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RELAIBILITY ASSESSMENT OF THE SOIL-WATER-RETENTION FOR UNSATURATED SAND SOILS

Mohammed Shakir Mahmood[1], Mustafa Jamal Abrahim[2] and Salah Mahdi Saleh[3]

[1] Professor, Ph.D., Civil Eng. Dept., University of Kufa, Al-Najaf, Iraq, mohammedsh.alshakarchi@uokufa.edu.iq.

[2] Asst. Lecturer, MSc., Civil Eng Dept., Al Iraqia University, Baghdad, Iraq, MustafaJamalibrahim@aliraqia.edu.iq.

[3] Formerly MSc. Student, Civil Eng. Dept., University of Kufa, Al-Najaf, Iraq, salahm.almshakeel@student.uokufa.edu.iq.

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ABSTRACT

In this investigation, the soil-water-retention is described in the soil-water-characteristics-curve (SWCC). SWCC contains the data required to explain the unsaturated soils' mechanical behavior. The reliable findings of unsaturated sand soil tests and the impact of initial density on the hydraulic properties under various matric suction and net normal stresses are examined. The tests are carried out on a sample of soil from the northern region of Al-Najaf city, Iraq. The sample of soil has been disturbed and remolded in the cell of Oedometer device. A modified high-air-entry-disc-based Oedometer is used with accessories to control the air and water pressures to achieve the specific matric suction in the unsaturated test. Two sets of tested specimens are prepared, first, at 90% and second at 95% of the maximum dry unit weight from the standard Proctor experiment. Each set is performed for different matric suction under 200 and 400 kPa net normal stress. (SWCC) The soil water retention curve is affected by the application of net normal stress and initial density. There is a decrease in water volume change with wetting progress in unsaturated soil tests due to an increase in soil density.

KEYWORDS

Gypseous sand, Najaf, unsaturated soil, SWCC, net normal stress.

1. INTRODUCTION

The relationship between the volumetric water content and the matric suction (soil-water characteristics curve, SWCC) in gypseous sandy soil under wetting, concerning varying stress levels and soil density, is essential. The SWCC can be used in engineering tasks such as the best irrigation systems, railroad and road embankments, …etc. The unsaturated soil's strength, volume change, permeability, thermal diffusivity and solute are all under the control of the SWCC (Saleh and Mahmood, 2023). Soil soaking reduces stiffness and shear strength as well as changes volume, many elements affect the type and degree of this alteration, including the structure of soil, stress state, and soaking degree that causes collapse. (Ng, and Menzies, 2007). Gypsum soils are being investigated using traditional saturated soil mechanics, but the soil's characteristics in unsaturated states, such as those seen in semi-arid and arid areas, could alter (Amed, 2013). Water infiltration causes a reduce in the suction of soil and may cause a destabilizing the subsurface services (Zhu et al., 2018). Gypsum soil is a collapsable soil that leads to issues for structures and buildings built on them because of a considerable reduction in the shear strength once they are subjected to moisture (Abdalhusein et al., 2023 and Asghari, 2018). This collapse is dependent on numerous factors, including the process of wetting (Al-Obaidi et al., 2020, Abdalhusein, et al. 2019a, Abdalhusein, et al. 2019b and Liu et al., 2011), permeability, void ratio, higher gypsum content (Fattah and Al-Shakarchi, 2008), initial saturation degree (Fattah et al.,2014 and Mahmood, 2018) and soil time-based wetting prior loading (Mahmood et al., 2020, Mahmood et al., 2018 and Mahmood, 2018). The re-bonding of the gypsum particles causes a little reduction in the final settlement during the curing period (Aldarraji and Ganjian, 2024 and Aldarraji et al., 2024).

Granular materials have exceptionally low air-entry values. Additionally, the forces of capillary generated by suction raise the stresses of inter-particle leading to a decrease in void ratio and a rise in dry density (Maleksaeedi et al., 2016). The state of unsaturated always exists in collapsible soils where massive collapse happens with a reduction in the (ua−uw) matric suction (Mahmood and Abrahim, 2021). During wetting in sand, a decrease in volume happens (Zimbardo et al., 2016 and Abdalhusein, et al. 2019b). The volumetric strain increases significantly as the gypsum concentration increases (Abdalhusein, et al. 2019b). The level of net normal stress (221 kPa) dominates the computation of (CP) collapse potential (Abrahim and Mahmood, 2021a). As the matric suction increased, the bearing capacity raised nonlinearly by 2.55 to the 3.95 times (Safarzadeh and Aminfar, 2019). During the wetting process, greater mean net stress (Pn) induced an even more severe collapse (Haeri et al., 2014). As the suction increases, both the dilatancy and yield stress of the samples rise (Estabragh and Javadi, 2012).

