A REVIEW STUDY ON THE OPTIMIZING THE PERFORMANCE OF SOIL USING NANOMATERIALS

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ABSTRACT

Improvement of soil by using Nanomaterial as a technique is essential to enhance the geotechnical properties of soils. In past years, several steps have been taken in the field of geotechnical engineering to improve the properties of the weak soil by using nanomaterial technique. So many investigations have been done using different soil test to know the influence of nanomaterials in soil geotechnical properties. This paper reviews most research done during the last ten years. Therefore, more researchers inspected the effect of adding Nanomaterial in soil properties. All result showed that an enhancement in physical and mechanical properties of soil when mixed with Nanomaterial, this improvement varies according to the type, quality, and Nano-ratio added, moreover the characteristics of the natural soil.

KEY WORDS

Nanomaterial, Geotechnical, Review Paper, Soil.

1. INTRODUCTION

Soft soils can be usually found in areas with high water content, namely, approaching that of the liquid limit, which results in a high settlement potential with low shear strength. Thus, a steady state should be achieved to satisfy the preconstruction and post-settlement and to ensure a stable strength and deformation.

Constructing on soft soils in many civil engineering projects has prompted the introduction of many approaches for soil improvement. Studies have focused on stabilizing soft soils using various additives such as Nanomaterials. Nanoparticles interact very actively with other particles and solution, and every minute amounts may lead to considerable effects on the physical and chemical properties of a material. Because of that, there has been a great deal of interest in Nanoparticles in many technological applications.

Various Nanomaterials (nano-silica, nano-clay, etc.) were investigated in geotechnical engineering, and different types of soil (clay, silty clay, and sand) were employed. The aim of these studies was finding the optimum dosage of Nanomaterial required to enhance soils. This study presents the results of a systematic investigation on the impact of adding Nanomaterials on the mechanical characteristics of soil such as bearing capacity, linear shrinkage, plasticity limit, compaction characteristics and shear strength. A chronological narrative style was employed to present the previous studies, and the reviews shall be classified based on the type of soil.

2. NANOMATERIAL

The history of employing nanotechnology has its origins in the BC period. Specifically, in Mesopotamia, wherein a trace of silver and copper Nanoparticles was observed on the clay pots surface, consequently, giving them a glistening appearance [1]. However, the first scientific usage of Nano-material has been reported in 1857 AD, where a solution was created using a gold Nano-particle. Later in the 1940s, commercial industries where utilizing silica Nanoparticles to reinforce rubber. Nevertheless, the potential of nanotechnology was first pointed out in a lecture by Richard Feynman in 1959 titled (There is plenty of room at the bottom). Also, it was the first time the term nanotechnology was used in the 1970s, where it was stated that nanotechnology fundamentally involves atomically and molecularly processed, separated, consolidated and materials deformation [2].

Although nanotechnology was involved in numerous branches of science, its potential in civil engineering was officially recognized until the 2000s [3]. In an email-survey was conducted in 2004 to evaluate the current development and awareness of nanotechnology in the construction field. The result of the survey has demonstrated the prospect of using nanotechnology to enhance the performance of materials. Since then, various practical studies regarding Nanomaterial were conducted in the scope of civil engineering, especially in geotechnical engineering, which uses Nanomaterial to improve the properties of soil. During the last ten years, numerous studies were conducted regarding the treatment of soft ground since they are a problematic soil suffering from the settlement
due to its high liquid limit and low bearing capacity.

Nanomaterials are one of the most comment materials used to solve such a problem. Different studies started in geotechnical engineering to know its specification and effects in soil properties. The technique of using Nanomaterial has changed the vision and expectations in controlling the engineering properties of soil [4]. Many groups of Nanomaterial can be distinguished based on their shape, their high ratio of surface to volume and their ability of cation exchange [5]. This activity overlaps with soil particles and Nanomaterials are sufficient to obtain significant enhancement on the physical and chemical properties of soil. This idea comes from the principle of intermolecular overlap, as the difference between the size of the overlapping particles reduces the percentage of voids. Various nanomaterials used to improve the geotechnical properties of soil such as Nano-clay, Nano-silica, Nano-copper, Nano-aluminium...etc. This paper shall discuss the recent studies regarding the usage of these materials in geotechnical engineering.

3. LITERATURE REVIEW

As previously mentioned, the conducted studies shall be presented chronically. However, the studies have employed different types of soil. Therefore, the reviews will be classified into groups depending on the type of tested soil, and each group shall be explained invasitively:

3.1 Clayey soil

Mohd Rain and Omer Mubie Eldeen at (2012) studied the effect of adding different nanomaterials such as (Nano-clay, Nano-alumina, and Nano-copper) on soft soil, with different amount of bentonite range between (5 to 20%) to study the swelling and shrinkage properties. The samples used in the test were compacted at the maximum dry density and optimum moisture content by using the standard compaction test. It was found that both shrinkage strain and swell strain are reduced with the addition of the optimum amount of Nano-material. However, a decrease in the development of desiccation cracks on the surface of the sample’s without reducing the permeability [6].

