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The Permeability Changes in Clayey Soil

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Abstract: Permeability is the state of porous materials that allow water or other liquids to flow through their link voids. Permeable is a term used to describe a substance that has a constant void. Gravel is very permeable, but stiff clay is the least permeable, and can be referred as impermeable for all practical purposes. However, this clay is well known for its sticky and wet soil texture able to move the internal structure of the soil. Void and porous state in particles makes the soil move easily as water passes through it. Therefore, this study was conducted to examine several factors that play an important role in the permeability of this clay. Although there are many factors that can affect the value of the clay permeability but only a few factors have been selected to focus on the effectiveness of these factors. Among the factors highlighted in influencing the permeability coefficient of clay are the void ratio, porosity, maximum dry density (MDD) and optimum moisture content (OMC). In addition, the data obtained in this research were combined from previous experimental data. Data for unstabilized natural clays were taken to control the scope of this study. Next, for the data selection method, it is necessary to go through several screening processes to show the eligibility of each data that has been selected. Therefore, several graphs were produced to show the relationship between the value of the permeability coefficient and the factors influencing it. Through this study, it can help geotechnical engineers in providing appropriate treatment to treat the soil depending on the factors that have been studied in this study.

Keywords: Permeability coefficient, void ratio, porosity, maximum dry density, optimum moisture content

1. Introduction

Clay is a crucial element in both geological and environmental processes. It's also broadly applied in human institutions. When subjected to any additional stress or external influence, clay soils produce deformation in any engineering structures built on them [1]. Even though differences in soil permeability can have a significant influence on the behaviour of a soil structure, such as embankment failure, precise measurement of soil permeability is essential for foundation engineering.

Clay is a type of sticky soil that has a high percentage of tiny particles as well as colloidal components. On the other hand, soil permeability is a characteristic of groundwater and air

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transmission. This is the most important factor to consider while building a structure. However, by using infiltration method, construction on impermeable soil will lose little water. The more permeable the soil can cause the greater secretion. Besides, fluid dynamic viscosity, fluid density, particle size, void ratio, and pore structure are all variables that are able to influence soil permeability [2]. The permeability of various soils varies greatly. The permeability of sands is easy to determine since it is strongly connected to several grain-size distribution properties [3]. Meanwhile, permeability for muddy clay actually is more possible to predict since it is impacted by a variety of variables, thus the correlations between which have yet to be discovered. Generally, clay permeability connected to the void ratio by a log-linear relationship, according to studies [4]. Hence, the graph of relationship between soil properties and permeability coefficient would be presented in this paper to indicate that the factors which impacted the permeability coefficient in clayey soil are genuine.

The purpose of this research is to analyze changes in permeability of clayey soil. This project Would be focused on three objectives. First, identify the behavior of clay soil and their permeability. Next, observe factors that influence the changes of permeability in clayey soil. Last but not least, is to determine the correlation between soil properties and permeability coefficient.

Scope of study for this research is to determine factors that influence the changes of permeability in clayey soil. This study would be focused on the relationship between the coefficient permeability and factors that affect the permeability. Otherwise, the method that is used to present the result is by building a graph between the coefficient permeability and factors that influence the permeability, which is void ratio, porosity, optimum moisture content (OMC) and maximum dry density (MDD). These researches are using several data from original clay in an experimental lab and different relationship graphs of coefficient permeability and the factors that influence the permeability will be determined.

2. Materials and Methods

The method that can be used to collect the data and result from the previous study is by using Systematic Literature Review (SLR). The research paper is collected from the authority resources such as Google Scholar, ScienceDirect and Springer. To focus on the specific scope in the project, the research question is constructed to determine whether the research paper is suitable to use in the research or not. Furthermore, there are 3 phases that are done to ensure that the research paper fulfills the criteria that are needed and also to extract the data and points from the previous study. Flow chart in **Figure 1** would visualize the process in this project.

Figure 1: Flowchart of the process

2.1 Resources

In order to run our research, previous data and results about permeability and properties of clay soil from previous study are required. So, there are a few platforms that can provide us with the previous study. The platforms that are used is Google Scholar, ScienceDirect and Springer. The Google Scholar is the one of the best platforms because there are over a million research papers that can be accessed in the platform which cover almost every aspect in the research field. Meanwhile, for science direct and Springer link also the best platform to discover any research paper, journal, book or technical report. It

is because, source for these platforms are wide and the interface is convenient to browse. From these three platforms are provided lots of quality and accurate journal for any research.