Several researchers conducted studies on remolded specimens, disregarding the soil's sensitivity (Haeri et al., 2012). The SWCC, which depicts the relation between a soil's suction and moisture content, is a fundamental connection in unsaturated soil mechanics, with most SWCCs being sigmoidal or unimodal in shape and bimodal SWCCs in some soils (Fredlund and Rahardjo, 1993 and Leong, 2019). This conceptual work may be utilized to investigate the complicated behavior of soil in an unsaturated state, and much study has been done in this field (Nam, 2010). The unsaturated soils behavior is influenced by the SWCC, which can be linked to other soil properties, such as the unsaturated coefficient of permeability and shear strength (Aldaood et al., 2015 and Abrahim and Mahmood, 2021b). For a particular soil, there are both indirect and direct techniques for estimating SWCCs (Leong, 2019) and (Gallag and Uchimura, 2010). The net normal stress level influences the unsaturated soil within wetting Progression (Saleh and Mahmood, 2023) and (Saleh and Mahmood, 2024). One week following the remolding causes a modest decrease in re-bonding in the settlement; however, a longer time frame may result in a more notable impact (Mahmood and Abrahim, 2024).

The current investigation declares the effect of the initial density of the remolded soil specimen on the hydraulic characteristics during wetting progress in the unsaturated soil test. The unsaturated tests are performed in the modified Oedometer apparatuses through the application of water and air pressures (ua and uw) into the soil sample.

2. METHODOLOGY

2.1. Soil Sampling and Classification Tests

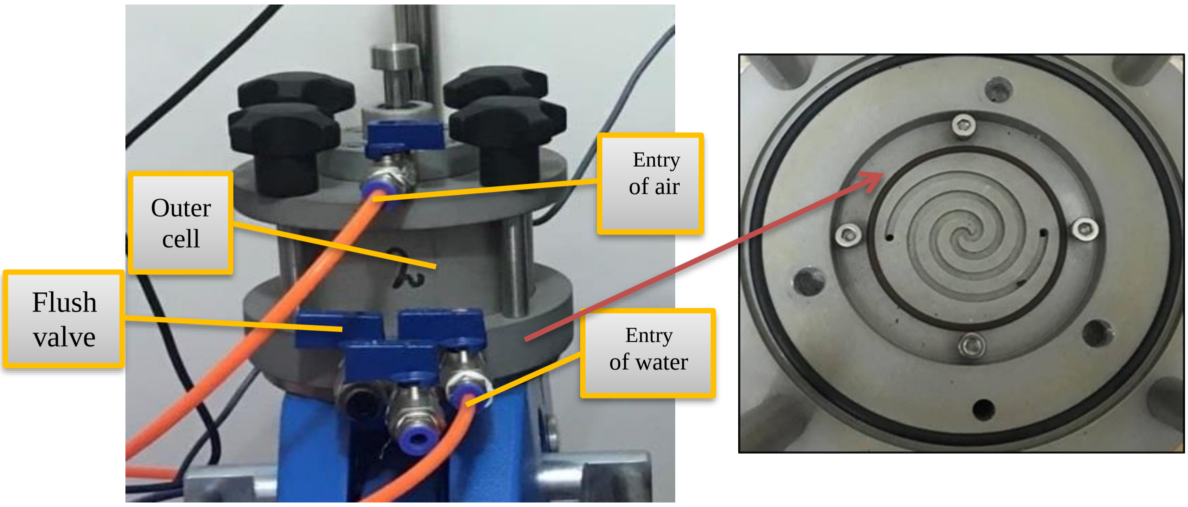
The tests are carried out on a sample of soil from the northern district in the city of Al-Najaf, Iraq. The soil sample is remolded in the cell of Oedometer device. The specimen will be at 90 percent and 95 percent of the maximum dry unit weight from the standard Proctor experiment. According to the (USCS) Unified Soil Classification System, the soil is classified as (SP) sand poorly graded sand. The maximum dry unit weight is 1.825 gm/cm3 with an optimum water content of 15 percent. Table 1 presents the experiment results of the identification of soil samples.

Table 1. The results of classification tests of soil sample.

