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Improvement of the Fluvial Soil Characteristics of Al-Kufa River by Using Cement Dust

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Abstract

This research focuses on the possibility of using wasted cement dust (CD) as a material to improve the properties of Al-Kufa River soil such as maximum dry density (□max.), optimum water content, liquid limit, plasticity index (PI), the expansion index (Cr), compression index (Cc), swelling percent (Sp) and shear strength parameters (C & □). A series of laboratory tests were conducted on selected soil treated with (0, 3, 6, 8 and 12% of CD), it was found that the adding of the CD to a soil generally results in disparate decreased in compression index, plasticity index, swelling index and disparate increased in maximum dry density and shear strength parameters with. It was also found that the improvements in the value of the maximum dry density of soil imparted by (6%) CD are (12.2%). The plasticity index decreases by 33.1% when 8% of CD is added to the soil under study. The liquid limit values for Al-Kufa River soil are equal to their values of the plasticity index. This study also shows that adding 3% of CD, as explained by consolidation tests, leads to decreasing in compression index by 73.6 %, whereas the swelling index reduced by (10 %). The results of analysis also show that adding 6% of CD results in decreasing of swelling index by 38.2 %. Moreover, the observed values for swelling indices reach its minimum values with time if the soil mixes with 6% of CD. The increase in the angle of internal friction of the soil due to add the CD with (3%) is (50%), while the increase in the cohesion of the soil is (23%). The percent (3%) of CD is very effective in decreasing the compression index and increasing in shear strength parameters.

Keywords: Cement Dust, Wasted, Fluvial Soil Properties, Al-Kufa River Soil

Notations

C	Cohesion of soil (Force/area)
C_c	Compression index (No dimension)
CD	Cement Dust
C_r	Expansion index (No dimension)
L.L	Liquid limit (%)
O.M.C	Optimum Moisture Content (%)
PI	Plasticity index (%)
P.L	Plastic Limit (%)
q_u	Unconfined compression strength (Force/area)
S_p	Swelling percent (%)
$(□_d)_{max.}$	Maximum dry density (Force/volume)
□	Angle of internal friction (deg.)

1- Introduction:

Fluvial soil deposits in Kufa River regions have relatively low shear strength and high compressibility. So improving these intrinsic properties has become urgent for geotechnical engineers. Adopting in-situ deep mixing technology to form compound ground is one way to deal with this issue and has been widely applied in engineering projects in the world. Generally, ground improvement can be defined as the process of increasing shear strength parameters and decreasing the permeability of the soil [1].

Cement manufacturing is one of the large industries in the world. Cement consists principally of limestone and shale, in addition to other materials such as AL_2O_3, Fe_2O_3 and sand. Cement is a mixture of Calcium oxide (CaO) (62% - 66%), Silicon oxide (SiO_2) (19% - 22%), Aluminum tri-oxide (AL_2O_3) (4%-8%), Ferric oxide (Fe_2O_3) (2% - 5%), Magnesium oxide (MgO) (1% - 2%) and other impurities [2].

Cement kiln dust (CKD), a by-pass dust, is generated in large quantities during the production of Portland cement. CKD is a fine powdery material similar in appearance to Portland cement. It is composed of micron-sized particles collected in the control devices (e.g. cyclone, bag house, or electrostatic precipitator) during the production of cement clinker [3].

Over 2.8 billion tones of cement were generated throughout the world in year 2009[4]. India, is the second largest cement producer in the world after China (1400 million tones) with the total capacity of 180 million tones, has got a huge cement industry of about 20 cement companies[4]**.** The generation of CD has been estimated to be 15–20% of clinker or cement production[5], which put worldwide CD generation at an estimated 420–560 million tones for the year 2009 and Indian production at 27–36 million tones.

The most common beneficial uses of CD are cement replacement, soil stabilization, waste treatment, asphalt pavement and other uses. As a stabilizing agent for wastes, the absorptive capacity and alkaline properties of CD can reduce the moisture content, increasing the bearing capacity, and therefore providing an alkaline environment for waste materials [3].

This research indicates that the experimental results on the use of different percents of cement dust to stabilize the fluvial soil in Al-Kufa River. Fluvial soil covers Al-Kufa River in Al-Najaf city and creates major problems for the construction of infrastructure such as bridges. The low bearing capacity of this soil makes constructing new structures on it unsafe without improving.

CD could form solid layer, which prevents water absorption from the soil surfaces. In addition, of that most the cement dust compositions are of non-dissolved materials[6].

Al- Kufa's Portland cement industry now produces about 100 000 tons of dust annually, and will increase in future as increasing of demand for Portland cement (Al-Kufa cement factory).

The suggested method of the stabilization of the soil is either wet method by rectification of cement dust to slurry or dry method by adding of cement dust directly to soil surface. For each method, the cement dust injects into boreholes. Generally, the mechanism of the adding of the cement dust must be careful.

The aim of this research is to study and improve the characteristics of Al-Kufa River soil in order to be used as a foundation for bridge piers. This is because several important structures such as bridges will construct there as indicated by Al-Najaf Master Plan. Therefore, this study tries to select the proper technique for stabilizing and improving this river soil.

2. Literature review

The CD has been widely used in different applications such as blended cements, soil stabilization, waste treatment, fertilizer, chemical recovery and backfilling. Other miscellaneous applications of cement dust are used such as mine backfilling, glass making, coagulant in waste-water treatments, and absorptive agent for oil spillages [7].

There are only a few studies that have investigated the effect of adding CD on the characteristics of the natural soil (8, 7, 6, 9, 10, 11 and 12).

Bhatty [7] suggested alternative uses of CKD. The author reported that the bulk of the CKD generated in North America is recycled as a raw feed substitute in cement manufacturing and a portion of it is used as a secondary material for selected commercial applications. The remaining CKD is often landfilled. This study also indicates that the major parameters that determine the CKD characteristics are the starting raw material, type of cement operation, dust collection systems, and fuel type. Since each plant has its own geological, operational, and economical position, the CKD use is generally considered by a plant-to-plant basis. Moreover, the applications of CKD are fertilizers and in chemical processing to recover alkali salts are based on its high Potassium contents.

Baghdadi et. al,[8] presented the method of soil modification by cement kiln dust CKD. Dune sand, an abundant marginal soil, was treated by varying amounts of CKD. In addition, they reported that 100% CKD was tested. So the compacted specimens were tested for unconfined compression (UC) after 7, 28, and 90 days of curing periods at different temperature levels. Further test was conducted for specimens with CKD percentages that gave satisfactory results for road sub-bases. These tests included durability, the California bearing ratio (CBR), and split tension. The results indicated that on the basis of utilization that the CKD between 12 and 50% may be satisfactory. Moreover, the authors found that the specimens of 75% and 100% CKD gave relatively high strengths but these specimens failed to satisfy the durability requirements.

