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Deformation Characteristics of Lime Stabilized Marine Clay Using Finite Element Method

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Abstract

The coastal area is one of the environmentally vulnerable areas, with soil characteristics such as weak soil and marine clay, which is classified as hazardous soft soil. Because marine clay has poor mechanical and physical properties, foundation conditions such as pad footing were unstable and prone to corruption. As a result, the lime column will be used to stabilize marine clay in this study. The purpose of this research is to investigate the deformation of marine clay with lime to increase shear strength and reduce excessive settlement by analyzing data from previous studies and conducting a review of the literature, as well as to investigate the deformation of untreated and treated marine clay with lime columns and PLAXIS software projection. Compared to the traditional method, PLAXIS 2D software is one of the most cost-effective ways to test a foundation, such as the pad footing. At the same time, PLAXIS 2D was able to shorten the time required to achieve an analytical result. The results of the settlement and stress value have been taken after the computation and analysis from PLAXIS 2D. The greatest percentage difference between untreated and treated marine clay for stress and displacement is 81.82 percent and 7.98 percent, respectively.

1. Introduction

Clay that is found in marine environments is a form of loamy soil known as marine clay. Marine clay can be found both offshore and along coastlines. According to [1], enormous amounts of coastal clay soil are often associated with poor technical characteristics such as low shear strength, high compressibility, and low permeability. These are only a few examples. The significant amount of moisture it contains is the primary reason why people consider it hazardous. There is a form of clay known as montmorillonite, which swells and shrinks in response to variations in the amount of moisture present in the soil. It contracts and expands during the dry season, while during the wet season, it does the opposite: it contracts and grows. Even minute changes in the amount of moisture present might result in undesirable physical changes such as shrinkage and swelling [2].

2. Materials and Methods

Fig. 1 shows the study methodology flow chart of this study. The soil material, the properties of the lime column, and the pad footing data have been obtained from the literature, and the simulation and deformation of the soil before and after treatment by the lime column by using the PLAXIS 2D.

