



## Collapse Problem Treatment of Gypseous Soil by Nanomaterials

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### ABSTRACT

Investigation of the effect of using nanomaterials for improving and Stabilizing the gypseous soil was carried out using laboratory works. The gypseous soils were collected from a site of intake in Bahar Al-Najaf and mixed with two types of nanomaterials (Nano-silica and, Nano-clay) where the nanomaterials were added in small amounts as a percent of the dry weight of the soil sample. Tests to determine the sieve analysis, specific gravity, and collapse potential were performed. The results of the experimental work showed significant modification in the geotechnical properties of the soil sample. The collapse potential decreases as soon as the used nanomaterials were increased until they reach a percentage after which the collapse potential will be increased. Thus, addition of nanomaterials, even at a low percentage, could improve the properties of gypseous soil. When adding the nano-silica to the soil, the collapse potential (CP) is decreased whenever the nano-silica increases until 1% of the added nanomaterials and then further stabilizer increases the (CP), the percent of decrease in CP is about 91% where the effect of the additive (nano-silica) changes the classification of severity of collapse from “moderate trouble” case to “no problem” case.

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### NOMENCLATURE

Cc	coefficient of curvature	$\Delta H_e$	changing in height of specimen which results from the wetting
C <sub>u</sub>	coefficient of uniformity	H <sub>o</sub>	specimen initial height
SP	poorly graded sands	$\Delta e$	changing of specimen void rate which results from wetting,
CP	collapse potential	e <sub>o</sub>	natural void ratio
SOT	Singule Oedometer Test		

## 1. INTRODUCTION

The soil texture, as a term, refers to the orientation and mineralogical composition of particles, the nature of properties of soil water and the forces of interaction between particles and soil water in a soil mass. An understanding of the soil structure is necessary because it influences the physical characteristics like swelling and engineering characteristics like strength and other properties of soil.

Collapsible soils are having metastable structure. This kind of soil has different properties due to various water conditions. It shows high strength and toughness when it

is at normal water condition while at the wetting condition, the soil will suffer an unexpected plastic deformation. Existing of collapsible soil can result in structural damages to the construction projects such as cracks in floor, foundations, and walls.

The saturation of soils without the flow of water under specific pressure is referred to as soaking such as site flooded with water during heavy rainfall, irrigation or breaking of sewerage and water pipes. Changing of water contents in gypsum makes the gypsum function as solidifying operator to debauch inside the soils mass which brings about single or mix of three procedures, firstly separating any bond that exists within soil particles

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bolstered via the gypseous followed by the collapsing of soils construction and this procedure happens very quickly. The subsequent procedure is union, while the third is draining procedure which shows up when the water stream proceeds through the dirt mass. Mixing such procedures can make the soils to be settled extensively as the load gets subjected [1].

In Iraq, particularly over the most recent three decades, broad improvements have been proved in the locales of gypseous soils because of the need for the development of numerous quantities of key ventures.

Numerous experimental researches in the world and Iraq motivated on remedial measures of collapsible gypseous soils. All of these techniques are focusing on governing the volume change and decreasing the permeability coefficient or inhibiting any interaction of moisture between the gypseous soil and water source to reduce the gypsum agent's dissolution. In general, the treatment measures of gypseous soils can be summarized as follows:

- 1) Chemical treatment: in which the remedial materials recommended are primarily cement, lime and crude and/or west oil products.
- 2) Physical treatment: these measures are based upon improvement of the geotechnical properties of gypseous soils to control the consequences of dissolution of gypsum.

The work presented by Fattah et al. [2] introduced the findings of tests conducted on four gypseous soils of various features and different contents of gypsum. Undisturbed soil specimens were tested to calculate the compressibility subjected to many conditions. An acrylate liquid was used as grouting material in which soil specimens were treated. The remediated specimens exhibited the ability of acrylate liquid to decrease the compressibility of the gypseous soil by more than 60–70%. The parameters of shear strength were influenced by acrylate liquid via the increase in the cohesion plus the decrease in the internal friction angle.

