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Effect of Wetting Progress on the Potential Collapse of Gypseous Sand Using Modified Oedometer

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ABSTRACT

Gypsum is a soluble material, and it is one of the problematic components in the soil in the west of Iraq. Al-Najaf is one of the governorates in Iraq which suffers from the gypsum content in different levels. The soil of the city is mainly sand-sized particles bonded by different percentages of gypsum. The main problem of this component is the dissolution upon the wetting process in unsaturated conditions. This paper investigates the effect of decreasing the matric suction (wetting) on soil deformation under a specific stress level. A modified Oedometer setup is used to perform the tests, including the application of air and water pressures up to achieve the specific matric suctions. The investigation includes three matrics suctions of (50, 20, and 0 kPa) and each under three net normal stresses of 221 kPa, 442 kPa and 885 kPa respectively. The soil specimens are remolded to 95% of the maximum dry density from the proctor test. The results revealed that the highest value of collapse potential (CP) is under the stress of 221kPa. The greatest part of the CP is achieved before the saturation of the soil. This issue must be considered in the analysis and design of the foundation in unsaturated gypseous sandy soils as an improvement issue.

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NOMENCLATURE

Cu	Soil water characteristics curve	USCS	Unified soil classification system
Cc	Initial void ratio	Sp	Sand poorly-graded
Wn	Natural moisture content	ρdry	dry density
Ua	Pore air pressure	θ	Volumetric water content
Uw	Pore water pressure	Gs	Specific gravity
owc	Optimum water content	Sm	Matric suction

1. INTRODUCTION

Al-Najaf city is an important city in Iraq due to its religious value, and there are many preserved and architectural heritage buildings which may be faced by the risk of conservation [1]. The city soil consists of more than 70% of sand to a depth of 14m with gypsum content varied from 10 to 30% in the upper 2m depth [2,3]. The spatial arrangement of sand, silt and clay grains, pore geometry, size distribution and network connectivity allows both capillary condensation and effective capillary transport of water [4]. Granular materials have a very low air-entry value. Besides, capillary forces induced by suction increase the inter-particle stresses resulted in a decrease in void ratio and increase of dry unit weight [5]. Metastable characteristics of soils due to high porosity and kind of cementation present a temporally unstable structure when undergoing an increase of wetting and/or variation of the stress state [6].

Gypseous soil is collapsible soil that causes problems to buildings and structures constructed on them due to a significant decrease in the shear strength as they are exposed to wetting [7,8]. This collapse depends on many factors, such as the wetting process [9,10,11,12], higher gypsum content, void ratio, permeability [13], initial degree of saturation [14,15] and soil time-based wetting prior loading [16,17,18]. Gypseous soils experience numerous changes in their physical and mechanical characteristics due to their exposure to continuous mass

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loss [19]. The soils' bearing capacity is decreased by about 50% due to the soaking process [20]. The shear strength of the soil can be improved by advancing the soaking time (long term) before shearing [21,22]. The settlement of the gypseous soils is increased and continued relating to the increase of the gypsum content due to wetting [18]. The shape and dimensions of remolded soil specimens affect the reliability of the deformation results, and the Oedometer cell (cylindrical) gave a clear trend of results compared to other specimen shapes (rectangular) [23].

The unsaturated state always presents in collapsible soils where large collapse occurs with a decrease in the matric suction ($ua{-}uw$) [19]. During wetting in the sand, a sudden reduction in volume occurs, as observed by means of granulometry, porosimetry, permeability, optical and ESEM-EDS microscopy, thermogravimetry and XR diffractometry, electric conductivity, and ionic chromatography [20]. Unsaturated soil changes its volume when the magnitude of the "$ua{-}uw$" or the net normal stress changes, and this leads to the occurrence of the phenomenon of collapse [24,25]. Richards' equation is a nonlinear constitutive relation that described the water flow in an unsaturated porous medium [26]. The bearing capacity increased nonlinearly from 2.55 to 3.95 times as the suction increased [27]. The more increase of the nano-clay to the gypseous soil sample, the more decrease in collapse potential. [28].

This paper investigates the effect of matric suction on the deformation of sandy soil with high gypsum content in Al-Najaf city, Iraq. This investigation is performed under different net normal stresses to represent the case of wetting progression under a certain construction load. The investigation is done using a modified Oedometer cell which controls the air and water pressures.

