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# Effects of cement and lime addition to soft clays on their strength in saturated condition of Mahshahr Port

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**Abstract**
The surface sediments in Mahshahr Port area are mainly consist of soft clayey soils. These soils have considerable strength in dray condition but as their moisture content moves up to saturated level a notable decrease in their strength is observed. This reduction, in turn, leads to decrease of California Bearing Ratio (CBR) and increase in soil settlement which consequently results in vast and destructive deformation in the surrounding buildings. In this research, the addition of cement and lime to the soil is considered to evaluate their effect of the soil strength by performing unconfined compressive (UCS) and Atterberg Limits tests. In this procedure, different ratios of lime and cement mixture (0.0 %, 2 %, 4 %, 6 %, 8 %, 10 %, and 15 %) with various curing times is considered. The results of these tests revealed that compressive strength of soft clay decreases by adding lime or cement due to disturbing its initial structure. This decrease of strength is induced by high sensitivity of the soil, however as the time passes compressive strength of the cement-added samples rapidly grows; as compressive strength in modified samples with 6 % cement and curing time of above 3 days has increased compared to undisturbed samples and their plasticity index has decreased. On the other hand, compressive strength of samples modified by lime gradually increased, as adding 6 % lime to the soil and applying curing time of 28 days did not lead to increase of their compressive strength compared to undisturbed soil samples and their plasticity index decreased.

**Key words:** soft clayey soil; cement; lime; unconfined compressive test (UCS); Atterberg limits.

## 1. Introduction

Prior to the development of soil stabilization, the only option for dealing with weak soils was to remove them from the construction site. Economic and environmental considerations mean that this is no longer acceptable and all materials often has to stay on site. The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures. With proper design and construction techniques, lime treatment chemically transforms unstable soils into usable materials. Treatment of fine-grained soils by adding lime is commonly used method for increasing the soil strength since the ancient history of Egyptian, Persian and Roman civilization. By invention of cement in 1867, the cement was considered as an optional substance for this purpose. Many research were conducted in recent years regarding the subject of interest, including; Horpibulsuk et al. (2014), Lemaire et al. (2013), Lorenzo & Bergado (2004), Sudhakar & Shivananda (2005), Haghshenas & Oryani (2010), Vatsala et al. (2001), Feng et al. (2001) and Al-Amoudi et al. (1995).

Generally, the main objectives of soil treatment in construction projects include: enhancement the soil strength, decreasing the deformability parameters such as rate of settlement and soil compressibility, elimination the susceptibility to swelling and shrinkage, and improve durability to weathering and load application.

### 1.1. Cement-soil reactions

Natural soils are often weakly cemented and the presence of cementation bonds plays an important role in their response. The strength of cemented soil can be considered to be made of two components, the usual strength of particle skeleton and the strength of cementation bound. Artificially cemented soil particles produce a matrix material with higher strength. Artificial cementation usually is applied to fine-grain and sensitive soil, since the strength of coarse-grain soils is largely depended to their internal friction angel (Clough et al. 1981). By adding cement to soil, different reactions occur between cement and soil. Here, the most important short-term reaction is positive ions substation and concentration-compaction reaction. Within these two reactions soil strength enhances and its texture changes through particles concentration - change of its grain size distribution. The finer cement particles leads to more intense and lengthier (even for several years) hydration reactions; these phenomena lead to increase of cement mix by the time (Coduto 2003).

### 1.2. Lime reactions with soil

Adding lime to clayey soil causes several reactions such as:

1. Cation (short-term) exchange reactions:

Calcium ions (Ca2+) in the lime are substituted with positive ions with lower capacity in the soil. This reaction occurs rapidly as soon as soil contact with lime. Through this reaction calcium ions surround clay particles and lead to changes in concentration of electrons around clay particles. So, the attracting force among clay particles enhances, soli texture changes by coagulation, and soil behaves like sand grains, which shows improvement of soils plasticity properties. The cycle of cation exchange reaction is controlled by the number of exchangeable cations in the soil. Typically, after substation of all exchangeable ions the reactions are stopped or minimized.

2. Carbonation reaction:

This is an undesirable and damaging reaction for soil stabilization using the lime. Via this reaction calcium carbonate or magnesium carbonate is produced according to the following steps:

$$H_2O + CO_2 \longrightarrow H_2CO_3$$

$$Ca(OH)_2 + H_2CO_3 \longrightarrow CaCO_3 + 2H_2O$$

This reaction caused reduction in the number of free ions in the soil-lime mix for cation exchange reaction and pozzolanic reactions. In addition, carbonation leads to reduction of pH in the reaction environment and its inclining to acidic environment, which in turn has an important role in cation exchange, change of soil texture, and soil coagulation. Caco3 and MgCo3 produced by this reaction are weakly adhesive substances which lead to the reduction in strength and durability of the soil stabilized by lime.

