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Response of Soft Soil Mixing with Recycled Gypsum (Plasterboard) as Stabilized Agent for Soil underneath oil tank as a case study.

A Al-Adili[#] N M Salim and K. Y. Al-Soudany

[#]University of Technology, Baghdad, Iraq

Corresponding author's e-mail address: aqeeladili@hotmail.com

Abstract. Soil stability plays a vital rule in projects' infrastructure such as embankment, retaining walls dams and highway. Structure built on soft soil may experience uncontrollable settlement and critical bearing capacity. This may not meet the design requirements for the geotechnical engineers. Soil stabilization is a process to change such undesirable properties in order to meet the requirements. The main objective of this study is to evaluate the use of recycled gypsum, which is derived from gypsum waste plasterboard, as a stabilized agent for soft clay. Twenty eight experimental tests have been conducted to improve a soil brought from a site in Basra (Garma Ali /south of Iraq) using four different recycled gypsum percentage varying from 0 to 15%. The properties which have been studied are grain size distribution, Atterberg limits, unconfined compressive strength, and compressibility. The results indicate that as the gypsum contents increase, the liquid limit decreases up to gypsum content of 3% and then increases. The plastic limit has been decrease up to 7 % of the gypsum content and then increases. Furthermore, the maximum dry density decreases while the optimum moisture content is increased as the percentage of gypsum content has increased. The compression index (C_c) has increased as the gypsum content increases while the swelling index has increased up to 5% then it has decreased. The unconfined compressive strength has increased by adding recycled gypsum up to 5% while it is reduced as the percentages of gypsum has increased beyond 5%. Adding 5% of recycled gypsum raise the bearing capacity to approximately 167% compared with the bearing capacity of untreated one.

1. Introduction

Stabilization is the method of merging different types of soil or adding additives to soil to improve characteristic, such as strength, gradation and plasticity which make the soil more stable. The main purpose of stabilization can be listed as follows:

- 1- Decrease volume expansion
- 2- Increase strength
- 3- Decrease cohesiveness

There are different methods of soil stabilization such as:

- a) - Mechanical stabilization.
- b) - Chemical stabilization.
- c) - Both mechanical and chemical stabilization



Chemical stabilization depends mainly on the chemical reaction between the additive material (cementation) and soil minerals (pozzolanic material) to achieve desired effect. Cement, lime, fly ash bitumen and combination of these can be used in this type of stabilization. Usually stabilized soils have a higher strength and lower compressibility than the original soils, that's why many researchers have used these types of stabilization. [1,7].

Nowadays, the researchers around the world have directed their research on improving soils by utilizing the millions of tons of local waste material, such as using waste plasterboard. A large quantity of gypsum plasterboard is produced during the three stages of production, construction and demolition. So, to avoid the increase of gypsum amount waste plasterboard that is disposed in landfill, it is necessary to find alternative ways to reduce the dispose waste which causes an increase in the cost of disposal and decrease the available ground space that are specified for landfills sites. Furthermore, gypsum waste plasterboard in landfills under certain circumstances the emission cause of hydrogen sulphide gases, which are potentially harmful and lethal. In general, recycled gypsum (Bassanite) which is derived from gypsum plasterboard has the potential to be used as a cementation material because gypsum is the main key of cementation materials.

Ahmed et al., [8], demonstrated that the results obtained from laboratory investigations for the utilization of recycled gypsum in ground improvement are not adequate to evaluate the use of recycled gypsum as a stabilized material due to the difficulty in stabilizing soft clay in the field and this attributed to the following:

- 1-The in-situ behavior of clay soil is mostly very complex due to various geological patterns of the soil in the same site
- 2- The water contained in the clay soil changes from time to time during the construction period due to weathering factors such as rainfall, humidity, temperature and season changes.
- 3- It is difficult to mix the stabilized material with clay in the field because clay is very sticky and it is difficult to bring homogeneous and isotropic properties to the mixture as compared to laboratory.
- 4- Information about the use of recycled gypsum in ground improvement project has not been clarified yet and the data for this issue is limited.

2. Previous studies

Different materials have been used for soil stabilization; the most common those which have been used for chemical are or mechanical soil stabilization such as lime and Portland cement. In addition there are several studies which have investigated the use different types of waste materials as stabilizing agents to improve the mechanical properties of soil. Example of using waste material to improve the strength of Iraqi soil, using nylon bags by product with different percentages corresponding to 1%, 3% and 5% of dried weight. The main conclusions drawn that, as the percentage of additive has been increased, the liquid limit has decreased s while the plastic limit has increased causes, the plasticity index to be decreased. The maximum dry density decreases while the optimum moisture content increases as the Nylon fibre percentage has been raised. The compression index decline as the Nylon fibre has inclined and reaches a maximum value of 43% by adding 5% of nylon fibre. Finally, the undrained shear strength has increased as nylon fibre increased as well [9].

