# THE GROUND IMPROVEMENT USING CEMENT AS A STABILIZER IN DIFFERENT SOIL CONDITIONS.

**Compiled as one of the requirements to complete the Undergraduate Study Program in the Department of Civil Engineering, Faculty Engineering**

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APPROVAL PAGE

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# GROUND IMPROVEMENT USING CEMENT AS A STABILIZER IN DIFFERENT SOIL CONDITIONS


## Abstract

Soil stabilization with cement is commonly used to improve the strength and hardness of natural soil formation by adding reinforcing aids such as cement, lime, gypsum and fly ash. It has many applications, such as foundation engineering, providing retaining walls for excavation, liquefaction mitigation, hydraulic retaining walls and environmental remediation. This paper presents a brief history and evaluation of soil stabilization using cement as an effective chemical stabilizer to improve the strength and durability requirements of sandy and sandy soils. lighting. In addition, several previous works regarding the strength of soils after mixing with cement in different ratios are considered, including analytical analysis, laboratory work and current tests. large school. This study will refer to 6 previous studies on cement stability on different soil conditions: sandy soil and clay soil. The study will analyze the results of unreinforced compressive strength for sandy and clayey soils at the hardening time of 28 days. The results indicate that cement as a stabilizer is effective in improving both soft and sandy clay soils, and based on the results of the unreinforced compression test, it is more effective on sandy soils than on clay soils.



**Key words**: admixture, cement, clay soil, deep soil mixing, sandy soil, stabilization.



## Abstrak

Stabilisasi tanah dengan semen umumnya digunakan untuk meningkatkan kekuatan dan kekerasan pembentukan tanah alami dengan menambahkan bahan-bahan penguat seperti semen, kapur, gypsum dan fly ash. Ini memiliki banyak aplikasi, seperti rekayasa pondasi, menyediakan dinding pendukung untuk penggalian, mitigasi likuifaksi, dinding pemutus hidrolik, dan remediasi lingkungan. Makalah saat ini menyajikan sejarah singkat dan tinjauan stabilisasi tanah dengan menggunakan semen sebagai stabilisator kimia yang efektif untuk meningkatkan persyaratan kekuatan dan daya tahan tanah pasir dan tanah liat. Selain itu, beberapa pekerjaan sebelumnya yang berkaitan dengan kekuatan tanah setelah dicampur dengan semen dengan proporsi yang berbeda ditinjau yang meliputi analisis analitis, pekerjaan laboratorium, dan uji lapangan skala penuh. Penelitian ini akan mengacu pada 6 penelitian sebelumnya tentang stabilisasi dengan semen pada kondisi tanah yang berbeda: tanah berpasir dan tanah liat. Penelitian ini akan menganalisis hasil kuat tekan bebas untuk tanah pasir dan tanah liat pada waktu pemeraman 28 hari. Hasil penelitian menunjukkan bahwa semen sebagai bahan penstabil efektif untuk memperbaiki tanah lempung lunak dan tanah berpasir, dan berdasarkan hasil uji tekan bebas diketahui lebih efektif pada tanah berpasir daripada tanah liat.



**Kata kunci**: admixture, deep soil mixing, semen, stabilisasi, tanah berpasir, tanah lempung.

# 1. INTRODUCTION

## 1.1 Background

Sometimes there is a restriction on the construction of a region considered as a problem that the basic calm of unstable soils is considered a problem. In this case, you must use the appropriate floor stabilization technology to improve the soil. Soil stabilization technology, a deep mixed column (DMC) is increasingly used in more and more countries. Deep soil stabilization improves not only the bearing capacities, but also reduces deposits, reduces deposits, to prevent the deformation of soil shear and use stabilizers to treat contaminated soil. According to the literature, this method has some advantages: Construction speed, strength calibration, reliability, various applications and efficient resources. There are many factors that affect the characteristics of deep mixture columns, soil characteristics and mixing and hardening conditions are the most important.

The soil stabilization using cement is often used as a means of improving the resistance and compressibility characteristics of the soft soil. The increase in intensity is accompanied by the increase of the module and the reduction of soil ductility. If the intensity after the peak decreases sharply, it is also the characteristic of the common care. All these attributes make the structure structured natural cement soil. The ground compression ratio is also replaced by the addition of cement and shared contaminated soil has a much more pre-strong pressure than untreated than untreated soil. The porosity after the pressure of the external pressure in the treated ground was quickly reduced. This means an increase in the compression index immediately after the prerequisite. This behavior has also been observed in naturally structured soil. When the cement is added to the ground generates compounds of primary and secondary cement in the dirt matrix that improves the characteristics.

