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ORIGINAL ARTICLE

Characterization of collapsible gypsum sand soil with the presence of matric suction using a modified odometer apparatus

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Abstract

This study looks into the influence of matric suction on the volume change of gypsum sand soil in unsaturated conditions. The specimens were collected from Al-Najaf, Iraq, and included 14 and 29% gypsum. Three series of initial stress laboratory tests were utilized in a modified oedometer device. For each gypsum content, twelve remolded specimens were examined in unsaturated circumstances with the initial stress and applied stress using four matrices suction (30 kPa, 18 kPa, 9 kPa, and saturated state). Three tests were performed for each matric suctions with initial stresses, no initial load, 56 and 112 kPa, respectively. The findings exhibit a clear pattern of increase in the vertical strain as gypsum content rises and matric suction reduces under a variety of situations. The wetting process softens the gypsum components, which are significantly resulting in an increase in vertical strains.

Keywords Matric suction · Gypsum sand soil · Al-Najaf · Modified oedometer · Volumetric strains · Wetting process

1 Introduction

Due to the collapsibility of gypsum, many structures built on gypsiferous soils have significant challenges, particularly in the drying-wetting loop, when compared to structures built on non-gypsum soils. When the water table is near the ground surface, evaporation of saline groundwater forms these soils. Gypsiferous soils are common in the Middle East, particularly in areas near the Red Sea and the Arabian Gulf. They span significant swaths of Iraq, possibly up to 20% of the country's entire territory [1]. Al-Najaf City is one of the governorates in Iraq that has various degrees of gypsum content. The city's soil is primarily made up of sand-sized particles bound together by varying concentrations of gypsum [2]. It has been reported that several structures built on these soils have cracks in various patterns and unleveled settlements when they are exposed to water [3].

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A number of researchers have looked into the impact of gypsum content on various soil qualities after soaking for various amounts of time. Razouki and Al-Azawi used CBR studies to show that soaking time has a significant impact on the deformation of gypsum-containing soils and that this deformation increases as the soaking time increases [4]. Rust investigated the effect of different soaking periods up to 2 weeks on low gypseous sand soils (5%) from Al-Najaf City using the Oedometer test and found that there was a noticeable increase in settlement, but no collapse potential in the soil samples [5].

The possibility for gypseous sand soils to collapse owing to settlement when wet is investigated by taking two differing gypsum contents that have been taken from Al-Najaf, Iraq (15 and 29%). Under six stress levels, the research is conducted utilizing a computerized normal Oedometer test cell. The impact of soil density as a percentage of field dry density is also explored (100 and 85%). To identify the influence of wetting on sample settlement-time for each stress level, the tests begin with unsaturated soil samples (water content of 4%), and the wetting process for a few minutes (short term) is conducted for each stress level. The findings show that as gypsum content was increased at the same conditions of stress level and temperature rise, there was a considerable increase in the settlement [6].

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Soil mechanics of gypsiferous soils has been researched in the past (saturated condition). Gypsiferous soils are found in arid and semi-arid (unsaturated) environments, and their features vary greatly [7]. Water penetration reduces soil suction, potentially affecting subsurface services such as water pipelines [8]. The main causes of collapse are soil deformation and shear strength loss due to presence of water [9].

Abdalhusein et al. published a study in which they studied volumetric strains of Oedometer device tests with varied wetting intervals associated with the unsaturated triaxial testing. In Iraq, the soil of Al-Najaf City is thought to be rich in gypsum materials. The gypsum content of the district's soil was found to be 29%. The tests were carried out in an Oedometer device with different soaking intervals: first in normal gypsum content, then again in half an hour, and lastly 2 weeks. The triaxial hydration stimulus allowed for the quantification of volumetric stresses at two different levels of stress (2.5 and 5 kg/m^2) and four levels of matric suction: zero ψ, 0.3 ψ_o, 0.6 ψ_o, and initial matric suction (ψ_o). The findings of unsaturated tests in the triaxial device show that as matric suction decreases, volumetric strains increase, and the stress–strain curve becomes steeper. The volumetric strains are not drastically changed when the sample is wetted in a natural test for half an hour and is near the high matric suction. According to oedometer tests, there is a significant rise in volumetric stresses when the soaking duration is prolonged to 1 week. However, subsequently the 2 weeks of the wetting process in the oedometer device, the vertical volumetric strains become more visible as the matric suction increases, and they are strikingly similar to the volumetric strains observed in unsaturated tests with low matric suction [10].

Mahmood et al. investigated how the soaking method affected gypsum sand soil. Recent research looks into a time-based soaking approach for soil samples with high gypsum content of 29%. The soaking process softens gypsum components, breaking the connections between soil particles and stabilizing the structures. Samples were obtained from a specific location in Al-Najaf, Iraq, and then reconstituted to a density of 85% of the maximum dry density of the Proctor test and a moisture content of 4%. The specimens were tested under varied pressure levels (1.11 kg/cm^2, 2.23 kg/cm^2, and 4.47 kg/cm^2) using a computerized oedometer device. The findings revealed that as soaking periods and stress levels increase, the likelihood of these soils collapsing increases. After soaking for half an hour, the chance of breakdown climbed to around 8% after 2 weeks [11].

Under varied loading circumstances, the inspiration of matric suction term on the shape deformation of gypsum sand soil in unsaturated conditions was described. The soil specimens came from Al-Najaf, Iraq, and contained 14%, 22%, and 29% gypsum, respectively. On these soils, in a modified triaxial cell, wetting-process studies were performed. This procedure is employed after any building has been constructed and the degree of saturation of the foundation soil has been raised (reducing in matric suction). Under two distinct mean net stresses of 100 and 200 kPa, four levels of matric suctions were used: 100%, 60%, 30%, and 0% initial matric suction. Rainfall, rising water tables, and/or sewage and water pipe leaks could all contribute to variations in saturation levels. The volumetric strains grow as the matric suction decreases and the gypsum content rises, according to the results of this approach [12].

In this research, the influence of matric suction on the amount of precipitation in the soil was tested using samples taken from the soil of the Al-Najaf city, which includes 14 and 29% gypsum content and 90% of the maximum dry density of the proctor test.

