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THE BEHAVIOR OF SHALLOW FOUNDATION RESTING ON CLAYEY SOIL STABILIZED WITH RUBBER WASTES AND CEMENT

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Abstract

Thirty-seven physical models were performed, with saturated clayey soil mixed with recycled tiers chips and stabilized by 2% of cement, to investigate the effect of clay-granulated rubber mixtures on the static response of a foundation resting on it. Three percentage of tiers chips were used 4%, 8%, and 12%. Different parameters were taken into consideration include mixing ratio by weight of clay, depth of improved layer, and cement and curing period. A steel box of size (500x300x300) mm is used as a container to perform all tests. The square steel footing used in this study is (60x60x5) mm in dimensions. Three improved depths were used as a percentage of the footing width B, these percentages are (0.25, 0.5, and 1) *B. The curing periods used in the present work were 1, 7, and 14 days. The results showed that as the percentage of tires chips-cement mixture increases, the bearing capacity increases compared with unimproved soils, and the maximum increase approach in bearing capacity using 12% tiers-chips cement mixture after 14 days' approaches 21 times that of untreated soil. It is worth mentioning that curing time has a remarkable effect on soil capacity.

Keywords: Shallow footing, Soil improvement, Soft soil, Tire-cement, Tire chips.

1. Introduction

In engineering word, the foundations are used to transmit static and/or dynamic loads to the underline bearing soil. The static loading implies that the load is transferred to the soil in a long time period which will not cause any vibration to the foundation-soil system. On the other hands loads that cause vibration to the foundation-soil system are denoted by dynamic. In both cases, stresses and strains are induced into the system. Soil stabilization means changing the soil properties by mechanical or chemical methods to suit specified engineering requirements such as compaction and admixtures. Lime and cement were commonly used as a chemical stabilizer to enhance the soil properties. Earth reinforcement is commonly used with mild steel rods, geosynthetics [1].

Recently, solid waste material such as waste tires and rice husk ash [2, 3] are used for this purpose with or without cement or lime. All the solids and semi-solids are included in the solid waste term. Unsuitable managing of solid waste leads to adverse environmental impacts that may cause the potential spread diseases or epidemics. Solid waste is classified into three categories which are agricultural waste, industrial waste, and municipal waste apart from other waste categories. In many industrialized countries, waste tire reached alarming numbers leading the engineers to search for new fields to reuse these discarded tires. The re-use of these tires will not only help in economic and environmental concerns but will also solve geotechnical issues regarding soil's low bearing capacity [3].

Geotechnical engineers will use these tires' good properties like strength and resilience and high frictional properties to enhance the behavior of highway embankment. In addition to that if waste tires are used as construction materials instead of burning it, this will be very useful in a sustainable material stream. Virgin construction materials made from non-renewable resources could be replaced by waste tires as a substitute. The previous studies show the benefit of using tire chips inclusion used with soil in enhancing its properties, but these studies need to quantification of that improvement and in addition to that the soil density effect also needs assessment so the further studied is essential to spotlight this area.

Also, the effect of tire chips size and aspect ratio are not determined yet, so the most studies are conducted using tire powder and not taken the size and shapes of these waste tire chips into consideration. Geotechnical researchers study the effect of recycled tire on the geotechnical properties of soil like soil stabilization and improving the bearing capacity and reducing settlement of soils. This method of treatment is very economical from the financial point of view.

Singh and Vinot [5] examined the adding of waste tire chips to two different type of soil the first type was clayey silt, and the second type was cohesionless soil. The waste tire chips of (5 to 20) % of the soil weight was added to the soil, they tested the soil by conducting a series of unconfined compression test, standard Proctor tests, and California bearing ratio tests on treated and untreated soil. A similar scenario was adopted for the cohesionless soil but the waste tire chips of (10 to 50) % of the cohesionless soil weight was added this time to the soil, direct shear tests and vibratory compaction tests were carried out to examine the effect of the added tire chips. The results showed that using 13% chip content for clayey soil and 30% chip content for cohesionless soil are optimum for the two reinforced soil mixtures.

Al-Neami [3] conducted a series of experimental model tests to investigate the response of adding different percentages of tire chips to sandy soil (2%, 4%, 6%, and 8%), and the main conclusion drawn that tire chips can effectively use to improve the mechanical properties of sandy soils.