Test Designation	Standards	Values
Sand, %	ASTM C136-96a	86
Soil classification	ASTM C136-96a	SP
Specific gravity (Gs)	ASTM D854	2.38
Gypsum content, %	ASTM C25-19	29
Maximum dry density, gm/cm^3	ASTM D698	1.825
Optimum water content, %	ASTM D698	15

2.2. Modified Unsaturated Oedometer and Accessories

The current study aims to examine the influence of the process of wetting on the volumetric strain of the gypsum soil from unsaturated experiments with various matric suctions utilizing a modified Oedometer cell, as in Fig. 1a. The modified Oedometer comprises of a grooved base plate, a top cap, as in Fig. 1b, (HAE) a High Air Entry ceramic disc, an outer cell, and an inner cell. The pore water pressure is applied through a 1 Bar (HAE) high air entry disc while the air pressure is applied and controlled using the top cap. A proposed control board, for water volume changes and the application of matric suction, is connected to a compressor has an 11 bars pressure capacity. A regulator has a pressure various up to 30 bars is used to apply and sustain pressures. To measure water and air pressure, sensors linked to a data logger with a computer and a control board. (LVDT) a linear variable differential transformer, 0.01 mm, to measure the vertical settlement of the specimen during the test. Fig. 2 shows the setup of the modified Oedometer with accessories.



(a) The modified Oedometer cell (b) Grooved base plate.

Fig. 1. Modified Oedometer Device

2.3. Test Procedure

The sample of soil is remolded in the cell of Oedometer device. Two sets of tested specimens are prepared, first, at 90 percent and second at 95 percent of the maximum dry density from the standard Proctor test. Each set is performed for various matric suction, 90, 50, 20, 10, 7, 2 and 0.1 kPa. First, for each set, a matric suction of 90 kPa is applied, then, a gradual net normal stress up to the specific level (200 or 400 kPa) is achieved. Under this stress, the matric suction decreased within the range of the values. Table 2 shows the summary of the test's procedure.

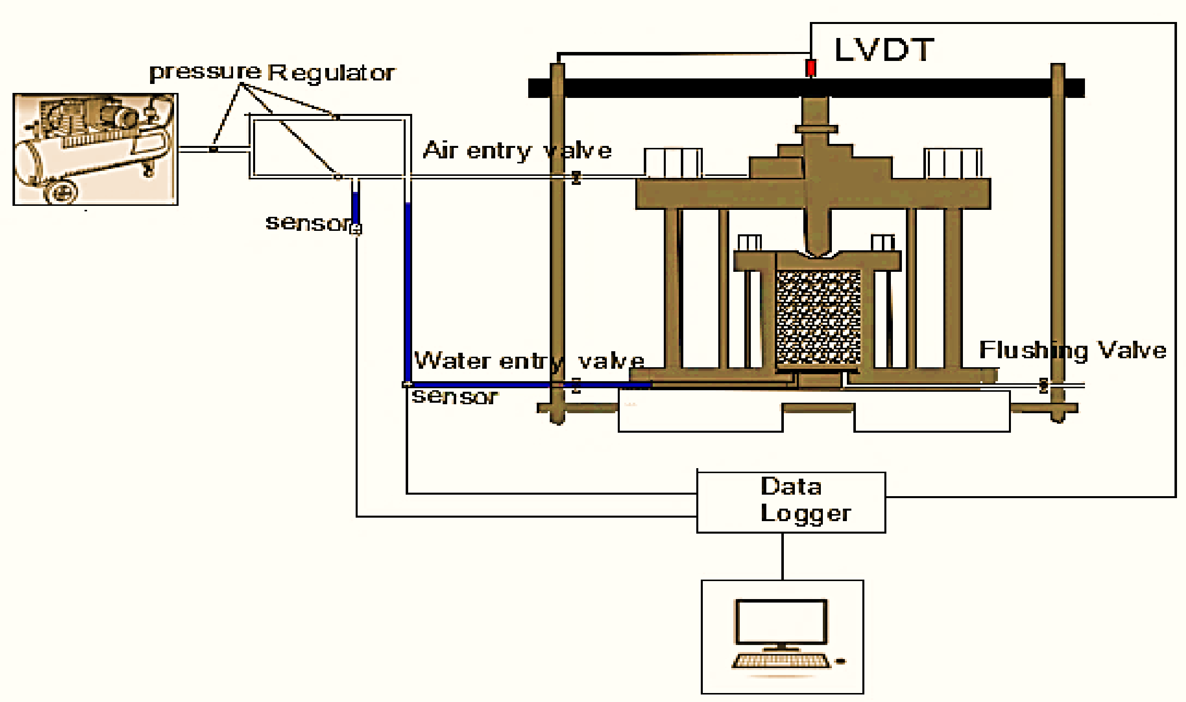


Fig. 2. The schematic of the test devices.