2 Material and methodology

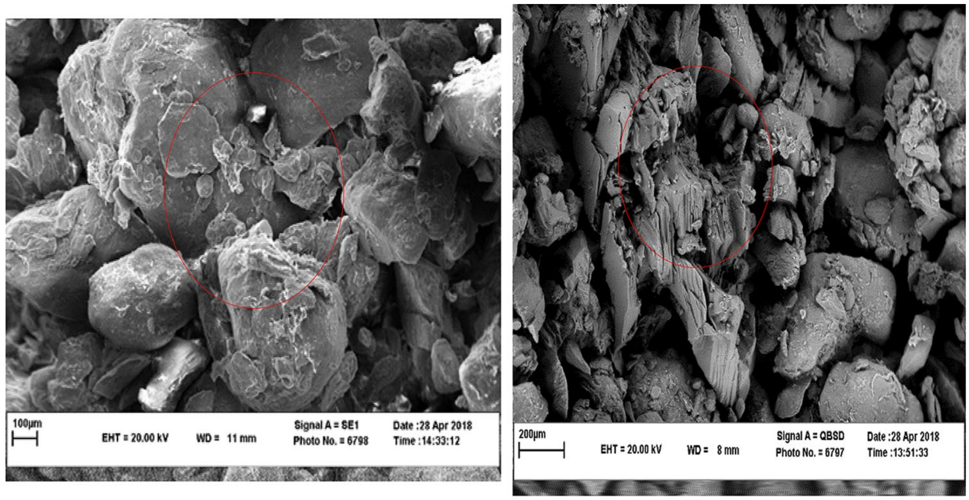
2.1 Material properties

The Sample was taken from the Al-Jameaa district in Al-Najaf city at depth of 0.5 m. The sampled soil is classified as sand well graded (SW) with a sand concentration of roughly 70%, according to the unified soil classification system (USCS). Table 1 shows the physical parameters of the sample used in this study.

According to Mustafa et al. categorization for gypseous soils, when the gypsum concentration is more than 25%, the soil is highly gypsiferous soils [16]. Scanning electron microscopy (SEM) results of remolded samples generated

Table 1 Soil properties of the selected site

Test name	Test specification	Results
Soil classification (sieve analysis), USCS	ASTM C136/C136M-14 [10]	SW
Specific gravity	ASTM D854-14 [11]	2.38
Gypsum content, %	ASTM C25-99 [12]	29
Natural water content, %	ASTM D698-00a [14]	4
Field density (sand con test), gm/cm^3	ASTM D1556/D1556M-15$^{\varepsilon}$1 [13]	1.829
Max. dry density (proctor test), gm/cm^3	ASTM D698-00a [14]	1.825
Optimum moisture content (proctor test), %	ASTM D698-00a [14]	15



(a) (b)

Fig. 1 SEM images for the tested specimens [16]. **a** Gypsum materials covered soil particles; **b** grouped gypsum materials

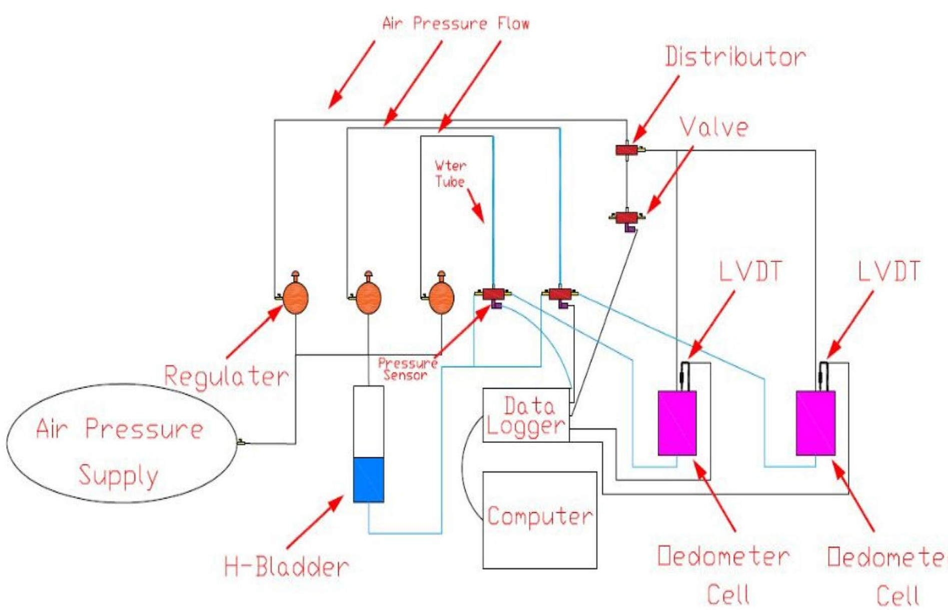
with natural moisture content revealed two states. Figure 1a depicts the first condition, in which soil particles are covered with a thin layer of gypsum that functions as a connection between them. Gypsum particles are clustered together in the second stage (Fig. 1b), forming strong connections between soil particles. Gypsum acts as a cementation element in both stages, and the soil appears to be cohesive. When the soil becomes wet, the gypsum softens, causing a decrease or loss of cohesiveness, which can lead to collapse.

2.2 Tools and equipment

Many attempts have been made to adapt traditional oedometer devices into systems that can perform unsaturated tests. The authors calibrated and used the unsaturated oedometer test apparatus of Al Maaqal University, Basra, Iraq, in the Soil Mechanics Laboratory in this investigation. Figure 2 illustrates a schematic representation of this device.

As described by Fredlund and Rahardjo [17], Fig. 3 describes the tools and equipment that are used for unsaturated testing; HAE ceramic disk (high air entry ceramic disk), grooved bade, air pressure system, water pressure system, and vertical linear displacement (volume change control device). In this test, the grooved section should be covered with the ceramic disc, as illustrated in Fig. 3a. The air trapped in the channels going to the pedestal, as well as any air bubbles that may occur during the test, are flushed out through these grooves. The water pressure is applied to the specimen through the grooved pedestal. This path is tightened by an O-ring to prevent water from leaking out

