Housing & Building National Research Center
Izhevsk State Technical University (ISTU)
12th International Conference on
NANO-TECHNOLOGY for
GREEN and SUSTAINABLE CONSTRUCTION
المؤتمر الدولى الثانى عشر لتكنولوجيا النانو
فى الإنشاء الأخضر والمستدام
(NTC 2020)
27-31 March, 2020, Sharm El-Sheikh, Egypt
Egyptian -Russian University (ERU)
الجامعة المصرية الروسية
Ministry of Housing, utilities & urban Communities

On the use of Nanoclay to improve the swelling properties of expansive soils

Mohamed A. Sakr[1], Wasiem R. Azzam[2], Mohamed A. Meguid[3] and Hebatalla A. Ghoneim[4]

[1]Professor of Geotechnical Engineering, Faculty of Engineering, Tanta University, Egypt
E-mail: mamsakr@f-eng.tanta.edu.eg
[2]Professor of Geotechnical Engineering, Faculty of Engineering, Tanta University, Egypt
E-mail: wassim.azzam@f-eng.tanta.edu.eg
[3]Professor of Geotechnical Engineering, Faculty of Engineering, McGill University, Canada
E-mail:mohamed.meguid@mcgill.ca
[4]Research Student, Geotechnical Engineering Research Laboratory, Tanta University, Egypt
E-mail: hebatalla_ghoneim@f-eng.tanta.edu.eg

ABSTRACT
Expansive soils are recognized as problematic soils that impose several challenges for civil engineers. Such soils undergo significant volume change when water penetrates into them, and shrink as they lose moisture. Lightly-loaded engineering structures such as pavements, single story buildings, railways and walkways may experience severe damages when they are founded on such soils. Investigating expansive soils and quantifying their swelling potential and pressure caused by their deformation are essential in geotechnical engineering. In this study, expansive soil specimens were tested in the laboratory using bentonite as swelling soil. XRD tests, free swell tests, compaction, and swelling pressure of the mixtures were performed. The effect of using Nanoclay to stabilize the swelling soil was studied through laboratory investigation. Test results showed that Nanoclay can considerably decrease the swelling potential of the soil from 410 kN/m^2 to nearly 315 and 300 kN/m^2 at Nanoclay content of 1 % and 3 %, respectively. Meanwhile, adding 1% and 3% Nanoclay, the free swell significantly decreased by as much as 48% and 57%, respectively. This demonstrates the effectiveness of the proposed Nanoclay as a material to be used in stabilizing and improving the swelling soils. This technique can be used in different civil engineering construction projects including foundations and road embankments.

Key Words
Nanoclay, stabilization, expansive soil, swelling potential and free swell.

INTRODUCTION
Swelling soil is the generic description of all soils containing montmorillonite mineral. Swelling soil deposits are mainly found near the arid areas of Egypt including the regions extending around the Nile valley in Upper Egypt [1]. The mitigation of the effects of expansive soil on engineering structures became quite a challenge to the designer of substructures supported on this type of soil. Therefore, the swelling and shrinking characteristics of the soil on which engineering structures are designed must be considered. The annual damage caused by expansive soils costs about $1 billion in the USA, £150 million in the United Kingdom and billions of pounds all over the world [2]. Several classifications based on parameters such as plasticity index, liquid limit, and clay content have been proposed in the Egyptian code of practice as indicators of the soil swelling behavior. Direct measurement of the swelling potential using laboratory and/or field tests, is essential once a soil showed indications of swelling response. Treatment methods such as soil replacement, compaction control and chemical stabilization showed significant reduction in the swelling

potential. The choice of the appropriate method depends on the depth of the soil, type of structure to be built and the cost and practicality of the method. In this paper, the effect of using a cheaper available material like Nanoclay to stabilize the swelling soils is investigated through a laboratory study. The conducted tests include free swell, swelling pressure, compaction and XRD tests on the swelling soils stabilized with different percentages of Nanoclay.

MATERIALS USED AND EXPERIMENTAL TESTING PROGRAM

Soil samples

The soil samples used in this research were obtained from Bentonite and Derivatives Company in Borg Al- Arab, Alexandria, Egypt, which presents the swelling soil in a homogenous phase. The main properties of the adopted samples are summarized in Tables (1 and 2).

