© Universiti Tun Hussein Onn Malaysia Publisher's Office

J-SUE

http://publisher.uthm.edu.my/ojs/index.php/j-sue

e-ISSN : 2821-2851

Journal of Sustainable Underground Exploration

Deformation Characteristics of Lime Stabilized Clay Soil Using Finite Element Method

Ain Soraya Roslan[1], Zeety Md Yusof[1]*

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jsue.2022.02.01.001
Received 02 October 2022; Accepted 09 November 2022; Available online 30 November 2022

Abstract: Clay soil provides a poor working platform due to its plastic characteristics that could affect a structure's safety and other common structure failure including excessive foundation settlement, the production of cracks in the superstructure and other structural element failure. Thus, there is a challenge for clay soil to be a support for a foundation. The objective of this study is to compile a set data from past research studies that include the parameters of untreated and treated clay soil properties as to be used in the PLAXIS 2D generate its deformation over no load and 100 kPa stress as well as increasing its shear strength and reduce the excessive settlement. Accordingly, the suitable lime content to improve clay strength can be determined. The numerical analysis is done by running the parameters collected from previous studies in PLAXIS 2D in order to generate the final deform soil. The soil with lime content 0%, 3%, 6%, and 9% deformed under both without and with loading of 100 kPa. The result that can be observed from the deformed soil, the treated clay behaved well under loading compared to the untreated. From the result, the amount of lime content did affect the properties of the soil by showing the settlement of each soil and the deformation pattern.

Keywords: Clay soil, foundation, lime content, PLAXIS 2D

1. Introduction

Gravel, sand, silt, and clay are the four classes of soil, and they are the most commonly used materials in civil and structural engineering buildings. Soil is utilized as a supporting foundation for buildings in addition to being used as a building material in a wide range of civil engineering projects. However, not all soils can be used for building, and some of them may need to undergo treatment in order to increase their shear strength such as clay soil. This is due to the fact that clay soil provides a poor working platform due to its plastic characteristics, causing construction delays (Iyappan & Geetha, 2016). As a result, the soil compressibility affects a structure's safety just as much as the poor shear strength. Untreated clay soil has a number of effects, including excessive foundation settlement, structure uplift, and the production of cracks in the superstructure, all of which can contribute to structural element failure. Consequently, clay is one type of soils which frequently stabilized due to its plastic and cohesive properties when wet. This because the particles of certain minerals giving plastic properties when mixed with water (Hastuty et al., 2018).

In high water content, clay soil becomes sticky and soften that will results in the soil swelling and shrinkage relatively fast (Arun Kumar et al., 2020). Therefore, clay stabilization is necessary to repair soil's mechanical properties as well as increase the bearing capacity and minimize their compressibility. In this study, the method used for soil stabilization is by stabilize clay soil with lime. It is the process of combining soil with lime to change the qualities of the soil so that it can be used for engineering works such as for the construction of a building. Lime reacts with soil water, altering its characteristics and reducing soil cohesion and softness. When lime and clay minerals react, a stiff gel called calcium silicate is formed, which binds to soil fine-grains or particles (Firoozi et al., 2017). Silica gel responds by coating and binding clay particles in the soil, covering the pores and lowering the plasticity index. The

Corresponding author: zeety@uthm.edu.my

decrease in the plasticity index is due to a rise in the plastic limit and a decrease in the liquid limit (Hastuty et al., 2018).

Contributed all the parameters of clay were deformed when subjected to loads. For clay soil, the load-deformation relationship is usually complex. A previous study from (Jamil et al., 2022) as simulated the stability of the performance foundation by applied the parameters from laboratory testing using the software to perform deformation and stability analyses.

1.1 Research Objective

The objective of this study is to determine the physical and mechanical parameters of soil materials based on previous study. To investigate the deformation of untreated and treated clay with lime. Lastly, to investigate the deformation of clay with lime by increasing the shear strength and reducing excessive settlement.

2. Methodology

There are several steps that need to be taken in order to accomplish the study purposes. Such measures are important since it provides a better understanding of the mechanism and the flow of this numerical analysis. The appropriate material model were chosen after reading and interpreting the necessary literature materials and the parameters needed were also selected and specified.

2.1 Data Collection

Untreated and treated soil were each given an own set of design parameters for this modelling. The model's parameters, which are listed in Table 2.1, were collected from previous studies and the data offers the parameters that were employed in this investigation based on the determined properties parameters.

