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Enhancing the Characteristics of Gypsum Soil by Adding Hydrated Lime and Cement

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ABSTRACT

Gypsum soil is highly vulnerable to moisture and water, which can cause disastrous and severe damage. Hence, the effect of adding cement and hydrated lime on the collapse and mechanical properties of the components was examined upon being exposed to water. Cement and hydrated lime are widely used to improve the geotechnical properties of problematic soils due to their cheap price and local availability. The gypsum soil samples were mixed with cement and hydrated lime in proportions of 4%, 8%, and 12%, proportional to the dry weight of the soil. The resulting mixtures were cured for 7 days and tested to evaluate their collapse behavior and shear strength parameters properties. The results showed that the addition process enhanced soil properties, reduced collapse, increased cohesion, and increased internal friction angle. The collapse of the gypsum soil decreased by 55.91%, 83.3%, and 92% for soil treated by cement, while it decreased by 47.1%, 76.82%, and 90% for soil treated with lime when the soil treated by 4%, 8% and 12% of additive, respectively. The direct shear tests showed a significant increase in the cohesion of gypsum soil after adding cement. The cohesion of the soil increased by 33.5%, 90%, and 86.5%, for soil treated by cement, while it decreased by 28%, 59%, and 65% for soil treated by lime when the soil treated by 4%, 8% and 12% of additive, respectively. The angle of internal friction rose 2.1%, 8.4%, and 18.7% for soil treated with cement and 1%, 6%, and 5.2% for soil treated with lime when the soil was treated with additive concentrations of 4%, 8%, and 12%, respectively. The ideal proportion of additions ranged from 8% to 12%, and the inclusion of cement proved to be more efficient than lime in enhancing the engineering characteristics of the gypsum soils.

1. INTRODUCTION

Gypsum soils extend approximately 100 million hectares globally, equivalent to one million square kilometers. These soils are found in various regions such as Iraq, Syria, Libya, Somalia, Algeria, Sudan, Argentina, Australia, Spain, the former USSR, and other semi-arid and arid nations with an annual rainfall of fewer than 500 millimeters [1]. Gypsum soils typically exhibit stiffness when they are dry. Nevertheless, these soils might have significant effects due to fluctuations in water content resulting from alterations in their water table or water penetration. This can cause the gypsum to dissolve, which in turn leads to the creation of cracks and empty spaces that increase the permeability of gypsum soils. In addition, these soils exhibit more than two stages when they are not fully saturated, and the pressure of the water in the pores is less than the pressure of the air in the pores. The main geotechnical concern related to these soils is that moisture leads to a fall in pore pressure, which in turn generates concentrated and effective stresses, changes in volume, and a loss in the soil's shear strength. Water can diminish the bonds between soil particles, resulting in a denser arrangement [2]. In arid conditions, the soil located close to the surface may experience negative pore-water pressure and become desaturated.

Saturated material is also produced by the remolding, excavation, and recompacting of soil. These substances make up a sizable fraction of soils, which are usually difficult to examine using conventional soil mechanics [3].

Therefore, any changes in the physical characteristics of these soils will have an impact on the stability and efficient functioning of the foundations of buildings and earth projects, including road dams and hydraulic systems [4].

Due to urban development and expansion in Iraq in recent decades, large areas are now covered with gypsum soil. Many strategic projects have been completed in these areas, although some were delayed because of worries regarding building on gypsum soil, which can cause collapse when water passes through it. Hence, the high level of gypsum in many parts of the country has inspired researchers to investigate this particular soil type.

Gypsum soils demonstrate quick and considerable settlement (collapse) upon adding water due to water-soluble minerals and small quantities of clay that bond the loose arrangement of their particles. Unfortunately, civil engineers have faced multiple issues related to gypsum soils, including failures in hydraulic structures, collapse and cracking of residential buildings, and settlement of pavement layers [5-9].

Many investigators have considered the performance of these soils and recommended various substances of additives. Multiple methods, including chemical stabilization, can improve the geotechnical characteristics of gypsum soils while avoiding damage caused by gypsum failure. Some of these compounds include chloride of barium, carbonate components, lime, silica fume, cement, iron fillings, and kaolin [10-14]

Regrettably, gypsum soil has a decline in durability that can lead to further problems when exposed to water over some time. These issues include the creation of minerals that expand, causing soil heaving and resulting in the breaking of pavement projects. These problems result in diminished stability and reduced bearing capacity [15-17].

