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Optimizing Different Gypseous Soil Characteristics Incorporating Clayey Soil

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Abstract

Gypsum soil is classified as problematic because it contains gypsum, a soluble substance in the presence of water. Therefore, it is recommended that it be improved before construction. This research examines the effect of clayey soils on enhancing the properties of gypseous soils. Two soil samples, designated as Soil 1 (with a gypsum concentration of 35.4%) and Soil 2 (with a gypsum content of 12.3%), were obtained from Al Najaf City, Iraq, and subjected to laboratory testing. The study investigates the use of cost-effective, locally available clayey soil to improve the engineering characteristics of gypseous soils, thereby mitigating the adverse effects of wetting. The experimental program encompassed a compaction, compressibility, and shear strength test. To assess the impact of clayey additives, gypseous soil was treated with varying percentages of clayey soil content (5% and 10%), and tests were conducted on both treated and untreated gypseous soil samples. The results indicated that using 10% clayey additives could decrease the collapse potential by 55% and 39% for Soil 1 and Soil 2, respectively. Additionally, the clayey additives significantly affected cohesion, with an enhancement percentage of 625% and 1315% under soaking conditions at 10% clayey additives for Soil 1 and Soil 2, respectively.

Keywords: Gypseous Soil, Clayey Additives, Collapse Potential, Cohesion, SEM

تحسين مختلف من الترب الجبسية باستخدام التربة الطينية

زين العابدين حسين عطا , عبد العزيز عبد الرسول عزيز

الخلاصة:

تصنف التربة الجبسية على أنها إشكالية لاحتوائها على الجبس وهي مادة قابلة للذوبان في وجود الماء. ولذلك فمن المستحسن أن يتم تحسينه قبل البناء.هذه الدراسة تختبر تأثير استخدام التربة الطينية لتحسين خواص التربة الجبسية. تربتان اثنتان حيث تم تسمية التربة الاولى (التي تحوي على جبس بنسبة 35.4%) و التربة الثانية (التي تحوي على جبس بنسبة 12.3%) التي تم اخذها من مدينة النجف, العراق و تم اخضاع تلك الترب الى مجموعة من التجارب المختبرية. تختبر هذه الدراسة استخدام تربة طينية محلية متوفرة و غير مكلفة لتحسين الخصائص الهندسية للتربة الجبسيةو و بالتالي تحديد من تأثير الغمر. يتضمن برنامج البحث فحص عينات التربة بفحص الحدل و الانضغاطية و فحص قوة القص. لتحديد تأثير اضافة الطين, الترب الجبسية تم معالجتها بمختلف نسب من محتوى الطين (5% و 10%) و الفحصوات تمت لتربة الجبسية المحسنة و غير المحسنة. الاتنائج بينت ان استخدام 10% من الطين المضاف يمكن ان يقلل من مخاطر الانهيار بنسبة 55% و 39% لتربة الاولى و التربة الثانية على توالي. اضافة الى ان اضافات التربة الطينية بينت تأثير ملحوظ بالنسبة لخاصية الالتصاق بنسبة التحسين 625% و 1315% تحت تأثير الغمر عند 10% من الطين المضاف للتربة الاولى و التربة الثانية على التوالي.

1. Introduction

Gypseous soil is frequently found in arid and semi-arid regions. In dry conditions, gypsum serves as a binding agent between soil particles. However, the presence of water, such as an increase in groundwater levels or water seepage from canals, can lead to the dissolution of gypsum, weakening and potentially

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causing the collapse of structures constructed on or within such soils [1, and 2].

Various structural failures have been reported in Iraq in different locations and provinces. One example of these failures is the ongoing dissolution of gypsum beneath the Al-Mosul dam in northern Iraq. Additionally, numerous issues resulting from gypseous soils have been reported worldwide, including in the United States, the Arabian Peninsula, Russia, Spain, and Armenia [3, and 4].