2.2 Research Question

To collect the data that is needed in the project, the question is constructed to specify the information that needs to be written into the thesis. There are 4 questions that are set in this project. The research question addressed by this study were:

Q1 – What the effect of porosity on soil permeability

Q2 – What the effect of void ratio on soil permeability

Q3 – Is it OMC and MDD affect the permeability

Q4 – What other factor that affect the permeability

Q5 – How permeability of soil happens

These kinds of questions are used to accomplish a certain purpose in this project. Q1 and Q2 used to determine whether porosity and void ratio can totally affect the permeability or not. These questions can identify how to influence the factor to the permeability of the clay soil. Q3 used to determine the factor of OMC and MDD can actually affect the permeability and prove that these factors can do it. Question Q4 and Q5 is constructed as an additional information to the project which is used to back up the main point of the project.

2.3 Identification

The first search process is started with the identification of the research paper or journal that relates to the project. The selected research paper is relevant and related to the factors that affect permeability.

Table 1: Selected journals and conferences proceedings

Source	Quartile
International Journal of Geotechnical Engineering	Q3
Engineering Geology	Q1
Fresenius Environmental Bulletin	Q4
Applied Clay Science	Q1
Scientia Iranica	Q2
Geotechnical and Geological Engineering	Q1
MDPI Water (Switzerland)	Q2
Ocean Engineering	Q1
Sains Malaysiana	Q2
Georisk	Q2

The selected research papers and conferences are shown in **Table 1**. The keyword was used to discover the research paper or journal is ‘permeability’. It was the main topic that was discussed in the thesis. However, the keyword ‘permeability’ alone is still general and difficult to find a specific journal that can be seek according to the question and objective. Hence, other keywords would be paired to the main keyword for small the scope of finding the research paper which are suitable with this project. The other keywords which are paired with the main keyword are ‘permeability – porosity’, ‘permeability – void ratio’, ‘permeability – maximum dry density’ and ‘permeability – optimum moisture content’.

These keywords are used mostly in the search engine of Google Scholar because of the system and features able to access lots of research paper from the other website such as springer and science direct. The range of year is selected in between 2000 to 2021. Although, there are some of research paper that

was used published early 2000 due to the similarity of information about certain subtopic and as additional information for this project.

2.4 Screening

In this screening phase, all the research papers that are searched will be evaluated based on the title and abstract of the research paper. The evaluation was run with some criteria to specify the point in research paper which answers the research question of the project. After that, the research paper was reviewed again and divided into a few points of the research question. The research paper that is related to the study is 20 research papers.

Table 2: Journal related to the objectives

References	Effect OMC MDD	Effect void Ratio	Effect Porosity
The Permeability of Portland Cement-Stabilized Clay Shale [5]	/		
Stabilization of soft kaolin clay with silica fume and lime [6]	/		
The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. [7]	/		
Permeability Characteristics of Compacted and Stabilized Clay with Cement, Peat Ash and Silica Sand [8]	/		
Adsorption and permeability of clays permeated with ferrous iron and Manganese [9]	/		
Cracking, water permeability and deformation of compacted clay liners improved by straw fiber [10]	/		
Effect of freezing and thawing on strength and permeability of lime-stabilized clays [11]	/		
Cohesive Soil Stabilized Using Sewage Sludge Ash/Cement and Nano Aluminium Oxide [12]	/		
Strength, Durability and Hydraulic Properties Of Clayey Soil Stabilized With Lime And Industrial Waste Lime [13]	/		
Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content [14]	/	/	
Permeability Coefficient of Low Permeable Soils as a Single-Variable Function of Soil Parameter [15]	/	/	/
Effect of Silica Fume Addition on the Behavior of Silty-Clayey Soils [16]	/		
Effect of Corncob ash on the geotechnical properties of Lateritic soil stabilized with Portland cement [17]	/		
Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay [18]	/		

Permeability of muddy clay and settlement simulation [19]		/	/
Investigation of Stabilised Batu Pahat Soft Soil Pertaining on its CBR and Permeability Properties for Road Construction [20]	/		
Permeability Characteristic of Clayey Soil Added with Fly Ash [21]	/		
Geotechnical Characterisation of Marine Clay As Potential Liner Material [22]	/		
Alluvial soils as subgrade material: Laboratory and statistical evaluation [23]	/		
Study of relation of Permeability and compaction characteristics of clayey soil with specific surface area [24]	/		

After that, the screening phase begins by focusing on the related point in the research paper and the objective of the project as in **Table 2**.