Several researchers have studied the effect of adding lime and cement on the physical and geotechnical properties of gypseous soils [18].

Ghiassian and Jahanshahi [19] performed a two-step experiment to examine the effects of combining lime with sulfate soil. The researchers determined that the mineral called formation, which has harmful consequences, is mitigated by completing some swelling procedures between the two steps. Consequently, adding lime during the second step allows the stabilized soil to achieve a steady state earlier.

AL-Numani [20] conducted a study on soils obtained from a specific area in the Al-Tar region, located to the west of the town of Al-Najaf, which had a gypsum level of 35%. An experimental examination was done to investigate the effect of three different additions on the compaction characteristics of gypsum soil. This experiment employed cement, ceramic, and a composite of both kinds of additives. According to the results, the compaction characteristics test of the specimen shows the greatest improvement when a combination of cement and ceramic is added. The highest dry density exhibits a positive correlation with the rise in mixing content, whereas the optimum amount of water has a negative impact. Based on the findings, the highest density of dry gypsum soil treated with ceramic material rises as the amount of ceramic content increases up to 8% but, after that, drops.

Awn et al. [21] used a laboratory model test to examine the possibility of improving gypseous soil by decreasing its collapsibility when wet. This was achieved by adding Portland cement in various percentages: 1.5%, 4%, 6%, 7.5%, and 10%, to gypsum soil with densities of 14 kN/m^3 and 11 kN/m^3. According to laboratory test results on model samples, soaking gypsiferous soil models in water significantly reduces their collapsibility after they have been treated with cement and compacted. When 10% cement was added to the treated model, the percentage of collapsibility decreased to 95%, and this drop increased as soil density reached 14 kN/m^3.

Aldaood et al. [22] employed soil with a 20% gypsum content that was acquired from a location close to the Al-Haer area, around 80 kilometers from Mosul city. As per the Illinois procedures, the soil samples were treated with an optimal percentage of lime (4%). Every stabilized soil sample conducted a 2-day curing process at 490°C. The findings show that the unconfined compressive strength reduced during the soaking process and continued to decline as the soaking time increased. For unstabilized soil samples, the leaching impact results in a constant rise in permeability values; however, for soil samples stabilized with lime, the effect is negligible.

Aldaood et al. [23] analyzed soil samples that underwent lime treatment and were created with different gypsum concentrations (0%, 5%, 15%, & 25%). Evaluated the samples at various curing durations and temperatures. The results of the experiment conducted on untreated gypsum soils demonstrated that the addition of gypsum improves both the soil's ability to expand and its resistance to compression without confinement. The gypsum percentage in lime-treated gypsum soil exerts a substantial influence on its geotechnical characteristics. Likewise, the conditions under which the curing process takes place also play a part in determining these features. When the curing temperature is increased from 20°C to 40°C, the unconfined compressive strength of soil samples that have been cured for 28 days nearly doubles.

Ibrahim et al. [24] recognized that all three additives (hydrated lime, hydrated calcium chloride, and kaolin) were effective in reducing the collapsibility of the soil. However, lime was observed to have a more pronounced effect in decreasing this property than the other two additives' impact of including to reduce the collapsibility of gypsum soil.

Kiliç et al. [25] discovered that the inclusion of gypsum may have been a more pragmatic option. Nevertheless, lime proved to be advantageous in a study examining the impact of lime, gypsum, and lime-gypsum combinations on the swelling and compression strength of extremely malleable clays that were compacted under ideal conditions.

Alsafi et al. [26] conducted an assessment of the stabilization of gypsum soil by utilizing Portland Cement, geopolymer binder, and fly ash. The findings indicated that fly ash is a superior stabilizing agent compared to Portland Cement. The increased strength and resistance to sulfates observed in fly ash can be related to its calcium-free structure, which distinguishes it from Portland Cement.

Al-Hadidi and AL-Maamori [27] study was conducted on a sample of soil at Karbala Governorate that had a gypsum concentration of 42.55%, which was combined with different quantities of cement (2, 3, 5, 8, 10, 13, and 15) % from weight and treated with soil cement. The resulting mixture was compressed to a max density of 16.5 kN/m3 with an optimal water content of 12.8% to conduct collapse and settling investigations. The investigations were conducted in a flume with an average speed of 0.148 m/sec and 10% cement, resulting in an 86.54% drop in collapsibility, while the soil gypsum remained steady after 28 days. Furthermore, the study indicates that a minimum time frame for treatment of 14 days is required.

