THIRD INTERNATIONAL
CONFERENCE ON GEOTECHNICAL
ENGINEERING-IRAQ

Paper Title : **Investigation of Shear Strength Parameters for Gypseous Soils Using a Modified Apparatus of Triaxial Test**
Paper ID : **991-SM011-22**
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Date : **March 24, 2022**

Acceptance Letter

Dear Mustafa M. Abdalhusein, Ali Akhtarpour, Rusul Almahmodi, and Mohammed Sh. Mahmood

On behalf of the scientific and organizing committees of the Third International Conference on Geotechnical Engineering-Iraq, 17-19 of May 2022, we are pleased to inform you that your paper entitled "**Investigation of Shear Strength Parameters for Gypseous Soils Using a Modified Apparatus of Triaxial Test**" has been preliminary accepted in the conference and will be published in a Scopus indexed journal, **AIP Conference Proceedings**.

Thank you for your interest in the 3ICGE-Iraq, and we are looking forward to meet you in this unique event.

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Third International Conference on
Geotechnical Engineering-Iraq
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May 17-19, 2022
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Investigation of shear strength parameters for gypseous soils using a modified apparatus for triaxial test

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Abstract.
The influence of matric suction on the compressibility of unsaturated gypseous sand soil under various loading conditions is investigated in this research. The gypseous percentage of the soil samples from Al-Najaf, Iraq, was 14 percent, 22 percent, and 29 percent. In a modified triaxial cell, these substances were subjected to loading-path, which occurs when a structure is built on these soils at a certain saturation level (specific matric suction). With two distinct confining stresses of 100 kPa and 200 kPa, four matric suctions were used: 100, 60, 30, and zero percentages of initial matric suction. Under the confining loads, two saturation tests (CD; Consolidated-Drained) were also conducted. The volumetric strains were found to be increased when the matric suction was reduced, and the gypseous content was increased. This type of soil experiences high volume variations during the wetting process, which can result in significant soil strain as a result of substructure damage. Also, the shear strength parameters are decreased by increasing the matric suction.

Keywords: Matric suction; gypseous sand soil; Al-Najaf; modified triaxial cell, shear strength parameters, volumetric strains

1. Introduction

Various structures built on gypseous soils have significant challenges, particularly in drying-wetting sequences, when compared to those built on non-gypseous soils due to gypseous's collapsibility. This work shows the reduction in soil parameters du to soaking process in gypseous sand soils.

The chemical condition of gypseous, which comes in a variety of forms, is one of the most essential features of the material. Calcium sulphate dihydrate, calcium sulphate hemihydrate, and calcium sulphate anhydrite are the most frequent. The chemical formula for calcium sulphate dihydrate, also known as gypseous, is CaSO42H2O. In terms of expansion, soluble rocks in this form are relatively stable. This is due to the two bonding water molecules, which allow the soil to absorb only a small amount of moisture while maintaining its chemical structure. To put it another way, soluble rocks in the form of calcium sulphate dihydrate will not expand or heave as much as those in the form of calcium sulphate anhydrite, which has no bonding water. However, extreme caution should be exercised because too much water will eventually change the chemical structure of calcium sulphate dihydrate, turning it into solution [1]. Calcium sulphate comes in a variety of forms, but they all have the same properties. Hydration, setting, and solubility are the most important properties of calcium sulphate, and they are all related to the strength of calcium sulphate [2]. Barzanji (1973) identified four types of gypseous soils in Iraq, from non-gypseous (gypseous <0.3%) to highly gypseous (gypseous 25-50%) [3].

Soil soaking causes a volume change as well as a reduction in shear strength and stiffness; the kind and extent of this change is determined by various parameters, including soil structure, soaking degree, and stress state, and leads to collapse [1,4,5].

Traditional saturated soil mechanics have been used to study gypseous soils, but soil properties in unsaturated conditions, such as those found in arid and semi-arid regions, may change [6]. Water infiltration causes a reduction in soil suction, which can contribute to the destabilization of buried utilities [7]. Gypseous soil is a collapsing soil that causes challenges for buildings and structures built on it since its shear strength decreases significantly when wet [8,9]. The wetting process [10-14], increased gypseous content, void ratio, permeability [15], initial degree of saturation [16,17], and soil time-based wetting prior to loading [18-23] are all elements that influence the collapse.