2.2 Methods

The modelling and analyzing tool used in PLAXIS 2D. A soil fill model illustrates the dimension of 14 m depth of clay soil with the raft foundation on top of the sloil surface. The dimeansion of the foundation is 4 m x 4 m x 0.15 m.

2.3 Soil Parameter

The soil parameters that provided in this modelling were divided into untreated and treated soil. The parameters value that used in the model as shown in Table 2.1 were considered and assigned accordingly. The data from prior study laboratory tests were utilized, as well as certain parameters related to natural clay soil that had been proposed by previous researchers in their past studies.

Table 2.1 - Clay soil properties of untreated and treated

a) Untreated Clay Soil Properties

Parameter	Name	Value	Unit
Unit weight above phreatic level	γ_{unsat}	16.75-17	kN/m^3
Unit weight below phreatic level	γ_{sat}	16	kN/m^3
Permeability	k_x & k_y	0	m/day
Young's modulus	E	1200-2000	kN/m^2
Poisson's ratio	υ	0.3-0.4	-
Friction angle	φ	17-24	°
Dilatancy angle	ψ	0	°
Cohesion	c	8-25	kN/m^2

b) Treated Clay Soil Properties (3% lime)

Parameter	Name	Value	Unit
Unit weight above phreatic level	γ_{unsat}	15.88-16.10	kN/m^3
Unit weight below phreatic level	γ_{sat}	16-22	kN/m^3
Permeability	k_x & k_y	0	m/day
Young's modulus	E	420-840	kN/m^2
Poisson's ratio	υ	0.3-0.4	-
Friction angle	φ	18.7	°
Dilatancy angle	ψ	0	°

Cohesion	c	57.9	kN/m^2

a) Treated Clay Soil Properties (6% lime)

Parameter	Name	Value	Unit
Unit weight above phreatic level	γ_{unsat}	14.1-15.64	kN/m^3
Unit weight below phreatic level	γ_{sat}	16-22	kN/m^3
Permeability	k_x & k_y	0	m/day
Young's modulus	E	1050-1400	kN/m^2
Poisson's ratio	υ	0.3-0.4	-
Friction angle	φ	20.5	°
Dilatancy angle	ψ	0	°
Cohesion	c	19-35	kN/m^2

b) Treated Clay Soil Properties (9% lime)

Parameter	Name	Value	Unit
Unit weight above phreatic level	γ_{unsat}	14-18.8	kN/m^3
Unit weight below phreatic level	γ_{sat}	16-22	kN/m^3
Permeability	k_x & k_y	0	m/day
Young's modulus	E	1750-2800	kN/m^2
Poisson's ratio	υ	0.3-0.4	-
Friction angle	φ	22.3	°
Dilatancy angle	ψ	0	°
Cohesion	c	81.4	kN/m^2

2.4 Soil Fill Model

This study assumed that a small storage room is about to be built on a clayey soil site and its foundation type is raft foundation. Mohamed & Bahloul (2021) suggested the depth for the soil fill model for be 14 m. Figure 1 shows the model of a resting 4 m x 4 m x 0.15 m raft foundation on the clay soil. The geometry model will be generated for this study as to be run in the software to see how the clay soil settle and how it deforms under 100 kPa loading applied on it.

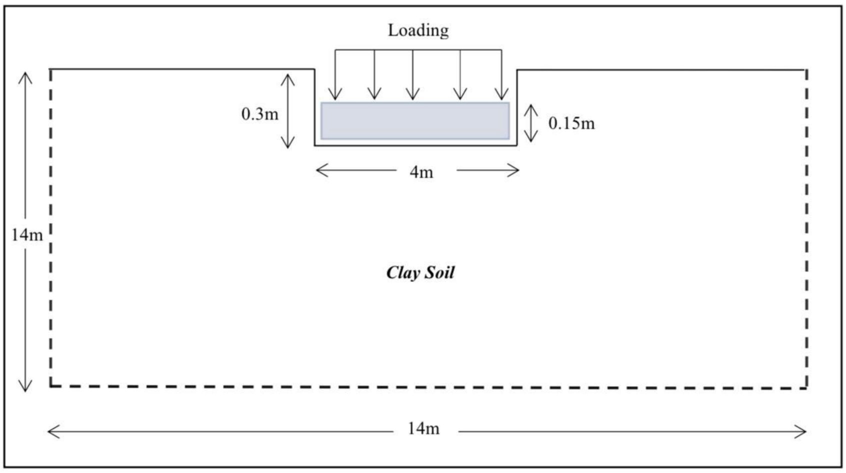


Fig. 1 - Geometry model of raft foundation on clay soil

3. Results and Discussion

The soil fill model were made analysed with different conditions including the unloaded of unteated and treated clay as well as the loaded of untreated and treated clay. The load used in this analysis was 100 kPa. The deformation mesh of the model with each condition is shown in the figure 2, figure 3, figure 4.