2. MATERIALS, TOOLS AND METHODOLOGY

The tests are performed on a soil sample from Al-Najaf city, Iraq. The sample was disturbed and collected in a plastic bag to maintain the natural water content. The soil sample is mainly sand. Table 1 summarizes the main soil identification properties and classification.

The natural water content is low (3%), and the soil may act as a dry behavior. The low Gs is related to the high gypsum content (29%), as to be stated in the literature. The higher dry density in the field (1.829 gm/cm3) with lower water content may be attributed to the bonding condition by gypsum material. Figures 1 and 2 illustrate the grain size distribution and standard Proctor tests results.

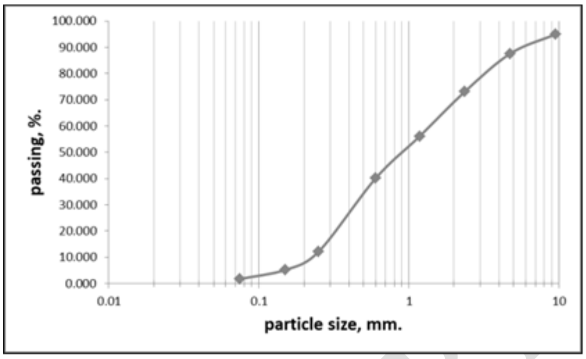

Figure 1: The particles size distribution of the soil sample

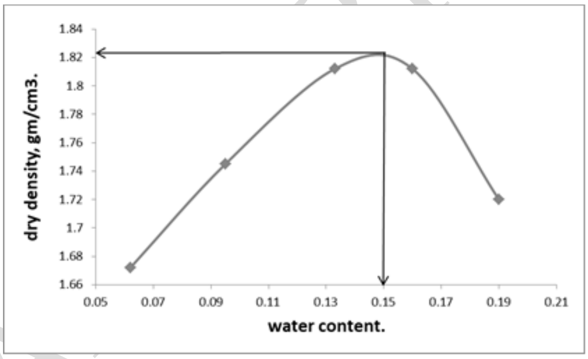

Figure 2: The results of standard Proctor test.

TABLE 1. The results of soil sample identification and classification tests..

Test name	specification	Value
Sand, %	ASTM D422	86%
Fine, %	ASTM D422	1.74%
D_{10}, D_{30} and D_{60}, mm	ASTM D422	0.22,0.47,1.45
Cu	ASTM D422	6.6
Cc	ASTM D422	0.703
USCS	ASTM D422	SP
Gs	ASTM D854	2.38
Gypsum content, %	ASTM C25-99	29
Wn, %	ASTM D2216	3
O.W.C., %	ASTM D698	15
ρdry, gm/cm^3	ASTM D698	1.825

3. Tools and Equipment

Figure 3 represents the scheme of the equipment and tools that have been used in the tests. The modified Oedometer is divided into three main categories. First, the modified cell, second, the control board (system of the pressure application) and third, the data logger. The following paragraphs illustrate the details of each part:

3.1. Modified Oedometer cell

A modified Oedometer cell was adopted to apply a specific matric suction in unsaturated testing (wetting process) by controlled application of air and water pressures. This Oedometer was modified and manufactured by Abdalhusain et al. [29]. The modified Oedometer consists of a top cap, a grooved base plate, a High Air Entry ceramic disc (HAE), an inner cell and an outer cell. The 5 cm diameter HAE disc is installed on the base plate (by screws), and the grooves in the base plate are acting as canals to drain the air bubbles out through the flush valve before the work begins. The pore air pressure (ua) is controlled and applied through the top cap, while the pore water pressure (uw) is exerted through the HAE ceramic disc and an O-ring (outer ring) to avoid water leakage. The soil specimen is remolded to the specific density in the inner cell. Plate 1 illustrates the final setup of the modified odometer test.

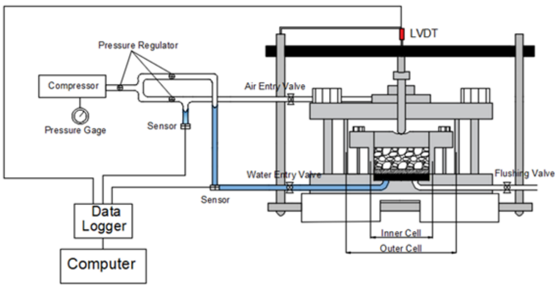

Figure 3. The scheme of the used tools and equipment.

