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Mechanical Behavior of Pre-Test-Curing Nanoclay-Treated Gypseous Sand

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Abstract. This work investigates the effect of pre-test curing at various durations on the stress-settlement of gypseous sand soil treated with varying percentages of nanoclay. The tests are performed on a soil sample from Al-Jameh district in northern Al-Najaf city, Iraq. The soil sample is disturbed and remolded in the Oedometer cell. The remolded specimen will be at 90% of the maximum dry density from the standard Proctor test. Four data sets related to the percentages of adding nanoclay, 0, 3, 6 and 12 %. Each data set includes three groups of pre-test curing periods (Tc), 0, 1 and 4 days. For each tested specimen, a gradual incremental normal stress is applied, i.e., 50, 100 and 200 kPa. For the soil without nanoclay, it was an interesting result for the performance under all vertical stresses that there is a slight decrease in the final settlement. This situation may be attributed to the re-bonded of the particles by the gypsum during the curing time. There was a clear decrease in the final settlement for the nanoclay-treated soil specimens compared to the natural state of the soil (without nanoclay). While a significant decrease in settlement is recorded for specimens with nanoclay (NC) of 6%, which is the best percentage of nanoclay.

1 Introduction

Rapid collapse is caused by vertical pressures (wetting processes or loading) that are greater than the yield strength of some bonding materials [1]. Rain had little effect because of their close penetration range [2,3,4]. Higher gypseous soils are more likely to collapse and alter the void ratio [5,6]. Higher gypseous sand soils behave differently with longer soak times, although they remain stable under all stress conditions. [7]. The soaking times and stress levels that lead to the collapse of such soils increase, according to studies conducted on sand soil with a 29% gypsum content [8]. The curing periods are correlated with a decrease in final collapsibility and an increase in collapsibility rate [9]. At higher mean net stress levels, the wetting-induced volumetric strain behavior in both undisturbed and remolded soil specimens was remarkably consistent [10].

Collapse soils usually have an unsaturated form when matric suction (ua-uw) is reduced (saturation) [11]. Sand loses volume when it becomes soaked from unsaturated to saturated conditions [12,13]. Unsaturated gypseous soil collapses at a higher rate when it becomes wet (soaked) [14,15,16]. The volume change of the unsaturated soils is influenced by several factors, including the wetting time [17,18], pores ratios, coefficient of permeability [19], primary saturation, and the amount of time the soil is wetted before loading [6,20,21].

A variety of additives, including bitumen compounds and lime, can be used to improve and stabilize the behavior of gypseous soil. One of the newest approaches to enhancing the problematic soil is the use of nanomaterials [22]. Soil collapse potential is reduced by about 73.8% when 10% nanoclay is applied [23]. The probability of soil collapse is decreased from severe to moderate when 4% nanoclay is added [22]. As the cure length increases, the change in the void ratio decreases [24]. The largest drop in collapse potential was seen in 6% of the nanoclay as a result of the decreased gypsum dissolving caused by the nanoclay [25].

In this work, the effect of pre-test curing at various durations (0, 1, 4 days) and nanoclay (0, 3, 6 and 12 %) on the stress-settlement of gypseous sand soil is investigated. The tests are performed using an Oedometer cell.

2 Materials And Methods

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2.1 Soil Sampling and Identification Tests

soil samples were collected from the northern district of Al-Najaf city (Al-Jameh district). In the Oedometer cell, the soil sample is shaken and remolded. Ninety percent of the maximum dry density from the standard Proctor test will be reached by the remolded specimen.

The soil is categorized as poorly graded sand (SP) by the Unified Soil Classification System (USCS). Figure 1 illustrates the grain size distribution of the soil sample. The maximum dry density, as specified by ASTM D698, is 1.825 gm/cm^3, while the ideal moisture content is 15%. The experiment findings for the identification of the soil sample are shown in Table 1.