An experiment was undertaken to determine the compressibility and collapsibility of Basrah gypsum soil [28]. The sand covering the top layer (up to 1m) of AL-Brgsia and AL-Zubair contained 63% and 34% gypsum, respectively. The dirt was "collapsible". The soil has been improved by cement. This study investigates if cement concentrations of (2, 4, 8, 10, and 12) % can improve certain soils. The behavior and the impact of untreated and treated gypsum soil samples on physical characteristics, collapsibility, and compressibility have been examined using 12 models. The addition of 12% cement to AL-Brgsia and AL-Zubair soil reduces collapsibility by 87% and 92%, respectively.

Aldaood et al. [29] analyze the influence of various proportions of gypsum and lime in the unconfined compressive strength (UCS) of soil with a high ratio of small particles. The mineralogical and microstructural studies employed X-ray diffraction, microscopy with scanning electrons, and mercury intrusion porosimetry to establish the correlation between the mechanical properties and the alterations in the microstructures. The soil was treated with different percentages of gypsum and dry soil weight, and the percentages were (0, 5, 15, 25) %, respectively, and then it was treated with three percentages of lime (3, 5, 10) %. The samples were then allowed to undergo curing for 2, 7, 28, or 180 days, respectively, at 20°C. The results showed that the process of adding lime, along with the duration of the treatment process, affected the mechanical properties of the soil sample when gypsum was present and that the optimal limit for improving the unconfined compressive strength (UCS) is 5% for the gypsum and lime content. Moreover, this barrier reduced the improvement in UCS.

During this research, work will be done to study the collapse coefficients, shear strength, and internal friction angle of gypsum soil treated with cement and hydrated lime with different addition ratios: 4, 8, and 12%, respectively, as the natural and treated soil will be compressed to its maximum density.

2. MATERIALS

2.1 Gypseous soil

To accomplish the research goal, the gypsum soil used in this study comprises naturally disturbed soil samples. The samples were obtained from a specific area in the Salah Al-Dean region of Iraq and had a gypseous content of 48%. The specimens were obtained from a depth of 1 meter below the intact soil surface. The soil in the location exhibited a density of 14.8 kilonewtons per cubic meter and a moisture content of 3.5%. Subsequently, the soil samples were carefully sealed in plastic bags and transported to a laboratory for analysis.

2.2 Hydrated lime and cement

Hydrated lime: Hydrated lime $Ca(OH)_2$ was obtained from Al-Mishraq Industrial compound in Nineveh Governorate and has been tested in chemical engineering labs at Tikrit University. Table 1 presents the exact chemical structure of the hydrated lime utilized in the investigation, while Figure 1 displays an illustration of hydrated lime.

Cement: Portland Cement is a common type of hydraulic cement widely used in construction and civil engineering. Portland Cement mainly comprises clinker and other raw materials, including limestone and clay. Clinker is the main ingredient that makes up Portland Cement, a powder produced by grinding a mixture of limestone, clay, and coal in a rotary kiln at extreme temperatures. Table 2 displays the precise physical properties of the cement utilized in the research and has undergone testing in chemical engineering laboratories at Tikrit University. Figure 2 depicts an image of Portland Cement utilized in the investigation.

Table 1. Chemical composition of Hydrated lime

Components	Percentage %
$Ca(OH_2)$	71.3%
CaO	6.1%
$CaCo_3$	6.2%
Al_2O_3	0.17%
Fe_2O_3	0.04%
SiO_2	11.1%
MgO	4.19%
H_2O	0.09%

Figure 1. The hydrated lime

Table 2. The physical specifications of the cement

Test	Result
Softness (m^2/kg)	255
Initial setting time (min)	52.8
Final setting time (hr)	7.1
Resist the pressure for three days	20.5
Resist the pressure for seven days	26.2

Figure 2. The Portland cements

3. EXPERIMENTAL WORK

3.1 Compaction test

ASTM 698 performed Procter compaction testing. The mold used has a diameter of 10 cm and a height of 16.5 cm. The 2.5 kg hammer was dropped from a height of 30.5 cm and hit each of the three layers of samples 25 times.