Zaid Hamm ed et al (2012), conducted laboratories studies to find the effect of Nano-CuO, Nano-MgO, and Nano-clay in geotechnical properties of soft soil. They added different percent of Nanomaterial (0.05 to 1%) to the soil. The result showed increases in the maximum dry density of the soil, reduced in linear shrinkage and plasticity index with increasing of nanomaterial content. The strength of soil increased up to a certain percentage[7].

C. W. N. Ng and L. G. Coo at (2014) attempted to investigate the change in permeability of clay soil mixed with two types of Nanomaterial namely, gamma aluminium oxide (γ-Al₂O₃) and Nano-copper oxide (CuO), were mixed at different amount i.e. (2, 4, and 6%) of dry weight soil. Permeability test was conducted. The results indicate that at 2% of (γ-Al₂O₃) and Nano-copper oxide (Nano-CuO) the permeability of clay decreased by 30% and 45% respectively. As the percentage of Nanomaterial increased by more than 2%, the permeability becomes less prominent, while the pore size reduced by 20% when the Nano-CuO per cent was 4% [8].

Z. Fahri et al. (2014) has experimentally investigated the influence of using Nano-clay in the kaolinite clay. A series of tests were conducted such as Atterberg limit, standard compaction, and cation exchange capacity test. The result has shown that adding 8%, Nano-clay has enhanced the value of the plasticity index by up to 184%. In contrast, the hydraulic conductivity has decreased 300 times when compared with natural soil. Also, the cation exchange capacity has increased from 12 to 21 meq/100gr. because of the rising amount of.

Ali Akbar et al (2014): investigate the influence of adding Nano-zeolite on geotechnical properties of soil. They noticed that the addition of Nano-zeolite until 0.5% caused increasing in liquid limit and plastic limit. After 0.5% the behaviour changed to a reduction in the plasticity indices, which indicate improvement in soil properties [10].

Norazlan Khalid et al (2014): concluded that a small amount of nano-kaolin significant enhances the geotechnical properties. The addition of 3% Nano-kaolin increased consistency limits, and maximum dry density decreased the moisture content [11].

Foad Changizi and Abdolhossein Haddad at (2015), have researched the effect of mixing Nano-SiO₂, with cohesive soil at different percentages (0.5, 0.7, 1%) on the geotechnical properties such as shear strength and maximum dry density, and it was concluded that increasing the content Nano-SiO₂, has inverted the cohesion (C), angle of friction, (φ), dmax and U C S of clayey soil. Besides, the parameters of strength have reached a peak point with 0.7% content of Nano-SiO₂ [12].

Jason L. et al. (2016), have studied the effect of nano-CuO and nano-Al₂O₃ on the clay shrinkage property. The nanomaterials were mixed by different amounts (2, 4 and 6%), the added water equals the liquid limit. It was concluded that the addition of 6% nano-CuO and nano-Al₂O₃, could increase the shrinkage limit by 17% and 8% respectively [13].

Zaid Hamm ed et al. (2016) found that adding 1% of nanomaterials such as (Nano-copper, Nano-alumina, Nano-magnesium) to soft soils improved strength. The percentage of Nanomaterial must be less than 1% [14].

Sanjeev Naval et al. (2017) have investigated the stabilization techniques by adding Nano-MgO and Nano-Al₂O₃ with different percentage, i.e. (0.5 - 2%) to enhance the expansive soil properties. The conducted experimental tests are consistency limit and consolidation test. The results have shown that increasing nanomaterial contents have reduced the consistency limit (liquid limit, plastic limit and plastic index). In turn, this has led to a decrease in the swelling potential of soil. Furthermore, Nanomaterial’s can stabilize the soil and reduce the voids, thus, allowing a small amount of water to penetrate the soil, which causing decrease the swelling of this soil. In conclusion, nanomaterials enhance soil properties and make it suitable for construction [15].

Silvia Gracia et al. (2017) have considered improving soft clay using Nano-SiO₂. It was concluded that the strength of soil has increased by adding 3% of Nano-SiO₂. Also, an increase in the interlock forces between the Nano-SiO₂ and soil particles was noted. Consequently, leading to the conclusion that using Nano-SiO₂ is an excellent alternate method for stabilizing soil [16].

Foad changizi and Abdolhossein Haddad at (2017): have investigated the influence of Nano-SiO₂ on geotechnical properties of soft clay. Several experiments have been conducted such as Atterberg limit, compaction test, C. B. R test, consolidation and unconfined compression test for natural soil and soil mixed with (0.5, 0.7, and 1%) of Nano-SiO₂. It was shown that the increase of the content of Nano-SiO₂ has improved Atterberg limit and (C. B. R), which also has led to a reduction in (P. I) and increasing in (S. L). Furthermore, it was noticed that stabilizing the soil with 0.7% Nano-SiO₂ shall result in a reduction in settlement due to the interaction between soil and Nanomaterial which, in turn, has caused a rise in the pre-consolidation stresses. The obtained results have displayed an enhancement in the unconfined compressive strength reaches by up to 56%. Finally, a reduction in failure strain and an increase in the elastic modulus of soil was also noticed [17].

Reza Ziaie and Hamidrezu Rohmani (2017) have studied the effect of Nano-SiO₂ solution on the unconfined compressive strength and young’s modulus of kaolinite. Sample with different Nano-SiO₂ content (1, 2, 3, 4 and 5%) was employed. The result has demonstrated an enhancement in the unconfined compressive strength of modified soil up to 1.45 times when compared to natural soil. Moreover, it was indicated that 5% of the content of Nano-SiO₂ has no significant impact. Hence, 4% was considered to be the optimum content [18].

