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Effect of Polypropylene Fibers, Lime and Ceramic Additives on the Compressibility of Silty-Clay Soil

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ABSTRACT : *Soil stabilization is widely used by geotechnical engineers in the world to increase soil strength, soil compressibility and reduce the permeability. The main aim of this paper is to investigate the effect of adding different materials to the silty clayey soil (i.e. polypropylene fibers, lime and ceramic) and to figure out how the compressibility behave under mixture soil and these stabilized material at different percent (investigation their effect on the value of settlement). Silty clay soil it is used in this research in the geotechnical laboratories of the University of Wasit and the samples of soil are subjected to two main stress level using one-dimensional compression apparatus (i.e. 40KP and 80 KPa) for both untreated and treated (stabilized) soil with additives. A total of 48 hours of loading time is used and conventional reading rate for one-dimensional compression test is followed. Two main percentages (i.e. 1.5% and 3.5%) from the total weight of soil specimens and they had been mixed with soil for 30 min using electrical mixer to attain a uniform soil-material mixture prior to consolidation cell preparation and loading procedure. The results of the experimental tests show that the compressibility of the treated soil specimens were decrease when the soil stabilized with these material and minimum compressibility was obtained when the polypropylene fibers at 1.5 % percentages is used at the higher stress level and 3.5% of lime-stabilized at low stress level.*

Keywords: *Compressibility, one-dimensional compression test, Polypropylene fiber, Ceramic, lime*

I. INTRODUCTION

The Soil Stabilization is the treatment of natural soil to improve its engineering properties and increase the shear strength and reduce the permeability. Soil stabilization can be divided into two categories (i.e. mechanical and chemical stabilization). The Mechanical stabilization is conducted by blending of different grads of soil to obtain required grads and compact the soil by using compaction machine (i.e. mechanical and electrical compactors). This method is widely used in construction of earth dams and road embankment and depends on the changing of physical properties of present soil by increasing the density of soil mechanically and making the soil particles closer by re-arranging them and minimize decrease the void ration and obviously the volume of air and stay the volume of water is constant.

The chemically stabilization (i.e. using additives) is the blending of the natural soil with chemical agent. Several blending agents can be used to obtain new soil characteristics and this strongly influence on the different physical and mechanical properties of soil. This method used when the mechanically methods is insufficient or replacement of undesirable soil by good soil is unable or expensive. More of chemical stabilization is commonly used in the engineering projects to improve soil characteristics (i.e. salt resistant cement, lime, flyash and asphalt emulsion). Many researchers have been conducted on a different soil and stabilized by different stabilizer. Attom and (1997) [1], carry out the experiment on a sandy soil to improve its properties and problems associated with weak soil by adding fiber of polypropylene. They used as an additive for stabilization of clay against swelling but they selected a sandy soil from around American University at Sharjah. They obtain increase in angle of internal friction also in different percentage and this percentage increase with increasing of normal stress and the ductility of sand soil increase by adding fiber. The increase in aspect ratio resulted increasing in both of shear strength and angle of internal frictional. The sandy soil showed no peak strength at the four percentage of fiber.

Lee et.al., (1973) [2] used randomly oriented fibers to maintain strength isotropy and the lack of potential weak planes was the main aim of their study and that may develop parallel to oriented reinforcement. Ziegler (1998) [3], studied the effect of short polymeric fibers on crack behavior of clay subjected to drying and wetting condition. He observed that the addition of fibers to clay soil is very effective in reducing the amount of desiccation cracking and increasing the tensile strength.

Esna-ashari and Asadi (2008) [4], used cord waste fiber to reinforce the sandy soil. They found that the inclusion of tire cord fiber can change significantly the brittle behavior of sandy soil to more ductile and also increased both the peak strength and angle of internal friction of sand. Rafalko et. al(2007) [5], used fibers of polypropylene as primary stabilizer increasing the dosage rate of fibers continued to increase the strength a of the soil, but the maximum dosage rate was limited to 1 % of the dry weight. When longer fibers used as primary stabilizers, they may have increase the strength more than shorter fibers because the soil was ductile and bulged at high strain before failure. Although adding fibers as a primary stabilizer to soft clay may have resulted in strength increases, the magnitude of the increase may not be enough for airfield.