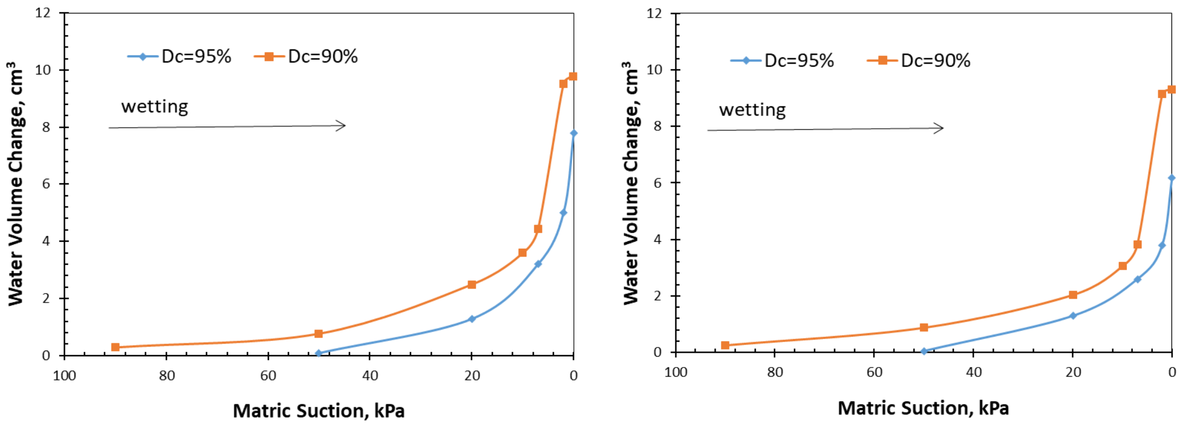
Table 2. The procedure of the tests.

Test group No.	Degree of compaction (Dc), %	Net normal stress (NNS), kPa	Matric suction (ua-uw), kPa
1	90	200	90, 50, 20, 10, 7, 2 then 0.1
2		400	90, 50, 20, 10, 7, 2 then 0.1
3	95	200	90, 50, 20, 10, 7, 2 then 0.1
4		400	90, 50, 20, 10, 7, 2 then 0.1

3. RESULTS AND DISCUTION

3.1. Reliable Matric Suction-Water Volume Change Relationship

Fig. 3(a) presents the matric suction versus water volume change under net normal stress of 200 kPa for two different initial densities, 95% and 90% of the maximum dry density in the Proctor test. Wetting progress is performed on the soil specimen, i.e., reducing the matric suction. There is a reduction in the water volume entering the soil with increasing density. Increasing the density leads to a decrease in the void ratio and decreases the volume of water entering the soil within different matric suctions. As in Fig. 3, all water volume changes (WVCs) have a similar trend. The values of WCV are low for matric suction < 7 kPa, then increase with decreasing matric suction (wetting). This state may be associated with the dissolution of the gypsum content with wetting progress, while the WCV becomes zero in the saturation state (matric suction = 0 kPa) due to the voids being filled with water before the state of zero matric suction (saturation). With raising the net normal stress to 400 kPa, as in Fig. 3(b), there are no changes in the trend with small decreases in the values of the water volume change due to the higher applied stress.



(a) under Net Normal Stress of 200 kPa (b) under Net Normal Stress of 400 kPa.