Al-Adhami et al. [4], conducted an experimental investigation on using sewage sludge as ash to improve the properties of clayey soil by adding 10%, 15%, and 20% with curing times 3, 14, and 28 days. The results showed that adding 10% of sludge with a curing time of 3 days increase the unconfined compressive strength. In addition adding 10% of sludge with 28 days curing increases the CBR by 2 times.

Recently various recycled materials have been used in construction. Such as using dumped fishing net as lightweight backfill material [6], using sand-rubber combinations using disposed tires [7]. These new additives materials solved the environmental problems and also economic problems. Discarded tires have been used in many forms such as a whole, shred, slit, and chip, crumb rubber or ground rubber shapes. In last decade, numerous researches have been investigated some essential engineering properties of rubber-soil mixtures, such as shear strength, compressibility, California Bearing Ratio (CBR), compaction characteristics, Poisson's ratio, modulus of elasticity, and permeability [8, 9]. Recently the application of waste tires has been developed in civil engineering. There are currently strong potentials for the use of waste materials and recycled tires such as reinforcing soft soil in road construction, highway embankments, backfilling in retaining structure as lightweight materials, road embankment, asphalt mixes and other earthworks [10-15] .

The use of this waste material in various fields can provide a solution to consume the huge stockpile of scrap tires from many places in the world, thus it can be cost-effective and reduce the danger of these waste materials on environmental and give this waste an environmental value. Therefore, the main objectives of the current work are to obtain the optimum proportion of tire and cement slices that can be added to Iraqi soil to increase soil strength.

2. Used Materials

i. Used soil

Soil used in this work was brought from Al- Sadda in the east of Baghdad city. The soil consists of 4.2% sand, 29.5% silt and 66.3% clay as demonstrated in Fig. 1. Table 1 demonstrates the properties of the soil; the soil classification is (CL) soil in accordance with the Unified Classification System.

ii. Granular rubber

The sizes of (0.07-3) mm of the used waste tire rubber in accordance with ASTMD 6270-12 is classified as granular rubber. Tire rubber's properties are shown in Table 2. The size distribution of granulated rubber is demonstrated in Fig. 2. Finally, the specific gravity of granular rubber is determined to be 0.88 in according to ASTM D 854.

iii. Cement

The used cement is Portland cement (type V) which is a sulphate resistance cement manufactured in Iraq and is used during this study. Table 3 shows the cement properties.

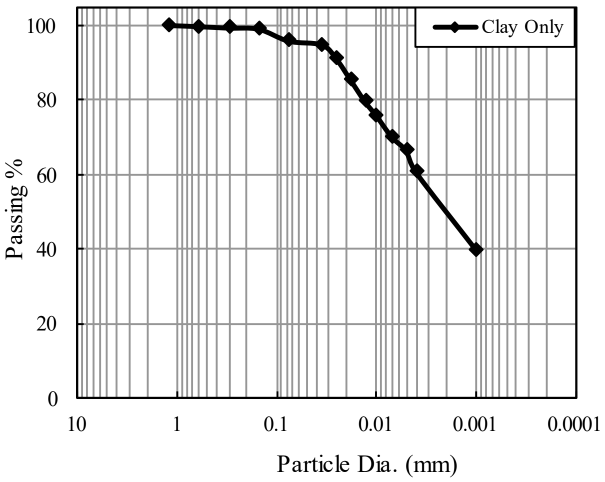

Fig. 1. Distribution of particle size for the used soil.

Table 1. Used soil physical properties.

Property	Soil used
Specific gravity (Gs)	2.69
Plastic limit % (P.L)	22.0
Liquid limit % (L.L)	47.0
Plasticity index % (P.I)	25
%Passing sieve No. 200	95.8
Gravel content %	0
Sand content %	4.2
Silt content %	29.5
Clay content % < 0.005 mm	66.3

Description according to the Unified Classification System: CL
Note: All Soil Testing were Performed According to
|the ASTM D422-63 (Reapproved 2002)