## 1.2 Soil stabilization with cement

Soil stabilization is the process by which special soils, cementitious materials, or other chemical or non-chemical materials are added to natural soils or modified on natural soils to improve one or more land properties. Stabilization can be achieved by physically mixing the natural soil and stabilizing materials to achieve a homogeneous mixture, or by adding stabilized material to an undisturbed layer of soil and creating an interaction by letting it seep through the voids of the soil. ground. Cement is one of the most common additives used as stabilizers for expanded flooring. Extensive evaluations have been made of the cement stability of expanded floors.

Soil cement stabilization is the binding of soil particles resulting from hydration of cement particles turning into crystals which can be bonded to produce high compressive strength. To achieve successful adhesion, the cement particles must cover most of the material. To ensure good contact between the soil particles and the cement, and thus effectively stabilize the cement in the soil, it is necessary to mix the cement and the soil with a certain particle size distribution.

### 1.3 Deep soil mixing method installation

The DMC is designed to meet the exact needs of any given situation by adjusting one or a combination of the following variables: column diameter, substitution area ratio, mix definition, amount of adhesive and adhesive binders. Column diameters vary from 0.5 to 1.75 m, spacing is typically centered 1.0 to 1.5 m, and length typically varies from 10 to 30 m in normal practice for land applications. In some cases, notably for harbor structures, cement columns 60 m long have been used.

The DMC is adjusted according to the following procedure, Figure 1, 2.

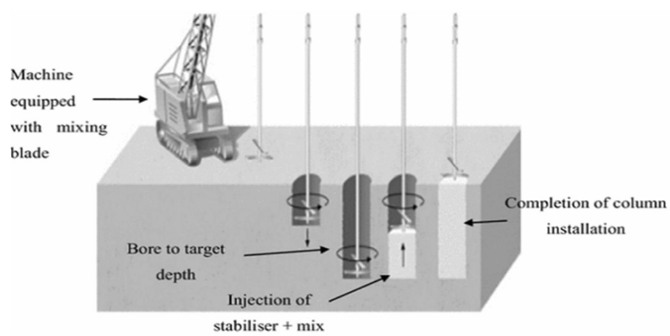


**Figure 1.** Design of Deep Mixing Method (Massarsch, K. R. 1999)

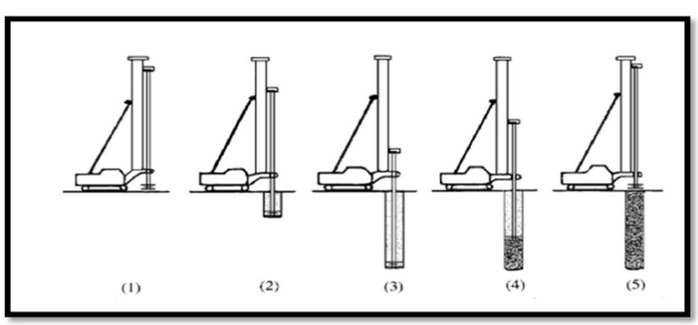


**Figure 2.** Sequence of installation by Deep Mixing Method (Massarsch, K. R. 1999)

1. Penetration/Drilling: The process begins by penetrating the unimproved area by pouring water only.

2. Grout injection and mixing (mechanical part): After reaching the top of the improvement area, the mixing shaft penetrates to the desired treatment depth with concurrent breaking of the soil by the mixing device.

3. Churning: When the treatment depth is reached, the slurry discharge is stopped. However, the mixing process continues for several minutes in order to obtain a homogeneous mixture of the soil, the binder is put into the soil in granular or powder form.

4. Removal with the injection and mixing process: the removal of the drill pipe is then continued. At the same time, the cement grout is discharged through the spray nozzle. The soil and binder are mixed by rotating the mixing tool in the horizontal plane.

5. Shrinkage with mixing: When the shrinkage reaches the top of the improvement area, the main parts of the soil improvement process are completed. The remaining process is simply to remove the drill mast to the surface while dumping a small amount of slurry.

The increase in strength of cement-stabilized soils is influenced by a number of factors. These factors can be roughly divided into four categories: I. Binder characteristics, II. Soil characteristics and conditions, III. Mixing conditions, and IV. Curing conditions.

In order to fully comprehend the impact of this strategy on soil strength stability, several previous studies related to DMCs soil are reviewed which include analytical analysis and laboratory work.