Nanoclay

The used additive for treating expansive soil is a commercial material known as Nanoclay (NC). The main properties of the used Nanoclay are illustrated in Tables (3 and 4).

TESTING METHODOLOGY

The bentonite presents the swelling soil in a homogenous phase. The preparation of reconstituted samples is an important step so that a homogenous mixture is formed. The main principle is to prepare a reconstituted soil sample with a certain additive content under controlled conditions, and then compact it to a certain dry unit weight (80% of maximum γ_{dry}) [3] in the oedometer cell or in the direct shear box. The compaction tool is presented in Fig. (1), as described by several investigators [3-7]. It is composed of a disc fixed to a rod with a load of 136 gm slides alongside of the rod, falls from 150 mm height and comes to strike the disc to compact the materials.

Table 1: The properties of the used bentonite (according to the manufacturer's data sheet)

Mineralogical properties	Quartz (%)	40
	Montmorillonite (%)	40
	Kaolinite (%)	16
	Others (%)	4
Chemical properties	SiO_2 (%)	61
	Al_2O_3 (%)	14.59
	Fe_2O_3 (%)	2.09
	TiO_2, SO_2, Cl, BaO (%)	< 0.5
	CaO, K_2O (%)	0.77
	MgO (%)	2.22
	Na_2O (%)	2.04
	Loss of ignition, LOI (%)	13.20

Table 2: Properties of the used bentonite

Property	Value
Free swell index (%)	501.98
Density, γ (kN/m³)	10.69
Liquid limit, L.L. (%)	331
Plastic limit, P.L. (%)	36
Plasticity index, P.I. (%)	295
Specific gravity, G_s	2.6
Initial average water content, W_c (%)	10

Table 3: The properties of the used Nanoclay (according to the manufacturer's data sheet)

Appearance (color)	Creamy
Appearance (form)	powder
Aspect ratio	300 - 500
Specific Gravity, G_s	2.6
Particle size (nm)	25-50

Table 4: Properties of the used Nanoclay

Property	Value
Free swell index (%)	0.0
Density, γ (kN/m³)	9.22
Liquid limit, L.L. (%)	70
Plastic limit, P.L. (%)	36
Plasticity index, P.I. (%)	34

Therefore to prepare the Bentonite - additive mixture; first, the samples were oven dried at 105°c, weighted according to the maximum dry unit weight of the soil and the chosen percentage of additive, and then physical mixing for 10 minutes to each portion was adopted. Then, the weighted amount of soil is compacted using the tool described previously in two layers with the same energy (20 blows/layer). The tested sample is levelled inside the ring of the oedometer cell or in the direct shear box taking into consideration keeping a flat upper surface.

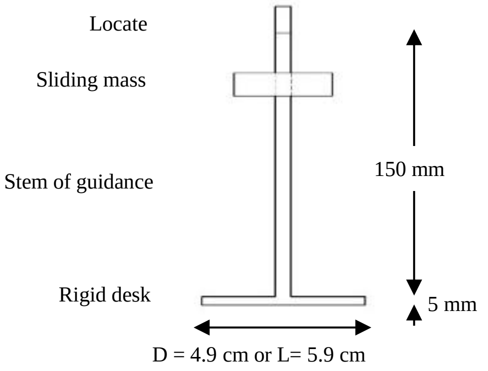

Fig. 1: Compaction tool [3-7]

TESTING PROGRAM

The focus of this research was to study the swell potential mitigation of the expansive soil. Other geotechnical characteristics of the soil were also investigated. In this study, the effect of adding Nanoclay on the free swell index, swelling pressure and compaction were investigated in the laboratory. The amounts of Nanoclay added to the expansive soil samples, as a percentage of the dry soil mass were 0.5, 1, 1.5, 2 and 3%.

TEST RESULTS

Influence of Nanoclay Content on the Free Swell Index

The free swell index was calculated as per ASTM 4546 [8]. It was found that the free swell index decreases with increasing the Nanoclay content as shown in Fig. (2) and summarized in Table (5). This behavior can be explained by the fact that Nanoclay fills the voids between soil particles making the expansive soil less capable of swelling.

