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A Study of Important Indices in Increasing Bearing Capacity of Troubled Soil in Order to Implement Hydraulic Structures Using Cement

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Abstract: *Today, with increasing need for soil as the main material used in water projects and water transfer channels and lack of quality and geotechnical characteristics required in all soils, soil improvement using materials and additives has been paid attention. Soil elasticity modulus indicates the amount of the strain of soil against a certain amount of stress. The greater, the value of this parameter is, the lesser, the deformation of soil against the stress will be. The present study aimed to study the impact of cement and changes in relative compaction on the modulus of elasticity and compressive strength of troubled clay soils. In this research, uniaxial test was performed on the specimens of %100 clay soil and %90 clay soil+%10 cement at optimum moisture levels and at densities of %85, %95 and %100. The results show that the modulus of elasticity increased 420 times with adding cement and with the increase in cement curing time and duration, elasticity modulus increases several times. The higher, the relative compaction of specimen is, the greater, the intensity of this increase is. Also, the cement increases compressive strength up to 20 times more than normal mode.*

Keywords: *elasticity modulus, cement, moisture, relative compaction, strain*

INTRODUCTION

The clay soils have usually low permeability and high expansion and contraction with low humidity change are of their properties. Due to the high cost of excavation and embankment in the construction and irrigation and drainage projects in areas where the soil has not appropriate characteristics for the implementation of projects, stabilization and improvement of the soil with the use of additives is very important. In other words, it is economically more efficient to improve soil and that soil moving operations from borrow source is not done. Generally, the soil available on the site is not ideal and absolutely desirable for construction from an engineering perspective and it must be prepared for construction activities such as construction of hydraulic structures like pumping stations, irrigation and drainage channels, etc. by making changes to it. so in geotechnical engineering, there are two different strategies in dealing with improper soils: changing the location of site and changing the properties of the site which is called improvement of soil or in some case, soil compatibility. Improvement (or sometimes modification) refers to a series of operations which remove some inappropriate behaviors of soil or impose appropriate behaviors on it. The main objectives of soil improvement are to increase the soil strength, to reduce the overall characteristics of deformability and to remove some inappropriate behaviors or to add some appropriate behaviors to soil mass. Conventional soil improvement methods are soil compaction, soil mixing and replacement of soil with other materials. All the above methods are not suitable for all sites and each site can be improving with one or more methods. For the first time, Amis (1917) had patented soil-cement mixture as a research initiative in Philadelphia, America. After him, this mixture has been used in stabilization of the roads and construction of the highways by South Dakota and Iowa highways organization (1922), followed by the South Carolina Department of Roads (1932) (Baxter, C. D. P;

King, J. W; Silva, A. J; Page, M; and Calabretta, V. V). During 1940-1950, some research has been conducted on the factors affecting the improved soil compacted in the bed of roads (Ingles, O. G; and Metcalf, J. B.). Four fundamental factors controlling the design and making of soil-cement mixture are moisture content, curing method and time of curing, relative compaction and amount of cement. Before making, these factors are determined by laboratory operations on the specimens. In general, cementation means the process of cementing or sticking things together using cement and in AASHTO and ASTM standards on soil, it means to stick soil particles together in order to create a cohesive mass with more strength.

Artificial cementation is usually investigated in the research on sands, because coarser materials such as coarse-grain sand and gravels don't need to improvement and they often have desired geotechnical characteristics. So, in order to improve the soil using its artificial cementation, the researchers have focused their research on sands and fine-grain materials (Clough, G. W; Sitar, N; Bachus, R. C; and Rad, N. S.). After adding cement to the soil, different reactions take place between the soil and cement. The most important reactions are positive ions substitution reaction and aggregation-compaction reaction. In these two reactions, the soil tissues changes by the aggregation of its particles and grading. The finer, the cement particles are, the more, the hydration is and it lasts for longer period, even many years and this leads to the increase in the strength of cement-soil mixture over time (Coduto, P. D;). Some application of soil-cement mixture or the soil stabilized by the cement are including protection of channel slope, use of it as basic layer in the foundations of pumping stations, protection of the bed and banks of rivers from erosion and use of it as low-permeable materials for the bottom of reservoirs and lakes and water treatment and so on.