3.2 Physical and chemical properties of gypseous soil

The prepared samples received analysis for physical characteristics employing standardized soil tests. When performing soil tests, ASTM requirements are followed. The sieve analysis in Figure 3 was carried out according to the ASTM D422-02 standard to classify the soil.

The soil gypsum percentage was calculated using Eq. (1) [30].

$$x = \frac{w_{45^oc} - w_{45^oc}}{w_{45^oc}} * 4.778 * 100 \quad (1)$$

where, x=content of the gypsum; $w_{45°C}$=At 45°C, the sample weight; $w_{105°C}$=At 105°C, the sample weight.

The pH and total sulfate quantity were determined by tests conducted at Tikrit University's laboratory unit for chemical engineering. In Table 3, we can see the soil's untreated physical and chemical properties.

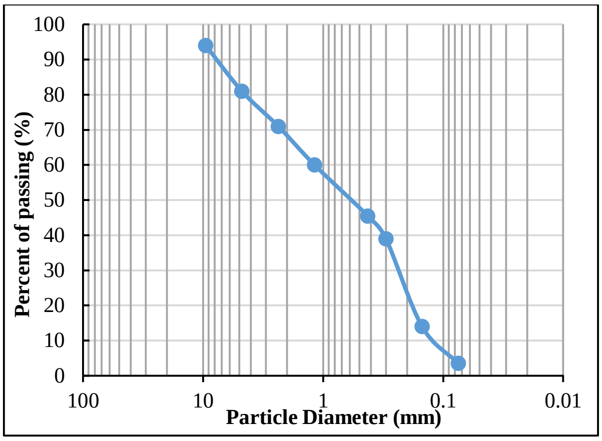

Figure 3. Gypseous grain size distribution

Table 3. The properties of untreated soil

Properties		Value	Standard
Moisture content, (ω)%		3.5	ASTM D2216 (2010)
Specific gravity (G_s)		2.67	ASTM D854 (2014)
Atterberg limits	Liquid limit (L.L) %	31	ASTM D4318-00
	Plastic limit (P.L) %	N.P	
	Plasticity index (P.I) %	------------	
Minimum dry density, (γ_{min}) kN/m³		12.46	ASTM D4254 (2016)
Maximum dry density, (γ_{max}) kN/m³		17.08	ASTM D4253 (2016)
Field density, (γ_f) kN/m³		14.8	-
Relative density, (Dr) %		61.8	ASTM D4254 (2016)
Total sulphate content (SO_3) %		37.5	BS 1377-3 (1990)
pH value		8.0	ASTM D4972 (2013)
Soil Classification According to (USCS)		S.P. (poor-grade sand)	ASTM D2487 (2007)

3.3 Collapse test

A single collapse test (SOT) was performed on naturally compacted and treated gypsum soil samples using an oedometer, following the ASTM D5333-03 standard. The objective was to determine the soil's collapse potential (Cp) by examining its response to different ratios of hydrated lime and cement. Refer to Figure 4 for further details.

The purpose of the evaluation was to examine the compressibility characteristics of gypsum soil using the oedometer collapse test. To calculate the dry weight of the specimens, a drawing with a 60mm diameter and 20mm height ring was used. The samples were immersed in water at a pressure of 200kPa for 24 hours, and the load was released whenever the static tension surpassed 800kPa. Once the sample level stabilized, the model was submerged and left alone. The sample with the highest weight underwent the fusion test. Table 4 shows the values of (Cp) as the predicted probability of collapsing, determined by plotting the voids ratio (Voids Ratio, e) against the logarithm of pressure (Log p) using Eq. (2) by Jennings and Knight [31].

$$C.p. = \frac{\Delta e}{(1 + e_o)} * 100 \tag{2}$$

where, Δe=change in void ratio; e_o=initial void ratio.

Figure 4. The oedometer test device

Table 4. The degree of collapse sensitivity at a stress level of 200kPa, as published by Jennings and Knight [33]

Collapse Potential (%)	Severity of Problem
0	No problem
0.1-2	Slight
2.1-6	Moderate
6.1-10	Moderately Severe
> 10	Severe

3.4 Direct shear test

The test was carried out according to the ASTM D3080-98 protocol for shear tests (Figure 5).

