Mitigation of Collapse of Gypseous Soil by Nano-Materials

Bushra S. Albusoda[1], Rosul A. Khdeir[2]

[1]Professor, College of Engineering, University of Baghdad Iraq

[2]M.Sc. Student, College of Engineering, University of Baghdad Iraq

Abstract: ***The objective of this study is to investigate the effect of fly ash and silica fume as nano-materials on the collapsibilityof disturbed gypseous soil brought up from Salah El-Deen Governorate with gypsum content (58%) collected at depth (1.0) m below the natural ground surface. Gypseous soil is a problematic soil due to its high-water sensitivity. In dry state, this soil shows relatively high apparent strength; however, when water flows through it or saturated by rainwater, the gypsum in these soils are leached out, so there are many problems can be occurred to the structures that built on making them prone to subsidence. Since permeability and chemical composition of these soils are varying in time due to the solubility and leaching of gypsum. Therefore, the properties of this type of soils must be studied and improved. The effect of adding fly ash and silica fume on collapsibility of gypseous soil using three crushed percentages (1, 2, and 4) % by weight of the dry gypseous soil were studied. The results of single collapse tests marked that (2) % of fly ash and (4) % of silica fume decreases the collapsibility sharply; more than 83 % of improvement in collapse potential has been achieved at these optimum percent of fly ash asnano-material.***

Keywords: Gypseous soil, nano-materials, collapse potential

1. Introduction

The term "Gypseous soil" is used to identify soil that contain gypsum. This soil is considered collapsible soils mostly found in arid and semi-arid regionsand it is a very hard material when it is in dry state due to the cementation effect of gypsum. However, upon wetting, due to partial or complete saturation of the soil, soluble substances dissolve and the binders between particles will be broken, that will cause great losses in strength and sudden increase in compressibility of the soil under the footing, thus sudden collapse of structures will occur [1].Gypseous soil is one of the problematic soils. Therefore, it is necessary to study the geotechnical properties of such soils and improving these properties due to the large damages that affect the structures constructed on or in it.

A method to reduce damage magnitude caused to the structure is excavate and replacement of some part or the whole of the soil. Also, several methods are applied to improve the soil. The improvement of gypseous soils means decreasing the effect of water on these soils to ensure the safety and stability of the engineering structures. Thistreatment can be achieved chemically or physically. The physical improvement means that the soil properties are improved by using mechanical methods, such as compaction, stone columns, pre-wetting, dynamic compaction, etc**,** [2-5] respectively while the chemical improvement means that the soil properties are improved with some chemical additives, such as dehydrate calcium chloride, cement, lime, bentonite, cutback asphalt, etc [6],[9-12]respectively. Soil improvement by reinforcement using geogrid and replacement by dune sand are another method of improvement, [7-8].Soil Mixing is a soil improvement technology used to treat soils in situ to improve strength and reduce compressibility and collapsibility. The use of soil mixing methods for providing stabilization to soils. The choice of method is often based on design requirements, site conditions/restraints and economics. The need was appeared for more applicable, durable and fast method to improve the collapsibility of gypseous soil. A new method was proposed in this study to improve the collapsibility of gypseous soil by nano-materials.

The nanotechnologies idea was suggested by Richard Feynman for the first time in 1959, with this sentence "There's plenty of room at the bottom" [13]. After that, this technology developed in all branch of sciences. Different descriptions of this technology exist in the literature. However national pioneers of nanotechnology in United States have presented a comprehensive definition of this technology (NNI 2007):

1) Research and technology development at the atomic, molecular, or macromolecular levels, at a length scale of approximately 1 to 100 nanometers (a nanometer is onebillionthof a meter, too small to be seen with a conventional laboratory microscope);
2) Creation and use of structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size, at the level of atoms and molecules;
3) Ability for atomic-scale control or manipulation Mixture of soil with some special additive could improve the soil strength parameters, and this procedure has been performed in the past for stabilization and improvement of weak soils. The main strategy of nanotechnology in geotechnical engineering is the improvement of soil parameters with application of nano-materials. The presence of only small amount of nano-material in the soil could influence significantly the physical and chemical behavior of soil due to a very high specific surface area of nano-materials, surface charges and their morphologic properties.

The present article investigates the effect of using coal fly ash and silica fume, as improving nano-materials, on the behavior and the characteristics of soil represented by its physical properties, collapsibility and compressibility.