Dupas and Packer (1979) have studied the statistical and mechanical properties of sand and cement in order to improve the sand and to avoid the risk of liquefaction. They showed that the soil cohesion increases by increasing the cementing material, and adding %5 Portland cement creates cohesion of 200 to 300 kPa in sandy soil (Dupas, J.; Pecker, A;). Clough et al (1981) examined the effect of artificial and natural cementation in California. In their research the final strength of specimens increased with cementation and with the increase in the cementation degree, increase in the volume when cutting took place in the smaller range of strain. Also, the effect of cement remains in the form of adhesion after the failure and the tensile strength of cemented material increased 10 time more than compressive strength in the uniaxial test (Dupas, J.; Pecker, A.). In recent years, some experimental studies have been conducted by Wartman et al. (2004). In their studies, the use of crushed glass to improve engineering properties of coarse-grain particles and sand and beach material such as kaolin and soft sand have been assessed. Frictional strength of granular soil particles significantly increased by adding crushed glass and adding crushed glass is suggested as a solution for improving engineering properties of other coastal materials (Wartman, J; D. G. Grubb; and A. S. M. Nasim).

Materials and method

As mentioned in previous parts, elasticity modulus of soil is one the engineering properties of soil which has play significant role in civil project. The basic equations for permanent deformation in a state of static equilibrium may be expressed for homogeneous materials using Hooke's Law, as follows:

$$\begin{aligned} \varepsilon_x &= \frac{1}{E}(\sigma'_x - \upsilon\sigma'_y - \upsilon\sigma'_z) \\ \varepsilon_y &= \frac{1}{E}(-\upsilon\sigma'_x + \sigma'_y - \upsilon\sigma'_z) \qquad (1) \\ \varepsilon_x &= \frac{1}{E}(-\upsilon\sigma'_x - \upsilon\sigma'_y + \sigma'_z) \end{aligned}$$

Eq.(1) represents strain tensor components which expressed by the vector quantity of ε. Structural relationships in the soil which describe the soil behavior are expressed as follows. In eq.1, components of normal stress are along the axes of x, y and z. In a tension plate where the equation is established, for a right-oriented material, Hooke's Law is as follows:

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{bmatrix} = \frac{1}{1-\upsilon_{xy}\upsilon_{yx}} \begin{bmatrix} E_x & \upsilon_{xy}E_y & 0 \\ \upsilon_{yx}E_x & E_y & 0 \\ 0 & 0 & G_{xy}(1-\upsilon_{xy}\upsilon_{yx} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ 2\varepsilon_{xy} \end{bmatrix} \quad (2)$$

Eq.2 can be summarized in the Eq.3:

$$\sigma = M\varepsilon \quad (3)$$

In the Eq.3, M is a matrix of soil rigidity and stiffness and expressed by elasticity modulus. In the present study, the changes in the elasticity modulus of clay soil improved by the cement were examined in terms of saturation and at densities of %85, %95 and %100. The present research has been conducted in the Soil Mechanics Research Laboratory, School of Water Science Engineering, Shahid Chamran University, Ahwaz. Clay soil specimens were provided from one of the borrow sources in Khuzistan Province used in multiple civil project. Geotechnical properties of the soil were determined in accordance with existing standards and the results were classified and listed in Table1. According to the results listed in Table1, the soil of this borrow source has weaknesses in geotechnical properties.

It was decided to mix the soil and cement in the ratio of 90:10. It should be noted that the chosen ratio for the soil-cement mixture was based on the stabilized soil porosity. In order to observe the effects of adding cement, moisture variations and different values of relative compaction on the changes in elasticity modulus, a specimen of soil without any additives at studied moisture levels was prepared and uniaxial test was performed on it and it was considered as control specimen.