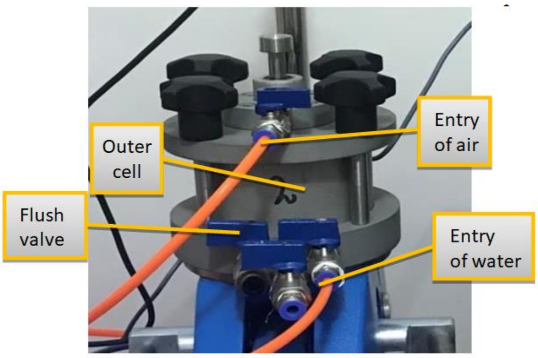

Plate 1. The modified Oedometer cell.

3.2. Control board

Plate 2 shows the control board through which the test is operated. The control board consists of a compressor with a pressure capacity of 11 bar (1100 kPa) to control the whole system, a cylindrical container is filled with water to use in the application of water pressure before the start of the test, non-stretching tubes of 6 cm in diameter, regulators that can regulate the pressure up to 30 bar, a ruler to measure the change in the water volume and sensors connected to a data logger to read the specific pressures. For the safety of the control board system, another regulator is connected to the compressor to maintain the pressure within suitable air pressure (3 bar) to the system.

3.3 Datalogger and software

Plate 3 illustrates the data logger, which consists of eight channels that enable to perform more than one test. The data logger is connected to a computer and to the control board by sensors to read the applied water and air pressures. A linear variable differential transformer (LVDT), 0.01 mm, to calculate the axial vertical displacement of the specimen throughout the test. The software is a program that is installed on the computer, through which the readings of the settlement, the air and water pressure are recorded per second or even milliseconds. The results are also recorded on the excel sheet.

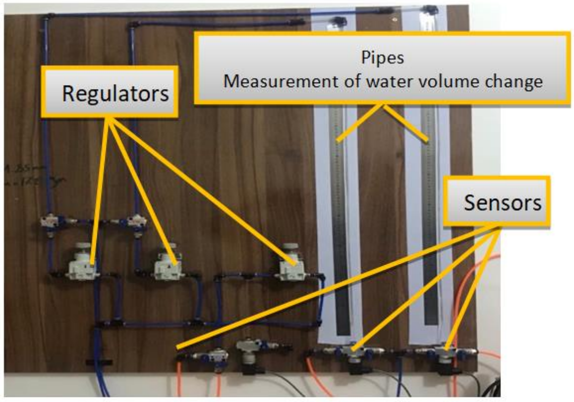

Plate 2. The control board

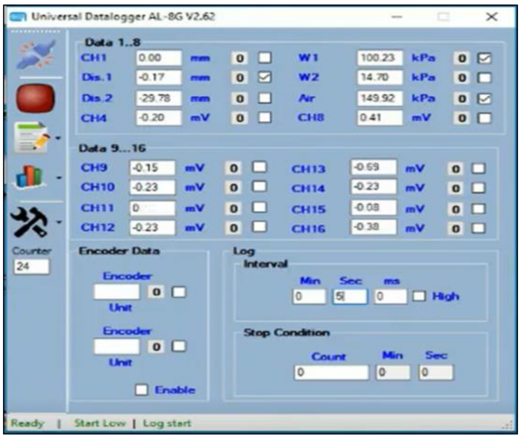

Plate 3. Setup of the computer software.

4. METHODOLOGY

For analysis, three soil specimens were prepared and remolded into an Oedometer cell of 19.38 mm in height and 50.31 mm in diameter, where the soil specimen was stacked in four layers, each layer having a height of 4.85 to achieve the required density. The dry density is 95% of the maximum dry density from the proctor test with 3% by weight water content.

The initial volumetric water content is around 2%, and concerning the soil water characteristics curve (SWCC) of the selected site, the initial matric suction

(Sm) is 50kPa. The initial matric suction of 50kPa is selected depending on the natural water content of the soil sample and using the soil water characteristics curve (SWCC) [2].