2. The Materials Used

2.1 Gypseous Soil

The soil used in this study is a disturbed natural gypseous soil was brought from one location at Salah El-Deen Province with a gypsum content of 58% extracted from a depth of (1.0)m below the natural ground surface and packed in double nylon bags. Then, it was air dried, pulverized and mixed thoroughly. After that, the soil becomes homogenous and ready for testing. A laboratory testing program was conducted to aid classification and to evaluate the physical, mechanical, & chemical properties of the soil.

2.1.1 Physical TestsOfGypseous Soil

The specific gravity of the soil is determined according to the British standards (BS 1377: 1975, Test No. 6 B), but ‘‘Kerosene’’ was used instead of water due to the dissolution action of gypsum in water. The grain size distribution illustrated in figure 3 was determined by sieve analysis test, which is conducted in accordance with (ASTM D422) with dry sieving.

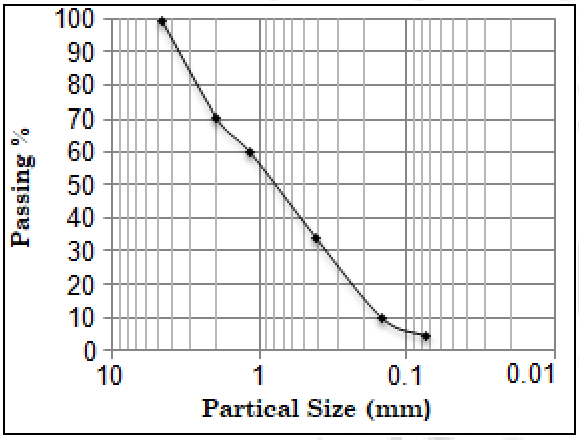


Figure 3: Grain size distribution

The maximum and minimum densities were conducted according to Procedure recommended by Bowles (1986) and water content were performed in accordance with (BS 1377: 1990, Test (A); Head (1980). The water content was determined at drying temperature of (45°C) in order to overcome gypsum dehydration thus preventing the loss of crystal water is required, Head (1980).

The grain size distribution curve of the soil sample is shown in figure 3. The figure clearly shows that the soil sample is classified as poorly graded sand (SP) according to Unified Soil Classification System (USCS). Thus, the soil has no consistency limits (liquid and plastic limits).

2.1.2 Chemical Tests

Some of chemical tests are carried out on the soil. These tests included: gypsum content determined by using the hydration method recommended by [16].

This method consists of oven drying the soil at (45°C) until the weight of the sample becomes constant. The weight of sample at (45°C) was recorded. After that, the same sample is dried at (110°C) until the weight becomes constant and recorded.

The gypsum content was calculated according to the following equation (1).

$$X\ (\%) = \frac{(W45°C - W110°C)}{W45°C} \times 4.778 \times 100 \quad (1)$$

Where:
χ = Gypsum content (%)
$W_{45°C}$ = Weight of the sample at (45°C)
$W_{110°C}$ = Weight of the sample at (110°C)
All results of chemical and physical properties of the tested natural soil are summarized in Table 1.

Table 1: Results of physical and chemical properties tests of gypseous soil

Physical and Chemical Property	*Value*
Specific gravity	2.47
Passing sieve #200(%) Dry Kerosene Water	 4.61 8.43 17.21
Maximum density (gm/cm^3)	1.269
Minimum density (gm/cm^3)	1.001
Maximum void ratio (-)	1.46
Minimum void ratio (-)	0.94
Relative density (%)	60
Effective particle size (mm)	0.17
Soil classification (USCS)	SP
Gypsum %	58
PH	7.24
EC(µS/ cm)	2.22