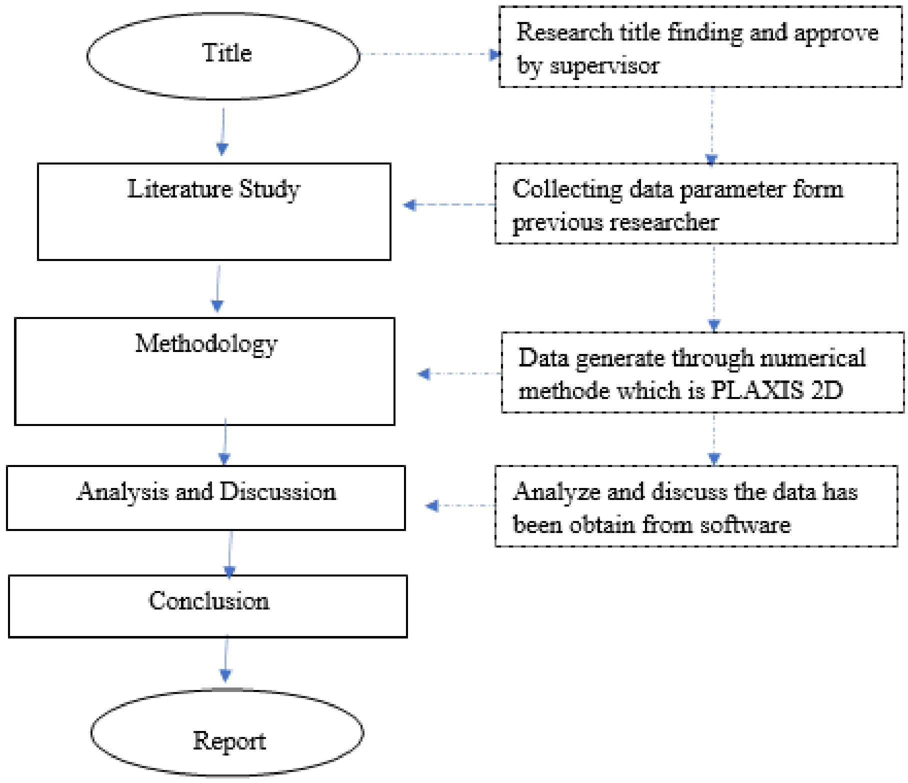

Fig. 1 *Methodology flowchart*

2.1 Types of Soil Used for PLAXIS Simulation

The foundation which is pad footing was discovered in the problematic soil which is marine clay, resulting in the foundation failure and rupture. Therefore, the marine clay at the pad footing circumstance was treated with the lime column. The marine clay soil model in the PLAXIS simulation has a height of 14 m and a width is 14 m. Then it was simulated by the PLAXIS 2D to generate the deformation that needed to be discussed.

2.2 Sets of Material

The material set allows the selection of material and model from a material model box. To generate the improvement in deformation and strength of the marine clay, a model and material parameters must be assigned to the geometry. PLAXIS collects soil characteristics into material data sets, which are kept in a material database. The Table 1 shows the parameters for the marine clay, Table 2 show the parameter for lime column, and Table 3 show the parameter for pad footing. In this simulation, the load applied on pad footing were 20 kN/m^2, 40 kN/m^2, and 60 kN/m^2. The marine clay was modeled in 2 conditions, two sets of geometric models of marine clay were simulated, the first model is for the untreated condition with pad footing and the second model is marine clay treated with the lime column at pad footing.

3. Results and Discussions

The results for deformation on marine clay are presented in terms of graph with linear regression to shows the different improvement for untreated and treated marine clay. The results that have been observed in the PLAXIS software were total displacement and effective stress for both conditions.

J. of Sustainable Underground Exploration Vol. 3 No. 2 (2023) 13-22

Table 1 *Parameters for marine clay properties [3]*

Model	Symbol	Unit	Value
Soft soil creep model	-	-	-
Undrained	-	-	-
Unit weight above phreatic level	γ_{unsat}	kN/m³	15
Unit weight below phreatic level	γ_{sat}	kN/m³	14
Permeability	k_x & k_y	m/day	1.45×10^{-4}
Poisson's ratio	v	-	0.5
Cohesion constant	$C_{untreated}$	kN/m²	3
Friction angle	ϕ	°	22