Abdull_kareem(1978) [6], was conducted a studying on soil that treated with lime at different temperatures ,he takes two types of soil (CL_ML) from different position (Tikrit & Baghdad) and treated them with different ratio of hydrated lime at different temperatures (20,30,40,50)C then the results show that the strength of soil increased with increasing of curing temperature and curing time ,and the optimum dry density decreased also he concluded that the decreasing in strength at leaching reduce by increasing the curing time or by increasing curing temperature ,the compression strength of soil increased to the ideal limit of lime, and then starts to reduce. Also he concluded that the soil of Baghdad doesn't show any effect at ideal limit of lime at different curing temperature when the soil of Tikrit shows that.

Geinman (2005) [7], studied soft clay soil in different situation at USA (Staunton, Lynchburg) and use additives like (cement, lime, proprietary cement stabilizer) and liquid additives stabilizer like (MgCL, polymers) and he concluded that the strength increase by adding (cement, lime) more than when the liquid additives stabilizer was added. He observed also that the proprietary cement stabilizer is more effective for soil in increasing the strength rather than lime at low dosage ratio, and also he noticed that the strength is approximately equals for soil treated with proprietary cement stabilizer and soil treated with ordinary cement.

Cai and Shi (2006) [8], reported that there is a significant improvement on the engineering properties of the fibers – lime treated soil.Kumar (2003), studies of ceramic to improve the mechanical soil properties and they concluded the test of CBR goes on increasing with increase the percentage of addition of ceramic. There is 150% increase in CBR value as compared to untreated soil when 30% ceramic is added. The cohesion value goes to decrease and angle of friction goes on increasing as increase in percentage of addition of ceramic. The swelling pressure goes on decreasing with addition of ceramic. There is 81.5% decrease in swelling pressure of soil as compared to untreated soil, when 30% ceramic is added.

Al- Numani (2010) [9], add ceramic with percent varied from 4 to 12 % by weight and the result show that the maximum dry density of treated soil increase with ceramic content up to 8% after which the density decrease; after this added mixing of cement and ceramic with percent 8 to 12 % for cement and 4 to 8% for ceramic and the result showed that the maximum dry density increase with increase of mixing content , while the opposite is true for the optimum water content .

Due to increasing of the cost and high quality materials are needed for different geotechnical projects engineers to improve the physical properties of local soil throughout different methods and techniques. The choice and effectiveness of an additive depends on the type of soil and its field condition. Nevertheless, knowledge of mechanistic behavior of treated soil is equally important as the selecting the stabilizer.

II. THE USED STABILIZER IN THE STUDY

2.1 Polypropylene fibers

The polypropylene fibers are common material used for fiber reinforcement of soils and these fibers are found in the market as short, discrete materials with different aspect ratio and they can be mixed randomly with soil. It is manufactured in two forms: Monofilament and Fibrillated. Monofilament fibers are individual, cylindrical fibers. Fibrillated fibers are flat, tape like fibers that can be described as latticework of "stems and webs" as the fibers break apart during mixing and compaction.

Stabilization with Lime is not new innovation. Various forms of lime stabilization have been used for thousands of years. Lime was widely used for buildings construction. Lime is form of quick lime (Calcium Oxide hydrated lime (calcium hydroxide Ca $(OH)_2$ or lime slurry can be used to treat soils. Quick lime is manufactured by chemically transforming calcium carbonate (Lime stone $CaCO_3$) into calcium oxide as shown in equation (1):

$$CaCO_3 + heat\ (1315\ C^o) \rightarrow CaO + CO_2 \quad (1)$$

Hydrated lime reacts with water to obtain calcium hydroxide (i.e. equation 2)

$$CaO + H_2O \rightarrow Ca(OH)_2 + heat \quad (2)$$

The source rock for the production of lime is lime stone (Calcium carbonate $CaCO_3$) which occurs naturally as a sedimentary rock.

2.2 Lime

The hydrated lime reacts with clay particles and permanently transforms them into a strong cementation matrix. Most lime used for soil treatment is "high calcium" limes, which contain no more than 5 % magnesium oxide or hydroxide on some occasions; however, "dolomite" lime is used. Dolomite lime contains 35% to 46% magnesium oxide or hydroxide. Dolomite lime can perform well in soil stabilization, although the magnesium fraction reacts more slowly than the calcium fraction. Sometimes the term "lime" is used to describe agricultural lime which is generally finely ground limestone. A useful soil amendment but not chemically active enough to lead to soil stabilization.

2.3Ceramic

It is solidified as a glass from the melt (solid or lump) glass. These amorphous glasses are essentially anhydrous and differ from ordinary glass in that they are soluble in water at elevated temperature and pressure leading to silicate solution (liquid glasses). Both solid and liquid glasses are often referred to as water glasses. Silicate solution is defined by their density and viscosity. This together with the silica to metal oxide ratio defines a unique composition for the silicate solution. By evaporation of silicate solution, normally unlike ground lump glasses, these materials dissolve readily in water to silicate solution.