A 1 bar (max difference between air and water pressure is 100 kPa) HAE ceramic disc was selected based on the natural water content that suited the 50 kPa matric suction (as initial matric suction) from the SWCCs, then, the matric suction is decreased up to saturation condition (zero matric suction). Three matrics suction values (Sm) were selected to perform the tests, initial (50kPa), intermediate (20kPa) and zero matric suction (saturated). The change in matric suction is performed by maintaining the pore air pressure (ua=150 kPa) and increase the pore water pressure (uw=100, 130 and 150kPa). Each of the three specimens initially was subjected to the initial matric suction (Sm=50 kPa), then a gradual net normal stress was applied (55, 111, 221, … kPa) until reaching the specific stress level, then a change in matric suction is applied (decreasing). These stress levels are selected to draw the e-logσ within the below and upper designed bearing capacity limit of the site soil. Table 2 illustrates the tests program.

Table 2. Tests program.

Sm, kPa.	Net Normal Stress, kPa		
	Wetting at 221 kPa	Wetting at 442 kPa	Wetting at 885 kPa
50	55, 111 then 221	55, 111, 221 then 442	55, 111, 221, 442 then 885
20	221	442	885
0	221	442	885
0	111*	221*	442*
0	221**	111*	221*
0	442	221**	111*
0	885	442**	221**
0		885	442**
0			885**

* unloading stage
** reloading stage

5. Results and Discussion

5.1. Effect of matric suction

Figures 4, 5 and 6 show the settlement in terms of void ratio versus log net normal stress for different matric suctions (50, 20, 0 kPa). Under all the investigated net normal stresses, there is a clear decrease in the void ratio due to the wetting process at matric suction of 20kPa, while this decrease is smaller at matric suction of 0kPa (saturation). This phenomenon may be caused by first; the potential settlement is completely achieved due to the stress level and dissolution of the gypsum, or, second, the lack of time, whereas the specimen needed a longer time to reach the matric suction of 20kPa than the 0kPa.

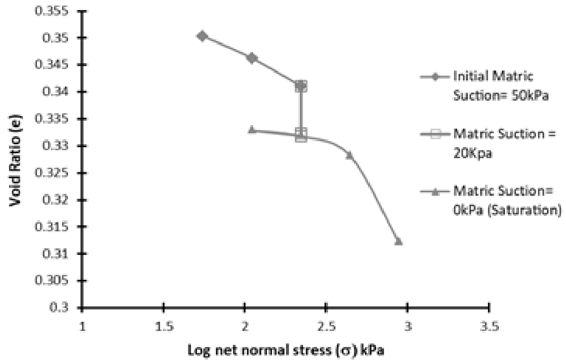

Figure 4. The void ratio versus the log net normal stress for different matric suction under a stress level of 221 kPa.

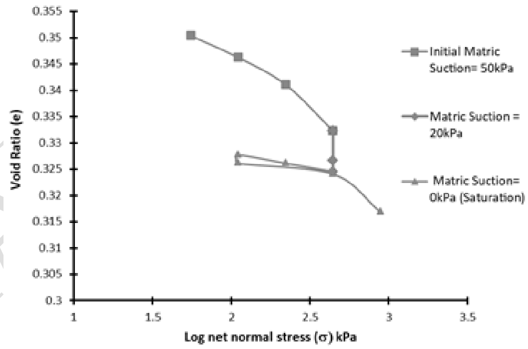

Figure 5. The void ratio versus log net normal stress for different matric suction under stress level of 442 kPa.

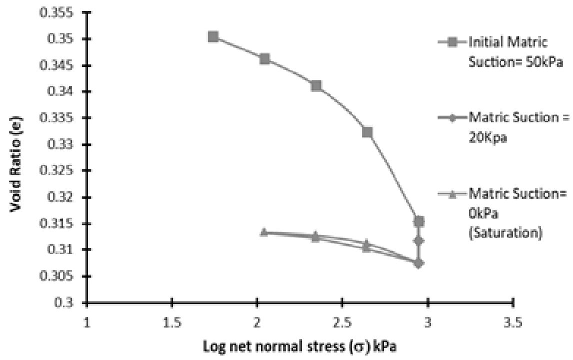

Figure 6. The void ratio versus log net normal stress for different matric suction under stress level of 885 kPa.

