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THE IMPROVEMENT OF GYPSUM SAND SOILS IN UNSATURATED CONDITIONS USING A MODIFIED OEDOMETER DEVICE

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ABSTRACT

This work offers recommendations on the best percentages of CKD (Cement Kiln Dust) to use for soil stabilization to reduce compressibility problems 1%, 2%, 3%, 4%, and 5% for projects where gypsum sand soil is common. The results could lead to more sustainable and effective engineering methods in these areas. 22% of the soil analyzed came from Al-Najaf City in Iraq. Each of the four groups in this work underwent six tests: the first group operated in a saturated state without the use of a High Air Entry (HAE) ceramic disc; the second group used HAE to demonstrate the differences between the two groups; the third group used a matric suction (ψ) of 20 kPA; and the fourth group used the original matric suction of 100 kPa. The findings showed that the settlements were reduced with increasing matric suction and improved with the optimal value of CKD when the CKD additive was increased and the optimum values for the saturation state, unsaturation states with zero matric suction, unsaturation tests with ψ = 20 kPa, and unsaturation tests with ψ = 100 kPa were 2.8%, 2.9%, 3%, and 2%, respectively.

KEYWORDS

Gypsum Sand Soil, HAE Ceramic Disc, CKD, Settlement, Matric Suction.

1. INTRODUCTION

One of the most intricate activities remains the estimation of geotechnical characteristics of soil and settlement predictions. It is indeed true to say that there are diverse factors that control soil behavior such as composition, density, moisture content, structure, and stress history. What is more, it is a well-acknowledged fact that soil behavior is highly non-linear and varies greatly over short distances within an area (Mahmood et al., 2020). To differentiate, infiltration is upward movement from the surface to the soil profile. It becomes evident where the flowing water fills the interstices between the soil particles under gravity and capillary forces.

Infiltration rates and depths rely on numerous factors such as soil texture, soil structure, compaction, slope, vegetation cover, and initial soil moisture (Al-Saoudi et al., 2014). In other words, settlement value and rate are inherently very important to the geotechnical engineer since they directly govern the safety, durability, and serviceability of any infrastructure he builds on or within the ground (Abdal Husain et al., 2019).

Permeable soils, for instance, are not associated with a significant volume change under continuous stress with a continuous increase in moisture. One of the properties of permeable soils such as the course-grained sands and gravels is high permeability, which means that water flows through it very freely. The soils usually undergoes very little volume changes with changes in the moisture content. This is because their void spaces are large enough and well connected such that water can flow easily without causing much compression or consolidation (Fazeli and Johari, 2014). City gypsum of Iraq is gypsum rich soils in Al-Najaf (Abdal Husain et al., 2019). Research towards gypsum soils has drawn the interest of lots of scientists and academes from the 1980s. Finding difficult soils is usually very essential in engineering geology and geotechnics (Akhtarpour et al., 2018). New pores formed and cementing bonds relaxed; when gypsum in the soil dissolves, new pores will be found in its matrix, which also relaxes cementing bonds between other soil particles. The meta-stable structure formed can easily enable soil particles to slip into either a more compact state or to collapse. With gypsum dissolution, meta-stable structure is said to because its stability is temporarily fixed and can change under variable conditions such as changing moisture contents or stressed conditions. Dissolution rates of gypsum control very by many factors, especially which type of gypsum presence and concentration changes were made within the temperature and permeability of soil and flow conditions. Higher temperature and higher moisture content are typical enhancers of the dissolution rate. The gypsum soil behavior elements are, to a big extent controlled by changes in moisture fluctuations caused by changes in water table levels or intermittent surface water. The variations in moisture content all control the rate of gypsum dissolution;

subsequently, the soil stability and collapsibility effects of structural control. Gypsum being within soil particles plays a certain cementation role in binding soil particles together. This apparent cementation fails as gypsum dissolves, hence contributing to gypsum soils collapsing. All in all, gypsum soils are known as one of the identifiable collapsible soils due to gypsum dissolution. Such knowledge is a must to evaluate the behavior of gypsum soils in works of engineering or construction (Abdal Husain et al., 2018).