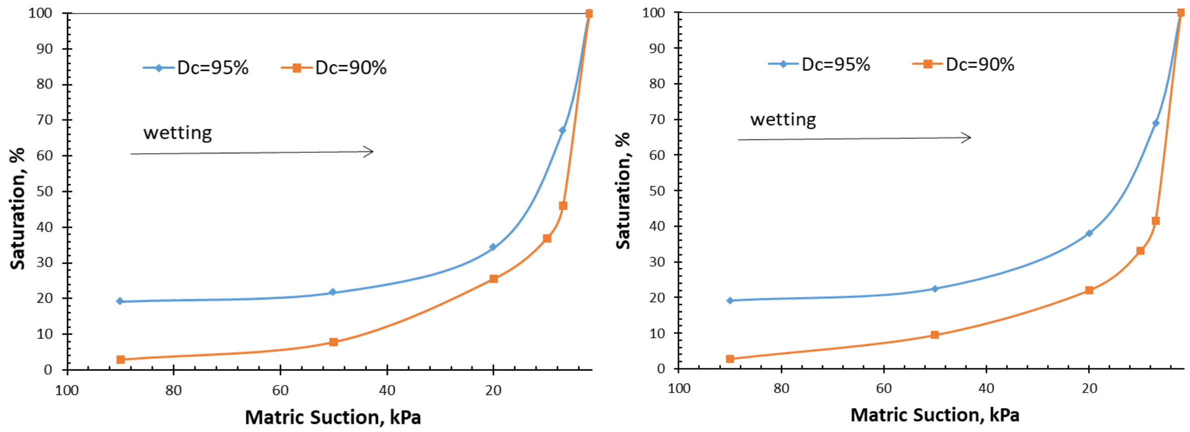
Fig. 3. The comparison of matric suction versus water volume change for both densities and net normal stress (NNS).

3.2. Reliable Matric Suction-Saturation Relationship

Fig. 4 illustrates the impact of the degree of compaction (density) on the saturation change during the wetting process (decreasing in the matric suction) under net normal stress (NNS) of 200 and 400 kPa. For both stress levels (200 and 400 Kpa), it is clear that the change in the initial density affects the values of the saturation related to the same matric suction, while with increasing the density, a reduction in the saturation degree occurs. This behavior is extended up to saturation (100%), where there is a matching trend in the relationships. In high matric suction (dry soil), the volume of the water change is confined by the density. In addition to the suction, after the wetting process (a reduction in the matric suction), a calibration in saturation is made with matched trends for different NNS and density, as the volume of the water is increased.

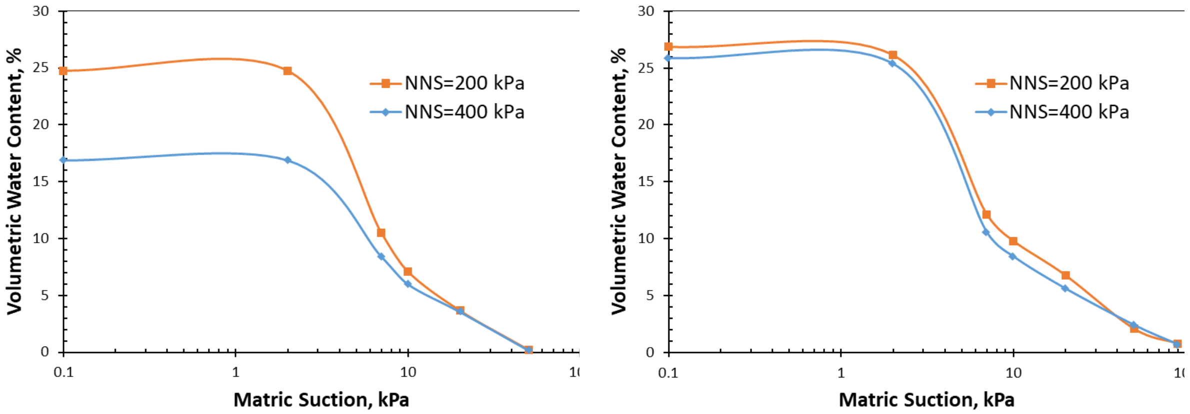
3.3. Reliable Matric Suction-Volumetric Water Content Relationship (SWCC)

Fig. 5 illustrates the impact of the net normal stress (NNS) on the relationship between the volumetric water content and matric suction for the degree of compaction (Dc) of 90 and 95 %. The higher the NNS means a lower VWC for the same matric suction. This difference is clear prior to saturation (low matric suction) and within higher density (Dc =95%), as shown in Fig.5(a). whereas both the net normal stress and high density have the main role in the quantity of water that enters the soil during the wetting progress.



(a) under NNS of 200 kPa (b) under NNS of 400 kPa.