It is widely acknowledged among researchers that stabilizing and enhancing gypseous soils is necessary before utilizing them in geotechnical applications. The adverse impacts of gypsum on soil properties can be mitigated through a variety of methods. However, the selection of a stabilization method for problematic soils is contingent upon factors such as site conditions, cost of implementation, availability of additive materials, design specifications, and environmental implications [5, 6 and 14].

Clay is utilized as an amendment for gypseous soil due to its ability to induce agglomeration and flocculation. This occurs as a result of the interaction between clay particles and gypsum, leading to the formation of cementation linkages, which render the clay particles less malleable, [7]. Numerous researchers have begun utilizing clay as a nanomaterial to explore its potential to mitigate the impact of gypseous soil. These researchers have employed nano clay and nano metakaolin as additive materials and have found that the likelihood of collapse in gypseous soil decreases with higher nanomaterial content. Additionally, the shear strength increases with greater nanomaterial content and longer curing periods, [8]. The researcher reached 77% as an improvement in parentage in gypseous soil collapsibility for 4% of nano clay additives, [9, and 10]. The scientist discovered that the use of nano clay material leads to an increase in shear strength properties (c and φ), optimal water content, and liquid limit. The addition of 4% nano-clay causes a substantial 53% reduction in the collapse index, as well as a 311% increase in soil cohesion and a 30% increase in the angle of internal friction, [11].

This study seeks to explore the use of natural clay soil as a cost-effective material for enhancing soil properties.

2. Materials and Methods

2.1 Soil Sampling and Properties

Natural gypseous soils (with a gypsum content of 35.4 %, 12.3%) were collected from two locations in Najaf city (Site 1: 32^{0} 8'13.38 "N, 44^{0} 17' 57.28" E), (Site 2: 31^{0} 59'14.93 "N, 44^{0} 20' 19.79" E) Najaf province. The sample was obtained from a depth of (1.0 to 1.5) m below the "top ground surface". The soil was transported to the laboratory where it underwent a drying process and was finely broken down to facilitate various physical and chemical tests, as detailed in Table 1. Additionally, Figure 1 and 2 depicts the granular distribution of the gypseous soil, and Figures 3 and 4 the SEM photos for both samples.

Table (1): Gypseous soil sample characteristics

Property	S1 Value	S2 Value	Standard
Physical test result for soil			
Moisture content [%]	4.00	3.00	ASTM D2216
Maximum dry density [kN/m^3]	17.10	17.44	ASTM D698 (2012)
Minimum dry density [kN/m3]	15.05	16.83	ASTM D698 (2012)
Optimum moisture content [%]	8.10	13.00	ASTM D698 (2012)
Liquid limit [%]	-	-	ASTM D4318
Plastic limit [%]	-	-	ASTM D4318
Plasticity index, PI%	NP	NP	ASTM D4318
Specific gravity, Gs	2.50	2.59	ASTM D854, B.S1377 1990
Effective Size, D10	0.118	0.143	ASTM D 422
D30	0.310	0.330	ASTM D 422
D60	0.711	0.718	ASTM D 422
Coefficient of Uniformity [CU]	6.030	5.012	ASTM D 422
Coefficient of Curvature [CC]	1.144	1.061	ASTM D 422
Gavel [%]	2.40	2.40	ASTM D 422
Fine [%]	5.20	4.40	ASTM D 422
Hydraulic Conductivity K [cm/sec]			
Soil Type (USCS)	SW	SP	ASTM D2487
Chemical test results for soil			
(T.D.S.)[%]	9.20	9.30	BS 1377:1990,
PH value	7.31	7.26	BS 1377:1990,
SO3 [%]	14.67	5.21	BS 1377:1990,
Gypsum Content [%]	35.4	12.3	Nashat and Al-Mufty (2000)

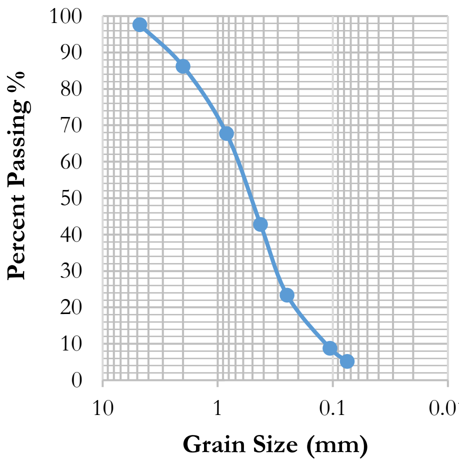

Figure (1): Grain size distribution for gypseous soil sample (S1).