Fig. 2 Schematic shape for oedometer device



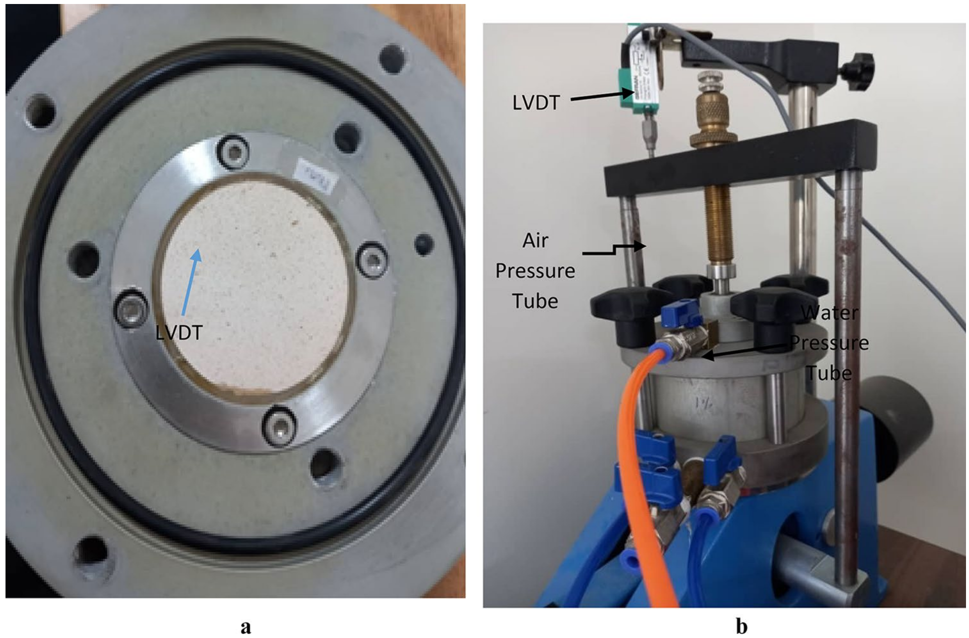


Fig. 3 Details of the tested cell specimen. **a** The bottom base; **b** the oedometer cell

of the HAE ceramic disk. The air pressure is passed to the specimen through the top cap (Fig. 3b). The linear vertical displacement tensor (LVDT), as shown in Fig. 3b, is used to calculate the vertical displacement. While volumetric water contents are measured according to the graded tube (Fig. 4a). All this system is connected to an air supply to apply the air and water pressures. A Hallow-Bladder (Fig. 4b) is used to apply the water pressure by applying the air pressure from the top to push the water to the graded tube that is connected to a pressure sensor to specify the wanted water pressure magnitude, and all the pressures are controlled by using air regulator (Fig. 4a). This system is linked to a data logger to collect all readings through a monitor. All the tests were started with the initial matric suction that was obtained from the initial water content in the selected site.

2.3 Determination of soil–water characteristic curve (SWCC)

For every specimen, the volumetric water content was calculated depending on the water content that was added to the specimen in the wetting and drying paths. Using the help of the apparatus for pressure plate test according to ASTM D2325-68 [15], the axis-translation method was applied to

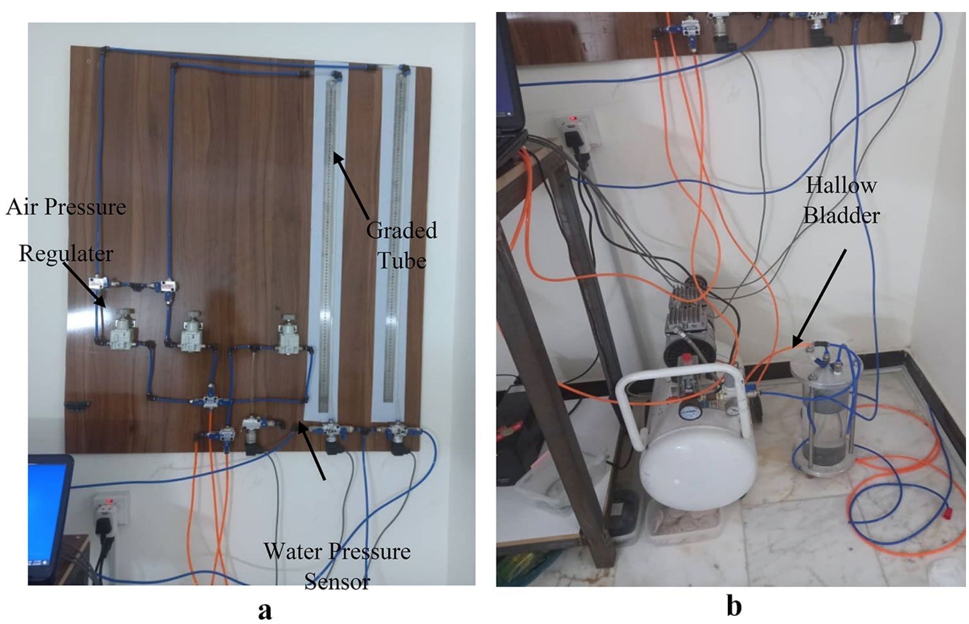


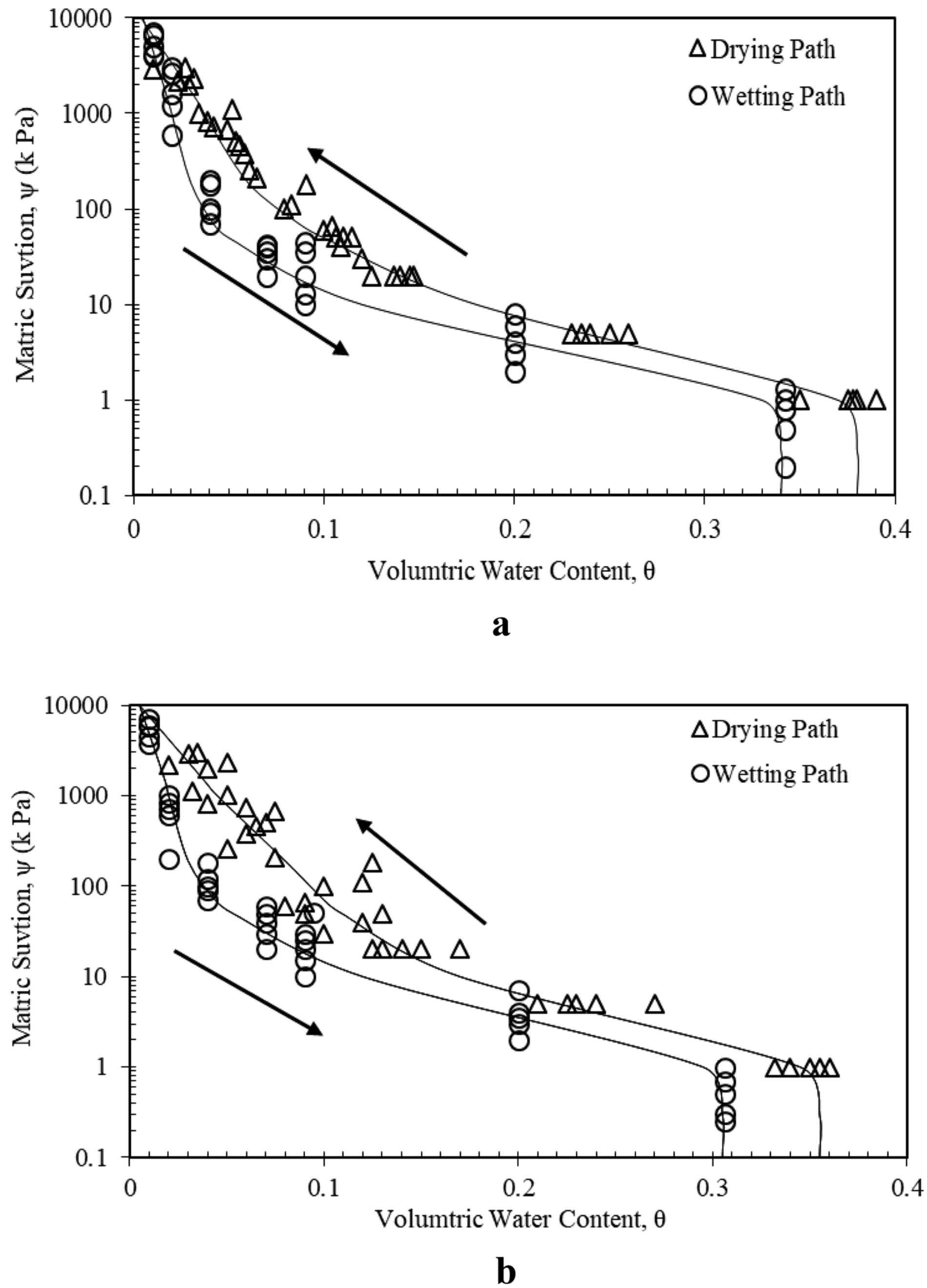
Fig. 4 Details of the system control. **a** System bord; **b** pressure applying system