The air-entry value of granular materials is extremely low. Furthermore, suction-induced capillary forces enhance inter-particle tensions, resulting in a drop in void ratio and an increase in dry unit weight [24]. In collapsible soils, the unsaturated condition is always present when substantial collapse occurs with a drop in the matric suction (Ua-Uw) [25]. A drop in volume happens when sand is wetted [12,26]. With increasing gypseous concentration, there is a massive rise in volumetric strain [12]. The estimation of collapse potential is dominated by the net normal stress level of 221 kPa (CP) [27]. The bearing capacity rose nonlinearly from 2.55 to 3.95 times as the matric suction increased [28]. Higher mean net stress (Pn) caused more severe collapse during the wetting process [29]. Both yield stress and sample dilatancy rise as the suction increases. [30,31]. Many researchers used remolded specimens in their investigations, ignoring the soil's sensitivity [32]. The collapsible potential of gypseous soils will be decreased using nano-clay additive [33]. Using screwed piles in gypseous soils is very effective and gave a higher axial carrying capacity and low settlement [34]

Modifications to the Oedometer and triaxial apparatuses have recently been made to perform unsaturated tests using air and water pressures (Ua and Uw) in the soil sample. These pressures were carefully monitored in to provide a certain matric suction (Ua-Uw). The experiments are carried out on gypseous sand soil from the Iraqi city of Al-Najaf. Using both modified apparatuses, Oedometer and Triaxial tests, the recent research explores the reliable volume change in gypseous sand soil owing to matric suction change (wetting) [35].

2. Materials and methodology

2.1. Soil Sampling

The disturbed samples were collected from three districts in the Iraqi city of Al-Najaf. The particle size distribution of the three soil samples is depicted in Fig. 1. More than 80% of the soil samples are made up of sand. The soil parameters of the studied specimens are summarized in Table 1.

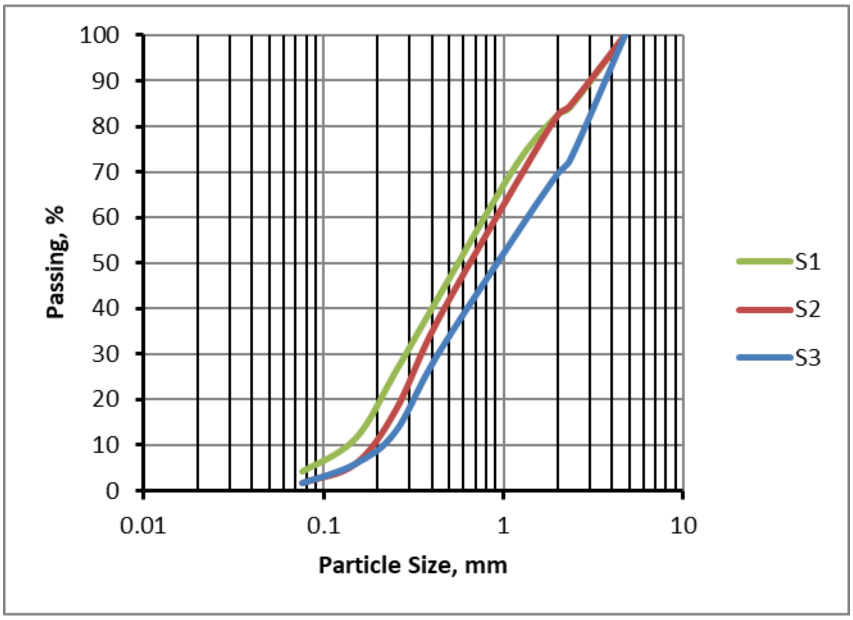


Figure 1. Particle Size Distribution for the Tested Samples.

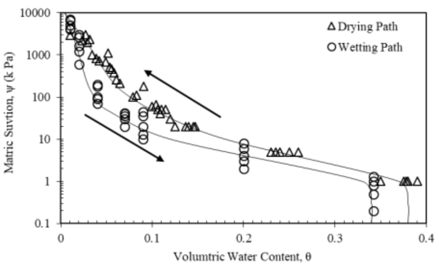
Table 1. Properties of the tested soil specimens.