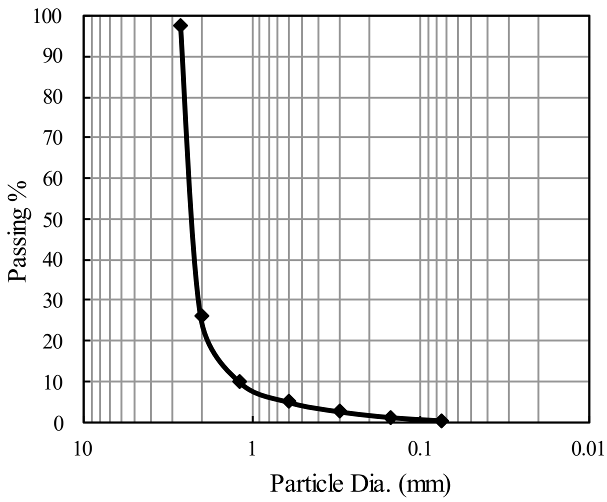

Fig. 2. Granular rubber's grain size distribution.

Table 2. Properties of tire rubber. Standard test ASTMD 6270-12.

Property	Value
Void ratio, e	0.9 - 1.2 compacted 1.5 - 2.5 uncompact
Water Absorption Capacity	2% - 4%
Modulus of Elasticity, E	1241 - 5171 kPa
Poisson's Ratio, μ	0.5

Table 3. Used cement properties.

Chemical content	Index Value	Iraq specifications No. 5/1984
Specific gravity (Gs)	3.15	-
Compressive strength after 7 days (MPa)	26	23 (min.)
Compressive strength after 3 days (MPa)	17	15 (min.)
Time of initial setting (minute)	93	45 (min.)
Time of final setting (hour)	4.28	10 (max.)
SO_3 (%)	2.15	2.5 (max.)
CaO (%)	63.8	-----------
SiO_2 (%)	19.79	-----------
MgO (%)	3.19	5 (max.)
L.O.I (%)	0.89	4.0 (max.)
C_3A%	3.27	0.72

3. Equipment Used

i. Steel container

All tests were performed inside a container made of steel with dimensions of (600×300×300 mm). The container is made of (4 mm) in thickness plates. The container shows no deformation during the preparation of the bed of soil and was sufficiently rigid. Figure 3 shows the loading assembly and the container.

Fig. 3. Loading assembly and steel container.

ii. Steel foundation

A (60 mm) square foundation made of steel and with (4 mm) in thickness, is used in all tests.

iii. Loading assembly

To apply static loads on the footing, A special loading frame was designed and manufactured. Figure 3 demonstrates the main structures of the loading assembly.

4. Model Preparation of the Bed of Soil and Testing

4.1. Control test

To determine the proper water content that gives the desired shear strength corresponding to the category of soft clay, two proposes were carried out to relate the water content with undrained shear strength. The first proposal (gradual method) was to saturate the dry soil by mixing it with water corresponding to one and a half the liquid limit. After mixing the soil was left for air drying and the soil undrained shear strength was measured at different time intervals, by using the portable vane shear device shown in Fig. 4.

Fig. 4. Portable vane shear device.

The second proposal (direct method) consisted of mixing dry soil thoroughly with the required amount of water corresponding to the specific moisture content. After mixing, the wet soil was spread inside a CBR mold in layers of (50 mm) thickness. To extract any entrapped air, each layer was tamped and pressed with a special tamping rod. The samples were then covered with a nylon sheet and left for 3 days to ensure that water has distributed equally and uniformly. After about three days the undrained shear strength reached a constant value, and the water content was checked again. The correlation between the undrained shear strength and water content by the two methods are shown in Fig. 5. After the preparation of soil bed was completed, the shear strength of the clay in mold was measured and checked again by unconfined compression tests and vane shear test.

The water content ranging between (29-30%) corresponding to the average undrained shear strength of (8-10) kN/m² was used in preparing the bed of soft saturated clay.