Several workers are interested in gypsum content effects on some soil properties after standing for designated amounts of time. The California Bearing Ratio (CBR) test studies implied that soil deformation has a direct relationship with various gypsum contents, with a relatively higher value of soil deformation attributed to higher soaking time (Razouki and Al-Azawi, 2003). Another work is carried out on matric suction influence over the volume change behaviour of gypsum sand soil in unsaturated conditions. The matric suction representing negative pore water pressure inside the soil that governs mechanical behaviour associated with the Iraqi site in Al-Najaf, where soil specimens with gypsum content of 14% and 29% were tested using a modified oedometer apparatus in a three-series initial stress-determined laboratory testing program. Each series containing twelve remolded specimens was prepared for unsaturated conditions at a different level of matric suction of 30 kPa, 18 kPa, 9 kPa, and the saturated state. Three tests were conducted for each gypsum content at each level of matric suction, with three different initial stresses for each gypsum content: no initial load, 56 kPa, and 112 kPa. The result of this study reveals that gypsum content increases with matric suction decreases, leading to vertical strain development under various conditions. Another point is that the process of wetting has softened gypsum components well and lead to a most significant increase of vertical strains. This paper most strongly supports the role of matric suction and gypsum content in the volume change behavior of gypsum sand soil under unsaturated conditions (Almahmodi et al., 2022). "2023" has classified geotechnical properties regarding compacted dune soil samples obtained from Tikrit, Iraq, and the unconfined compressive strength (UCS) of this dune soil stabilized with various percentages of cement kiln dust (CKD) beginning from 4% ending at 20% by the dry weight of the dune soil. These percentages have been used as solid stabilizers in improving the geotechnical properties of the dune soil. An appreciable effective value of CKD has been observed in the compaction properties of the Tikrit dune soil. This implies that CKD played the role of a stabilizing agent, enhancing compactability efficiency of soil- this being the utmost requirement for construction work. Results from the study concluded that the introduction of CKD decreases the compressibility of the dune soil. This implies that with CKD treatment, the soil emerges having less susceptibility to deformation under the effect of applied loads, which is good for engineering structures' long-term stability that is to be founded on that soil (Altameemi et al., 2023). Furthermore, some swellable soils could be investigational under unsaturation situations and can be ameliorated by use of cement material (Nadi Yazdi et al., 2023). One of the requirements for unsaturated studies, therefore, would be a triaxial device with which to perform investigations of the soil-firm properties (Abdal Husain et al., 2022a) and (Abdalhusein et al., 2019). Thus the feasibility to assess the influence of cement treatment on the water peripheral conduct and likely to minimize it are AlNaddaf et al. Two types of gypseous soils, a moderate gypsum content from Karbala city, and high gypsum content from Tikrit city were analyzed in the present study. Single oedometer tests were conducted with both soils by combining them with different percentages of cement to find the proportion of soil-cement that can satisfactorily lower collapse potential (CP). The results show that besides decreasing the CP of gypseous soils, the addition of cement significantly affects their SWRC (Abdulameer AlNaddaf et al., 2024). Obead et al. (2023) studiedof soluble minerals in certain hydromechanical properties of Iraqi gypseous soils. Soil samples were leached using hydraulic gradients of 6.67 or 1.0 m head. Collapse tests were carried out on the samples both before to and after leaching. Leaching increased sand percentage, void ratio, and coefficient of permeability but had less impact on parameters such as specific gravity, gravel percentage, fine percentage, and shear strength. One output variable (Ksat.) and several important input variables (TDS, EC, pH, t) were considered during multiple linear regression modeling (MLR). Statistical parameters were applied to check these models and have shown that the MLR model is good for estimating the coefficient of permeability per site (Obead et al., 2023). Al-Gharbawi et al. (2022) used theirs to assess curing times carbonation and the effects of that treatment on keeping magnesia in gypseous soil stabilized. Their study uses (0, 5, 10, and 15%) with two relative densities (35 and 75%) and carbonation at varied carbonation times (0, 1, 3, and 24 hours) to enhance a collapsible gypseous soil. The effects of the carbonation periods on improved soils have been studied using modified collapse tests and conventional collapse experiments, in addition to single and double odeometers. The potential for collapse of untreated and nontreated carbonated soil studied dropped by over 65% and 55%, respectively. It almost dropped by about 55% in both the standard tests and the modified collapse test treated soil with 10% magnesium oxide and three hours of carbonation. The results of their study were that there was no difference in the collapse potential of the soil for more than three hours. In this case, the carbonation period time is used to delay as well as hasten the development of the soil (Al-Gharbawi et al., 2022).