Ibrahim and Schanz [3] analyzed the enhancement of the features of gypsiferous soils by utilizing silicone oils to limit the impacts of dampness and gypsum losing. The analysis had been directed on fake gypsiferous soils (30% Silber sand and 70% unadulterated gypsum) treated with silicone oil in different percentages. Silicone oil was selected as an additive because of leakages of oil-related products from an oil refinery north of Iraq built on gypsiferous soil. Thus, this oil product provides a suitable analogue for that which has infiltrated the foundation soil of the refinery buildings. The results showed that the silicone oil is a suitable material for modifying the basic properties of the gypsiferous soil, such as collapsibility and shear strength.

Verma and Maheshwari [4] stated that there are various types of nano materials such as nano silica ( $\text{SiO}_2$ ), nano titanium oxide ( $\text{TiO}_2$ ) etc. are available.

They carried out experiment in which the nano silica was mixed with soil samples (CI) in varying proportions of (0.0%, 0.25%, 0.50%, 0.75% and 1.0%) to study the geotechnical properties of soil. The results showed that the unconfined compressive strength and CBR characteristics of soils get increases with increasing the percentages upto 0.75 % of nano  $\text{SiO}_2$  and afterwards a gradual decrease was obtained.

The objectives of the present study is to enhance the collapsibility of gypseous soils using two types of nanomaterial; nano clay and nano silica. Collapse tests were conducted in samples treated by different percentages of these materials.

## 2. LABORATORY INVESTIGATION

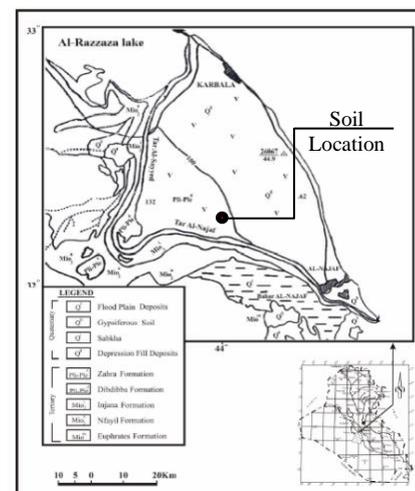
**2. 1. Material** The soils utilized in the current work represents disturbed regular gypsums soils (collapsible soil).

Soil samples of this study were collected from several sites in Bahar Al-Najaf south west Baghdad city in Iraq. All samples are representing disturbed soils brought together from a depth (1.5-2.5) m under the ground surface and the samples are collected from the bed of the intake. Figure 1 presents the geological conditions of the study area. The intake region is located at about (10) km from the city center of Al-Najaf.

The filed dry unit weight of the soil was measured by the sand replacement method. It was found to be  $15.2 \text{ kN/m}^3$ .

## 2. 2. Laboratory Work

**2. 2. 1. Sieve Analysis** Particle size analysis is used to determine the particle size distributing. The sample got washed via a number of sieves having



**Figure 1.** Location and geologic map of Karbala – Najaf area in Iraq

dimensions of gradually smaller screen to define the percentages of sand-sized particles of the examples consistent with ASTM D-422 [5] specification. Approximately 50 grams of dry soil which was passing sieve No. 200 was treated with a dispersing agent and analyzed using a hydrometer. From Figure 2, the coefficient of uniformity  $C_u$  is 4.34 and the coefficient of curvature  $C_c$  is 0.59, so the soil is classified as SP (poorly graded sand) according to the unified soil classification system.

**2.2.2. Specific Gravity** Values for specific gravity of the soil solids were determined according to ASTM D-854 [6]. Kerosene was used instead of water to avoid dissolution of gypsum. The result shows that the specific gravity value for the untreated gypseous soil is 2.34.

**2.2.3. Collapse Test** Such testing was performed through utilizing oedometer tool. A single oedometer test had been conducted to decide the collapsing potential (CP) for the soils. At that point, the testing proceeds by extra load and emptying as in the customary consolidating testing. Table 1 presents the criterion used to classify gypseous soils based on collapse potential. It is evident that the increase in CP refers to increase of the problem of gypseous soil collapse upon wetting.