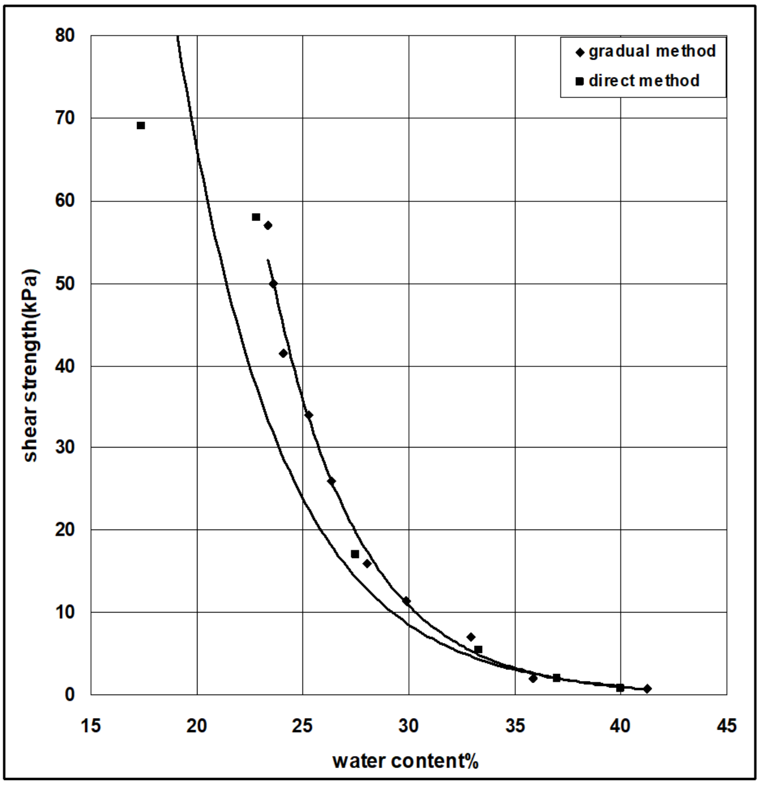

Fig. 5. Undrained shear strength variation with water content.

4.2. The bed of soil

The subsequent steps were adopted in forming the bed of soil in the steel container: (refer to Fig. 6)

- Firstly, the soil was crushed by means of a hammer into small pieces and left for one day to be air-dried, then it was inserted into a crushing machine for further crushing.
- The crushed soil was divided into groups having 5 kg in mass for each.
- Water was then added to each group of soil and mixed thoroughly to the desired water content range of (29-30%) to ensure obtaining a shear strength between (8-10) kN/m² depending on the saturated method correlation.
- After water mixing process, the clay lumps were inserted into the steel container in layers of (100 mm) in thickness for each layer with the aid of a tamping tool. This procedure was repeated till reaching the required thickness of 300 mm .
- To prevent losing moisture, the surface of soil was covered by a nylon sheet and left for days for the purpose of curing and to ensure the equalization of the moisture content. Care was taken to ensure no loss of moisture during the curing period by means of a wooden board of (500×300) mm which was placed on the surface; a 5 kN/m^2 seating load was placed for one day.

Fig. 6. Preparation of the bed of soil.

4.2 Testing Procedures

After completion of the bed of soil preparation and curing period. The following steps are commenced:

- The loading frame is mounted in position so that the center of each of the footing and steel box are both coincides as demonstrated in Fig. 3.
- A loading disk is used to carry and apply the loads on the footing in the form of loads increments.
- Applying the loads for each increment for 6 minutes before the next load is applied on the loading disk.
- Readings of dial gauge is measured at the end of each loading process; then the following load is applied.
- The loading process continuous till failure of the soil below the footing.

5. Experimental Program

The model tests can be classified into four categories. The first represents a footing placed on a soft saturated bed of soil of undrained shear strength values (8-10 kPa) and ~~a~~ water content between (29-30%) without any treatment as a reference to measure the degree of improvement after introducing the improvement technique.

The second category attempts to improve the soil bed under the footing by using mixture of soil-tires chips for three depths (0.25, 0.5 and 1)*B*, where *B* represents the width of footing, the adopted percentages by weight of clay of granulated rubber are

(4, 8, and 12)% for each depth. the third category attempts to improve the soil bed under the footing by using a mixture of soil-tires chips with cement for three depths (0.25, 0.5 and 1)*B*, the percentages by weight of clay of granulated rubber are (4, 8, and 12)% for each depth and the percentage of cement added is fixed for all rubber ratios, which is 2% of the weight of the mixture and curing period (1, 7 and 14) day. The fourth category introduces the curing process. For all model tests, failure is defined as proposal given by Terzaghi [16] as the stress causes settlement corresponding to 10% of the footing width. The analysis results are presented in terms of bearing ratio denoted as q/cu plotted against the settlement ratio denoted as S/B%.