3.1 Deformation Mesh

The results consist of the unloaded treated and untreated clay soil mesh and the loaded treated and untreated clay soil mesh. Therefore, the first deformation mesh was conducted to show the deformation of the unloaded treated and untreated clay soil. While for the second deformation mesh was performed to show the deformation of the loaded untreated and treated clay soil. The load is set to 100 kPa to see how the variation of lime content in the clay soil would behave under the load.

3.1.1 Untreated

Figure 2 shows the result of the deformation of the untreated clay soil from the numerical analysis using PLAXIS 2D. It already observed that there is slight settlement of the soil model. This is because the deformation mesh does not play with any load. In other context, Figure 2 is the outcome of the unloaded and untreated clay soil.

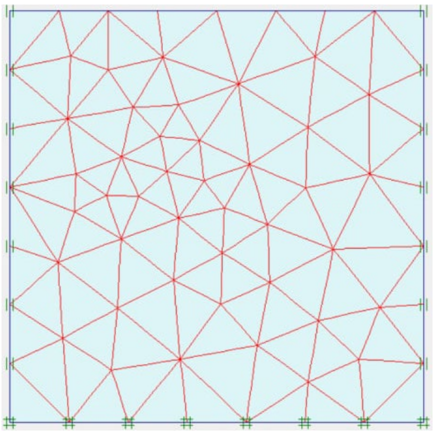
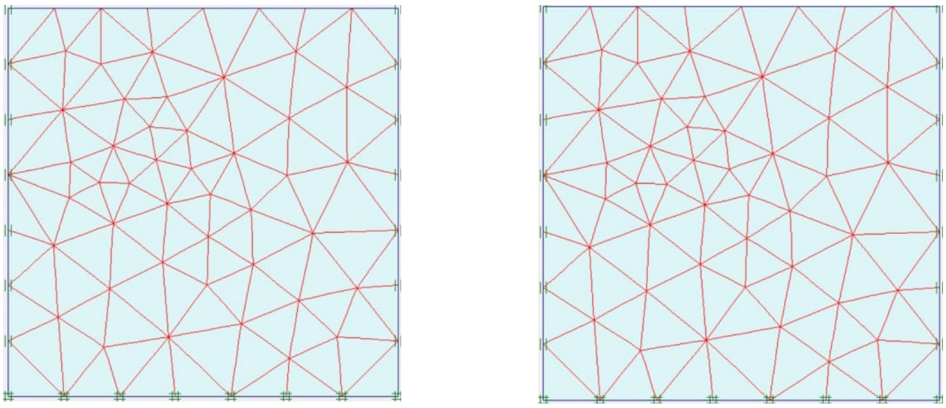


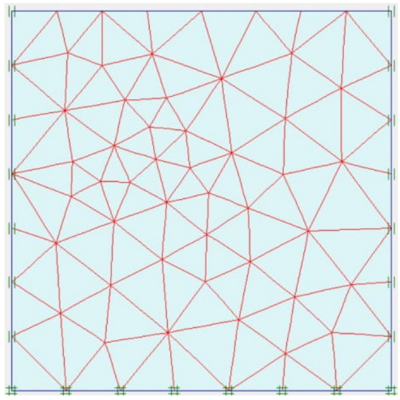
Fig. 2 - Deformation mesh of unloaded unteated clay soil

3.1.2 Treated

Figure 3 shows the result of the deformation of the treated clay soil from the numerical analysis using PLAXIS 2D. The treated clay soils are the clay soil that contained 3%, 6%, and 9% lime accordingly and as labeled in the figure. Compared with Figure 2, the treated deformation mesh should show a better performance than the deformed mesh of the untreated. Since the properties of the soil is improved when treated, the soil settled but not too obvious compared to the untreated. This is due to the settlement decreases in magnitude with an increase in lime content, although not linearly. Notice that, four of the deformed soil figures showed almost similar pattern of deformation during the numerical analysis. This is clearly because this part of analysis did not use any load to apply on top of the soil's surfaces.