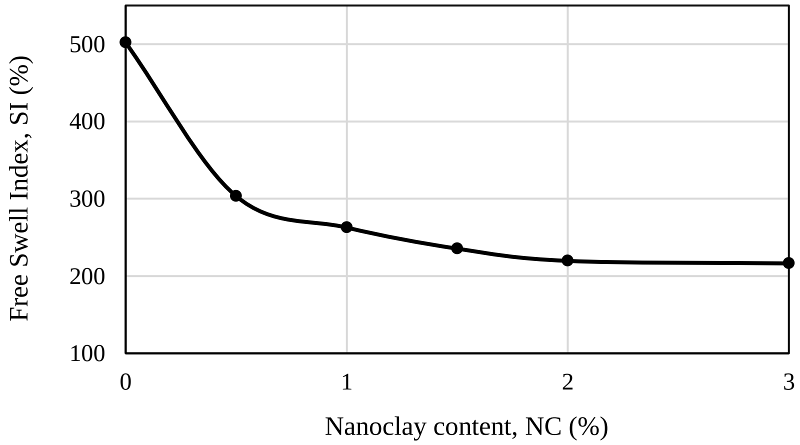

Fig. 2: Relation between free swell index and Nanoclay content

Table 5: % (NC) content and corresponding (SI)

NC content %	SI %
0.0	501.98
0.5	303.37
1.0	262.73
1.5	235.43
2.0	219.59
3.0	216.35

NC: Nanoclay Content; SI: free swell index

Influence of Nanoclay Content on the Swelling Pressure

Swelling pressure tests were performed according to ASTM 4829 [9], and the Egyptian code of practice [10]. It is observed clearly that the addition of Nanoclay (NC) gradually by the percentages mentioned above to the swelling soil samples decreases the swelling behavior of soil. Hence the swelling pressure (Sp) decreases with the increase of Nanoclay content up to 1%, after that the swelling pressure is almost constant. The oedometer test results for different Nanoclay contents are shown in Figs. (3 and 4) and summarized in Table (6). The optimum content for NC is 1% as there is no much change in the swelling pressure after this content. A possible explanation for the enhancement of the free swell index, and the swelling pressure is that the Nanoclay particles will settle within the soil intra-particle voids. By adding water, the Nanoclay particles, which has a high affinity to water by its nature, will absorb most of the water thus preventing it from interacting with the soil particles. Most of the increase in volume due to water addition will be within the intra-particle voids as Nanoclay particles will stay within the soil intra-particle voids. So, the rest of water reaches the soil particles causing the soil to expand a little. These results are in conformity with the results obtained by Sharo and Alawneh (2016).

Influence of Nanoclay Content on the Compaction Parameters

According to ASTM 1557 [12], the compaction parameters of the expansive soil stabilized with Nanoclay were determined. It was noticed that increasing the Nanoclay content has a slight effect on the dry density and the optimum moisture content. As shown in Fig. 5, at the low percentages of Nanoclay addition, the maximum dry unit weight of the expansive soil decreased and its optimum moisture content increased as the 1% of Nanoclay addition was not sufficient to complete the soil – Nanoclay interaction during the initial chemical reaction. After that, the dry unit weight and the optimum moisture content of the expansive soil reached their optimum values at 2% Nanoclay content as shown in Figs. (6 and 7). The slight increase in the dry unit weight accompanied by the decrease in the optimum moisture content might be explained by the fact that the volume of the sample decreased and its weight increased as the Nanoclay tied the soil particles together. In addition to that, the Nanoclay particles within the soil samples absorbed the excess water by the exchange of the ions within the expansive soil particles. However, the chosen optimum percentage of Nanoclay addition was chosen to be 1% Nanoclay from the economical point of view as there is no much difference in the values the maximum dry unit weight of the expansive soil when mixed with higher percentages of Nanoclay.