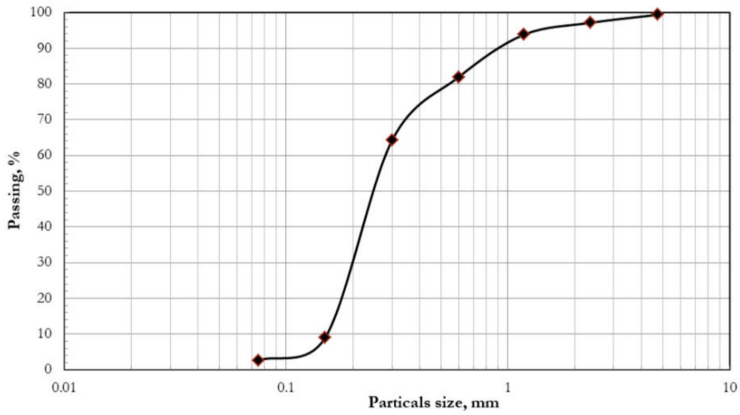

Fig. 1. The grain size distribution of the soil sample.

Table 1. The results of soil sample primary tests.

Test Designation	Standards	values
Sand, %	ASTM C136-96a	96.733
Fine, %		2.652
Soil classification (USCS)		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 moisture content, %		15

2.2 Nanoclay

The nanoclay "Montmorillonite K10" is employed, and according to the material safety data sheet, it is non-toxic. The general properties of nanoclay powder are shown in Table 2.

Table 2. Physical properties and chemical composition of nanoclay [23].

Property	Value
Particle size, nm	100
Density, g/cm^3	2.3-2.5
Surface area, m^2/g	220-270
pH	3-4
Purity, %	99.9

2.3 Tools and Equipment

The computerized Oedometer is used for performing the tests. The soil sample's settlement (in the steel ring) is monitored using a Linear Variable Differential Transformer (LVDT). As shown in Figure 2, these LVDTs are linked to the computer software program and data logger. The inner cell is 20mm in height and 50.4mm in diameter.

2.4 Test Procedure

Four test groups related to the percentages of adding nanoclay, 0, 3, 6 and 12 %. Each group includes three groups of pre-test curing periods (Tc), 0, 1 and 4 days and for different soaking periods (Ts), 0, 1, 3 and 7 days. All Oedometer tests have the same initial soil specimen properties (constant): a dry density of 1.6425 g/cm^3, a water content of 3%, and a gypsum content of 29%. The initial dry density is 90% of the maximum dry density from the standard Proctor test. For each tested specimen, a gradual incremental normal stress is applied, i.e., 50, 100, 200, and 400 kPa.

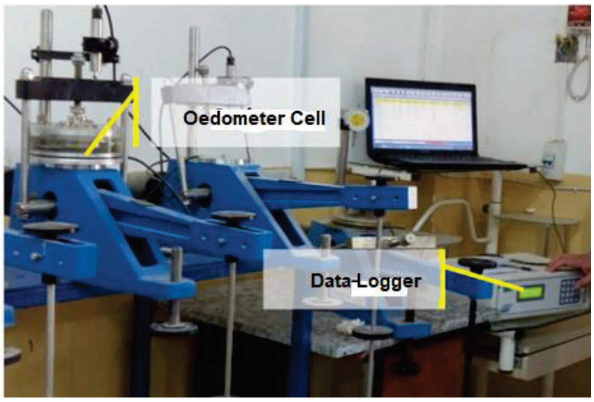

Fig. 2. The Computerized Oedometer.

3 Results And Discussion

3.1 Stress-settlement for reference soil (no-added nanoclay)

Figure 3 illustrates the results of the stress-settlement-time of this specimen. It is clearly to identify that with increasing the normal stress (NS) level there is an increase in the settlement. This settlement is quick (within a few minutes) and the dominant value (50%) is achieved within a few seconds (15-20 seconds). The final settlements are 2.08, 2.9 and 3.54mm under normal stress (NS) of 50, 100 and 200kPa, respectively.

To investigate the effect of the curing duration (pre-testing), Figure 4 illustrates the stress-settlement-time of the soil specimens after 1-day curing in the initial water content (3%). The results present an increase in the settlement under the same stress level within the same time duration (15-20 seconds). The final settlements are 2.23, 2.85 and 3.58mm under normal stress of 50, 100 and 200kPa, respectively.

