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Interaction of Curing and Soaking on Collapse Potential of Nanoclay-Treated Soil

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Abstract

This study examines the combined impact of pre-test curing and soaking periods on the soil's resistance to collapse those results from treating gypseous sand with varying amounts of nanoclay. The soil comes from the Iraqi city of Najaf. The soil sample is mainly sand. The nanoclay named "Montmorillonite K10" is used, and it is non-toxic. The tests are performed with a computerized Oedometer. The collapse potential is estimated according to a single Oedometer test (SOT), where the specimens are initially dry and then soaked under a stress level of 200 kPa. Four data sets related to the percentages of 0, 3, 6, and 12% nanoclay are used. Each data set comprises three groups of pre-tests for curing duration and different soaking durations. All experiments have a constant initial dry density of 1.64 g/cm3, water moisture of 3%, and gypsum content of 29%. The findings of this study show that the collapse potential (CP) of natural soil specimens decreases as the pre-test curing time increases. Generally, there is a decrease in CP due to adding the nanoclay and 6% of the nanoclay exhibited the highest reduction in CP. Also, there is an increase in the pre-test curing for the nanoclay-treated soil specimens, which leads to an increase in the CP related to the no-curing state.

Keywords: Collapse potential; Curing time; Gypsum content; Najaf city; Sandy soil; Soaking

1. Introduction

Whenever collapsible soils occur, whether by natural processes or human activities, they pose serious engineering and geotechnical issues [1]. The effects of the rains were minimal because of their close range of penetration [2]-[4]. Soils with a high percentage of gypsum (collapsible soils) have a greater potential to collapse [5],[6]. The behavior of higher gypsum sand soils varies according to how long it soaks, it remains consistent across all stress levels [7]. The studies on the 29% gypsum content sand soil revealed that the soaking times and stress levels that cause such soils to collapse increase [8]. Corresponding to the pre-test curing durations, the collapsibility rate increases as the final collapsibility decreases [9]. Both undisturbed and reconstituted soil specimens exhibited wetting-induced volumetric strain behavior at higher mean net stress values in a remarkably comparable way [10].

In collapsed soils, such as those that collapsed significantly when matric suction (ua-uw) is diminished, the unsaturated form is always present [11]. Sand loses bulk as it gets wet [12],[13]. When gypseous soil is subjected to moisture (soaking), it collapses [14]-[16]. Numerous variables, such as the wetting time [17],[18], pore-to-volume ratios, permeability [19], initial saturation levels, and soil time-based wetting before loading, all affect the soil collapsibility [6],[20].

Several studies have been conducted to categorize the soils' collapsibility [14]. The modified version of the Jennings and Knight method [21] is a test procedure performed in laboratories to measure the potential of soil collapsibility using the single oedometer test (SOT). This procedure uses Eq.1 to calculate the collapse potential (CP).

$$CP = \frac{\Delta l}{lo} \quad (1)$$

where lo represents the original specimen height and Δl the change in specimen height from natural water content to saturated. Jennings and Knight [21] and ASTM D5333 [22] suggested a classification of the collapse problem severity based on the soil's collapse potential. Nevertheless, there is a slight difference in the CP range between the two sources that relate to the problem severity.

The probability of soil collapse is decreased by approximately 9.7%, 60%, and 73.8%, respectively, when 2.5, 5, or 10% of nanoclay is added [23]. The collapse potential of soil samples with 4% nanoclay was decreased by 77%. Also, the chemical and physical properties of gypseous soils were improved after adding 4% of nanoclay [24]. The need to restore the characteristics of the problematic or contaminated soils suggests the necessity to use remediation or stabilization techniques [25]-[27].

This study explores how pre-test curing and soaking intervals affect the collapse potential of gypseous sand that has been treated with different amounts of nanoclay.

2. Materials and Methods

2.1 Soil Identification Tests

The soil samples used in this paper were conveyed from Al-Najaf City which is located about 200 km south of Baghdad city, Iraq. After being disturbed, the soil is remolded within the cell of the Oedometer.