On the other hand, the effect of CD on the chemical properties of neutral soil of the area surrounding of Zileation, Leibda, Almergib, and Suok-Alkamis was studied by **Morghom[6]**. In that study, soil samples for each factory have been taken at the four coordinates: North, South, East and West at different distances. These distances are on radius vector equal to 20 km^2 form the emission sources. The author concluded that the values of LOI, Silica, Potassium and Calcium could be used as indication for the level of environment pollution at the area surrounding the cement factory. By using this category, it could be found that higher pollutant to surroundings environment are Zileation, Leibda, Suok-Alkamis, and Almergib cement factory respectively.

Abou Seeda et. al. [9] investigated the effect of CD applied with two levels i.e. 2.5 and 5% on the remediation of Pb, Cd, Ni and Cr in sludge treated soil using the kinetic approach represented by the modified Freundlich, Elovich, the first order, Z(t), and the parabolic diffusion equations through the electrical stirred flow unit (ESFU) technique. Field experiment was also carried out on El-Gabal El-Asfar region to evaluate and assess the potential effect of cement dust by using corn (Zea maize L.) as an indicator. The obtained results showed that application of sludge significantly accumulated and showed increases in studied heavy metals especially in high applied level i.e. 20 m^3 .fed^{-1} compared with the low level one i.e. 10 m^3 fed^{-1}.

Shabel [10] studied the stabilization of Jizan sabkha soil using cement and CKD. Since Saudi Arabia has a large number of sabkha's, covered a wide areas and take essential geographical positions. Jizan city is situated on the south west coast of the kingdom of Saudi Arabia, and a black gray silty sand sabkha's are covered all vast areas around the city[10]. Tests were conducted to evaluate engineering properties of sabkha soil treated with different percent of cement, CKD, combination of CKD + cement under the effect of curing time and conditions. Analysis of tests results were tabulated and curves were drown and compared , then , low cement content mixture ranged and selected for satisfying all requirements and specifications . Last, this study was conducted on Jizan silty sand sabkha soil, the results should be considered, and be careful when they used in other sabkha soil investigations[10].

Al-Aghbari et al.[11] investigated the effect of cement and cement dust on the stabilization of desert sands in Oman. He presented experimental results on the use of different additives to stabilize desert sands for possible use as a foundation-bearing soil. Stabilizing agents included Portland cement and cement by-pass dust (or cement kiln dust). The results showed substantial improvements in maximum dry density, unconfined compressive strength, and shear strength parameters (*c* and □). Thus cement and cement by-pass dust can be used to improve the compressibility and shear strength characteristics of desert sands.

Elmashad [12] studied the effects of the cement and cement dust on compressive strength and permeability of the sandy soil. The used mixer (waste material with sand) prove high performance, durability to environmental condition, low cost and high benefits. He concluded that the compaction characteristic of the sand was improved by cement dust. Considering the seepage control, compressive strength, cement dust was approved to have more pronounced effect on the reduction of the sand permeability and enhance of the compressive strength of sand.

3-Cement dust used

Cement dust may consider as an important research for soil stabilization studies because of its low cost. The bulk of the CD generated in many different regions Iraq. The cement dust used was brought from Al-Kufa cement factory. The use of this cement dust is in soil stabilization.

Methods for determining and evaluating characteristics of CD suitable for various applications are given in ASTM D5050 Standard Guide for Commercial Use of Lime Kiln Dusts and Portland Cement Kiln Dusts. A brief description of the chemical composition of typical cement dust is given in Table (1). This dust soils can be involved in a series of complex chemical components. The grain size distribution curve of the cement dust can be shown in Figure (1).

4- Soil used

In-situ site (Al-Kufa River) locates in the Kufa City which is in the eastern Master Plain of Al-Najaf city. In this region, topsoil is mostly comprised of soft soils which are widely distributed here whose engineering properties are relatively poor. In order to determine the basic geotechnical parameters of the soil here, Standard Penetration Test (SPT) was performed at different depth, from which it is can be obtained that soil in this site is relatively homogeneous. The top part of the soil with a thickness of (0 – 3 m) mainly consists of clayey silt particles and silt layer is beneath it.

Figure 1 Grain size distribution of soil used and cement dust.

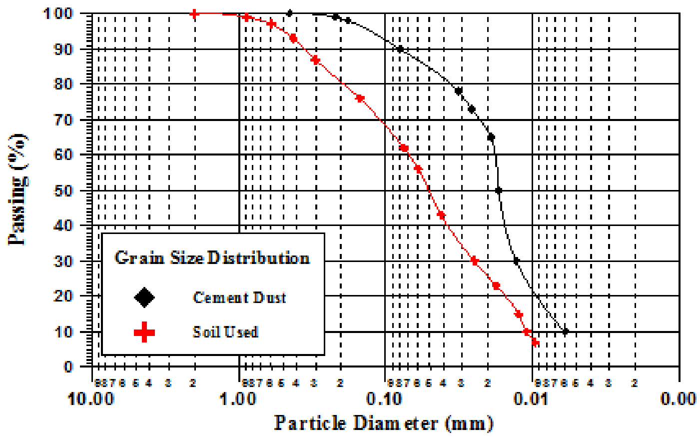

Table (1): Chemical properties of cement dust

Silica	21
Alumina	6.5
Iron oxide	2.5
Calcium oxide	10
Magnesium oxide	2.5
Third sulfate oxide	2.1
Silica calcium third	8
Silica calcium second	27
Alumina calcium third	12
Alumina iron calcium fourth	8

Experimental trials were conducted on the fluvial soil of Al-Kufa River. The properties of this soil are estimated and tabulated in Table (2). The particle size distribution of this studied soil (Figure 1) is as follows, Fine Sand=38 %, Silt= 62 % and Clay = 0 %. All soil samples are dried and passed through sieve No.8 (2.38 mm), then mixed with water corresponding to natural water content.

Al- Kufa River soil has complicated construction problems such as large concentration of salts, increasing compressibility, and reducing shear strength, and other associated problems. Al- Kufa River is situated on the east of Al- Najaf city, and a black gray sandy silt soil is covered all positions along the river.

Table (2): Properties of natural soil.

Specific gravity	2.7
Maximum dry density, kN/m^3	1.556
Optimum water content, %	15.4
Plastic limit, %	0
Liquid limit, %	21.3

5- Sensitivity of soil used

The soil in this research has been used as a remolded soil. The unconfined test is performed on the remolded samples (q_u=1.03 kg/cm^2) and on the undisturbed samples (q_u=1.42 kg/cm^2) at the same moisture content. From previous results, the sensitivity of this soil is equal to (S_t=1.38) (low sensitivity), therefore the remolded process are not effected on the accuracy of the results. This soil may regain at least part of its original strength and stiffness. This increase in strength is due to the gradual reorientation of the absorbed molecules of water, and is known as thixotropy (from the Greek thix, meaning 'touch' and tropein, meaning 'to change')[13].

