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Research Article

An Analysis on Geotechnical Properties of Soil with Different Nanomaterials

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Abstract: In this paper, we analyze the geotechnical properties of the natural soft soil and its mixture with different nano materials at different percentages by conducting different number of experiments. The main objective of our work is to find whether the nano materials and their percentage level will increase the soft soil geotechnical properties or not. To accomplish this process, initially the natural soil sample is collected and the different geotechnical properties of the collected sample are computed. Then, the nano materials with different percentages are added to the natural soil sample and obtained the corresponding geotechnical properties for the mixture soil sample. Subsequently, a mathematical model is developed to find the optimal geotechnical properties value in different nano materials with different percentages. The developed mathematical model shows the geotechnical properties levels of nano mixture soil for unknown experiments. Finally, a fine tuning model process is conducted to check whether the nano material mixture of the natural soil will increase its geotechnical property or not. In this way, our proposed technique finds the optimal geotechnical property value for the unknown experiments and also produces an accurate result in fine tuning process. The implementation result demonstrates the geotechnical properties results of natural soil and nano mixture soil under different experiments. Our proposed technique shows that the geotechnical property values of the nano mixture soil are high compared to the natural soil. Moreover, the developed mathematical model is better to find the optimal geotechnical property value for unknown experiments.

Keywords: geotechnical properties, natural soil, nano materials.

INTRODUCTION

In general, soft soil includes large fractions of fine silt, peat and loose sand deposits below the ground water table [1]. According to Brand and Brenner (1981), soft soil has the shear strength of less than 25 kPa. It is a mineral combination of hydrous aluminum, silicates, quartz, feldspar, carbonate, oxides, hydroxides, and organic materials. Soft soil has the smallest particle which is less than 2 µm. It produces from weathering process, hydrothermal activities, or settled as sediment. The Unified Soil Classification System (USCS) classifies soft soil as small particle soil that 50% pass sieve No.200 Specification US (0.075mm). Soft soils [5] possess high moisture content of up to more than 85% and has high compressibility and sensitivity [6] and very easy to be interrupted from any activities on its surface. The structures constructed on soft soil can produce problems mainly in settlement, and stabilization. Soft soil is found out in the coastal areas and lowland areas with high compressibility and low shear strength. The enhancement of such properties is being attractive for researchers [6].

In 1970s and 1980s, soil stabilization by admixture was developed in Japan. The soil that is treated in such manner was good in terms of strength, reduced compressibility and hydraulic conductivity than the original soil [8]. Different Soil improvement methodologies are also in practice to ensure high geotechnical properties, for example, improvement of soft soil grounds before making upper constructions [9]. Some of the soil improvement methods include compacting grouting, permeation grouting, hydraulic fracture grouting and Jet Grouting [11] and deep mixing [11].

RELATED WORKS

Some of the literary works that analyzes the soils with different techniques are reviewed here. Kenneth B. Andromalos *et al.* [2] have discussed that the use of soil mixing for providing stabilization of soft or loose soils was considered a fairly new technology in the United States. Soil mixing has been successfully applied for liquefaction mitigation, steel reinforced retaining walls, groundwater cutoff walls, and stabilization of contaminated soils. Applications of that technology have recently been further expanded. Such applications have included settlement control of soils, slope stabilization and the formation of composite gravity structures. To design for these applications, the unconfined compressive strength, elastic modulus and shear strength of the soil and soil-cement columns must be determined or estimated. Settlement control of soft or loose soils under service loads can be sufficiently controlled with treatment ratios in the 20% to 35% range. On a recent project in Honolulu, Hawaii, loose soils were sufficiently stabilized with a 23% treatment ratio, and at a site in Lakeland, Florida, a very soft and compressible clay layer was sufficiently stabilized with only a 12% treatment ratio. In slope stability applications, soil mixing improves the overall shear strength of the soil formation to adequately increase the factor of safety, and also the soil-cement columns can forced the potential failure surface deeper. Lastly, soil mixing has been applied to construct in-situ gravity structures where its composite action design assumption was confirmed with an instrumented test wall, and used in two recent commercial applications.

H.P. Neher [3] has presented the two constitutive models were introduced briefly and user for back analysis of two test embankments in order to assess their performance. The soft-soil model based on the modified cam-clay model was employed as a reference model. The soft soil creep model was an extension which includes time and strain rate effects. It simply needs one additional input parameter compared to the soft soil model. Therefore the performance of these two models can be compared relatively easily. The first embankment considered is the well known Boston trial embankment. For this embankment, however, measurements of settlements and horizontal displacements have not been continued long enough to include secondary compression. Consequently, for the second 2D FE-analysis an embankment with a long period of secondary settlements has been considered. This is an embankment from the Ska Edeby test site in Sweden.

Saravut Jaritngam [4] has presented an innovative use of soil-cement mixing method using jet grouting technique to improve the bearing capacity of sub base foundation for road construction in Thailand. The construction sequences and the basic design example of jet grouting for embankment works on soft clay were also presented in that paper. The design concept and method of analysis of jet grouting work using finite element technique, results of finite element analysis, the installation adopted and effectiveness of soil improvement system were given and discussed. It was found that the total settlement is reduced by the jet grouting. A case history at Pak Phanang Diversion Dam project, Nakornsrithamarat, Thailand was presented describing the engineering design and construction aspects of a successful project, which demonstrated the advantage of soil-cement mixing method over conventional pile driving for this site.

M.R. Taha [5] has presented the Laboratory experiments to study the fundamental geotechnical properties of mixtures of natural soils and its product after ball milling operation. The product after ball milling process was termed nano-soil herein. SEM analysis showed that much more nano size particles were obtained after the milling process. Testing and comparison of the properties of original kaolinite, montmorillonite and UKM soil with regard to its liquid limit, plastic limit, plasticity index, and specific surface and after addition of its nano-soil were also conducted. Laboratory tests results showed that the values of liquid limit and plastic limits were higher after nano-soil addition. However, its plasticity index reduces which is advantageous in many geotechnical constructions. Compressive strength of original soil-cement-1% nano-soil mixture showed almost double its value without nano-soil. It demonstrated that a small amount of these crushed particles or nano-soil can provide significant improvement in the geotechnical properties of soil. Thus, nanoparticles were potentially suitable for improving the properties of soil/clay for various applications. Kazemain [8] has investigated different methods for soil stabilization in order to suggest suitable method to geotechnical engineers.