3.5 Samples preparations

After a specific volume of soil was dehydrated in an oven, it was manually combined with an equal quantity of additives and water through mechanical mixing. In the case of untreated soil, water is introduced to the soil and allowed to sit for 24 hours within a sealed plastic bag to achieve a uniform mixture. In contrast, for treated soil, the mixture is allowed to rest for one hour to undergo a mellowing period before compaction is carried out [32]. Light tamping was used to compact the soil until the sample's height was equal to the specified mold height. Subsequently, the manufactured samples were enveloped with a dual layer of nylon and left to undergo a curing procedure at a temperature of 25 °C for seven days.

Figure 5. The device for the direct shear box test

4. RESULT AND DISCUSSIONS

Gypsum soil collapse, or "gypsum collapse", is a distinct engineering phenomenon in soils with a high content of gypsum. When gypsum comes into contact with water, it has a propensity to dissolve and break down, resulting in a reduction in soil height, deterioration of its structure, and collapse. Gypsum soil often has large quantities of gypsum or gypsum salts, rendering it subject to collapse and fracture upon absorbing water. This results in the gypsum structure's disintegration and loss of resilience and hardness.

A study has been carried out to determine the degree of collapse and shear strength parameter in treated gypseous soils and compare the results with that of natural gypseous soil. Collapse tests were carried out on (7) soil samples separated into untreated and treated groups samples with different percentages of hydrated lime and cement. (4%, 8%, 12%). The results of collapse of the soil (Collapse Potential), are shown in Table 5 and Figures 6 to 11. It could be noticed that as the cement and hydrated lime content increase, the collapse potential decreases. Specifically, the decrease percentage when adding cement is 56%, 83%, and 92%, respectively, while the corresponding values for adding Hydrated lime are 47%, 77%, and 90%, respectively. The reduction in collapse potential for soil treated with cement is higher than that for soil treated with hydrated lime. The highest rates of reduction in collapse potential for both additives when additive content of 12%.

Cement is greater than Hydrated lime in the ability to enhance and reduce the collapse of gypsum soil. The reason for cement's effectiveness is its capacity to chemically react with the earth, leading to the creation of robust buildings and increased resistance to collapse. Nevertheless, treated with lime also significantly improves and reduces soil collapsibility, although to a slightly smaller degree than cement.

Table 5. Summary of the results of the Oedometer test

No.	Type of Soil	Dry Unit Weight (kN/m^3)	Cp%	Degree of Collapse
1	Untreated soil	14.79	7.94%	Moderately severe
2	Soil+4%Cement	15.14	3.5%	Moderate
3	Soil+8%Cement	15.407	1.32%	Slight
4	Soil+12%Cement	15.68	0.65%	Slight
5	Soil+4%Hydrated lime	14.59	4.2%	Moderate
6	Soil+8%Hydrated lime	15.2	1.84%	Moderate
7	Soil+12%Hydrated lime	15.37	0.8%	Slight