The soil sample is primarily composed of sand (>85%). The results of the identification and classification tests are summarized in Table 1.

Table 1. The results of soil tests.

Test Designation	Standards	Values
Sand/Fine, %	ASTM C136-96a [28]	86/1.74
USCS	ASTM C136-96a [28]	SP
Specific gravity (Gs)	ASTM D854 [29]	2.38
Gypsum content, %	ASTM C25-19 [29]	29
Max. dry density, gm/cm^3	ASTM D698 [30]	1.825
Optimum moisture content, %	ASTM D698 [30]	15

2.2. Nanoclay

The nanoclay named "Montmorillonite K10" is used and it is non-toxic as mentioned in the material safety data sheet issued by the producer. Safety assurance tools are necessary when using nanoclay, despite its non-toxic nature. These tools include glasses for eye protection, gloves, a mask with a filter, and a lab coat.

2.3 Tools and Equipment

The single Oedometer collapse tests are performed using a computerized Oedometer. A Linear Variable Differential Transformer (LVDT) is used to track changes in the soil sample's settlement (in the steel ring). These LVDTs are connected to the data logger and software, as shown in Fig.1. The recorded data can be exported using Microsoft -Excel files.

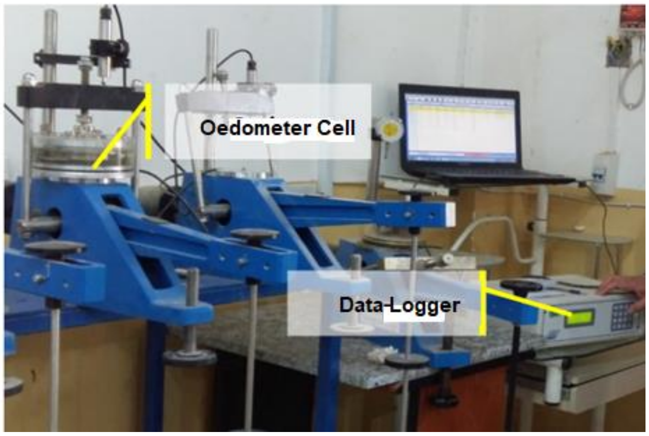

Figure 1. Setup of the Computerized Oedometer.

2.4 Test Procedure

The experimental method is adopted to estimate the soil collapse potential, according to Jennings and Knight's method [21]. The tests are based on a single Oedometer test (SOT) method. Four data sets are used, which are related to adding, 0, 3, 6, and 12% nanoclay. Each data set includes three groups of 0, 1, and 4 pre-test curing days and 0, 1, 3, and 7 soaking days. All tests have a constant initial dry density (1.6425 g/cm^3), water content (3%), and gypsum content (29%). The initial dry density is 90% of the maximum dry density (1.825 g/cm^3) obtained from the standard Proctor test. Table 2 illustrates the test program. The resulting data are presented in the form of collapse potential (CP) under normal stress of 200 kPa from Equation 1.

Table 2. Tests program.

Curing period (Tc), day	Nanoclay, %	Soaking period, day
0	0	0, 1, 3 and 7
	3	0, 1, 3 and 7
	6	0, 1, 3 and 7
	12	0, 1, 3 and 7
1	0	0, 1, 3 and 7
	3	0, 1, 3 and 7
	6	0, 1, 3 and 7
	12	0, 1, 3 and 7
4	0	0, 1, 3 and 7
	3	0, 1, 3 and 7
	6	0, 1, 3 and 7
	12	0, 1, 3 and 7

3. Results and Discussion

3.1 Effect of Nanoclay on Soil Collapsibility

Fig. 2, 3, and 4 present the collapse potential (CP) versus the soaking duration (Ts) under the 200 kPa normal stress for different pre-test curing durations (Tc). As mentioned above, nanoclay improved the soil by decreasing the CP.