Alirez Tabarsa et al. (2017) have considered the impact of Nano-clay on geotechnical properties of soil. Specimens with different Nano-clay content (0.2% - 3%) were employed in this study. Several tests were conducted, such as consistency limit, compaction, unconfined compressive strength, triaxial compression, and collapse. From the results, it was found that adding Nano-clay has altered the strength, plasticity, and stiffness behaviour of soil samples. Furthermore, both field and laboratory tests are in general agreement [19].

Nader Abbas et al. (2017) have studied the effect of Nano-clay on the geotechnical properties of low plasticity and high plasticity soil. The soil samples have different Nano-clay (0 - 4%) and were cured at 1.3 and 7 days. It was found that adding nano-clay has considerably decreased the dispersivity potential [20].
samples and samples mixed with 2% Nano-SiO₂ were employed, and several tests were carried out: consistency limit, unconfined compressive shear strength. The result had displayed an increase in the unconfined compressive strength significantly when Nano-materials increased. Also, they observed that the optimum value of the Nano-material amount was around 1.5%[21].

Karumanchi Meeravalli and Kadi Raugaswany at (2018) have studied the impact of Terrasil (a Nano-chemical) on soft soil. The tested sample was in a state of maximum dry density and optimum moisture content using a different percentage of Nano-chemical. The compressibility, permeability and unconfined compressive tests were performed. The results showed that the compressibility was reduced and the permeability was increased with respective percentages[22].

Lei Gao et al (2018) have investigated the relationship between the Nano-MgO and soil shear strength. The soil was mixed with different dosages of Nano-MgO (2 – 6%), and it was concluded that the adding 6% dosage of Nano-MgO has the most apparent impact on the strength and cohesion of the soil by but has little effect on the angle of friction[23].

Moha R. Taha and Jamal M. A. Alshahre, (2018), carried out various tests using carbon nanomaterials and carbon nanotube to stabilize soil, the proportions were around 0.05 – 0.2%. Several experimental tests were conducted, such as Atterberg limit, compaction, permeability, specific gravity, and PH value. It was indicated that 0.2% of mixed Nanomaterial by dry weight had achieved the optimum result. They showed that both nanomaterials have slightly enhanced the dry densities, specific gravity, and PH value, while the permeability has decreased. In conclusion, using a small amount of nanomaterials improved geotechnical properties of the soil[24].

Moha R. Taha et al (2018) have investigated the effect of mixing carbon Nanofiber (0.05 - 0.2%) and carbon nanotube with residual soil having bentonite (up to 20%) at different evaluated plasticity’s. Test such as unconfined compressive strength, indirect tensile strength and young’s modulus were conducted. It was found that carbon Nanofibers are better than carbon nanotubes in enhancing the geotechnical properties of soil. For instance, the compressive strength, tensile strength and young’s modulus have reached the peak point by only using 0.1% Nanocarbon content. Also, the result displaced an improving in indirect tensile strength when increasing amount of Nanocarbon and carbon nanotube. Furthermore, the compressive strength was equal to five times the tensile strength, and this relationship tends to decrease when the plasticity increased[25].

Malik A. et al (2019) have studied the influence of adding mixed Nano-silica on the strength properties of clayey soil. Several experimental tests have been conducted on soils mixed with Nano-silica at an amount ranging from (5 - 20%) by dry soil weight. The result showed a rise in the optimum moisture content with the increasing in Nano-silica content. Furthermore, the unconfined compressive strength increased with stabilization the soil by Nano-silica. Finally, the investigation concluded that Nano-silica improves the geotechnical properties of the clayey soil[26].

Shahzada Omer and Adil Yousuf at (2019) have researched the influence of adding multiple nanomaterials (Nano-clay and Nano-cement) on soft soil. The nanomaterials are added at per cent varied from (1 to 3%). Several tests were conducted such compressive strength, consistency limit and compaction. The result indicates that increasing the amount of Nanomaterial has enhanced the unconfined compressive strength and maximum dry density up to a particular per cent. In contrast, plasticity Index has decreased with increasing Nanomaterial. Both of the liquid limit and plastic limit has also increased and optimized the shear strength of the soil[27].

Amir Kalhor et al (2019) have investigated the influence of freeze-thaw (Nine freeze-thaw cycles) on soil sample stabilized by Nano-SiO₂. Natural samples and samples mixed with 2% Nano-SiO₂ were employed, and several tests were carried out: consistency limit, unconfined compressive strength and maximum dry density. It was shown that the samples with 42 curing days were stabilized and its OMC has demonstrated an enhancement in their LL and P.L, while their maximum dry density and plastic index have decreased. Also, it was noticed that the uncontained compulsive strength had increased by about 63%. However, the cycle of fruiting-thawing has reduced the strength of natural soil and treated soils by 64% and 42% respectively[28].