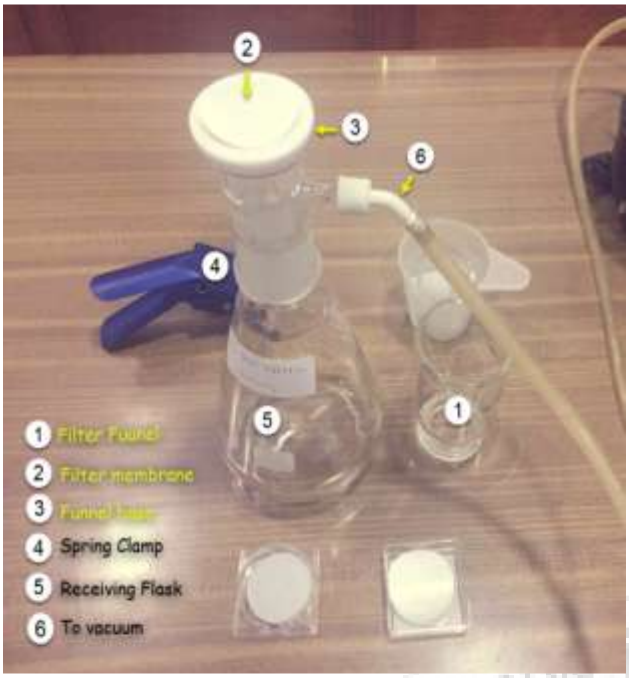
2.2 Nano-Materials

The fly ash (FA) used for the study came from the local market. Table 2 shows the chemical and physical properties of the fly ash (FA) used. Based on the chemical composition [SiO_2 (53.21%), Al_2O_3 (22.5%), CaO (4.6%), MgO (1.7%), K_2O (1.98%), Fe_2O_3(5.70%)].fly ash classifies as Class F (ASTM C618, 2008). Chemical composition of the materials was used in this study, determined via X-ray fluorescence.

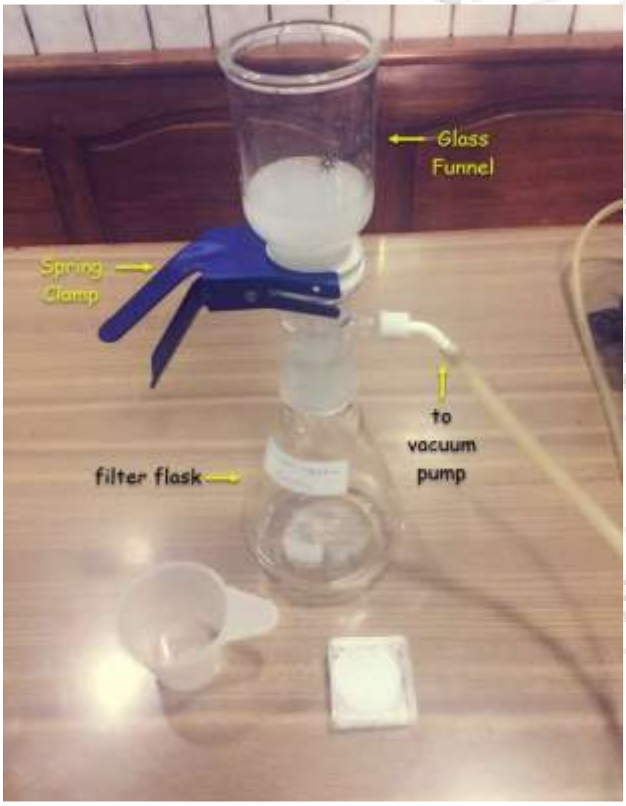
The other material used in this study was silica fume (SF), which was supplied by a commercial provider. Fly ash and silica fume were filtered via. Millipore filter to obtain these materials as nano-materials.

2.1 Millipore Filter

Millipore filter technique is an effective and accepted technique for preparing nano-materials. It involves less preparation than many traditional methods. The Millipore filter shown in figure 1(a and b) consist of funnel, filter support grid, anodized aluminum assembly clamp, base and cap with Pyrex lateral tubing, 1liter vacuum vial with ground neck.



(a)



(b)

Figure 1 (a and b): Millipore filter system

Membrane filters with 50mm diameter Shawn in figure 2 have a known uniform porosity of predetermined size (0.45 µm) sufficiently small to trap nanoparticles.Using the membrane filter technique, sample is passed through the membrane using a filter funnel and vacuum system.

Figure 2: Membrane filter

- The membrane filter was placed onto the center of the filter holder support base, grid side up, using forceps that have been cleaned with alcohol wipes. Membrane filtering should be placed in the middle before using in case of possible leakage.
- Clamp funnel was placed into position.
- Suspension was poured into the assembled filtration device. Exact amount will depend on the density of the suspension, and grain size of the particles into funnel (100mL of sample is ideal).
- The vacuum was turn on that allow the liquid to draw completely through the filter.
- Each part of the entire assembly should be cleaned before use. Pure water was used for initial cleaning and distilled water for the second wash.