Dilamatancy angle	ϕ	°	0
Unit weight of water	γ_{water}	kN/m³	10

Table 2 *Parameters for lime column properties [4]*

Name	Unit	Value
Diameter	m	0.8
Length	m	9
Unit weight, (γ_c)	kN/m³	18
Poisson ratio	-	0.45
Modulus Elasticity (E)	kN/m²	7500
Shear strength (c_u)	kN/m²	100

Table 3 *Parameters for pad footing [5]*

Thickness (m)	Elastic Modulus (kN/m²)	Poisson's Ratio	Density (kN/m³)
0.2	3×10^7	0.2	24

3.1 Deformation for the Footing of the Loading Pad for Both Conditions

Fig. 2 shows the deformation of the marine clay under untreated conditions. The settlement of the total displacement under that condition is 0.0036 m. This condition was that noload was applied to the pad footing. While Fig. 3 depicts the deformation of marine clay in the absence of treatment. As a result, the overall displacement is 0.00451 m. The pad footing was not under any load at the time of this condition. This deformation demonstrates that the marine clay has improved before the imposition of load at the pad footing. Deformation is reduced in the treated marine clay compared to the untreated marine clay. As stated by [6], based on field testing, reported that the lime columns could operate as vertical drains and succeeded in stabilizing the soil. Displacement is improved by 20% when treated marine clay is used instead of untreated marine clay. When comparing the deformation of untreated and treated marine clay, the lime column was successful in improving the marine clay.

3.2 Deformation of Marine Clay for Untreated and Treated Marine Clay

It is shown in Fig. 4 how much untreated marine clay soil was deformed when given a 20 kN load at a predetermined node. When 20 kN of force is applied, it causes 0.016 m of soil displacement. While Fig. 5 shows the deformation of untreated marine clay when 40 kN of force is applied and the soil displacement is 0.039 m, as shown. Using 60 kN of force, the displacement is 0.13 m in Fig. 6. From Fig. 7 it can show that the highest displacement was 0.13m which is 60 kN of load applied. The displacement of the soil for all the applied loads does not have a big difference in displacement.