2.5 Eligibility

In this phase, the data are reviewed and checked in the screening phase will be assembled. The research paper in this phase is answer and suitable to the objective of the project which is the effect of factors such as porosity, void ratio on the permeability of the soil. However, for some research paper which not suitable for this project has been excluded.

3. Results and Discussion

In this part, the data from the preceding study was evaluated and discussed. The data and results of four parameters were focused on this study which effect permeability changes of clayey soil such as void ratio, porosity, maximum dry density (MDD) and optimum water content (OMC).

3.1 Results

3.1.1 Effect of void ratio on permeability

The correlation between the void ratio and the coefficient of permeability is shown in **Figure 2**. This shows the increased coefficient of permeability, as the void ratio increases. Based on the graph, the highest value of void ratio makes the highest value of permeability coefficient. It may be happening due to the effects of imperfect compaction and errors in conducting soil compaction sessions before conducting permeability tests. According to previous research, there are many factors that can affect permeability including viscosity, fluid density, particle size distribution, void ratio, and pore morphology [2]. Therefore, it is clear that the void ratio condition is able to affect the coefficient permeability value in the soil and the higher the void ratio value makes the soil moisture. It is because of the widening of the flow channel, so water is able to pass freely through the vacant space in the soil particles [2]. The water present in the soil will act to fill the empty space resulting from imperfect compaction activity. In addition, because of their flocculated structure, clay soils have a greater void ratio, but their permeability is still lower because the flow route through voids in clays is very tiny and poorly connected [25].

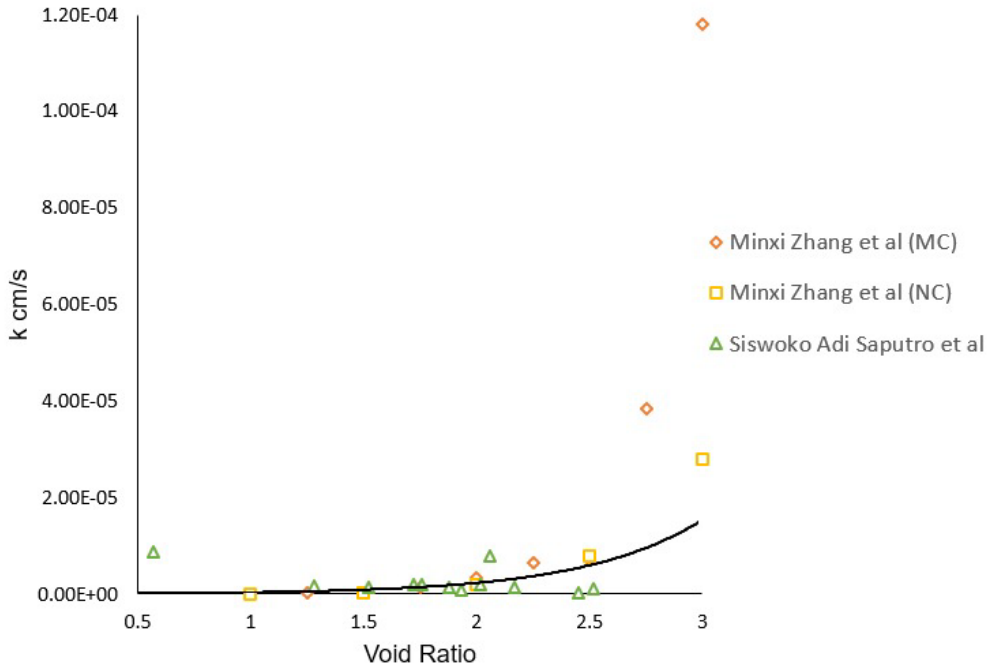

Figure 2: The relationship for the values permeability coefficient and void ratio

3.1.1.1 Effect of porosity on void ratio

The correlation between porosity and void ratio is shown in **Figure 3**. The graph shows where the void ratio increases due to the porosity increase and another part where the void ratio decreases when the porosity decreases. This proves that porosity and void ratio have a directly proportional relationship. This is because the void ratio and porosity are both indicators of the soil's looseness or density. The lower the void ratio and porosity, the denser the soil mass. Loose soils have a porosity of approximately n=50 %, while compact soils have a porosity of about n=30 % [26]. The possible reason for this result is porosity not only the factor that influences the permeability. Previous research has shown that a variety of factors can influence permeability, including grain size, void ratio, external pressure, and the fabric arrangement of soil particles [27]. Hence, it is possible to have another element that influences permeability.