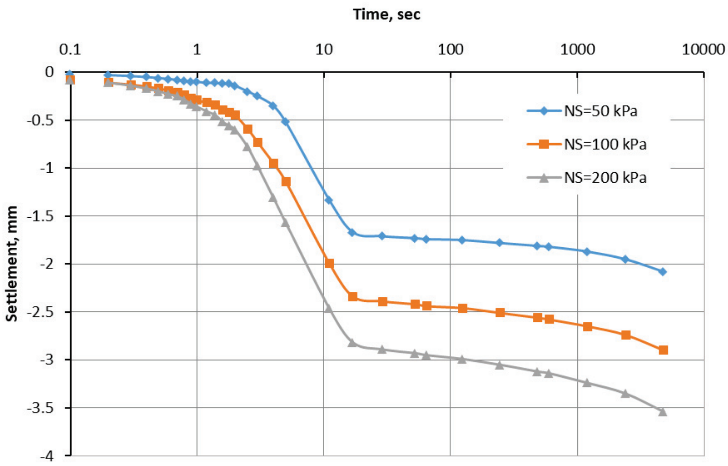

Fig. 3. Stress-settlement after 0-day curing duration (no curing).

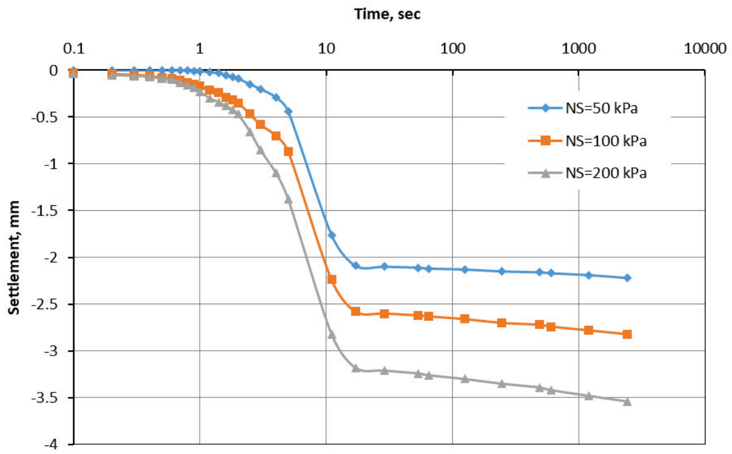

Fig. 4. Stress-settlement after 1-day curing duration.

Similar to the 1-day curing results, 4-day curing illustrates the same stress-settlement-time with a little decrease in the settlement compared to the 1-day curing duration, as in Figure 5. The final settlements are 2.19, 2.72 and 3.348mm under normal stress of 50, 100 and 200kPa, respectively. This may be caused by the decrease in gypsum dissolution and the increase in gypsum deposition.

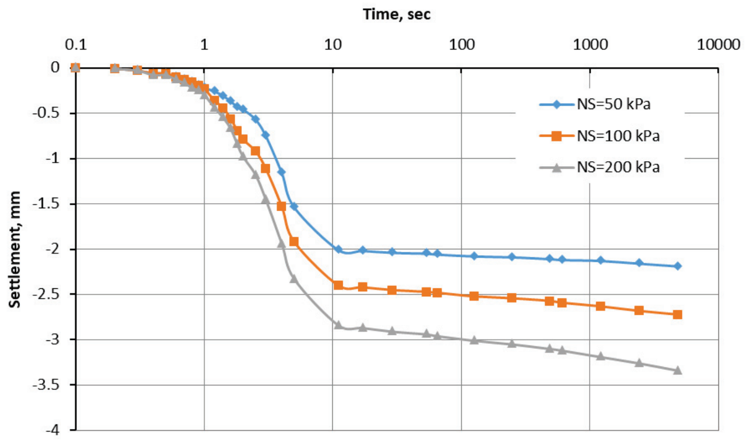

Fig. 5. Stress-settlement after 4-day curing duration.

Table 3 summarizes the results of the load-settlement and settlement change (ΔSc), as in Equation 1, due to the effect of curing durations. Under normal stress of 50 kPa, there is shifting to the left into 4-day curing, i.e., for the same settlement, there is a reduced time, i.e., an increase in the settlement rate. While the final settlement in the 4-day curing matches the 1-day curing value. This may be attributed to gypsum softening and/or increasing of grains sliding. With increasing the normal stress up to 100kPa and 200kPa, there is a similar initial trend, but the final settlement is identical for all curing durations.

$$\Delta Sc = Sc_{after\ curing} - Sc_{before\ curing} \qquad (1)$$

Table 3. Summary of the load-settlement and curing duration for no adding condition.