3. Pozzolan reactions:

This is a rather slow reactions which strongly controlled by time, temperature, and moisture. This reaction occurs between water, lime, silicon and alumina bearing materials, and ferric oxide existing in the soil and produces stable elements such as calcium silicate and calcium aluminate. These are similar to the components produced in Portland cement hydration which enhance strength and durability – this is why the strength of soils stabilized by the lime is gradually being increased. These processes in soil and lime can be shown as following reactions (Zanganeh & Ghazifard 2010):

$$Ca\,(OH)_2 \longrightarrow Ca^{2+} + 2(OH)$$

$$Ca^{2+} + 2(OH)^- + SiO_2 \longrightarrow CaO,SiO_2 + H_2O$$

$$Ca^{2+} + 2(OH)^- + H_2\,CO_3 \longrightarrow CaO,AL_2O_3 + H_2O$$

Here, the important point about adding cement or lime to soil is determination of their optimum added amount for its treatment.

## 2. Literature review

Adding chemical components for soil stabilization and treatment is among the techniques vastly used in operational projects. In 1917, for the first time Amise registered soil-cement mix as invention in the Unites States, Philadelphia. Then, in 1922 Highway Department of South Dakota and Iowa and after that in 1932 Roads Department of South Carolinaapplied this mix in treatment and stabilization of the roads and highway construction (Baxter et al. 2005). In a study (1992) conducted on Khuzestan Plain soils in by Agricultural Researches Center, adding 2 % of dry weight from anti-sulphate cement is recommended for soil treatment (Rahimi & Bazzaz 1992). Also Rahimi performed another study in a soil sample from Karaj region to investigate the effect of adding cement to the soil. According to unified system classification (USC), the mentioned soil was categorized into CL-ML group. The samples prepared in curing days 7 and 28 were evaluated through unconfined compressive strength test and the obtained results showed that adding 3 % of cement to the samples significantly increases their strength. In their research, it was tried to offer the optimum value of cement to add to the soil, regarding economic issues (Rahimi & Fakoor 1992). The addition of 3% cement to treat lime soils was suggested by Guthrie et al. (2002). Stabilizing unstable moister soils by a quantity of 3 to 5 percent was recommended by Syed et al. (2007). The use of

4 to 6 percent of cement or 5 to 7 percent of lime for treatment of all type of soils is suggested by the office of geotechnical engineers, Indianapolis (Design procedures for modification or stabilization 2013). In one of the oldest researches in Iran (1989) the effect of adding lime for soil stabilization in Gotvand irrigation project was investigated. Through the studies performed in this project it was found that adding 3 % of lime converts dispersive soil to a non-dispersive stable soil (Jedari Salehzadeh 2001). Moreover, Mohamadzadeh (2007) reported the amount of lime for stabilization of the soils around Khoramshahr region as 20 %. Although performance in this operational project was considerable, in huge projects it is not economically advisable (Mohamadzadeh 2007). In 2008, Tabatabai & Araei reported that adding 6 % of quicklime (in the case of considering safety issues) will be favorable for improvement of shear parameters of Ardabil Province soils (Tabatabaei & Araei 2008). Heydari et al. (2008) investigated the effect of adding lime to salty soils of Tealeghan region through two methods (plasticity limit and pH measurement) and suggested that adding 6 % of lime is the optimum value obtained by both of these methods (Heydari et al. 2008). Also, Zanganeh (2009) performed a study through which he reported that adding 6 % of lime to the soil, considering technical and economic standards, is the optimum value for fine-grain clayey soils (Zanganeh & Ghazifard 2010). In addition, there have been performed some advanced researches in other countries to investigate the effect of adding lime to improve different soils properties. Little (1995) suggest adding 4 % to 8 % lime to the soil to improve soils with pH of 12 (Little 1995). Furthermore, in one of newest researches conducted by Al-Rawas et al. (2005) it was reported that adding 6 % lime to the soil remarkably increases its plasticity and strength properties (Al-Rawas et al. 2005). Finally, Lin et al. (2007) performed an advanced study and through which they reported that adding 5 % and 7 % of lime, respectively, improves geotechnical properties of non-plastic and plastic soils (Lin et al. 2007).

## 3. Materials

### 3.1. Investigation of studied soil and geographical profile of the region

Mahshahr Town, with are of 7304 km$^2$and altitude of this region is 3 m form free sea level, is located in southeast of Khuzestan Province in the vicinity of Khur Musa. This region is limited by Ahvaz and Ramhormoz in the north, Behbahan in the east, Khoramshahr in the west, and Persian Gulf in the south. The geographical coordinates of the region is as: 48° 54E to 50° 12E and 30° 13N to 30° 84N. The best way for accessing to the project location is Ahvaz-Abadan-Mahshahr asphalt road. Figure 1 shows generalposition of the region. The surface sediments of Mahshahr Port area are mainly composed of clay. These soils have considerable strength in dry state but they noticeably lose their strength by increase of their moisture content, particularly in saturated state. This loss of strength, in turn, leads to decrease of baring capacity and increase of compaction settlements in the soil, which will be ultimately followed bybroad and destructive deformations in constructed structures.