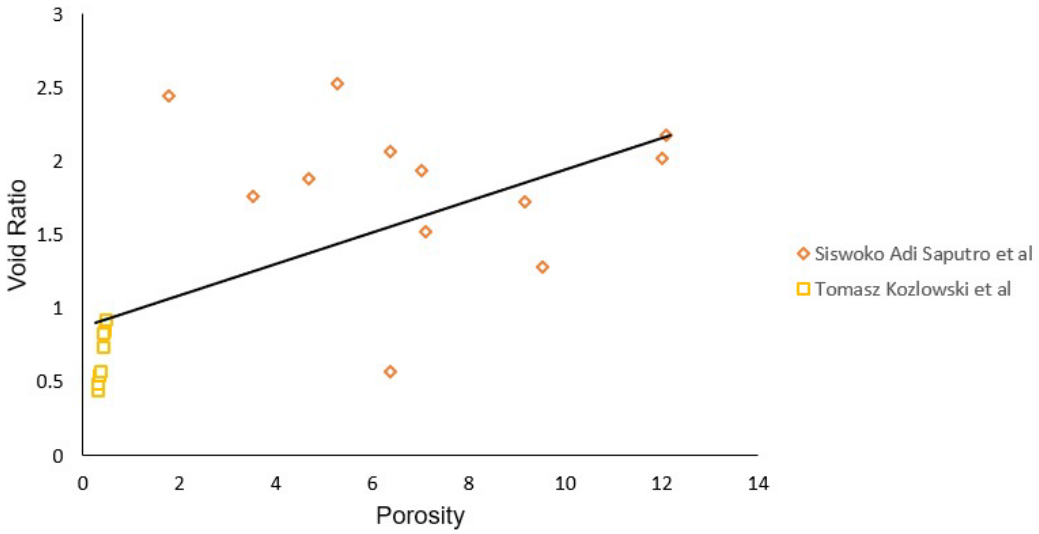

Figure 3: The relationship between void ratio and porosity

3.1.2 Effect of maximum dry density on permeability

Figure 4 shows the relationship between maximum dry density (MDD) and coefficient of permeability. From the outcome, it shows that the coefficient of permeability decreases as maximum dry density increases. This is because previous studies show that the soils with CL classification are considered to have poor to reasonable subgrade strength and are practically impermeable [24]. The range of permeability values corresponds to the low drainage characteristic that is practically impermeable. Chitra [28] have pointed out that grain size distribution of granular soils influences their permeability. Poorly graded soils have higher porosity and permeability values than well graded soils in which smaller grains tend to fill the voids between larger grains as density and void ratio are inversely related.

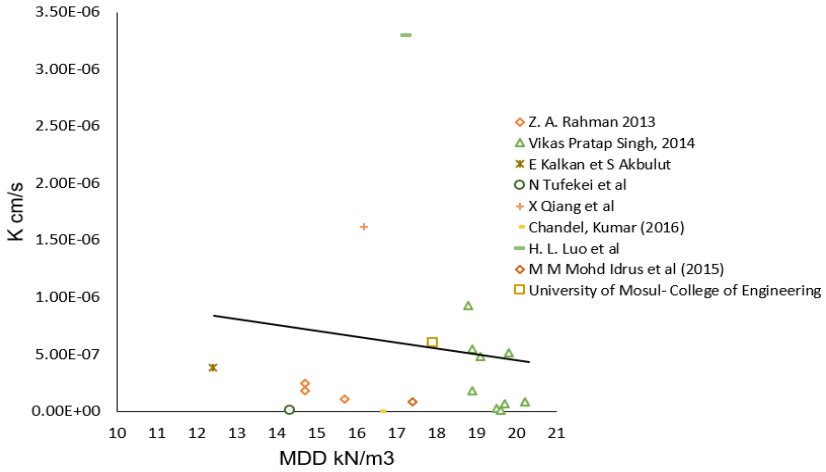

Figure 4: The relationship between maximum dry density (MDD) and coefficient of permeability

3.1.3 Effect of optimum moisture content on permeability

Figure 5 represents the relationships between optimum moisture content (OMC) and coefficient of permeability. The soil permeability is decreased as the optimum moisture content increases. This shows that there is a poor correlation between optimum moisture content and the permeability coefficient. Previous research has shown that soil permeability and compaction properties are heavily impacted by the specific area of solid particles since it determines the water flow and water adsorption as high-compression clay (CH) and CH-MH [24]. This shows that the permeability of cohesive soils is not changing significantly beyond optimum moisture content [29].