5.1. Model test result of untreated soil

This test is considered as a reference to get the degree of improvement. Figure 7 shows the bearing ratio at failure (q/cu) will be equal 2.4 at deformation ratio (S/DB%) equal to 10% corresponding to the model footing width of 60 mm.

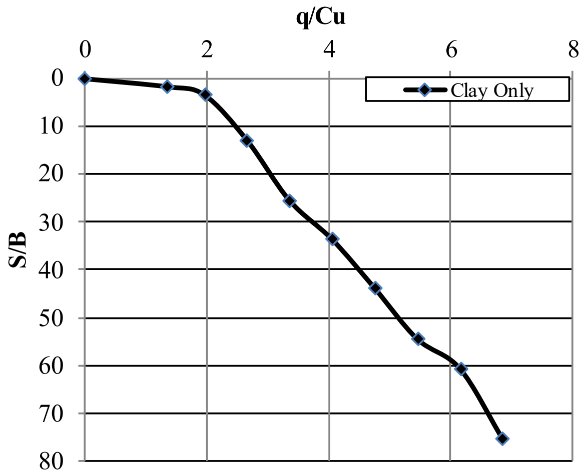

Fig. 7. q/Cu variation with S/B for untreated soil.

5.2. Model tests on treated soil by (4, 8, 12%) tire chips and 2% cement with time (*D*=0.25*B*)

Four model tests were carried out on soft clay reinforced with tire chips and cement. Figures 8 to 10 demonstrate the relationship of bearing ratio q/Cu versus settlement ratio S/B %. The results are compared with untreated soil conditions. For all models tested, a remarkable improvement in the bearing ratio of the model tests is noticed as the percentages of tires-chips cement increases. This is due to the fact; that introduced the tires chips into soft clay which acts as a reinforcing agent and secondly the cement provides the binding aid which mortifies the soil improves the shear strength and improving the friction. In addition the mixture cured for 14 days gives a higher increase in bearing ratio in comparison with the corresponding model test cured for 1 day and 7 days; this increase is results from hardening process that established during the 14 days curing period of and it may be attributed to the gain in the shear strength in the reinforced soil mass from the inclusion of the tire chips and cement that has prevented the soil mass from moving under loads.

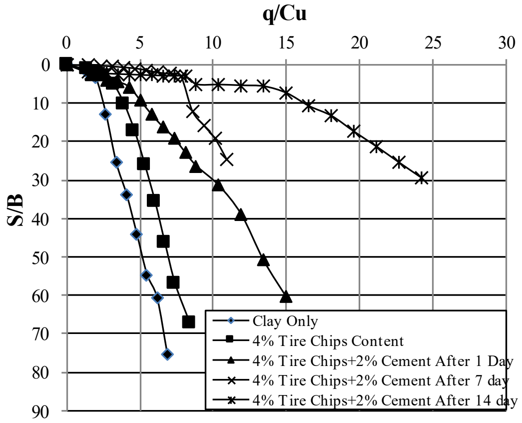

Fig. 8. q/Cu Variation with S/B for treated soil by 4% tire chips content and cement with time (*D*= 0.25*B*).

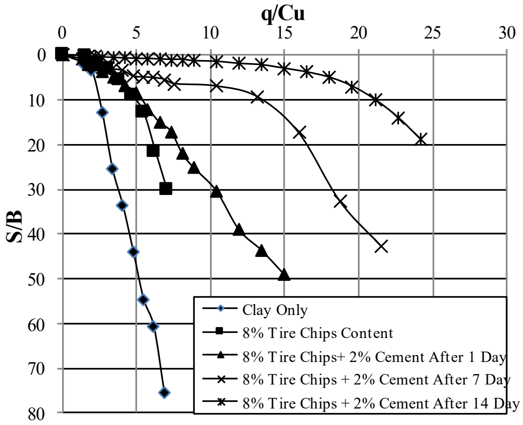

Fig. 9. q/Cu Variation with S/B for treated soil by 8% tire chips content and cement with time (*D*= 0.25*B*).