The use of recycled gypsum, which is derived from gypsum waste plasterboard, in ground improvement is limited around the world are very limited researches available in this area. Therefore, this section deals with previous studies using this type of additive.

Kamei et al., [10]. used different contents of basanite, which derived from gypsum waste plasterboard to improve sand and clay soils. They concluded that using the stabilization agent has improved the stress strain behaviour of the used soil., [11].The study conducted a series of unconfined compression, splitting tensile and capillary rise tests to study the effect of using sandy soil reinforced with gypsum waste plasterboard. Plaster waste was used as a cementation agent to improve the compressive strength while strips of waste plastic trays were used to enhance the tensile strength of the improved soil with gypsum wastes. The results reveal an increase in both compressive and splitting

strengths, which happened with the presences of recycled gypsum content.

3. Soil Properties

In this part, the experimental work has been carried out using standard procedures. The untreated soils have been tested for their classification and index properties, as well as their consistency properties. In addition, testing program has conducted on the clayey soil stabilized with different percentage of recycled gypsum, including Atterberg's limits, static compaction, consolidation test. The grain size distribution (sieve analysis and hydrometer test) was performed in accordance with ASTM D421-58 as shown in Fig. 1. All the physical and mechanical properties of tested soil are listed in Table 1. The soil is classified as clay with low plasticity (CL) according to the unified soil classification system (USCS).

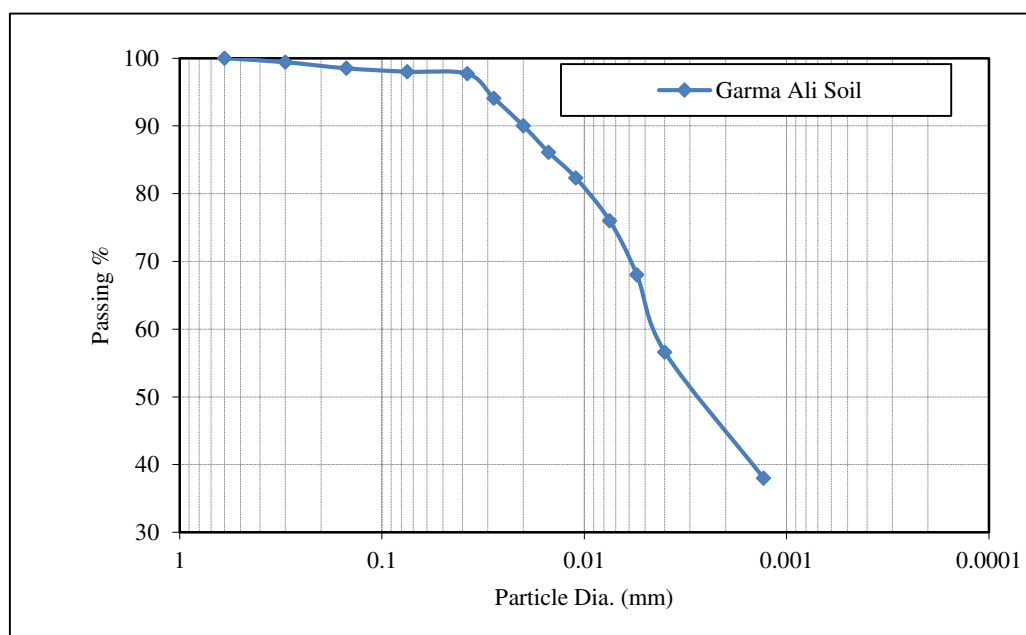


Fig. 1 Grain size distribution curve for soil used

Table 1. Physical and mechanical properties of tested soil

Engineering property	value
Liquid Limit, LL, %	46
Plastic Limit, PL, %	20
Plasticity index, PI, %	26
Shrinkage Limit, SL, %	17
Activity of Clay, AT, *	0.6
Specific gravity, G_s	2.69
Clay content ($< 0.005\text{ mm}$), C %	64
Silt ($0.005 - 0.075\text{ mm}$), M	34

%	
Sand (0.075 to 4.75 mm), S	2
%	
Classification (USCS)	CL
Organic Matter (O.M, %)	< 0.01
SO ₃ Content, %	0.38
Total Solved Salt (TSS), %	6.89
pH value, %	8.69
MDD (kN/m ³)	18
OMC, %	15.71
Initial water content, (%)	3.1

4. Material and Methods

4.1. Soil Samples

Gray slant to green clayey soil is brought from a site in Bsara (Garma Ali, South of Iraq). The natural moisture content is determined immediately in the soil mechanic laboratory, University of Technology. After that soil samples are spread out for two weeks for air-drying at room temperature. Then the soil has sieved to obtain the final soil sample for the test. To investigate the effect of recycled gypsum material on the geotechnical properties of the soft soil, soil-gypsum mixture have been prepared using three different percentages of gypsum material (5, 10 and 15%) passing sieve No (0.425 mm).