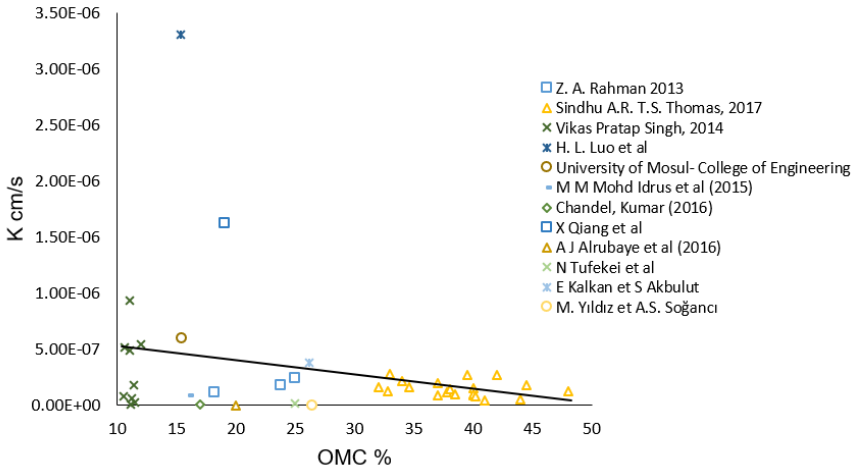

Figure 5: The relationships between optimum moisture content (OMC) and coefficient of permeability

3.2 Discussions

3.2.1 Effect of void ratio on permeability

The void ratio of soil is the proportion of soil void volume to soil solid volume in a given soil mass. Despite the fact that solid particle crushing and fracture under applied pressures are negligible, the void ratio has a significant impact on soil behaviour, such as compressibility, which is typically practiced in contexts of changes in the soil void ratio while neglecting changes in the volume of specific solid particles. Based on the data, the relationship between the permeability coefficient and void ratio can be determined as directly proportional. It showed that the permeability coefficient increases when the void ratio increases. As the result of the flow channel expands, the soil void ratio will rise, the permeability rises as well.

3.2.2 Effect of porosity on void ratio

The relationship between porosity and void ratio can be concluded as void ratio increases, porosity increases. Based on previous studies, porosity can be divided into two categories which is original porosity and secondary porosity [30]. Original porosity is the value to the porosity of material when they initially formed. Secondary porosity can be described as the change of the original porosity after the material has processed through some condition that may increase or decrease the original porosity. In addition, there are some factors that change the porosity of the soil such as their shape, size, distribution, and continuity. When the particle size and gradation of soil changes, the porosity of the soil changes as well [31]. However, the porosity is influenced by a mixture of factors, and some factors may not have an impact on the others. Furthermore, using rigorous univariate analysis, the sensitivity of numerous variables to permeability is as follows, ranked from larger to smaller which is porosity is followed by particle size distribution, particle surface, and particle shape [31]. This proves that porosity has a significant impact on the permeability value. Porosity is high and independent of particle size in well-sorted unconsolidated sands, but permeability is related to particle size squared [32]. According to earlier research, me data set might well be split depending on eidier pore structure factor or direshold pressure to improve permeability-porosity correlations [32].

3.2.3 Effect of maximum dry density on permeability

The maximum dry unit weight and optimum moisture content are greatly influenced by the soil type in terms of grain size distribution, shape of soil grains, specific gravity of soil solids, percentage of fine content, and kind of fine [33]. When water can easily flow through a soil, it is said to be extremely pervious. The permeability of an impermeable soil is relatively low, and water cannot easily move through it [24]. Changes in soil density or moisture will only impact the interparticle void size, resulting in a small change in permeability on a microscopic scale [34].