From the review, it can be seen that most of the previous research works have performed the soil geotechnical properties improvement process using some ground grind methods or adding mixtures to the natural soil. These existing techniques only improve any one of the geotechnical property of the soft soil and not for all. The geotechnical properties of the soft soil are highly compressible, weak, and low shear strength. Existing methods perform the geotechnical property improvement process by increasing the shear strength or making the soil strong. To accomplish this process, these existing methods have utilized different mixture models at different percentage and obtained the geotechnical property improvement result. But, these techniques have not achieved the adequate performance level in their geotechnical property improvement in soft soil and also they have not accurately addressed the material type to increase the soil strength at certain percent. Thus, due to the lack of solution in existing methods, there is a need to solve such drawbacks in the soft soil geotechnical property improvement. So, we proposed an efficient technique to analyze the different material performance in different percentage. To better understand the development and operation of the proposed model firstly, the paper describes the proposed technique in Section 3. The process of experimental model is presented in subsection 3.1 and the derivation of mathematical & fine tuning modeling process are discussed in subsection 3.2 & 3.3 respectively with necessary illustrations and mathematical formulations. Section 4 details the experimental requirements, Section 5 shows the performance of the proposed mathematical model, Section 6 shows discussion, and Section 7 concludes the paper.

PROPOSED TECHNIQUE FOR ANALYZING GEOTECHNICAL PROPERTIES OF SOIL WITH DIFFERENT NANO MATERIALS

The proposed technique finds the variation of geotechnical properties during the nano material mixture within the natural soil and computes the optimal geotechnical property value for the given soil as well as the specific nano material mixture. In order to accomplish this process, the entire work is divided into three phases namely, (i) Experimental Model, (ii) Developing mathematical model, and (iii) Fine tuning of modeling process.

Initially, we collect the soil and its related geotechnical properties performance levels. Then, different nano materials are selected and added with the natural soil, and computed the geotechnical property values. Subsequently, we develop a mathematical model to find the optimal geotechnical property value for unknown experiments. The mathematical model is developed based on the known experiments natural soil geotechnical property values and the corresponding nano mixture percentage level. Finally, the fine tuning modeling process performs the comparison process between the natural soil geotechnical property values and nano mixture soil geotechnical property values obtained from the developed mathematical model. The comparison result shows that minimum value has been yielded by the natural soil geotechnical properties. The process of each phase is briefly explained in the following subsections.

Experimental Model

In this phase, the experimental data is collected to carry out the geotechnical property analysis. To compute the geotechnical properties of the soil, we collect the soil from the USM Engineering Campus in Nibong Tebal, Pulan Pinang. The geotechnical properties are computed from the collected natural soil sample, which is represented as,

$$G_n(s) = \{g_1, g_2, \cdots g_i\}; i = 1,2,\cdots N \quad (1)$$

In Equ. (1), s denotes the collected natural soil and N represents the number of geotechnical properties related to the collected sample soil. g_i represents the i^{th} geotechnical property of the sample s .These computed geotechnical properties of natural soil are stored for further analysis. Subsequently, the nano materials with different percentage are selected and combined with the natural soil sample. Then, the geotechnical properties are identified for this nano mixture soil. The nano materials and its geotechnical properties are denoted as,

$$N_a = \{n_1, n_2, \cdots n_j\};\ j = 1,2,\cdots M \quad (2)$$

$$G(n_j(s)) = \{g_1^j, g_2^j, \cdots g_i^j\}; i = 1,2,\cdots N \quad (3)$$

In Equ. (2), N_a represents the nano materials and M is the number of selected nano materials. These nano materials are combined with the natural soil to produce the geotechnical properties, which is presented in Equ (3). To analyze the soil geotechnical property, the nano materials are added to natural soil with different percentage (R) at different experiments.

DEVELOPING MATHEMATICAL MODEL

After the experimental model phase, the mathematical model is developed for each geotechnical property. Different experiments are conducted and no accurate values are produced at all times. If any experiment produces an accurate result, it will take more time to compute the geotechnical property value. To give simplicity in the process, we developed a mathematical model for producing the optimal results in the geotechnical property computation and for reducing the processing time. Here, the mathematical model is developed by exploiting the natural soil geotechnical property values $G_n(s)$ and the nano material with different percentage (R). The developed mathematical model is,

$$(g_i^{n_j})_d = \sum_{k=0}^{K-1} \alpha_k \frac{1}{1 - \exp(g_i \beta_{ik} + R_i(n_j)\beta_{ik})} \quad (4)$$

where, $(g_i^{n_j})_d$ represents the d^{th} experiment data of i^{th} geotechnical property value of the soil with the nano material mixture type n_j , g_i is the i^{th} geotechnical property of the natural soil, and $R_i(n_j)$ is the percentage of the n_j^{th} nano material mixture. α_k and β_{ik} are the initial weights to be optimized. The mathematical model is optimized by selecting the α^{best}_k and $\beta^{best}_0, \beta^{best}_1, \ldots, \beta^{best}_{K-1}$ values to make it fit to the experimental data. Genetic Algorithm is used to perform the optimization process. The procedures that are involved in the optimization process are described below.

Step 1: Generate a population pool $P_l\ ;\ l = 0,1,\cdots,N_p - 1$ where, N_p is the pool size, in which each chromosome is of length $K+1$. The chromosome length $K+1$ indicates the number of genes i.e., the number of weights to be optimized such as $K+1$, α_k and $\beta_0,\beta_1,\ldots,\beta_{K-1}$. Each gene value of every chromosome is an arbitrary number generated within the interval $[0,1]$.