4.2. Recycled Gypsum

The recycled gypsum which is derived from gypsum waste plasterboard, used in this project has been collected from different construction sites, crushed by crushing machine and then screened to remove any solid waste such as paper, fibres, wood. The crushed gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is heated at temperature 45°C to produce Bassanite CaSO_4 .

4.3. Experimental Tests

In this study, laboratory experiments are achieved to assess the effect of recycled gypsum on the physical properties, compaction, undrained shear strength and consolidation parameters of the untreated (unstabilized) and treated (stabilized) soft clayey soil samples.

As aforementioned, all the tests have been conducted after choosing the worst case, i.e., by taking the lowest density and maximum water content. Then, static compaction is applied by using the modified proctor mold to study the effect of different gypsum percentages on clay by checking the unconfined compressive strength, and consolidation tests.

5. Effect of recycled gypsum on Soil Properties

For the natural and stabilized samples (after adding 5, 10 and 15 % gypsum), the above-mentioned same tests and procedures are as followed.

5.1. Specific gravity

The specific gravity of soil is determined according to ASTM D 854-02-Standard test for specific gravity of soil solids by water pycnometer. Fig. 2 shows the specific gravity variation with different gypsum contents.

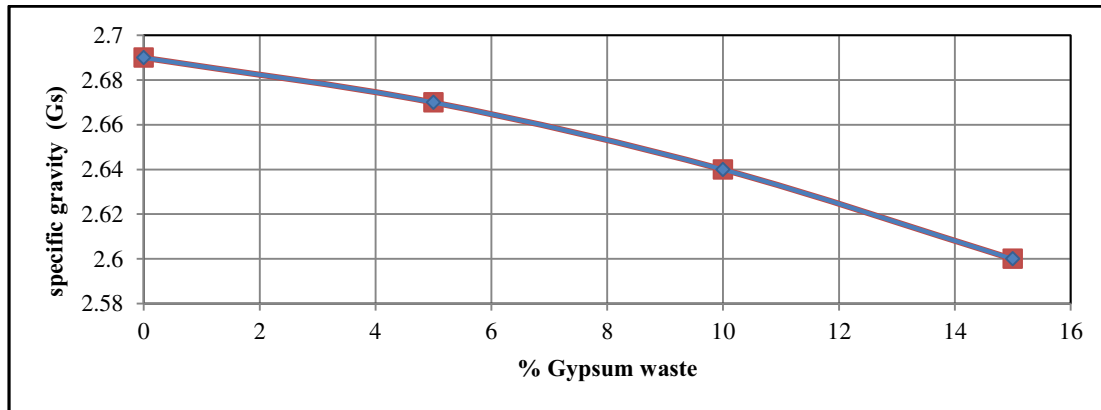


Fig. (2) Specific gravity variation with different gypsum contents.

5.2. Compaction

This test is performed according to ASTM D 1557 to define the relation between the dry unit weight and the moisture content of the soil. Fig. 3 shows the optimum moisture content (OMC) obtained from compaction test for untreated (0 % gypsum) and treated (5, 10 and 15% gypsum) soils.