Table1. The engineering properties of the soil used

Property	Percentage of clay soil	Percentage of silt	Percentage of sand	Liquid limit	Plastic limit	USCS class	AASHTO class	Unconfined compressive strength KN/m^2	Elasticity modulus KN/m^2
Value	22	71	6	31.9	20.44	CL	A-6	46	800

Some of the results listed in table 1 were derived from the studies conducted by Daryaei (2009) (Daryayi, M). The values listed in table 1 show that the studied soil has low elasticity modulus (about 0.8 MPa) so it is not suitable to be used in the activities in which little deformation of soil is required. So, in the present study, it was tried to increase the value of this parameter by adding cement and increasing curing time. In order to prepare the specimens for uniaxial test and calculation of elasticity modulus of soil-cement mixture, firstly, in any mixing ratio, standard Proctor test was performed to determine the maximum dry unit weight of soil and optimum moisture content. Compaction test was performed according to ASTM d698 standard by standard Proctor technique. The specimens should be kept at the optimum moisture level till the time of curing. This test is simpler and faster compared to other soil strength tests. The dimensions of specimens should be chosen such that the maximum grain size of the specimen is not less than 0.16 of the smallest dimension of the mold. Also, the diameter and height of the specimen should not be less than 3.2 cm and 6.9 cm, respectively. It is recommended that the diameter to height ratio is in the range of 0.33 to 0.5 because it is greater than it, it would cause buckling and columnar property in the soil and this underestimates the soil strength (ASTM D5102).

The load speed in the simple compression test was of strain control test and in the range of 0.5 to 2 mm/min. the result of this test is the unconfined compressive strength (qu). For the specimens stabilized by cement, ASTM D1633 standard proposes two types of cylindrical molds with height to diameter ratio of 1.5 or 2 for testing compressive strength. In this study, the cylindrical molds with a diameter of 5 and height of 10 were used, the height to diameter ratio was 2. Figure 1 shows the tools used for the preparation of specimens and Figure 2 shows an example of the tested soil-cement cylinders.

Figure1. Mold and hammer used to prepare the specimens
Figure2. Broken cement specimen

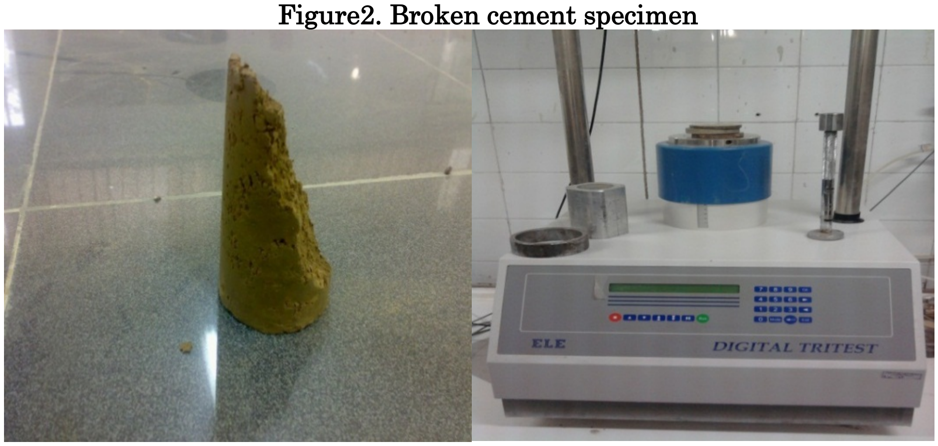

Figure3. The tools used to make the specimen and uniaxial test
Figure4. Broken clay specimen (at the relative compaction of %100

After measuring the maximum dry unit weight of soil, standard Proctor test was used to measure the wet unit weight of any mixing ratio (Ibn Jalal and Shafaei, 1992) [9]. The results of the standard Proctor test for clay soil and clay soil- cement mixture are listed in Table2.