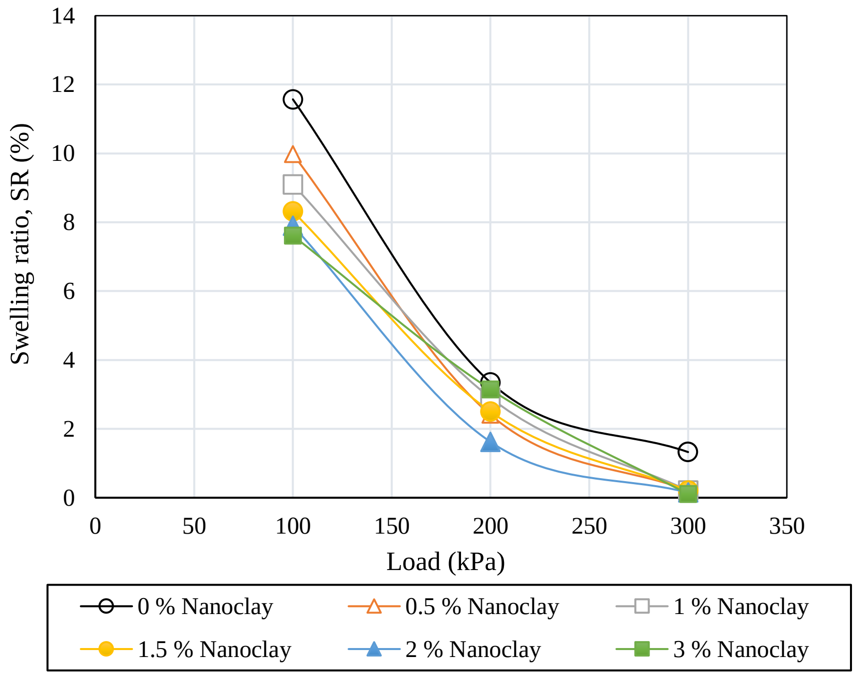

Fig. 3: Relationship between swelling ratio and applied loads on the oedometer cell

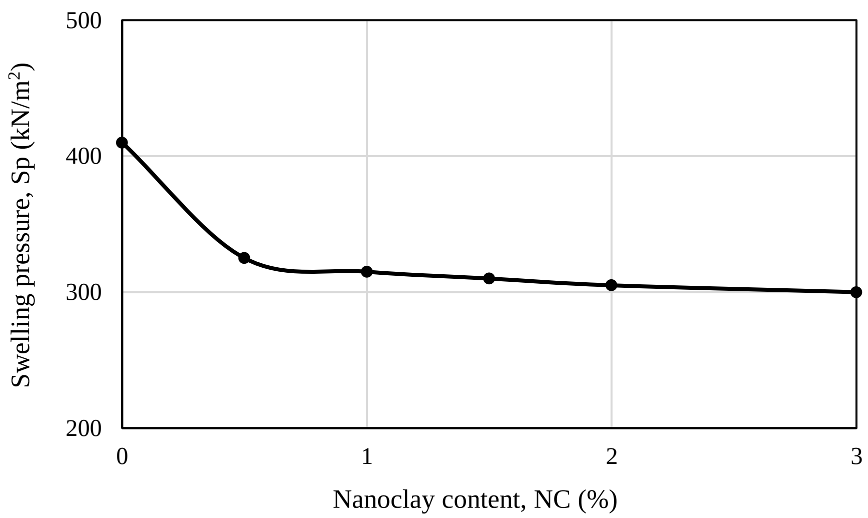

Fig. 4: The relation between Nanoclay content, and swelling pressure

Table 6: % (NC) content and corresponding (S_P)