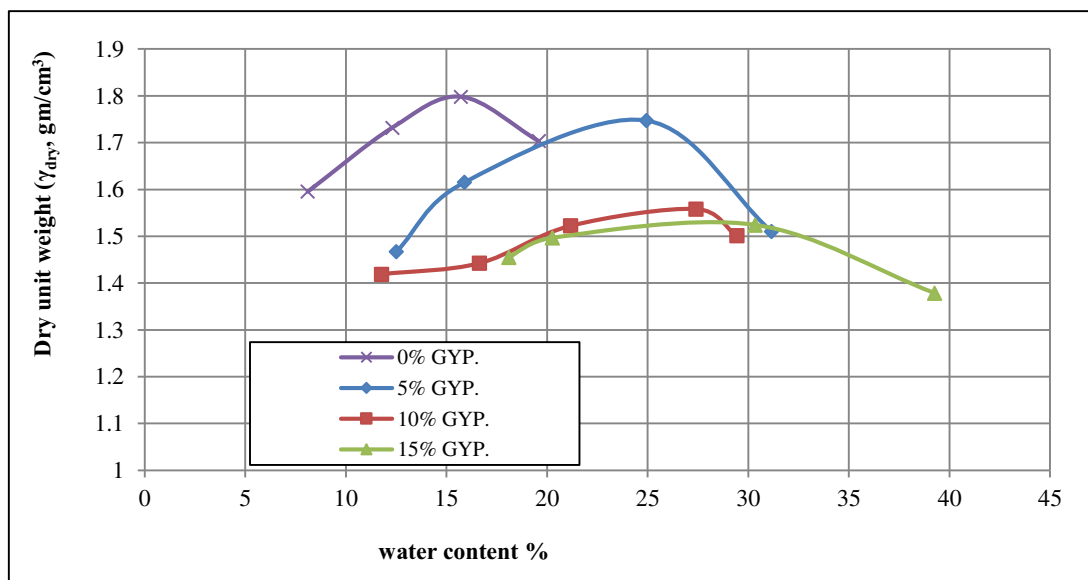


Fig. (3) Optimum moisture content (OMC) obtained from the compaction test for untreated and treated soils.

From compaction test, the maximum dry density variation and the optimum moisture content (O.M.C) with different gypsum contents are presented in Fig. 4 and 5.

The effect of adding recycled gypsum beyond 5% causes an increase in optimum moisture reached to a maximum value 25% by adding 15% recycled gypsum, then there is a sharp drop in dry unit weight beyond 5% recycled gypsum additive

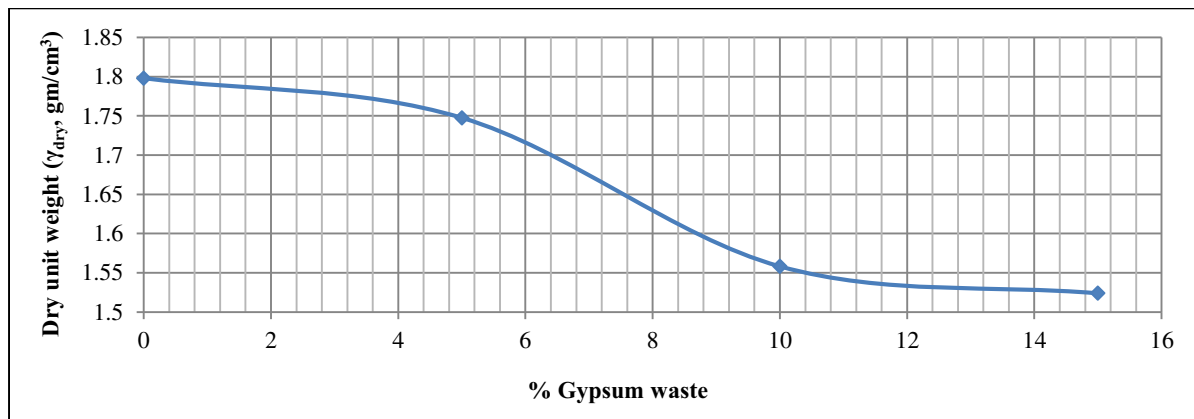


Fig. (4) Maximum dry unit weight variation with different gypsum contents.

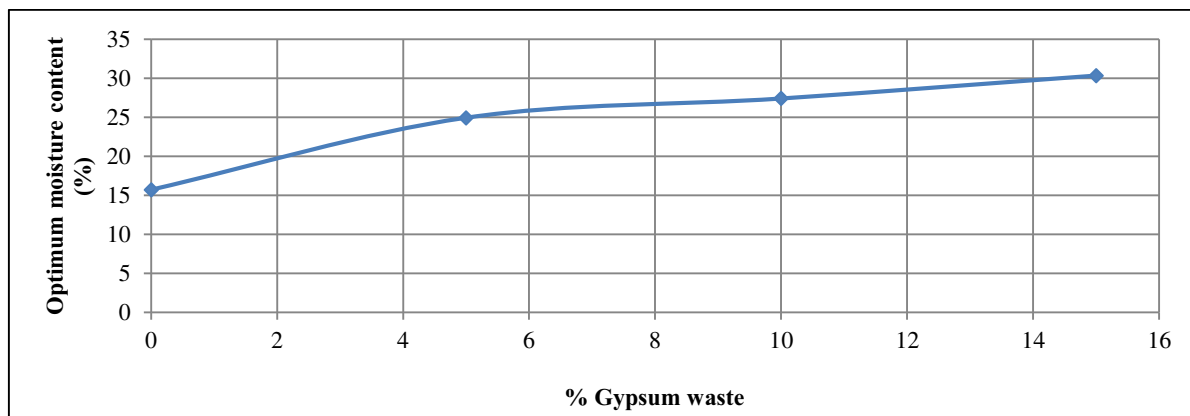


Fig. (5) Optimum moisture content variation with different polymer contents.