There are 6 references to study the soil behavior for different soil conditions when using the deep mixing column method as a soil improvement:

First, the analysis of the effect of DMC on soft clay, and the study of the effect of the cement adding, as stabilizing additives, on the technical behavior of this soil. For the second reference, it is the stiff clay, using trial mix design test mixing to compare the properties of the soil before and after treatment, and then, for the third reference, it is the soft lean clay, it was discovered that the cement content enhanced the unconfined compressive strength and stiffness of the treated samples and the ideal content of water and cement for clay mixed with cement is 7% and 8% to 10% respectively. To discuss the effectiveness of deep soil mixing method on sandy soil, three different studies will be analyzed and compared, the first study was done in Saudi Arabia on Various percentages of Portland cement were added to waste sand (0, 2, 4, 6, and 8 percent ), and based on the results of unconfined test it was found that as the percentage of cement increases the strength increased as well. The next study was done on desert sand adding different amounts of cement 2%, 4%, 8%, 10%, and 12%, and it was concluded like the previous study that the strength increased with the increase of cement, moving to the last study conducted on sandy soil adding different proportions of cement 1%, 2%, 3%, 4%, and 8%. Based on the results of unconfined compression tests (UCT) and direct shear tests (DST), it was discovered that as soil strength attributes grow, settling characteristics decrease.

Finally, this paper examines the effectiveness of this promising technique, and suggests further topics for study and development to determine the type of soil where DMC and soil stabilization using cement may be more effective.

**Table1**. The references of the data of this research

| NO | Year | Soil Type | Binder Type | Binder % | Test | Maximum UCT value | Location | Researcher |
|---|---|---|---|---|---|---|---|---|
| 1 | 2015 | Soft clay | Cement | 8, 10, 12, 14 | Unconfined Compression Tests (UCT) | 1400 kPa | Egypt | M A Mansour , A M Samieh and H E Matter |
| 2 | 2020 | Stiff Clay | Cement | 6, 8, 10 | Unconfined Compression Tests (UCT) | 585 kPa | Egypt | Mohamed Mamdouh Zakaria, Kamal Mohamed Hafez, Walid Hamdy El Kamash, Azza Hassan Moubarak |
| 3 | 2012 | Soft lean clay | Cement | 4, 6, 8, 10 | Unconfined Compression Tests (UCT) | 480 kPa | Iran | Pakbaz, Mohammad & Alipour, Rasoul |
| 4 | 2019 | Waste Sand | Cement | 4, 6, 8 | Unconfined Compressive Test (UCT) | 1680 kPa | Saudi Arabia | Faisal . Shalabi Javed Mazher,Kaffayatullah Khan, |
| 5 | 2009 | Desert Sand | Cement | 4, 8, 10, 12 | Unconfined Compressive Test (UCT) | 2440 kPa | Oman | M. Y. Al-Aghbari, Y. E.-A. Mohamedzein and R. Taha |
| 6 | 2020 | Sandy soil | Cement | 2, 3, 4, 8 | Unconfined Compressive Test (UCT) | 1390 kPa | India | K Raja, E Elakkya, A T Manikandan, B Surya, M Nekila. |

Many studies research about the possibility of stabilizing soft soil with cement or lime admixture using the mixing method, and only a few has investigated the stabilization of sandy soil and peat using different admixtures such as fly ash. In this research will collect and summarize all the previous studies that conducted on different soil conditions.

The aims of this study are:

- Describing the soil stabilization with cement, its advantages and disadvantages.
- Describing the Deep mixing installation pattern and Deep Mixing Design.
- Reviewing previous studies and explained the deep mixing as a technique in the category of admixture stabilization by cement as a binder in: clay soil and loose sandy soil.
- Investigating the ability of DMC to improve which type of soil by comparing the results for each of the unconfined compression test.

## 2. RESEARCH METHOD

To reach the aims and the objectives of this research, a literature study method will be used by collecting data from several journals concerned with research, and providing the background information and a review of the relevant literature relating to DMCs. This study focuses more on the researches that have been done in different countries because it is not yet a common type among soil improvement techniques.

The following aspects are examined: soil conditions, type of binder, settlement and bearing capacity. The beginning of this research will provide a brief review about deep soil mixing method, the factors affecting on it, the way of installation with clear steps and the way of working. Then for the chapter of analysis, it will be a detailed review by collecting different data from of the previous studies for clay and sandy soil were done in different locations and discussed each result at then of this study a conclusion will be given based on the comparison of the results of each type of soil.