III. EXPERIMENTAL WORK

3.1 Soil properties

The soil used in this study has been brought from Al- Kut center, Wasit discrete from (1-2) m depth of handmade borehole. Natural moisture content for the soil is 24 % with specific gravity was 2.75 and the density (unit weight) was 17 kN/m³, classification test made for the soil include liquid and plastic limits which values were (22% and 40%) respectively; therefore, the soil was classified as (CL) type.

3.2 The used container and model preparation

One face transparent contained, 0.8m in length, 0.5 width and 0.45m height is used in this paper and the soil with normal state from field is compacted to the desired density (around17 kN/m^3).The method of improvement is used by mixing randomly with soil the different materials by determination percent (percent of weight). Soil density was controlled by diving it three layers; each individually compacted to record level until reaching the last layer, the soil surface was leveled with aid of sharp instrument. A square footing (50x50) mm made of steel was placed at center of model, over last bed of the soil.

3.3 Loading frame and settlement control

The system of loading frame has been chosen for all laboratory model tests is it has fixed loading type, to ensure continuous and long term loading application and easy stress controlling and additional loading during test. The model consists of vertical steel straight shaft of square section 10x10 mm and 1.2 m long. The settlement is measured using (0.01) mm sensitive dial gage, fixed out of the model with the aid of magnetic holder. The loading frame and settlement control was designed especially for these tests on model samples to investigate the specimens compressibility during the loading stages.

The settlement is recorded with time for model tests at normal state, this state takes about 48 hours which represents the settlement. The loading frame is placed on steel footing whereas weights are attached on it to achieve a pressure on soil of 40 kpa and 80 kpa. This stresses are chosen as it is expected that most domestic houses and small engineering projects may apply a similar stress level on soil (i.e. 2.5-5.5m). Figure 1 shows the loading frame and loaded specimen.

Figure 1: Loading frame

IV. RESULTS AND DISSCUSSION

As mentioned earlier in the sample preparation, to improve its properties, there were three materials added to soil (polypropylene, Lime & ceramic). The results of first experiment (soil without additives) are shown in Fig. 2. These curves show the time settlement relationships for the natural soil, the soil tested at stress 40 Kpa and 80 Kpa with soil density exceed 17 kN/m^3 These stresses level represent shallow depth for a lot of engineering projects (i.e. 2.5-5m). The values of settlement of no additional stabilizers reach to the value 2.49mm at stress 40 Kpa and 3.49mm at stress 80 Kpa at time 48 hr.

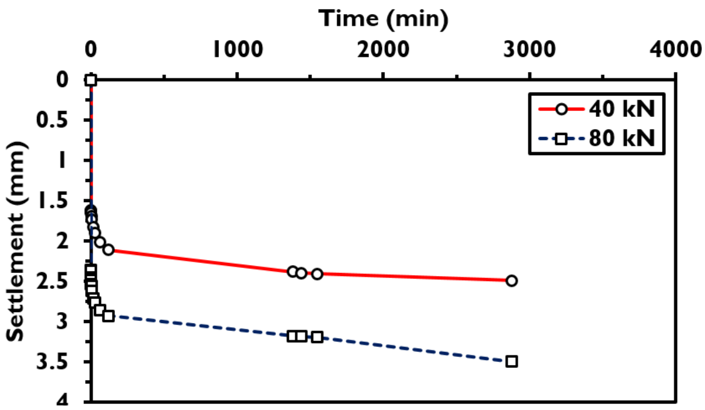

Figure 2: Time-settlement relationship for unsterilized soil

Fig. 3 and 4 show the relationship between the settlement and the time with additional percentage of stabilizer 1% and 3% (i.e. a and b) for 40 and 80 kPa. It should be noticed that for specimens treated by polypropylene fibers, lime and ceramic, the workability of soil is become good and the polypropylene makes a good bonding between soil particle and this leads to improve in the compressibility along the loading time, but distinguishable improvement is seen for specimens treated by lime. All treated specimens have been given a measured compressibility less than the measured value of experiment with no addition with a little difference. It can be seen also that the improvement in the compressibility is at low additive percentage (i.e. 1.5%) is much more that the other percentage. This can be attributed to the decreasing of the adhesive between particles and leads to sliding during compression load.

