Effect of sand percentage on the compaction properties and undrained shear strength of low plasticity soft clay

Iyad Alkroosh[1], Ali A. Al-Robay[1], Prabir Sarker[2], Saif Alzabeebee[3]

[1] Department of Civil Engineering, College of Engineering, University of Al-Qadisiyah, Al-Qadisiyah, Iraq
[2] School of Civil and Mechanical Engineering, Curtin University, WA, Australia
[3]Department of Roads and Transport Engineering, College of Engineering, University of Al-Qadisiyah, Al-Qadisiyah, Iraq

***Abstract*— This study investigated the influence of sand content on the mechanical behaviour of a low plasticity clay found in Iraq. Samples were prepared with sand contents of 0%, 10%, 20%, 30%, and 40% of the weight of the clay. Standard Proctor and unconfined compression tests were carried out and the optimum moisture content, maximum dry density, and undrained shear strength were determined. The results showed a gradual increasing trend of the maximum dry density with the increase of the sand content up to 30%. The highest dry density reached was 1.90 gm/cm^3 corresponding to an optimum moisture content of 12%. In addition, it was also found that the undrained shear strength was inversely proportional to the increase of the percentage of sand. Thus, the dry density of the clay could be increased well above 1.70 g/cm^3, which is the minimum dry density accepted as a compacted subgrade according to the Iraqi General Specifications for Roads and Bridges (2003); hence, the rejected low plasticity clay could be utilised by mixing with sand. The reasons for the increase of the dry density and the decrease of the undrained shear strength has been extensively discussed in the paper.**

***Index Terms*— clay sand mixture; optimum moisture content; undrained shear strength; low plasticity.**

I. INTRODUCTION

Soil beneath building foundations is often made up of layers of clay or sand or both. The clay occasionally exists in a form described as soft clay which is characterized by low strength and high compressibility [1]. Due to these undesirable properties, this type of clay may be considered unsuitable for supporting foundations. Building on soft clay sites usually needs dredging and replacement of the clay by stronger soils. Alternatively, soil improvement techniques need to be adopted when it is difficult and costly to conduct soil replacement.

Improvement of soft clay properties can be achieved by compaction or with the addition of other suitable materials. Compaction is a commonly used method to improve the mechanical properties of soil supporting foundations. It is also considered as a favorited method extensively used to improve subgrade for highway embankments, earth dams and many other engineering structures [1]. The compaction involves soil densification by removing air with application of mechanical energy. The main advantage of this process is the increase of bearing capacity and reduction of the undesirable settlements of structures [2].

Dynamic compaction was found to be useful for improving the engineering properties of soft clay and silts [3]. However, compaction does not always bring satisfactory results, particularly when the compacted soil is a soft clay. For instance, compacted soils of quarries were often rejected because they failed to meet the minimum limit of dry density specified by the Iraqi General Specifications for Roads and Bridges [4]. Consequently, huge earth quarries of such soil were abandoned making the contractor consuming additional cost and efforts. Therefore, addition of suitable materials is considered when compaction of soft clay does not yield satisfactory results.

Addition of materials to improve the physical properties of soft clay have received the interests of many researchers. Khemissa and Mahamedi [5] proved significant increase in strength and durability of expansive over-consolidated clay when 8% of cement and 4% of lime were added to the clay. Garzón et al. [6] concluded that the composites of phyllite clay and cement improved the engineering properties including plasticity index, maximum dry density, unconfined shear strength and coefficient of permeability. Mixing of clay with a percentage of sand usually improves the density and strength characteristics of clay. Therefore, the compacted mixture of clay with sand could meet the minimum requirements of acceptable maximum dry density according to the Iraqi General Specifications for Roads and Bridges [4]. Several researchers attempted studies investigating into the behaviour of clay-sand mixtures and reported improved properties. Shafiee et al. [7] investigated the undrained behaviour of compacted sand-clay mixtures under monotonic load and found that the addition of sand improved the undrained shear strength. Khan et al. [8] studied the influence of adding 20-40% of sand to a natural clay of high plasticity and reported an increase in clay density and compressive strength. Kim et al. [9] reported that for mixtures of sand and clay, the cyclic shear strength of low-density mixtures increased and that of high-density mixtures decreased with the increase of fines content. Deng et al. [10] studied the

http://doi.org/10.24086/aces2020/paper.143

effect of sand fraction on the hydro-mechanical behaviour of sand-clay mixture and found different compression behaviour from that of common clays.