Table 2 Chemical composition and physical properties of the materials used in this study

Wt. %	FA	SF
SiO_2	53.21	92.30
Al_2O_3	22.5	2.03
Fe_2O_3	5.70	1.05
CaO	4.60	0.45
MgO	1.70	0.53
K_2O	1.98	0.04
SO_3	1.11	0.41
Physical properties		
Particle size(µm)	<0.45	<0.45
Specific gravity	2.36	2.23
Specific surface area (gm/m^2)	12.8	9.52
Color	gray	Light gray

3. Experimental Work

3.1 Mixing Method

In order to match the proper conditions and increasing the accuracy of test results, amounts of additives used to prepare mixtures of different combinations are taken on the basis of percentage by dry weight of the soil. Primarily, a desired amount of fly ash or silica fume is mixed thoroughly with the soil to get a uniform mixture. A predetermined quantity of chemical additives is added to the soil–fly ash and mixedthoroughly in dry state until the mixture appears uniform in color and texture. After that, a desired amount of distilled water is added and it is remixed again thoroughly. The untreated and treated samples are kept for curing up to 48 to ensure a uniform distribution of moisture throughout the soil mass and further experimental procedures have been performed after completion of curing period. Similar procedures for sample preparation have been followed by several researchers.

3.2 Collapse test

Consisting of six mixtures which were prepared from various percentages of fly ash and silica fume and added to the natural gypseous soil samples in order to perform the testing program. The percentages of silica fume and fly ash are 1%, 2% and 4%, by dry weight of soil, choosing these values depended on numerous references that stated and specified. The mixed samples were determined by single collapse (or single oedometer) test using oedometer cell and the procedure test is according to [17] and ASTM D5333, 2003. The soil samples with 75mm diameter and 19mm thickness. This method is similar to the standard odeometer test except that the porous stones were dry as well as the specimens. The stresses were doubled every 24 hrs up to the desired stress (200 kPa). In this test, vertical static load increments were applied at regular time intervals (24 hr) and the pressure load was doubled with each increment up to the required maximum (12.5, 25, 50, 100, 200, 400 and 800 kPa). After the application of a stress of 200 kPa and waiting for 24 hrs, distilled water was added to the cell and left for 24 hrs. The additional thickness changes (ΔH) were recorded. The collapse potential (Cp) is calculated using equation (2).Table 3 shows The severity problem of collapse potential. Finally, it should be stated that in all types of tests performed a seating load 1kPa was used at the beginning of each test to ensure elimination of any gaps between the specimen and the porous stones or the confining ring.

$$C.P = \frac{\Delta e}{(1+eo)} \quad (2)$$

Where:
C.P = Collapse Potential
Δe= void ratio before and after soaking
eo= Initial voids ratio

Table 3: The severity of collapse potential at 200kPa stress level after [18]

Collapse Potential (%)	Severity Of Problem
0	No problem
0.1-2	Slight
2.1-6	Moderate
6.1-10	Moderately severe
>10	Severe

4. Results and Dissection

4.1 Collapse Test

The results of single Oedometer collapse test can be shown in Table 4 and Figure (4-8) the addition of silica fume (or fly ash) as nano-materials led to a reduction in collapse potential and increasing dry unit weight depending on the added improving material quantity.As shown in Fig.4 The collapse potential (C.P) decreased from 13.6% to 2.16% with increase in the silica fume percentage to 4%, by soil dry weight, and decreased to 1.29% with increase fly ash percentage to 2%. This behavior is attributed to the high surface area and pozzolanic activity of silica fume and fly ashaffected the particle orientation which acts as a cohesive bond between soil particles and to provide a water proofing coat around the gypseous soil particles.