Table 3 displays the collapse potential (CP) for each level of the net normal stress and the matric suction, according to Jennings & Knight modified method [19,30]. Obviously, the highest CP (0.677) is under the net normal stress of 221 kPa, and the highest part (0.639) of the CP is due to wetting progress at matric suction of

20 kPa. With increasing the net normal stress, the CP is decreased at 20 kPa of matric suction and increased in saturation, and this can be explained due to the effect of loading and gypsum dissolution interaction. This certifies that the stress level of 200 kPa is an effective level to evaluate the soil collapse, as indicated in the Jennings & Knight modified method. All values of CP are within the "no problem" category according to the classification of severity by Jennings & Knight modified method, and these values are within collapse degree of "slight" according to ASTM D5333. These results may be attributed to the high initial density of the specimen (95% of the maximum dry density).

Table 3. The Collapse potential under different net normal stresses and matric suction.

Net normal stress, kPa	Collapse potential (CP)		
	Ψ=20	Ψ=0	Total
221	0.639	0.038	0.677
442	0.413	0.150	0.564
885	0.263	0.301	0.564

5.2. Effect of loading

To investigate the effect of net normal stress level on the behavior of the soil specimen, two other specimens prepared from the same sample are subjected to other levels of stress, 442 kPa and 885 kPa. Figures 5 and 6 show the results under the stress levels of 442 kPa and 885 kPa, respectively.

With higher initial settlement (initial Sm=50 kPa), the trends of the deformation versus time are close to that under net stress of 221 kPa. With an initial higher stress level, the effect of the wetting process is low. The settlement ratio increases with Sm=20 kPa is 1.1404 under the stress of 442 kPa, while the settlement ratio increase is 1.0629 under the stress of 885kPa.

In higher stress levels, there is an increase in the time required to achieve both the specific matric suction and the total settlement, and this may be attributed to the restriction of the stress on the water volume change in the soil voids. The settlement ratio increases with Sm=0 kPa is 1.0448 under the stress of 442 kPa, while the settlement ratio increase is 1.0676 under the stress of 885 kPa.

6. Conclusions

The recent paper investigates the effect of wetting progression due to different matric suction (50, 20 and 0kPa) in unsaturated gypseous sand using a modified Oedometer. This investigation is performed under three different levels of net normal stresses (221, 442 and 885 kPa). From the current investigation, the following points can be concluded:

- With decreasing in the matric suction (wetting), there is an increase in soil settlement under the different net normal stress levels.
- From the investigation, the net normal stress level of 221 kPa is dominated in the calculation of collapse potential (CP), where the related CP is the highest during wetting advancement in the unsaturated soils.
- The main part of the collapse is before the saturation (matric suction = 0 kPa) in unsaturated soils, which is the most important issue to be considered in the analysis and design of foundations in unsaturated gypseous sandy soils.
- It is recommended to investigate the effect of different stress levels, matric suction, and initial soil properties on the stability of the structures.

7. REFERENCES

[1] Mahmood, Mohammed Sh., Strip Model Footing Located above a Cavity, MSc Thesis, (2000), University of Technology, Baghdad, Iraq.

[2] Al-Shakerchy, Mohammed Sh., Geotechnical Properties of Al Najaf City Soil with Emphasis on the Infiltration and Strength Characteristics (Doctoral dissertation, Doctoral dissertation, Ph. D. Thesis, Building and Construction Dept., University of Technology, Baghdad, Iraq).

[3] Al-Saoudi, Namir K. S. and Al-Shakerchy, Mohammed Sh. (2010). Statistical Analysis of Some Geotechnical Properties of Najaf City, Proceedings of International Geotechnical Conference, (3), (2007), 1173-1180, Moscow, Russia.

[4] Scaffaro, R., Lopresti, F., Botta, L., Rigogliuso, S., Ghersi, G., Integration of PCL and PLA in a monolithic porous scaffold for interface tissue engineering. ***Journal of the Mechanical Behavior of Biomedical Materials, Vol. 63 (2016): 303-313.*** https://doi.org/10.1016/j.jmbbm.2016.06.021

[5] Maleksaeedi, Emad, Nuth, Mathieu and Chekired, Mohamed, A modified Oedometer apparatus for experimentally obtaining the soil-water retention curve. Proceedings of: Geovancouver Conference, (2016).