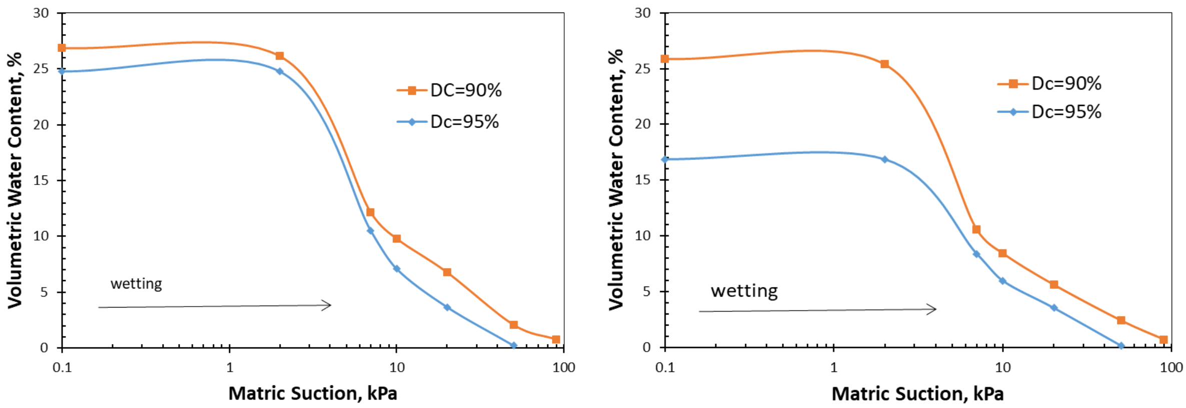
Fig. 4. The comparison of the matric suction versus saturation degree for both densities and net normal stress (NNS).



(a) for Degree of Compaction (Dc) of 95% (b) for Degree of Compaction (Dc) of 90%

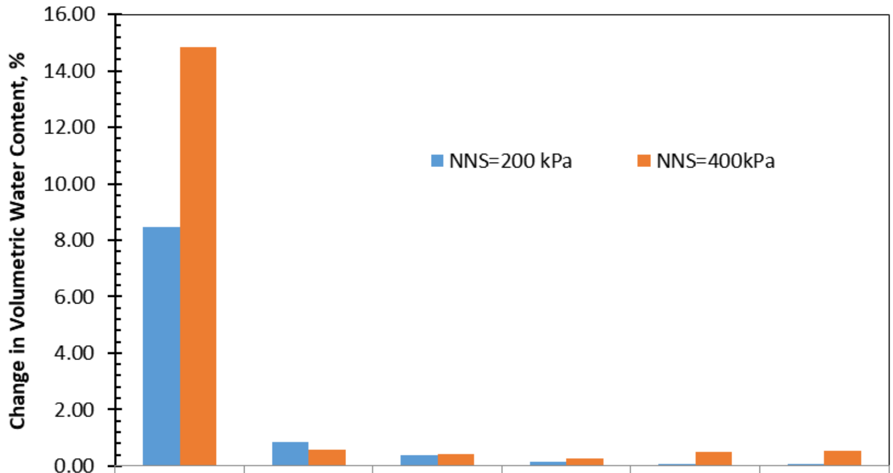
Fig. 5. The comparison of matric suction versus volumetric water content for both densities and net normal stress (NNS).

Fig. 6 shows the effect of the density (Dc of 90 and 95 %) on the relationship between the volumetric moisture content and matric suction. The figure declares the previous statement that there is a combined effect from the normal stress and initial density of the behavior of the SWCC and it is an important achievement for the consideration in analysis and design above such conditions. Generally, the values of the percentage changes of the water volume content are increases with decreasing of the density (up to Dc of 90%), as in Fig. 7. This behavior is obvious within the high matric suction (dry soil), then this change is lowered within wetting condition (decreasing in the matric suction) up to saturation.



(a) under NNS = 200 kPa. (b) under NNS = 400 kPa.

Fig. 6. The comparison of Matric Suction versus Volumetric Water Content (SWCC) for both densities and net normal stress (NNS).



	50	20	10	7	2	0
NNS=200 kPa	8.45	0.85	0.38	0.16	0.06	0.08
NNS=400kPa	14.83	0.59	0.41	0.26	0.50	0.53

Fig. 7. Percentage Change in the Volumetric Water Content for Dc = 90% related to Dc = 95% under different NNS.

4. CONCLUSIONS

As the soil-water characteristics curve (SWCC) is important for different engineering projects, it is important to characterize this relationship for the different soil states and properties, such as soil density and stress level. From the current investigation, it is obvious that there is a decrease in water volume change within wetting progress in unsaturated soil tests due to an increase in the soil density. The saturation is increased with increasing the soil density, as the void ratio is decreased with similar water volume change. The SWCC is affected by the applied net normal stress and initial density at different stress level.

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