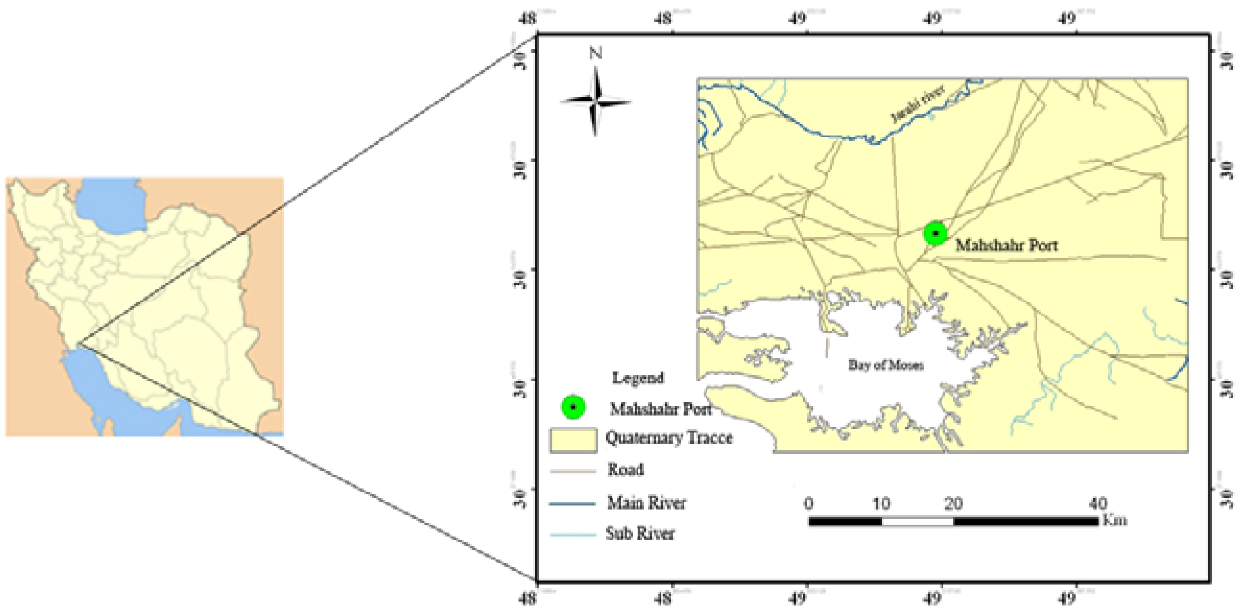


**Fig. 1 Geological map of Mahshahr Town and its position (soil sampling area) on the map**

Regarding high levels of groundwater table (1.5 m from ground surface) in this area and soft clays condition, instability of these soils was clearly observed in the walls and bed of designed trenches for various construction projects in and around the town. In addition, several uneven settlements were observed in structures beds and streets surfaces in the city. Figure 2 well present the importance of soil treatment and stabilization in the studied area before constructing different structures. Besides, Table 1 and Figure 3 indicate properties of studied soil.


**Fig. 2 ground instability in the studied area**

**Table 1 The properties of studied soil**

| Gs | PI | PL | LL | PH | Soil Classification (Unified) |
|---|---|---|---|---|---|
| 2.75 | 13 | 22 | 35 | 7.56 | CL |