Gang Cheng et al (2019) have suggested enhancing the engineering properties of soil by adding Nano-bentonite. Five different clayey soil specimen were employed, the first one is a natural soil (no additives), the rest were mixed with, and permeability tests were applied in this study. It was noticed that only the sample with 0.5% Nano-bentonite content had demonstrated an improvement in compression, while the final void ratio decreased. Besides, under high-stress state, the permeability and coefficient of consolidation increase with increasing the content of nano-bentonite. In conclusion, an improvement was seen in soil particles which effectively reduce the compressibility of clayey soil. Different percentages of nano-bentonite (0.5 – 2%), both of consolidation[29].

Al-Swaiedani, Aref M. et al (2019) have researched the influence of Nano-calced clay and Nano-lime on some of the engineering properties of the expansive clayey soil. Three expansive soils from three different sites were employed for the study after being thermally treated at 450 °C 650 °C and 850 °C for 3 hours. After that, they were mixed with 1 and 2% of Nano-calced clay and 0.6% of Nano-lime. Different tests were conducted, such as Atterberg limits, compaction, linear shrinkage, swelling pressure, free swell and shear strength. The mixed soil has displayed a positive result. For instance, using 2% Nano-calced shall reduce the plasticity index by more than 50%. Furthermore, mixing both Nano-calced and Nano-lime with soil shall optimize its performance by reducing linear shrinkage and swelling pressure by up to 15%[30].

Meeravalli Karumanchi et al (2020) have studied the effect of Nano-clay on geotechnical properties of soft soil. Several tests were done in this study, such as specific gravity, compaction, consistency limit, unconfined compressive strength and hydraulic conductivity. The result has displayed improvement in all soil properties[31].

Karumanch Meeravalli et al (2020) have investigated the improvement of Kuttanad soft soil by adding Nanomaterial (Terrasil). Soft clay was mixed with different percentage of Nanomaterial, and several tests were carried out to inspect the engineering characteristics of treated soil such as the compaction strength, permeability and compressibility. The results have demonstrated that the tensile strength increase in some properties such as shear strength, permeability and decreasing incompressibility[32].

Rosales Garcia, Jula et al (2020) have studied the influence of mixed a solution of silicates as nanomaterials to improve the geotechnical characteristics and bearing capacity of the swelling soil. Different mixture of swelling soil and Nanomaterial were used. The conducted tests are compressive strength and California bearing ratio. The result has displayed an increased in compressive strength and California bearing ratio. Also, the use of nanomaterials enhances the behaviour of sub-base stabilized layer and reduces its environmental impact through life cycle assessment[33].

A.Ghassemianpah et al (2020) have researched the impact of adding Nano -bentonites on the geotechnical properties of the soil. Different soil sample where used. Except for reference sample, the rest were mixed with different percentage of Nano -bentonite (3, 5 and 7%), and were subjected to varying periods of curing (1, 7, and 28 days). The conducted tests include unconfined compression test, Atterberg limit and compaction. It was shown that mixing Nano-bentonite with soil has optimized its geotechnical properties such as unconfined compressive strength, liquid, plastic limits of the clayey soil and reduction in plasticity index. Besides, the curing time has a significant influence on the strength properties of stabilized soil[34].

Anie Geogre and K.Kannan (2020) have studied the influence of montmorillonite nano-clay on the geotechnical characteristics of clayey soil. The specimens have different Nano-clay content (0.2% -3.5%). Various tests were conducted, such as shear strength, Atterberg limit, and standard proctor. From the results, it was shown that a small amount of Nano-clay is sufficient to optimize dry density and other engineering properties[35].
3.2 Sandy soil

Junrik et al. (2011) have studied the effect of different concentrations of Nanomaterial on the geotechnical properties of soil. Several tests were conducted for natural soil and soil mixed with nanoparticles such as shear strength, compressibility and permeability. The results have indicated an improvement in geotechnical properties of soil, and the liquefaction potential of cohesionless soil has been improved[36].

3.3 Silty soil

Mohammed Nikookor et al. (2013) have considered stabilizing silty soil using Nano-clay. The samples were mixed with different percentages (0.5 - 2%) and were tested for unconfined compressive strength and California bearing ratio (CBR). It was shown that both of the unconfined compressive strength and CBR have risen with increasing the content of Nano-clay[37].

Rasool Yazarloo et al. (2017) have studied the possibility of improving loose soil by adding Nano-kaolinite. The different test was performed on soils such as compressibility, Atterberg limit and standard proctor test. It was demonstrated that the dry soil density improves with increasing the Nano-kaolinite content up to 2% where it has started to decrease afterwards, and the optimum moisture content begins to rise at the same time. Furthermore, both liquid limit and plastic limit has increased until the Nano-kaolinite content has exceeded 5% where the later descends after that[38].

3.4 Silty clay

Ren, Xiaochuan and Hu, Kal. (2014) have studied the influence of Nano-SiO2 on the physical and engineering characteristics of silty clay. Different tests were conducted such as scanning electron microscopy, Atterberg limit, specific gravity and uniaxial compression, and it was shown that employing Nano-SiO2 shall increase the plastic limit (P.L), liquid limit (LL) and uniaxial compression. At the same time, there was no change in the specific gravity of the samples. Furthermore, it was indicated that the Nano-SiO2 did not affect the composition of the clay sample, reduced pore size in samples[39].