Table2. The results of standard Proctor test for clay soil and clay soil- cement mixture

Type of soil	Maximum dry unit weight of soil $(\rho_d)_{max}$ Kg/m^3	Optimum moisture ω_{opt} (%)
Clay soil	1828	17
Clay soil-cement	1738	19

According to Table2, with the increase in the amount of sand, weight per unit volume of soil reduced and optimum moisture increased. Given the mold shown in figure 1, the volume of mold is determined and weight per unit volume obtained for each mixing ration was used to estimate the amount of mixture of soil and cement needed to be poured in the mold and also hammered. According to standard Proctor test, the specimens were hammered in three layers. Accordingly, the amount of clay soil-cement that should be poured in the cylindrical mold to perform the uniaxial strength test was divided into 3 equal parts and at each step, one part was compressed in the mold. So, firstly, one third of the amount of soil was poured in the cylindrical mold, then each layer was compressed using the designed hammer and triaxial testing machine with speed of 1.5 rpm so that it was filled one-third of the mold volume. The 2nd and third layers were compressed in a same way. Then the specimens were placed in the steamer. With the arrival of a certain amount of cool water vapor, the locating space retained the specimens as saturated. To avoid any error in the measurements, 3 specimens of each soil cylinder were prepared and uniaxial test was used on all the three specimens and the results were presented after averaging. One of the lab problems at this stage was that the soil stuck to the inner wall of the mold and it was impossible to removing it healthily. In order to solve this problem, a very thin film was used on the inner wall of the cylinder. Of course, it should be noted that in the original design of the study, the relative compaction of %110 was considered but since in practice, it was impossible to prepare all the specimens with such relative compaction and also in order to homogenized the experiments, this relative compaction was omitted. During the test, each 2mm changes in the specimens and its corresponding force were recorded. For example, the results of testing clay soil-cement specimen at the relative compaction of %85 were listed in table3.

Table3. The results of testing 28-day soil-cement specimen at the relative compaction of %85

Strain (m/m)	Force (N)	Area (cm^2)	Stress (N/cm^2)
0.0005	29.93	19.62	1.52
0.001	76.98	19.61	3.92
0.0015	141.56	19.6	7.22
0.002	228	19.59	11.64
0.0025	259.3	19.58	18.34
0.003	638.4	19.57	32.61
0.0035	1524	19.56	77.94
0.004	2244	19.55	114.81
0.0045	3658	19.54	187.17

For all the experiments in this study, calculations and measurements similar to those listed in Table 3 were carried out. In all the measurements, finally, the stress-strain curve was obtained. For each specimen, a stress-strain curve shown in figure 5 was drawn and the slop of the curve to the point of maximum elasticity modulus was calculated.

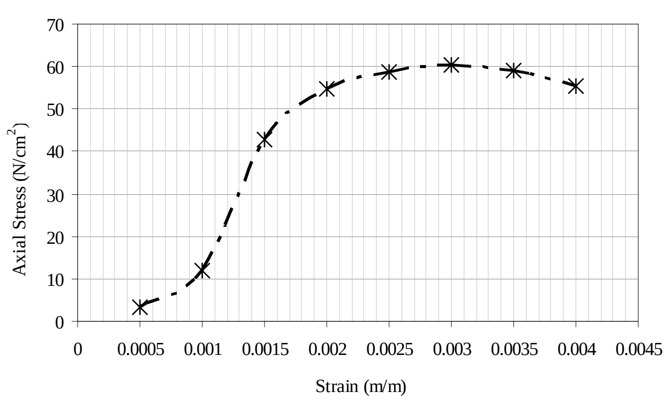

Figure5. The changes in stress-strain for 7-day soil-cement mixture at the relative compaction of %85 (%10 cement)

Results and discussion

Figure6 shows the changes in the clay soil elasticity modulus at different densities. At the optimum moisture level, break in curve was observed and then the curve slope reduces. It should be noted that at the optimum moisture, the elasticity modulus values of all the three densities are approximately equal and after the point of optimum moisture, all the curves are overlapped. In other words, at the point of optimum moisture and also the points of higher moisture, the values of elasticity modulus are not the function of relative compaction. The reason for it can be found in the relative compaction curve, because, at the points of moisture higher than optimum moisture, the water located between the particles of soil reduces the soil compressibility and stresses applied not only to soil particles but also to water between the particles. So, at the higher moisture level, it has no impact on the soil elasticity modulus.