3.2.4 Effect of optimum moisture content on permeability

In other cases, the compacted soil for wet of optimum tends to have a lesser permeability when compacted dry of optimum at the same density [35]. This is because increasing the energy of the compaction reduces the permeability. When the compaction energies increased, the maximum permeability near the optimum water content decreased non-linearly. The decrease in permeability as compact energy increases appears to be the result of the increase in dry density because of increasing compact energy. Dry moisture content flows mainly through the soil because of the dominance of the particle gravity [34].

4. Conclusion

This study explored the permeability changes in clayey soil in terms of effect of void ratio, porosity, maximum dry density and optimum water content. The study results can be summarized that the coefficient of permeability decreases as maximum dry density increases while the soil permeability decreases as the optimum moisture content increases. This is because the types of soil from different

locations based on previous studies provides a major influence on the maximum dry density and optimum moisture content. Besides, the effect of the void ratio on permeability shows that the permeability coefficient increases when the void ratio increases. Meanwhile, the porosity and void ratio relationship can be concluded as increases the void ratio, porosity increases. As a conclusion, it's obvious that numerous key parameters including maximum dry density, optimum moisture content, viscosity, particle size distribution, void ratio, and porosity might affect permeability [2].

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References

[1] W. R. Azzam. "Utilization of polymer stabilization for improvement of clay microstructures", Structural Eng. Dept., Faculty of Engineering, Tanta University, Tanta, Egypt, (2014)

[2] B. Huang et al., "Experimental Study on the Permeability Characteristic of Fused Quartz Sand and Mixed Oil as a Transparent Soil", Center for Hypergravity Experimental and Interdisciplinary Research, Zhejiang University, Hangzhou 310058, China, 28 November 2019

[3] A. Hazen, "Discussion of dams on sand foundations." Trans. Am. Soc. Civ. Eng. 73, 199, 1911.

[4] D.W. Taylor, "Fundamentals of soil mechanics." Soil Sci. 66 (2), 161, 1948.

[5] W Diana, E Hartono and A S Muntohar, "The Permeability of Portland Cement-Stabilized Clay Shale." IOP Conf. Series: Materials Science and Engineering, 650 012027, 2019.

[6] A. J. Alrubaye, M. Hasan and M. Y. Fattah, "Stabilization of soft kaolin clay with silica fume and lime," International Journal of Geotechnical Engineering, 2016, doi: 10.1080/19386362.2016.1187884

[7] E. Kalkan and S. Akbulut, "The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners," Engineering Geology, vol. 73, no.2004, pp.145–156, 2004.

[8] S.E. Mousavi, and L.S. Wong, "Permeability Characteristics of Compacted and Stabilized Clay with Cement, Peat Ash and Silica Sand," Civil Engineering Infrastructures Journal, vol.49, no.1, pp. 149 – 164, 2016.

[9] N. Tüfekçi et al., "Adsorption and Permeability of Clays Permeated with Ferrous Iron and Manganese," Fresenius Environmental Bulletin, vol. 19, No 8b, 2010.

[10] X. Qiang et al., "Cracking, water permeability and deformation of compacted clay liners improved by straw fiber," Engineering Geology, 2014, doi: 10.1016/j.enggeo.2014.05.013

[11] M. Yıldız, A.S. Soğancı, "Effect of freezing and thawing on strength and permeability of lime-stabilized clays," Scientia Iranica A, vol. 19, no.4,pp. 1013–1017, 2012.

[12] H. L. Luo, et al., "Cohesive Soil Stabilized Using Sewage Sludge Ash/Cement and Nano Aluminum Oxide," International Journal of Transportation Science and Technology, vol. 1, no. 1, pp.83 – 100, 2012.

[13] University of Mosul- College of Engineering (2008): Strength, Durability and Hydraulic Properties of Clayey Soil Stabilized with Lime and Industrial Waste Lime, Al-Rafidain Engineering Vol.16 No.1

[14] Mohamed A. Sakr, Mohamed A. Shahin & Yasser M. Metwally (2009): Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content, Geotech Geol Eng (2009) 27:105–113

[15] Tomasz Kozlowski and Agata Ludynia (2019), Permeability Coe cient of Low Permeable Soils as a Single-Variable Function of Soil Parameter, Water 2019, 11, 2500; doi:10.3390/w11122500

[16] Adel A. Al-Azzawi, Khalida A. Daud and Muhammed A. Abdul Sattar (2012), Effect of Silica Fume Addition on the Behavior of Silty-Clayey Soils, Journal of Engineering and Development, Vol. 16, No.1.