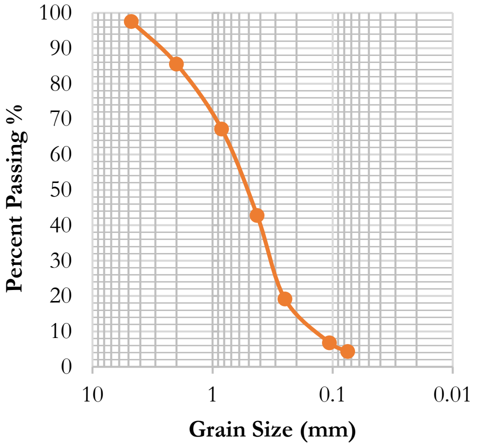

Figure (2): Grain size distribution for gypseous soil sample (S2).

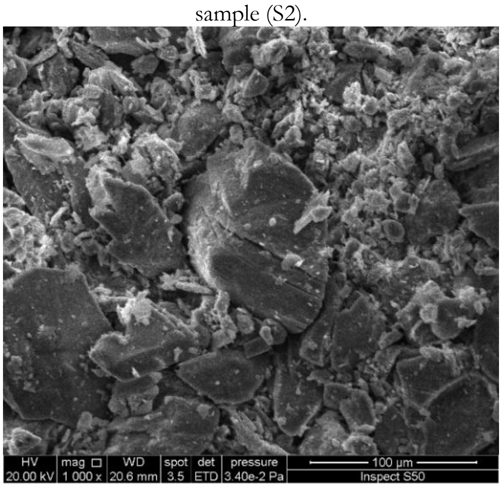

Figure (3): Gypseous soil sample (S1) image using SEM device.

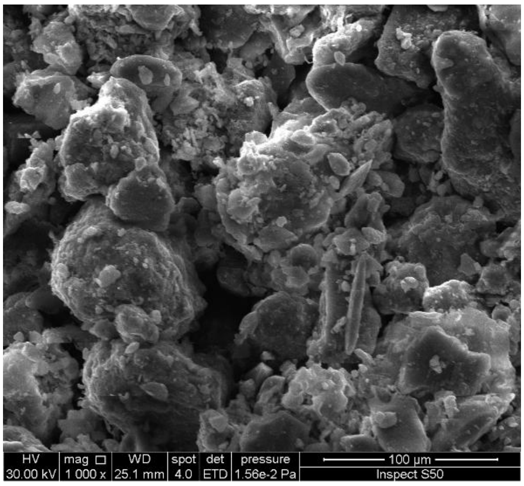

Figure (4): Gypseous soil sample (S2) image using SEM device.

2.2 Additives Material

The additive material implemented in this research is clayey soil collected from one location in Kut city (32^0 26' 27.85" N, 45^0 42' 44.34" E) Wasit province. The sample was obtained from a depth of (1.7 to 2.0) m from the top ground surface. The collected sample was statured and packed in plastic bags before being transferred to the laboratory of Civil Engineering College at Al-Nahrain University, and the laboratory of Civil Engineering College at Wasit University. The physical and chemical properties are shown in Table 2, and Figure 5 shows the gain size distribution for the clayey soil sample.