3% 6%



9%

Fig. 3 - Deformation mesh of unloaded treated clay soil

3.1.3 Untreated (100 kPa)

Figure 4 shows the outcome of the deformation of the untreated clay soil with the load 100 kPa applied on top of the soil surface. Observed that there is settlement occurred around the area of the raft foundation. The extreme total displacement measured from the numerical analysis is 916.92*10^{-3}m. The value of the displacement is quite large because the soil did not undergo stabilization treatment and contained 0% lime to modify its natural properties as it has low bearing capacity, swelling owing to moisture content changes, and high compressibility (Al-Saeedi & H. Hameed, 2021). Therefore, the soil did not resist the load well and tends to collapse if structure is built on top of the soil surface. Hence, there is an obvious different pattern of the clay soil deformation between the untreated and treated clay soil fill model.

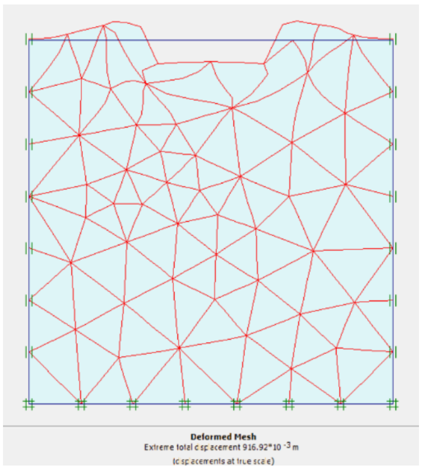


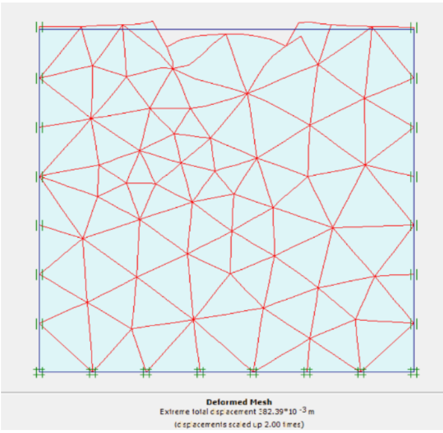
Fig. 4 - Deformation mesh of loaded untreated clay soil

3.1.4 Treated (100 kPa)

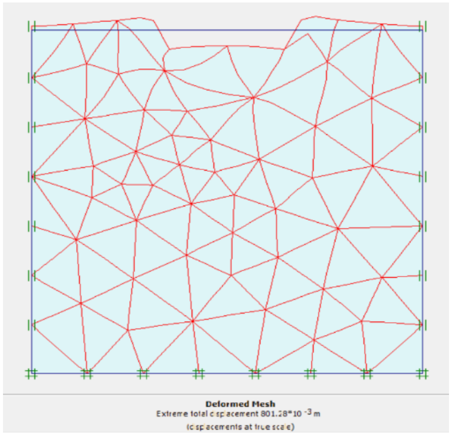
Figure 5 shows the outcome of the deformation of the treated clay soil with the load 100 kPa applied on top of the soil surface. On the top left, the figure appeared to be the deformation of the clay soil stabilized with 3% lime while on the top right, it shows the deformation of the clay soil with 6% lime content and for the bottom figure, it displays the result of the deformation of the clay soil stabilized with 9% lime. Notice that the three of the deformation profile are differ between one another. This is because different lime content indicates different strength of each soil. The settlement that occurred on very soil fill model shows different pattern because this method of soil improvement which various of lime content added to the soil will improve its properties (Ampera & Aydogmus, 2005). Hence, every lime content in the soil will affect the strength of the soil to cope with certain loads. Deformation of treated clay soil was recorded the lowest when the soil added with 6% lime.

The deformed mesh of each soil does not show an obvious different pattern. Consequently, the extreme total displacement for each soil fill model also differs. For the 3% lime content, the displacement measured is 382.39*10^{-3}m which 58.3% lower than the settlement of the untreated. While for the 6% lime content, the displacement is 801.28*10^{-3}m and is 12.61% lower than the untreated displacement evaluated. Lastly, the displacement scaled for the 9% lime content is 25.81% lower from the untreated that is 680.23*10^{-3}m. Observe that the trend of the displacement value for 3%, 6%, and 9% lime content did not linear. The displacement of the soil fill with 6% lime content is higher than both 3% and 9% lime content value. Should be, the higher the lime content in the method of stabilizing will result in the smaller deformation of the soil model, but in this study analysis, the smallest soil deformation is the soil with lime content of 3%. While 9% and 6% lime resulted in greater settlement than the soil with 3% lime. This is due to the collection of the data was from various of laboratory testing results and it did not consistent that the trend of the displacement and the effective stress value for the soil fill models did not linear and fixed. On a side note, from the results, can be seen that lime stabilized clay soil did affect and improve the soil properties in terms of when the soil dealing with loads acting on it and how it deforms afterwards.