[17] Akinwumi I.I. and Aidomojie O.I. (2015), Effect of Corncob ash on the geotechnical properties of Lateritic soil stabilized with Portland cement, INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES Volume 5, No 3.

[18] Akinwumi I. I., Diwa D and Obianigwe N (2014), Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay, Int. Journal of Applied Sciences and Engineering Research, Vol. 3, Issue 4

[19] Minxi Zhang, XiwenZhu, GuoliangYu, JianmingYan, XianbenWang, Menglin Chen and WeimingWang (2015), Permeability of muddy clay and settlement simulation, Ocean Engineering, 104(2015)521–529

[20] M M Mohd Idrus et al (2016), Investigation of Stabilised Batu Pahat Soft Soil Pertaining on its CBR and Permeability Properties for Road Construction, IOP Conference Series: Materials Science and Engineering, 136 012026

[21] Anoopsingh Chandel and Umesh Kumar (2016), Permeability Characteristics of Clayey Soil Added with Fly Ash, Anoopsingh Chandel.

[22] Z.A. Rahman, W.Z.W. Yaacob, S.A. Rahim, T. Lihan, W.M.R. Idris & W.N.F. Mohd Sani (2013), Geotechnical Characterisation of Marine Clay as Potential Liner Material, Sains Malaysiana 42(8) (2013): 1081–1089

[23] Pratap Singh, V. (2009). Alluvial soils as subgrade material: Laboratory and statistical evaluation. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 3(4), 232–239. https://doi.org/10.1080/17499510902937440

[24] Sindhu A.R., Tiju Susan Thomas. “Study of relation of Permeability and compaction characteristics of clayey soil with specific surface area”, International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 04 | Apr -2017.

[25] Gopal Ranjan and A.S.R. Rao, Basic and Applied Soil Mechanics. New Delhi, 1991.

[26] Faur Krisztina Beáta, Szabó Imre. Physical properties of soils, A tananyag kifejlesztése a TÁMOP 4.1.2-08/1/A-2009-0033 pályázat keretében valósult meg, 2011.

[27] Mitchell, J.K., 1976. Fundamentals of Soil Behaviour. John Wiley and Sons, New York.

[28] Dr. R Chitra, Dr. Manish Gupta, Harendra Prakash and Shahid Noor. Prediction of Permeability Characteristics of Fine-Grained Soils and its Validation, International Journal of Recent Development in Engineering and Technology. Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 7, Issue 4, April 2018).

[29] S. P. Wright, P. J. Walden, C. M. Sangha & N. J. Langdon. “Observations on soil permeability, moulding moisture content and dry density relationships”, Department of Civil Engineering, University of Portsmouth, Burnaby Building, Burnaby Road, Portsmouth, PO1 3QL, UK.

Quarterly Journal of Engineering Geology, 29, 249-255. 0481-2085/96 $07.00 © 1996 The Geological Society

[30] H. J. Fraser. Experimental Study of the Porosity and Permeability of Clastic Sediments, California Institute of Technology, 154.059.124.102 on February 12.

[31] Y.F. Liua, D-S Jenga. Pore scale study of the influence of particle geometry on soil permeability, Advances in Water Resources journal homepage: www.elsevier.com/locate/advwatres , 2019.

[32] Shouxiang Ma and Norman R. Morrow. Relationships Between Porosity and Permeability for Porous Rocks, 1996 International Symposium of the Society of Core Analysts, Sept. 8-10, Montpelier, France. 1966 SCA Conference Paper Number 9610.

[33] Arvelo, Andres, "Effects of The Soil Properties on the Maximum Dry Density Obtained Fro" (2004). Electronic Theses and Dissertations, 2004-2019. 161.

[34] Asep-SAPEI, M. Azron Dhalhar and Masashi Nakano. “The Effects of Soil Compaction on the Physical Properties of Indonesian Latosol”, Journal of Irrigation Engineering and Rural Planning No. 30 (1996. 2) pp.108`16

[35] Watabe, Y., Leroueil, S., & le Bihan, J. P. (2000). Influence of compaction conditions on pore-size distribution and saturated hydraulic conductivity of a glacial till. Canadian Geotechnical Journal, 37(6), 1184–1194. https://doi.org/10.1139/t00-053