Procter test and unconfined compression strength test are commonly carried out in order to evaluate the quality of the improved soil. The Procter test is usually undertaken to determine the maximum dry density of compacted soil specimens. The ratio of field to laboratory densities indicates whether or not the field compaction achieved an acceptable level. The unconfined compression test is useful for estimating the undrained bearing capacity of fine-grained soil for foundations, stability of slopes, and determining the stress-strain characteristics under undrained conditions [11-13]. It is also used for design of road embankments, shallow foundations, and retaining walls [14].

This study investigated the effect of the percentage of sand on the density of compacted clay in order to meet the acceptable level of density by the Iraqi General Specifications for Roads and Bridges [4]. The effect of sand percentage on the undrained shear strength of the compacted clay was also evaluated.

II. METHODOLOGY

A. *Site and Sample Collection:*

A sampling site was selected which has the same soil properties as those of the rejected quarries. In order to determine a suitable site for sample collection, technical advice was sought from professional consultants who are experts in soil investigations business in the region of the middle provinces of Iraq. Sumer town, which is located at 30 km north east of Al-Diwaniyah city, was determined as an ideal site for sample collection. A review of the reports of past site investigations in the area found that the type of clay in demand usually exists at a depth of 1.0 meter below the ground surface. This study adopted the american standard for testsing and materials (ASTM) practice for soil investigation and sampling [15]. A hand auger, shovel, and manual digging accessories were used to dig the ground to reach the sampling depth. A soil of clayey nature began to appear from a depth of 0.7 m. Initial evaluation was made to the excavated soil in the field by visual inspection and a simple field test. The soil showed sticky behaviour when water was added to it and thus it was concluded that the soil is clay [11]. The excavated soil sample was grey in colour, had a homogeneous structure and could be easily moulded by fingers. The samples were transported to the Soil Mechanics Laboratory of College of Engineering, University of Al-Qadisiyah as per standard practice for preserving and transporting soil samples [16]. Final Stage

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B. *Laboratory Work*

1. *Soil sample classification*

After the initial evaluation of the extracted sample by field test, it was evaluated further in the laboratory in order to ensure that the sample was clay of low plasticity. The plasticity test was carried out to determine the type of soil sample. In this test, a relationship between liquid limit and plasticity index was defined. The liquid limit and plastic limit tests were performed as per the ASTM D4318-17e1 [17] and the unified soil classification system (USCS) was adopted to classify the soil sample [18].

2. *Removing coarse particles from the sample*

Although the collected soil sample is evaluated as clayey soil, a percentage of coarse particles were expected to exist in the sample. To obtain a purely fine- grained soil, the sample was sieved and then washed on the sieve # 200. The passing solution was collected in a bowl and then placed in an oven with a temperature of 100 c° and for 24 hours to remove the water. It was found that the percentage of the soil passing sieve # 200 is more than 95%.

3. *Preparing sand fraction*

The sand used in this study was available locally. It was brought from Al-Najaf province which usually supplies sand as a construction material to most regions in Iraq. Based on the ASTM D2487-17 [18], USCS defines sand as a portion of soil particles that pass sieve #4 (4.75 mm) and retained on sieve # 200 (75 μm). Usually sand contains a percentage of coarse particles of size larger than 4.75 mm and fine particles of size smaller than 0.075 mm. To collect the sand grains only, an amount of soil was sieved as per the standard test method for sieve-analysis analysis of soils [19]. The particles passing through sieve # 4 and retaining on sieve # 200 were used in the subsequent tests.

4. *Compaction test*

The soil sample was compacted using standard Proctor's compaction tests as per the ASTM D698-12e2 [20] to determine its maximum dry density and optimum moisture content. The test was carried out on the sample that contains zero percentage of sand and then on samples with 10% to 40% of sand. The sand fraction was added as a percentage by weight varying in 10% increment. Prior to the test, measurements of the mould dimensions and its weight with the baseplate were recorded. The soil sample was prepared by adding an amount of water to the dry sample and then mixing it thoroughly to get a consistent distribution of the moisture. The sample was then compacted in Proctor's mould of 100 mm diameter and 117 mm height. The sample was placed in the mould in three layers and each layer was given 25 blows distributed evenly on its surface using a standard rammer which weighs 2.5 kg and falls off from a height of 300 mm. Then the mould and the compacted soil with the base plate were weighted. A sample was taken from the core of the compacted specimen for determination of the moisture content in accordance with the ASTM standard [21]. This process was continued until the weight of the compacted soil began to drop.