determine the drying path. While the filter paper method was approved to obtain the wetting path as described in ASTM D5298-03 [16]. The determined SWCC in wetting and drying paths has the same trend except for the saturation and dried zones have different magnitudes, as shown in Fig. 5.

2.4 Sample preparation and laboratory tests

The unsaturated oedometer test apparatus defined in the preceding section was utilized to study the behavior of the sampled gypseous soil with the presence of matric suction. This inquiry was performed using the loading–unloading path with specific matric suction for the same test. Different matric suctions were pointed to study the effect of degree of saturation like, where a structure is constructed, but the water content is changed due to the water table rising (decreasing in matric suction). The first matric suction is the equivalent to the moisture content in the site (30 kPa) and the other three matric suctions were 60%, 30%, and 0% of the initial matric suction to cover all the area below the calculated SWCC as shown in Fig. 5. The filed densities of the tested samples are 1.827 and 1.825 g/cm^3 for the 14 and 29% gypsum content, respectively.

Fig. 5 Soil–water characteristic curve of the tested samples. **a** 14% Gypsum content sample; **b** 29% gypsum content sample



Twelve remolded specimens were tested in unsaturated conditions for each gypsum content with initial stress and applied stress with the four matrices suctions that have been selected before. For each matric suctions, three tests were done. Table 2 illustrates the test procedure. The specimens were remolded with the initial moisture content that had been detected in the sits and they were 4.2% for the 14% gypsum content sample and 5% for the 29% gypsum content sample.

All the tested specimens were tested in a cylindrical mold of the oedometer device in four layers. The mold has a diameter of 5 cm and a height of 2 cm. The HAE ceramic disk is pleased on the grooved base to ensure that all the area of the disk has water contact as illustrated in Fig. 3a. A wetting path procedure was conducted to investigate the water table rising case in foundations. The water pressure is applied from the bottom of the disk and the air pressure is applied from the top of the oedometer cell, as shown in Fig. 3b. The dry density of the tested samples was 90% of the dry density in the site and Proctor test (Table 1). The initial matric suction was obtained depending on the water content that was calculated in the field (30 kPa for the selected two samples according to SWCCs as in Fig. 5). The air pressure and water pressure were 150 and 120 kPa, respectively. For another matric suctions, air pressure was fixed, and water pressure was increased until reaching to the wanted matric suction throughout calculating the entered water quantity to the specimen by recording the water falling in the graded tube, as shown in Fig. 4a.

As illustrated in Table 1, it was two methods of loading. The first one is the specimen was loaded after reaching the pointed level of matric suction and the second one was that, with the presence of a specific load, the decreasing of matric suction was started. When the specimen reached to the equilibrium state (the was no entry of water), the loading stage was started. The time of saturated state was 72 h, so this time was fixed for the other three levels of matric suction. For the loading stage, the time of each level was set to 30 min because the settlement in the sand soils occurred immediately and the needed time to reach the final settlement ranged from 10 to 15 min, so the selected time was sufficient.

3 Results and discussion

In the present work, in the setting of matric suction stages, the air pressure and water pressure were applied at the same time, and the water entering was recorded until reaching the

Table 2 Work procedure

Gypsum content (%)	Matric suction (kPa)	Test no	Initial stress (kPa)	Applied stress (kPa)								
14	30	1	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		2	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		3	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	18	4	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		5	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		6	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	9	7	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		8	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		9	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	0	10	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		11	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		12	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
29	30	1	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		2	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		3	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	18	4	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		5	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		6	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	9	7	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		8	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		9	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L
	0	10	—	56 L	112 L	224 L	448 L	224 U	112 U	224 R	448 R	896 L
		11	56	—	112 L	224 L	448 L	224 U	112 U	224 R	448 R	897 L
		12	112	—	—	224 L	448 L	224 U	112 U	224 R	448 R	898 L

* *L* loading, *U* unloading, *R* reloading

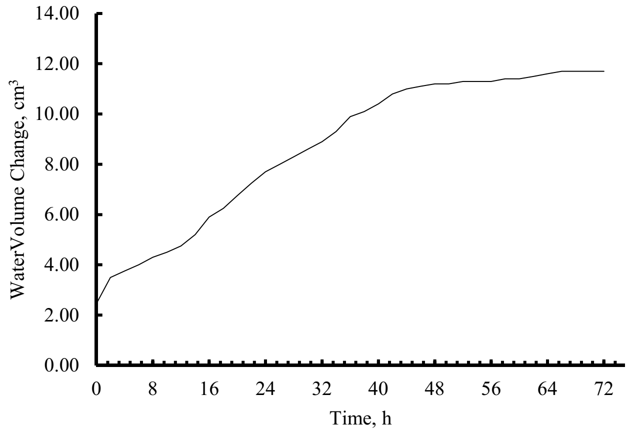


Fig. 6 Water volume changes of the tested specimen

specified degree of saturation that was selected before. In all tests, the air pressure was 150 kPa, and the water pressures were 120 kPa, 132 kPa, 141 kPa, and 150 kPa for the following matric suctions: 30 kPa, 18 kPa, 9 kPa, and saturated state (zero matric suction), respectively. These matric suctions were carefully chosen to cover all the areas under the curve of SWCC of the two selected samples. The matric suctions were controlled depending on the volumetric water content (θ) according to the quantity of water that entered the specimen through the graded tube. Figure 6 shows the water volume changes during the test that has been conducted before starting the loading stage to reach the specific matric suction (14% gypsum content with zero matric suction as an example) by the term of the water entering the specimen versus time. The 2.46 cm^3 is the initial water content of the tested specimen. After applying the matric suction pressure, the water started entering the oedometer cell throughout the HAE ceramic disk, and then the specimen begins the saturation state until filling up the voids between soil particles.