Step 2: Evaluate the fitness of the population pool using the below mentioned formula,

$$F_l = \frac{2}{\sum_{d=0}^{K_d-1}((g_i^{n_j})_d - (g_i^j)_d)^2} \qquad (5)$$

where, $(g_i^j)_d$ is the actual value of the geotechnical property g_i^j.

Step 3: Select $N_p/2$ chromosomes that have maximum fitness value from the population pool, and place them in the selection pool.

Step 4: Perform single point crossover operation with crossover probability C_p. The crossover operation exchange $N.C_p$ genes between two parent chromosomes and produces $N_p/2$ children chromosomes $C_h^{off}\ ;\ h = 0,1,\cdots,N_p/2-1$.

Step 5: Perform uniform random mutation operation with a mutation probability M_p. In the mutation technique, a uniform random integer is generated and replaced in $N.M_p$ random positions of C_h^{off}, and C_h^{new} is produced.

Step 6: The resultant C_h^{new} and the selection pool chromosomes are placed in the population pool and the process is repeated until the termination criteria is met. In our case, the termination criterion is set as reaching a maximum number of repetitions of process. Once the maximum number of process repetition is happened, the process is terminated and the chromosome (can be represented as α_k^{best} and $\beta_0^{best},\beta_1^{best},\ldots,\beta_{K-1}^{best}$), which has maximum fitness, in the population pool is extracted.

The obtained best weights are substituted in Eq. (5) to derive the final mathematical model as,

$$(g_i^{n_j})_d = \sum_{k=0}^{K-1}\alpha_k^{best}\frac{1}{1-\exp(g_i\beta_{ik}^{best} + R_i(n_j)\beta_{ik}^{best})} \qquad (6)$$

The final mathematical model is able to determine the geotechnical property of the mixture soil more precisely.

Fine Tuning Modeling

In fine tuning model, we find the deviation between the geotechnical properties of natural soft soil and the geotechnical properties of nano mixture soil. The percentage level of nano mixture in the sample soil increases the geotechnical properties. The fine tune model ensures that the nano mixtures in the sample soil at different percentage levels increases the geotechnical property levels. The experimental description of our proposed technique is briefly explained in the following section.

EXPERIMENTAL SETUP

The validation of the proposed method is performed using MATLAB (7.12.0®2011a), installed in machine with configuration as mentioned in Table 1.

Table 1: Machine Configuration

Sl. No	**Parameters**	**Specifications**
1	Processor	Intel core i5
2	Clock Speed	3.20 GHz
3	RAM	4 GB

In our experiment, the sample soil was collected from the USM Engineering Campus in nibong tebal, pulan Pinang. The computed geotechnical properties from the collected soil are maximum dry density, optimum water content, liquid limit (LL) , plastic limit (PL), plasticity index (PI) and unconfined compressive strength (qu). The experimental values of geotechnical properties of the collected sample soil are mentioned in Table 2.

Table 2: Geotechnical Properties of the Sample Soil

Geotechnical Properties	Values	Standard Method
Maximum Dry Density (kN/m^3)	45.05	ASTM D 698
Optimum Water Content (%)	21.60	ASTM D 698
LL (%)	47	BS (1377-part 2 -90)
PL (%)	28	BS (1377-part 2 -90)
PI (%)	19	BS (1377-part 2 -90)
qu (kN/m^3)	90	ASTM D (2166-65)

After that, the sample soil is combined with different nano materials at different percentage in different experiments. In our technique, we have considered four nano materials namely, nano Cu, nano Al_2O_3, nano Clay, and nano MgO. In each experiment, the nano materials are combined with the sample soil at different percentage. In our technique, we have conducted four experiments at different percentage of the nano mixtures with sample soil and the corresponding geotechnical properties in four experiments are illustrated in Table 3.

Table 3: Geotechnical Properties of Different Nano Mixtures at Different Percentage in Four Experiments

NanoCu	**Experiment I**	**Experiment II**	**Experiment III**	**Experiment IV**
Geotechnical Properties	**0.0**	**0.3**	**0.5**	**0.7**
Maximum Dry Density (kN/m^3)	14.44	14.56	14.88	14.95
Optimum Water Content (%)	21.60	23.00	23.50	24.60
LL (%)	47	48	46	44
PL (%)	28	30	29	29
PI (%)	19	18	17	15
qu (kN/m^3)	90.0	104.0	122.0	146.0
NanoAl_2O_3	**Experiment I**	**Experiment II**	**Experiment III**	**Experiment IV**
Geotechnical Properties	**0.0**	**0.05**	**0.1**	**0.3**
Maximum Dry Density (kN/m^3)	14.44	14.56	14.60	14.75
Optimum Water Content (%)	21.60	26.5	25.2	24.1
LL (%)	47	46	45	46
PL (%)	28	29	27	30
PI (%)	19	17	18	16
qu (kN/m^3)	90.0	127	133	188
NanoClay	**Experiment I**	**Experiment II**	**Experiment III**	**Experiment IV**
Geotechnical Properties	**0.0**	**0.1**	**0.15**	**0.2**
Maximum Dry Density (kN/m^3)	14.44	14.56	14.65	14.77
Optimum Water Content (%)	21.60	24.0	24.2	24.5
LL (%)	47	49	48	45
PL (%)	28	30	30	28
PI (%)	19	19	18	17
qu (kN/m^3)	90.0	131	147	156
NanoMgO	**Experiment I**	**Experiment II**	**Experiment III**	**Experiment IV**
Geotechnical Properties	**0.0**	**0.1**	**0.2**	**0.3**
Maximum Dry Density (kN/m^3)	14.44	14.51	14.60	14.72
Optimum Water Content (%)	21.60	26.0	24.20	25.0
LL (%)	47	46	47	47
PL (%)	28	29	30	30
PI (%)	19	17	17	17
qu (kN/m^3)	90.0	91	96	101

In our research work, we have developed a mathematical model, which was already explained in the section 3.2. This mathematical model is utilized to find the geotechnical properties of nano material mixture soil for unknown experiments, and this process reduces the time taken for conducting the experimental process. The developed mathematical model performance analysis is briefly discussed in the following section.