2. METHODOLOGY

2.1. Material Characteristics

A gypsum content map provided by Al-Shakerchy was what the selection of site sampled-test material was based on in Al-Najaf City (Mahmood, 2007). It is recommended that samples should be collected from a depth of 0.75 meters, where organic matter is found to vary between 0-0.5 meters (Abdal Husain et al., 2022b).

As shown in Fig. 1, maximum dry density was recorded at 18.01 kN/m3 with an optimum water content of 8%. Field density as calculated using the Sand Cone Test technique (ASTM D1556-00) reported 17.88 kN/m3 while the water content on-site read 3.85% and soil type reading Sand Well-Graded (SW).

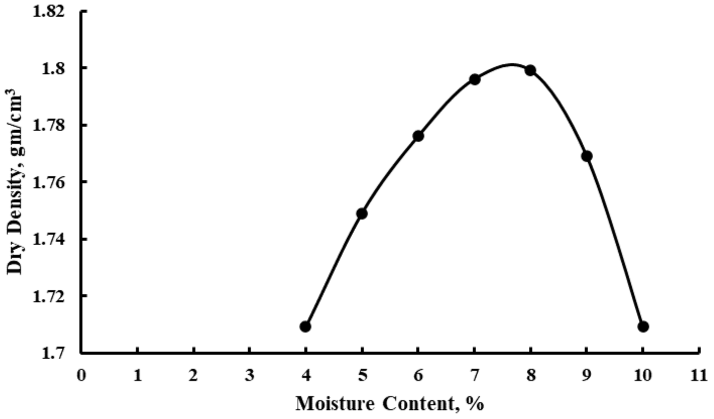


Fig. 1: Proctor Test Results of the Tested Sample.

The Unified Soil Classification System (USCS) produced well-graded sand (SW) based on the particle size distribution, as shown in Fig. 2 and by ASTM C136.

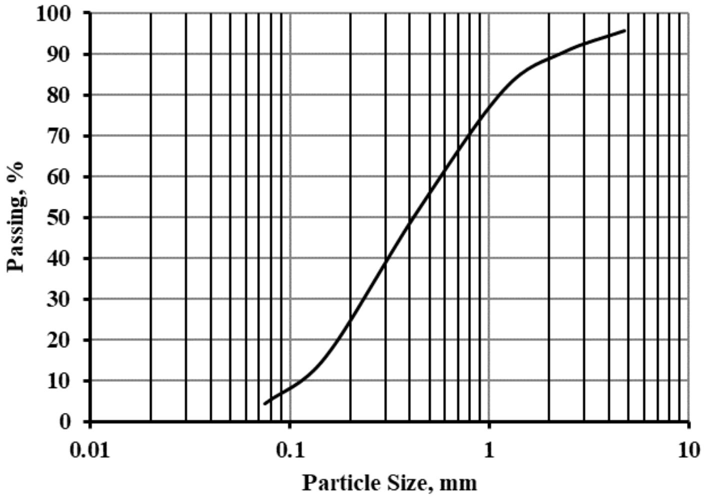


Fig. 2: Particle Size Distribution of the Tested Sample.