D.E.Ewa et al. (2016) have investigated the influence of Nano-chemical (Terrasil) on the geotechnical properties of subgrade. Various soil samples were stabilized with Nano-chemical at different percentages (2% - 8%), and they were subjected to dry density test and California bearing ratio (CBR) test. The stabilized soils have demonstrated an enhancement in plasticity while the value of maximum dry density by up to 9.2%. Furthermore, adding Nano-chemical has caused a rise in the optimum moisture content, and the CBR has improved for unsoaked and soaked subgrade by 5.6% respectively. In conclusion, 4% of Nano-chemical was considered to be the optimum content[40].

3.5 Silty sand

Zaid Hammud et al. (2014): investigate the effect of Nano-copper, Nano-clay and Nano-magnesium on engineering properties of soft soil, the results showed an increase in the maximum dry density, compressive strength, plasticity index and linear shrinkage. The low doses of Nanomaterial enhanced the properties of soil[41].

Behnam Iranpour and Abdolhossein Haddad et al. (2016) have studied the impact of added Nanomaterial on the behaviour of collapsible soil. The collapsible soil sample was treated with different nanomaterials (Nano-clay, Nano-silica, Nano- alumina, and Nano-copper) and was added at different percentages. Consolidation test was conducted to know the effect of Nanomaterial on collapsibility of the soil, and it was shown that the enhancement in collapsible soil behaviour differs from Nano to another[42].

3.6 Sandy silt

Norzalan Khalid et al. (2015) have presented the effect of adding Nano-soil particles on the geotechnical properties of the treated soft soil. The Nano-soil content ranges between 2% and 4%, and the samples for compressive strength, Atterberg limit and shear strength tests. It was found that the presence of Nano-soil has enhanced the shear strength and strength of the soil, while the value of plasticity was dropped. In conclusion, improving the geotechnical properties of soil can be accomplished using a small amount of Nano-soil[43].

3.7 Sandy clayey silt

Zofia Zieba et al. (2018) have inspected the influence of frost-susceptible soil with Nano-SiO2, and micro silica on the permeability coefficient. A triaxial test has been performed on natural samples and samples mixed with 5% micro silica and 5% Nano-SiO2. The result of the permeability coefficient for the unfrozen samples and the samples subjected to 10 cycles of freezing and thawing have been beneficial to the properties of the soil[44].

4. ANALYZING THE RESULTS OF SOME PREVIOUS STUDIES

As shown, numerous studies were conducted to inspect the behaviour of soil using various nanomaterials. However, only a few of them have demonstrated a significant result. This section shall discuss the results obtained from these studies, which can be summarized in the following points:

1 - A slight increase in the dry density due to the reduction of the optimum moisture content. Shows that the Kaolin soil has improved after the 3% addition of Nano – kaolin. Also, it can be seen that ( LL ) and (P.L ) value have demonstrated a minor rise, which is because of the increase in the surface area particle of Nano-kaolin, thus, leading to absorbing more water. At the same time, the value of the (P.I) has decreased, which indicates an improvement of Soil, Table (1).

2 - Adding nanomaterials (Nano MgO, Nano Al2O3 ) has reduced the values of (LL),(P.L), and (P.I). The reduction of (P.I) has led to a decrease in the swelling potential of soil. That is because adding nanomaterials shall reduce the porosity of Kaolinite clay, consequently, Preventing water penetration. The maximum dry density increases and optimum moisture content increases when adding nanomaterials. However, the latter moisture content starts to decrease after at a certain point (after adding 1.5, 2% nanomaterials), Table (2).

3 - Adding Nano-SiO2 has improved the peak strength and young modulus of the kaolinite soil. The increases ratio of unconfined compressive strength value comparing with natural soil is 1.09, 1.12, 1.17, 1.35 and 1.43, respectively. While, 1.15, 1.28, 1.43, 2.47 and 2.61, respectively for young modulus, Table (3).

4 - Employing different percentages of nanomaterials can enhance the qB of soil. Furthermore, the unconfined compressive strength has increased by twice. It was found that the optimum value of nanomaterials was about 1.5%, where the compressive strength of the soil decrease. Table (4) is about 1.5% where the compressive strength of the soil decrease, Table (4).

5 - The results of the proctor test show that the best amount of Nano kaolinite is around 2%. However, after that, the max unit weight decrease while the optimum moisture content increases. That is because the nanomaterials fill the pores of soil instead of air and water. Nevertheless, an extravagant amount can cause aggregation and agglomeration. While the (LL) and (P.L) have increased; the (P.I) was constant until adding 5% of Nano kaolinite where it started to decrease. The high reactivity of nanomaterials can occur at a higher level of the surface to volume ratio of Nano kaolinite (specific surface) as it is explained in Table (5).

6 - The Increase in the γrsu can be attributed to the Nanomaterial’s particles density which is larger than the ones of soil. Besides, the soil porosity was reduced due to nanomaterials filling the voids, and binding the soil particles. A rise in the maximum dry density of soil shows an improvement in the manner of strength, Table (6).