NC content (%)	S_P (kPa)
0.0	410
0.5	325
1.0	315
1.5	310
2.0	307
3.0	300

NC: Nanoclay; S_p: swelling pressure

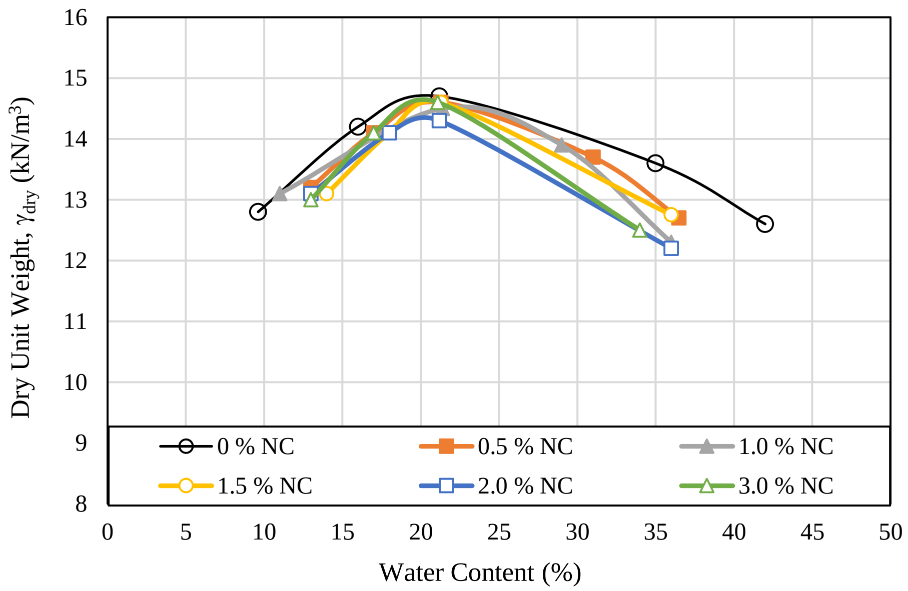

Fig. 5: The relation between dry unit weight and water content for different Nanoclay contents

Influence of Nanoclay Content on the X-Ray Diffiraction Curves of Swelling Soil

It is clear that Nanoclay addition improves the swelling behavior of the investigated expansive soil, though the XRD images for the treated soil with Nanoclay indicated that there is no change in the mineralogical characteristics of the treated soil as shown in Figs. (8 and 9). This is because adding Nanoclay is only physical mixing without any effect on the crystalline structure of bentonite. This result is in agreement with the results observed by Taha and Taha (2012).