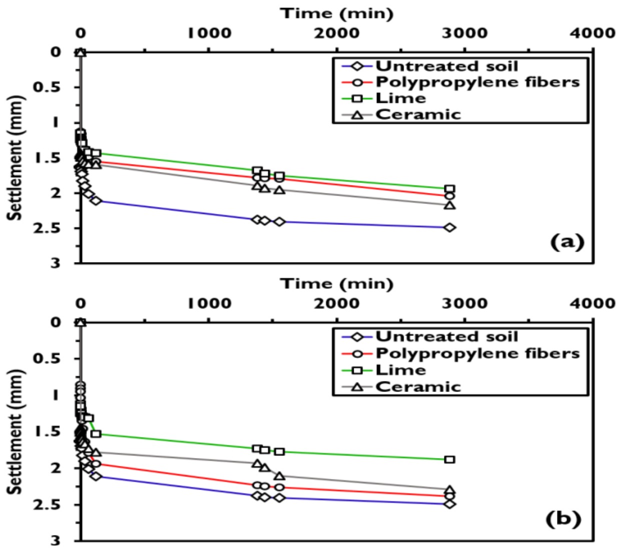

Figure 3: time –settlement curve for 40kPa stress level for; (a) 1.5% additivesand (b) 3.5% additives

At higher stress level (i.e. Fig. 4, 80kPa), The specimen that treated by polypropylene gives a great improvement for low percentage (i.e. 1.5%) and a little improvement at 3.5% additives. Whereas the specimen that treated by lime gives a little improvement in the compressibility at low percentage and it was very bad on the compressibility at higher percentages. This might be to the destruction of the formed bonds between soil particles due to high stress level. The specimens stabilized by Ceramic, its trend to give good resistance due to stresses (i.e. improvement in the compressibility) at intermediate and high loading time at low percentage (i.e. Fig. 4 a), nevertheless, it tends giving a worst compressibility comparing with all specimens in this paper when higher percentage is used.

stress level. At stress level 80Kpa and percent 1.5% the value reaches to 3.07mm, but the soil with percent 3.5% of ceramic the values wasn't improve and the same behavior of lime the values became greater than the natural values to reach 4.6mm. The mechanism of reduced settlement for lime and which added to soil as powder and this fine particle is filled the voids and reacts with water which is present in voids and make a good structure between particles of soil and this make soil stronger than the soil without any addition and these leads to reduced settlement. Also adding of ceramic material to the soil leads to decrease in collapse potential as the ceramic content increase.

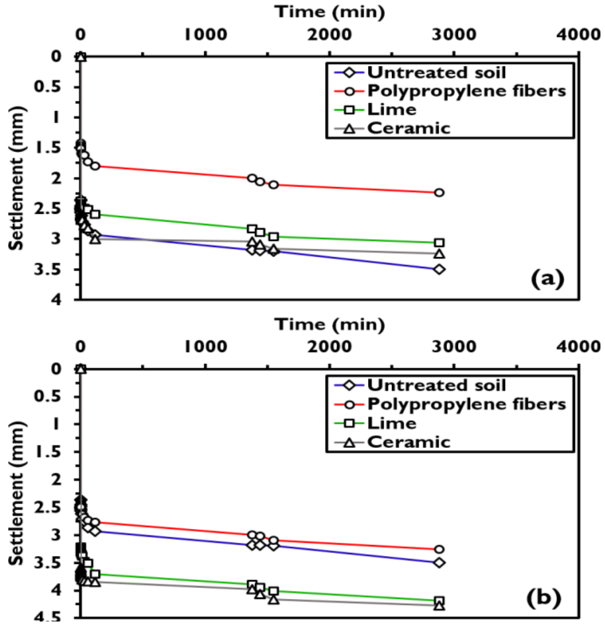

Figure 4: time –settlement curve for 80kPa stress level for; (a) 1.5% additivesand (b) 3.5% additives

From table 1, it should be noticed that the polypropylene gives highest percent of improvement at load 80Kpa with percent 1.5%, thus, the polypropylene can be used at high stress level with low percent while the high percent gives low value in improvement of soil and this has negative effect on soil. On other hand the use of polypropylene in small percent is useful from economic cost because polypropylene is expensive material compression with lime and ceramic.

Table 1: Summary of the compressibility improvement

Loads	Percent of adding material	Percent of improvement
40Kpa	1.5% polypropylene	19.3%
40Kpa	3.5% polypropylene	4 %
80Kpa	1.5% polypropylene	35.5 %
80Kpa	3.5% polypropylene	3.24 %
40Kpa	1.5% lime	32.1 %
40Kpa	3.5% lime	34.14 %
80Kpa	1.5% lime	13 %
80Kpa	3.5% lime	-24 %
40Kpa	1.5% ceramic	17.3%
40Kpa	3.5% ceramic	27.7 %
80Kpa	1% ceramic	12 %
80Kpa	3% ceramic	-32 %

Also, this table shows that specimens that treatedwith lime givea good results and a reasonable improvement. This means that the lime can be use with high percent under small loads and this useful from economic cost because lime is cheapest material and available in market. For ceramic, it was clearly shown of the lowest percent of improvement.