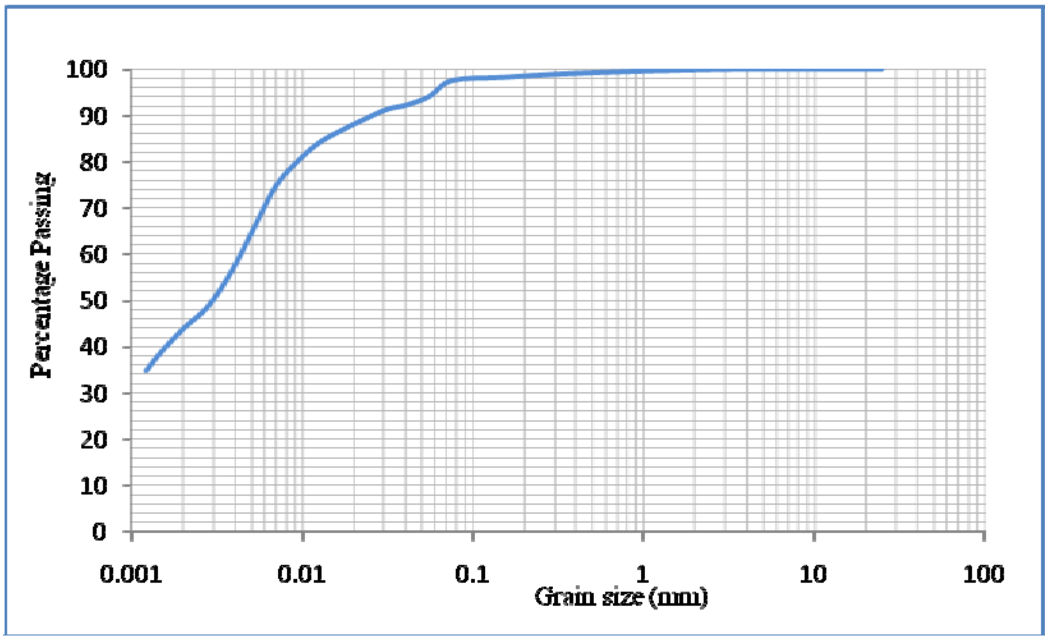


**Fig. 3 Grain size distribution graph**

### 3.2. Mineralogical properties of the soil (XRD and XRF)

In order to detect the material of taken samples, in this research XRD analysis was also utilized. The graph obtained by XRD analysis of clay soil sample taken from Mahshahr region is presented in Figure 4. Figure 4 shows that peak points are mainly for calcite and in this aspect quartz is in the second place. The other minerals, by the order of their frequency, are Clinochlore, dolomite, gypsum, Muscovite, and montmorillonite, respectively. Also, to determine chemical composition of the oxides in the samples X-ray Fluorescence (XRF) was applied. The results of this test are shown in table 2. Based on ASTM C150 standard the SO3 content of the environment must be to maximum value of 3 %, to be ensured of lack sulfate ions invasion in the case of cement injection. Based on the results of table 2, the SO3 content of samples is allowable.

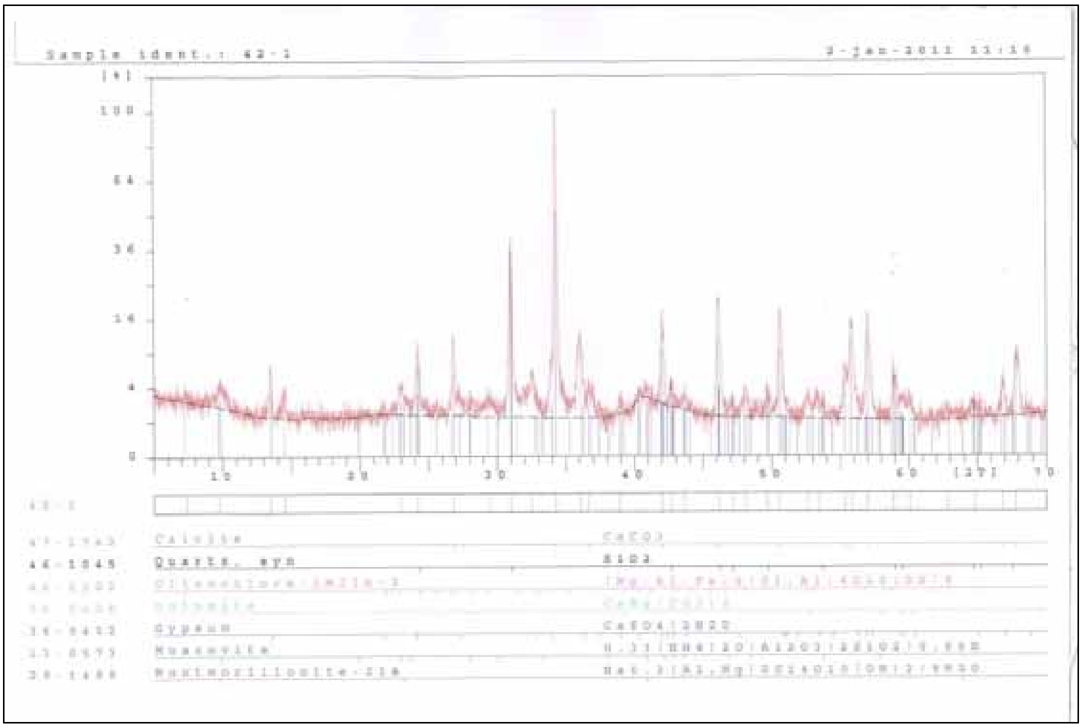

**Fig. 4 Characteristic XRD graph of clayey soil (depth of 2.5 m from the trench B)**

**Table 2 The results of XRF tests**

Clayey soil

| Components | % |
|---|---|
| L.O.I | 29 |
| $Na_2O$ | 0.846 |
| MgO | 4.278 |
| $Al_2O_3$ | 6.109 |
| $SiO_2$ | 26.109 |
| $P_2O_5$ | 0.096 |
| CL | 0.359 |
| $K_2O$ | 0.958 |
| CaO | 27.546 |
| $TiO_2$ | 0.321 |
| $Fe_2O_3$ | 2.878 |
| Sr | 0.128 |

### 3.3. Properties of consumed cement

The cement consumed in this research was cement type 2 of Tehran. This cement is known as modified Portland cement and compared to cement type 1 have higher sulfate resistance, produceshydration heat, and is hardened with lower rate.