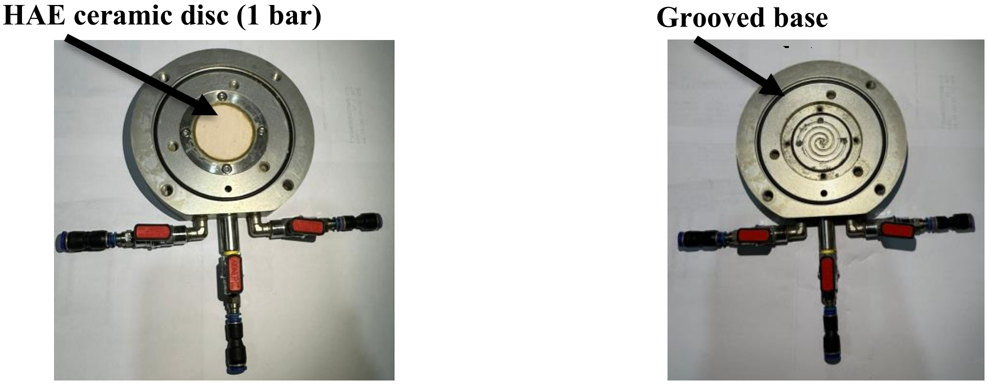
Table 1 illustrates the soil properties of the tested specimens.

Table 1. The Soil Properties of the Tested Specimens

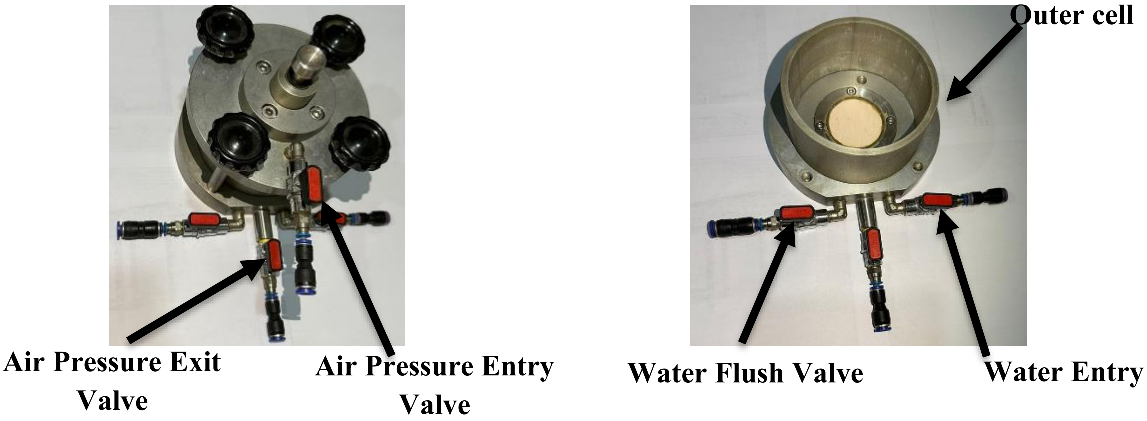
Test Specification	Test Procedure	Results
Gypsum Content	ASTM C-2599	22%
Specific Gravity, Gs	ASTM D854-14	2.35
Proctor Test (Max. Dry Density)	ASTM D698-00a	18.01 kN/m^3
Proctor Test (Optimum Water Content)		8%
Sand Cone Test (Field Density)	ASTM D1556-00	17.88 kN/m^3
Water Content in Site	----	3.85%
Soil Type	Unified Soil Classification System) USCS, ASTM C136	SW