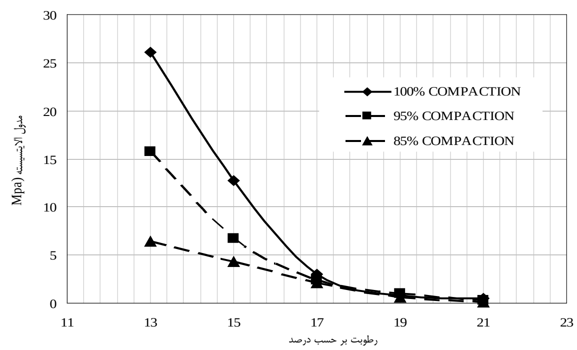

Figure6. The changes in the elasticity modulus to the moisture at the different relative compaction for clay soil

Figure7 shows the soil compressive strength to the moisture at different densities. According to figure7, with the increase in the moisture, compressive strength reduces. At the relative compaction of %100, compressive strength at the moisture of %13 is 8.52 times greater than it at the moisture of %21. At the relative compaction of %85, it is 4.52 times greater. With the increase in the moisture, the curves close to each other so that at the moisture of %21, the difference between their values is minimized.

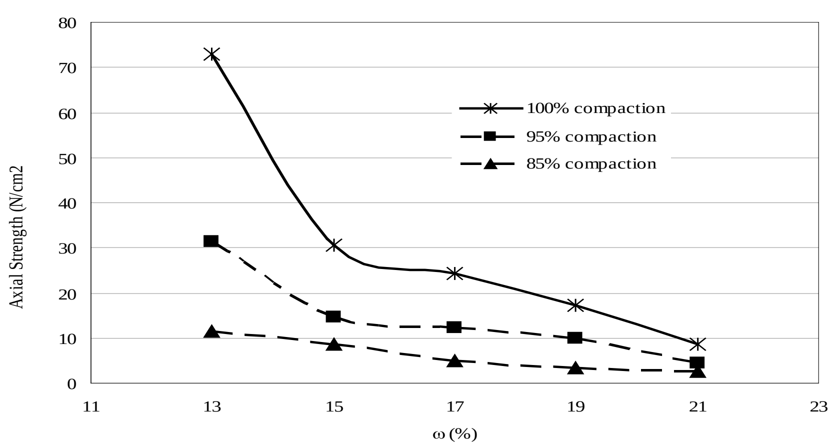

Figure7. Soil compressive strength at different densities

As mentioned in previous parts, the present study was conducted at three densities and on clay soil-cement mixture. Figure 8 to 10 show the results obtained from the changes in elasticity modulus in different modes of clay soil-cement mixture at different densities of %85, %95 and %100. Figure 8 shows the changes in the elasticity modulus of clay soil-cement mixture to the curing time in terms of saturation. It is clear that with the increase in curing time, elasticity modulus increases. But it should be noted that the higher, the relative compaction is, the greater, the increase intensity is. Within 7 to 14 days, at the relative compaction of %100, the curve slope is 2.1 and 3.8 times greater than the curve slope at the relative compaction of %95 and %85, respectively. Within 14 to 28 days, it is 3.7 and 22.2 times. So, with the increase in relative compaction, both elasticity modulus and the intensity of its increase will increase.

