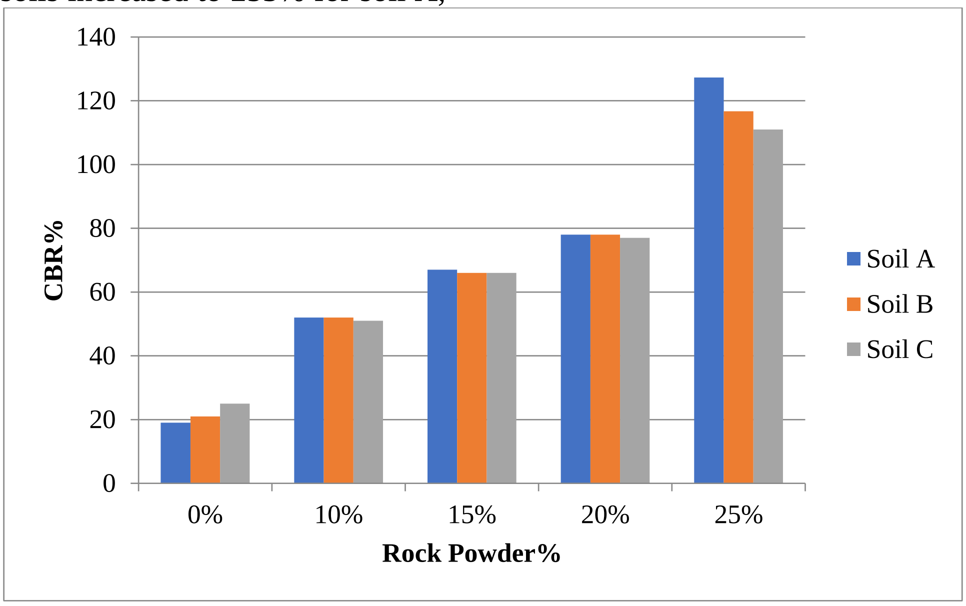

Figure 5. Effect of rock powder on CBR

Relative to the results of soil stabilization with the crushed waste concrete (the fourth additive in order of the laboratory work of this publication), the results showed a direct proportionality in the increase along with the CBR values and in the three stabilizer ratios used, as is the case in the quicklime and rock powder. The improvement rates at 5% of this stabilizer for soils A, B, and C were 242%, 210 and, 152%, then they increased to 305%, 267% and 208% at 10% crushed concrete powder, to finally reach at 15% of it to an increase made this percentage considered the optimum in treating the three soils, as the CBR amounts increased by 421%, 362% and 268% for the three soil samples, respectively. Figure (6) shows the results of the CBR values after adding this residue material to the three soils that have just been discussed in this paragraph.