5.3. Atterberg's limits

Wide varieties of soil engineering properties have been correlated with consistency limits (Atterberg's limits). Liquid Limit (L.L) and plastic limit (P.L) are carried out according to the ASTM D 4318-00. Figs 6-8 illustrates the variations of these limits with gypsum content. Adding recycled gypsum up to 5% causes a reduction in liquid limit, this behavior is due to the bonds between the soil particles and recycled gypsum which causes the change in chemical composition of bassanite ($CaSO_4$) to hydrate calcium sulphate ($CaSO_4 \cdot 2H_2O$) followed by water being absorbed from the clay soil. In addition the chemical composition of the hydrate calcium sulphate as oxide contains a significant amount of calcium lime (Cao). The increase of silica content has caused the increase of pozzolanic reactions which produces increased quantity of the water holding gelatinous products. This causes an increase in liquid limit.

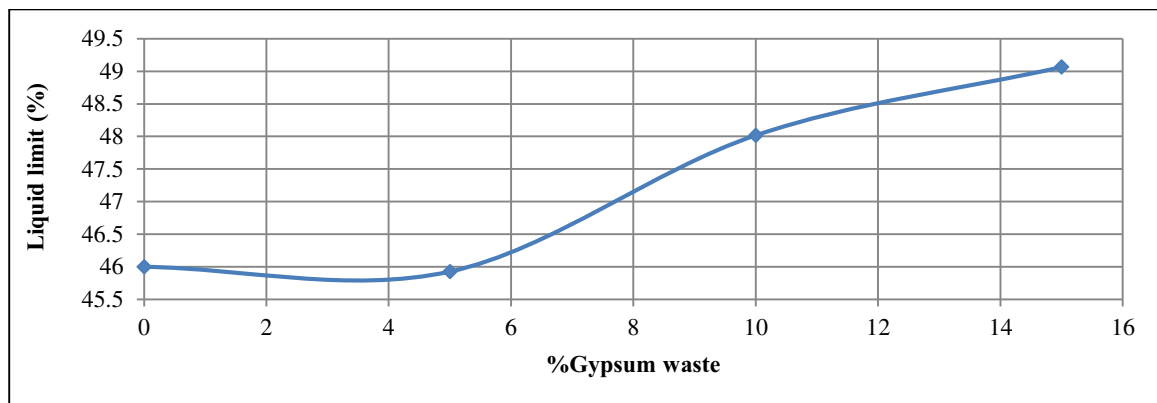


Fig. (6) Liquid limits variation with gypsum content.

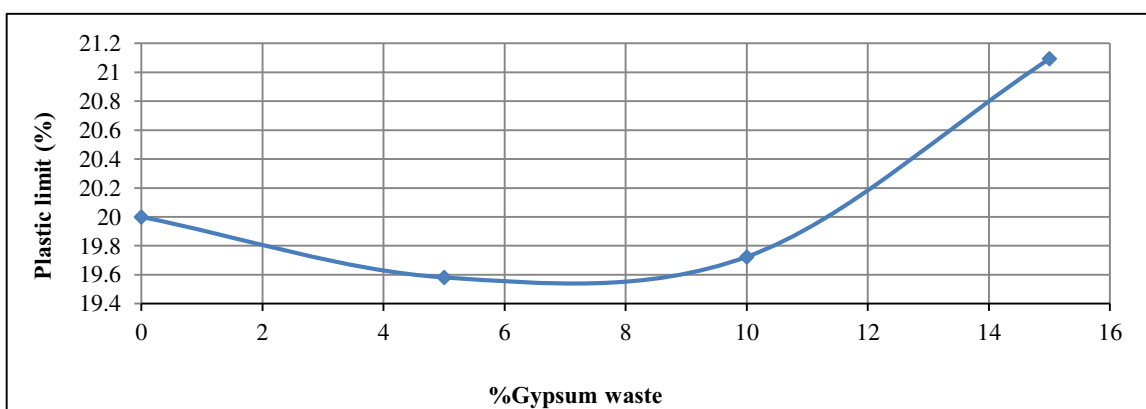


Fig. (7) Plastic limits variation with gypsum content.