6- Experimental work

This search utilized laboratory tests to evaluate the feasibility of using cement dust CD generated as an industrial by – product produced by Al-Kufa cement factory as a cementations material for stabilization of the fluvial soil into Al-Kufa River. Tests were conducted to evaluate engineering properties of

fluvial soil treated with different percents of cement dust, CD (0, 3, 6, 8 and 12%).

Laboratory tests such as compaction, liquid limit, plastic limit, consolidation, swelling percent, unconfined compression, and shear box tests were performed to measure the engineering characteristics of the stabilized soil. The Figures (2), (3), (4) and (5) demonstrate the photo images of the steps of the performed of these laboratory tests. All experimental results are represented by parameters as shown in Table (3). These tests were also carried out according

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to the methods described by specifications shown in the same Table (3). All analyses were carried out in double and the mean values of the replications are reported in this paper.

Figure (2) Stages for performing the liquid limit test

Figure (3): Steps for achievement the compaction test.

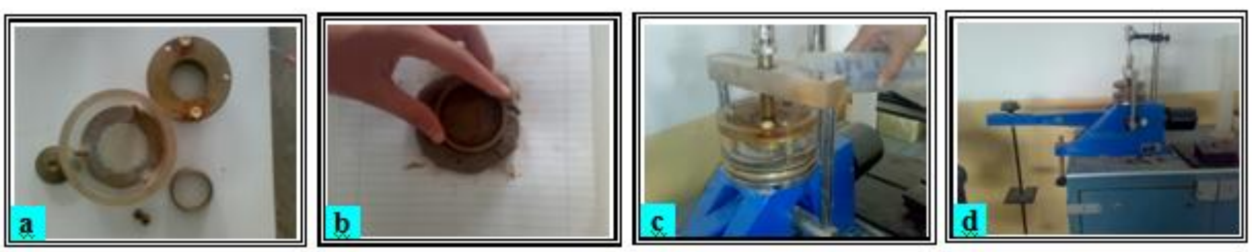

Figure (4): Stages for performing the consolidation test.

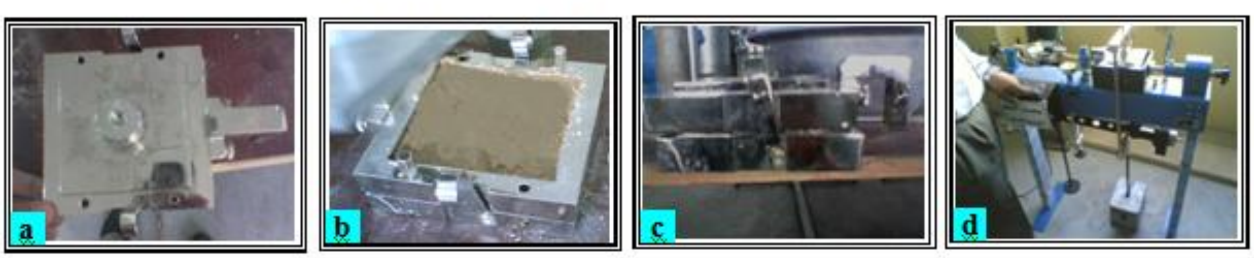

Figure (5): Stages for achievement the direct shear test.

Table (3): The parameters and specifications of experimental tests

Test	Parameter	Specification
Liquid Limit and Plastic Limit	Plasticity Index	ASTM D 4318
Compaction	Maximum Dry Density and Optimum Water Content	ASTM D 698
Consolidation	Compression and Expansion Index	ASTM D 2435
Swelling Test	Swelling Percent	ASTM-D1883- 94
Unconfined Compression	Unconfined Compression Stress	ASTM D 2166
Direct Shear Box	Angle of Internal Friction and Cohesion	ASTM D 3080

7- Results Discusses of Tests

7-1 Compaction Test

Figure (6) illustrates the relationship between the water content and dry density of Al-Kufa River soil at different percents of adding cement dust (0, 3, 6 and 8%). The figure showed that all four shapes of compaction curve are presented in three points. There is a closed correlation in shape and in the value of the optimum water content between the curves of the cases of the soil mixed with cement dust percent (3% and 6%). The values of the optimum water content are (8, 11.6, 12.6 and 8%) for the soil treated cases with (0, 3, 6 and 8%) CD, respectively.

Positive significant correlation found between the adding of the CD with (6%) to the natural fluvial soil and maximum dry density of the soil as seen in Figure (7). Also, the figure shows that the value of the maximum dry density of the treated soil case with (3%) CD is greater than that of the treated soil case with cement dust (8%), while the case of the soil treated with (6%) CD exhibits higher value of the maximum dry density than those of the case with (3%) CD.

To clarify the effect of CD on the maximum dry density, the increase in maximum dry density denoted as the difference in maximum dry density between the untreated and the treated soil as a percent of the maximum dry density of the untreated soil. These values of the increase in maximum dry density are (6, 11, and 2.1%) for the cases of the soil mixed with CD (3, 6 and 8%) respectively.

From the previous finding, it could be concluded that the percent of the CD (6%) could be used as an optimum percent must be added to the fluvial soil (Al-Kufa river soil) in order to increase these values of the maximum dry density.

7-2 Atterberge Limits Tests

The results description of the liquid limit tests are given in Figures from (8a) to (8e). It can be seen that these curves are when the natural fluvial soil treated with different CD percents (3, 6, 8 and 12%) in additional to the untreated soil case.

At a constant number of blows (25), the values of the liquid limit for all cases are selected from the relationship between the number of blows and the water content. The slope of the water content – number of blows curve for the soil treated with (8%) CD is steeper than that for the soil mixed with (0, 3, 6 and 12%) CD. The flatter curve can be noted when 6% of CD mix with the natural fluvial soil.

The relationship between the CD percents with the values of the liquid limit is summarized in Figure (9). It can be seen from this figure, that at CD percent (8%), the reduction in the value of the liquid limit is very high and approximately equal to (32.7%). This value is greater than that for the case of the soil treated with CD (12%) which it equal to 17.4%.

The plastic limit test can not performed for untreated and treated soil (i.e I_p=NP), therefore the values of the plasticity index are equal to the values of the liquid limit. This is probably due to the fact that the spatial heterogeneity in the Al- Kufa River soil (fluvial soil).

7-3 Consolidation Tests

Five consolidation tests were conducted with different percent of CD. Figures from (10a to 10e) depicts a typical void ratio – logarithm effective stress curves for the cases of the soil treated with (0, 3, 6, 8 and 12%) CD, respectively.