The samples were prepared at the field dry unit weight of  $15.2 \text{ kN/m}^3$  by making a gentle tamping on sample in a compaction mold. Then an oedometer ring was pressed on the soil to get the collapse test specimen.

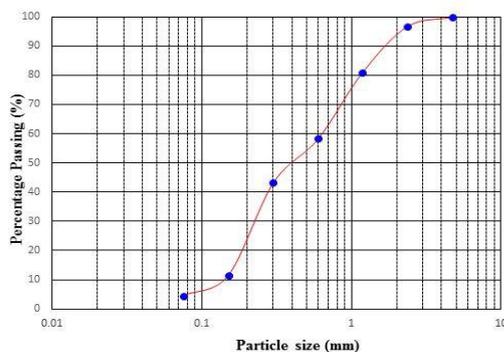


Figure 2. Grain size distributing of the soil used

TABLE 1. Relationship of collapsing potential to the severity of Foundation problems [7]

CP (%)	Severity of problem
0-1	No problem
1-5	Moderate trouble
5-10	Trouble
10-20	Severe trouble
20	Very severe trouble

For single oedometer testing (sot) such testing, the soil's sample is stacked steadily at starting condition till the sample arrives at vertical stress of (200 kPa) with loading increase proportion (LIR) of 1. After that, the sample gets soaked with water within 24 hours. The extra settling was recorded at (200 kPa) stress because of splashing process. The collapse potential (CP) can be determined by utilizing the accompanying condition:

$$c_p = \frac{\Delta H_e \Delta e}{H_o (1+e_o)} \times 100 \quad (1)$$

### 3. NANO MATERIALS

There are two types of additives material as nanomaterials (nano-clay and nano-silica) that are used in this study in different ways by mixing and grouting while nano-silica as (0.5%, 1%, 2% and 3%) and nano-clay as (2.5%, 5% and 10%).

Nanoclay is composed of phyllosilicates which include groups of minerals such as talc, Mica, kaolin, montmorillonite, Serpentine or sepiolite. Among other things, nanoclay differs in the size and sequence of the regions in which the  $\text{SiO}_4$  tetrahedra are oriented upwards or downwards in the layers. Montmorillonite, the most technically significant clay mineral as the main constituent of bentonite, is composed of  $\text{SiO}_4$  tetrahedron bilayers with deep-rooted octahedral layers of aluminium, iron, and hydroxide ions. A common montmorillonite particle comprises of approximately 1 nm thick alumina-silicate layers with lateral sizes in the series of 700 nm to about  $10 \mu\text{m}$ , which accumulate into big stacks.

Also amorphous nano-silica powder was used with a solid content of more than 99.8%, an average size of 12 nm and surface area of  $200 \pm 25 \text{ m}^2/\text{g}$ . Nano-silica consists of 48.83% silicon and 53.33 oxygen.

### 4. RESULTS AND DISCUSSION

#### 4. 1. Collapsible Test Results without Nanomaterial

Figure 3 delineates a normal reaction where a seating stresses of 25 kPa had been utilized to set up an initial state. Each compressing under such stress was credited to specimen disturbing. The initial compressing bend refers to the soil's reaction at its in situ water content. Weight was applied until the stress on the sample was equivalent to, or bigger than, the normal one in the field or up to 200 kPa as standardized by ASTM D-5333 [8].

Figure 3 illustrates a typical response in which a seating stress of 25 kPa was used to establish an initial state. Any compression under this stress was attributed to sample disturbance. The initial compression curve

represents the response of the soil at its in situ water content. Pressure was applied until the stress on the sample was equal to, or greater than, that expected in the field or up to 200 kPa as standardized by ASTM D-5333 [8].

The result of collapse test shows that collapse potential (CP) of the sample of the soil is equal to (3.6) %, so the soil is classified as moderately trouble according to Table 1.

Generally, collapsible soils are under unsaturated conditions in the dry state, with negative pore pressure resulting in higher effective stresses and greater shear strength. Additionally, cementing agents such as  $\text{CaCO}_3$  can also contribute to maintaining an open “honeycombed” structure. Upon wetting, the pore pressure become less negative and the effective stresses are reduced causing a decrease in shear strength. Additionally, the water can dissolve or soften the bonds between the particles, allowing them to take a denser packing. This mechanism, referred to as wetting-induced collapse, or hydrocompression, can take place with or without extra loading.