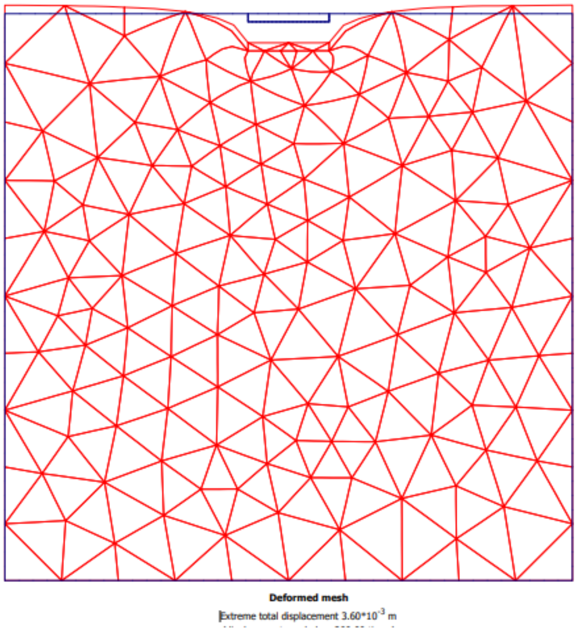

Fig. 2 *Untreated marine clay*

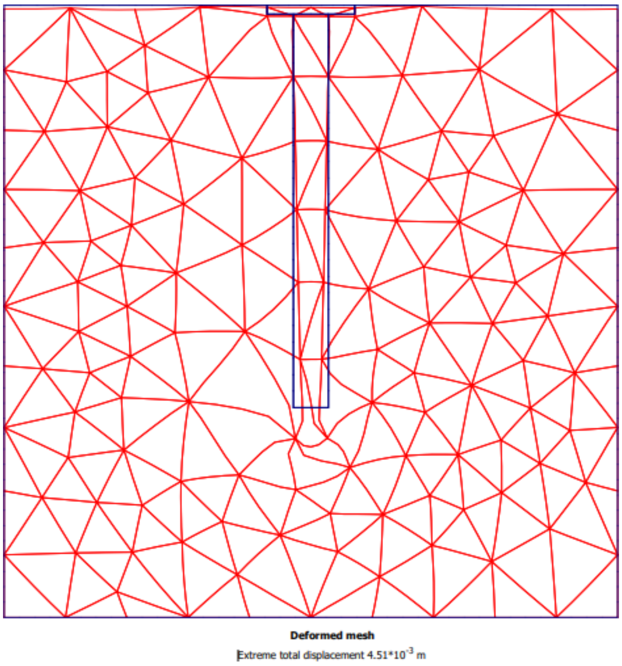

Fig. 3 *Treated marine clay*

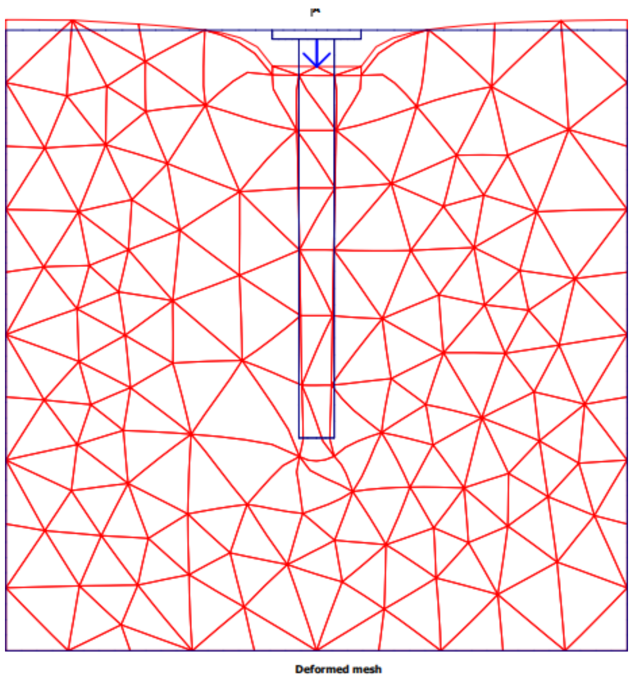

Fig. 4 *Load applied 20 kN*

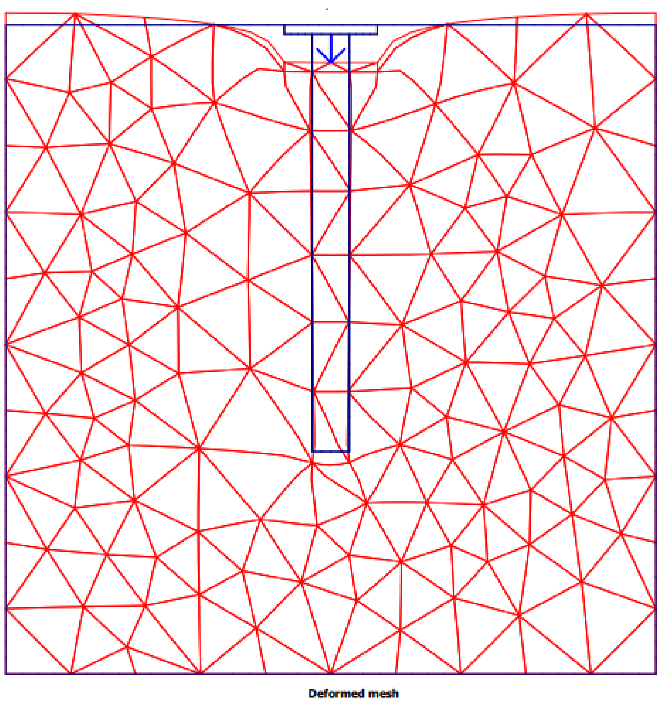

Fig. 5 *Load applied 40 kN*

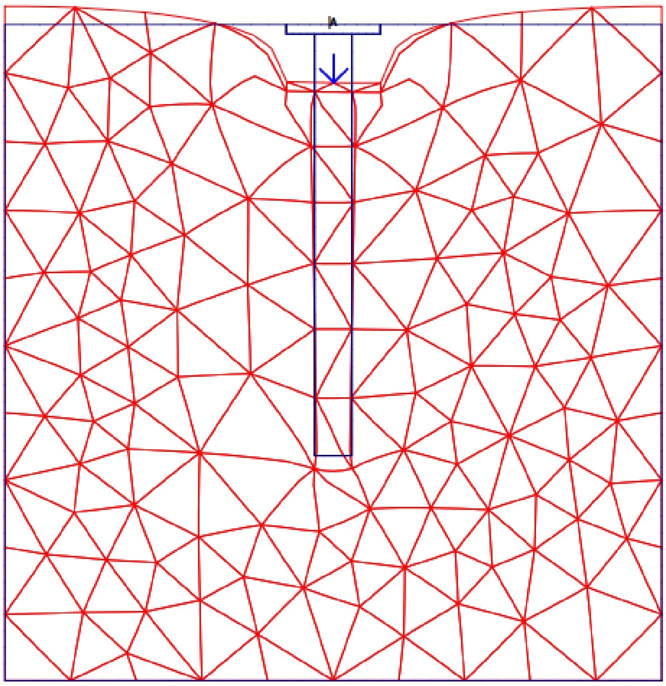

Fig. 6 *Load applied 60 kN*

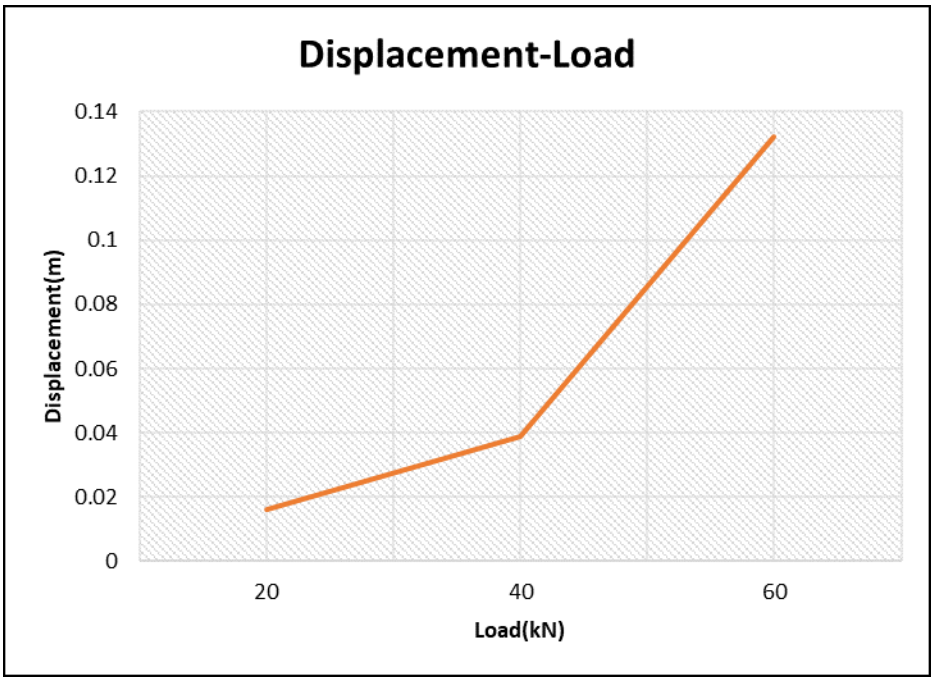

Fig. 7 *Displacement-load graph*

Figure 8 shows the deformation mesh for the treated marine clay soil when it was applied with a load of 20 kN. The displacement on the soil under this condition is 0.008 m. While Figure 9 shows the deformation of the treated marine clay soil was applied with a 40 kN load. It generates 0.013m of displacement of soil. In Figure 10, it is shown that the deformation of the soil when 60 kN of the load is applied. It shows that 0.024 m displacement of marine clay produces. When compared to the displacement of the untreated marine clay, it shows an improvement in the decrease of displacement of the soil.

