

THE SHEAR STRENGTH OF SOFT CLAY
REINFORCED WITH SINGLE CRUSHED
BRICK COLUMN

OH CHUN WEI

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG



SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

(Supervisor's Signature)

Full Name : ASSOC. PROF. DR. MUZAMIR BIN HASAN

Position : DIRECTOR OF CERRM/ SENIOR LECTURER

Date : 1 JUNE 2018



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : OH CHUN WEI

ID Number : AA14049

Date : 1 JUNE 2018

THE SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH SINGLE
CRUSHED BRICK COLUMN

OH CHUN WEI

Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

I would like to express my earnest gratitude to everyone who has helped me along my research. It would not have been possible for me to complete this research without the help from others.

I would like to express my deepest appreciation to all those who provided me the possibility to complete this final year project. A special gratitude I give to my supervisor, Assoc. Prof. Dr. Muzamir bin Hasan, who contribute his suggestions and encouragements all the times as well as providing me necessary information regarding this thesis and helped me in my writing of this thesis.

Furthermore, I would like to thank the laboratory assistants who gave the permission to use all the required equipment and apparatus to complete the experiment and provided all the helps needed.

Besides that, I would like to thank my family for their support and encouragement throughout this period of time. I am grateful to my friends who have supported me along the way.

ABSTRAK

Tanah liat lembut sering dikenali sebagai tanah yang bermasalah dalam pembinaan kerana kekuatan yang rendah dan sifat mampatan tinggi. Sebelum pembinaan bermula, penambahbaikan tanah perlu dilakukan untuk meningkatkan keupayaan galas tanah supaya struktur super boleh diletakkan di atasnya dan mengurangkan penyelesaian dan penyatuan. Dalam kajian ini, tanah liat lembut akan diperkuat dengan tiang batu bata yang dihancurkan yang merupakan sebahagian daripada sisa pembinaan yang dihasilkan semasa peringkat pembinaan untuk mencapai pembinaan mampan. Kajian ini bertujuan untuk mengkaji keberkesanan lajur bata tunggal yang dihancurkan untuk meningkatkan kekuatan ricih dengan menggunakan model skala makmal. Kaolin digunakan sebagai sampel tanah manakala bata dihancurkan sebagai lajur bertetulang. Beberapa ujian makmal dijalankan untuk menentukan sifat tanah liat kaolin dan bata dihancurkan. Ujian mampatan yang tak terkurung (UCT) juga digunakan untuk menguji kekuatan ricih sampel kaolin bertetulang. Dimensi spesimen yang digunakan adalah diameter 50mm dan ketinggian 100mm dan sejumlah 3 kelompok sampel kaolin diuji dan setiap kumpulan mengandungi sampel kawalan dan sampel diperkuat dengan 10mm dan 16mm dengan nisbah penembusan lajur yang berlainan. Terdapat dua jenis diameter bata tunggal dihancurkan yang digunakan dalam kajian ini iaitu 10mm dan 16mm. Ketinggian lajur dipasang ke tanah liat lembut adalah 60mm, 80mm dan 100mm. Peningkatan kekuatan ricih lajur bata yang dihancurkan tunggal dengan nisbah penggantian kawasan 4.00% (diameter lajur 10mm) adalah 3.34%, 4.60% dan 1.07% pada nisbah penembusan sampel, H_c / H_s 0.6, 0.8 dan 1.0 manakala untuk penggantian kawasan daripada 10.24% (diameter lajur 16 mm) adalah 7.56%, 16.37% dan 4.97% pada nisbah penembusan yang sama. Dapat disimpulkan bahawa kekuatan ricih tanah liat lembut dapat ditingkatkan dengan pemasangan lajur batu tunggal yang dihancurkan.