Normal Stress, kPa		No curing	1-day curing		4-day curing	
		Settl. (Sc), mm	Settl. (Sc), mm	ΔSc, mm	Settl. (Sc), mm	ΔSc, mm
50	after 10 sec.	1.33	1.76	+0.43	2.01	+0.68
	Final sett.	2.08	2.22	+0.14	2.19	+0.11
100	after 10 sec.	1.99	2.24	+0.25	2.40	+0.41

	Final sett.	2.90	2.82	-0.08*	2.72	-0.18*
200	after 10 sec.	2.46	2.82	+0.36	2.84	+0.38
	Final sett.	3.54	3.54	+0.00	3.34	-0.20*

3.2 Effect of Nanoclay

To investigate the effect of the added nanoclay, Figure 6 shows the settlement-time for the different percentages of nanoclay under normal stress of 200kPa for no-curing conditions for the mixture (soil+nanoclay). A clear decrease in the settlement within the time and in the final settlement compared to the natural state of the soil (without nanoclay). Whereas a significant decrease is recorded for the 6% nanoclay (NC) as the best nanoclay percentage. This result disagrees with Karkush et.al., 2020 (NC<2%) and Hayal et al. 2020 (NC up to 10%).

Increasing the curing duration up to 1-day, coincides with results of 6% and 12% nanoclay, as in Figure 7. A decrease in settlement rate A similar trend occurred with increasing the curing duration to 4-day, as in Figure 8. For all normal investigated stresses, the 6% added nanoclay indicates the most improvement trend among the investigated percentages (3%, 6% and 12%).

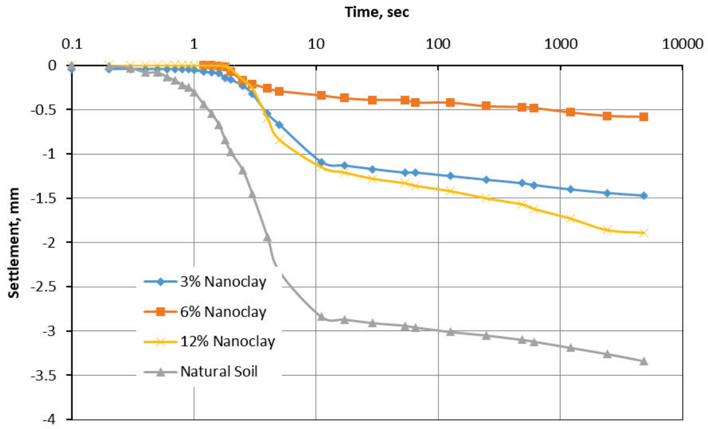

Fig. 6. Settlement-time for the different percentages of nanoclay under normal stress of 200kPa (no curing).

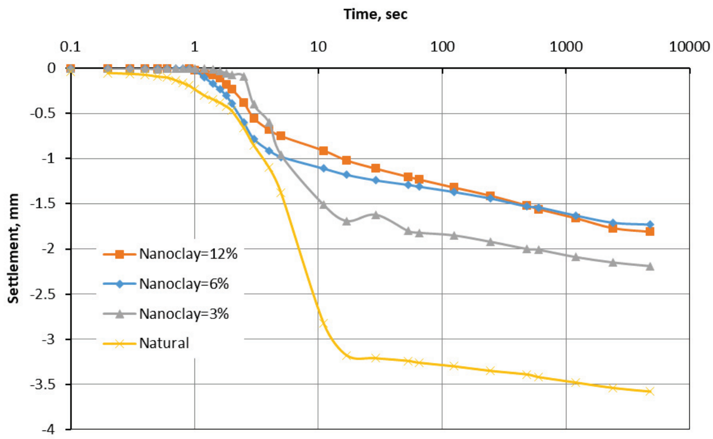

Fig. 7. Settlement-time for the different percentages of nanoclay under normal stress of 200kPa (1-day curing).