J. of Sustainable Underground Exploration Vol. 3 No. 2 (2023) 13-22

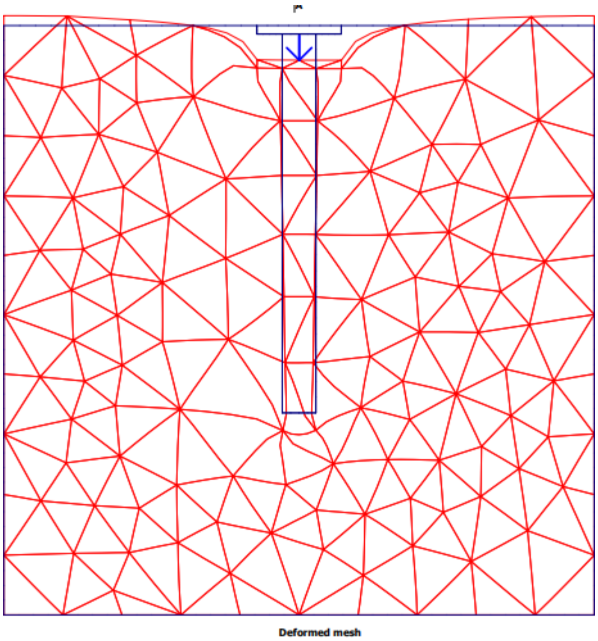

Fig. 8 *Load applied 20 kN*

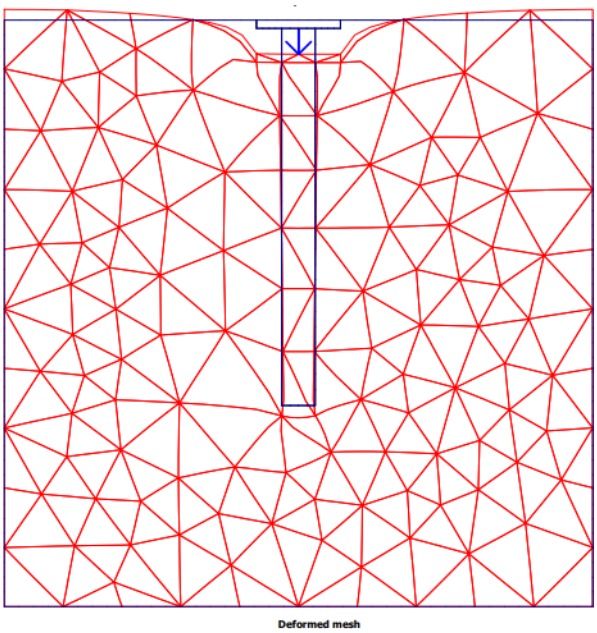

Fig. 9 *Load applied 40 kN*

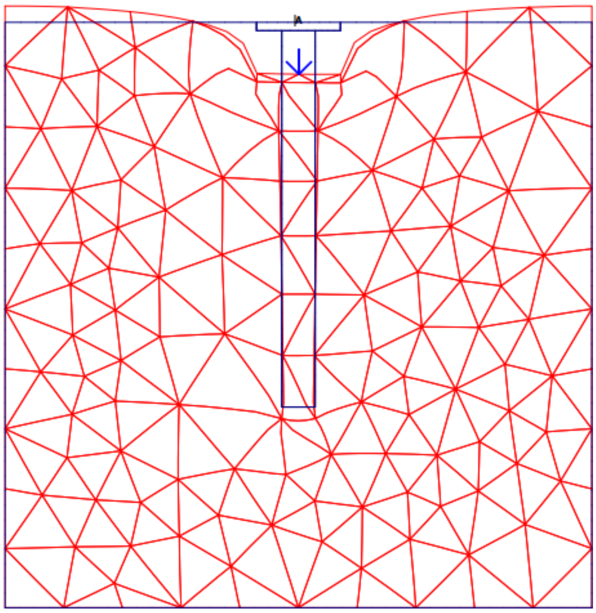

Fig. 10 *Load applied 60 kN*

The maximum displacement, as shown in Figure 11, was 60 kN or 0.024 m. In terms of displacement, all applied loads have little to no difference. This graph illustrates that marine clay soil has improved in terms of displacement. This suggests that lime columns used to cure coastal clay are effective. Untreated and treated footings have a 50% difference in displacement when 20 kN of force is applied. As a result, there is a 50% improvement in displacement of untreated marine clay as a result. The displacement difference between untreated marine clay and treated marine clay is 66.67 percent when a 40 kN load is applied to the foundation. This suggests that after treatment, the treated marine clay improves displacement by 66.7%. When subjected to a 60 kN force, the treated marine clay deviates by 81.82 percent in terms of displacement. Using data from [3], the percentage of displacement that is different when 10 kN of load is imposed on the foundation after the treatment of marine clay by using PU foam is 90% in the same parameter of marine clay properties. This shows that lime column can also be used to cure coastal clay.