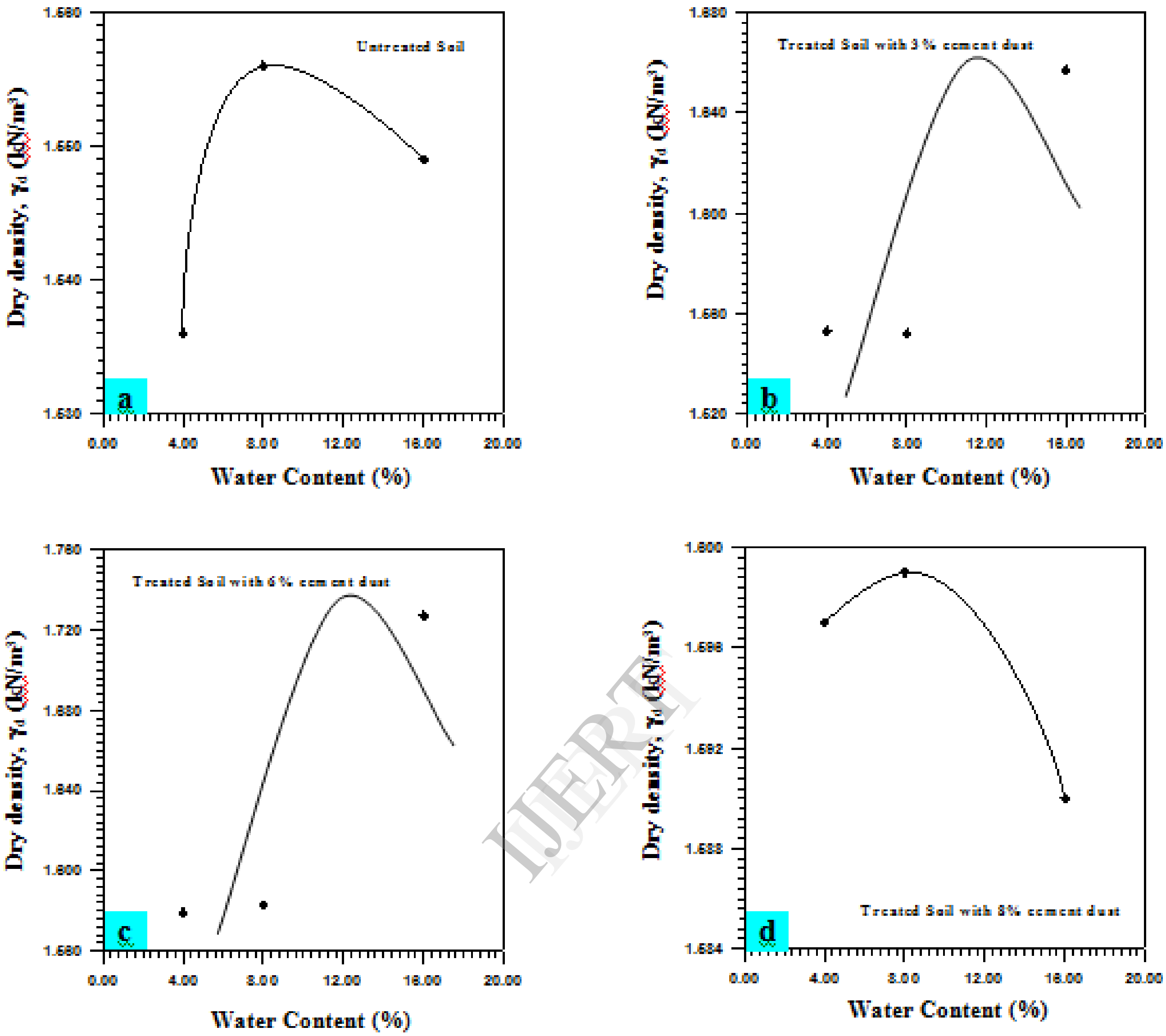

Figure (6): Compaction curves for different percents of cement dust (0, 3, 6 and 8%).

The

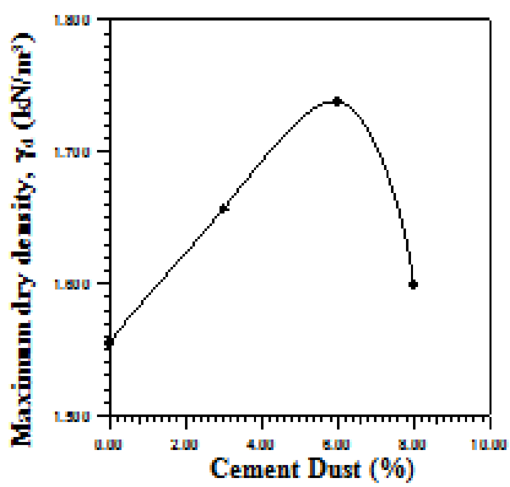

Figure (7): Relationship between the maximum dry density and cement dust percent.

compression index (C_c) and the expansion index (C_r) are estimated from the slope of the linear portion of the compression and the swelling curves which it plotted between void ratio and logarithm effective stress. The values of these indexes are dimensionless.

From the figures, the value of the compression index for the untreated soil case is 0.009093, this value is decreased to 0.005237 for the case of treated soil with CD percent (3%), and then it increased to 0.0094001 when the soil mixed with (6%) cement dust percent. From the previous results, the highest decrease in compression index was observed for the soil treated with CD percent of (3%), but the lowest value of the expansion index was observed for the case of the soil treated with (6%) cement dust. In other words, when the fluvial soil mixed with (6%) CD, the reduction in compression and expansion indexes are equal to (3.3%) and (38.2%) respectively.

The values of the compression index are plotted against to the percent of CD as shown in Figure (11). It is evident from this, which the reduction in compression index value for the case of the soil treated with (3%) CD is very high and equal to (73.6 %).

Generally, the swelling void ratio – logarithm effective stress curve of the case of the natural soil mixed with (6%) cement dust has an approximately horizontal slope. In other words, the flatter curve can be noted at the soil treated case with cement dust (6%). Therefore this percent of the CD is much more significant on the expansion index.

7-4 Rate of swelling

In all the models of the swelling tests, the soil samples are prepared by mixing dry natural fluvial soil with the percent of the CD, then the mixture (soil + CD) is mixed with water in percents corresponding to natural water content, then spreading the mixture (soil + CD + water) inside the mould of CBR in five layers. Each layer is compacted to a unit weight equal to the natural wet unit weight in the field (Al-Kufa River).

The compacted soil sample into the mould cover with paraffin wax and left ten days at temperature (33 C^o) in order to the sample curved. After the end of the require period of curing, the paraffin wax remove and the base of the mould replace with perforate dish and dial gauge fixed in the top of the mould to measure the vertical displacement of the soil (swelling percent). The mould fill with water, then the vertical displacements are measured with time. This test is continued until the values of the swelling percent with time are very small.