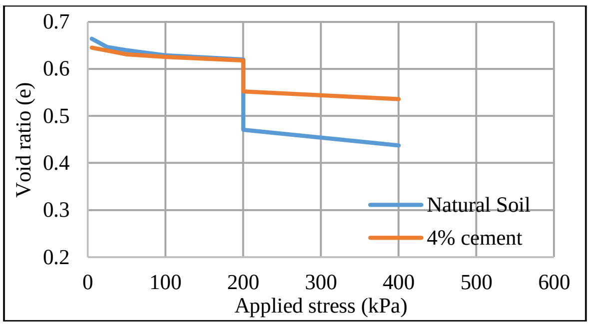

Figure 6. The test results for soil treated with 4% cement

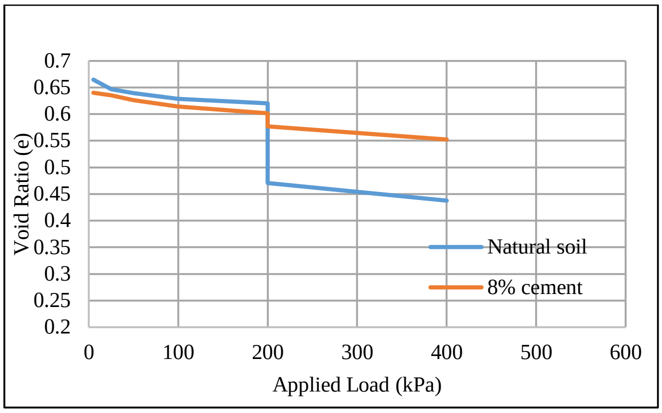

Figure 7. The test results for soil treated with 8% cement

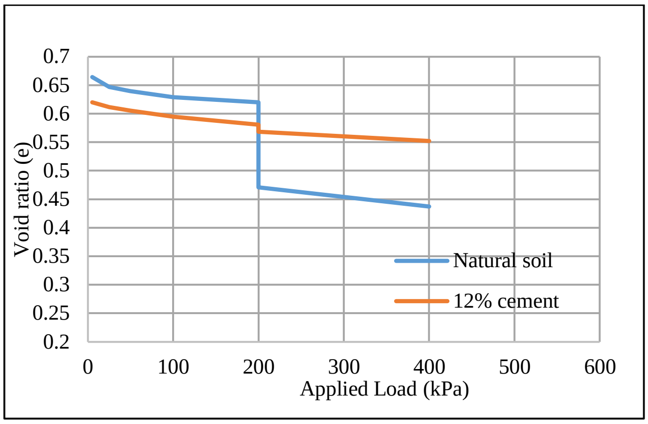

Figure 8. The test results for soil treated with 12% cement.

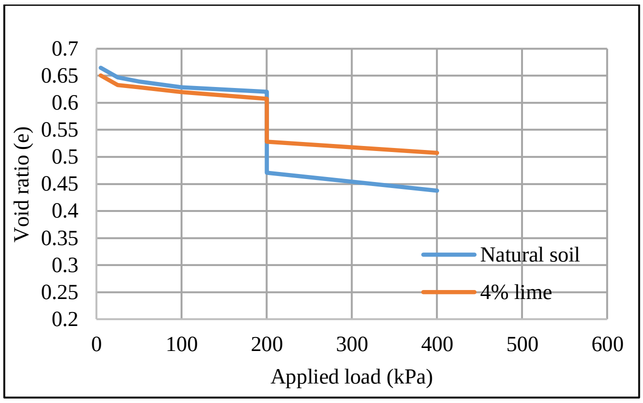

Figure 9. The test results for soil treated with 4% lime

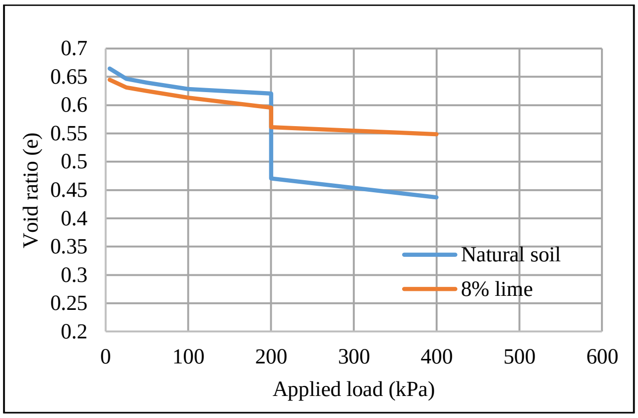

Figure 10. The test results for soil treated with 8% lime

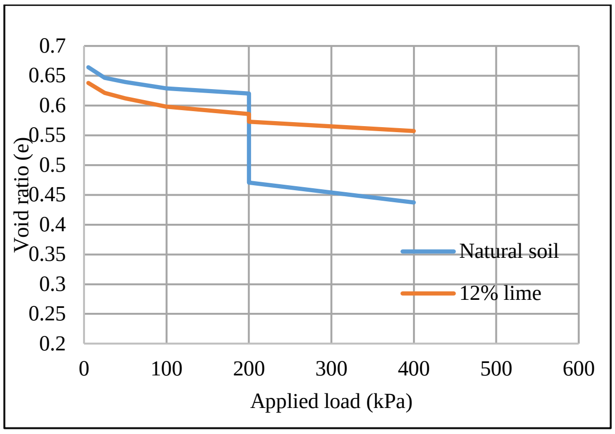

Figure 11. The test results for soil treated with 12% lime

Table 6. Summary of the results of the Direct shear test

No.	Type of Soil	Cohesion (kPa)	Internal Friction Angle (ϕ°)
1	Untreated soil	25.6	37.3
2	Soil + 4%Cement	34.17	38.09
3	Soil + 8%Cement	48.65	40.44
4	Soil + 12%Cement	47.76	44.29
5	Soil + 4%Hydrated lime	32.76	37.7
6	Soil + 8%Hydrated lime	40.71	39.52
7	Soil + 12%Hydrated lime	42.24	39.26

The soil's behavior under shear loading was assessed by conducting direct shear tests to investigate the effect of incorporating hydrated lime and cement. Seven soil samples were tested, and they were divided into two groups: untreated samples and treated samples. The treated samples were mixed with different proportions of hydrated lime and cement. The values are (4%, 8%, 12%).