PERFORMANCE ANALYSIS

The developed mathematical model performance is analyzed by giving unknown experiment values and compared with experimental setup values. The mathematical model gets two inputs namely, sample soil geotechnical property value and nano material percentage value. The output from our developed mathematical model is a geotechnical property value of the nano mixture soil. The result shows that the values of our mathematical model are almost near to the experimental values. The performance of different nano materials geotechnical properties at experimental and mathematical model is shown in Table 4 and 5.

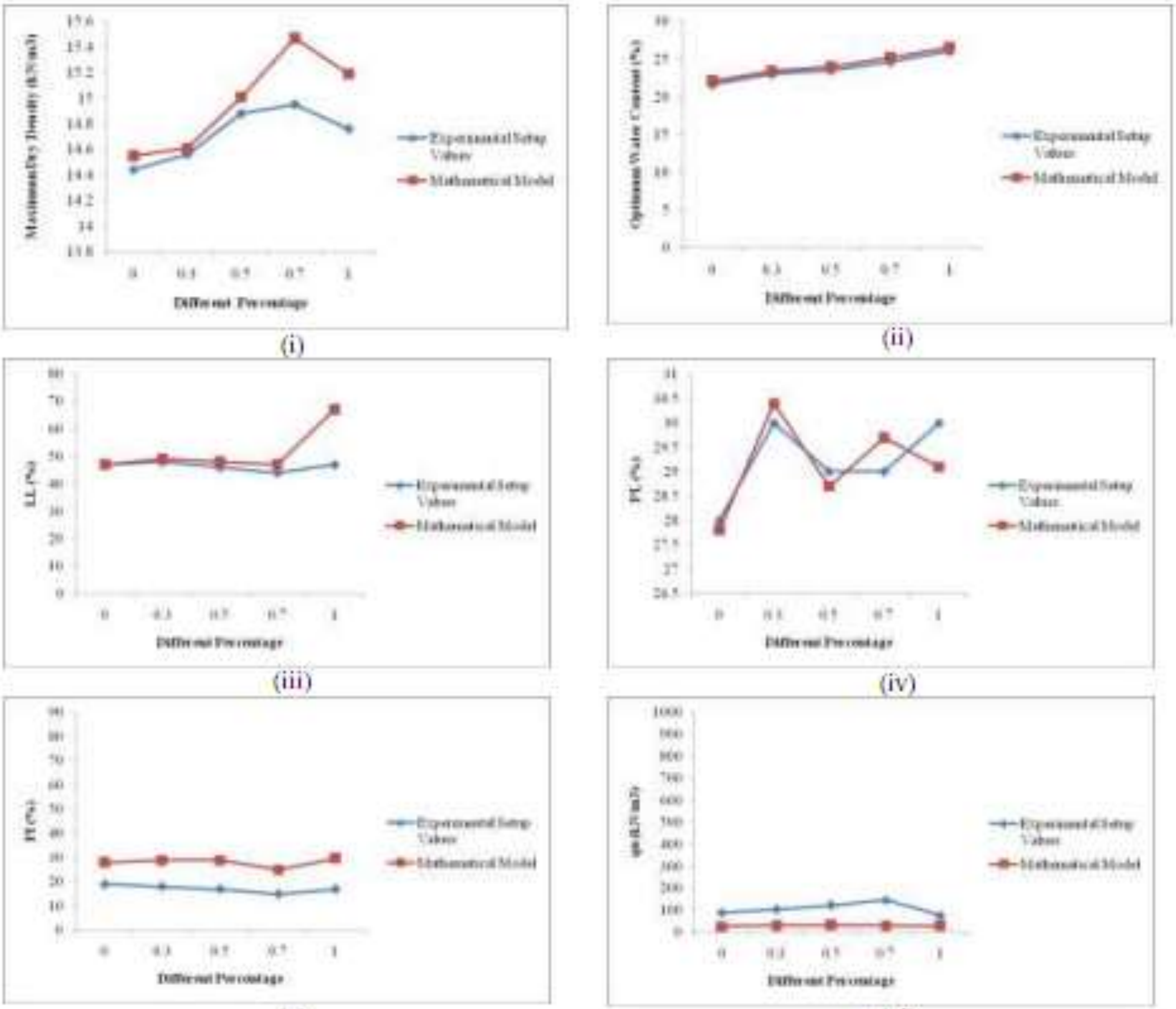
Table 4: Experimental Values of Geotechnical Property Results

Geotechnical Properties	**Experimental Values**				
	Sample Soil	**NanoCu at 1.0 (%)**	**NanoAl$_2$O$_3$ at 0.5 (%)**	**NanoClay at 0.3 (%)**	**NanoMgO at 0.4 (%)**
Maximum Dry Density (kN/m^3)	45.05	14.76	14.67	14.68	14.52
Optimum Water Content (%)	21.60	26.00	25.8	25.5	25.60
LL (%)	47	47	49	48	48
PL (%)	28	30	32	31	31
PI (%)	19	17	17	17	17
qu (kN/m^3)	90	77.0	9.67	7.4	10.73