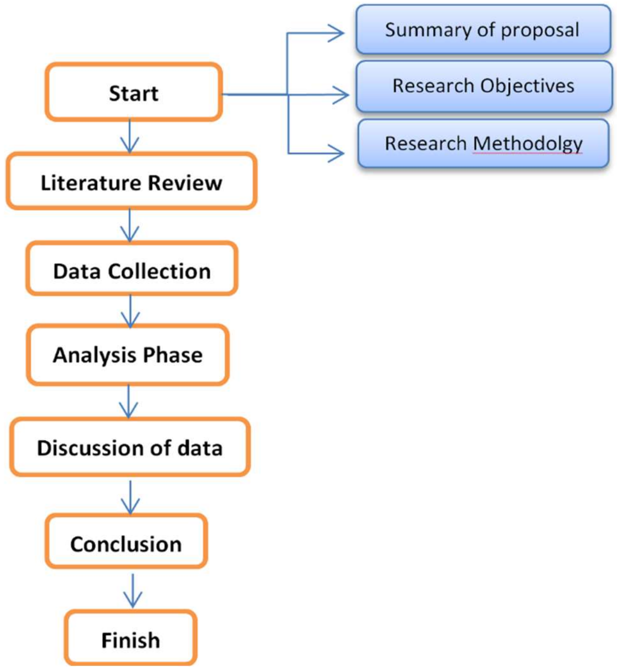


**Figure 3.** Flowchart of the study

## 3. RESULTS AND DISCUSSION

### 3.1 Soil- Cement samples preparation

In this study, two types of soil are examined, a sandy soil and a clay soil, mixed with cement to stabilize them. The soil samples are taken from different locations and also have different property characteristics.

The cement admixture is used for the purpose of stabilizing the soil samples. And the mixing procedure was different, in some researches it was used the deep soil mixing method as a method to improve the soil by adding the cement and for other researches was used the cement as a stabilizer by adding it directly to the soil sample (clay/sand).

The cement content used for each type of soil varied between 2%, 3%, 4%, 6%, 8%, 10% and 12% added to the dry soil. All specimens were cured for 28 days. The soil and cement samples were taken from the cylindrical molds when they reached the required strength. The unconfined compressive strength was determined at this time to determine the strength of the soil-cement after curing.

### 3.2 The curing time

From all the previous studies, the curing time of the specimens was varied between 7, 14 and 28 days, from the outcomes of the strength gained at each curing period, it was discovered that as the curing period increased, so did the strength, and after 28 days the strength gained is the highest, that is why in this paper, the curing time will be discussed is 28 days.

After the procedure of mixing the soil specimen with the cement content as mentioned above, the sealer should be applied to the specimen in the mold to avoid changes in water content, and the specimen should be cured for 28 days at 20 3C. After 28 days, the specimens are ready for unconfined compressive strength testing.

### 3.3 Laboratory test: Unconfined compressive strength test

In accordance with the six studies used in this study, other cement content were added and the coordinated compression resistance test was made to determine soil resistance (clay / sand).

The non-embarrassment compression test is the fastest and inexpensive method of measuring shear strength and is defined as compression force resistance not confused (exits) compression resistance undefined as intensity uncompressed. Simple cylindrical specimens of coherent power are disconnected from a single compression test. In addition, in this test method, the simple compression intensity is considered to be taken forward during the performance of the test, rather than the load on the maximum load or axial deformation at 15% per unit unit , rather than a unit area. This method is mainly used for saturated coherent soil recovered in a thin sample tube. The non-confined compression tests are not suitable for dry sandals or terrible clays because these materials are not reduced without lateral constraints.

The test is suitable for saturated, uncracked cohesive soils, for which the shear strength angle can be assumed to be zero. The test cannot be performed on sandy soil, so to measure the strength, the sandy soil must be mixed with cement.

Figure 4 depicts an unconfined compression testing equipment that can perform strain-controlled testing. The machine is made up of two loading plates, one on top and one on the bottom. The top loading plate is linked to the bottom of a test ring. The test ring's top is connected to a crossbar, which is connected to two metal posts. The loading plate at the bottom can be adjusted up and down.

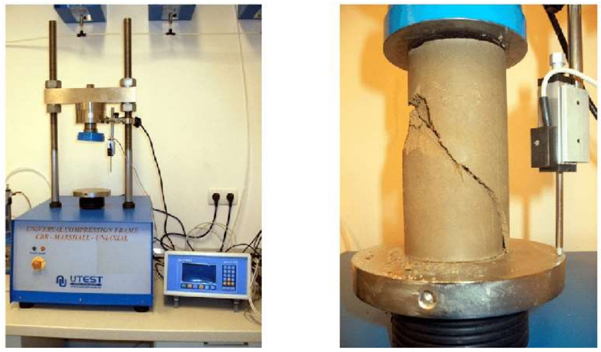

**Figure 4.** The unconfined compressive strength test

- **Unconfined compressive strength for the sand-cement soil**

The samples for the UCC test were prepared before to the test. Sand, cement, and water can be combined in any quantity to make a homogenous paste that can be poured into plastic molds of any size. To reduce adhesion, the inner surface of the molds should be greased. The mass of the sand is used to calculate the relative density.