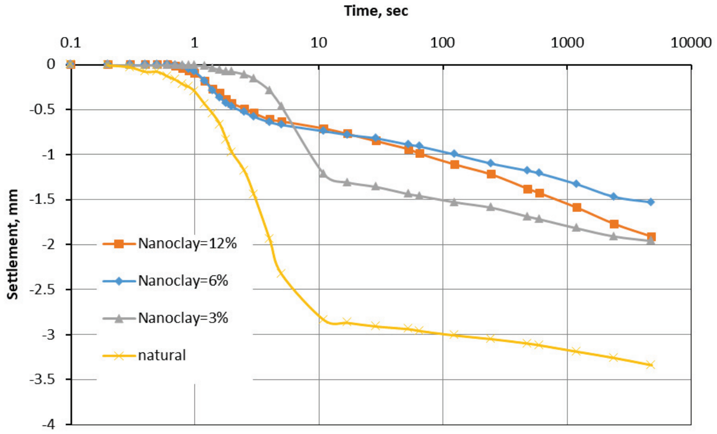

Fig. 8. Settlement-time for the different percentages of nanoclay under normal stress of 200kPa (4-day curing).

3.3 Effect of Curing Duration (Tc)

Figures 9, 10 and 11 shows the effect of the curing durations for the mixture (soil+nanoclay) on the results of stress-settlement-time for different percentages of nanoclay (3%, 6% and 12%) under normal stress of 200 kPa. For 3% and 6% nannoclay, it is obvious that there is an increase in settlement with increasing curing duration, but, recovery is performed with 4-day curing. This behavior can be correlated to the effect of initial low water content and the effect of nanoclay in preventing of re-bonding of particles by the gypsum.

With increasing of the nanoclay up to 12%, the behavior of the soil is in a different trend and this might be attributed to the effect of fine material, i.e., low settlement rate.

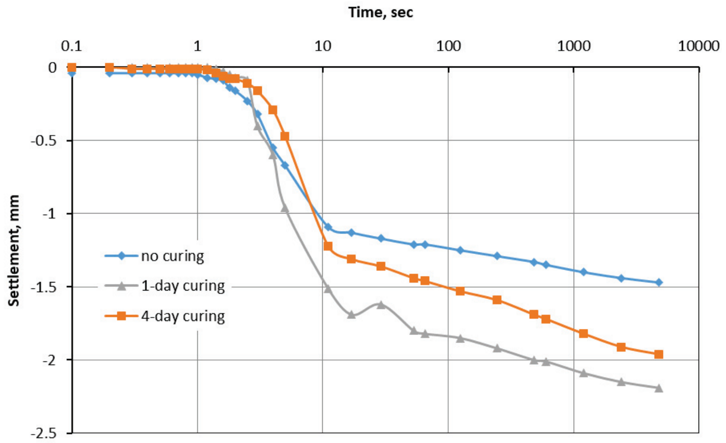

Fig. 9. Effect of curing duration on the settlement-time of 3% nanoclay treated soil specimen under stress of 200kPa.

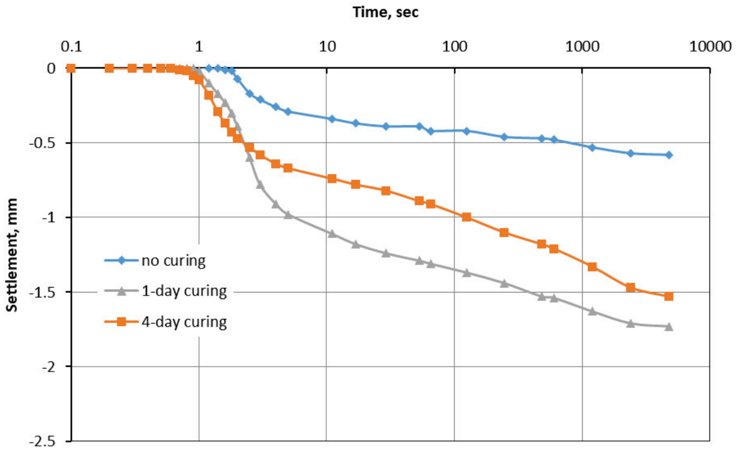

Fig. 10. Effect of curing duration on the settlement-time of 6% nanoclay treated soil specimen under stress of 200kPa.