Figure (13) shows the evolution of the swelling percent of the soil treated with CD (0, 3, 6, 8 and 12%) with time. It can be noted from this figure that the observed swelling percent reduces when the natural soil mixed with CD percent (6%) to the minimum values, but it increases with increasing or decreasing the percent of the CD about (6%). As expected the instantaneous swelling is rather high during the early time, while an essentially approximation constant swelling rate is attained after (190 hours) for all cases of the soil treated.

7-5 Shear strength test

In this section, direct shear test is performed to examine the effect of adding CD on the natural soil of Al-Kufa River. Different amounts of CD were used to improve the shear strength properties of this fluvial soil.

The family of the shear stress – horizontal displacement curves are presented in the Figures from (14a) to (14d) for the cases of the natural soil mixed with percents of CD (0, 3, 6 and 8%) respectively. As expected and as judge from these figures, it can be noted that the horizontal displacements increase with the shear stress at the beginning until it reaches a maximum value, then it decreases. All these curves eventually become a horizontal line specially for the case of the soil treated with (3%) and (6%) CD.

To facilitate the comparisons between different cases, the shear strength tests results are presented in terms of the cohesion and the angle of internal friction. The peak values of the shear stress in Figure (14) are plotted with the constant values of the normal stress in order to estimate the magnitudes of the shear strength parameters as seen in Figure (16). The figure shows significant increase in the shear strength parameters (Cohesion , **C** and Angle of internal friction, □) when the soil mixed with CD percent (3%), but there is very high increase in the values of the angle of internal friction as compared with the cohesion of the soil at the same percent of the CD. The magnitudes of the increase in the cohesion of the soil are [23%, 9% and -10 %(no improvement)] , but the values of the increase in the angle of internal friction are [50%, 23% and -43% (no improvement)] for the percents of the cement dust (3, 6 and 8%) respectively.

Analysis of the tests results are drawn as a relation between the percent of the CD and the cohesion of the soil as shown in Figure (16). In the same trend, Figure (17) illustrate that the percents of the CD are plotted with the values of the angle of internal friction. From these figures, the optimum percent of the CD content mixture (which it adding requirements) is (3%) (This percent gives high shear strength parameters).

8- Conclusions

The main conclusions of this study could be summarized by the following points:

1- Using 6% of CD with the fluvial soil from Al-Kufa River leads to slightly increase for the maximum dry density according to the results of the compaction test.

2- For (≥ 8%) and (0 %) percents of the CD cases, the value of the optimum water content is (8%), while this value of the water content increased to (11.6% and 12.6%) for the cases with CD percent (3 % and 6%) respectively.

3- The lowest value of the liquid limit is found in the case of the soil treated with (8%) CD.

4- The flatter curve of the liquid limit test can be observed when (6%) of CD mixed with the natural fluvial soil.

5- The plastic limit values still constant even the percent of the CD increases from 0% to 12%.

6- The highest and the lowest decrease in compression index were observed for the soil treated with CD percents of (8%) and (6%) respectively.

7- The adding of the CD with (6%) to the natural soil leads to a positive significant effect on expansion index, but a negative significant effect on the compression index.

8- The swelling percent for the fluvial soil decreases with time until reaches its minimum value as the 6% of CD is added to this soil.

9- For all cases of treatment, it was found that the swelling percent values are high at the early time of addition but these values are still constant beyond 190 hours.

10- The results indicate that the magnitudes of shear strength parameter for the soil under study increase as all CD percents except 12%.

11- In general, large increase in the angle of internal friction can be observed at any percent of the CD compared with the low increase in the cohesion of the soil.

12- The percent of the CD (3%) has a priority in minimizing the values of the compression index, but at the same time gave the highest value of the shear strength parameters. In other words, the percent of the CD (3%) can be used to improve the compressibility and the shear strength characteristics of the fluvial soil.

13- Generally, the results of the all tests showed that the amounts of the cement dust must be small (≤ 6 %) (The small percent of the CD is very useful) and the high added percent of CD gave negative effect on the properties of the fluvial soil.

9- Recommendations for Future Work

1- Investigate the influences of the cement dust on the soil of Al- Najaf Sea (Al-Najaf Bahr).

2- The adding of the CD percents must be in accurate amounts by dry weight of the natural soil.

3- Prediction of the effect of the new additive (such as lime or fabrics or combination between CD and lime) on the fluvial soil.