Table (2): Gypseous soil sample characteristics

Property	Clay Soil Sample	Standard
Color	Brown Clay	ASTM D2488
Moisture content [%]	21.0	ASTM D2216
Maximum dry density [kN/m³]	18.2	ASTM D698 (2012) Method A
Field density [kN/m³]	20.0	ASTM D698 (2012) Method A
Liquid limit [%]	37	ASTM D4318
Plastic limit [%]	22	ASTM D4318
Plasticity index, PI [%]	15	ASTM D4318
Specific gravity, Gs	2.706	ASTM D854, B.S1377 1990
Soil Type (USCS)	CL	ASTM D2487
(T.D.S.) [%]	1.85	BS 1377:1990,
ph value	7.8	BS 1377:1990,
SO^3 [%]	0.34	BS 1377:1990,
Gypsum Content [%]	0.74	BS 1377:1990,

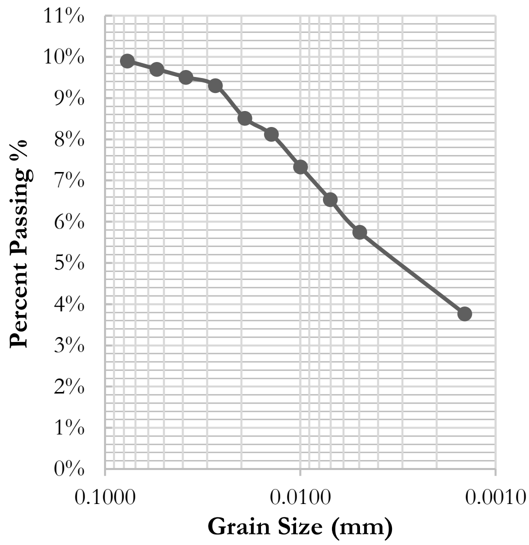

Figure (5): Grain size distribution for clay soil sample

2.3 Testing Program

Before and following the addition of 5% and 10% clayey soil by weight, two gypseous soil samples underwent various tests, encompassing chemical, physical, and mechanical analyses. Chemical testing was performed on the soil samples before and after treatment, involving the measurement of gypsum concentration and soil PH. Numerous tests were carried out to demonstrate the impact of the additive material on soil properties. Mechanical tests, including the compaction test [ASTM D698], single oedometer test [ASTM D5233], and shear strength test [ASTM D3080], were conducted on the soil samples pre- and post-clay addition.

3. Results and Discussions

3.1 Compaction Test

The compaction test results showing in Figures (6 and 7) that adding clayey soil improves the maximum dry unit weight and optimum moisture content of gypseous soil samples. The highest concentration of clayey soil additive leads to the highest maximum dry unit weight and moisture content due to the high surface area of clayey soil when combined with natural gypseous soil. This increases the optimum water content required to moisten the soil particles and raises the water required for clayey soil dissociation, increasing the optimum moisture content.

Similar improvements in soil compaction due to clay additives were observed in studies by [9, 10, 11, 12 and 21], where increases in dry unit weight and moisture content were attributed to clay's high plasticity and surface area.

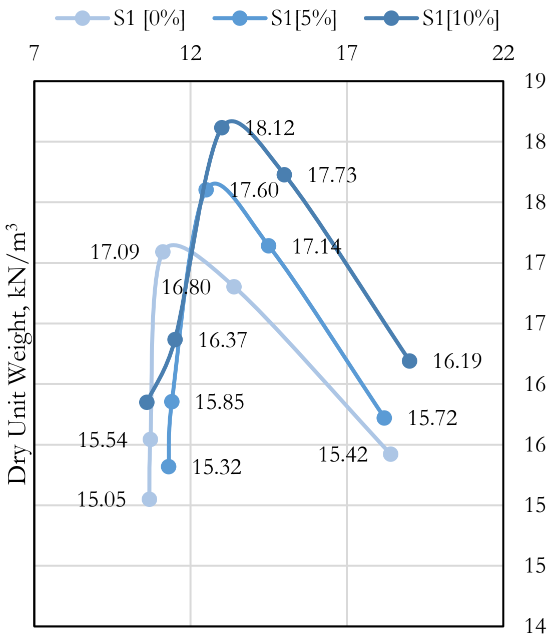

Figure (6): Compaction curves with various percentages of clayey soil for S1.