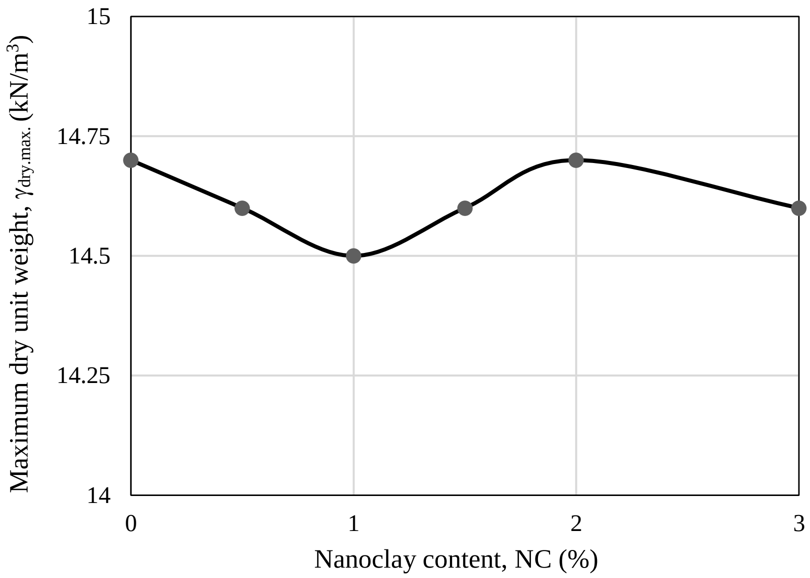

Fig. 6: The influence of adding Nanoclay on the maximum dry unit weight of soil

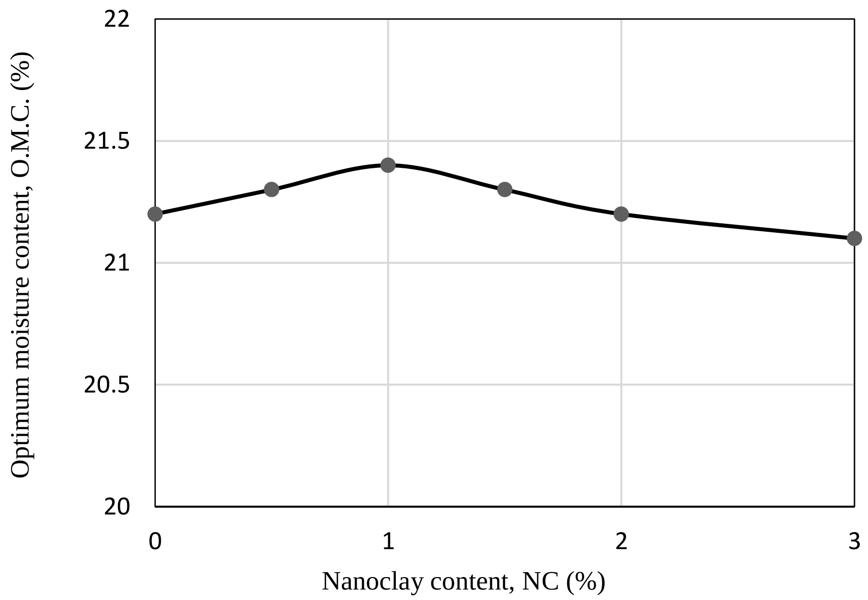

Fig. 7: The influence of adding Nanoclay on the optimum moisture content of soil

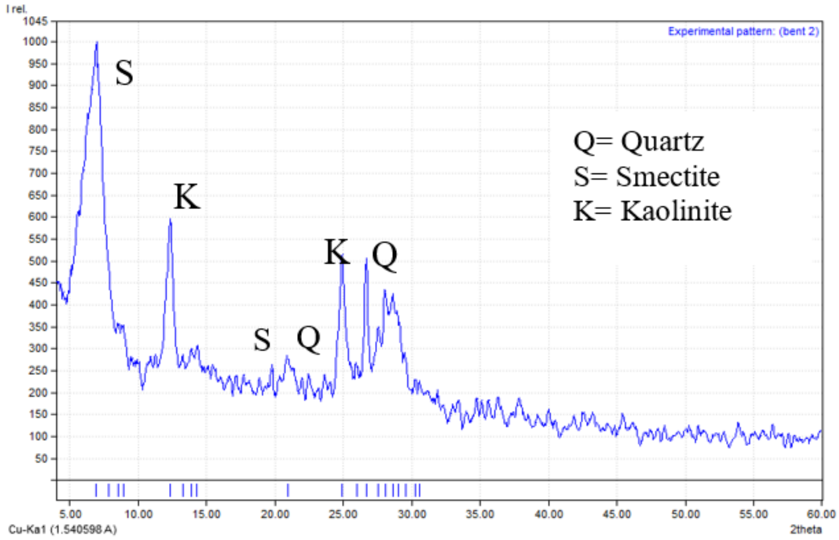

Fig. 8: 2Theta curve of the untreated expansive soil

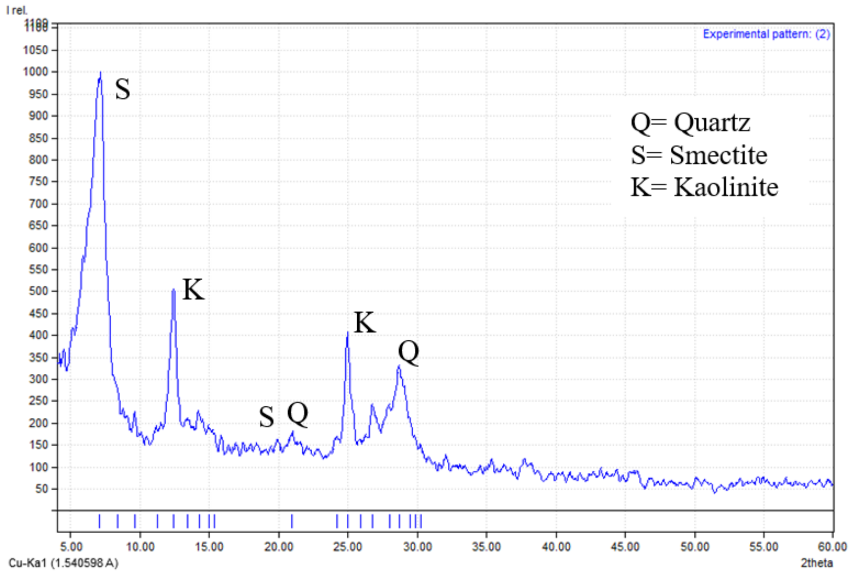

Fig. 9: 2Theta curve of the expansive soil mixed with 1% Nanoclay by dry weight

CONCLUSIONS

A laboratory testing program was performed to study the effect of using Nanoclay on the characteristics of very high swelling soils. The observations and conclusions can be summarized as follows:

• Treatment of swelling soil with Nanoclay showed significantly lower swelling potential and swelling pressure in comparison with untreated soil. Adding 1% and 3% Nanoclay led to a reduction in the free swell index of the tested soil by 48% and 57%, respectively

• Using Nanoclay reduced the swelling pressure from 410 kN/m^2 to 315 kN/m^2 and 300 kN/m^2 at 1% and 3% Nanoclay content, respectively.

• It was noticed that increasing the Nanoclay content has a slight effect on the dry density. The maximum dry density and minimum optimum moisture content are found at 2% Nanoclay content.
• No change was noticed on the X-Ray diffraction curve of swelling soils upon adding Nanoclay
• Based on the test results, it is recommended to use Nanoclay as a cheap, environmentally friendly stabilizer for swelling soil at 1% Nanoclay content.

REFERENCES

1. Elmashad, M. E., “Effect of chemical additives on consistency, infiltration rate and swelling characteristics of bentonite”, Water Science, Vol. 31, No. 2, Pp. 177–188, (2017).
2. Forouzan, A. J., “Prediction of swelling behavior of expansive soils using modified free swell index, methylene blue and swell oedometer tests”, M. Sc. thesis, Middle East Technical University, Turkey, Pp. 135, (2016).