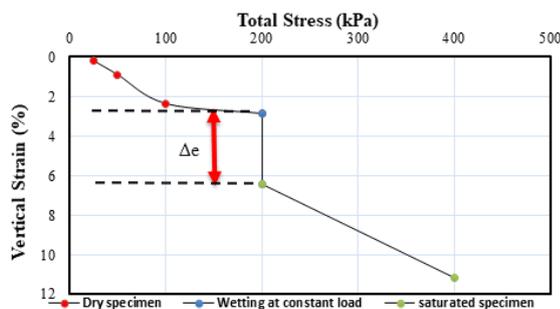
**4. 2. Effect of Adding Nanomaterials**

**4. 2. 1. Nano-Clay** This type is classified as montmorillonite K 10 and this substance is not classified as dangerous material. The Nano-clay is added to the soil of percentage as (2.5%, 5% and 10%) and the results showed the following improvement.

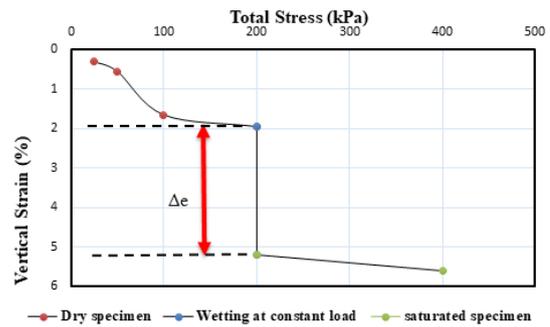
Figure 4 presents single collapse test result on gypsum saturated soil samples treated with 2.5% of Nano- clay and at pressure equal to 200 kPa. It is noticed that the vertical strain changed from (2%) to (5.35%) and the collapse potential was decreased to 3.25%.

The Collapse mechanism can be explained by initial collapse of metastable texture of soil due to dissolution of gypsum when the soil is subjected to the wetting condition by which bonds between grains are broken down.

Molecular forces between particles are the weakest and the strength decreases with an increase in water saturation. The ionic-electrostatic force and capillary force are similar in magnitude, however ionic-



**Figure 3.** Collapse test results on the natural soil



**Figure 4.** Collapse test results on the gypseous soil treated with 2.5% Nano clay

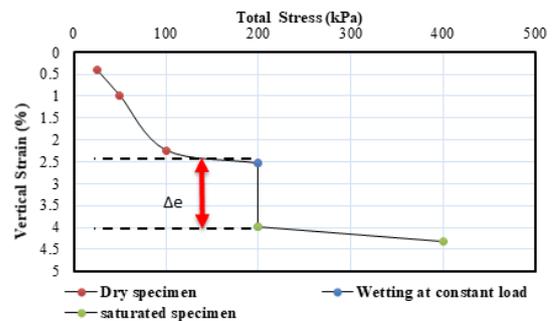
electrostatic force is not stable in the presence of water, and capillary forces only exist at degrees of saturation between 0.35 and 0.80. Chemical agents, such as ions present in nano-materials, can form cementation bridges with the strongest force. In addition, the collapsibility of stabilized gypseous soils also depends on the distortion and size of the inter-aggregate and intra-aggregate pores.

From Figure 5 that presents single collapse test result on gypsum soil samples treated with 5% Nano clay the outcomes show that changing of vertical strain at pressure equal to 200 kPa from a value of (2.5%) to (4%) which makes the collapse potential 1.44%.

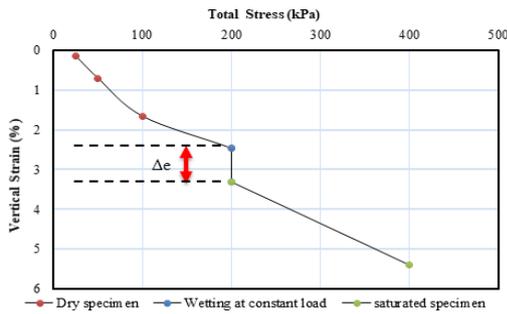
Figure 6 presents single collapse test result on gypsum soil samples treated with 10% of Nano clay. The collapse potential was decreased to 0.945% because of the vertical strain change from 2.3% to 3.4% in consequence of applying 200 kPa (stress).