V. COMPRESSIBILITY REDUCTION FACTOR

The compressibility resuction factor is the ratio between the measured settlement for each case (i.e. treated specimens) to the measured settlement of the untreated soil (i.e. natural soil). Using this formula gives a great indication of which material gives a better results base on the reduction factor less that unity (i.e. 1).

As shown in Fig. 5 a and b, the compressibility reduction factors are not strongly influenced by the type of the additives (i.e. figure 5 a) particularly for lime and ceramic at both low and high stress level (i.e. 40 kPa and 80 kPa respectively) except for polypropylene at high stress level which gives the best reduction factor (64%) and subsequently the minimum compressibility for this specimen. Also, at high stress level, the reduction in the compressibility was very little (i.e. the compressibility reduction factor close to unity and this may be due to losing of the bonds between particles.

For high additives percentages (i.e. Fig. 5 b, 3.5%), only specimens stabilized by lime at low stress level gives a reasonable treatment (compressibility reduction factor a round 76%), otherwise all other specimens for both low and high stress level trend to be bad treatments particularly at high stress level which the compressibility reduction factor was more than unity (i.e. 120% for both lime and ceramic).

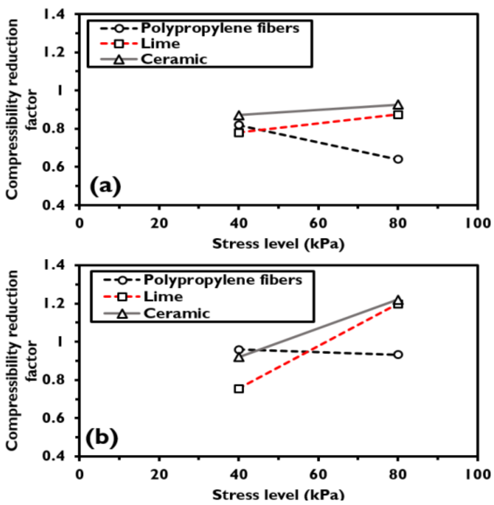

Figure 5: Compressibility reduction factor for; **(a)** 1.5% additives and **(b)** 3.5% additives

Fig. 6 shows the effect of the additive percentages on the treated specimens compared with untreated specimens. As explained before, increasing of the percentage does not means giving an improvement on the compressibility of the soil, it may give a worst result as clearly shown in figure (6 b). On the other hand, some additives do not give a reduction in the compressibility at any percentage (or may its very little comparing with the time consuming and the efforts.

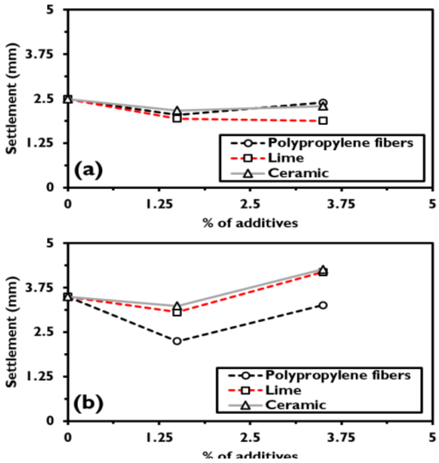

Figure 6: The settlement of specimens at; **(a)** 40 kPa **(b)** 80 kPa

VI. CONCLUSION

An extensive 1-g load tests are conducted on stabilized silty clay soil with three different stabilizers to investigate how the compressibility od the soil strata behave under load test. Two main stress level are used for representing both low and medium in-situ stress. The mains finding are summarized below:

1- All stabilizer materials give an improvement on the compressibility of soil specimens, however, the Polypropylene fibers specimens gives a maximum improvement particularly at low stress level.
2- Increasing the percentages of the stabilizer, at low stress level, do not give a distinguishable compressibility improvement for all treated specimens. At high stress level, the measured settlement at high percentages of additives were more than the measured for untreated soil for both lime and ceramic stabilizer. Whereas it was tiny improvement for specimens treated with polypropylene fibers.
3- Increasing the percentages of stabilizer might lead to an opposite result, so its recommended to use a minimum percentage to decrease the cost of the treatment and to achieve a reasonable output.

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