3. Sakr, M. A., Sawaf, M. A., Nazir, A. K., and Rabah, A. K., “Behavior of collapsible soils stabilized with fibers”, Proceedings of the AICSGE 8, Alexandria, Egypt, Pp. 119-129, (2014).
4. Ayadat, T. and Belouahri, B., “Influence du coefficient d'uniformité sur l'amplitude etle taux de l'affaissement des sols”, Revue Française de Géotechnique, in French, (77), (1996).
5. Ayadat, T., Belouahri, B. and Ait Ammar, R., “La migration des particules fines comme approche d'explication du mécanisme de l'effondrement des sols”, Revue Française de Géotechnique, in French, (83), (1998).
6. Ayadat, T., and Benkadja, R., “Influence du mouillage par des hydrocarbures sur le taux d’affaissement des sols”, Revue marocaine de génie civil, in French, (97), Pp. 26-32, (2002).
7. Ayadat, T. and Bellili, F., “Sols susceptibles d'affaissement: identification, mécanismes et traitement”, Revue Algérie – Equipement, in French, (20), Pp.18-23, (1995).
8. Designation: D 4546, “Standard test methods for one-dimensional swell or settlement potential of cohesive soils”, American society for testing and materials (ASTM), Pp. 9, (2008).
9. Designation: D 4829, “Standard test method for expansion index of soils”, American society for testing and materials (ASTM), Pp. 5, (2008)
10. Egyptian code of practice for soil mechanics, design and construction of foundations (ECP 202), “part 5: Foundations on problematic soils”, HBRC, Cairo, Egypt, Pp. 124, (2006).
11. Sharo, A. A., and Alawneh, A. S., “Enhancement of the strength and swelling characteristics of expansive clayey soil using Nanoclay material”, GSP No. 269, Pp. 451–457, (2016).
12. Designation: D 1557, “Standard test methods for laboratory compaction characteristics of soil using modified effort”, American society for testing and materials (ASTM), Pp. 14, (2008).
13. Taha, M. R. and Taha, O. M. E., “Influence of Nano-material on the expansive and shrinkage soil behavior”, Journal of Nanoparticle Research, Vol. 14 (10), Pp. 1 – 13, (2012).