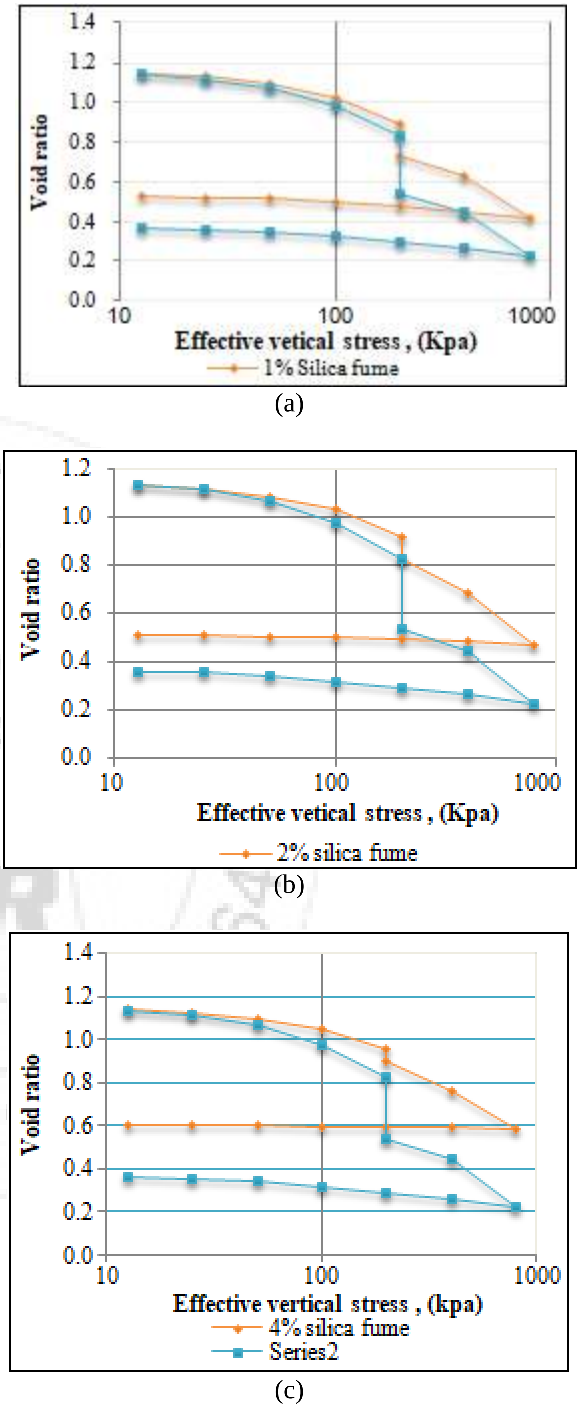
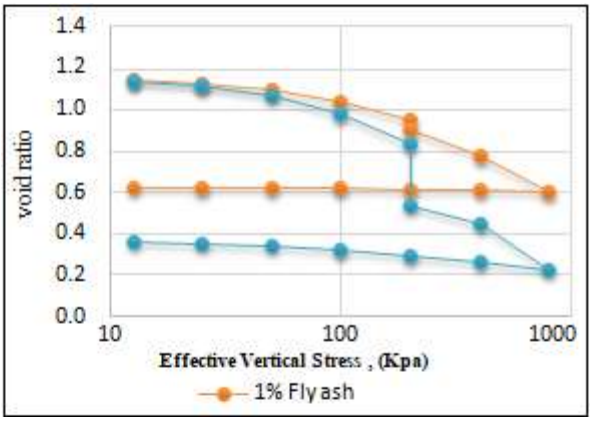
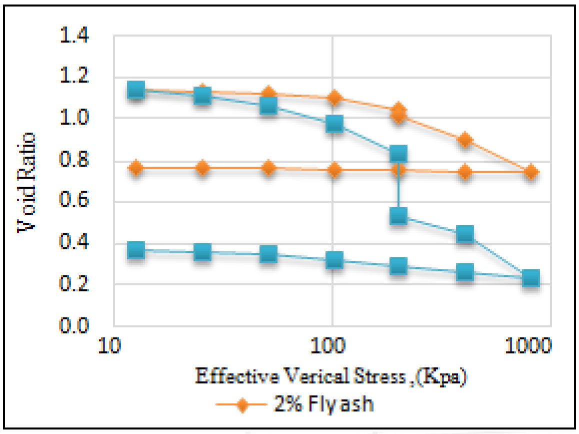


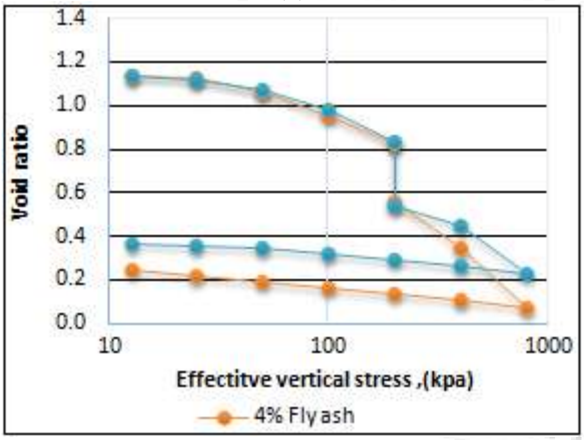
Figure 4(a, b and c) : single collapse test of gypsous soil treated by silica fume