Results of the combination of both untreated and treated gypsum soil are presented in Table 6 and Figure 12. It is apparent that when the quantities of cement and hydrated lime rise, the cohesion of the soil increases. The rate of increase in cohesion for soil treated with cement was 33.5%, 90%, and 86.5%, while for the soil treated with hydrated lime was 28%, 59%, and 65%. The soil cohesion exhibited the highest rate of improvement at a ratio of mixing of 8% cement, after which it declined gradually. The soil treated using hydrated lime got the best cohesive value when it was blended with a concentration of 12%. After comparing the percentage increases in cohesion achieved using the two materials, it was observed that the greatest improvement in cohesion was achieved for the soil treated with 8% cement by 90%, while for the soil treated with hydrated lime the greatest improvement of 65% was achieved with amount of lime of 12%. Cement is more effective than lime in this matter.

Adding materials such as cement and hydrated lime affects the internal friction angle of gypsum soil. The results of the angle of internal friction of natural and treated gypseous soil are shown in Table 6 and Figure 13; it is evident that as the proportions of cement and hydrated lime increase, the angle of internal friction of the soil increases. The rate of increase in the angle of internal friction for soil treated with cement was 2.1%, 8.4%, and 18.7%, while for the soil treated with hydrated lime was 1%, 6%, and 5.2%. The angle of internal friction showed the greatest enhancement rate at a mixing ratio of 12% cement. Regarding the soil treated with hydrated lime, it was observed that the highest angle of internal friction value was achieved when the soil was mixed with 8% hydrated lime and decreased with a further increase in lime. After comparing the percentage increases in the angle of internal friction achieved using the two materials, it was observed that the greatest improvement in the angle of internal friction was achieved for the soil treated with 12% cement by 18.7%, while for the soil treated with hydrated lime the greatest improvement of 6% was achieved with the amount of lime of 8%.

After studying the effect of cement and hydrated lime on the shear strength parameter of gypseous soil, it was apparent that adding these additives resulted in a strong bound and cohesive structure when mixed with water and gypsum soil. This enhances the cohesion of particles in the soil, reducing the vulnerability of gypsum to breakdown caused by water. This behavior can be explained by the process of cement and lime particles filling the holes in the soil structure. This leads to an increase in the strength of the bonds among the soil particles, as well as a covering of the soil particles, resulting in a reduction in the dissolution of gypsum. The vacancy ratio of untreated gypsum soil is 0.664. Subsequently, the void ratio of the treated soil was gradually reduced by augmenting the proportion of additional material till it achieved its utmost decline at 8 to 12% concentration of the additive. The void ratio volume in the soil structure may be reversed when various percentages of additives are present. The presence of fine materials, such as lime and cement, in gypsum soil (sandy) prevents an adequate description of the soil's behavior just based on the total void ratio. This behavior can be ascribed to the fact that, until a certain amount of addition concentration, the addition material occupies the vacant spaces and has minimal effect on the mechanical characteristics of the treated soil mix.

Cement showed greater effectiveness in increasing the shear strength parameter of gypsum soil compared to hydrated lime, owing to its chemical interaction with the soil, resulting in the development of robust and durable structures. Nonetheless, hydrated lime significantly influences soil characteristics and particle cohesion, although to a slightly smaller extent than cement.

The enhancement of lime treatment is accomplished by two fundamental chemical reactions: one that occurs in the short term and another that takes place over a more extended period. The initial reactions are the exchange of cations, flocculation/aggregation, and carbonation, which reduce the soil's elasticity and improve its manipulation. The pozzolanic reaction can result in a lasting effect where the calcium in the lime interacts with the alumina and silica in the clay to form stable compounds, such as calcium alumina-silicate hydrates (CASH), calcium aluminate hydrates (CAH), and calcium silicate hydrate (CSH). The factors above can be the primary cause of the soil's increased strength, improved compressibility, and changes in its volume properties [33, 34]. Following treatment, the gypsum soil promptly exhibits a captivating assortment of engineering properties and behaviors.