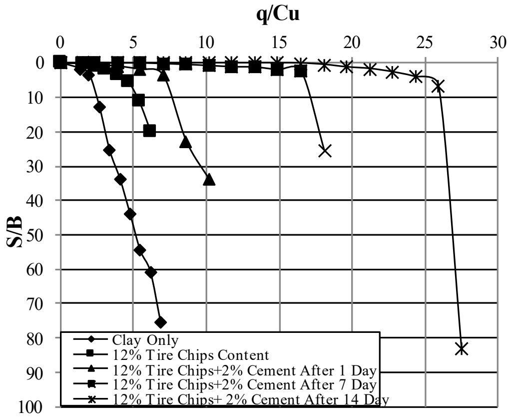

Fig. 10. q/Cu Variation with S/B for treated soil by 12% tire chips content and cement with time (*D*= 0.25*B*).

5.3. Model tests on treated soil by (4, 8, 12%) tire chips and 2% cement with time (*D*=0.5*B*)

To study the effect of tire chips on the bearing capacity and settlement at depth 0.5 B, four laboratory tests are done by using the local manufactured physical model was performed on soft clay reinforced. Figures 11 to 13 illustrate the relationship between q/Cu versus S/B%. The results are compared with untreated soil conditions, with treated soil by 4, 8, 12% tire chips and 2% cement. The results show that there is a tremendous increase in bearing ratio of the model test that cured for 14 days in comparison with the model tests cured for 1 day and 7 days; this increment is due to the hardening process that established for the 14 days curing period.

Variations of q/Cu rubber waste from 0% to 12% and with increased curing period from 0 to 14 days are presented in these figures which show two remarkable points; the first one is the increase in tires chips percentage as an additive increases the stiffness of the soil. This is obvious from the shape of the curves corresponding to the variation of the tire chip percent. The second one is that the effect of the curing period will result in increasing the stiffness of the model test this can be noticed when comparing the results of 14 days curing period with that for one-day curing period, this could be a results of hardening process that developed during the relatively high curing period.

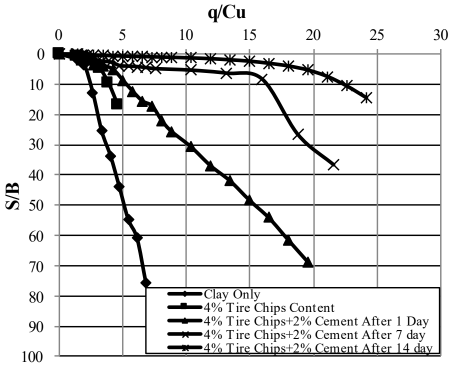

Fig. 11. q/Cu Variation with S/B for treated soil by 4% tire chips content and cement with time (*D*= 0.5*B*).

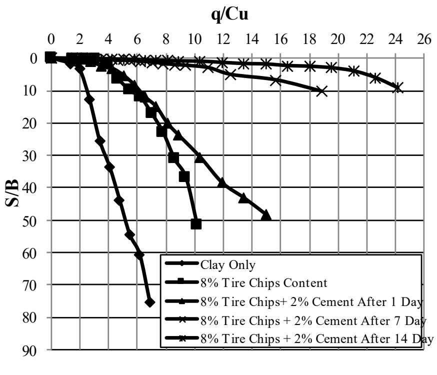

Fig. 12. q/Cu Variation with S/B for treated soil by 8% tire chips content and cement with time (*D*= 0.5*B*).

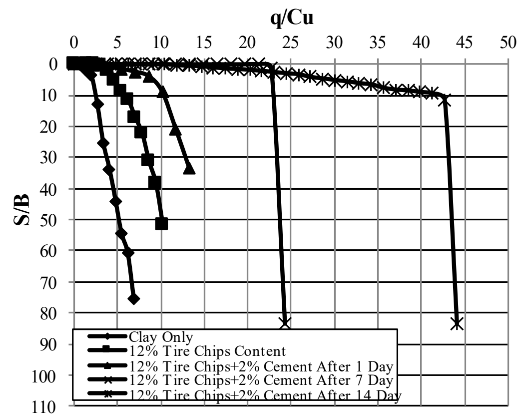

Fig. 13. q/Cu Variation with S/B for treated soil by 12% tire chips content and cement with time (*D*= 0.5*B*).