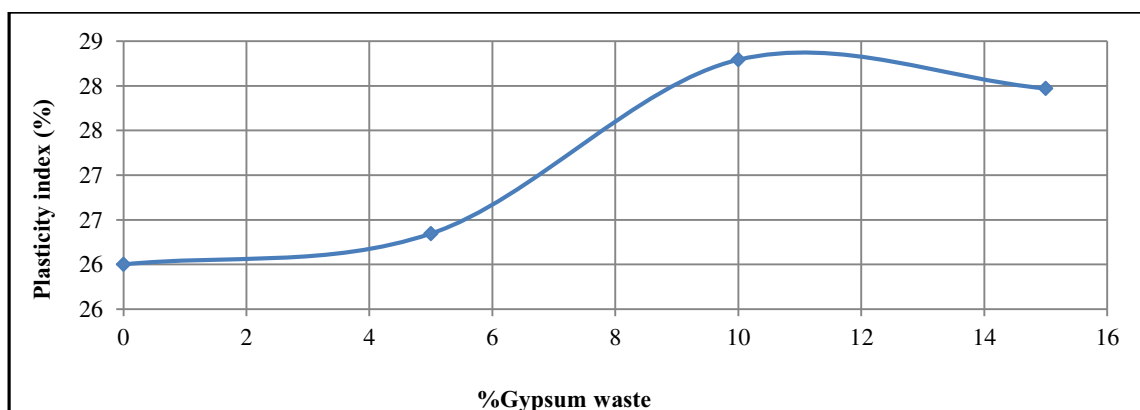


Fig. (8) Plasticity index variation with gypsum content.

5.4. Unconfined compressive strength

Unconfined compressive test is conducted to determine the unconfined compressive strength (UCS,

q_u) following the procedure of the ASTM D 2166-00 Standard Test Method for a cohesive soil. Then, the undrained shear strength (or undrained cohesion, s_u) of a cohesive soil is calculated which is equal to one-half of the unconfined compressive strength (q_u). Figure 9 illustrates the stress-strain relationship from the unconfined compression test for the treated and untreated soils. The results of undrained shear strength values of UCS tests on natural and stabilized soils with different gypsum contents are shown in Figs. 9 and 10. It is clear that the maximum increase in compressive strength with 5% of increase of recycled gypsum, this can be attributed to the hardening of the soil particles in the clay soil after adding the recycled gypsum resulting in an increase in the cohesion strength between soil particles. The hardening between the soil particles and recycled gypsum is due to the change in chemical composition of bassanite ($CaSO_4 \cdot \frac{1}{2} H_2O$) to hydrate calcium sulphate ($CaSO_4 \cdot 2H_2O$) followed by water being absorbed from the clay soil, which reduced the voids between the soil particles and increase the soil strength. The chemical composition of the hydrate calcium sulphate as oxide contains a significant amount of calcium lime (Cao) which has been act like cohesive agent in soils because of its ability to increase the strength of cohesive (Bell, 1996). Finally, Gypsum contains a significant amount of calcium sulphate, when is mixed with soil, dissolve slowly and dissociates into Ca^{++} and $So4^{--}$ ions. Calcium positively charged and becomes attracted to clay particles, which having negative charges. This attraction between the soil particles and calcium, improves the bond between the soil particles and strengthens the soil.

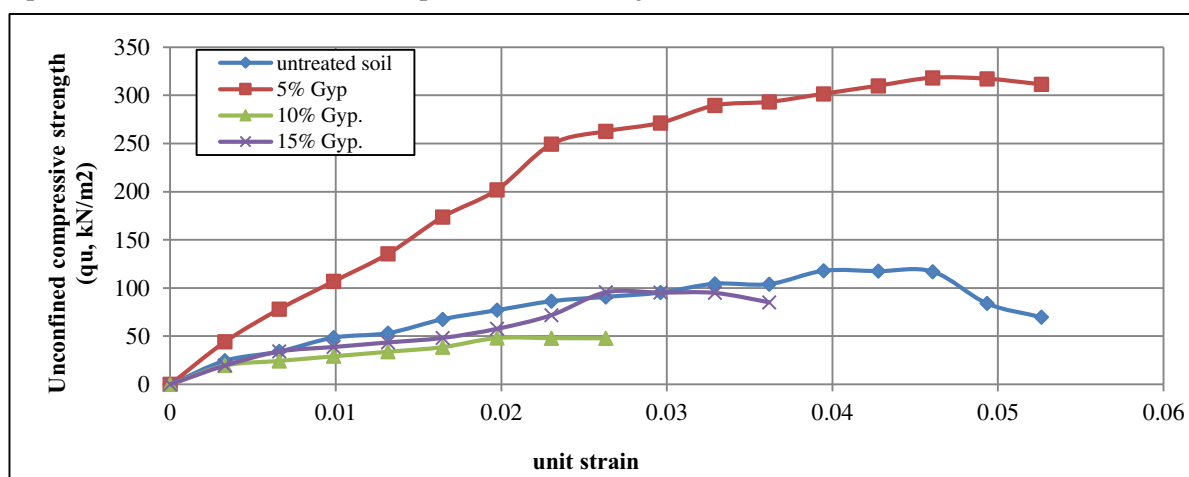


Fig. (9) Effect of gypsum content on the unconfined compressive strength.