The 6% nanoclay revealed the maximum decrease in the CP, about one-third of the no nanoclay condition. This behavior is clear in the no-curing condition, as shown in Fig. 2. Table 3 illustrates the percentages of change in CPs for the different nanoclay contents for no-curing conditions and periods of soaking (1, 3, and 7 days). These percentages of CP change are related to the collapse potential of natural soil specimens. There is a decrease in the CP with adding nanoclay, whereas 6% nanoclay gave the maximum decrease. This result does not match the results obtained by Hayal et al. [23], and Karkush et al. [24], and this may be related to the different initial conditions (different initial densities), where the recent research has the highest initial density.

Also, it was noticed that the CPs tend to increase with increasing soaking durations (Ts). The maximum CP values after 7 days of soaking with 6% nanoclay are in a condition of "moderately trouble" according to the severity of the collapse potential, according to Jennings & Knight, [21].

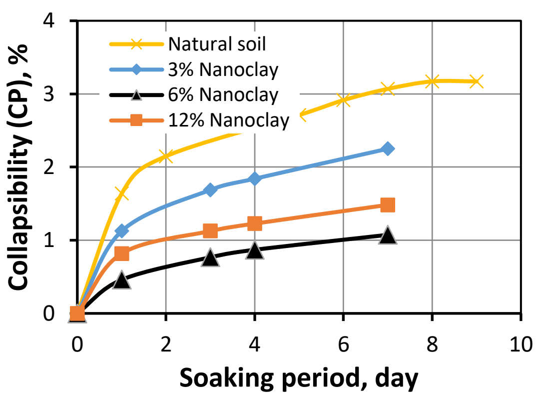

Figure 2. Collapse potential (CP) versus soaking period for no-curing.

Table 3. Summary of percentages of collapse potential change for no-curing condition.

Soaking duration, day	CP, %	CP change, %		
	Natural soil (no add)	3% nanoclay	6% nanoclay	12% nanoclay
1	1.64	-31	-72	-50
3	2.34	-28	-67	-52
7	3.07	-27	-65	-52

After 1-day curing, as in Fig. 3, 3% nanoclay shows no change in the collapse potential related to the natural specimen. This state may be attributed to the effect of the low nanoclay content during the curing condition and/or preventing the re-bonding of the soil particles. The other nanoclay percentages, 6%, and 12% decrease the collapse potential, but less than in the no-curing condition, as described in Table 4. Furthermore, it was noticed that a convergence between the results of 6% and 12% nanoclay compared to the no-curing condition. All values of CP after 7 days of soaking were found within the moderate trouble range concerning Jennings and Knight [21] and from a moderate to slight according to ASTM D5333 [22].

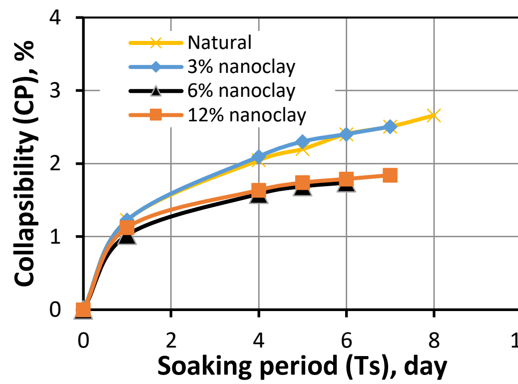

Figure 3. Collapse potential (CP) versus soaking period for 1-day curing.

Table 4. Percentages of collapse potential change for 1-day curing condition.

Soaking duration, day	CP, %	CP change, %		
	Natural soil (no add)	3% nanoclay	6% nanoclay	12% nanoclay
1	1.23	+00	-17	-08
3	1.77	+02	-21	-17
7	2.51	+00	-29	-27

After 4-day curing, as shown in Fig. 4. the natural specimen shows lower collapse potential within the first 2 days of soaking, and then the natural specimen exhibits an increase in CP concerning the nanoclay-treated specimens. The highest decrease in the CP is achieved when the nanoclay is 6%. whereas when the percentage of nanoclay is 3%, and 12%, are matching values and less than 6% nanoclay, as in Table 5.