5.4. Model tests on treated soil by (4, 8, 12%) tire chips and 2% cement with time (*D*=1*B*)

Figures 14 to 16 show the contrast in bearing capacity with the thickness of reinforced soil for the three different rubber contents of 4%, 8%, and 12% with 2% of cement and unreinforced soil. The reinforced layer was placed for 1 B from the base of the footing. From these figures, it can be noticed that the bearing ratio increased with percentages of tires chips and 2 percentage of cement and its increased approach to maximum value after curing time of 14 days in comparison with the corresponding model test that cured for 1 day and 7 days. This can be related to the shear strength increase of the mixture. In addition, the figures approve that as the clay layer thickness increases the bearing ratio also increases. These results confirm the previous results of [15], they specified that shear zones below the footing tend to increase due to reinforcement and the width of shear zones enlarged with increasing the composite soils stiffness due to inclusion of strengthening which increases the stiffness and increasing the bond due to cement action.

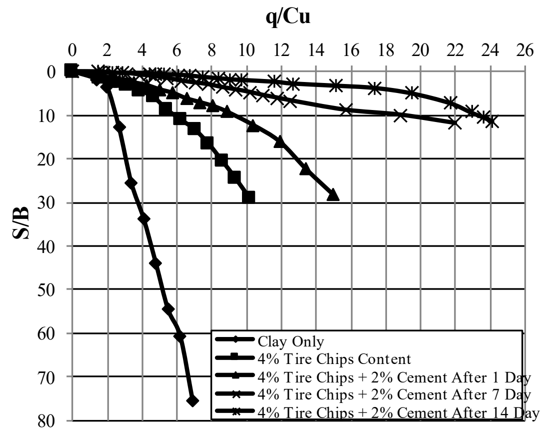

Fig. 14. q/Cu Variation with S/B for treated soil by 4% tire chips content and cement with time (*D*= 1*B*).

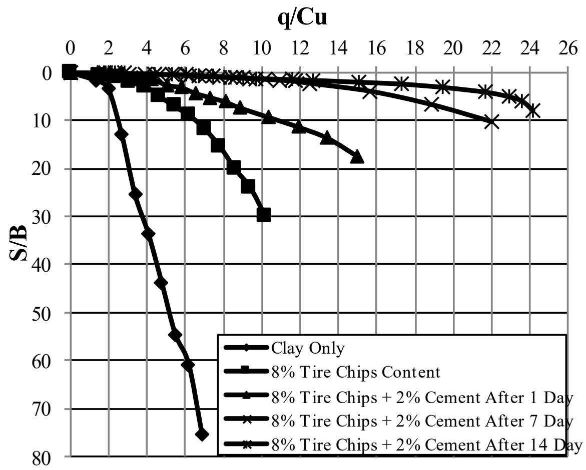

Fig. 15. q/Cu Variation with S/B for treated soil by 8% tire chips content and cement with time(*D*= 1*B*).

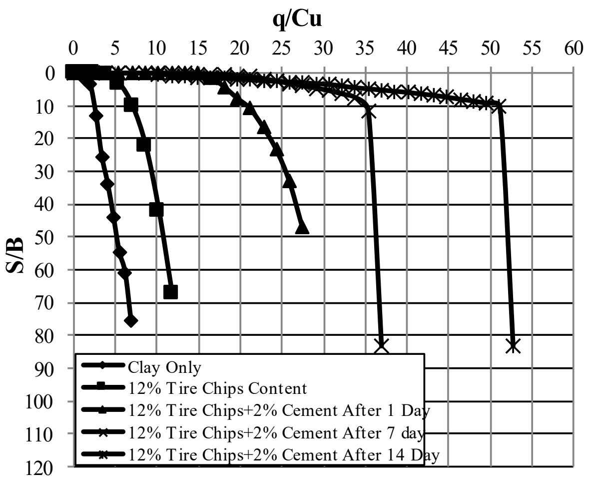

Fig. 16. q/Cu Variation with S/B for treated soil by 12% tire chips content and cement with time (*D*= 1*B*).