(a)



(b)



(c)

Figure 5 (a, b and c) : single collapse test of gypsous soil treated by fly ash

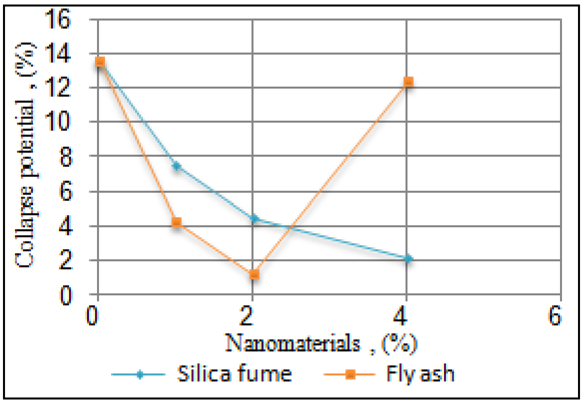


Figure 4: The relationship between collapse potential and percent of nano-materials

The results also indicate large quantities of fly ash in the mixture, due to agglomerate effect, lead to increase the collapsibility of the soil. The combination of soil and nano-materials is very sensitive and the amount and type of nano-materials added to the soil could have both positive and negative impact on desired attributes and using an appropriate percentage of nano-materials would result in the improvement of soil specifications[19]. The improvement results showed that the optimum percentage of fly ash and silica fume for collapse potential reduction was (2%& 4%) respectively.

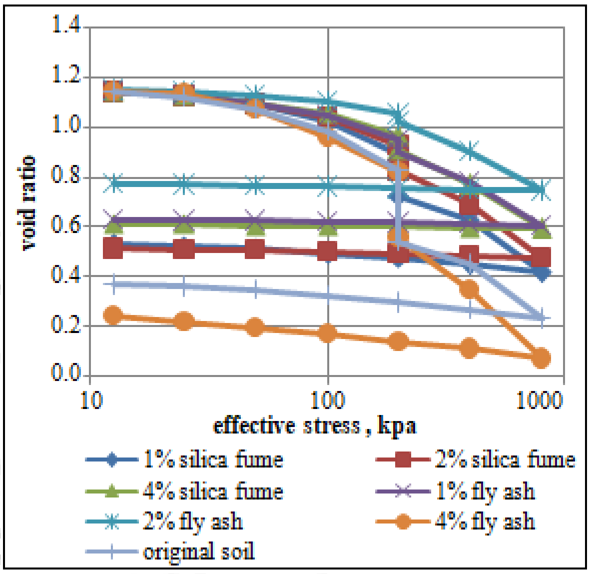


Figure 7: Single collapse test of gypsous soil treated by silica fume and fly ash

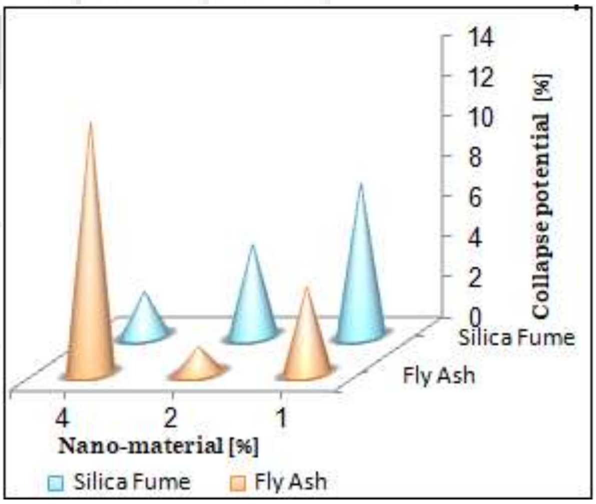


Figure 8: Comparison of the effect of nano-materials on the collapse potential

4.2 Micro structural studies

Scanning Electron Microscopy (SEM) images of natural soil and varying combinationsof natural soil treated with different percentage of fly ash and silica fume shown in **Fig. 9 and fig.10(a–c)**. It is clearly observed that fly ash and silica fume have a significant impact on the microstructure of treatedsoil with fly ash. The SEM images confirmed theenhancement in cementations compounds with samples improved by (2% fly ash and 4% of silica fume) which represent the optimum percentages.