3.1 Results of 14% gypsum content specimens

Figure 7 and Table 3 illustrate the volumetric strains of the tested specimens of 14% gypsum content (G with the four levels of matric suctions (30 kPa, 18 kPa, 9 kPa, and

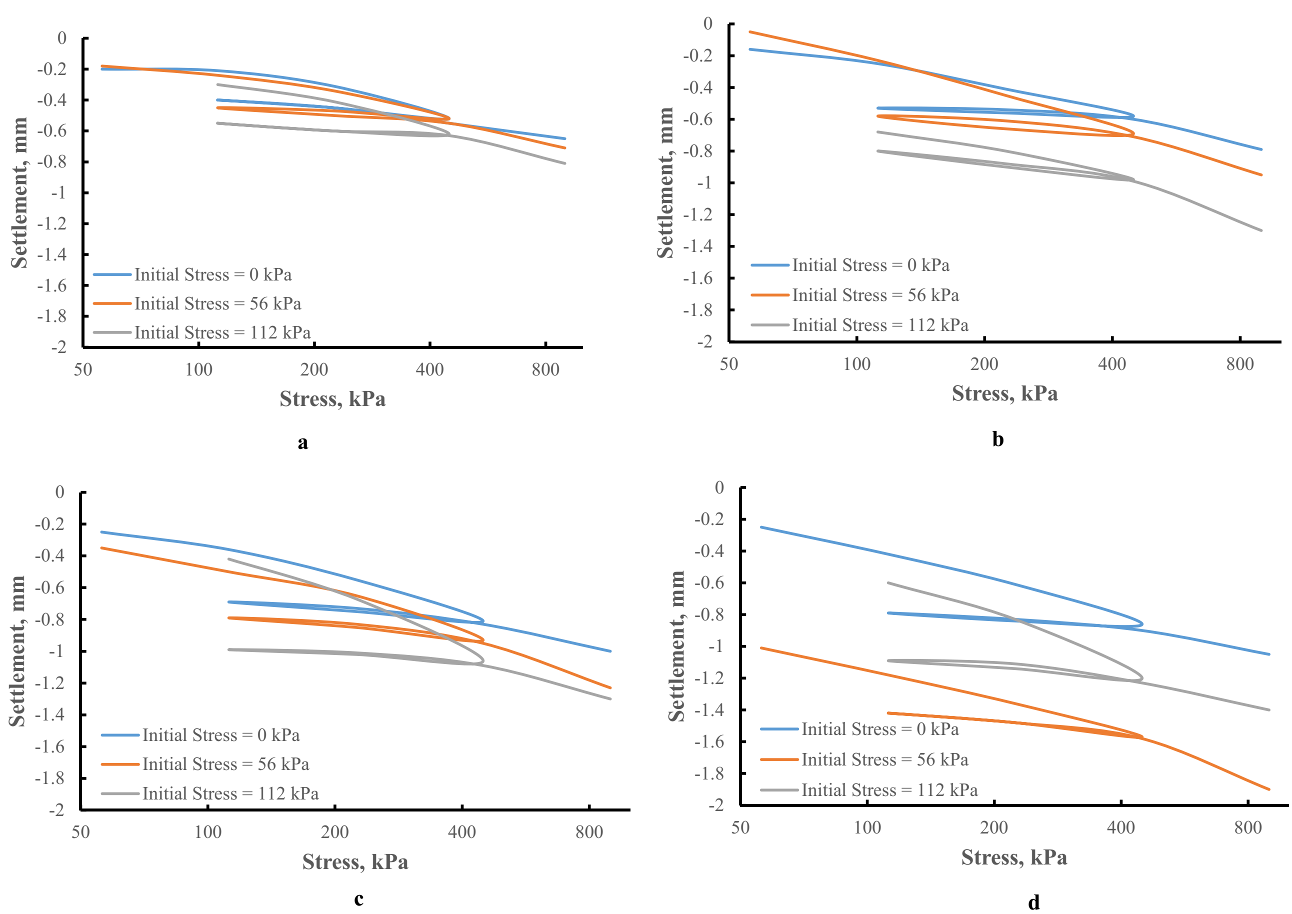


Fig. 7 The settlement of the tested specimens of 14% gypsum content. **a** Initial matric suction (30 kPa); **b** matric suction of 18 kPa; **c** matric suction of 9 kPa; **d** saturated condition

Table 3 The volumetric strains of the tested specimens of 14% gypsum content

Matric suction, kPa	Stress, kPa	Volumetric strain, %		
		0 kPa Initial stress	56 kPa Initial stress	112 kPa Initial stress
30	**56**	−1	−0.9	0
	112	−1.05	−1.2	−1.5
	224	−1.55	−1.7	−2.05
	448	−2.6	−2.6	−3.1
	224	−2.25	−2.35	−3
	112	−2	−2.25	−2.75
	224	−2.25	−2.5	−3
	448	−2.75	−2.75	−3.15
	896	−3.25	−3.55	−4.05
18	**56**	−0.8	−0.25	0
	112	−1.25	−1.15	−3.4
	224	−2.05	−2.25	−4
	448	−2.9	−3.45	−4.9
	224	−2.8	−3.3	−4.5
	112	−2.65	−3.15	−4
	224	−2.7	−3.05	−4.4
	448	−3	−3.55	−4.95
	896	−3.95	−4.75	−6.5
9	**56**	−1.25	−1.75	0
	112	−1.8	−2.5	−2.1
	224	−2.75	−3.25	−3.35
	448	−4.05	−4.65	−5.3
	224	−3.75	−4.25	−5.1
	112	−3.45	−3.95	−4.95
	224	−3.65	−4.15	−5.05
	448	−4.15	−4.75	−5.45
	896	−5	−6.15	−6.5
Zero	**56**	−1.25	−5.05	0
	112	−2.1	−5.9	−3
	224	−3.25	−6.8	−4
	448	−4.3	−7.85	−6
	224	−4.2	−7.4	−5.7
	112	−3.95	−7.1	−5.45
	224	−4.15	−7.4	−5.55
	448	−4.5	−7.9	−6.15
	896	−5.25	−9.5	−7