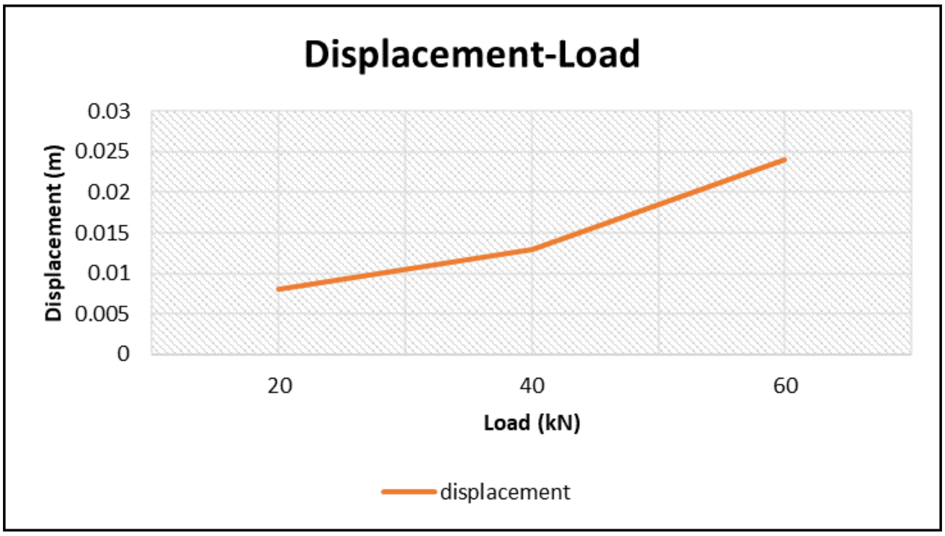

Fig. 11 *Displacement-load curve*

3.3 Stress Deformation of Marine Clay for Untreated and Treated Marine Clay

Figure 12 shows the highest stress which is 200.28 kN/m^2 when the displacement is at 0.039 m. There is a stress displacement curve depicted in Figure 13. Marine clay treated with a lime column shows a decrease in stress as shown by the curve. There is a significant difference between Figure 12 and Figure 13 in displacement (0.016 m) and stress (198.84 kN/m^2). It demonstrates that the marine clay's soil physical qualities have been improved by the treatment with the lime column. When the foundation is subjected to a load of 20 kN, the percent difference in stress has increased to 3.94%. It shows an increase in marine clay after treatment. When a 40 kN load is applied to both circumstances, the percentage difference in stress increases to 4.09%. An additional 7.98% difference in stress is seen when 60 kN of the load is applied to foundations under both conditions. It demonstrates that after being treated with a lime column, the strength of the marine clay has improved. As stated by [7] that untreated marine clay had a shear strength of 16 kN/m^2 and supported [5] mentioned that the lime treatment was able to boost the strength 8 to 10 times over the untreated clay. As a result, lime treatment has been shown to increase marine clay's strength.