**4. 2. 2. Nano-Silica** It is added to the soil of percentage (0.5%,1%, 2% and 3%). The results illustrated the following values of the collapsing potential (CP) and the following curves indicated the effect of adding nanomaterials.

Figure 7 presents single collapse test result on gypsum soil samples treated with 0.5% of Nano silica where the vertical strain shifted from (2.4%) to (3.3%) under the compression at 200 kPa making the collapse



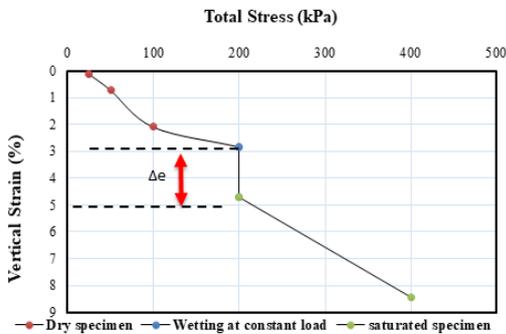
**Figure 5.** Collapse test results on the gypseous soil treated with 5% Nano clay



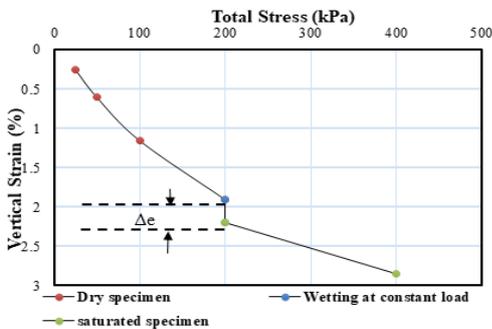
**Figure 6.** Collapse test results on the gypseous soil treated with 10% Nano clay

potential decrease to 1.89%. The lower collapse potential in treated samples can be related to stronger bond in the binder. Figure 8 presents single collapse test result on saturated gypsum soil samples treated with 1% of nano silica. In this curve, when the total stress reaches 200 kPa, the value of vertical strain changed from (1.75%) to (2.3%) and the collapse potential was decreased to 1.537%.

Figure 9 presents single collapse test result on saturated gypsum soil samples treated with 2% of nano silica where the vertical strain value is changed from (2.2%) to (4.8%) because under the stress 200 kPa the collapse potential was decreased to 2.45%.



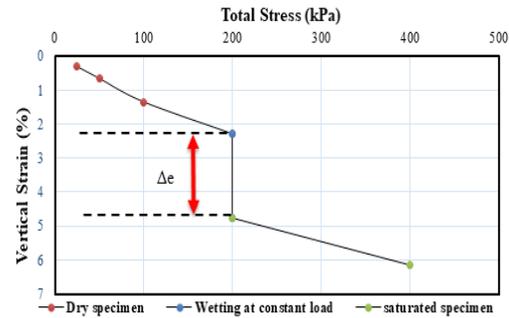
**Figure 7.** Collapse test results on the gypseous soil treated with 0.5% Nano silica



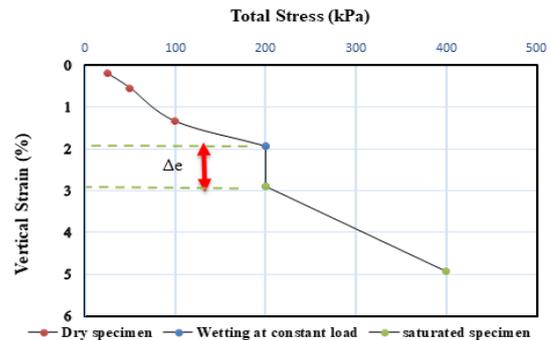
**Figure 8.** Collapse test results on the gypseous soil treated with 1% Nano silica

Figure 10 presents result of single collapse test on the saturated gypseous soil treated with 3% of Nano silica. The collapse potential is equal to 0.945% as a result to adding a constant stress of 200 kPa which makes the vertical strain change from (1.9%) to (2.8%).