http://doi.org/10.24086/aces2020/paper.143

5. *Unconfined compression test*

This test is usually used to determine the undrained shear strength of the soil. It was also used by previous studies to invetigate the shear strength of the soil (e.g. [22-24]). Therefore, this test is used in this study to determine the influence of the adding the sand on the undrained shear strength of the clayey soil. The test was conducted according to the ASTM D2166 / D2166M-16 [25]. The samples used in the test were extracted from the compacted soil specimen in Proctor's mould at the optimum moisture content. A steel tube of dimensions 35 mm in diameter and 76 mm in height, which is specified for the test sample, was pushed into the compacted soil sample and pulled off with unconfined compression test sample. The sample was then extracted from the tube using the sample extruder and placed in the test frame as per the standard test method [25]. After that a vertical stress was applied on the sample and the produced settlement was measured. The peak stress was considered as the undrained shear strength of the soil.

III. RESULTS AND DISCUSSIONS

As the percentage of the soil passing sieve # 200 was found to be more than 95%, this means that the classification of the soil is based on the liquid and plastic limits as per the USCS [18]. The plasticity test results showed that the liquid limit and plastic limit of the soil were 39% and 22%, respectively. Using the plasticity chart of the USCS, the soil was classified as CL as shown in Figure 1. This mean that the soil was a clay of low plasticity.

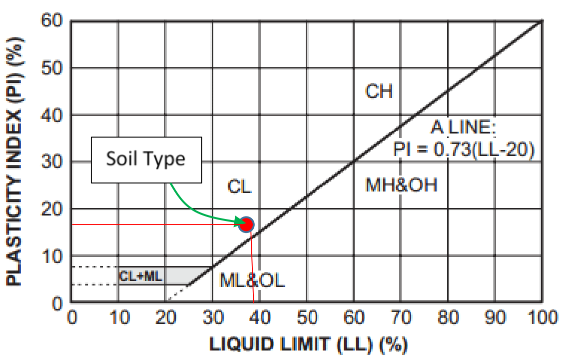

Fig. 1. Plasticity chart for classifying the soil

A. *Variation of the OMC and Maximum Dry Density with the Sand Content:*

The results of the Proctor's test for the clay-sand samples which contained different fractions of sand are presented in Figure 2. The results show that the pure clay sample had the highest moisture content, whereas the sample that contains 40% sand had the lowest moisture content. The figure also shows that the least dry density was reached when clay contained no sand; however, the sample reached its highest dry density when it contained 30% of sand fraction. In addition, the figure shows that for the clay with no sand, the maximum dry density was 1.65 g/cm^3 and the corresponding OMC was 20%. For samples containing 10%, 20%, 30% and 40% sand, the maximum dry densities were 1.80, 1.84, 1.9 and 1.78 g/cm^3, respectively. The range of OMC variations was between 12% and 20%, where largest OMC was obtained in the sample of pure clay. This is because the clay particles have more capability to absorb water than sand particle; hence, as the sand percentage increases the capability of the soil (clay-sand mixture) to absorb water decreases.

Variations of maximum dry density and OMC with the percentage of sand fraction are presented graphically in Figure 3. The OMC varied in a falling rate from 20% for the sample with no sand to 12% for the sample containing 40% sand. On the other hand, the maximum dry density varied in increasing rate from 1.65 g/cm^3 to reach the maximum value of 1.90 g/cm^3 when the sand faction was 30%. The maximum dry density then dropped to 1.78 g/cm^3 when the sand fraction was increased to 40%. Importantly, it is clear from the figure that the dry density of clayey sample improved and reached a level much higher than that specified by the Iraqi General Specifications for Roads and Bridges [4] for acceptable density of compacted subgrade clay as 1.70 g/cm^3.

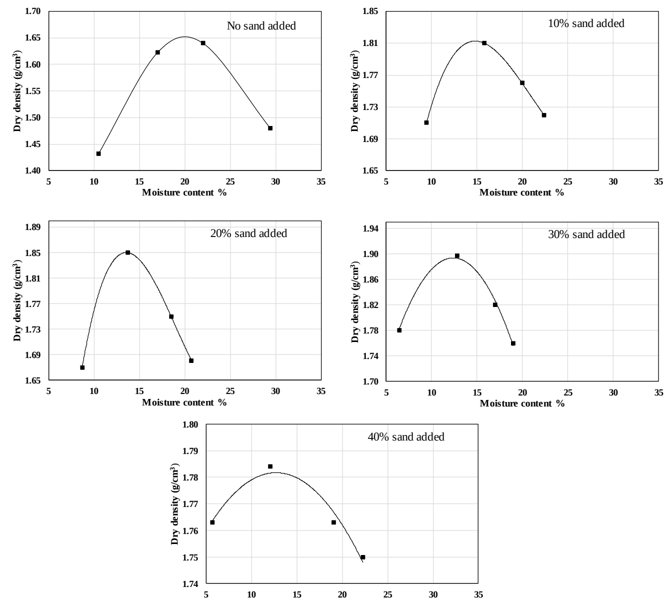

Fig. 2. Relationship of moisture content vs dry density for clay contains various sand percentages