5. SUMMARY

This paper has summarized the studies (in a chronological matter) since 2011 regarding the geotechnical properties of soils using a different type of nanomaterials. It can be seen that eleven studies have employed nano-clay, where ten studies have investigated the influence of Nano-SiO2 and the other nine have employed Nano-CuO. On the other hand, 6 and 5 types of research have applied Nano-MgO and Nano-Al2O3 respectively. 2 have investigated the impact of Nano-Kaolin, Nano-
chemical, Nano-Bentonite and Carbon Nanotube. And finally, the other nanomaterials were suggested by 1 study only (see Figure 1). A review of previous studies which also indicated in the figure (2) and Table (7), we find that most of the studies were on the effect of nanomaterials on clay soils, especially soft ones. The type of soil caused serious problems in geotechnical engineering because weak soil may cause damage to the foundation of building due to its high moisture content and the ability to collapse when exposed to high loads.

6. CONCLUSION

This research paper has reported the previous studies on the soil stabilization using nano additives. Several conclusions can be drawn from them:

1. The nanomaterials exhibit different properties such as smaller size, high specific area, therefore react strongly with the particle in the soil matrix.

2. The existence of a small amount of nanomaterials can have significant effects on geotechnical properties of soil (improve soil characteristics).

3. The influence of the different type of nanomaterials depends on the type of particle, percentage, and soil mixed.

4. A large amount of nanoparticles causes agglomeration of particles and harms the geotechnical properties of the soil.

5. The use of nanomaterials in a soil mixture significantly enhancement in the compaction effort, strength, shear strength, consistency limit, compressibility, and permeability

6. A reduction in plasticity shows an enhancement of soil.

### Table 1: Effect of Nano-kaolin on the Atterberg limits and maximum dry density of kaolin soil sample[11].

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>LL (%)</th>
<th>P.L (%)</th>
<th>P.I (%)</th>
<th>Wc (%)</th>
<th>dmax&lt;sub&gt;m&lt;/sub&gt; mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolin soil</td>
<td>69</td>
<td>36</td>
<td>33</td>
<td>37</td>
<td>1.3</td>
</tr>
<tr>
<td>Kaolin soil + 3%</td>
<td>70</td>
<td>48</td>
<td>22</td>
<td>27</td>
<td>1.4</td>
</tr>
</tbody>
</table>

### Table 2: Effect of Nano-material on Atterberg limit, swelling potential, maximum dry density, and optimum moisture content of kaolinite clay [15].

<table>
<thead>
<tr>
<th>Type of soil Properties</th>
<th>% Nano-materilss</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay+ Nano-Mgo</td>
<td>L.L%</td>
<td>70</td>
<td>52</td>
<td>43</td>
<td>43</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>P.L%</td>
<td>31.94</td>
<td>28.7</td>
<td>23.15</td>
<td>25.03</td>
<td>18.56</td>
</tr>
<tr>
<td></td>
<td>P.I%</td>
<td>38.06</td>
<td>4.69</td>
<td>3.17</td>
<td>2.50</td>
<td>0.203</td>
</tr>
<tr>
<td></td>
<td>Swelling Potential</td>
<td>15.51</td>
<td>1.669</td>
<td>1.716</td>
<td>1.742</td>
<td>1.753</td>
</tr>
<tr>
<td></td>
<td>γ(max&lt;sub&gt;s&lt;/sub&gt;) gm/cm³</td>
<td>1.604</td>
<td>1.649</td>
<td>1.694</td>
<td>1.721</td>
<td>1.743</td>
</tr>
<tr>
<td></td>
<td>Wc%</td>
<td>14.28</td>
<td>21.43</td>
<td>20.59</td>
<td>14.70</td>
<td>12.50</td>
</tr>
<tr>
<td>Clay+ Nano-CaSO&lt;sub&gt;4&lt;/sub&gt;2H&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>L.L%</td>
<td>70</td>
<td>48</td>
<td>42</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>P.L%</td>
<td>31.94</td>
<td>25.46</td>
<td>23.15</td>
<td>19.35</td>
<td>16.86</td>
</tr>
<tr>
<td></td>
<td>P.I%</td>
<td>38.06</td>
<td>22.54</td>
<td>18.85</td>
<td>13.65</td>
<td>9.14</td>
</tr>
<tr>
<td></td>
<td>Swelling Potential</td>
<td>15.51</td>
<td>1.653</td>
<td>1.694</td>
<td>1.721</td>
<td>1.743</td>
</tr>
<tr>
<td></td>
<td>γ(max&lt;sub&gt;s&lt;/sub&gt;) gm/cm³</td>
<td>1.604</td>
<td>1.653</td>
<td>1.694</td>
<td>1.721</td>
<td>1.743</td>
</tr>
<tr>
<td></td>
<td>Wc%</td>
<td>14.28</td>
<td>19.65</td>
<td>21.83</td>
<td>18.47</td>
<td>14.29</td>
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</table>

### Table 3: Effect of Nano-SiO<sub>2</sub> on unconfined compressive strength and Young modulus of kaolinite soil [18].

<table>
<thead>
<tr>
<th>Type of soil Properties</th>
<th>% Nano-material</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay soil</td>
<td>q&lt;sub&gt;u&lt;/sub&gt; (KN/m²)</td>
<td>6.8</td>
<td>7.42</td>
<td>7.63</td>
<td>7.98</td>
<td>9.17</td>
<td>9.72</td>
</tr>
<tr>
<td></td>
<td>E (kg/cm²)</td>
<td>59.4</td>
<td>63.1</td>
<td>70.2</td>
<td>78.5</td>
<td>135.5</td>
<td>143.4</td>
</tr>
</tbody>
</table>

### Table 4: Effect of Nano-Cuo and Nano-CaSO<sub>4</sub>2H<sub>2</sub>O on unconfined compressive strength of clay soil[21].