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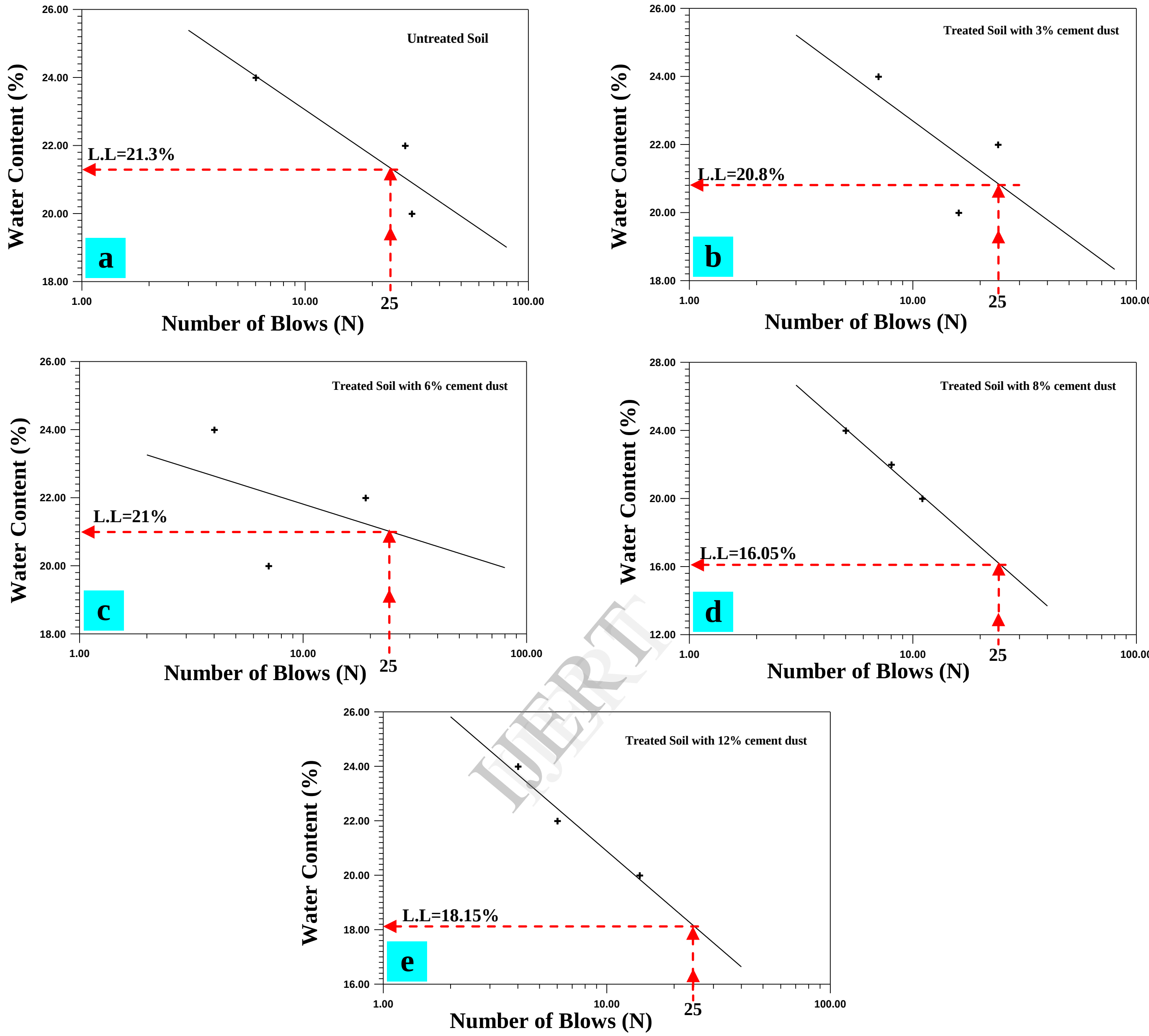
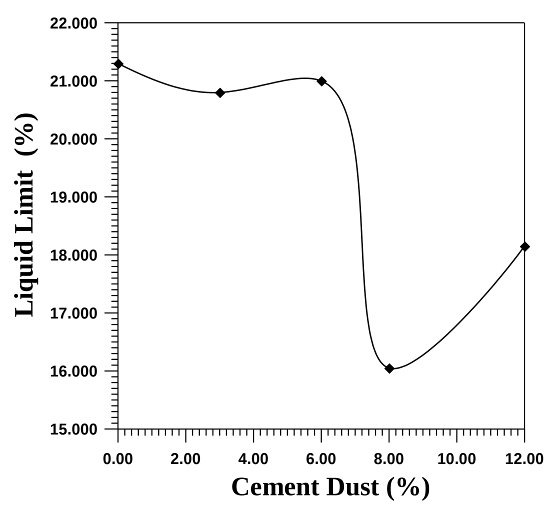
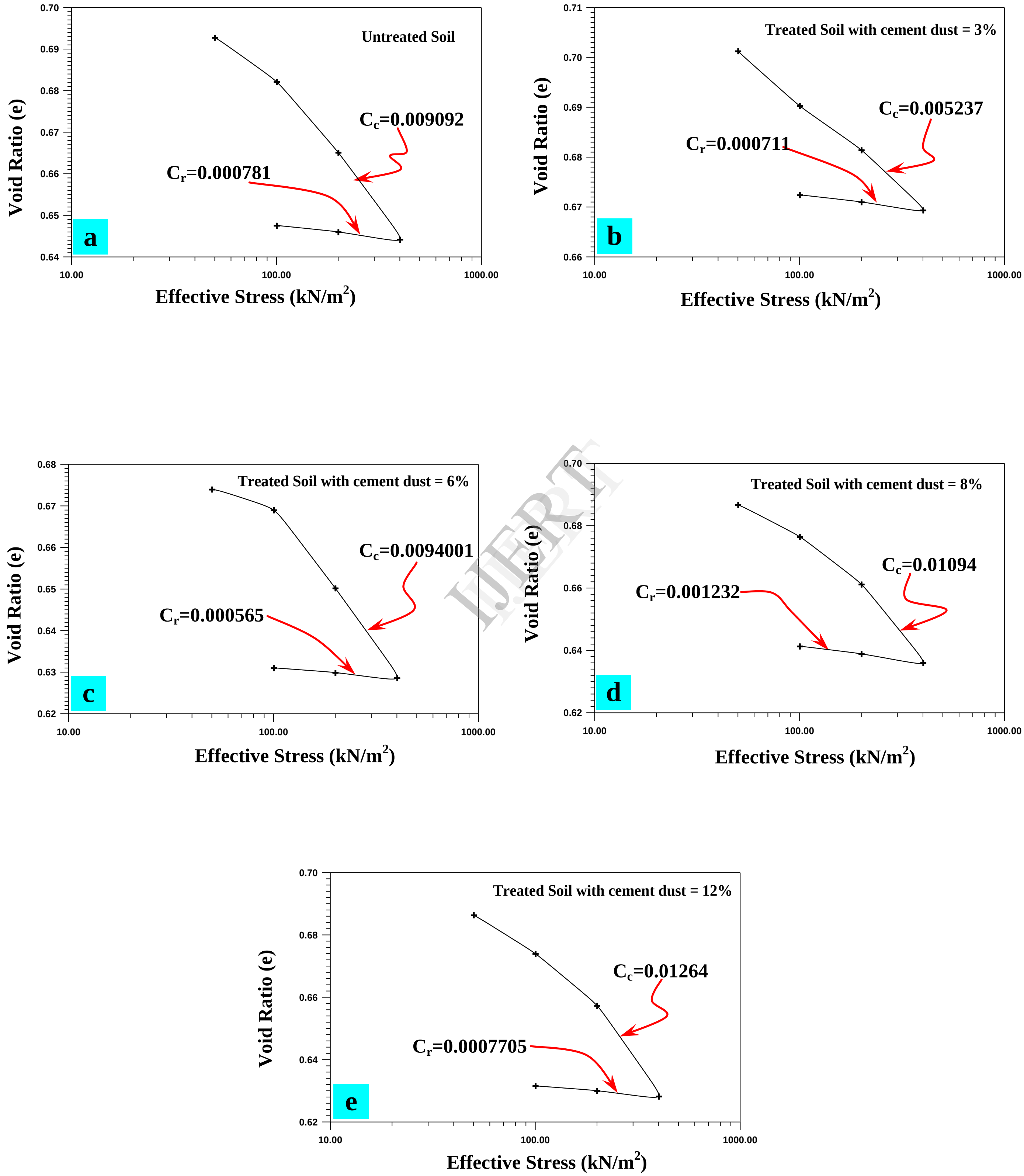