It is also clear from Figure 3 that, there is a fast increase in dry density with increase of sand content 10% to 30%, beyond which the density declined rapidly. As the tested clay is soft, the void ratio of this type of clay is in a range of 0.90 to 1.40 [1]. When sand was added to the samples, the coarse particles were arranged by compaction in a way that increased the volume of solids per unit of total volume. Hence, the void ratio decreased while dry density increased with the increase of sand fraction. This continued until the fraction of fine particles became less than that required for optimum arrangement of solid particles per unit volume. Therefore, the void ratio began to rise again, whereas dry density started to fall. The inverse variations in the optimum moisture content with increasing sand percentage is due to the decrease in the surface area of soil particles with the presence of sand. This led to reducing the amount of water required to facilitate the arrangement of soil particles by compaction to reach the maximum dry density [14].

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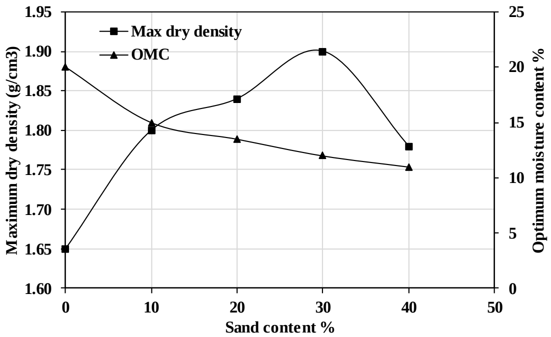

Fig. 3. Effect of sand percentage on dry density and optimum moisture content of compacted clay

B. Variation of Undrained Shear Strength with the Sand Content:

The influence of sand fraction on the values of undrained shear strength of the compacted clay is provided in Figure 4. It is clear from the figure that the undrained shear strength dropped from 220 kPa for zero percent sand to 111 kPa for 40% sand in the sample. The rate of drop in the undrained shear strength continued with the increase of sand to the sample. The decline in undrained shear strength with increasing sand percentage in the sample is due to the reduction in cohesion. When sand was added to the sample, the attraction between the clay particles was reduced due to the separation of clay particles by sand particles. Thus, the undrained shear strength continued to drop with the increasing sand fraction. Moreover, the reduction in shear strength could be attributed to the path of failure plane which passes through a weaker zone in a case of clay-sand mixes [26]. In addition, the cross-sectional area of the sample may reduce when the sample contains sand particles which fell out from the sides in the test samples. As a result, stress concentration increases making the sample fail under smaller applied load [8].

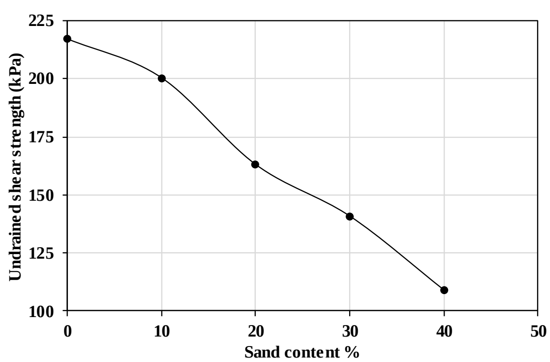

Fig. 4. Effect of sand percentage on undrained shear strength of compacted clay

IV. CONCLUSION

This study investigated the characteristics of compacted clay of low plasticity mixed with sand at different percentages. The results have shown that dry density increased with increase of sand fraction up to 30% of the sample by weight. The maximum increase in dry density was reached when the added sand fraction was 30%. The optimum moisture content decreased with the increasing percentage of added sand. The undrained shear strength varied inversely with increasing percentage of sand. A significant decrease in the undrained shear strength was observed initially with a steady decrease thereafter with the increase of sand fraction. The dry density of clay improved and reached a level much higher than that specified by Iraqi General Specifications for Roads and Bridges [4] for acceptable density of compacted subgrade clay as 1.70 g/cm^3. A great advantage of the outcome of this study was that it proved the feasibility of improving the soil of rejected quarries and make it useable.

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