### 3.4. Properties of consumed lime

Also quicklime, owing to its higher content of CaO, has stronger effect on treatment and stabilization of the soil compared with hydrated lime or slaked limeit is more commonly used in the industries since it is easier to work with it. In term of chemical interactions there is no difference between these two types of lime. The lime used in this study was slaked lime.

### 3.5. Properties of consumed water

The water used in this study was potable water without any harmful materials such as acids and organic components with the following properties:
PH = 7.76, CL = 1.7 meq/l, Ca-Mg = 9.4meq/l

## 4. Study method

In this research, evaluation of the effect of adding cement and lime on improvement of shear parameters of soft clayey soils of Mahshahr region in saturated condition was conducted through a laboratory study and the effects of these added materials were analyzed through compressive

strength and Atterberg limits tests. To do so, first Atterberg limits tests and unconfined compressive tests were carried out on undisturbed soils. Then, clayey soil waschanged into suspension state by adding moisture
content larger than liquidity limit. In the next step, 12 samples were made with this clayey soil by adding different weight ratios (2 %, 4 %, 6 %, 8 %, 10 %, and 15 %) of cement (6 samples) and lime (6 samples). Once the samples were prepared, they were again subjected to Atterberg limits and UCS test with curing times of 3, 7, 14, 28, 60, and 120 days. For making the samples more homogenous and achieving better results, in this study the lime and cement passed from sieve 40 were applied and the materials were mixed for 10 minutes. In addition, the samples were saturated to simulate test conditions with the real conditions of the region – where water table is placed in high level.

## 5. Discussion

### 5.1 Atterberg limits test

In this work, Atterberg limits determination was carried out according to the ASTM standards (ASTM, D4318). This test was performed on natural undisturbed soil as well as 12 clayey soil samples mixed with cement and lime. The results of this test (determination of plasticity index) are shown in tables 3 and 4.

**Table 3 The results of Atterberg limits tests on the samples treated by cement**

| PI | | | | | | - |
|---|---|---|---|---|---|---|
| 120 days | 60 days | 28 days | 14 days | 7 days | 3 days | Time / Percentage of added cement |
| 13 | 13 | 13 | 13 | 13 | 13 | 0 |
| - | - | - | 9 | 11 | 11 | 2 |
| - | - | - | 5 | 8 | 9 | 4 |
| - | - | - | - | 4 | 6 | 6 |
| - | - | - | - | - | - | 8 |
| - | - | - | - | - | - | 10 |
| - | - | - | - | - | - | 15 |

**Table 4. The results of Atterberg limits tests on the samples treated by lime**

| PI | | | | | | - |
|---|---|---|---|---|---|---|
| 120 days | 60 days | 28 days | 14 days | 7 days | 3 days | Time / Percentage of added lime |
| 13 | 13 | 13 | 13 | 13 | 13 | 0 |
| - | 8 | 10 | 11 | 12 | 12 | 2 |
| - | 7 | 8 | 10 | 11 | 12 | 4 |
| - | 3 | 5 | 8 | 9 | 12 | 6 |
| - | 8 | 8 | 10 | 12 | 13 | 8 |
| - | 8 | 10 | 11 | 12 | 13 | 10 |
| - | 9 | 10 | 12 | 13 | 13 | 15 |

The results of Atterberg limits tests showed that adding cement to the samples increases their liquidity and plasticity limits and decreases their plasticity index. This trend is considerable up to 6 %. It must be added that in the samples with cement ratios of higher than 6 % determination of Atterberg limits were not possible because of samples hardening. For the samples treated with lime the results are rather different. As shown in table 4, also adding lime to the soil samples enhances liquidity and plasticity limits of the samples and decrease their plasticity index. But this descending trend of plasticity index is notable up to 6 % and after that the changes of plasticity index is somehow slight.

### 5.2. UCS test

In this research UCS test was carried out on undisturbed clayey soil and 12 clayey soil samples mixed with cement and lime - according to the ASTM standards (ASTM D2166). The results of these tests are presented in tables 5 and 6. The results of this study showed that compressive strength of soft clayey soils decreases by adding cement or lime due to collapse of its initial structure. This decrease of strength is due to high sensitivity of these soils and by the pass of time their compressive strength rapidly increases, e.g. compressive strength of samples treated with 6 % of cement after 3 days increased in contrast to its undisturbed state. On the other hand, compressive strength of samples treated with lime was increasing in a more gradual process, i.e. after even 28 days the strength of samples treated with (6 %) lime was not higher than that of undisturbed soil. However, after 60 days this parameter has noticeably increased in all samples, implying that the effect of lime on improvement of geotechnical properties of clayey soils in saturated state is strongly controlled by time.