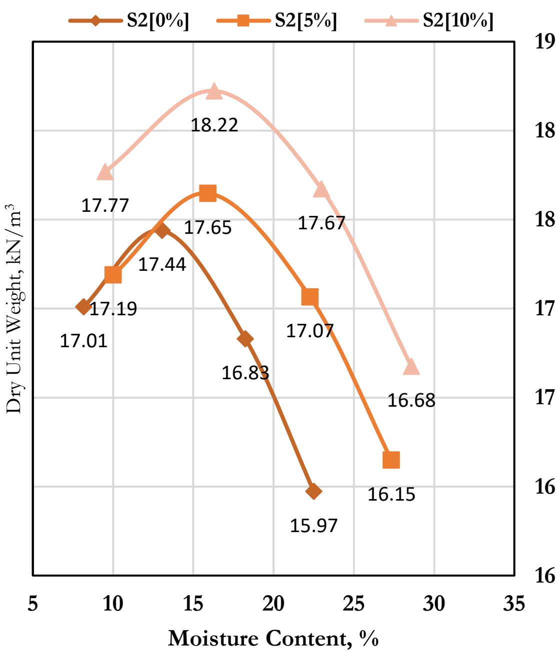

Figure (7): Compaction curves with various percentages of clayey soil for S2.

3.2 Single Oedometer Test (SOT)

Several single oedometer tests were conducted to determine the collapsibility parameters of the gypseous soil in its natural and treated states, under both soaked and unsoaked conditions. Where the soil sample is compacted to 90% of the maximum dry density.

The results of a single odometer test for untreated gypseous soils (90% RD) show that the collapse potential degree is moderate at 400 kPa stress as shown in Table 3.

A set of single oedometer tests was conducted on soil samples treated with varying amounts of clayey soil to address soil collapsibility. The findings for treated gypseous soil with cohesive clayey soil at two different percentages (5% and 10%) are outlined. The outcomes were illustrated in Table 4, and graphs displaying void ratio and effective applied stress, as depicted in Figures 8, 9, and 10.

Table (3): Collapse potential (SOT) for gypseous soil samples.

Soil Type	Collapse Stress, kPa	CP, %	Degree of Specimen Collapse, ASTM D5333
S1	400	5.100	Moderate
S2	400	2.211	Moderate

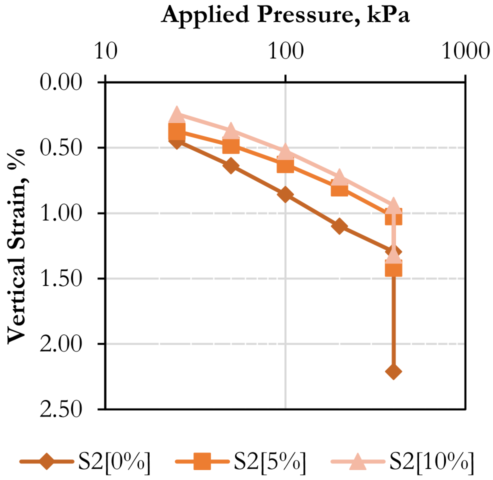

Figure (8): Compression curve of the collapse potential test for treated and untreated gypseous soil S2

The results in Figures 8 and 9 and Table 4 show that as the clayey soil content increases, the collapsibility decreases. The soil collapsibility for gypseous soil samples gradually increased due to clayey additives. The effect of clayey soil is limited in unsoaked conditions but becomes significant in the presence of water, leading to the breakdown of molecular forces between particles. The presence of ions in cohesive soil can form cementation bridges with the strongest force. In addition, the collapsibility of stabilized gypseous soils also depends on the distortion and size of the inter-aggregate and intra-aggregate pores [13].