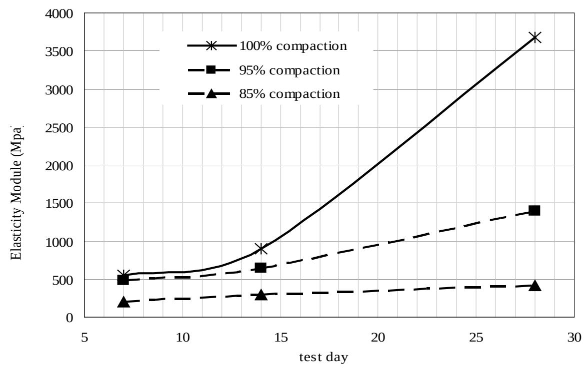

Figure8. The changes in the elasticity modulus of clay soil-cement mixture during the curing time

In the above curves, it is observed that although adding cement to the soil increases the strength of the specimen compared to the natural soil, it created brittle in the specimen and in the uniaxial test, the samples reach the mode of failure under less strain compared to the natural soil. The results show that the increased strength of cement-soil mixture depends on the percentage of cement and curing time. The impact of cement on the increase in soil strength can be related to the decrease in plasticity and cementation. When a cohesive soil is mixed with a certain percentage of cement, under hydration, calcium ions is released, causing the change in the electric field around the particles of clay soil and the soil particle become granular and plasticity reduces and this increases the strength of the specimens. Hydration is a time consuming process and is done gradually and will continue several years and the soil is cemented further over time and its elasticity modulus increases so, figure 8 is justified well. Figure 9 shows sub-changes in elasticity modulus of soil-cement mixture at different densities for a certain time. As shown in it, with the increase in relative compaction, elasticity modulus increases. In 7 and 14 days, intensity of increase in the elasticity modulus is less compared to 28 days. The curve slope in 28 days is 5.4 and 9.3 times greater than the curve slopes in 14 and 7 days, respectively. This means that the increase in the relative compaction, in addition to reducing porosity and increasing interlocking of soil particles, increases the cementation of the cement.

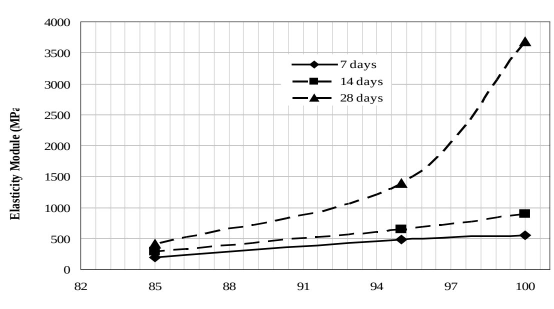

Figure9. Changes gradient of elasticity modulus of soil-cement mixture to time (curing time)

Figure10 shows the changes in compressive strength of soil-cement mixture in day at different densities. It is obvious that with the increase in time, compressive strength increases. The reason for it is similar the reason for the increase in elasticity modulus, i.e. hydration increases over time and the particles become cemented further and soil strength increases. It should be noted that the curve slope within 7 to 14 days is more than the curve slope within 14 to 28 days. This means that in the first week, the intensity of increase in the compressive strength is more and it gradually reduces. Another important point is that in a relatively long time, compressive strength values are approximately equal at the densities of %95 and %100. This means that at the relative compaction of%95, clay-cement mixture provide more appropriate compression in terms of economic issues.

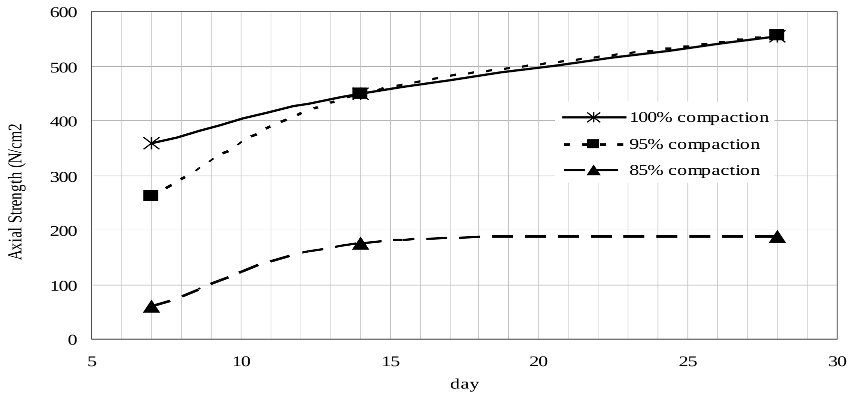

Figure10. The changes in compressive strength of clay-cement mixture in day at different densities