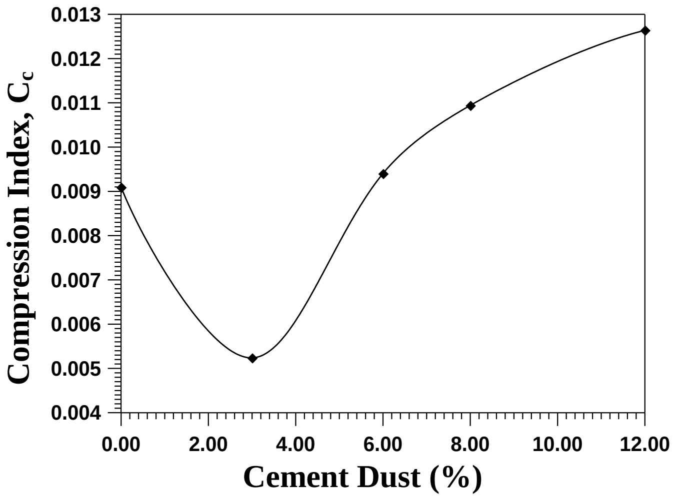
Figure(8): Correlation between water content and number of blows (liquid limit test)



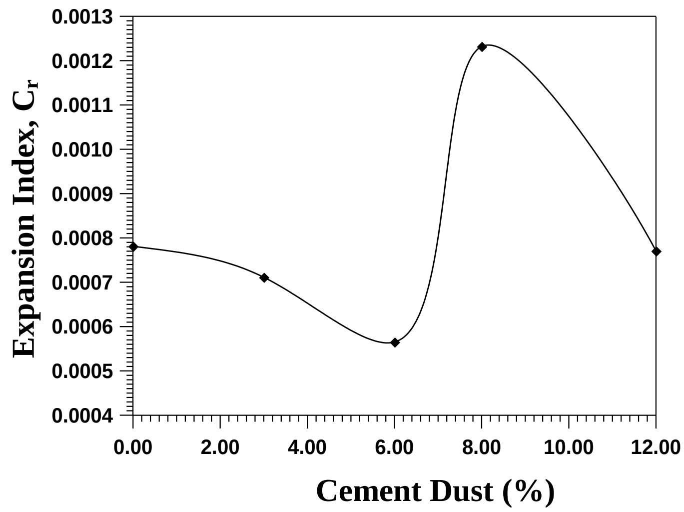
Figure(9): Relationship between the values of liquid limit and cement dust percent



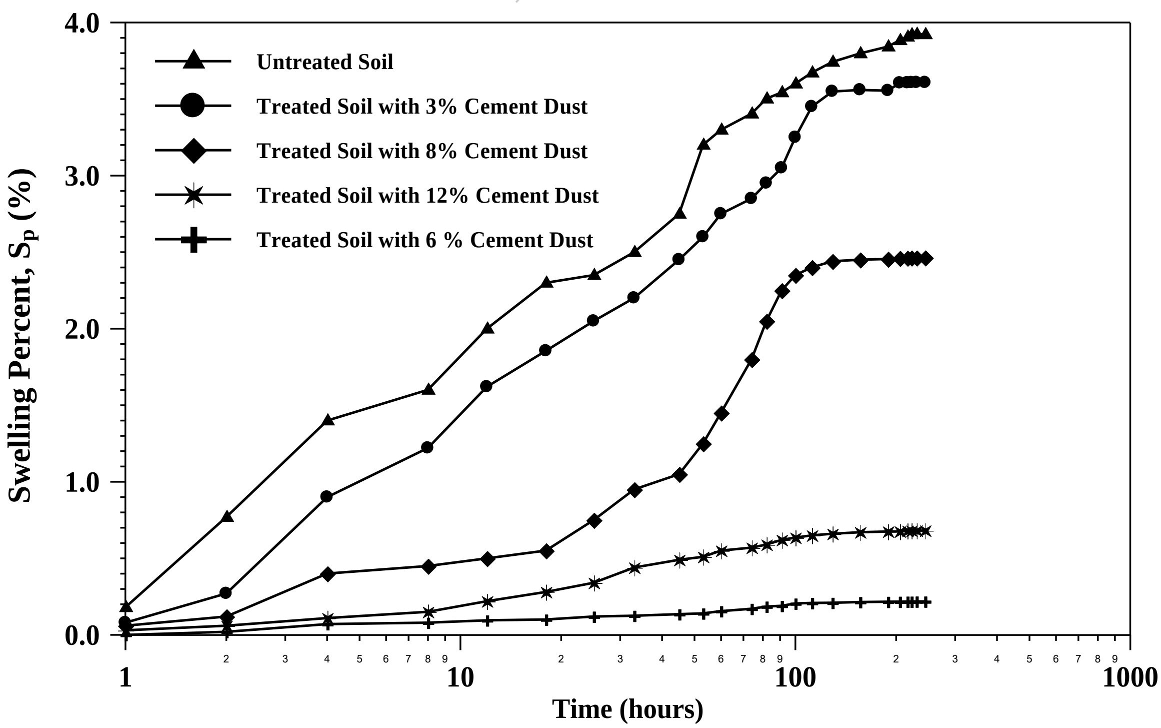
Figure(10): Variation of the void ratio of the soil with the effective stress (Oedometer test)