A UCC mold was created just for this project. Sand with various cement concentrations is mixed with a certain percentage of distilled water to make samples. It should be emphasized that the sample used for UCC should have a height that is at least twice its diameter. In the UCC apparatus, the prepared samples were put on the fixed bottom plate. The deformation in the sample was measured using a dial indicator, and the top plate was turned to reveal the distortion.

- **Unconfined compressive strength for clay-cement soil**

The clay is dried before being used in the mixture. First, the required amount of cement in the optimum percentage of moisture is mixed and then added to the dry soil.

As the soil tends to clump together, it takes a great deal of time and care to achieve an even distribution of the mixture. All samples were then compacted to their respective maximum dry density in their optimum moisture content, corresponding to values obtained in improved machine compaction tests (ASTM D1557). Cylindrical samples were stored in a curing chamber at a temperature of 21-25 ° and then tested after 28 days of curing. To determine the unlimited compressive strength parameters of unstable and stable specimens, a series of unlimited compression tests at 1.2 mm / min was performed in accordance with ASTM D2166.

### 3.4 Discussion

**a) Soft clay**

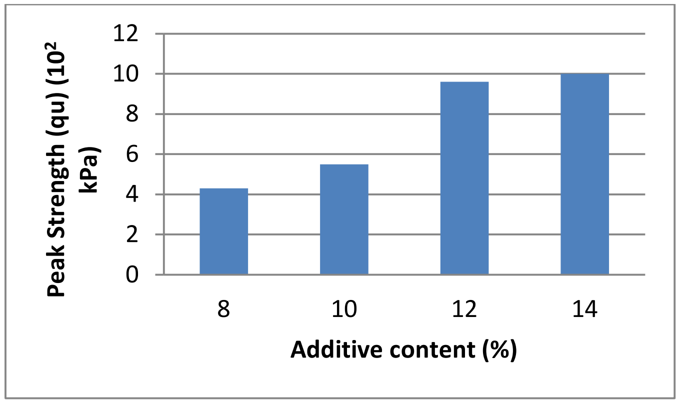


**Figure 5.** The unconfined test results of the stabilized of soft clay soil at 28 days as curing periods for cement as admixture

From figure 5 it's clear that the additive contents at the percentage of 8% the strength gained is 430 kPa while at the percentage of 10%, 12% the strength increased to 550 kPa, 960 kPa respectively at the curing time more than 28 days. So, from this result it's clear that at the additive content 10% and more the strength gained increased.

**b) Stiff clay**

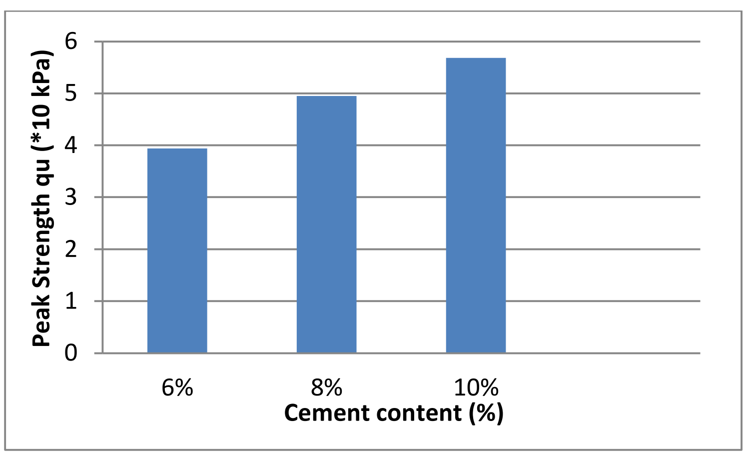


**Figure 6.** Unconfined Compression Test Results for Stiff Clay treated with different cement content at 28 days.

Figure 6 shows the stiff clay soil strength gained due to adding various cement by respecting the curing time of 28 days. Figure 6 reveals that with the increase of the additive content, the strength of the stabilized clay increase also. Using the cement content from 6 to 10 % improves the unconfined compression strength by 35.5%. Increasing the time to 28 days increases the strength and that means that curing time has a significant effect on the unconfined compression strength. As a result, the use of high cement content of 10% and curing time of 28 days lead to get high unconfined compression strength and make clay soil more stabilized.