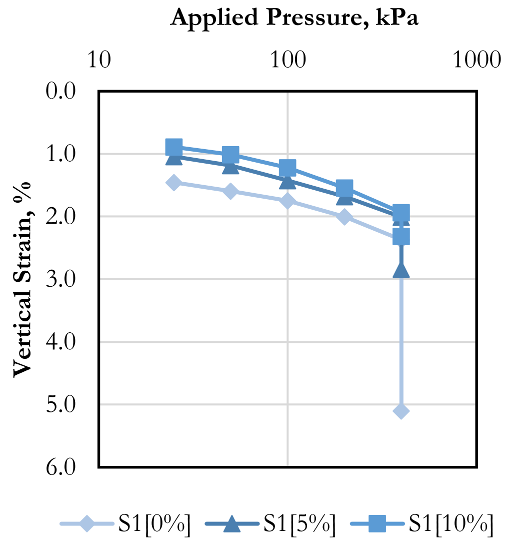

Figure (9): Compression curve of the collapse potential test for treated and untreated gypseous soil S1

Table (4): Collapse potential (SOT) for gypseous soil treated with clayey soil.

Type of Soil	Treatment %	CP %	CRF %	Degree of Specimen Collapse, ASTM D5333
S1	0	5.100	-	Moderate
S1	5	2.837	44%	Moderate
S1	10	2.316	55%	Slight
S2	0	2.211	-	Moderate
S2	5	1.421	36%	Slight
S2	10	1.316	39%	Slight

In Figure 10, the correlation between the proportion of clayey additives and the collapsibility of two samples, S1 and S2, is illustrated. As the percentage of clayey additives increases, the presence of ions in clayey soil can form cementation bridges with the strongest force. In addition, the collapsibility of stabilized gypseous soils also depends on the distortion and size of the inter-aggregate and intra-aggregate pores, [16 and 17]. The collapsibility of S1 initially experiences a rapid decline. However, the rate of decline slows down between 5% and 10% of clayey additives. The collapsibility of S2 also decreases as the clayey additives increase, but the rate of decrease is generally slower compared to S1. As showed in Figure 10 that gypsum content at soil sample had a clear effect on rate of increasing of additives curves.

3.3 Direct Shear Test

In the natural soil test, the gypseous soil with a relative density of 90%, and three additive materials (0%, 5%, and 10%) were tested using "direct shear apparatus" under both unsoaked and soaked conditions for each soil sample. The results of a direct shear test under both unsoaked and soaked conditions show that lower gypsum content (S2) recorded the highest value in internal friction angle the high gypsum content (S1) while in cohesion was the direct opposite, as shown in the following Table 5, and Figures 11, and 12.

While the soil was tested after soaking in water, the cohesion and the angle of internal friction were decreased. This decrease in strength parameters is related to the solubility of gypsum in the soil by water as shown in Figures 11, and 12.

This result is agreed with those of [18 and 19]

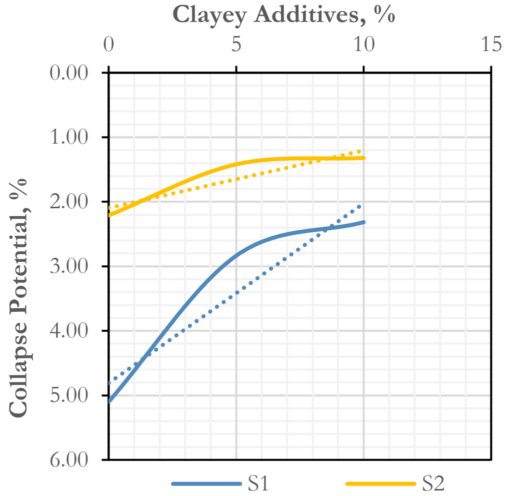

Figure (10): The effect of additives on gypseous soil sample's collapsibility [SOT].