According to the predictions, in all time values the amount of compressive strength increase from 2 % to 15 % cement ratio; however this increase is more considerable in 6 % of cement compared with 2 % and 4 %. According to the results in samples with 8 % of cement, strength increases in a more gradual fashion. Here, it must be noticed that despite considerable increase in the strength of samples modified with 10 % and 15 % of cement, in construction, beside technical and scientific justification of the treatment project, its economic issues are also important. Thus, adding this deal of cement to soils in treatment projects is not recommended.

**Table 5 The results of UCS tests on the samples treated with cement**

| Unconfined Compressive Strength (kPa) | | | | | | - |
|---|---|---|---|---|---|---|
| 120 days | 60 days | 28 days | 14 days | 7 days | 3 days | Time / Percentage of added cement |
| 60 | 60 | 60 | 60 | 60 | 60 | (Undisturbed) 0% |
| 0 | 0 | 0 | 0 | 0 | 0 | (Disturbed) 0% |
| 104 | 98 | 89 | 55 | 38 | 21 | 2 |
| 197 | 180 | 168 | 74 | 66 | 45 | 4 |
| 294 | 278 | 265 | 207 | 134 | 74 | 6 |
| 326 | 312 | 303 | 259 | 183 | 118 | 8 |
| 500 | 477 | 456 | 362 | 245 | 167 | 10 |
| 639 | 615 | 596 | 542 | 433 | 205 | 15 |

**Table 6 The results of UCS tests on the samples treated with lime**

| Unconfined Compressive Strength (kPa) | | | | | | - |
|---|---|---|---|---|---|---|
| 120 days | 60 days | 28 days | 14 days | 7 days | 3 days | Time / Percentage of added cement |
| 60 | 60 | 60 | 60 | 60 | 60 | (Undisturbed) 0% |
| 0 | 0 | 0 | 0 | 0 | 0 | (Disturbed) 0% |
| 85 | 74 | 38 | 19 | 6 | 4 | 2 |
| 110 | 96 | 52 | 23 | 8 | 5 | 4 |
| 160 | 142 | 75 | 30 | 14 | 8 | 6 |
| 105 | 93 | 50 | 22 | 7 | 4 | 8 |
| 80 | 74 | 41 | 20 | 6 | 4 | 10 |
| 65 | 59 | 37 | 19 | 5 | 4 | 15 |

In the samples cured by lime, it is worth to mention that the trend of changes in compressive strength is different from that of cement. In all time values, the amount of compressive strength has increased in 2 % to 6 % of lime but increase of strength in the lime content of 6 % was surprisingly higher than the samples modified with 2 % and 4 % or lime. It is must be noted that in the samples with lime contents of higher than 6 % enhance of compressive strength is less than those with 6 % lime; as compressive strength has increased from ratios of 6 % to 15 %. Figures 5, 6, 7 and 8 well present these changes.