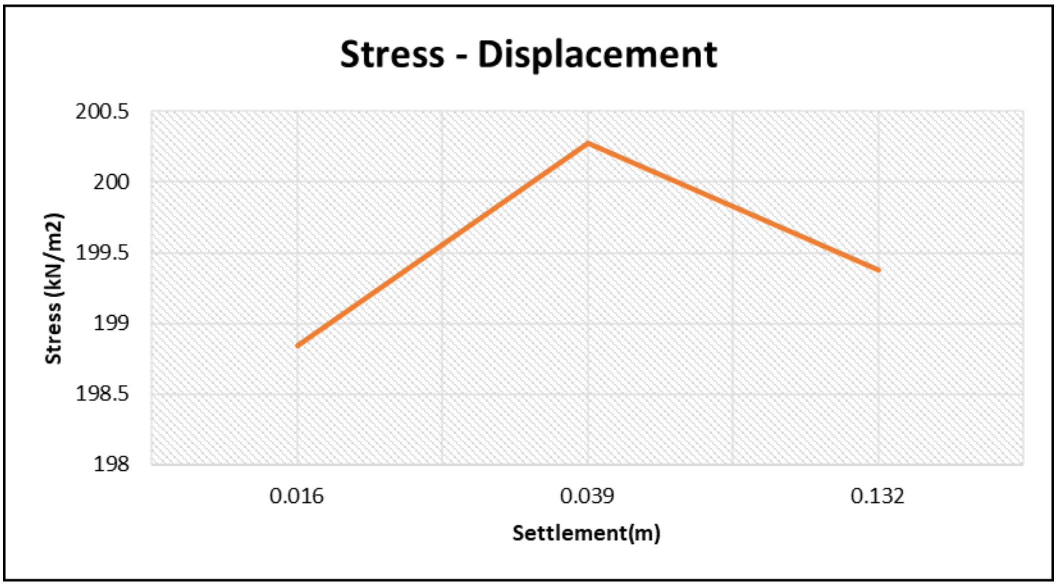

Fig. 12 *Stress-displacement for untreated marine clay*

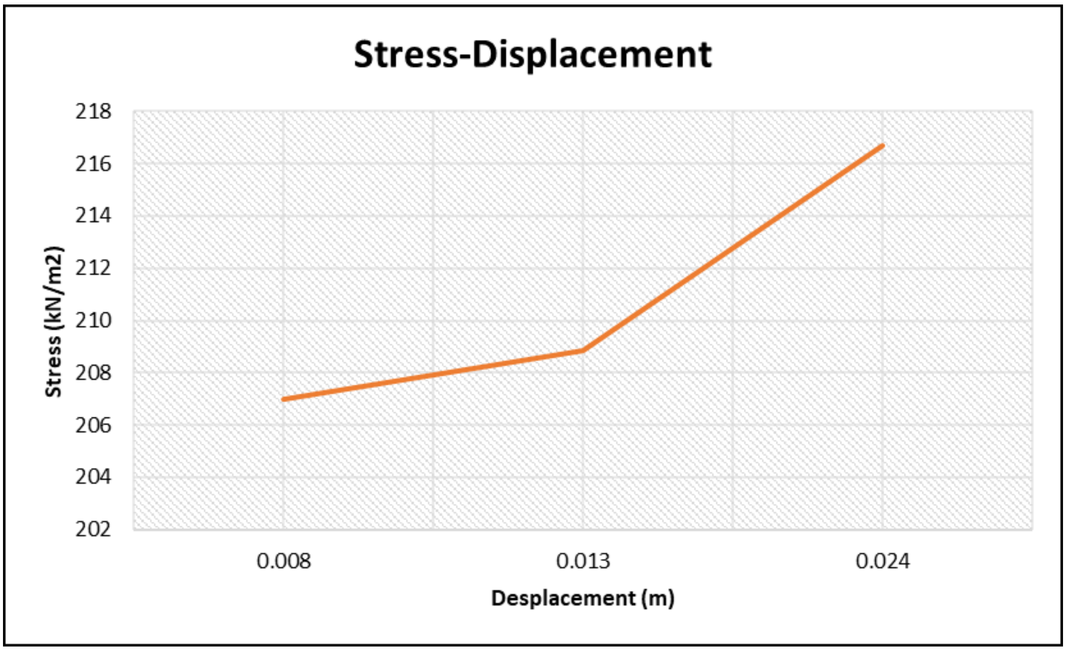

Fig. 13 *Stress-displacement for treated marine clay*

4. Conclusion

The laboratory test results were compiled based on the findings of the previous investigation. Unloaded, the distortion is a little bigger. Loads of these three kinds came from the same source 20 kN, 40 kN and 60 kN are administered as appropriate. As a result, each of the three goals has been met. The primary goal of this investigation was to confirm prior findings about soil physical and mechanical properties. Furthermore, PLAXIS 2D was effectively used to examine the deformation of lime-treated marine clay and left untreated. To study the effect of lime on the deformation of marine clay by improving the shear strength and reducing excessive settling. The percentage of displacement that differed between the two conditions when 20 kN, 40 kN, and 60 kN were imposed was 50%, 66.7%, and 81.82%. The treatment of the lime column resulted in a significant increase in displacement at a load of 60 kN. There is a 3.94%, 4.09%, and 7.98% difference in stress reduction percentages. It demonstrates that a load of 60 kN imposes the greatest stress improvement for marine clay. It's clear that soil strength and displacement improve following lime column treatment because of the maximum load impost, which is 60 kN, showing the greatest improvement in displacement and stress.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Zeety Md Yusof;* ***data collection:*** *Mohammad Raihan Bohari;* ***analysis and interpretation of results:*** *Mohammad Raihan Bohari;* ***draft manuscript preparation:*** *Mohammad Raihan Bohari, Zeety Md Yusof. All authors reviewed the results and approved the final version of the manuscript.*

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