Table (5): Direct shear test result for natural gypseous soil

Gypseous soil type	Gypseous soil condition	the angle of internal friction	Cohesion, kPa
S1	Unsoaked	36.6°	9.75
S1	Soaked	26.0°	3.90
S2	Unsoaked	40.3°	6.92
S2	Soaked	33.7°	3.59

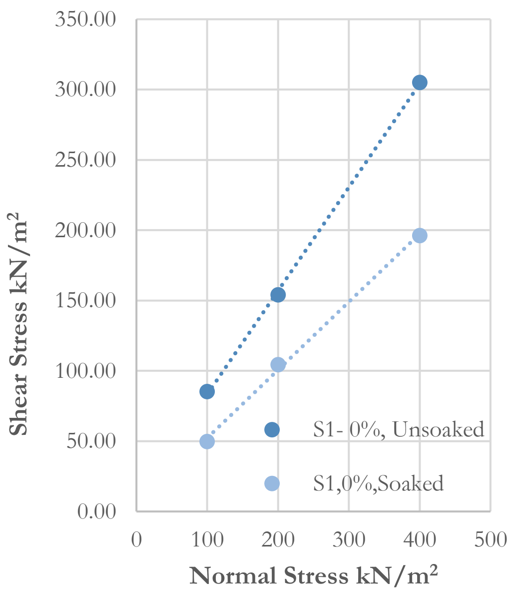

Figure (11): Normal stresses vs. shear stress for natural soil [S1] from the direct shear test

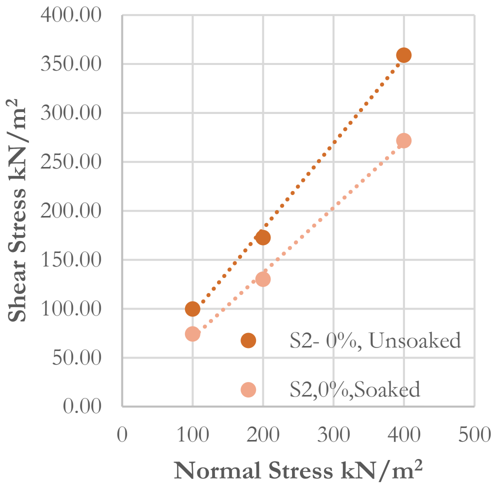

Figure (12): Normal stresses vs. shear stress for natural soil [S2] from the direct shear test

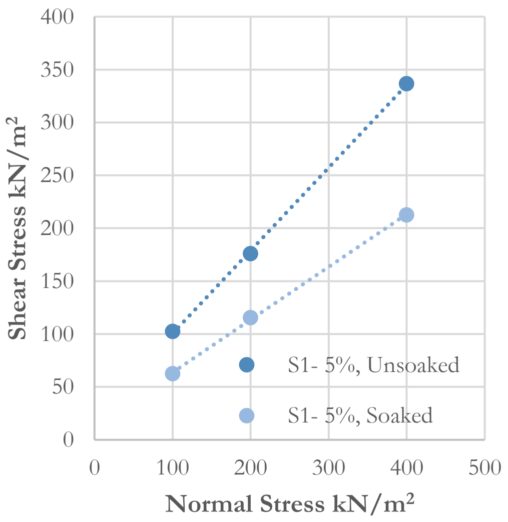

Figure (13): Normal stresses vs. shear stress for gypseous soil [S1] with 5% clayey soil.

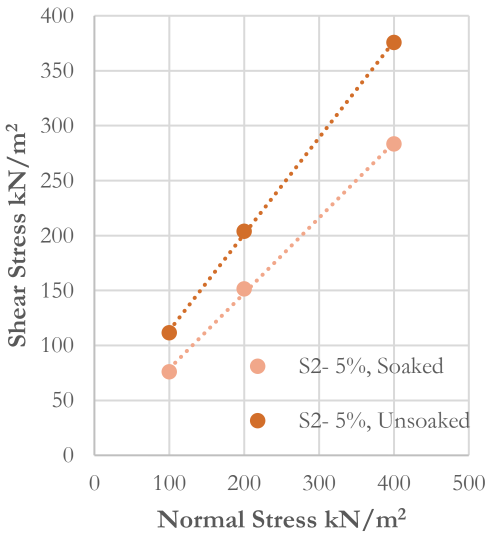

Figure (14): Normal stresses vs. shear stress for gypseous soil [S2] with 5% clayey soil.