2.2. Instruments and apparatus

Suction control has been included in some devices that modify the conventional Oedometer test equipment into an unsaturated condition. The instrument utilized in this experiment, an unsaturated oedometer, was calibrated and adjusted. The unsaturated equipment as described by Fredlund and Rahardjo (1993) is shown in Fig. 3 (Fredlund and Rahardjo, 1993). Among its components are the air pressure controller, top cap, and "High Air Entry ceramic disc (HAE)." Placed on the base plate having an inlet for trapped air bubbles release before the test is performed with the flush valve, the 5cm HAE is made of a grooved base Fig. 3(b). To ensure there is no high-pressure water leakage, the groove in the base plate was fitted with High Air Entry (HAE) disc, where screws and an O-ring were used to apply the pore water pressure setting. For HAE disc pore water pressure, it was applied with screws and an O-ring into the grooved base thereafter; top cap controlled the air pressure in the interim, as seen in Fig. 3(c). An HAE 1 Bar ceramic disc with a 100 kPa air entry value is the natural choice based on the natural moisture content of the tested sample, which corresponds to a matric suction of 50 kPa from the Soil Water Retention Curves (SWCCs). As shown in Fig. 5, the dimensions of the test samples for the Oedometer are 2 cm deep and 5 cm in diameter. An outer cell (see Fig. 3(d)) is used to saturate the sample with air during the test. An LVDT with an accuracy of 0.01 mm is placed outside of the cell to measure axial displacement of the sample during the test. The LVDT is able to measure a maximum displacement of about 2.5 cm (Al-Almahmodi R, 2022). A Water Volume Change (WVC) using an LVDT recording movement of 7.5 cm was used to measure the total volume change of the tested soil as displayed in Fig. 4. The water capacity of the WVC is an average of 125 cc. The supply to the specimen, which goes to the specimen to make the equilibrium condition should pass this and get recorded in the data logger and the change in water volume will have to be calculated to put the specimen in the proper conditions.



HAE ceramic disc (1 bar) **(b) Grooved base plate**



(c) Inner cell **(d) Outer cell**

Fig. 3: Details of the Unsaturated Oedometer Cell.

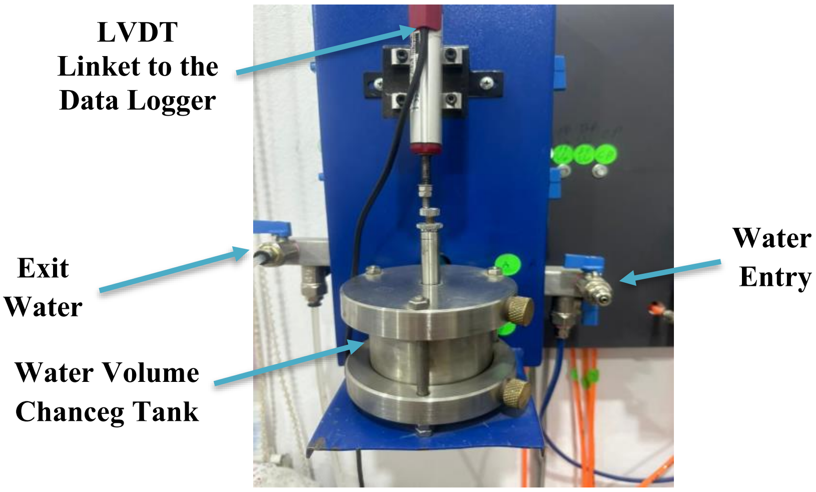


Fig. 4: Water Volume Device (WVC).

2.3. Calculating the Soil-Water Characteristic Curve (SWCC)

Through testing a variety of soil types, a modified Oedometer device for SWCC determination has been assessed, and best practices for using this device have been suggested. Over and above the matric suction (ψ=Ua-Uw), it permits the application and adjustment of the net normal stress, σ - Ua. As a result, it can be applied to model different overburden stresses as well as other relevant stress states. Additionally, it authorizes the measurement of specimen volume change and the SWCC to be determined from a single specimen. The assessment covers problems with temperature regulation, air diffusion via ceramic disks with high air entry, and an investigation of possible sources of inaccuracy in the SWCC's water content calculation (Abdal Husain et al., 2024). Fig. 5 illustrates the SWCC of the tested specimen.