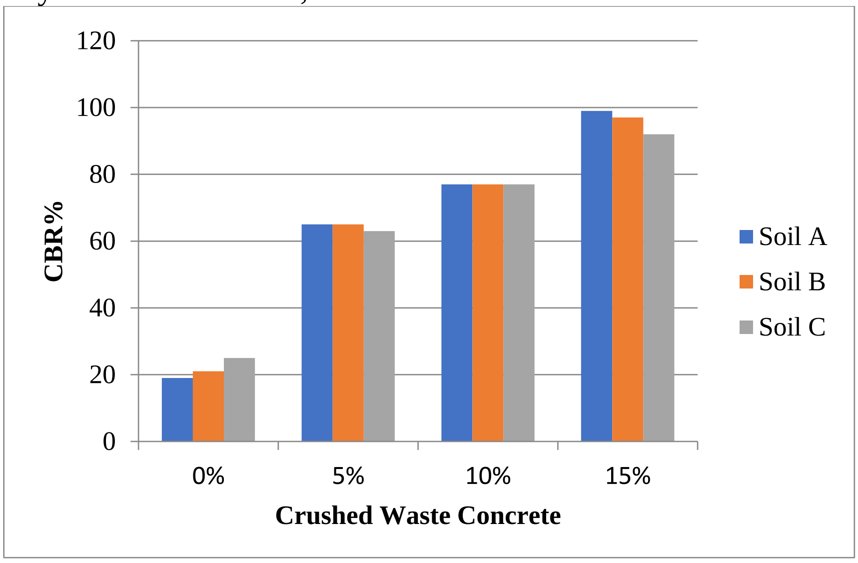

Figure 6. Effect of crushed waste concrete on CBR

Fifthly, and finally, the results of the physical stabilizer (tire rubber crumbs) showed similar random behavior in the three soils. This behavior is explained in Figure (7). Following the rates used 2%, 4%, 6%, and 8% of this stabilizer, the rates of soil resistivity improvement calculated with the CBR scale for soil A were 105%, 326%, 258%, and 200%. For soil B, with the same order of percentages added from this stabilizer, the increases in the CBR over its normal value were 67%, 280%, 224%, and 152%. For soil C, the CBR values increased by an improvement of 4%, 216%, 172%, and 112% in the same order of sequence for the ratios of tire rubber crumbs added to the soil. Here it becomes clear that the CBR values with this stabilizer keep the increase up to 4% of it, to start dropping at 6% and maintain the descent up to 8% of the stabilizer. The decrease in CBR values after 4% is the result of an increase in the amount of rubber relative to the soil, which increases the compressibility of soil. Also, the elasticity of this rubber after increasing its percentage is considered high to the elasticity of the soil. Through the above results and discussion of the rates of improvement of soil resistance using tire rubber crumbs, and through Figure (7) we conclude that the optimal ratio of this stabilizer is the (4%) that appeared as the best percentage that gave the highest resistance to the three soils.

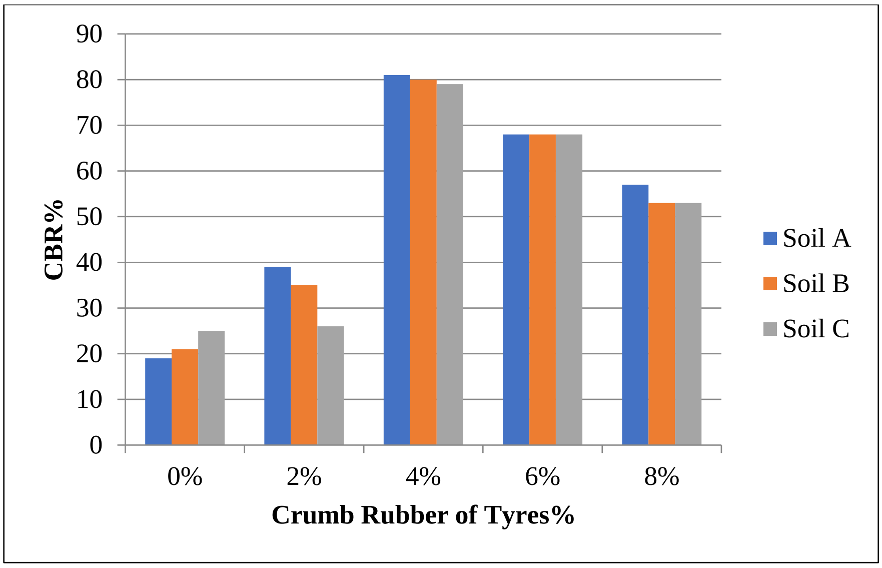

Figure 7. Effect of crumb rubber of types on CBR

The ideal fixator in the study can be considered the rock powder, whereby the CBR was multiplied approximately five times above its normal level as an average in the three soils at 25% of it to the weight of the dry soil. The second-level fixer is crushed waste concrete, which in the same way increased soil resistance 3.5 times at 15%. And after that, he came up with results, third, fly ash, which is suspended in cement, which raised the resistance of the three soils about twice at 5% and three times at 15% of it. The fourth stabilizer ranked in the degree of improvement is quicklime, which raised the soil resistance twice at 7% and then increased it at 9% to about three times. Fifthly and finally, the last stabilizer used in the laboratory work, which is tire rubber crumbs, came in the fifth and last rank, concerning the results it gave, which raised the soil resistance to 2.75 times above its original amount, at 4% of this stabilizer. As previously mentioned, each percentage of the stabilizer used was taken that doubled the soil resistance the highest thing as an optimal ratio of that fixer.

4. Conclusions

From the foregoing, the following conclusions can be drawn:

- There are soils with problems in some locations in the Diyala governorate that need geotechnical treatment before building projects on them.
- All the five stabilizers used in the paper gave positive results, and the taken soils responded to them.
- The ideal fixator in this study can be considered the rock powder, which was proven by the results of its treatment as if it was a cement stabilizer or an alternative substitute for it in stabilizing the soil.
- The California Bearing Ratio (CBR) test can be considered a very successful experiment and is ideal for measuring the tolerance and resistivity of soils.
- Soil was the most responsive to treatment with the five additives is soil A, and this may be attributed to the weakness of this soil represented by its high activity. Besides, although it is classified according to the USCS system as the remaining two soils B and C being three clay soils of low plasticity (CL), but we note of AASHTO's Sample A classification A-7-6(35), it is the weakest of the three soils.
- Soils first in response to treatment are followed by soils B and then C as a possibility for AASHTO classification of them; A-6(18) for soil B and A-6(12) for soil C.
- The success of using industrial stabilizers (lime and cement) and residues (fly ash, rock powder, waste concrete, and crumb rubber of tires) in stabilizing the soil is the

success of having structural, economic, and environmentally friendly benefits.

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