saturated state) according to the initial stress levels as mentioned in Table 2. When the specimen was tested with the initial matric suction (30 kPa), as shown in Fig. 7a, the settlement of the initial load of 112 kPa is higher than the other two conditions (no initial load and 56 kPa), and the test with 56 kPa is between zero initial stress and 112 kPa. This behavior is seen in the condition of 18 and 9 kPa of matric suction, as in Figs. 7b and 10c, respectively. But in the zero matric suction condition, the test with the 56 kPa of initial stress has the highest settlement, as illustrated in Fig. 7d. This behavior is because the gypsum particles work as bonds between soil particles and, due to the wetting process when the matric suction is applied, the bonds will be broken at the stress of 56 kPa because of the wetting process to reach the wanted matric suction. But in the initial stress of 112 kPa, the soil particles have been settled because of the applied

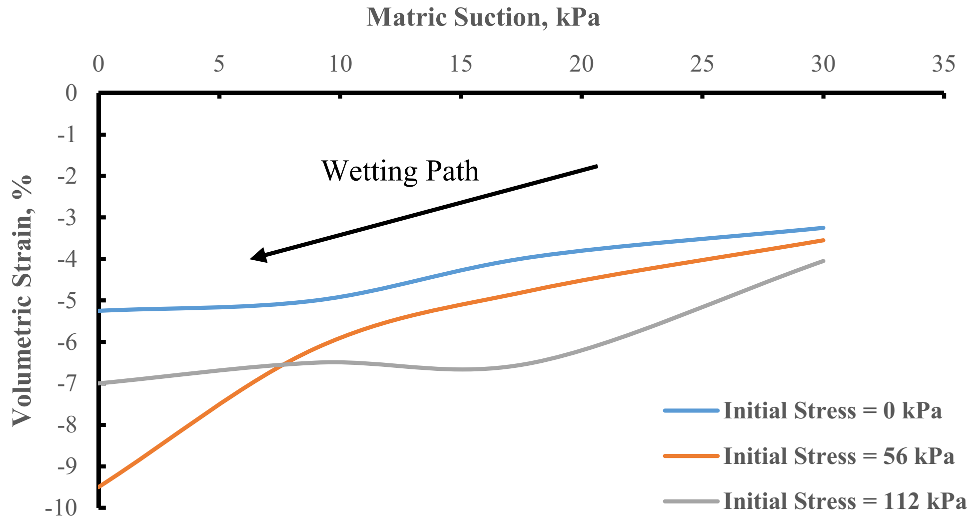


Fig. 8 The volumetric strain of the tested specimens of 14% gypsum content versus matric suction

load, the voids between the particles were decreased, and the water quantity required to enter the specimen was less than the initial stress of 56 kPa. Figure 8 shows the summary of the tested specimens according to the matric suctions.

3.2 Results of 29% gypsum content specimens

As demonstrated in Fig. 9 and Table 4, the behavior of 29% gypsum content specimens is the same behavior of 14%

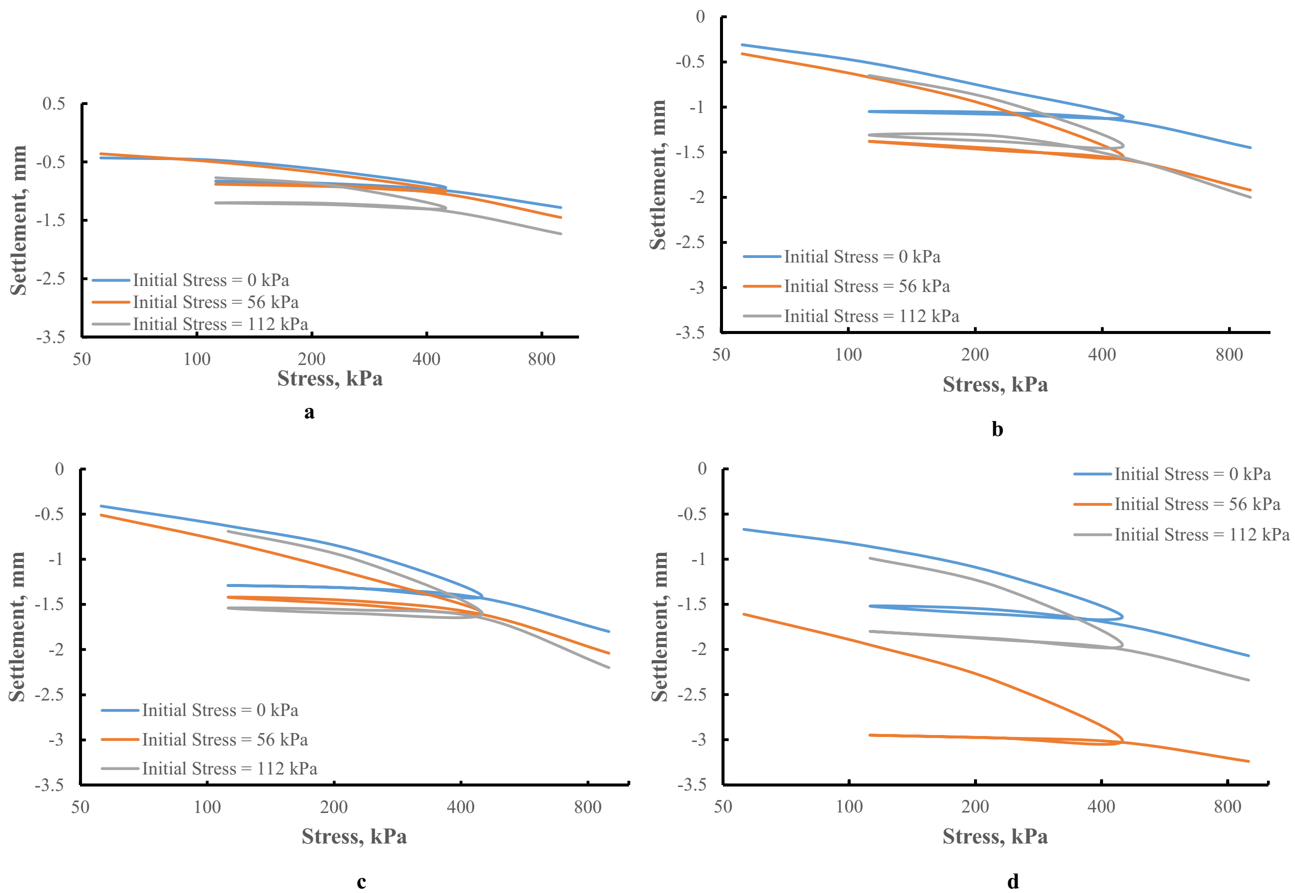


Fig. 9 The settlement of the tested specimens of 29% gypsum content. **a** Initial matric suction (30 kPa); **b** matric suction of 18 kPa; **c** matric suction of 9 kPa; **d** saturated condition