**c) Soft lean clay**

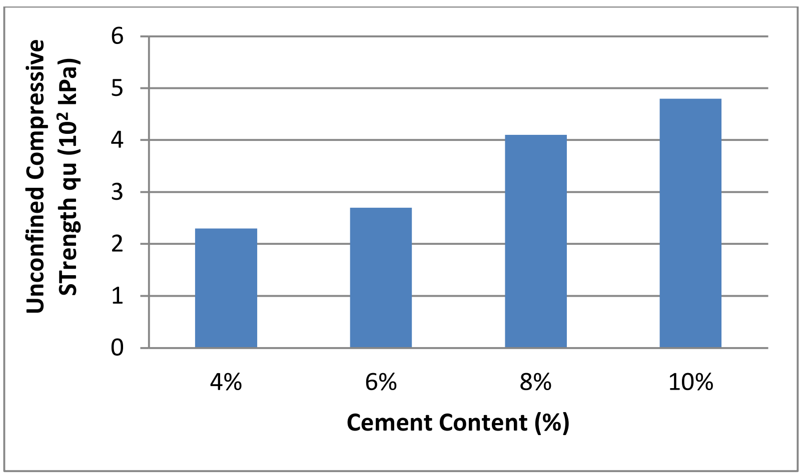


**Figure 7.** The unconfined compressive strength results for treated soil with cement contents (28 days of curing).

Figure 7 shows the strength gained after stabilizing the soft lean clay with different cement content. Soft lean clay has the Plasticity Index greater than 7 or plots above the "A" line with a relatively high content of silt or sand.

It’s clear from the graph above that even at the lowest value of cement content 6%, the increase in the strength is evident.

At the highest cement content used in this study of 10% the strength increased more, so that at 4% of cement content the strength is 230 kPa and at 10% the strength increased to 480 kPa.

**Clay Results**

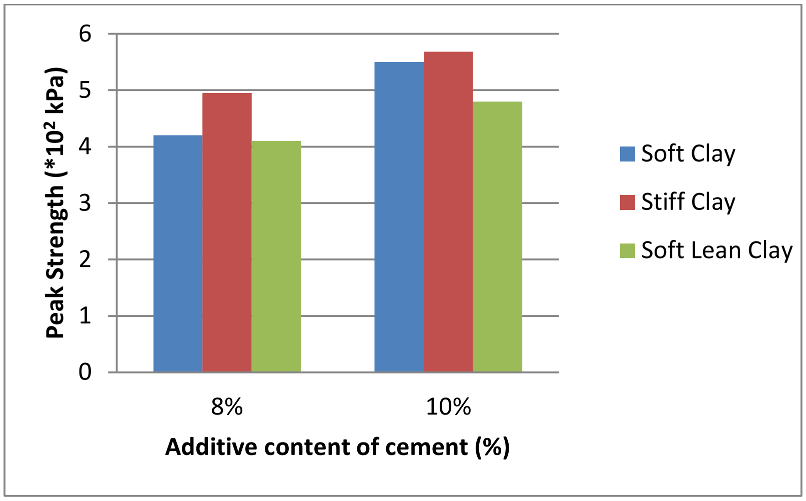


**Figure 8.** The peak strength values at different additive content at 28 days of curing time.

The graph above is the summary of the three different references mentioned above about the impact of adding cement to clay soil on the peak strength, there are different portion of cement: 8% and 10%, and at the same curing time of 28 days. For 8% of cement as admixture to clay soil by using mix design column, it's clear from the graph that the values are almost same with few difference, this is due to the specification of soil which is not totally same, and the conditions of mixing. The minimum value of peak strength for 8% of additive content is 410 kPa and the maximum value is 495 kPa. For 10% of cement as admixture to clay soil, it's clear that the values of three references for peak strength are higher than the peak strength for 8% of cement. With the increase of additive content the peak strength increased too. So, mixing cement with clay is very effective, and it's better to use additive content more than 10% to get high strength.