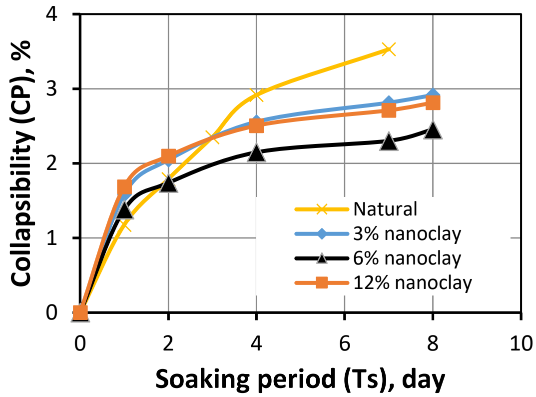

Figure 4. Collapse potential (CP) versus soaking period for 4-day curing.

Table 5. Summary of percentages of collapse potential change for 4-day curing condition.

Soaking duration, day	CP, %	CP change, %		
	Natural soil (no add)	3% nanoclay	6% nanoclay	12% nanoclay
1	1.18	+35	**+17**	+43
3	2.35	-23	**-17**	-02
7	3.53	-20	**-35**	-23

3.2. Curing Effects on the Soil Collapsibility

3.2.1. For natural soil (without nanoclay)

There is a gradual increase in collapse potential (CP) with the progress of the soaking duration (Ts), as shown in Fig. 5. While this increased rate was very low after 8 days of soaking, The method of curing (pre-soaking) represents an improved method for such soils (gypseous soils).

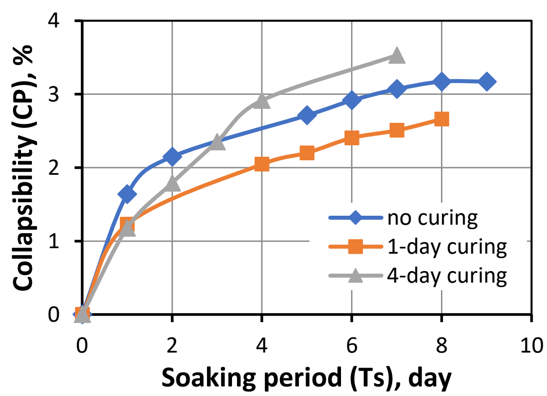

Figure 5. Collapse potential (CP) versus soaking period for no-added soil (natural).

Table 6 indicates that the values of the collapse potential were noticed within the moderate range of collapse severity. Generally, an increase in the curing duration causes a reduction in the collapse potential. This condition may be attributed to the re-bonding process of the particles with the gypsum. With the extended soaking process (7 days), the bonding is eliminated due to the gypsum dissolution.

Table 6. Summary of the percentages of collapse potential change for the natural soil specimen due to curing duration.

Soaking duration, day	CP, %	CP change, %	
	no-curing	1-day curing	4-day curing
1	1.64	-25	-28
3	2.34	-24	+01
7	3.07	-18	+15

3.2.2. For nanoclay-treated soil

Fig. 6, 7, and 8 show an increase in collapse potential due to curing durations (Tc) for different nanoclay percentages and soaking process durations (Ts). The change in CP is within narrow ranges for the 3% nanoclay, and this range diverges for the 6% and 12% nanoclay. This may be attributed to the effect of nanoclay on the re-bonding process within the curing duration.

Table 7 illustrates the summary of the percentage changes in the CP related to the no-curing condition for the different nanoclay percentages. The highest increase in CP values is for 6% nanoclay. Generally, this increase in CP is decreased with the rise of the soaking duration, and this may be affected by the problem of the soaking being stronger than the curing process.