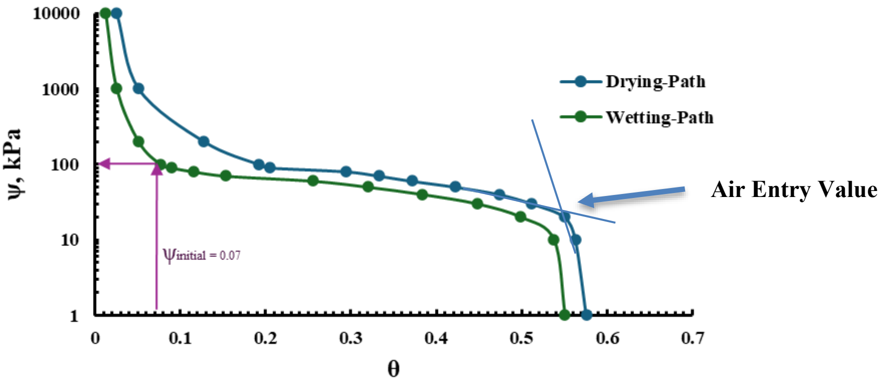


Fig. 5: SWCC of the Tested Sample.

2.4. Test Procedure

Twenty-four consolidation tests utilizing the Unsaturated Oedometer Device were performed in this paper; the first group was performed in the saturated state and the second group was in the saturated state also but in unsaturated conditions (with the presence of HAE ceramic disc). Table 2 shows the test procedure.

Table 2. The Test Procedure of the Tested Specimens for the Four Conditions

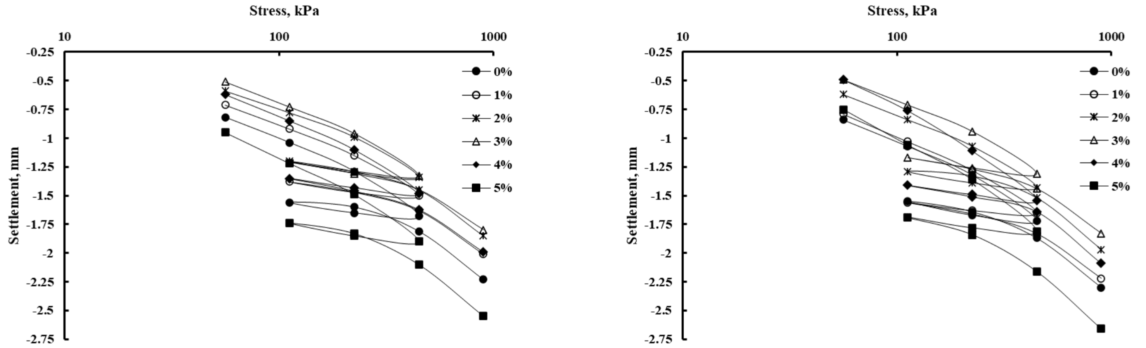
Test No.	Description	Matric Suction (ψ), kPa	CKD, %
1	Saturation without HAE Ceramic Disc (Conventional Test)	N/A	0
2			1
3			2
4			3
5			4
6			5
7	Saturation with HAE Ceramic Disc	0	0
8			1
9			2
10			3
11			4
12			5
13	Unsaturation (Initial Matric Suction)	100	0
14			1
15			2
16			3
17			4
18			5
19	Unsaturation	20	0
20			1
21			2
22			3
23			4
24			5

3. RESULTS AND DISCUSSION

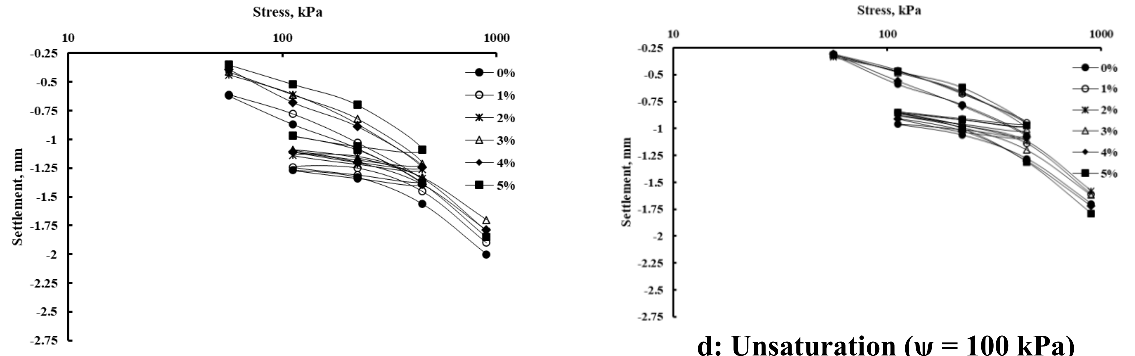
Fig. 6 illustrates the stress-settlement of the tested specimens according to Table 1. The difference between Fig. 6a and 6b is the saturation test Fig. 6b was done with the presence of HAE ceramic disc (1 bar) to show the effectivity of saturation in unsaturation conditions (zero matric suction) and there was a significant variance, and the total settlements were increased.