Consoli et al. [35] discovered that the addition of cement to sandy soil, at a proportion of up to 10% by weight of dry sand, substantially enhanced its rigidity and maximum strength, causing the sand to exhibit a more scientifically brittle behavior.

The rate of cohesiveness increase following soil treatment exceeds that of the angle of internal friction. This behavior can be attributed to the presence of an additional substance that covers and surrounds the soil particles. This substance decreases the interaction and friction between the particles, hence reducing the rate at which the angle of internal friction inside the soil structure increases.

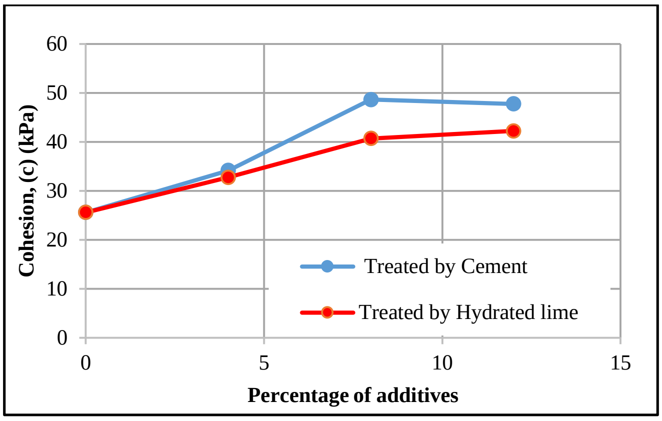

Figure 12. The cohesion test results of soil treated with cement and hydrated lime

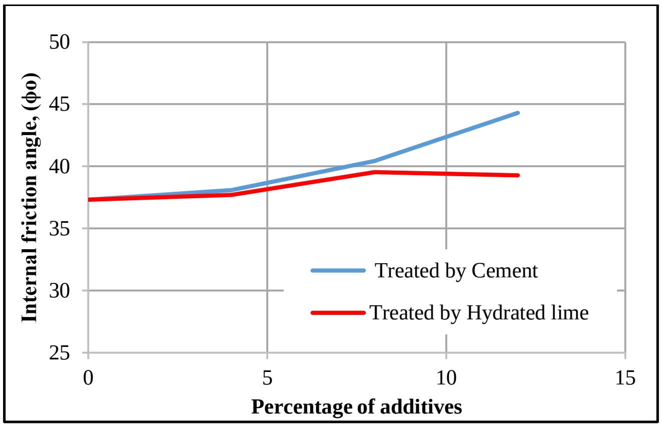

Figure 13. The internal friction angle test results of soil treated with cement and hydrated lime

5. CONCLUSIONS

The research that was conducted examined the impact of additions on gypsum soil, explicitly investigating the varying quantities of cement and hydrated lime. Experiments were performed on gypsum soil to quantify the extent of its collapse, cohesiveness, and angle of internal friction for each addition case. The samples that were treated with additives conducted collapse as well as direct shear tests to analyze variables and their alterations. The results demonstrated diverse enhancements in the outcomes achieved by using cement and hydrated lime. The findings can be briefly outlined as follows:

(1) The addition of cement and hydrated lime to the gypsum soil effectively decreased the possibility of collapse. The most substantial enhancement was observed when cement was applied at a concentration of 12%, resulting in a 92% improvement. Similarly, soil treated with 12% lime exhibited a 90% improvement rate.

(2) Demonstrated that the inclusion of cement has a clear and essential impact on the cohesion of gypsum soil. The optimal soil cohesion enhancement was attained with a cement mix ratio of 8% and a soil content of 90%. The soil treated using hydrated lime showed an impressive rise of 65% when a mix ratio of 12% hydrated lime was used. It can be observed that cement is more efficient than hydrated lime in this regard.

(3) Adding cement and hydrated lime was found to affect the internal friction angle of the gypsum soil. The highest enhancement rate was 18.7% for gypsum soil when adding 12% cement, while the highest enhancement rate was 6% when adding hydrated lime with an 8% mixing ratio.

(4) In all examined situations, the impact of hydrated lime was consistently lower than that of cement, with various degrees, at different levels of addition.

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