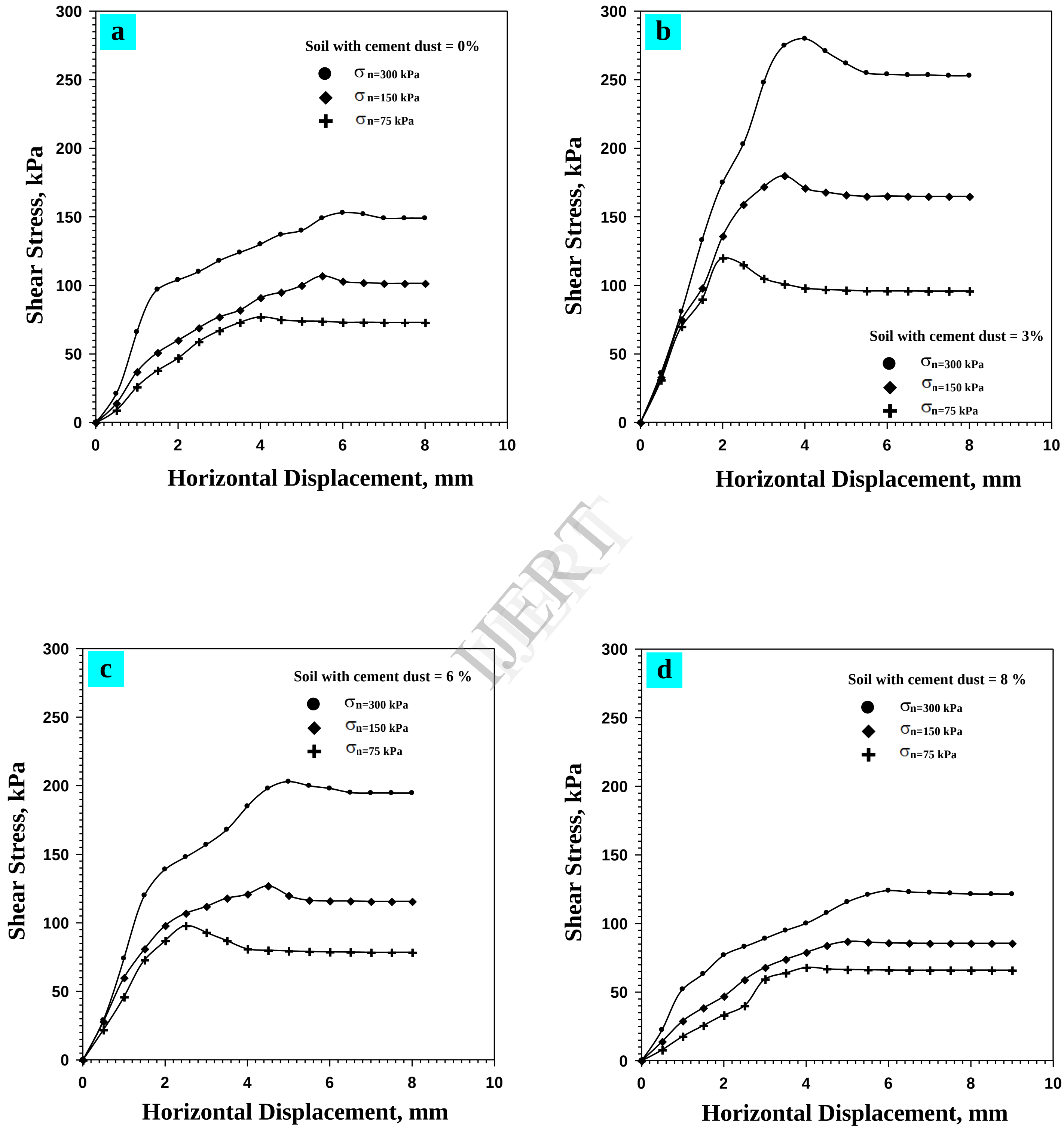
Figure(11): Compression index versus cement dust percent



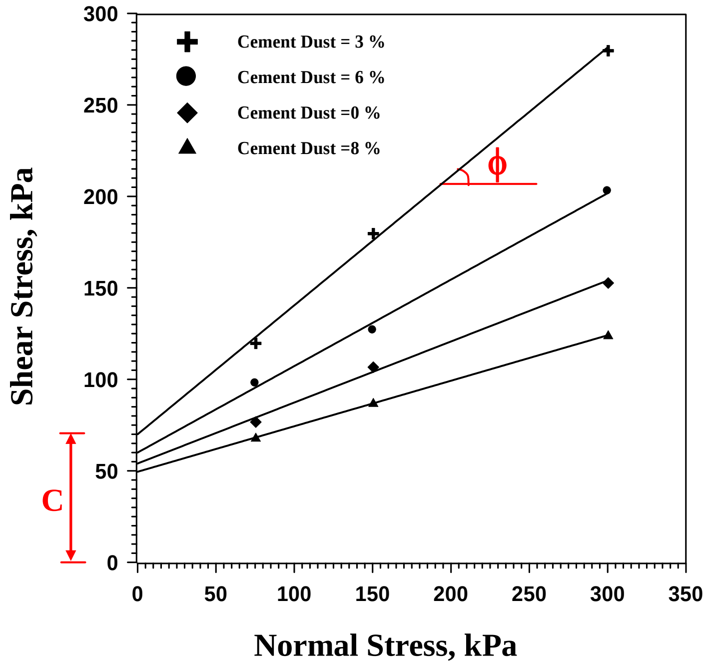
Figure(12): Expansion index versus cement dust percent



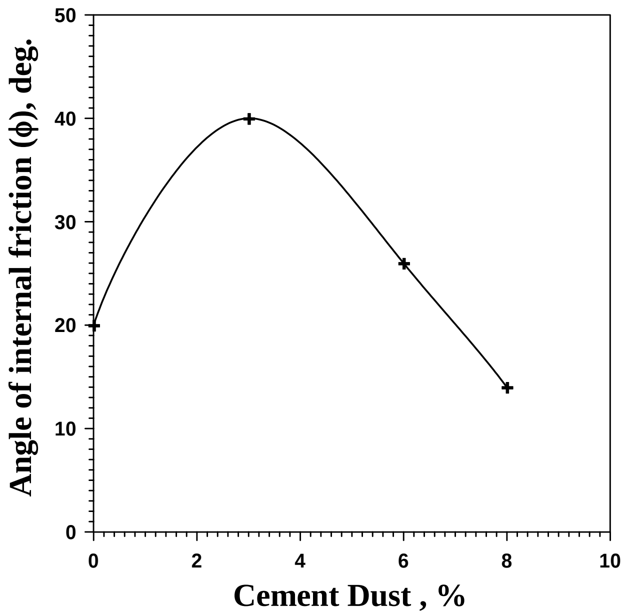
Figure(13): Observations of the values of the swelling percent with time



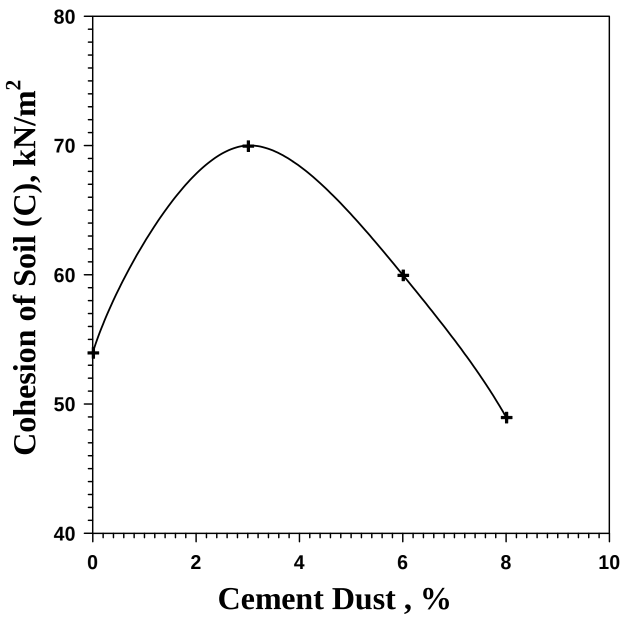
Figure(14): Shear stress versus horizontal displacement for soil treated with cement dust percents (0, 3, 6 and 8%)



Figure(15): Correlation between shear stress and normal stress at different percents of cement dust



Figure(16): Effect of cement dust on the Angle of internal friction



Figure(17): Effect of cement dust on the cohesion