Test Name	Test Specification	S1	S2	S3
Maximum Dry Density (Proctor Test), gr/cm^3	ASTM D698-00a	1.84	1.83	1.825
Optimum Water Content (Proctor Test), %	ASTM D698-00a	14.2	14.8	15
Gypseous Content	ASTM C25-99	14	22	29
Specific Gravity	ASTM D854-14	2.5	2.43	2.38

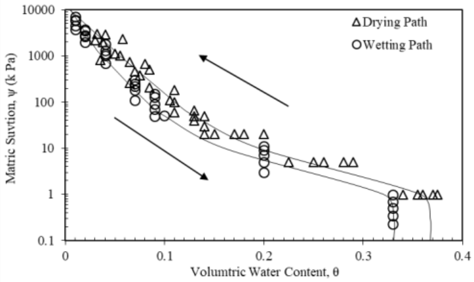
2.2. Soil-Water Characteristic Curves (SWCCs)

The SWCC was calculated for each sample using the filter paper method for the wetting path and the pressure plate test for the drying path. The filter paper test was carried out in accordance with ASTM D5298-03, whereas the pressure plate test was performed in accordance with ASTM D2325-68. Because the membrane of the mold will be perforated in triaxial specimens due to the sharp forms of gypseous materials, all specimens were remolded with 90% of the field density. 35 soil samples were investigated in the wetting path by placing them in a circle container. 7 groups of specified volumetric water contents (ϴ) were chosen (5 specimens for each group) to completely cover area below the SWCC line, and these volumetric water contents were pointed based on the soil type. The round container was then placed in an airtight plastic and airtight container (in a dry environment) for 7 days to ensure that the filter paper absorbed the soil's water content. The matric suctions were estimated from the water content of the filter papers at the end of the experiments, and the wetting path curves were produced.

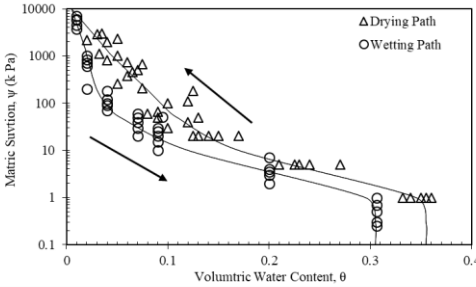
In the drying path, 7 groups of specific matric suction were chosen (5 specimens per group) and a matric suction was defined for each group. The specimens were remolded in a cylindrical mold with the same initial moisture content as in site and placed in contact with a saturated porous plate within a pressure chamber at the start of the test. The specimens were saturated after the bottom of the plate was kept at atmospheric pressure with the help of a tiny drain. A pressure drops over the porous plate was achieved by allowing desired air pressure into the pressure chamber and, as a result, to the top of the porous plate. The water in the plate was in equilibrium with the saturated soil samples on the plates. The water then proceeded out of the soil, through the plate, and out of the drain tube, held at a tension less than the pressure drop across the porous plate. The moisture content of each sample was assessed, and the volumetric water content was estimated after water stopped flowing from the sample and porous plate (showing equilibrium for that particular tension). To generate a comprehensive curve of the capillary-moisture connection (drying route) for tested soil, a series of these tests at varied tensions were required. The results of the wetting – path and drying – path tests are shown in Fig. 2.



(a) S1 Specimen



(b) S2 Specimen



(c) S3 Specimen

Figure 2. The Tested Specimens' Soil-Water Characteristic Curves.

2.3. Modified Unsaturated Devices

The goal of this study is to see how the wetting process affects the volumetric strain of gypseous soil in unsaturated testing with various matric suction utilizing modified triaxial tests. The tested specimen is shown in Fig. 3 in the modified triaxial device characterized by Fredlund and Rahardjo (1993) [31]. The air pressure is applied and controlled using the top cap, while the pore water pressure is applied by a 1 Bar high air entry (HAE) disc. In the triaxial test, the sample is 7 cm in diameter and 14 cm in height. Sensors connected a data logger to a computer and the control board to read the applied water and air pressures. To calculate the axial vertical displacement of the specimen throughout the test, a 0.01 mm linear variable differential transformer (LVDT) was used.

Figure 3. The modified triaxial device.

3. Work Methodology

The test plan is like when a building is built on a soil with consistent matric suction; this situation is an excellent example (increasing in load under the constant matric suction).