Table 5: Mathematical Model of Geotechnical Property Results

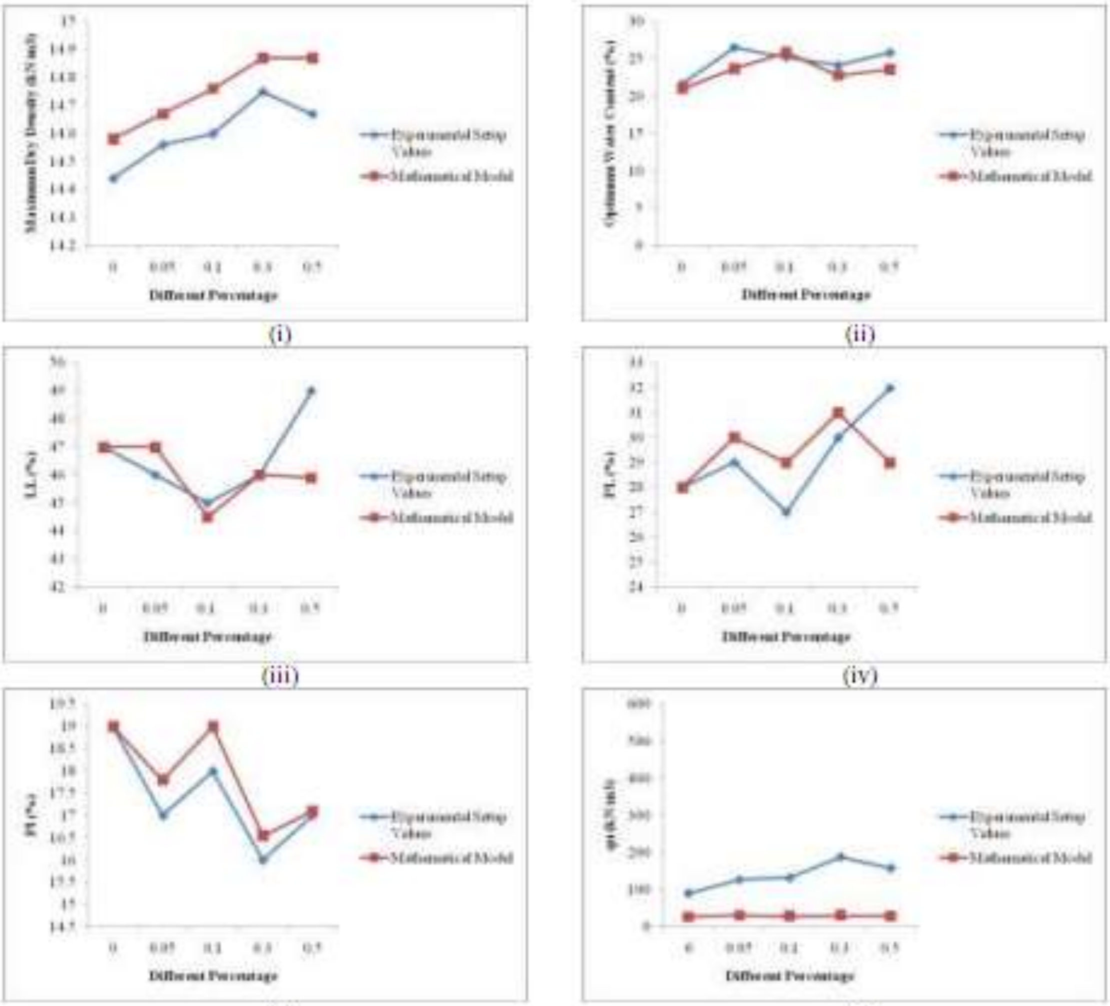
Geotechnical Properties	**Mathematical Model**				
	Sample Soil	**NanoCu at 1.0 (%)**	**NanoAl$_2$O$_3$ at 0.5 (%)**	**NanoClay at 0.3 (%)**	**NanoMgO at 0.4 (%)**
Maximum Dry Density (kN/m^3)	45.05	15.19	14.87	14.64	14.87
Optimum Water Content (%)	21.60	26.49	23.59	23	25.78
LL (%)	47	67.2	45.9	48	49
PL (%)	28	29.1	29	30	30
PI (%)	19	29.7	17.1	18	18.2
qu (kN/m^3)	90	28	29	32	28

The graphical representation of the proposed mathematical and experimental performance is shown in figure 1, 2, 3 and 4.



(i) (ii) (iii) (iv) (v) (vi)

Fig-1: Comparison graph between experimental and mathematical model for NanoCu mixture soil geotechnical properties (i) Maximum Dry Density (ii) Optimum Water Content (iii) LL (iv) PL (v) PI (vi) qu