Figure11 compare the clay soil with 7-day clay-soil-cement mixture in terms of elasticity modulus. It is obvious that elasticity modulus significantly increases. At the densities of %85, %95 and %100, the increase averagely becomes greater 63.91 and 73 times, respectively. These values show that adding cement to the clay soil will result in the increase in elasticity modulus even after a short time. Another important note is that at the relative compaction of %95, the elasticity modulus of soil-cement mixture increases compared to the clay soil but elasticity modulus at the relative compaction of %100 is greater compared to the relative compaction of %95 because at the relative compaction of %100, there are more interlocking of particles and this increases the cementation.

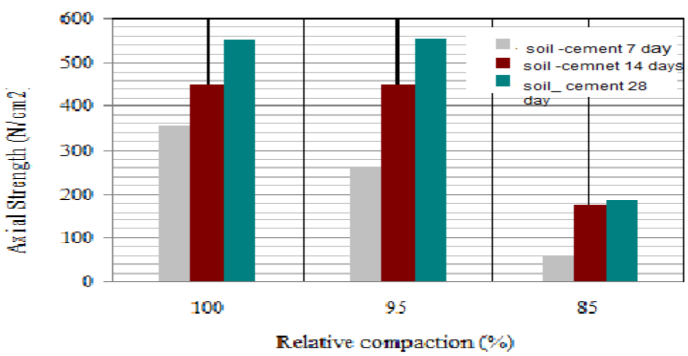

Figure11. Comparison between clay soil and clay soil-cement mixture in terms of elasticity modulus

Figure 12 shows the changes in the elasticity modulus for the soil-cement mixture at different relative compactions. At the relative compaction of %100, compared to the clay soil, the increase in elasticity modulus of soil-cement mixture in 14 and 28 days is 103 and 427 times greater than it in 7 days. This shows that cement significantly increase the elasticity modulus even in short time.

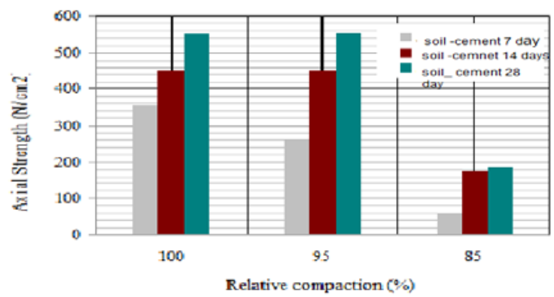

Figure12. Column chart of elasticity modulus for clay soil-cement

Figure13 shows the column chart of compressive strength of clay soil compared to 7-day clay soil-cement mixture. It is clear that compressive strength significantly increases. Compared to the clay soil, compressive strength of 7-day soil-cement mixture increases 12, 18 and 10 times at the relative compaction of %100, %95 and %85, respectively. Another point is that at the relative compaction of %95, increase in compressive strength is due to the increase in the amount of cement so it is the better relative compaction for the soil-cement mixture.

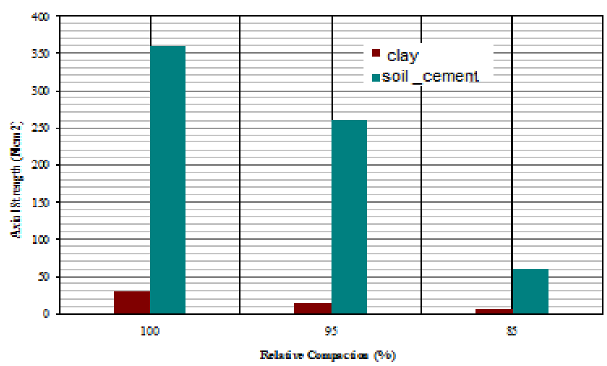

Figure13. Comparison between clay soil and clay soil-cement mixture in terms of compressive strength

Given to figure 13 and comparing the clay soil with clay soil-cement mixture in terms of compressive strength, figure 14 presents a clearer image on increase in compressive strength of soil-cement mixture. At the relative compaction of %100, the increase in compressive strength in 28 days is 1.22 and 1.54 times greater than the ones in 14 and 7 days, respectively. This shows that time has no significant effect on the increase in compressive strength.