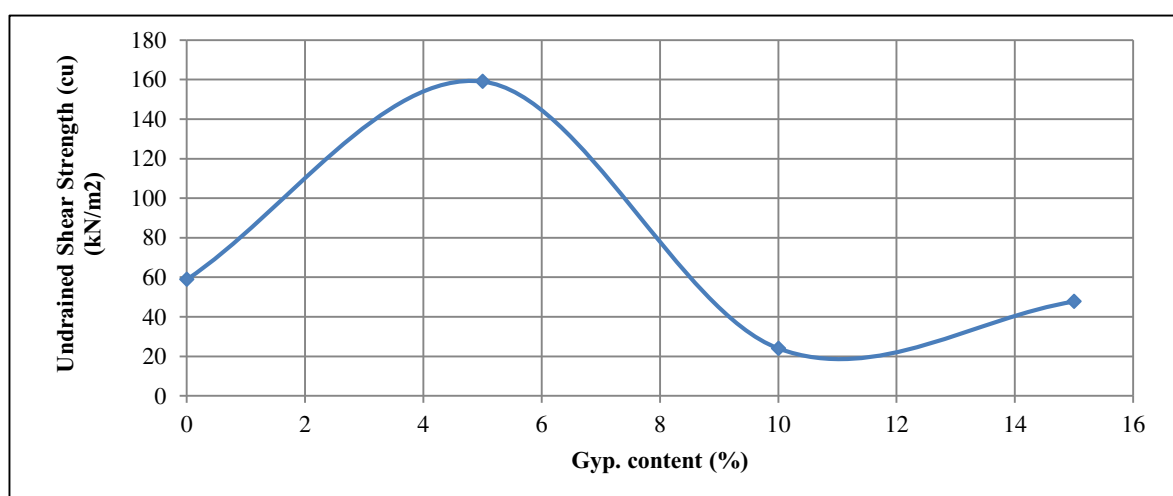


Fig. (10) Effect of gypsum fibers content on undrained shear strength of soil.

5.5. Consolidation test

This test is performed according to ASTM D 2435-02 Standard Test Method for One-Dimensional Consolidation Properties of Soils. Loading pressures are 25, 50, 100, 200, 400 and 800 kPa and reloading pressures are 800, 200 and 50 kPa. From e-log p relation, the compression index (C_c) and recompression index or swelling index (C_r) during unloading are determined at different gypsum contents. Fig. 11 shows the consolidation test results by relating e-log p with gypsum addition.

Fig. 12 shows The compression index (C_c) increase sharply up to 5% of recycled gypsum additive. This increment is reduced beyond 5%.

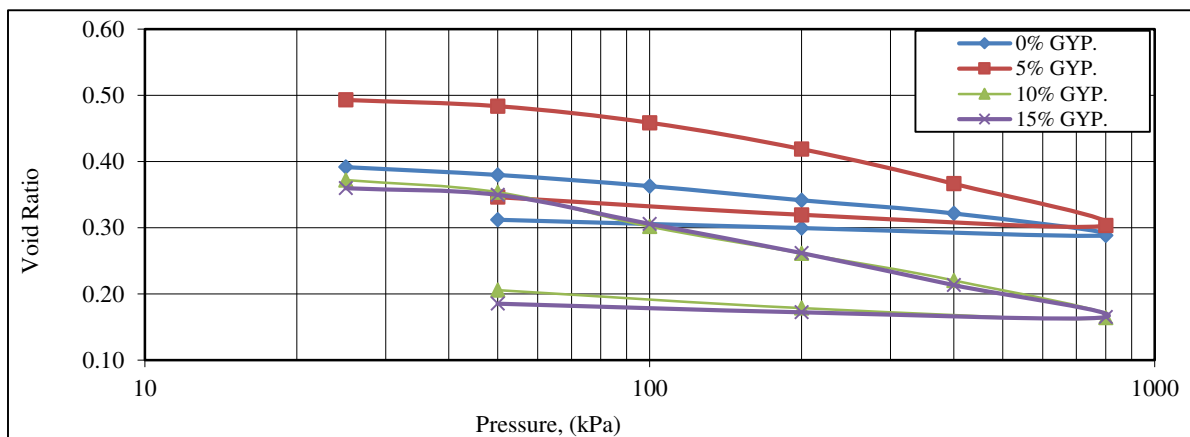


Figure (11) Relation of e-log p for untreated and treated soils with gypsum addition.