Fig. 6a shows the results of the tested specimens in the saturation state in the conventional conditions (no presence of HAE ceramic disc) to infer the benefit of HAE in comparison between the unsaturation tests as in Fig. 6 (b, c, and d). Fig. 6b represents the unsaturation conditions with zero matric suction (ψ = 0 kPa) and in comparison with the conventional test as in Fig. 6a, there was an increase in the final settlement in all of the test types. When the matric suction was increased to 20 kPa as in Fig. 6c, the final settlement was reduced in all of the test types. Also, in matric suction of 100 kPa Fig. 6d, the tested specimens had the same trend of case ψ = 20 kPa.

Fig. 7 illustrate the summary of the total settlement vs. ckd percent and the findings showed that the settlements were reduced with increasing matric suction and improved with the optimal value of CKD when the CKD additive was increased and the optimum values for the saturation state, unsaturation states with zero matric suction, unsaturation tests with ψ = 20 kPa, and unsaturation tests with ψ = 100 kPa were 2.8%, 2.9%, 3%, and 2%, respectively.



a: Saturation **b: Saturation with HAE**



c: Unsaturation (ψ = 20 kPa) **d: Unsaturation (ψ = 100 kPa)**

Fig. 6: The Stress-Settlement Results of the Tested Specimens.

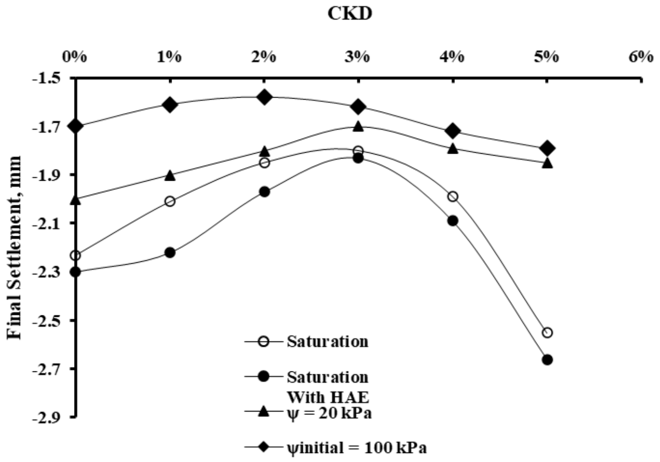


Fig. 7: The Summary of the Total Settlement Vs. CKD Percent.

4. CONCLUSIONS

As shown in Fig. 7, the increasing total settlements in comparison between the saturated tests with and without HAE ceramic disc were lower in the cases of saturated state without the presence of HAE ceramic disc as 3%, 10%, 6%, 2%, 5%, and 4% for adding CKD of 0%, 1%, 2%, 3%, 4%, and 5%, respectively. The conclusion could be lited as the following:

1. When matric suction changed from zero to 20 kPa, the settlement decreased by 13%, 14%, 9%, 7%, 14%, and 30% for the same CKD percentages, respectively.
2. By changing the matric suction from 20 kPa to 100 kPa, the total settlement decreased by 15%, 15%, 12%, 5%, 4%, and 3%.
3. In a comparison between zero matric suction and ψ = 100 kPa, the decreases in settlements were 26%, 27%, 20%, 11%, 18%, and 33%.

Therefore, it can be concluded that the presence of the matrix suction and the transformation of the soil from the saturated state in the absence of HAE gives less precipitation than with it, and the degree of precipitation also increases with the increase in soil saturation depending on the matrix suction. The unsaturation state gives real results and approaches to the field settlements.

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