ABSTRACT

Soft Clay is often known to be a problematic soils in construction because of its low strength and high compressibility characteristic. Before construction begins, ground improvement needs to be done to improve the soil bearing capacity so that the superstructure can be placed on top of it and reduce settlement and consolidation. In this study, the soft clay is going to be reinforced with crushed brick column which is part of construction waste produced during construction stage to achieve sustainable construction. This study was aimed to investigate the effectiveness of single crushed brick column in improving the shear strength by using laboratory scale model. Kaolin is being used as soil sample while crushed brick as the reinforced column. Few laboratory tests are conducted to determine the properties of kaolin clay and crushed brick. Unconfined Compression Test (UCT) also used to test the shear strength of the reinforced kaolin samples. The dimension of the specimen used is 50mm in diameter and 100mm in height and a total 3 batches of kaolin samples were tested and each batch contains control sample and samples reinforced with 10mm and 16mm with different column penetration ratio. There are two different types of diameter of single crushed brick column used in this study which are 10mm and 16mm. The heights of the column installed into soft clay are 60mm, 80mm and 100mm. The improvement of shear strength of single crushed brick column with area replacement ratio of 4.00% (10mm column diameter) are 3.34%, 4.60% and 1.07% at sample penetration ratio, H_c/H_s of 0.6, 0.8 and 1.0 respectively while for area replacement of 10.24% (16 mm column diameter) are 7.56%, %, 16.37% and 4.97% at the same penetration ratio. It can be concluded that the shear strength of soft clay could be improved by installation of single crushed brick column.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xiii
CHAPTER 1 INTRODUCTION	1
1.1 Background of Study	1
1.2 Problem Statement	3
1.3 Objective of Study	4
1.4 Scope of Study	4
1.5 Significance of Study	5
CHAPTER 2 LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Soft Clay	6
2.2.1 Classification of Soils	9
2.2.2 Physical Properties of Soft Clay	12

2.3	Kaolin	14
2.3.1	Physical and chemical properties of kaolin	18
2.3.2	Compressibility and pre-consolidation pressure	21
2.3.3	Undrained Shear Strength	24
2.4	Brick	26
2.4.1	Physical Properties	27
2.4.2	Compressive Strength	28
2.4.3	Water Absorption	30
2.4.4	Apparent Density	31
2.4.5	Modulus of Elasticity	32
2.5	Vertical Granular Column	32
2.6	Small Scale Modelling	34
2.7	Sustainable Construction	36
CHAPTER 3 METHODOLOGY		39
3.1	Introduction	39
3.2	Selection of Ground Improvement Technique	41
3.3	Selection of Material	41
3.4	Laboratory Works	42
3.4.1	Atterberg Limit Test (BS 1377: Part 2: 1990: 4; BS 1377: Part 2: 1990: 5)	42
3.4.2	Dry Sieve Test (BS 1377: Part 2: 1990: 9)	43
3.4.3	Hydrometer Test (BS 1377: Part 2 1990: 9.6)	44
3.4.4	Specific Gravity Test (BS 1377: Part 2: 1990: 8)	45
3.4.5	Permeability Test (ASTM D 2434)	46
3.4.6	Standard Compaction Test (BS 1377: Part 4: 1990: 3.3)	47

3.4.7	Unconfined Compression Test (ASTM D 2166)	48
3.5	Reinforcing Kaolin with Single Crushed Brick Column	48
3.5.1	Soft Clay Preparation	49
3.5.2	Installation of Crushed Brick Column	50
3.5.3	Pattern and Size	51
CHAPTER 4 RESULTS AND DISCUSSION		53
4.1	Introduction	53
4.2	Properties of Kaolin and Crushed Brick	53
4.3	Physical Properties	54
4.3.1	Atterberg Limit Test	54
4.3.2	Specific Gravity	55
4.3.3	Particle Size Distribution	56
4.4	Mechanical Properties	57
4.4.1	Standard Proctor Compaction Test	57
4.4.2	Permeability	60
4.5	Soft Clay Reinforced with Single Crushed Brick Column	60
4.5.1	Stress-Strain Behaviour under Axial Load	60
4.5.2	Effect of Single Crushed Brick Column on Shear Strength	62
4.5.3	Effect of Column Penetration Ratio	65
4.5.4	Effect of Height over Diameter of Column Ratio	68
4.5.5	Effect of Volume Replacement Ratio	71
CHAPTER 5 CONCLUSION		76
5.1	Introduction	76
5.2	Conclusion	76