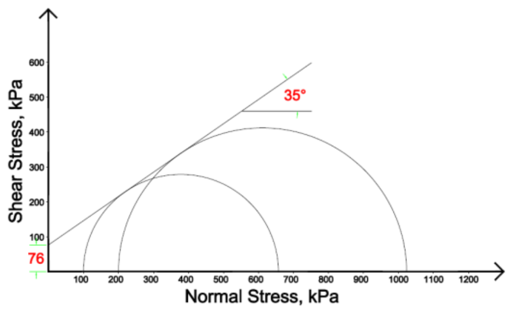
With Ua=190 kPa, each test began with a constant matric suction chosen from the Soil-Water Characteristic Curve (SWCC-Wetting-Path/Drying-Path as shown in Fig. 2), such as initial matric suction, 0.6 of the initial matric suction, 0.3 of the initial matric suction, and zero matric suction (saturated state). The air pressure, Ua, and the water pressure, Uw, were chosen in this matric suction with a difference between them to get the desired matric suction. The top and bottom of the specimen are subjected to air and water pressures, respectively. The specimen takes a long time to reach equilibrium in this boundary condition. The loading tests are started with two distinct net confining strains (σ3-Ua=100 and 200 kPa) as shown in Table 2 once each test has reached equilibrium (no entry or exit water from the specimen).

Table 2. Loading-Path Tests Program.

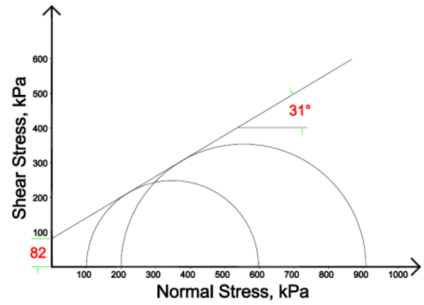
Specimen No.	Gypseous Percentage, %	Initial Water Content, %	Unsaturated Triaxial Tests			
			Test No.	Stage 1	Stage 2	Stage 3
				Net Confining Stress (σ_3), kPa	Matric Suction, kPa	Loading
1	15	3.9	1	100	$\psi_{initial}$	20% Strain
			2	100	0.6 $\psi_{initial}$	20% Strain
			3	100	0. 3 $\psi_{initial}$	20% Strain
			4	100	Saturated	20% Strain
			1	200	$\psi_{initial}$	20% Strain
			2	200	0.6 $\psi_{initial}$	20% Strain
			3	200	0. 3 $\psi_{initial}$	20% Strain
			4	200	Saturated	20% Strain
2	22	4	1	100	$\psi_{initial}$	20% Strain
			2	100	0.6 $\psi_{initial}$	20% Strain
			3	100	0. 3 $\psi_{initial}$	20% Strain
			4	100	Saturated	20% Strain
			1	200	$\psi_{initial}$	20% Strain
			2	200	0.6 $\psi_{initial}$	20% Strain
			3	200	0. 3 $\psi_{initial}$	20% Strain
			4	200	Saturated	20% Strain
3	29	4	1	100	$\psi_{initial}$	20% Strain
			2	100	0.6 $\psi_{initial}$	20% Strain
			3	100	0. 3 $\psi_{initial}$	20% Strain
			4	100	Saturated	20% Strain
			1	200	$\psi_{initial}$	20% Strain
			2	200	0.6 $\psi_{initial}$	20% Strain
			3	200	0. 3 $\psi_{initial}$	20% Strain
			4	200	Saturated	20% Strain