<table>
<thead>
<tr>
<th>Type of soil Properties</th>
<th>% Nano-material</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay soil+ Nano-Cuo</td>
<td>q&lt;sub&gt;u&lt;/sub&gt; (KN/m²)</td>
<td>70 (S1)</td>
<td>132</td>
<td>142</td>
<td>170</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>E (kg/cm²)</td>
<td>68 (S1)</td>
<td>112</td>
<td>120</td>
<td>130</td>
<td>135</td>
</tr>
<tr>
<td>Clay soil+ Nano-CaSO&lt;sub&gt;4&lt;/sub&gt;2H&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>q&lt;sub&gt;u&lt;/sub&gt; (KN/m²)</td>
<td>75 (S2)</td>
<td>126</td>
<td>130</td>
<td>152</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td>E (kg/cm²)</td>
<td>67 (S2)</td>
<td>91</td>
<td>112</td>
<td>119</td>
<td>114</td>
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### Table 5: Effect of Nano-kaolinite on the Atterberg limits and maximum dry density on silty loess soil (CL- ML)[38].

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Properties</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty loess soil+ Nano-kaolinite</td>
<td>γ(max&lt;sub&gt;s&lt;/sub&gt;) gm/cm³</td>
<td>1.97</td>
<td>1.97</td>
<td>1.98</td>
<td>1.98</td>
<td>1.99</td>
<td>1.97</td>
<td>1.96</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>L.L%</td>
<td>26</td>
<td>26.98</td>
<td>27.64</td>
<td>28.68</td>
<td>29.73</td>
<td>31.39</td>
<td>33.06</td>
<td>34.92</td>
</tr>
<tr>
<td></td>
<td>P.L%</td>
<td>19</td>
<td>20</td>
<td>20.69</td>
<td>21.74</td>
<td>22.80</td>
<td>24.91</td>
<td>27.02</td>
<td>28.92</td>
</tr>
<tr>
<td></td>
<td>P.I%</td>
<td>7</td>
<td>6.98</td>
<td>6.93</td>
<td>6.94</td>
<td>6.93</td>
<td>6.92</td>
<td>6.92</td>
<td>6.00</td>
</tr>
</tbody>
</table>
### Table 6: The Effect of adding Nanomaterials on maximum dry density and unconfined compressive strength on sandy silty clay (CH) [41].

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>properties</th>
<th>% Nano-magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil + Nano-copper</td>
<td>$\gamma_{(max)}$ (KN/m$^3$)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>UCS (kpa)</td>
<td>15.68</td>
</tr>
<tr>
<td>Soil + Nano-clay</td>
<td>$\gamma_{(max)}$ (KN/m$^3$)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>UCS (kpa)</td>
<td>15.68</td>
</tr>
<tr>
<td>Soil + Nano-magnesium</td>
<td>$\gamma_{(max)}$ (KN/m$^3$)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>UCS (kpa)</td>
<td>15.68</td>
</tr>
</tbody>
</table>