Table 4 The volumetric strains of the tested specimens of 29% gypsum content

Matric suction, kPa	Stress, kPa	Volumetric strain, %		
		0 kPa initial stress	56 kPa initial stress	112 kPa initial stress
30	**56**	−2.15	−1.8	0
	112	−2.35	−2.5	−3.85
	224	−3.25	−3.55	−4.5
	448	−4.7	−5	−6.45
	224	−4.5	−4.6	−6.15
	112	−4.15	−4.4	−6
	224	−4.35	−4.5	−6.05
	448	−4.95	−5.25	−6.7
	896	−6.4	−7.25	−8.65
18	**56**	−1.55	−2.05	0
	112	−2.55	−3.35	−3.25
	224	−4	−5.05	−4.6
	448	−5.55	−7.75	−7.15
	224	−5.4	−7.3	−6.9
	112	−5.25	−6.9	−6.55
	224	−5.3	−7.4	−6.6
	448	−5.75	−7.9	−7.8
	896	−7.25	−9.6	−10
9	**56**	−2.05	−2.55	0
	112	−3.15	−4.05	−3.45
	224	−4.5	−5.85	−5
	448	−7.05	−7.95	−8
	224	−6.6	−7.5	−8
	112	−6.45	−7.1	−7.7
	224	−6.6	−7.3	−7.8
	448	−7.15	−8.05	−8.25
	896	−9	−10.2	−11
Zero	**56**	−3.35	−8.05	0
	112	−4.3	−9.75	−4.95
	224	−5.75	−11.75	−6.5
	448	−8.2	−15.05	−9.75
	224	−8.05	−14.9	−9.4
	112	−7.6	−14.75	−9
	224	−7.8	−14.9	−9.45
	448	−8.65	−15.15	−10
	896	−10.35	−16.2	−11.7

gypsum content testes. But in the settlement part, the settlement is higher than the previous tests. Gradual softening of gypsum materials throughout the soaking process resulted in a 150 to 160% increase in volumetric. Figure 10 demonstrates the summary of the tested specimens according to the matric suctions.

3.3 Discussion

The findings of the unsaturated tests along the wetting path in terms of final volumetric strain under various conditions are summarized in Tables 3 and 4. In general, these findings demonstrate a clear pattern of increasing volumetric

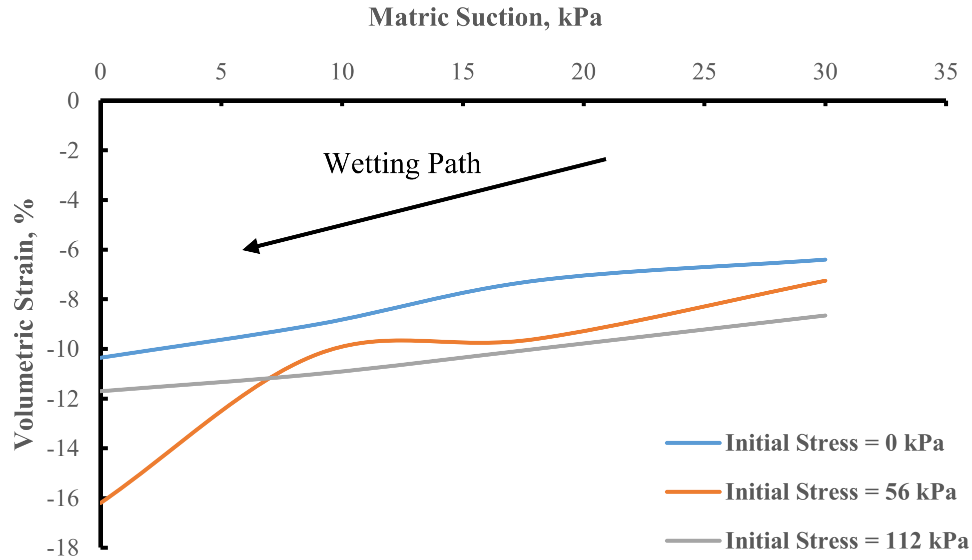


Fig. 10 The settlement of the tested specimens of 29% gypsum content versus matric suction

strain as gypsum concentration increases and matric suction decreases.

4 Effect of the matric suction on the stiffness (*E*)

The linear component of the stress–strain curve, the slope of the tangent line, is used to compute the elastic modulus. The modulus of elasticity (E) for each matric suctions was calculated using the trendline with the exponential equation. For example, Fig. 11 illustrates the modulus of elasticity for a 14% gypsum content specimen with saturation condition (zero matric suction) by taking the trendline of the curve. This trendline has $\sigma_1 = 56$ kPa, $\mathcal{E}_1 = 5.05\%$, $\sigma_2 = 896$ kPa, $\mathcal{E}_2 = 9.5\%$, and determined E is 26,571 kPa. This method is applied for the other stress–strain curves to calculate the modulus of elasticity of 14 and 29% gypsum content specimens, as shown in Fig. 12.

For the two gypsum content samples, Fig. 12 depicts the stiffness variations of the tested specimens in the presence of matric suction with the conditions of initial stresses. According to the formulae in the figures, the stiffness is raised by raising the matric suction. It may be deduced that decreasing the gypsum content increases stiffness, which is dependent on matric suction. Geotechnical engineers can use these equations to calculate soil stiffness based on matric suction.