4. Determination of Shear Strength Parameters

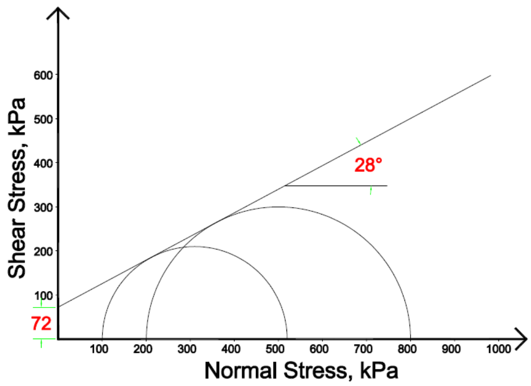
Figs. 4 to 6 show the shear strength characteristics calculated from Mohr circles based on the major stresses obtained from unsaturated triaxial tests. For the different examined factors (gypseous content, matric suction, and restricted stress), there is a roughly constant amount of cohesion, **c** (70-80 kPa), however the cohesions range from 25 to 36 kPa at zero matric suction. While the cohesiveness from traditional triaxial testing (CD) is higher than that from zero matric suction (approximately 70 kPa) in varied values, the results are matched with the lowest at the highest gypseous content. For various gypseous compositions, the values of angle of internal friction, decrease as the matric suction decreases (S1, S2 and S3). The angles have been shifted from roughly 35° to 28°. In general, the angle of internal friction values obtained from CD testing are smaller than those obtained from zero matric suction.



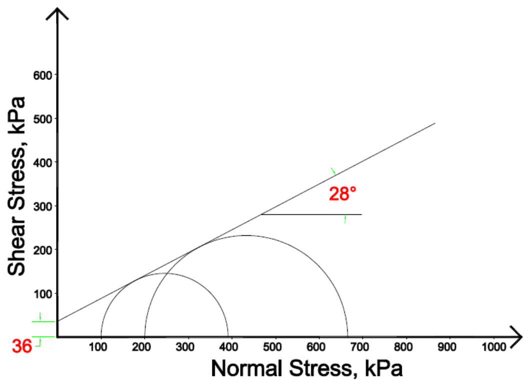
Initial Matric Suction Test



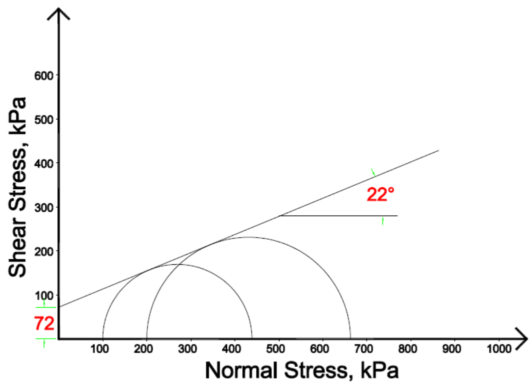
60% of Initial Matric Suction Test



30% of Initial Matric Suction Test

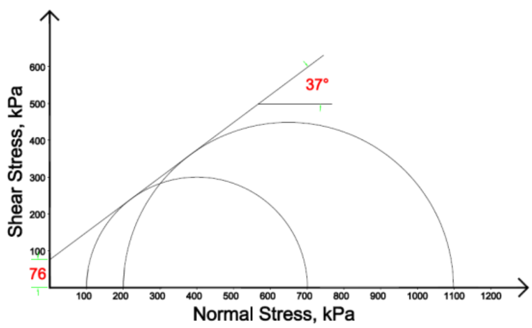


Zero Matric Suction Test

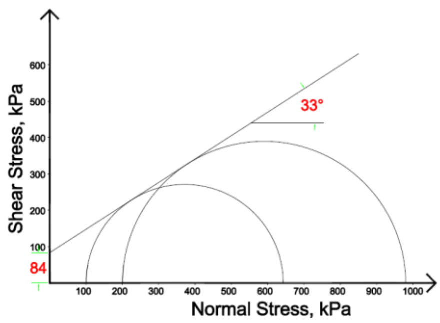


CD Test

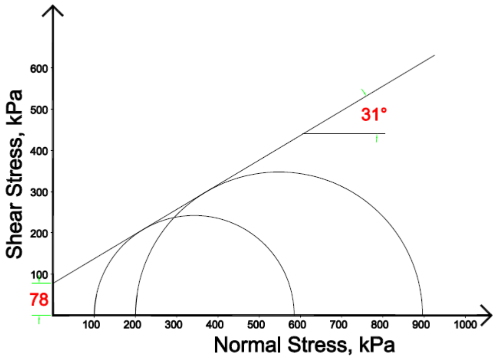
Figure 4. Mohr Circles of S1 Sample.