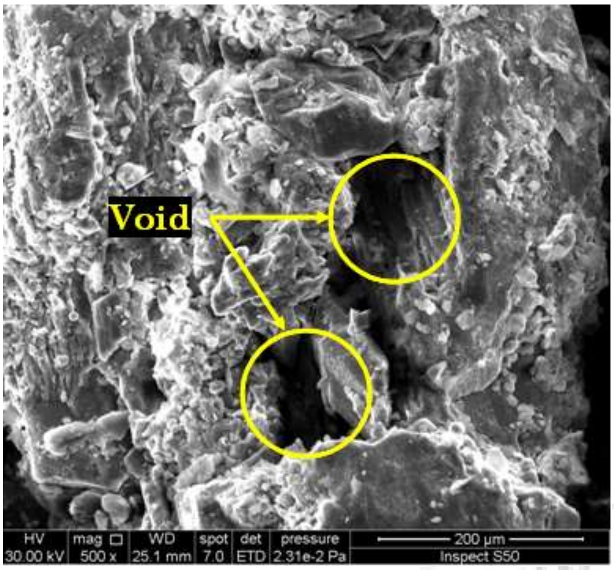
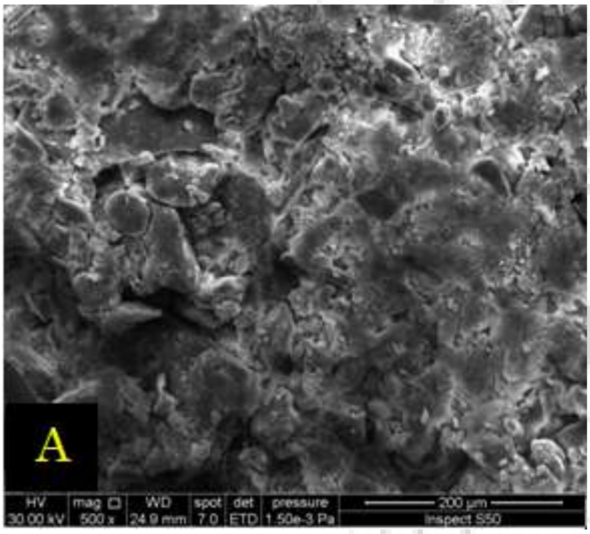
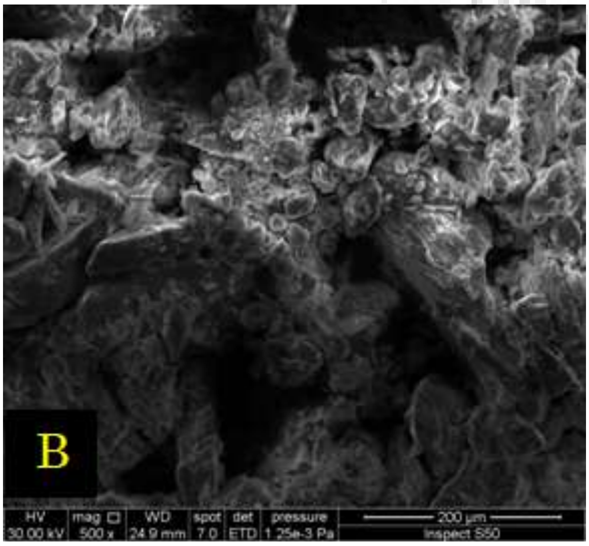


Figure 9: Scanning electron microscope micrographs of natural soil.





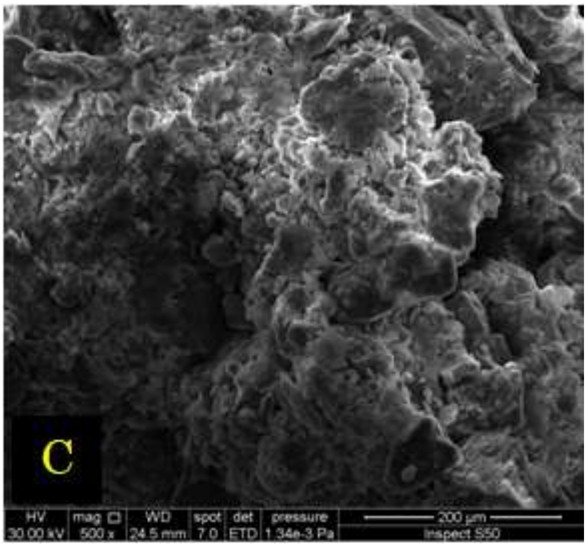


Figure 10: Scanning electron microscope micrographs of A) 2 % fly ash, B) 4% fly ash and C) 4% silica fume.