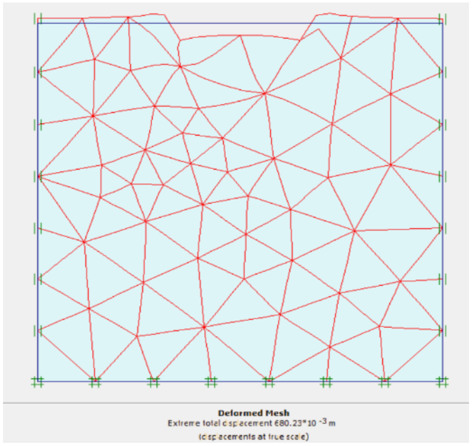
In order to analyze the trend of the soil fill model settlement over its various lime content, stress-settlement curve is plotted. Provided below is the effective stresses and extreme total displacement value that is obtained from the numerical analysis in PLAXIS 2D (shown in Table 3.1).



3%



6%



9%

Fig. 5 - Deformation mesh of loaded treated clay soil

Table 3.1 - Effective stress and displacement of clay soil

Clay Soil	Effective Stresses	Extreme Total Displacement
0% lime	-222.84 kN/m^2	$916.92*10^{-3}m$
3% lime	-224.23 kN/m^2	$382.39*10^{-3}m$
6% lime	-217.82 kN/m^2	$801.28*10^{-3}m$
9% lime	-228.41 kN/m^2	$680.23*10^{-3}m$

Compared to the study of peat soil by Zambri & Limit (2017), the deformation was recorded the lowest when 6% of lime is added to the peat soil. While in this study, the lowest deformation recorded when the clay soil is added with 3% lime. This happened because these two types of soil have different properties and characteristics as well as how the soil respond when the load acted on it. In addition, when the peat is added with 9% lime, the deformation increased by 14.3% from the recorded deformation of the untreated peat soil.

3.2 Stress-Settlement Curve

Figure 6 shows the stress-settlement curve of all soil fill models that was applied with 100 kPa stress. The lowest curve indicates the untreated clay soil when it is applied with the load. On top of the untreated curve is the stabilized clay soil with 6% lime content and the following upper curve is the stabilized clay soil with 9% and 3% lime content respectively. The trendline of the clay soil stabilized with 3% lime content shows that the displacement only occurred 382.39* 10^{-3}m under 100 kPa stress indicates that the amount 3% is acceptable by referring to the optimum percentage of lime that required to be added to stabilize the soil is between 2% and 8% (Al-Swaidani et al., 2016; Tuncer & Basma, 1991). Bell (1990) also found that the moderate amount added to modify clay soil varies from 1 to 3 percent. Hence, in order to reduce the excessive settlement of clay soils, the range value of 3 to 9 percent lime content can be considered for the clay soil when undergoing the lime stabilization treatment.

From the stress-settlement curve, it is also showed that the trend of the curve did not present in order. Theoretically, the higher the content of lime, the soil should be well improved. Since this study collected data from varies of laboratory test results, the data might not be as consistent as the data obtained from a direct laboratory testing.