**d) Desert Sands**

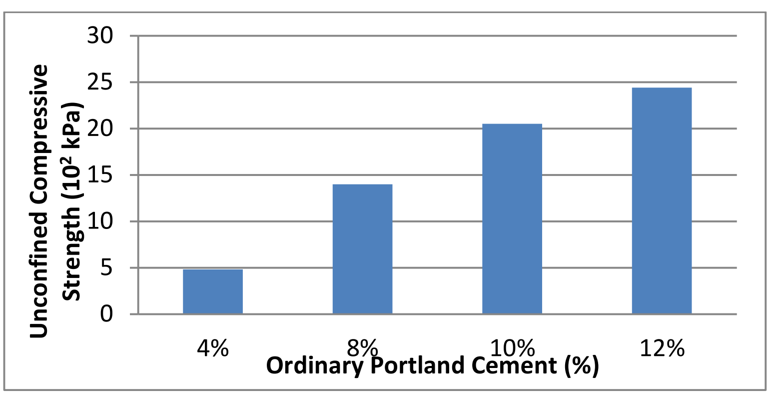


**Figure 9.** Unconfined compressive strength (sand– Ordinary Portland cement (OPC) mixture) in 28 days.

In general, the graph demonstrates that the unconfined compressive strength increases dramatically as the amount of regular Portland cement increases. At the percentage of 4% of ordinary Portland cement the strength of soil was 480 kPa while at 8%, 10% and 12% the strength is 1400, 2050 and 2440 Kpa and, so that means that the engineering properties of sandy soil are improved when using high ordinary Portland cement as stabilizer.

The increase of strength is more important when the cement content is more than 8% at the curing time of 28 days.

**e) Sandy soil**

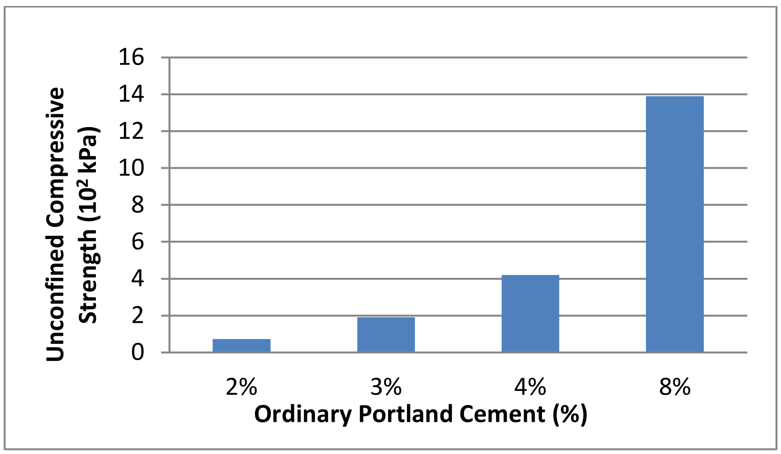


**Figure 10.** Unconfined Compressive Strength test on cemented sand cured at 28 days

The figure shows the value of strength gained with different percentage of Ordinary Portland Cement added to sandy soil. The Unconfined Compressive Test rose with rise in percentage of cement at the curing time of 28 days.

The specimens prepared with sand and 2and 3 % cement shows a least increase in the strength while at 4 and 8% the increase of strength is evident, at 8% the results gotten from the test showed 1390kpa of strength gained, but sometimes getting high strength can deal to failure, because the samples have hardened from their original ductile state, they likely to fail brittle.

### f) Waste sand

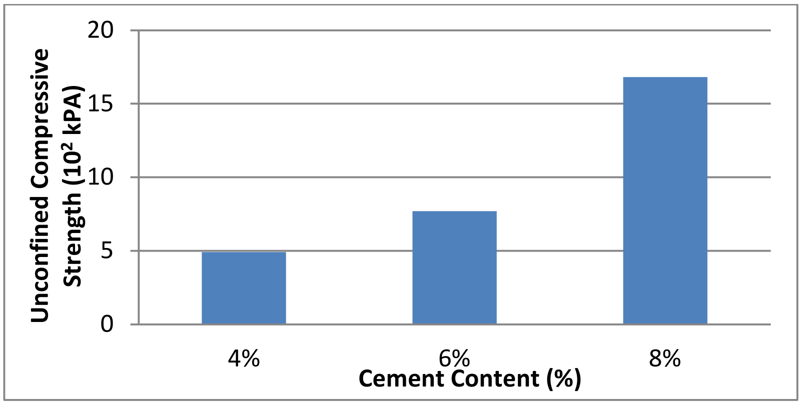


**Figure 11.** Unconfined compressive strength of the treated waste sand as a function of cement content for 28 days as curing times.

Figure 11 shows the results of unconfined compressive test when using different cement content: At 4% of cement content the strength is 490 KPa while at 8% the strength gained is 1680 KPa, and that because the engineering properties of sandy soil improved when using high cement content.

Using curing time of 28 days leads to the increase in the cement reaction with water (hydration) and as result, the strength increased.