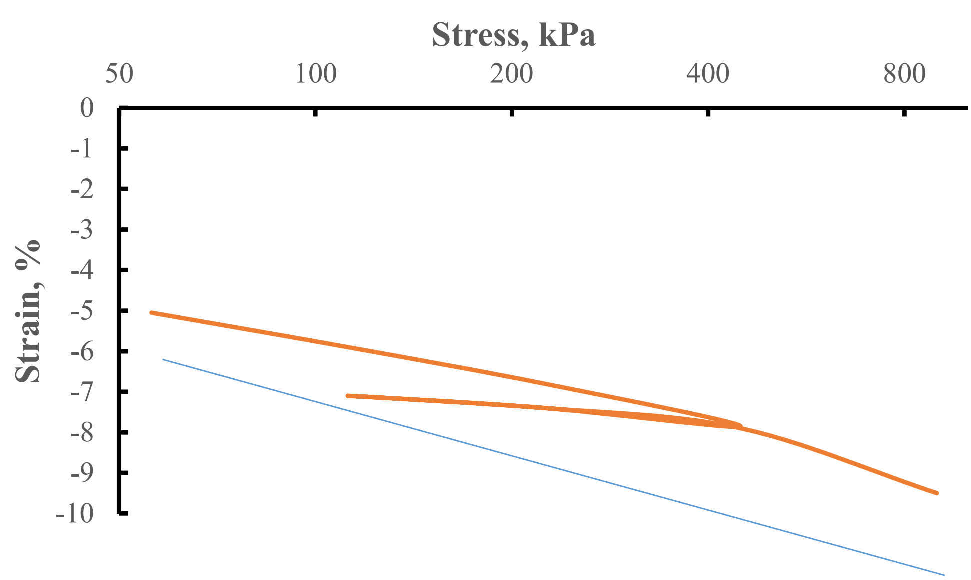


Fig. 11 The stress–strain curve of the tested specimens of 14% gypsum with zero matric suction and 56 kPa of initial stress

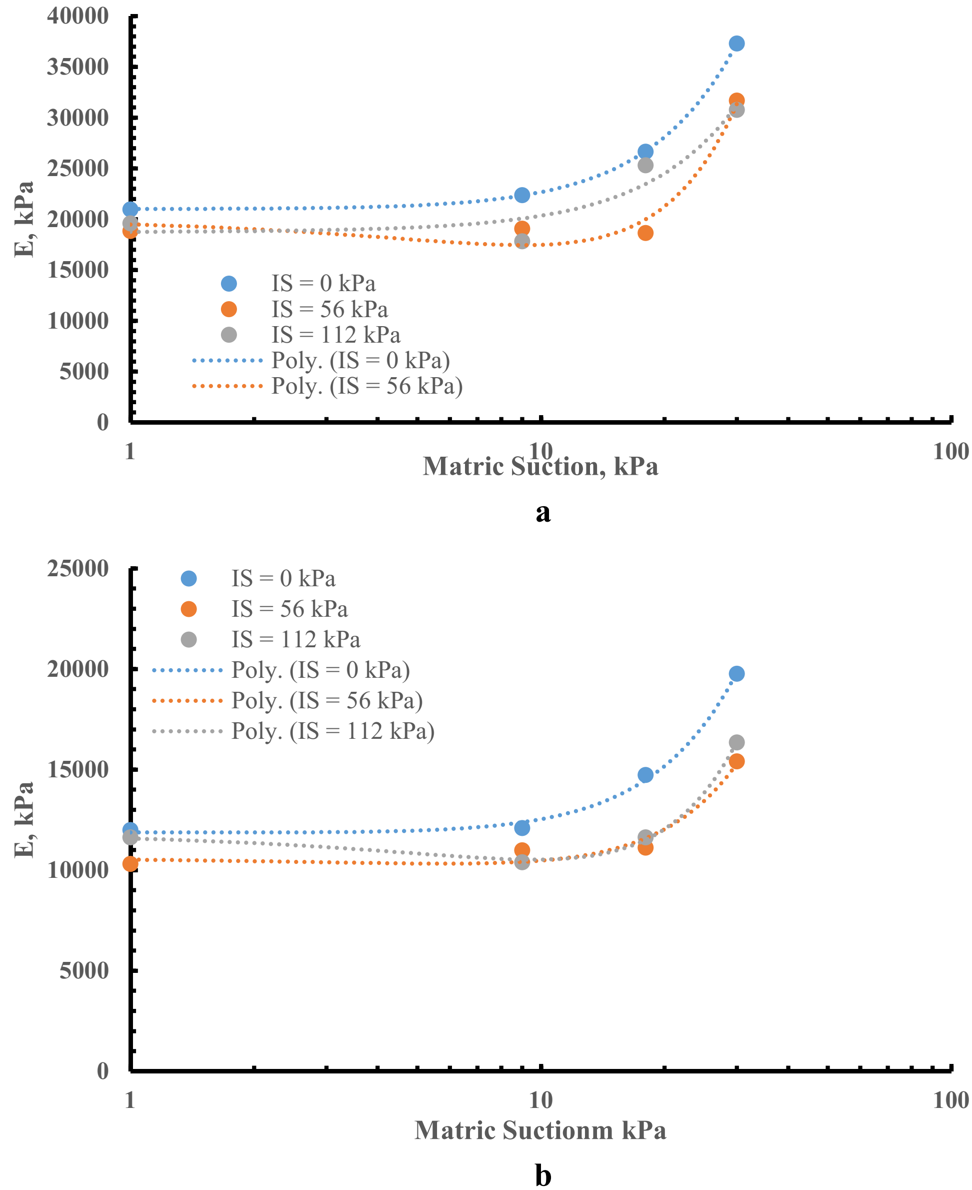


Fig. 12 E-matric suction curve of the tested specimens G1 and G2 samples. **a** G1 samples. **b** G2 samples

5 Summary and conclusions

Because there is a scarcity of study and information on the behavior of gypseous soils after wetting, these soils can be troublesome from a geotechnical and structural standpoint. As a result, more research on the effect of saturation variations on the behavior of these soils to fix incremental loading circumstances is required. The volume variations in gypseous soils with changes in matric suction were measured using an unsaturated oedometer testing apparatus in this work.

The influence of matric suction on volume changes in disturbed samples with varying gypsum concentrations at different initial stresses was studied in this study. The tests were carried out using two different gypsum contents (14 and 29%), with four levels of matric suction (30 kPa, 18 kPa, 9 kPa, and zero) and three levels of initial stress in the former. The results in the wetting path demonstrated a definite increase in volumetric strains as matric suction decreased, as well as a fast increase in these strains when the gypsum content of the soil increased at each given matric suction and initial stress level. The hydraulic conductivity of the soil has never been measured. The authors propose developing their understanding of the behavior of these soils in order to detect the hydraulic behavior in a future investigation.

Author contribution Rusul Almahmodi conceived and designed the analysis, collected the data, and wrote the paper. Mustafa M. Abdalhusein contributed data and analysis tools. Ali Akhtarpour performed an analysis. Mohammed Sh. Mahmood performed manuscript editing and figure design.

Data availability N/A.

Materials availability N/A.

Code availability N/A.

Declarations

Ethics approval This article does not contain any studies with animals performed by any of the authors.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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