5. Conclusions

- The collapse potential is reduced with increase of nano-materials percent. The lowest collapsible potential was obtained when the gypseous soil was improved with fly ash.
- The specific surface is The important parameter in regard to nano-material . As can be seen, the fly ash had a larger specific surface in comparison to the silica fume hence showing a more considerable reduction of collapse potential with its addition to the soil. However, this parameter can have a negative effect too. Therefore, in the combination of (4) % fly ash with gypseous soil, collapse potential was increased . the most appropriate percentage should be used. The addition of nano-materials to more than the optimum value causes the agglomeration of particles, thereby leading to negative side effects on the mechanical properties of the gypseous soil.

References

[1] Al-Mohammadi, N.M., Nashat, I.H. and Bake, G.Y., 1987. Compressibility and Collapse of GypsiferousSoils ,6th Asian Conference on Soil Mechanics, Tokyo.

[2] Al-Khafaji, A.,1997. Densification of Gypseous Soils by Compaction, Ground Improvement Geo Systems London, pp: 96-102.

[3] Al-Barzanji, A.F. 1973, Gypseous Soils of Iraq, Ph.D. thesis, Dissertation, Ghent University, Belgium.

[4] Abid –Awn, S. H., 2011.Improvement of gypseous soil by Pre-wetting, Diyala Journal of Engineering Sciences, Vol 04,No.01, pp:71-82.

[5] Al-Saffar, Q. N. , 2014 Improving The Engineering Properties of The Gypseous Soil Using Dynamic Compaction Method, AL Rafdain Engineering Journal, Volume 22, pp: 109-122.

[6] Al-Busoda, B. S., 1999.Studies on the Behavior of Gypseous Soil and Its Treatment during Loading, M.Sc. Thesis, Civil Eng. Dept. University of Baghdad. pp11-25.

[7] Albusoda, B.S. and Salman, R. 2013 BearingCapacity of Shallow Footing on Compacted Filling DuneSand Over Reinforced Gypseous Soil, Journal ofengineering, Volume 19, No. 5, pp 532-542.

[8] Albusoda, B.S. and Hussein, R.S. 2013 Bearing Capacity of Eccentrically Loaded Square Foundation on Compacted Reinforced Dune Sand over Gypseous Soil, Journal of Earth Sciences and Geotechnical Engineering, Volume 3, No. 4, pp 47-62.

[9] AL-Numani,Huda N. T. ,2010. Improvement of the mechanical properties of gypseous soil by additives, Al-Qadisiya J. Eng. Sci., vol 3(3), pp: 287-296.

[10] Al-Zubaydi, Abdulrahman H. T., 2011 , strength and erosion of lime stabilized gypseous soil under different flow conditions, Al-Rafadain Engineering Journal . 2011, Vol. 19 Issue 2, p12-28.

[11] Karim, H. H., Schanz, T. and Nasif, M. H., 2013, Study Shear Strength Characteristics of Gypseous Sandy SoilUsing Additives, Eng. &Tech. Journal, Vol. 31, No.8,PP 1431-1446.

[12] Shakir,zainab H., 2017.Improvement of Gypseous Soil Using Cutback Asphalt, Journal of Engineering, vol.23 No.10 , October 2017,pp:44-61.

[13] Feynman. R., 1960. There's plenty of room at the bottom, reprint from speech given at annual meeting of the American Physical Society. EngSci;23:22–36.

[14] Bowles, J. E.,1986, Engineering properties of soils and their measurement, Mc Graw-Hill Book Co., New York.

[15] Head, K. H. , (1980), "Manual of Soil Laboratory Testing", Vol 1, Prentch, press, London.

[16] Al- Mufty, A. A. and Nashat, I. H . , (2000) , Gypsum content determination in gypseous soils and rocks, 3rd International Jordanian Conference on Mining, pp. 500-506.

[17] Jennings, J.E., and Knight, K. ,1957.The Additional Settlement of Foundation Due to a collapse of Structure of Sandy Subsoil on Wetting, Proceedings of 4th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, PP:316-319.

[18] Jennings JE, Knight K (1975) The additional settlement of foundation due to collapse of sandy soils on wetting, Proc 4th Inter Conf on Soil Mechanics and Foundation Engineering, PP:316–319.

[19] Iranpour,B. and haddad, A.,2016.The influence of Nano-materials on collapsible soil treatment, Engineering Geology.