[6] Ruge C., Juan & Cunha, Renato & Mašín, David., Results of unsaturated tests on metastable soils. Advances in Unsaturated Soils - Proceedings of the 1st Pan-American Conference on Unsaturated Soils, (2013), 469-474. Doi: 10.1201/b14393-72.

[7] Aldaood A, Bouasker M, Al-Mukhtar M., Effect of long-term soaking and leaching on the behaviour of lime-stabilized gypseous soil. International Journal of Pavement Engineering. Vol. 6, No. 1, (2015), 11-26.

[8] Asghari S, Ghafoori M, Tabatabai SS, Changes in chemical composition and engineering properties of gypseous soils through leaching: an example from Mashhad, Iran, Bulletin of Engineering Geology and the Environment, Vol. 77, No. 1, (2018), 165-175.

[9] HAERI, S. M., BEIGI, M., SABERI, S. & GARAKANI, A. A. Study on the stress path dependency of collapse behavior of Gorgan loess implementing unsaturated oedometer devices. E3S Web of Conferences, (2016). EDP Sciences, 14019.

[10] Abdalhusein, M. M., Akhtarpour, A., Mahmood, M. Sh., Effect of Soaking on Unsaturated Gypseous Sand Soils, International Journal of Civil Engineering and Technology, Vol. 10, No. 5, (2019), 550-558.

[11] Abdalhusain, M. M., Akhtarpour, A., Mahmood, Mohammed Sh., Effect of wetting process with presence of matric suction on unsaturated gypseous sand soils, Journal of Southwest Jiaotong University, Vol. 54, No. 5, (2019), 1-11. DOI: 10.35741/issn.0258-2724.54.5.3.

[12] Liu C, He P, Huang Q, Influence of matrix suction on engineering properties of unsaturated soil. Second International Conference on Mechanic Automation and Control Engineering; (2011), IEEE.

[13] Fattah, M. Y., Al-Shakarchi, Y. J., Long-term deformation of some gypseous soils, Engineering and Technology Journal, Vol. 26, No. 12, (2008), 1461-1483.

[14] Fattah, M. Y., Al-Ani, M. M., Al-Lamy, M. T., Studying collapse potential of gypseous soil treated by grouting, Soils and Foundations, Vol. 54, No. 3, (2014), 396-404. DOI: 10.1016/j.sandf.2014.04.008

[15] Mahmood, Mohammed Sh., Effect of Soaking on the Compaction Characteristics of Al-Najaf Sand Soil. Kufa Journal of Engineering, Vol. 9, No. 2, (2018), 1-12. DOI: 10.30572/2018/kje/090201.

[16] Mahmood, Mohammed Sh., Akhtarpour, A., Almahmodi, R., Husain, M. M. A,, Settlement assessment of gypseous sand after time-based soaking IOP Conference Series: Materials Science and Engineering 737, 2020, DOI: 10.1088/1757-899X/737/1/012080.

[17] Mahmood, Mohammed Sh., Aziz LJ, Al-Gharrawi A., Settlement Behavior of Sand Soil Upon Soaking Process, International Journal of Civil Engineering and Technology, India, Vol. 9, No. 11, (2018), 860–869.

[18] Mahmood, Mohammed Sh., Prediction of Discrepancy Settlement Behaviour of Sand Soils, Applied Research Journal, Iran, Vol. 4, No. 2, (2018), 30-37.

[19] Mahmood, Mohammed Sh. and Abrahim, Mustafa J., A Review of Collapsible Soils Behavior and Prediction, IOP Conference Series: Materials Science and Engineering, IOP *Conference Series: Materials Science and Engineering*, vol. 1094, no. 1, p. 012044. IOP Publishing, 2021. DOI: 10.1088/1757-899X/1094/1/012044.

[20] Zimbardo, M., Ercoli, L., Megna, B.: The open metastable structure of a collapsible sand: fabric and bonding. *Bulletin of Engineering Geology and the Environment* 75, no. 1 (2016): 125-139. https://doi.org/10.1007/s10064-015-0752-7

[21] Mahmood, Mohammed Sh., Effect of Time-Based Soaking on Shear Strength Parameters of Sand Soils, Applied Research Journal, Iran, Vol. 3, No. 5, (2017), 142-149.