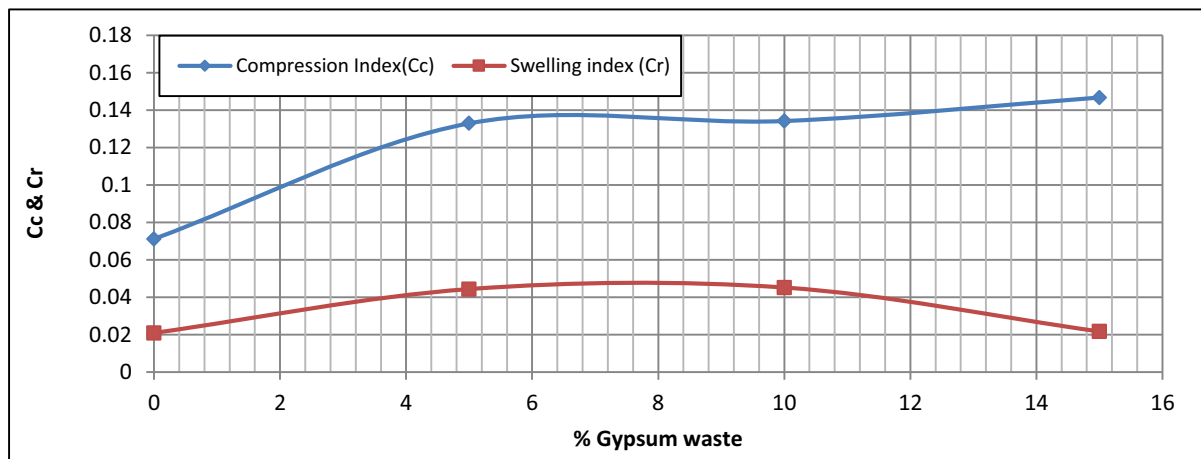


Fig. (12): The relationship between compression Index (C_c) and rebound (swelling) Index (C_r) with different Gypsum Content.

6. Effect of Recycled Gypsum additive on the Bearing Capacity

Construction on soft clay is a great challenge. Soft clays are available in the middle and southern parts of Iraq. Al-Basra governorate is one of the most regions in the ancient and modern Iraq. Al Basra is the most Socio-economic hub of the southern of Iraq and becomes an important commercial and industrial centre, which demands the construction of large structures such as electrical power stations, port platforms, and a huge oil tanks. Since the undrained shear, strength of base soil is low which restricts the construction of such type of structures. These problems can possibly be solved soil improvement, using recycled gypsum. The ultimate bearing capacity of soft clay can be compared

when with and without additive by using the following equation[12].

$$q_{ult} = CNc \quad (1)$$

$$q_{ult} = 5.7 Cu \quad (2)$$

Where N_c is the bearing capacity factor, and
 C_u is the undrained shear strength of soil

For oil tank, the processes of filling and empty occur rapidly, so this causes to use the undrained shear strength, which means that there is not enough time for excess pore water pressure to dissipate.

Case 1: The ultimate bearing capacity without soil improvement:

The maximum undrained shear strength ($C_u = 60 \text{ kN/m}^2$) so the

$$q_{ult} = 5.7 \times 60 = 342 \text{ kPa}$$

Case 2: with 5% recycled Gypsum the undrained shear strength ($C_u = 160 \text{ kN/m}^2$) so the

$$q_{ult} = 5.7 \times 160 = 912 \text{ kPa}$$

$$\text{Percentage of increase in bearing capacity} = \frac{912-342}{342} = 167 \%$$

$$\text{To find } q_{all} = \frac{q_{ult}}{2.5} = 137 \text{ kPa (without soil improvement)}$$

$$q_{all} = \frac{q_{ult}}{2.5} = 365 \text{ kPa (with soil improvement)}$$

If we compared these values with average oil tanks load

Average tank diameter = 21-46 m

The weight of tank = 1800 kN - 3600 kN

The height of oil in Tank = 16 m - 29 m

Unit weight of the oil = 11.1 kN/m³

Total weight = 1980 kN - 35600 kN

Pressure excretes under the tank vary from 5.7 kPa - 214 kPa

From these results, it is clearly shown that tanker with 46 m diameter cannot stand over soft clay without improvement with recycled Gypsum board because pressure due to the oil tank (214) and this is greater than the allowable load of soft clay (137kPa).

7. Conclusions

The main purpose of this work is to investigate and confirm the potential use of recycled gypsum as a stabilizer material for soft clay. Reducing the cost of soil improvement and in addition to improve the sustainability of the environment. Based on the results of the tests on strength, compressibility and durability, the following conclusions have been drawn:

- The effect of adding recycled gypsum beyond 5% causes an increase in the optimum moisture content and reached a maximum value by adding 15% recycled gypsum while there is a sharp drops in dry unit weight is beyond 5% recycled gypsum additive.
- By adding recycled gypsum up to 5%, there is a reduction in liquid limit while beyond this value; there is a great increase in liquid limit.
- The compression index (C_c) increase sharply up to 5% of recycled gypsum additive. This increment reduced beyond the 5% gypsum additive.
- The Percentage of increase in bearing capacity approaches 167% by using 5% Gypsum board as stabilized material compared with untreated one.

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