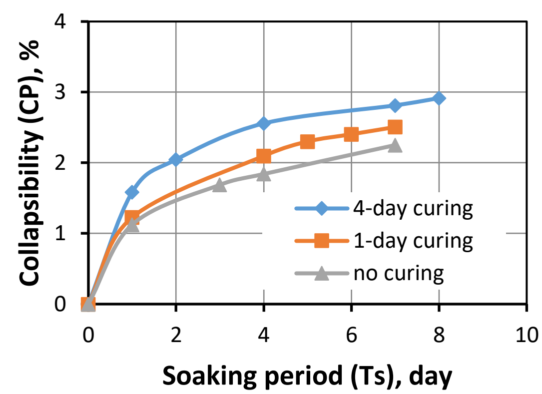

Figure 6. Collapse potential (CP) for 3% nanoclay and different curing durations.

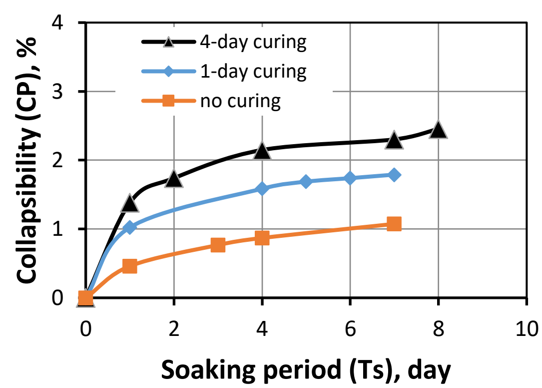

Figure 7. Collapse potential (CP) for 6% nanoclay and different curing durations.

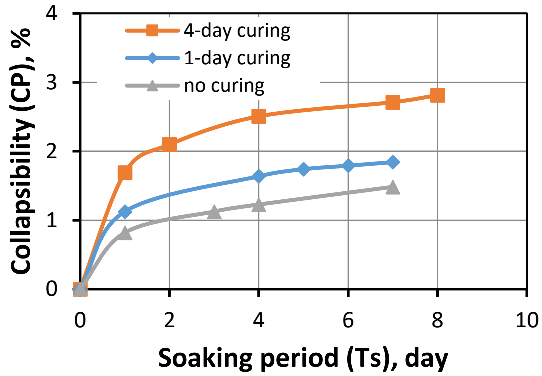

Figure 8. Collapse potential (CP) for 12% nanoclay and different curing durations.

Table 7. Summary of the collapse potential percentage change due to the curing process.

Soaking duration, day	3% Nanoclay		6% Nanoclay		12% Nanoclay	
	one-day curing	four-day curing	one-day curing	four-day curing	one-day curing	four-day curing
1	+09	+41	+122	+200	+38	+106
3	+07	+08	+82	+153	+30	+105
7	+11	+25	+67	+114	+24	+83

4. Conclusions

The combination effects of curing, soaking, and nanoclay under normal stress of 200 kPa on the collapse potential are investigated. For no-added soil specimens, it can be stated that when the curing period increases, the collapse potential (CP) decreases due to the re-bonding from the gypsum. This re-bonding is destroyed by increasing the soaking process for up to 7 days. For the nanoclay-added soil specimens, there is a decrease in collapse potential (CP) due to a decrease in gypsum dissolution. A nanoclay of 6% exhibited the highest decrease in CP. An increase in the curing for the nanoclay-treated soil specimens leads to an increase in the CP related to the no-curing state. It is well established that soaking and curing have a combined impact on the behavior of the gypseous sand soil. Future research on the impact of initial water content and density may be suggested.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Suha A. Hameed and Navid Ganjian: proposed the research problem.

Navid Ganjian: developed the theory and performed the computations.

Suha A. Hameed: verified the analytical methods and investigated the findings of this work.

Navid Ganjian: supervised the findings of this work.

Both authors discussed the results and contributed to the final manuscript.

Nomenclature

ASTM	American society for testing material
CP	Collapse potential, %
Gs	Specific gravity
lo	initial specimen height, L
Tc	Pre-test curing duration, T
Ts	Soaking duration, T
SOT	single oedometer test
SP	poorly graded sand
USCS	Unified soil classification system

Greek symbols

Δl	change in specimen height from natural water content to saturated

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