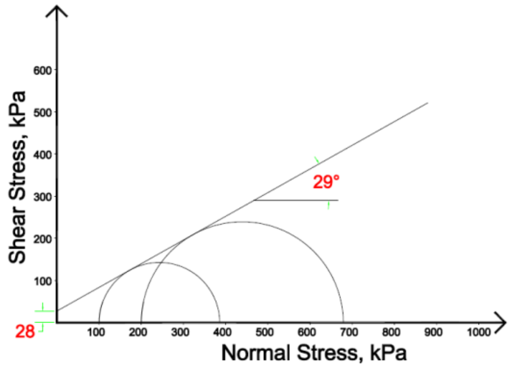
Initial Matric Suction Test



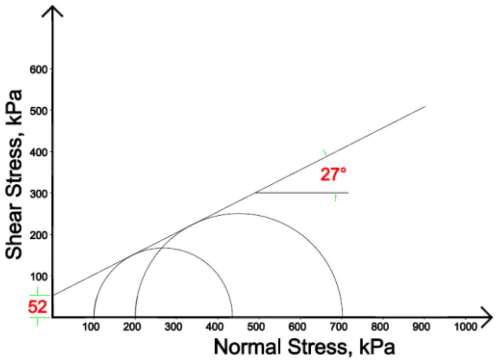
60% of Initial Matric Suction Test



30% of Initial Matric Suction Test

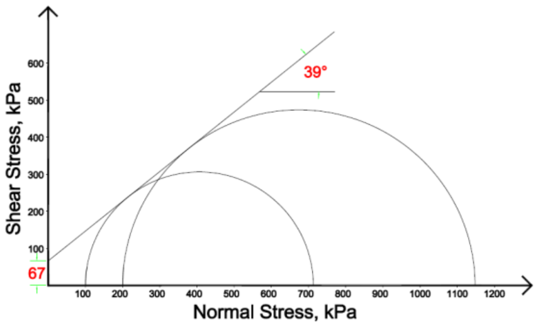


Zero Matric Suction Test

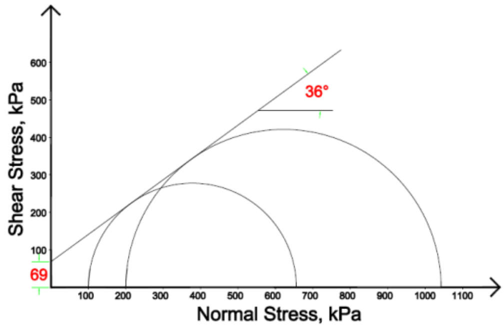


CD Test

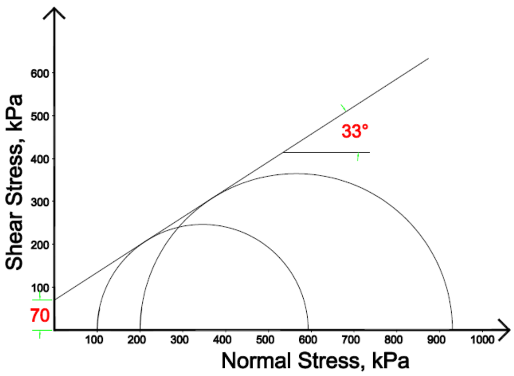
Figure 5. Mohr Circles of S2 Sample.



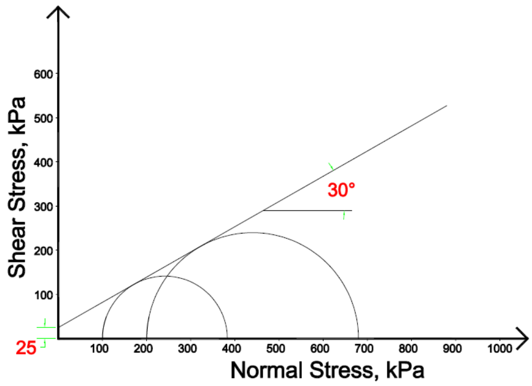
Initial Matric Suction Test



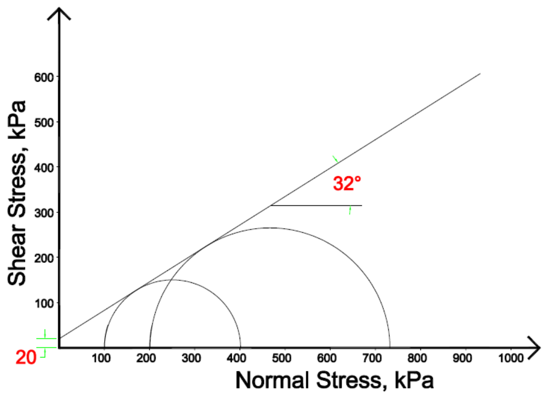
60% of Initial Matric Suction Test



30% of Initial Matric Suction Test



Zero Matric Suction Test



CD Test

Figure 6. Mohr Circles of S3 Sample.