**Sand results**

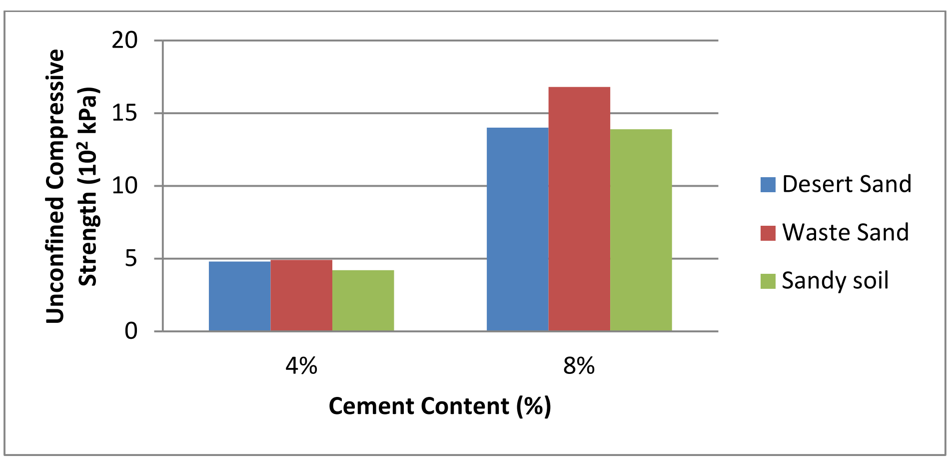


**Figure 12.** Comparision between the results of UCC for different cement content at 28 days for sandy soil**.**

From the previous studies it's found that the best curing time is 28 days where the strength is at the ideal values. From figure.12 it's clear that the strength of the soil is gained when the cement content increased, for 4% as cement content to dry soil the strength is nearly 500 kPa while for 8% as cement content, the results of unconfined strength test is almost 1500kPa, from these results is clear that as the cement content increased the strength of soil increased, and that means that cement as admixture produced by deep mixing is a good additive to sandy soil to improve it increase its strength. This conclusion is based only on the results of strength at 4% and 8% for cement content, but to make it clearer, the results of sandy soil can be used, where it was adding the minimum percentage of cement of 2% so that the strength gained is only 72 kPa. So, that means when adding less cement or without it the strength gained is very small and to improve it should use cement with high proportions.

## 4. CONCLUSION

In this study, two types of soil were examined, clay and sandy soil. Through different studies about the effectiveness of soil deep mixing method and soil stabilization as a ground improvement by using cement as admixture, all studies were analyzed at the curing time of 28 days and the results from Unconfined compressive strength. it was found that from the results of unconfined test for clay soil, to examine the strength that using cement content in the range of 8% and 10% or more is more efficient to get high strength, from the unconfined compressive test results were clear that at the curing time of 28 days the strength of the soil used increased with the increase of cement content. For sandy soil, it's used cement content of 4% and 8%, it was found that using cement content more that 4% gain to high strength so that the soil becomes more ductile and improved to use in any project. From these results, it's clear that deep soil mixing is more efficient with sand, because adding the proportion of 4% or 8% is enough to improve the soil in addition to that the strength gained on sandy soil is higher than the strength gained on clay soil, also to improve clay soil it was need to add more than 8% or 10% to be improved, and this refers to some factors such as the physical characteristics of sand and clay soil.

## REFERENCES


Ahmed Farouk, Marawan M. Shahien. (2013). Ground improvement using soil–cement columns. Experimental investigation. Alexandria Engineering Journal.

Al Aghbari, Mohammed & Mohamedzein, Yahia & Taha, Ramzi. (2009). Stabilization of desert sands using Portland cement and cement-by-pass dust. Ground Improvement.

Caraşca, O. (2016). Soil Improvement by Mixing: Techniques and Performances. Energy Procedia.

Kitazume, M., & Terashi, M. (2013). The deep mixing method. Leiden: CRC Press.

M A Mansour et al. (2015). Engineering properties of cement/lime-stabilized Egyptian soft clay. IOP Conf. Ser.: Earth Environ.

Mohamed Mamdouh Zakaria, Kamal Mohamed Hafez, Walid Hamdy El Kamash, Azza Hassan Moubarak. (2020). Stabilization of Soft Clay Soil by Deep Mixing. Life Sci J.

Mohamed Sakr, Ashraf Nazir, Waseim Azzam, & Farag A. Aamer. (2019). Model study of deep soil mixing in loose sand.

Pakbaz, Mohammad & Alipour, Rasoul. (2012). Influence of cement addition on the geotechnical properties of an Iranian clay. Applied Clay Science.

Raja, K., Elakkya, E., Manikandan, A.~T., Surya, B., Nekila, M. (2020) Strength characteristics developed in cement stabilized soil. Materials Science and Engineering Conference Series.

Shalabi, Faisal I et al. (019). Cement-Stabilized Waste Sand as Sustainable Construction Materials for Foundations and Highway Roads. Materials (Basel, Switzerland)