Table 2 summarizes the results of collapse test on treated samples. The table reveals that the gypseous soil collapse potential decreases by about 9.7%, 60% and 73.8% when the soil is mixed with 2.5, 5 and 10% Nano clay. While the decrease of CP by about 73.8% required adding only 3% of Nano silica.



**Figure 9.** Collapse test results on the gypseous soil treated with 2% Nano silica



**Figure 10.** Collapse test results on the gypseous soil treated with 3% Nano silica

**TABLE 2.** Results of single collapse test

Without treatment	Treated with Nano-clay					
	CP (%)	% change in CP	CP (%)	% change in CP	CP (%)	% change in CP
3.6	2.5		5		10	
	3.25	9.027	1.44	60	0.945	73.8
3.6	Treated with Nano-silica					
	CP (%)	% change in CP	CP (%)	% change in CP	CP (%)	% change in CP
3.6	1		2		3	
	1.537	57.3	2.45	32.0	0.945	73.8

After full inundation of collapsible soil, the cementing bonds between particles get broken, and the remaining shear strength is derived from the inter-granular frictional forces. Consequently, the angle of internal friction can be utilized as an adequate measure of shear strength [9, 10]. In addition, nanomaterials provide another type of bond that resists inundation of collapsible soil, it is added to cohesion of soil particles.

## 5. CONCLUSIONS

In this paper, some of the experiment work was performed on collapsible soil mixed with different percentages of nano-clay and nano-silica fume stabilizers, to investigate the collapse potential (CP). The following conclusions may be written:

1. Nano-clay; when increasing the additive nano-clay to the soil sample, a decrease in (CP) was obtained.
2. The increment of the nano-clay leads to decrease in the collapse potential (CP) as a ratio of (73.75%) and this means that the additive modifies the soil to no problem case.
3. When adding the nano-silica to the soil, the collapse potential (CP) is decreased whenever the nano-silica increases until 1% of the added nanomaterials and then further stabilizer increases the (CP), the percent of decrease in CP is about 91% where the effect of the additive (nano-silica) changes the classification of severity of collapse from "moderate trouble" case to "no problem" case.

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## Persian Abstract

### چکیده

بررسی تأثیر استفاده از نانومواد برای بهبود و تثبیت بررسی تأثیر استفاده از نانومواد برای بهبود و تثبیت خاک گچ با استفاده از کارهای آزمایشگاهی انجام شد. خاکهای گچی از محلی از بهار النجف جمع آوری و با دو نوع نانومواد (نانو سیلیس و ، نانو رس) مخلوط شدند که در آن نانومواد به مقدار درصد به عنوان درصد وزن خشک خاک اضافه می شوند. نمونه آزمایش هایی برای تعیین تحلیل غربال، وزن مخصوص و پتانسیل فروپاشی انجام شد. نتایج حاصل از آزمایش آزمایشی اصلاحات قابل توجهی در خصوصیات ژئوتکنیکی نمونه خاک نشان داد. پتانسیل فروپاشی به محض افزایش نانومواد مورد استفاده کاهش می یابد تا رسیدن به درصد و در نتیجه پتانسیل فروپاشی افزایش می یابد. بنابراین، افزودن نانومواد، حتی با درصد کمی، می تواند باعث بهبود خواص خاک گچی شود. با افزودن نانو سیلیس به خاک، هرگاه نانو سیلیس افزایش یابد تا ۱٪ از نانومواد اضافه شده افزایش یابد و سپس تثبیت کننده بیشتر باعث افزایش (CP) شود، پتانسیل فروپاشی (CP) ۹۱٪ کاهش می یابد، جایی که اثر افزودنی (نانو سیلیس) طبقه بندی شدت سقوط را از پرونده "مشکل متوسط" به پرونده "بدون مشکل" تغییر می دهد.