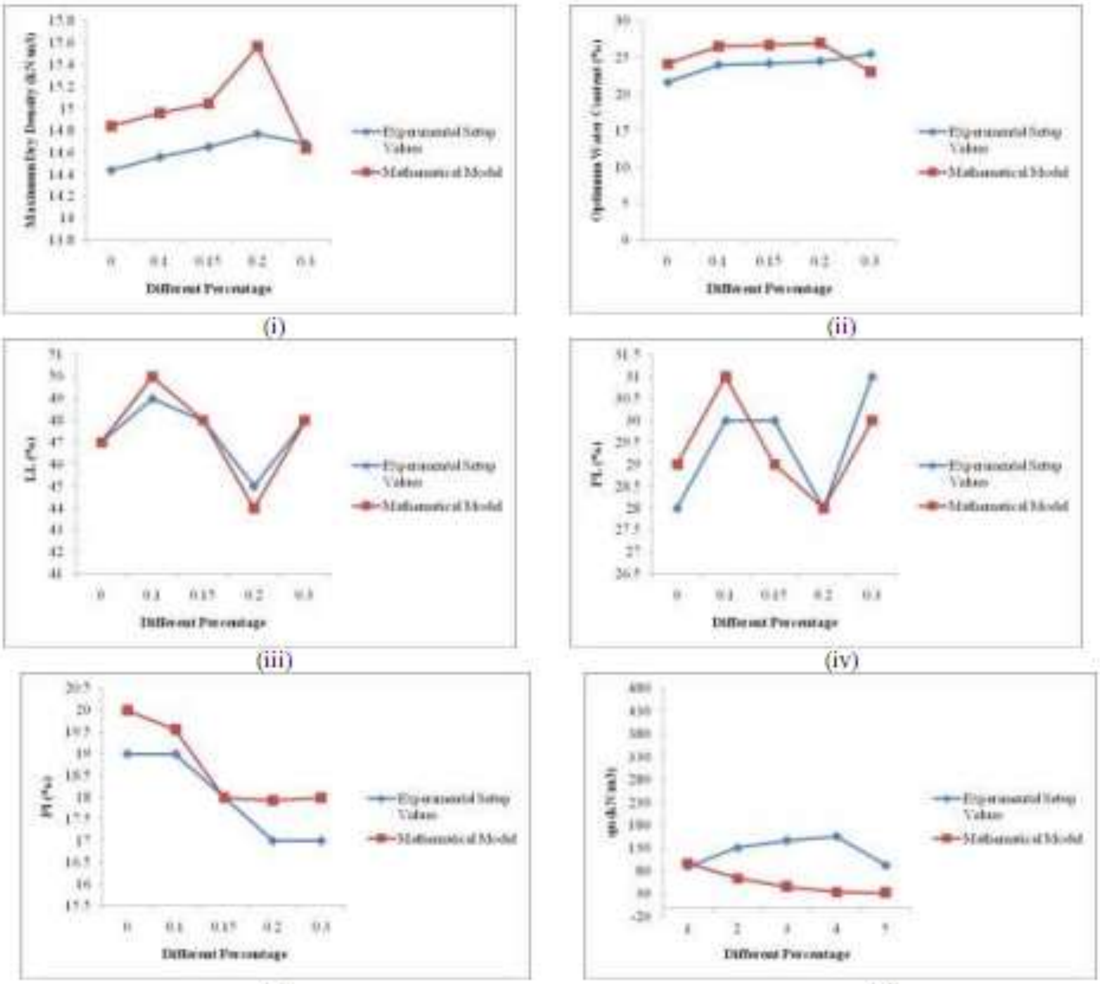


(i) (ii)

(iii) (iv)

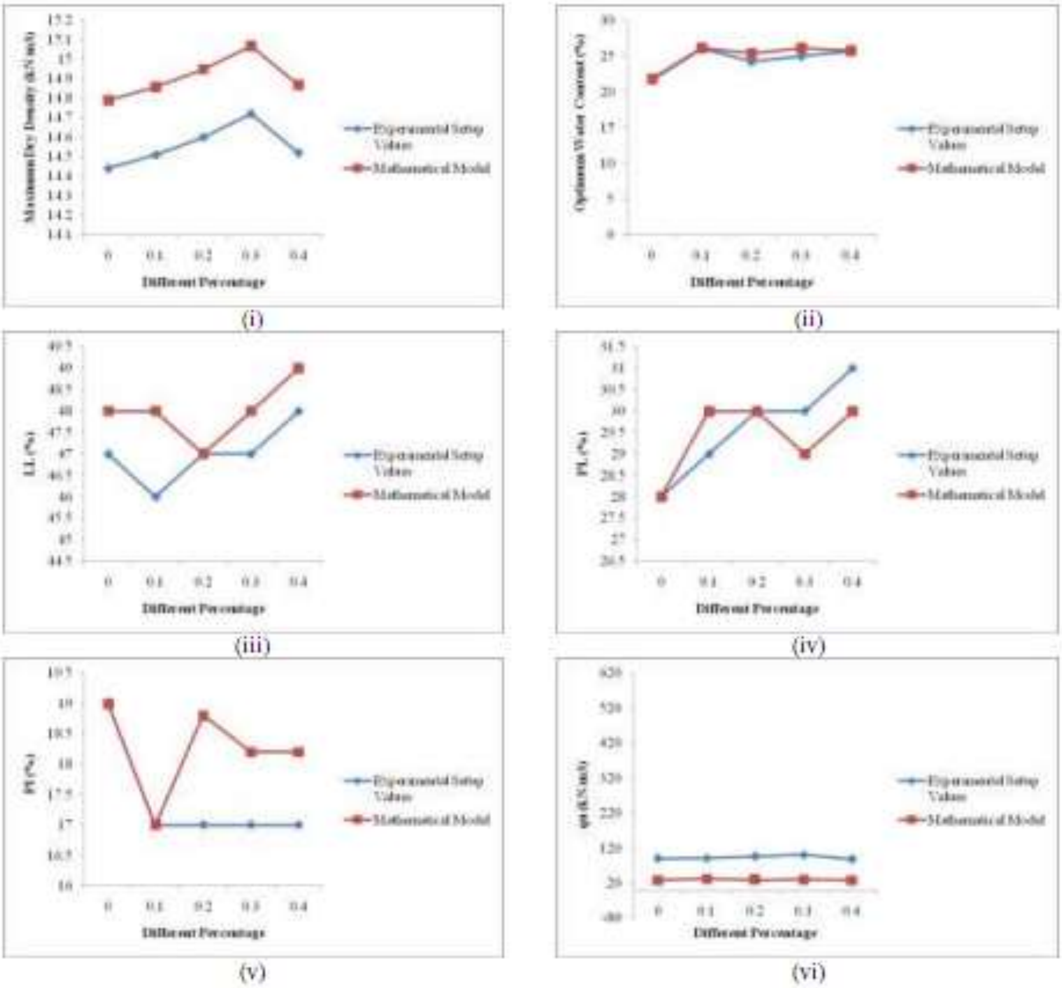
(v) (vi)

Fig-2: Comparison graph between experimental and mathematical model for NanoAl$_2$O$_3$ mixture soil geotechnical properties (i) Maximum Dry Density (ii) Optimum Water Content (iii) LL (iv) PL (v) PI (vi) qu



(i) (ii) (iii) (iv) (v) (vi)

Fig-3: Comparison graph between experimental and mathematical model for NanoClay mixture soil geotechnical properties (i) Maximum Dry Density (ii) Optimum Water Content (iii) LL (iv) PL (v) PI (vi) qu



(i) (ii) (iii) (iv) (v) (vi)

Fig-4: Comparison graph between experimental and mathematical model for NanoMgO mixture soil geotechnical properties (i) Maximum Dry Density (ii) Optimum Water Content (iii) LL (iv) PL (v) PI (vi) qu