Table 3 gives an overview of shear strength parameters obtained from unsaturated and conventional triaxial testing for the various parameters investigated.

Table 3. The Results of Shear Strength Parameters for the Tested Specimens.

Soil Symbol	Test Type		Angle of Friction, Degree	Cohesion, kPa
S1	Matric Suction Ratio	ψ_o	35	78
		0.6 ψ_o	31	82
		0.3 ψ_o	28	72
		Sat.	28	36
	Conventional (CD)		22	72
S2	Matric Suction Ratio	ψ_o	37	76
		0.6 ψ_o	33	84
		0.3 ψ_o	31	78
		Sat.	29	28
	Conventional (CD)		27	52
S3	Matric Suction Ratio	ψ_o	39	67
		0.6 ψ_o	36	69
		0.3 ψ_o	33	70
		Sat.	32	20
	Conventional (CD)		30	25

The reduction in angle of friction (Ø) is due to the softening of gypseous materials and the dissolving of some gypseous materials, which can create a change in particle surface roughness that happened when the specimens were wetted. The soil structure had unique void shapes and particle interactions, but by sliding the particles together and dissolving them, the soil structure was transformed into a new interlocking system.

Table 3 shows that for saturated conditions (zero matric suction and CD), the friction angle increases as the gypseous content of the specimens increases, but the cohesion parameter exhibits the reverse trend. Because the gypseous bindings between the soil particles are thin layers that link the soil particles together, they act as a cemented agent when the gypseous level is low.

Fig. 7 illustrates the variations between matric suction with the angle of internal friction. It is clear by decreasing the matric suction, the angle of internal friction is also decreased. Additionally, for the same matric suction, when the gypseous content is increased, there is a linear relationship between the angle of internal friction and the gypseous content. The same behavior in the cohesion with the matric suction as shown in Fig. 8, when the matric suction is decreased, the cohesion is also decreased.

Figs. 12 and 13 depict the connections between angle of internal friction and cohesion with gypseous content in the saturated state of the conventional test (CD) and the unsaturated condition (with zero matric suction). The CD test suggests more than in the zero matric suction for the angle of internal friction, as shown in Fig. 9, but when the gypseous content is decreased, most also decreases, as shown in Fig. 9. When the gypseous content is reduced, the cohesion is likewise reduced (Fig. 10).

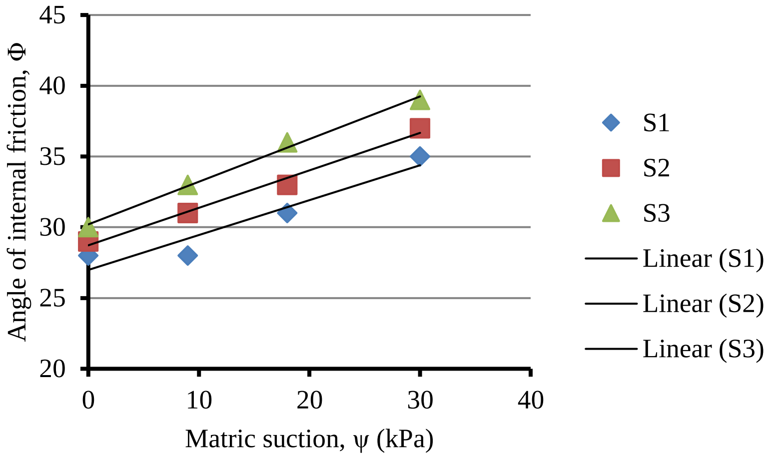


Figure 7. Matric suction versus angle of internal friction.