6. Bearing Improvement Ratio

To calculate the improvement ratio attained by tiers-cement mixture in improving clayey soil, the improvement carried out under the foundation, three depth were used (0.25, 0.5, and 1) *B*. The improvement ratio can be defined as the ratio between the treated soils over untreated soil. Figures 17 to 19 demonstrate that the bearing improvement ratio increased as Rubber waste content increased, and the maximum improvement achieved by using 12% of the tiers-cement mixture and after 14 days curing. Depth of improvement has a significant effect on the bearing ratio, as the results show that maximum increment achieved by improving up to a depth of B which gives maximum improvement at a mixture of 12% and after 14 days of curing.

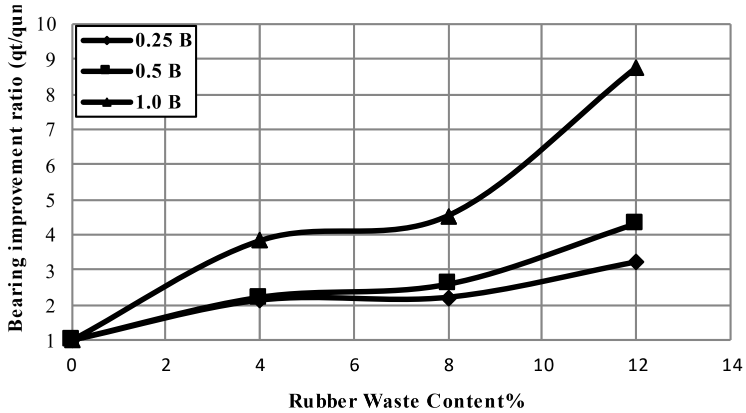

Fig. 17. Bearing improvement ratio versus rubber waste content after 1-day curing.

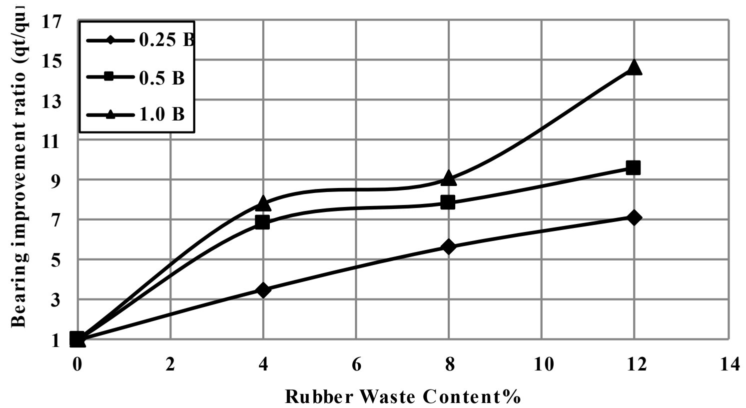

Fig. 18. Bearing improvement ratio versus rubber waste content after 7-day curing.

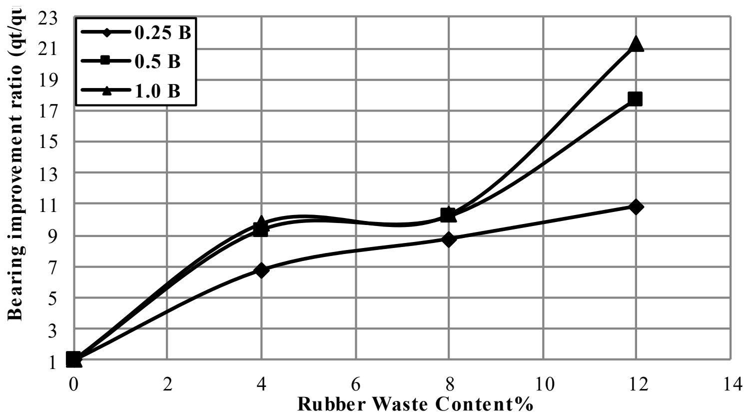

Fig. 19. Bearing improvement ratio versus rubber waste content after a 14-day curing.

7. Conclusions

Based on the results of the tests, the following conclusion can be stated:

- The results showed that as percentages of tiers-chips with cement mixture increase the bearing capacities increases compared with the unimproved model. In addition, the bearing capacity increases as the curing period increases .
- The effective bearing capacity of soil improved by a mixture of tiers-chips-cement was found to be approximately five times the unimproved soils.
- The results showed that the tiers chips with cement mixture effectively could be used as improved agents for soft clayey soil.
- Using Tiers waste in the soil will act as reinforcing agent, and the cement provides the binding aid with improved the soil.

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