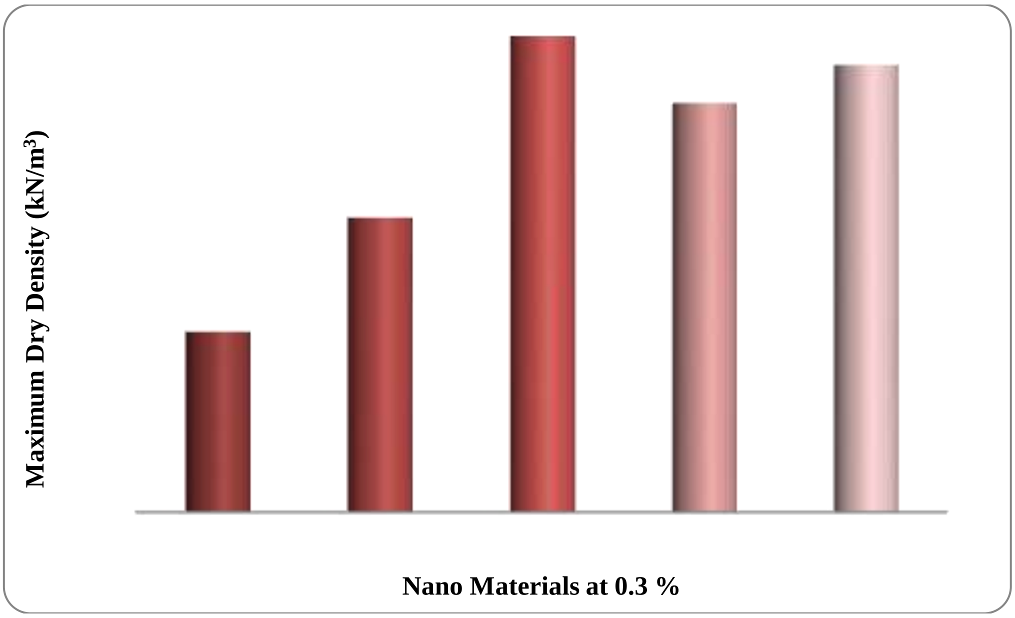


Fig-5: Performance Deviation of the different nano materials Maximum Dry Density geotechnical property at the percentage 0.3

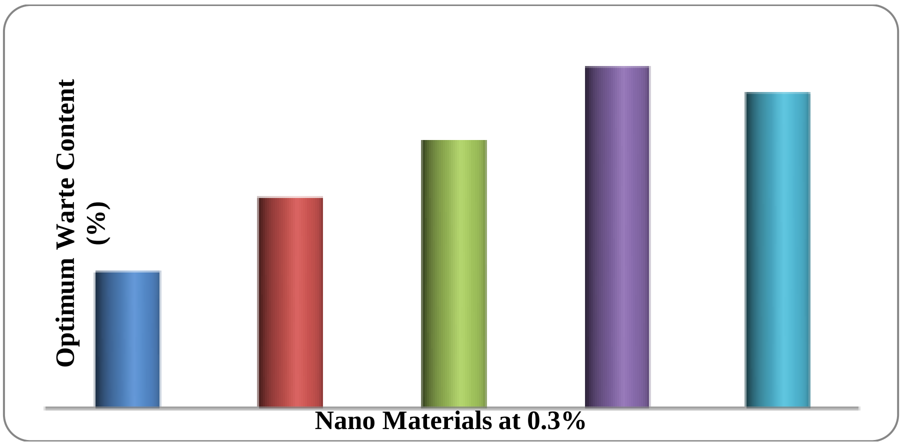


Fig-6: Performance Deviation of the different nano materials Optimum Water Content geotechnical property at the percentage 0.3

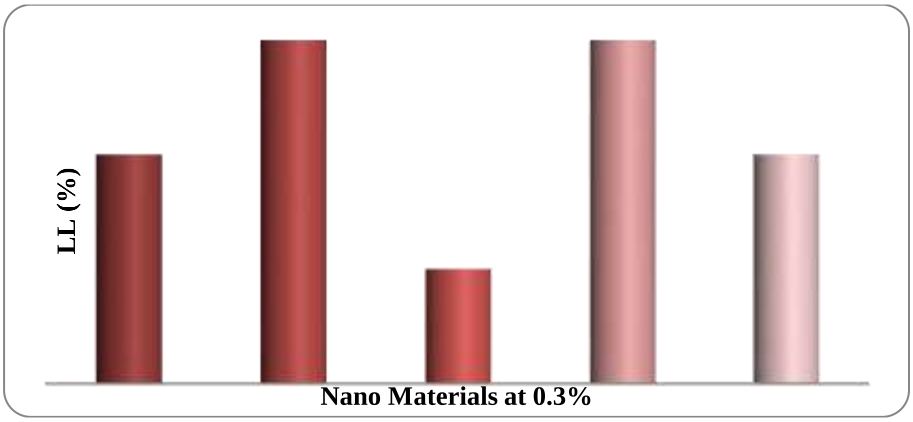


Fig-7: Performance Deviation of the different nano materials LL geotechnical property at the percentage 0.3

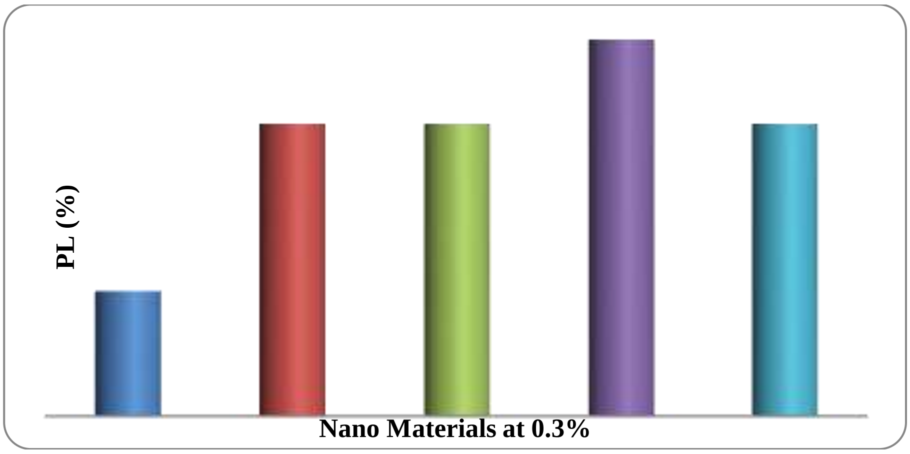


Fig-8: Performance Deviation of the different nano materials PL geotechnical property at the percentage 0.3