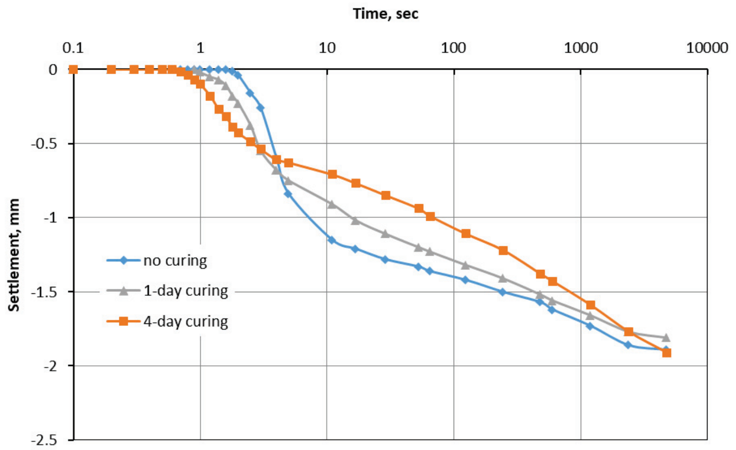

Fig. 11. Effect of curing duration on the settlement-time of 12% nanoclay treated soil specimen under the stress of 200kPa.

Table 4 illustrates the stress-settlement and settlement change (ΔSc), as in Equation 1, due to the effect of curing durations under normal stress of 200kPa. Generally, there is an increase in the settlement with increasing the curing period.

Figure 12 presents the settlement ratio, SR (sett. with nanoclay/sett. without). This figure clarifies that there is a noticeable decrease in the settlement from adding nanoclay to soil specimens, whereas there is a significant decrease in the settlement with SR equal to about 0.16 under the normal stress of 200 kPa for no-curing conditions. The 3% nanoclay is not enough as 6%, while with increasing of nanoclay to 12%, the SR there an action of fine particles results in decreasing of the settlement rate. The increase in the curing duration leads to an increase in the SR up to 0.48 for 1-day curing and this may be correlated to the lack of the re-bonding due to low initial water content and the existence of the nanoclay. A little recovery of the SR with increasing of the curing duration up to 4-day.

Table 4. Summary of the load-settlement and curing duration for different nanoclay percentages under a stress level of 200kPa.

Nanoclay, %		No curing	1-day curing		4-day curing	
		Sett. (Sc), mm	Settl. (Sc), mm	ΔSc, mm	Settl. (Sc), mm	ΔSc, mm
3	after 10 sec., mm	1.09	1.51	+0.42	1.22	+0.13
	Final sett.,mm	1.47	2.19	+0.72	1.96	+0.49
6	after 10 sec., mm	0.34	1.11	+0.77	0.74	+0.40
	Final sett.,mm	0.58	1.73	+1.15	1.53	+0.95
12	after 10 sec., mm	1.15	0.91	-0.24	0.71	-0.44

	Final sett.,mm	1.89	1.81	-0.08	1.91	+0.02

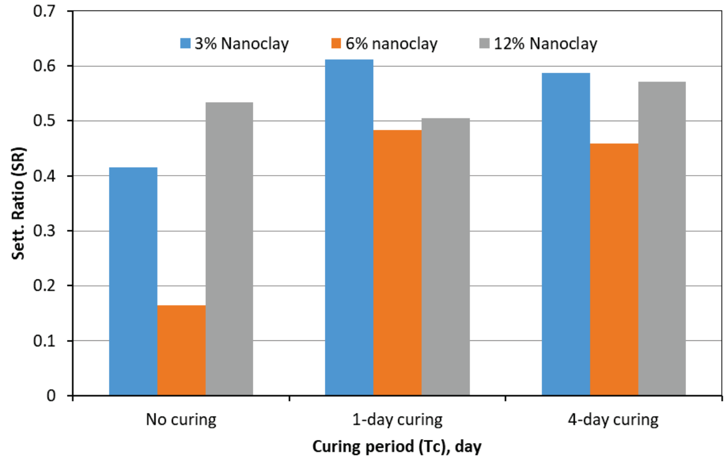

Fig. 12. Effect of nanoclay and curing duration on the gypseous sand under a stress level of 200kPa.

4 Conclusion

The recent work investigates the stress-settlement behavior of the gypseous sand soil from Al-Najaf City, Iraq. The soil specimen is pre-test cured for different durations and treated with different percentages of nanoclay material. There is a decrease in settlement with adding the nanoclay. For the soil without nanoclay, it was an interesting result for the performance under all vertical stresses that there is a slight decrease in the final settlement. This situation may be attributed to the re-bonded of the particles by the gypsum during the curing time. A clear decrease in the settlement in time and the final settlement compared to the natural state of the soil (without nanoclay). While a significant decrease for nanoclay (NC) 6% was recorded as the best percentage of nanoclay.

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