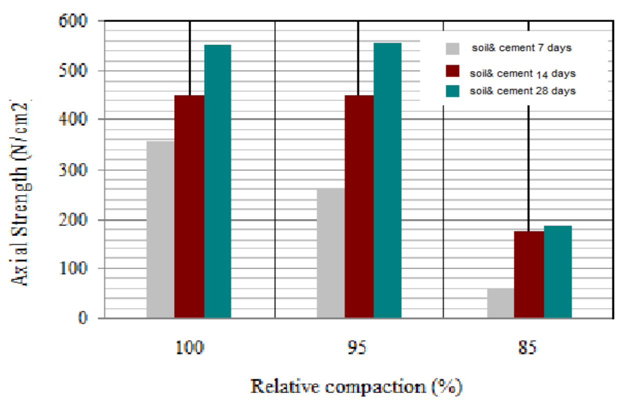

Figure14. Column chart of compressive strength of clay soil-cement mixture

According to figure14, at the relative compaction of %95, the increase in compressive strength in 28 days is 1.24 and 2.15 times greater than the ones in 14 and 7 days, respectively. And at the relative compaction of %85, it is 1.05 and 3 times greater. This shows that the lower, the relative compaction is, the more, the effect of cement on the increase in the strength, especially in the first week. The reason is that the soil has a higher void ratio and cementation in the pores takes place more easily.

Conclusion

Based on what studied in the present study, the results are summarized as follows:

- With the increase in curing time, the elasticity modulus increases. The higher, the relative compaction of specimen is, the greater, the intensity of the increase is.
- Within 7 to 14 days, at the relative compaction of %100, the curve slope is 2.1 and 3.8 times greater than the curve slope at the relative compaction of %95 and %85, respectively.
- With the increase in the relative compaction, both the elasticity modulus and its increase intensity will increase.
- At the optimum and higher moisture levels, the values of elasticity modulus are not the function of relative compaction.
- Although adding cement to the soil increases the strength of the specimen compared to the natural soil, it created brittle in the specimen and in the uniaxial test, the samples reach the mode of failure under less strain compared to the natural soil.
- The increase in the relative compaction significantly results in the increase in axial strength. Averagely, at all moisture levels, it increases 5 times. It means with the increase in relative compaction from %85 to %100, axial strength of soil increases 5 times.
- The increase in the relative compaction has much more impact at the lower moisture level, at the moisture level of %13, with the increase in relative compaction from %85 to %100, compressive strength of soil increases 6.3 times. But at the moisture level of %21, it increases 4 times. At the relative compaction of %85, the curves become closer to each other. This means that at the relative compaction of %85, the effect of the changes in moisture level on the compressive strength becomes less.
- At the relative compaction of %100, fully interlocking of particles takes place and by applying stress, the particles easily slip on each other and instant deformation is caused in the soil and at the relative compaction of %85, applying primary stress increases interlocking of soil particles and with more stresses, the particles slip on each other and result in large deformation.
- The compressive strength increases over time and in the first week, its increase intensity is more due to adding cement and then it gradually reduces. In a relatively long time, compressive strength values are approximately equal at the densities of %95 and %100.
- By adding cement, elasticity modulus has increased significantly. At the densities of %85, %95 and %100, the increase averagely becomes greater 63.91 and 73 times, respectively.
- At the relative compaction of %100, compared to the clay soil, the increase in elasticity modulus of soil-cement mixture in 14 and 28 days is 103 and 427 times.
- Compared to the clay soil, compressive strength of 7-day soil-cement mixture increases 12, 18 and 10 times at the relative compaction of %100, %95 and %85, respectively.
- Given the economic issues and based on the results obtained for elasticity modulus and compressive strength, the relative compaction of %95 is more suitable compaction level for both clay soil and clay soil-cement mixture.

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