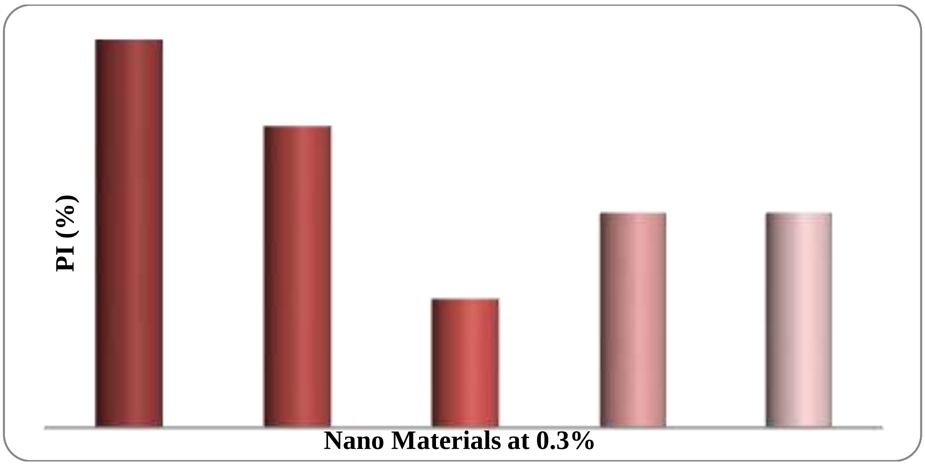


Fig-9: Performance Deviation of the different nano materials PI geotechnical property at the percentage 0.3

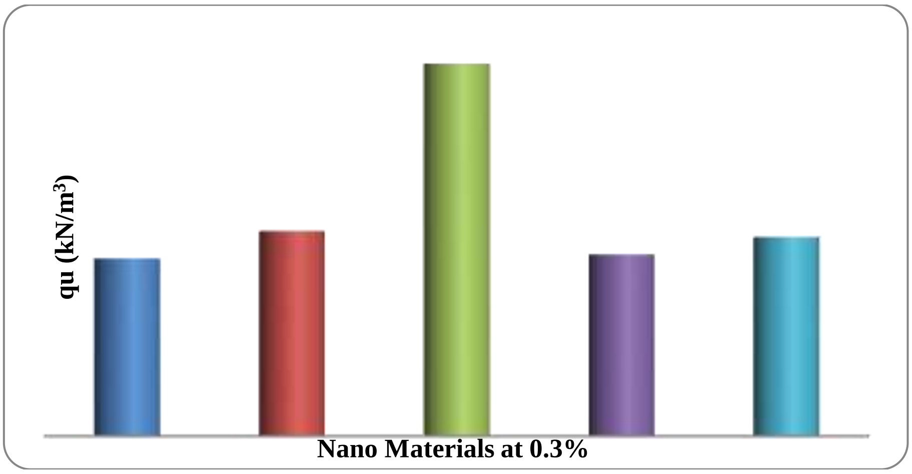


Fig-10: Performance Deviation of the different nano materials qu geotechnical property at the percentage 0.3

DISCUSSION

Fig. 1 to 4 shows that the mathematical model performance is almost near to the experimental values. But in some graphs, the mathematical model performance was low than the experimental values. This result shows that the values of both these models are well balanced to each other.

The deviation values of geotechnical properties of both the sample soil and the nano mixture soil are illustrated in Figure 5, 6, 7, 8, 9 and 10. This process proves that the nano mixture soil geotechnical properties level is high compared to the sample soil geotechnical properties.

As can be seen from figure 5 to 10, the sample soil geotechnical properties level is low compared to the nano mixture soil geotechnical properties level. In Fig. 5, the maximum dry density property is high for the nano material soil Al_2O_3 i.e., the sample soil was combined with the nano material Al_2O_3 at the percentage 0.3. Moreover, the other nano mixtures have also shown high deviation than the sample soil but it is low compared to nano material Al_2O_3. In Fig. 6, the soil optimum water content property level is high when the sample soil was combined with the nano Clay at the percentage 0.3. Also, the water content property level of nano MgO is only little lower than the nano Clay. The next geotechnical property liquid limit (LL) in Fig. 7 has shown the same level for the nano materials Cu and Clay, and also this geotechnical property level of the sample soil has shown small deviation compared to the nano material mixture results. The plastic limit (PL) geotechnical property level is high for the nano material Clay, which is shown in Fig. 8. The properties from sample soil were very low compared to the other nano mixtures. The plasticity index (PI) geotechnical property of sample soil is high than the nano mixtures at the percentage 0.3. Among the different nano mixtures, the nano Al_2O_3 has shown very low performance, which is illustrated in Fig. 9. The nano material Al_2O_3 has shown high performance only in the geotechnical property of unconfined compressive strength (qu). But, this qu geotechnical property level for the sample soil and other nano materials was very low compared to the performance of nano Al_2O_3.

CONCLUSION

In this paper, the natural soil sample was collected from the USM Engineering Campus in Nibong Tebal, Pulan Pinang. The different geotechnical properties of the soil sample and nano mixture soil were calculated. Here, four different nano materials were experimented. The developed mathematical model has found the optimal geotechnical property value of the nano material mixture with different percentage for unknown experiments. Thus, our proposed technique proves that the nano material mixture was better than the natural soil geotechnical properties. Hence, our proposed technique reduces the drawbacks of existing methods and also found the optimal geotechnical property value by the developed mathematical model.

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