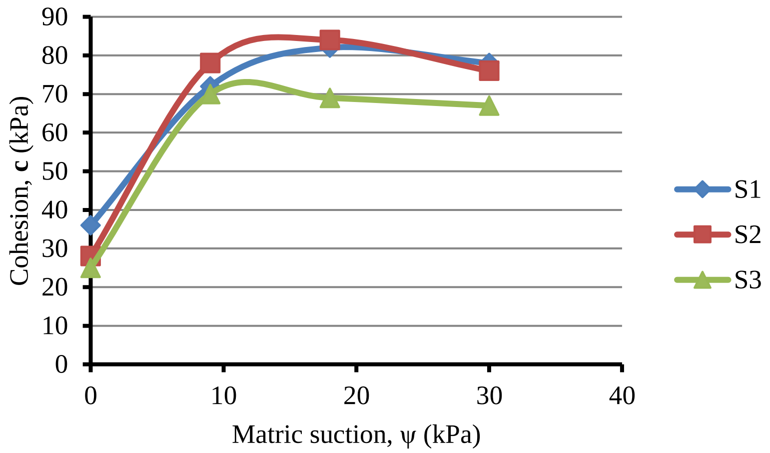


Figure 8. Matric suction versus cohesion.

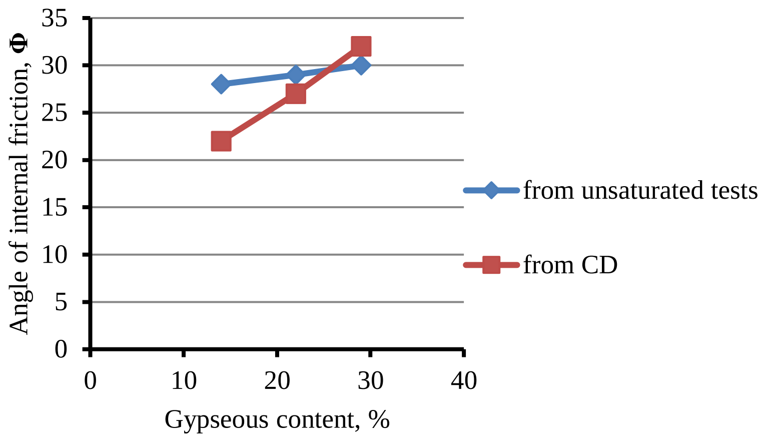


Figure 9. Gypseous content versus angle of internal friction at saturation.

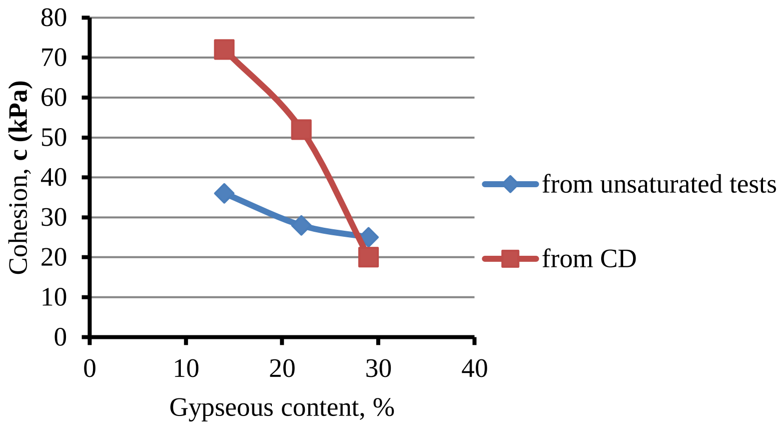


Figure 10. Gypseous content versus cohesion at saturation.

5. Conclusions

These soils can provide geotechnical and structural issues due to a lack of data and study on the performance of gypseous soils after wetting. As a result, more research is needed to see how saturation variations affect the reactivity of these soils under constant and progressive loading situations. The volumetric strains in gypseous soils with changes in matric suction were determined using an unsaturated triaxial testing apparatus in this work.

This research investigated the influence of matric suction on volumetric trains in remolded specimens with varying in the content of gypseous materials and different mean net stresses. In the experiment, the loading path was used, the levels of matric suctions and the confining stresses that were used are four levels and two levels, respectively. The most important conclusion was that when matric suction decreased, volumetric strain considerably rose.

Based on these findings, it is suggested that the construction of structures to be built on gypseous soils be changed to account for potential volume changes and settlements in the soil profile in the case of water availability, such as caused by changes in groundwater level.

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