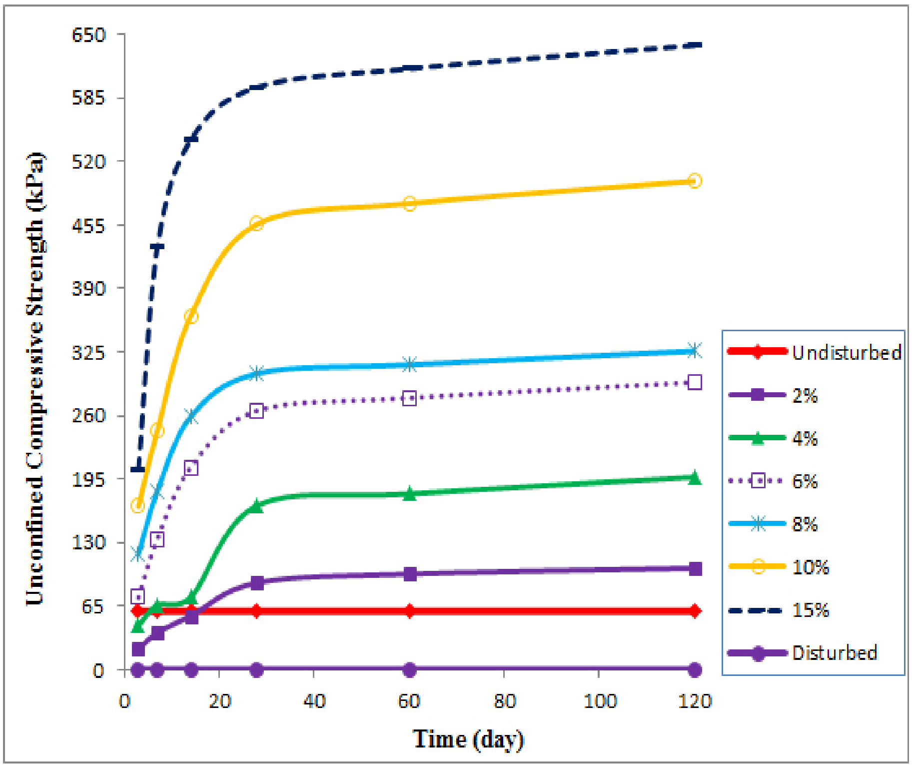


**Figure 5 Changes of compressive strength of the soil sample with different ratios of cement to the time**

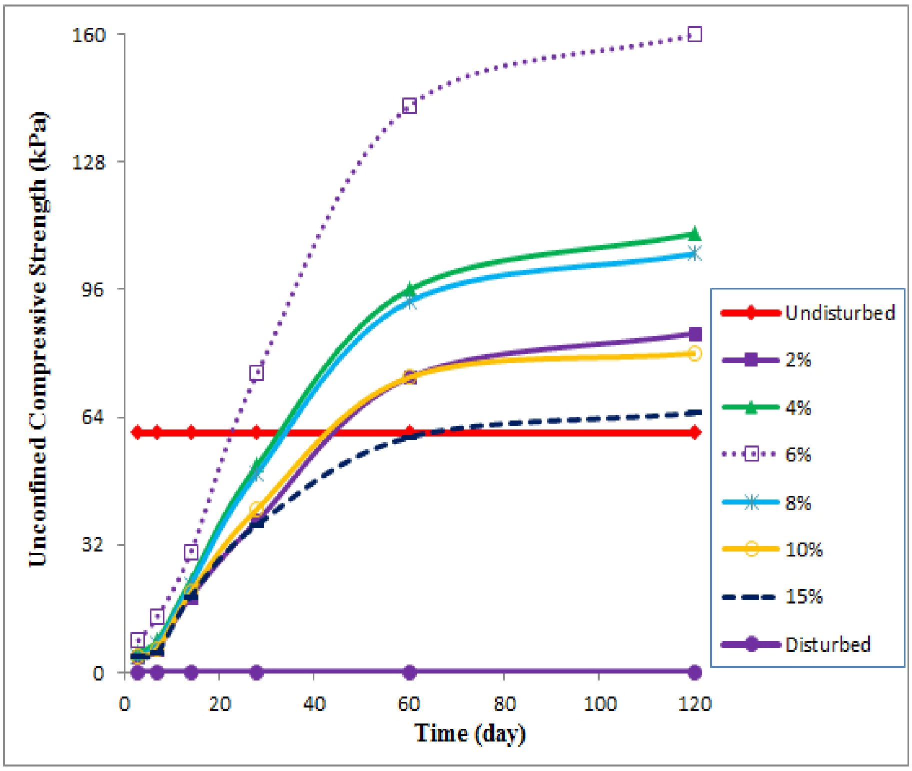


**Figure 6 Changes of compressive strength of the soil sample with different ratios of lime to the time**

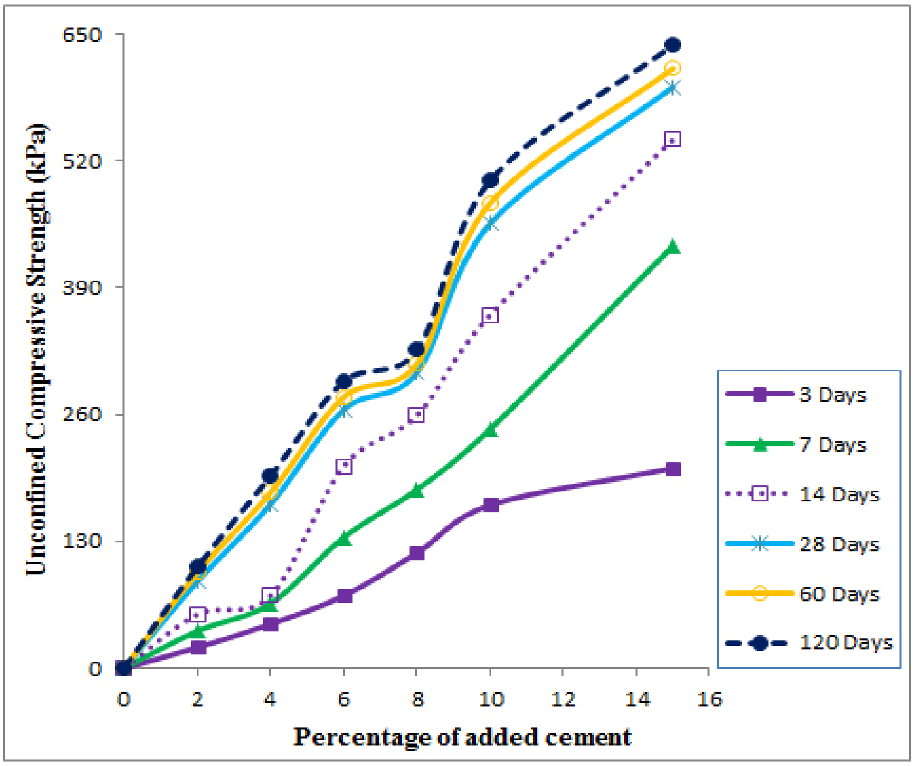


**Fig. 7 Changes of compressive strength of the soil sample in different times to the cement ratio**

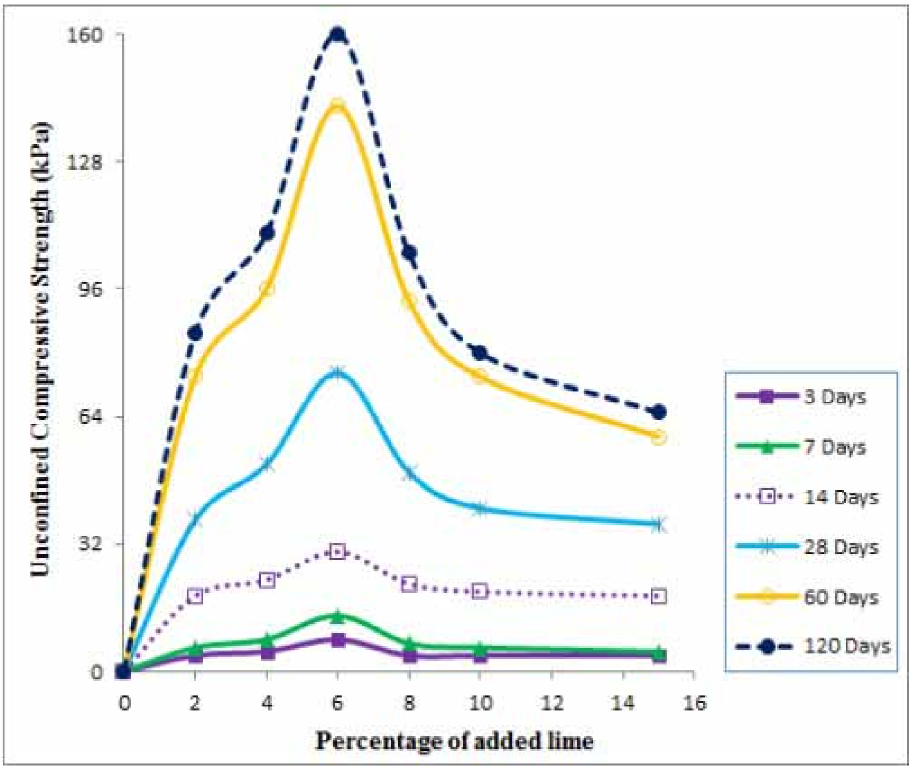


**Fig. 8 Changes of compressive strength of the soil sample in different times to the lime ratio**

## 6. Conclusion

Remembering the fact that this investigation was conducted in saturation and suspension conditions (for simulating laboratory conditions with the real conditions), the results obtained by this research are as follows:

1. Due to collapse of initial structures, the strength characteristics of soft clayey soils of Mahshahr port are strongly reducing by adding cement and lime.
2. Treatment of fine grained clayey soils with cement and lime leads toincrease of their liquidity and plasticity limits and constant decrease of their plasticity index with time.
3. By adding lime and cement to the soil, its particles are concentrated and its texture – or in other words its grain distribution – changes. Due to this granular behavior of clay particles, plasticity index of the soil decreases and as a result its strength enhances.
4. In all times, the value of compressive strength have increased from cement ratios of 2 % to 15 %, but this increase in ratio of 6 % is more outstanding compared with ratios of 2 % and 4 %. On the other hand, in the samples with 8 %, 10 %, and 15 % of cement, the compressive strength increases gradually and with lower rates.
5. In all times, the amount of compressive strength for treated soils increase from lime ratios of 2 % to 6 % but strength enhancement with lime ratio of 6 % is highly notable compared with ratios of 2 % and 6 %. After ratio of 6 %, the trend of increase in the strength has descending rate. Hence, it can be claimed that adding lime to the soil can enhance soil strength up to a particular ratio, i.e. until silicate ions are present in the soil, and after that adding lime to the soil decreases its compressive strength.
6. The compressive strength of soils treated by cements and lime increases as curing time increases. In the samples cured by cement, strength increase in the first days occurs with higher rates and as the time passes this trend is decreased. On the contrary, for soil samples treated by lime strength values gradually increase.

Based on findings of this study, jet injection of 5 to 6 weight percentage of lime or 4 to 6 weight percentage of cement to the studied soil can created the needed strength. Besides, the time needed for stabilization of the soil by cement is fairly lower than that of lime.

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