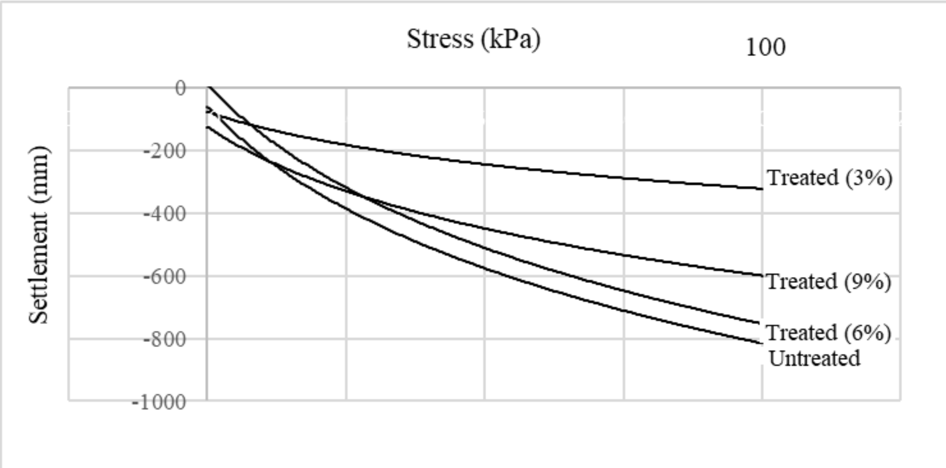


Fig. 6 - Stress-settlement curve

4. Conclusion

Based on previous study the compilation of laboratory test result was determined. The result which is from physical and mechanical properties. From the result and discussion, can be seen that the deformed mesh generated for the unloaded untreated and treated clay soil shows the similar pattern with one another. Moreover, for the loaded analysis, the untreated soil came up with the highest value of displacement measured which is 916.92*10^{-3}m and while for the lowest value of displacement measured was the treated clay soil with 3% lime content with only 382.39*10^{-3}m displacement occurred. Although the result from the analysis performed in this study did not come out linearly as it should, it eventually successfully showed that the lime stabilization of clay soil can increase its shear strength and reduces deformation. Lastly, by conducting this study using the method of numerical analysis, the optimum percentage of lime added that required to stabilize the clay soil would be 3%.

Acknowledgement

The authors would like to express their gratitude to the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

References

Al-Saeedi, A. A., & H. Hameed, D. (2021). Use of construction materials to improve the properties of clay soil. Periodicals of Engineering and Natural Sciences, 9(2), 593–598. https://doi.org/10.21533/pen.v9i2.1842

al-Swaidani, A., Hammoud, I., & Meziab, A. (2016). Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil. Journal of Rock Mechanics and Geotechnical Engineering, 8(5), 714–725. https://doi.org/10.1016/j.jrmge.2016.04.002

Ampera, B., & Aydogmus, T. (2005). Recent Experiences with Cement and Lime – Stabilization of Local Typical Recent Experiences with Cement and Lime – Stabilization of local typical poor cohesive soil Introduction Soil is one of the oldest building materials . It has been used for centuries. March 2005. https://www.researchgate.net/publication/321874148

Arun Kumar, M., Kulanthaivel, P., Selvapraveen, S., Vinodhkumar, S., & Naveenraj, V. (2020). Strength Behaviour of Clay Soil Stabilized with Lime. IOP Conference Series: Materials Science and Engineering, 961(1). https://doi.org/10.1088/1757-899X/961/1/012003

Bell, F. G. (1990). Lime stabilisation of clay soils. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 27(2), A105. https://doi.org/10.1016/0148-9062(90)95189-8

Firoozi, A. A., Guney Olgun, C., Firoozi, A. A., & Baghini, M. S. (2017). Fundamentals of soil stabilization. International Journal of Geo-Engineering, 8(1). https://doi.org/10.1186/s40703-017-0064-9

Hastuty, I. P., Roesyanto, Limbong, M. N., & J Oberlyn, S. (2018). California Bearing Ratio (CBR) test on stabilization of clay with lime addition. IOP Conference Series: Materials Science and Engineering, 309(1). https://doi.org/10.1088/1757-899X/309/1/012076

Iyappan, G. R., & Geetha, G. (2016). Experimental Investigation on Clay Soil Stabilization using Lime and Rice Husk Ash. International Journal for Innovative Research in Science and Technology, 2(12), 158–164.

Jamil, I., Ahmad, I., Khan, S. A., Ullah, W., Amjad, M., Khan, B. J., & Nasir, H. (2022). Analysis and Design of Piled Raft Foundation Taking into Account Interaction Factors. 2022.

Mohamed, K., & Bahloul, M. (2021). Prediction of Foundation Settlement Resting on Peaty Soil Layer at Kafr Saad , Domiat , Egypt. 5(2), 73–79. https://doi.org/10.11648/j.ajcbm.20210502.15

Tuncer, E. R., & Basma, A. (1991). Strength and stress-srtain characteristics of a lime-treated cohesive soil. Transportation Research Record, 1295, 70–79.

Zambri, N. M., & Limit, A. A. (2017). Deformation Characteristics of Lime Stabilized Peat. December, 21–25