### Table 7: Existing experimental research findings

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Type of soil</th>
<th>Nanomaterial</th>
<th>Content (%)</th>
<th>tests</th>
<th>Results</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Majeed, Z. H. and Taha, M. R.</td>
<td>Clay</td>
<td>Nano CuO Nano MgO Nano Clay</td>
<td>0.05 - 1</td>
<td>Compaction</td>
<td>Maximum dry density</td>
<td>2012</td>
</tr>
<tr>
<td>3. Ng, C. W. W. and Coo, J. L. Coo</td>
<td>Clay</td>
<td>Nano-$\text{AL}_2\text{O}_3$ Nano CuO</td>
<td>2 - 6</td>
<td>Permeability</td>
<td>Permeability at 2%</td>
<td>2014</td>
</tr>
<tr>
<td>5. Firoozi, A., Taha, M. R., Firoozi, A. A., Khan, T. A.</td>
<td>Clay</td>
<td>Nano-Zeolite</td>
<td>0.1 - 3</td>
<td>Atterberg limit</td>
<td>P.I, L.L, and P.L (increased until 0.5% after that reduction occurs)</td>
<td>2014</td>
</tr>
<tr>
<td>7. Changizi, F. and Haddad, A.</td>
<td>Clay</td>
<td>Nano-$\text{SiO}_2$</td>
<td>0.5 - 1</td>
<td>Atterberg limit</td>
<td>Maximum dry density</td>
<td>2015</td>
</tr>
<tr>
<td>No.</td>
<td>Authors</td>
<td>Clay Type</td>
<td>Nanomaterials</td>
<td>Atterberg limit</td>
<td>Performance</td>
<td>Year</td>
</tr>
<tr>
<td>-----</td>
<td>---------</td>
<td>-----------</td>
<td>---------------</td>
<td>----------------</td>
<td>-------------</td>
<td>------</td>
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<tr>
<td>10</td>
<td>Naval, S., Chandan, K. and Harma, D.</td>
<td>Clay</td>
<td>Nano-MgO Nano-AL₂O₃</td>
<td>0.5 - 2</td>
<td>Unconfined consolidation</td>
<td>2017</td>
</tr>
<tr>
<td>11</td>
<td>Garcia, S., Trejo, P., Ramirez, O., Lopez-Molina, J., Hernandez, N.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>0.5 - 3</td>
<td>Unconfined compressive strength</td>
<td>2017</td>
</tr>
<tr>
<td>12</td>
<td>Changizi, F. and Haddad, A.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>0.5 - 1%</td>
<td>Atterberg limit consolidation</td>
<td>2017</td>
</tr>
<tr>
<td>13</td>
<td>Moayed, R. Z. and Rahmani, H.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>1 - 5%</td>
<td>Unconfined compression strength</td>
<td>2017</td>
</tr>
<tr>
<td>14</td>
<td>Tabarsa, A., Latifi, N., Meehan, C. L., Manahiloh, K. N.</td>
<td>Clay</td>
<td>Nano-clay</td>
<td>0.2 - 3</td>
<td>Unconfined compressive strength</td>
<td>2017</td>
</tr>
<tr>
<td>15</td>
<td>Abbas, N., Fariad, A. and Sepehri, S.</td>
<td>Clay</td>
<td>Nano-clay</td>
<td>0.25 - 4</td>
<td>Triaxial compression consolidation</td>
<td>2017</td>
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<tr>
<td>16</td>
<td>Mir, B. A. and Reddy, H.</td>
<td>Clay</td>
<td>Nano-CuO Nano-CuSO₄·2H₂O</td>
<td>0.5 - 2</td>
<td>Unconfined compressive strength</td>
<td>2018</td>
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<tr>
<td>17</td>
<td>Meeravalli, K. and Raugaswany, K.</td>
<td>Clay</td>
<td>Nano-chemical</td>
<td>0.02 - 0.15</td>
<td>California bearing ratio</td>
<td>2018</td>
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<tr>
<td>18</td>
<td>Gao, L., Ren, K., Ren, Z., Yu, X.J.</td>
<td>Clay</td>
<td>Nano-MgO</td>
<td>2 - 6</td>
<td>Triaxial consolidation</td>
<td>2018</td>
</tr>
<tr>
<td>19</td>
<td>Taha, M. R., Alsharef, J. M. A.</td>
<td>Clay</td>
<td>Carbon Nano fiber Carbon nanotube</td>
<td>0.05 - 0.2</td>
<td>Unconfined compressive strength</td>
<td>2018</td>
</tr>
<tr>
<td>20</td>
<td>Taha, M. R., Alsharef, J. M. A., Khan, T. A.</td>
<td>Clay</td>
<td>Carbon nanotube</td>
<td>0.2</td>
<td>Specific gravity</td>
<td>2018</td>
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<td>21</td>
<td>Malik, A., Puri, S. O., Singla, N., Naval, S.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>5 - 20</td>
<td>Comaction</td>
<td>2019</td>
</tr>
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<td>22</td>
<td>Manzoor, S. M. and Yousuf, A.</td>
<td>Clay</td>
<td>Nano-clay Nanocement</td>
<td>1 - 3</td>
<td>Unconfined consolidation strength</td>
<td>2019</td>
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<td>Kalhor, A., Ghazavi, M., Roustaeei, M., Mirhosseini, M.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>2</td>
<td>Unconfined compressive strength</td>
<td>2019</td>
</tr>
<tr>
<td>No.</td>
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<td>Type</td>
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<td>Property</td>
<td>Year</td>
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<td>-----</td>
<td>-------------------------------</td>
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<td>-----------------------</td>
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<td>26</td>
<td>Meerawali, k. et al.</td>
<td>Clay</td>
<td>Nano-clay</td>
<td>Unconfined compressive strength</td>
<td>2020</td>
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<td>Meerawali, k., Ruben, N. and Rangaswamy, K.</td>
<td>Clay</td>
<td>Nanomaterial (Terrasil)</td>
<td>Permeability</td>
<td>2020</td>
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<td>28</td>
<td>Garcia, J. R., Agrella, I., Maracobal, J. R.</td>
<td>Clay</td>
<td>Nano-SiO₂</td>
<td>Unconfined compressive strength</td>
<td>2020</td>
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<td>Geoge, A. and Kannan, K</td>
<td>Clay</td>
<td>Nano-clay</td>
<td>Atterberg limit</td>
<td>2020</td>
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<td>31</td>
<td>kingawitek, Z. Z. and Monks, J</td>
<td>Sandy clayey silt</td>
<td>Micro and Nano-SiO₂</td>
<td>Permeability coefficient</td>
<td>2018</td>
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<td>Nikookar, M., Bahari, M., Nikoor, H., Arabani, M.</td>
<td>Silty</td>
<td>Nano clay</td>
<td>California bearing ratio</td>
<td>2013</td>
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<td>Yazarloo, R., Gholizadeh, J., Amanzadeh, A., Mortazavi, S. A.</td>
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<td>Nano kaolinite</td>
<td>Compaction</td>
<td>2014</td>
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<td>35</td>
<td>Ren, X. and Hu, K</td>
<td>Silty clay</td>
<td>Nano, SiO₂</td>
<td>Uniaxial compression</td>
<td>2014</td>
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