[22] Mahmood, Mohammed Sh., Al-Baghdadi, W. H., Rabee, A. M., Almahbobi, S. H., Reliability of Shear-Box Tests Upon Soaking Process on the Sand Soil in Al-Najaf City, Key Engineering Materials; Vol. 857, (2020), 212–220. https://doi.org/10.4028/www.scientific.net/kem.857.212

[23] Mahmood, Mohammed Sh., Almahbobi, S. H., Rabee, A. M., Rahim, A. M., Naama, M. A., and Mohammed, M. F., Reliable prediction of structure settlement in Al-Najaf city using laboratory testing, 2020 IOP *Conference Series: Materials Science and Engineering*, Vol. 888 012013 DOI: https://doi.org/10.1088/1757-899X/888/1/012013.

[24] Lloret A, Alonso E., Consolidation of unsaturated soils including swelling and collapse behaviour. Géotechnique, Vol. 30, No. 4, (1980), 449-477.

[25] Fredlund, D. G., Rahardjo, H., Soil mechanics for unsaturated soils, John Wiley & Sons; (1993).

[26] M. Sayful Islam, "Selection of Intermodal Conductivity Averaging Scheme for Unsaturated Flow in Homogeneous Media", International Journal of Engineering, Transactions A: Basics Vol. 28, No. 4, (2015), 490-498Z. doi: 10.5829/idosi.ije.2015.28.04a.01

[27] Safarzadeh, M. H. Aminfar, "Experimental and Numerical Modeling of the Effect of Groundwater Table Lowering on Bearing Capacity of Shallow Square Footings", International Journal of Engineering, Transactions A: Basics Vol. 32, No. 10, (2019), 1429-1436. doi: 10.5829/ije.2019.32.10a.12

[28] A. L. Hayal, A. M. B. Al-Gharrawi, M. Y. Fattah, Collapse Problem Treatment of Gypseous Soil by Nanomaterials, International Journal of Engineering, Transactions C: Aspects Vol. 33, No. 9, (2020) 1737-1742. doi: 10.5829/ije.2020.33.09c.06

[29] Almahmodi, Rusul H., "Experimental and Numerical Investigation of Time Dependent Unsaturated Behavior of Iraqi Gypsum Sand Soils Using Oedometer Tests ", Ph.D. proposal, (2021), Ferdowsi University of Mashhad, Iran.

[30] Jennings, J.E. and Knight, K. " A Guide to Construction on or with materials exhibiting additional settlement Due to Collapse of Grain structure", proceeding of 6th Regional Conference for Africa on soil mechanics and Foundation Engineering, Durban, South Africa, (1975),.99-105.

گچ یک ماده محلول است و یکی از اجزای مشکل ساز خاک در غرب عراق است. نجف یکی از استان های عراق است که از سطوح گچی در سطوح مختلف رنج می برد. خاک شهر عمدتا از ذرات به اندازه ماسه است که با درصدهای گچی به هم متصل شده اند. مشکل اصلی این جزء انحلال در فرآیند خیس شدن در شرایط غیر اشباع است. این مقاله به بررسی تأثیر کاهش مکش ماتریک (خیس شدن) بر تغییر شکل خاک تحت یک سطح تنش خاص می پردازد. برای انجام آزمایشات ، از جمله اعمال فشار هوا و آب به منظور دستیابی به مکش های ماتریک خاص ، از یک تنظیم کننده اندازه گیری شده استفاده می شود. این تحقیق شامل سه مکش ماتریکی (۵۰ ، ۲۰ و ۰ کیلو پاسکال) و هریک تحت سه تنش نرمال خالص به ترتیب ۲۲۱ کیلو پاسکال ، ۴۴۲ کیلو پاسکال و ۸۸۵ کیلو پاسکال است. نمونه های خاک در آزمایش پروکتور تا ۹۵ درصد حداکثر چگالی خشک مجدداً بازسازی می شوند. نتایج نشان داد که بیشترین مقدار پتانسیل فروپاشی (CP) تحت فشار ۲۲۱ kPa است. بیشترین مقدار CP قبل از اشباع خاک به دست می آید. این مسئله باید در تجزیه و تحلیل و طراحی فونداسیون در خاکهای شنی گچی غیر اشباع به عنوان یک مساله بهبودیافته مورد توجه قرار گیرد.