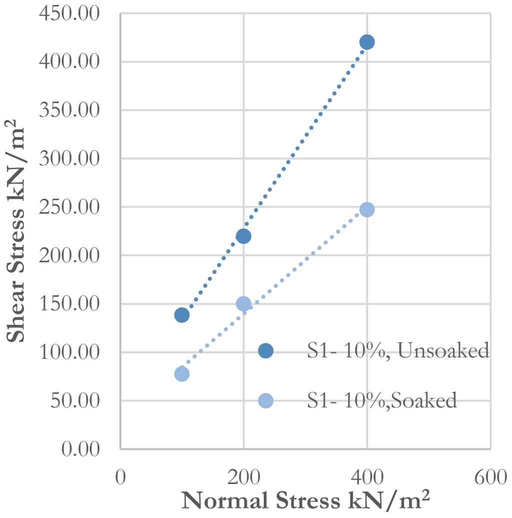

Figure (15): Normal stresses vs. shear stress for gypseous soil S1 with 10% clayey soil.

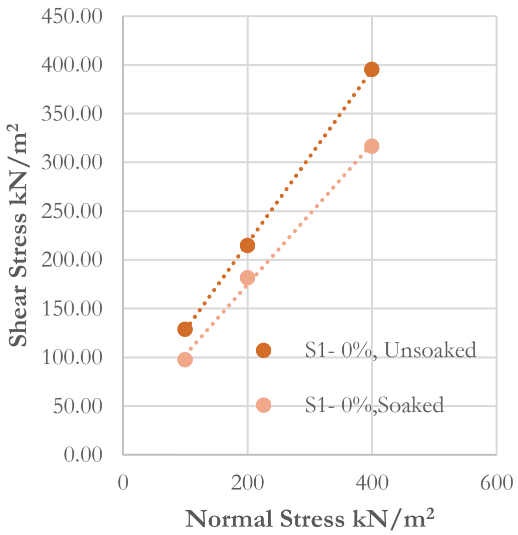

Figure (16): Normal stresses vs. shear stress for gypseous soil S2 with 10% clayey soil.

In figures 13 to 16, the impact of clayey additives on enhancing the strength of gypseous soil samples (S1 and S2) is demonstrated. The clay additives led to increased cohesion and angle of internal friction by causing a rearrangement of the soil structure, enhancing the bonds between soil particles, and decreasing voids, [20]. The cohesion of the unsoaked gypseous soil sample (S1) was significantly improved by 126% and 294% for 5% and 10% clayey additives, respectively, while for soaked gypseous soil (S1), the improvement was 252% and 644% for 5% and 10% of clayey additives, respectively.

For gypseous soil samples (S2) under unsoaked conditions, the cohesion was enhanced by 272% and 457% for 5% and 10% of clayey additives, respectively. In soaking conditions, the impact of the additives was even more pronounced, with improvements of 378% and 1315% for 5% and 10% of clayey additives, respectively.

The impact of clayey additives on the internal friction angle was limited, with a slight increase in the angle values. The improvement was 2.3% and 13.4% for 5% and 10% of clayey additives, respectively, for gypseous soil (S1) under soaked conditions, and 3.2%

and 7.7% for 5% and 10% of clayey additives, respectively, for gypseous soil (S2) under soaked conditions.

4. Conclusion

Based on the results of this study, the following conclusions may be drawn:

1- The higher the percentage of clayey additive, the greater the enhancement of gypseous soil properties.
2- The clayey additives had a better effect on high gypsum content than low gypsum soil samples, enhancing the test soil properties.
3- The adding clayey additives led to an increase in max dry density and optimum moisture content of tested soil.
4- Collapse potential increased by increasing the clayey additives where the improvement was 55% for high gypsum content soil sample and 39% for gypsum content soil sample.
5- The soil cohesion and internal friction angle of the soil both increase noticeably due to the addition of clay particles, resulting in improved soil cohesion.
6- Mixing clayey additives with gypseous soil leads to a decrease in the permeability of gypseous soil due to the pores blocking and interaction by clay additives.

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