5.3	Recommendations	78
	REFERENCES	79
	APPENDIX A ATTERBERG LIMIT TEST	82
	APPENDIX B SPECIFIC GRAVITY TEST	83
	APPENDIX C HYDROMETER TEST RESULT	84
	APPENDIX D SIEVE ANALYSIS TEST RESULT	86
	APPENDIX E COMPACTION TEST RESULT	87
	APPENDIX F CONSTANT HEAD TEST RESULT	90
	APPENDIX G FALLING HEAD TEST RESULT	91

LIST OF TABLES

Table 2.1	Particles size distribution of soils from Peninsular Malaysia	7
Table 2.2	British Soil Classification System	10
Table 2.3	Properties of soils	13
Table 2.4	Results of basic soil tests	14
Table 2.5	Comparison of basic properties of different clays	14
Table 2.6	Chemical analysis of kaolin	17
Table 2.7	Kaolin properties	19
Table 2.8	Particle size distribution of kaolin	20
Table 2.9	Correlation factor from piezocone	25
Table 2.10	Properties of crushed clay brick aggregate	27
Table 2.11	Wet sieve analysis of clay brick powder	28
Table 2.12	Chemical composition of clay brick powder	28
Table 2.13	Compressive strength requirement, BS 3921: 1985	29
Table 2.14	Compressive strength requirement, ASTM C62	29
Table 2.15	Compressive strength of brick unit	30
Table 2.16	Water absorption requirement, BS 3921: 1985	31
Table 2.17	Water absorption requirement, ASTM C62	31
Table 3.1	Test and Standards for the materials	42
Table 3.2	Detail of crushed brick column installed in kaolin specimens	50
Table 4.1	Properties of kaolin clay	54
Table 4.2	Properties of crushed brick	54
Table 4.3	Comparison on the specific gravity of kaolin from previous research works	56
Table 4.4	Comparison on the maximum dry density and optimum moisture content of kaolin S300 from previous research works	58
Table 4.5	Comparison on permeability coefficient of kaolin of previous researchers	60
Table 4.6	Maximum deviator stress and axial strain values with different area replacement ratio and different height penetration ratio	61
Table 4.7	Result of unconfined compression test	63
Table 4.8	Improvement of shear strength	64
Table 4.9	Summary of the equation of correlation of shear strength and improvement of shear strength for different types of ratio	75

LIST OF FIGURES

Figure 1.1	Waste generation and composition	2
Figure 2.1	Malaysian soft clay soils distribution map	7
Figure 2.2	Soft clay soil thickness in Peninsular Malaysia	8
Figure 2.3	Soft clay soils profile in Peninsular Malaysia	9
Figure 2.4	AASHTO classification system	11
Figure 2.5	Textural triangle soil classification	12
Figure 2.6	Kaolin clay	15
Figure 2.7	Scanning electron microscopy of kaolin	16
Figure 2.8	Particle size distribution of kaolin	20
Figure 2.9	Compression index equations	22
Figure 2.10	The features of soil compression characteristic	23
Figure 2.11	Casagrande method for estimating pre-consolidation pressure	24
Figure 2.12	$e - \log \sigma'$ curve for samples at different depth from a same borehole	24
Figure 2.13	Undrained shear strength and sensitivity of Klang clay	26
Figure 2.14	Variation of modulus of elasticity of brick correspond to compressive strength	32
Figure 2.15	Vibro-replacement installation of stone column	34
Figure 2.16	Loading pattern (a) and column arrangement (b)	35
Figure 2.17	The loading frame and accessories	36
Figure 2.18	Diagram of sustainability in construction	37
Figure 2.19	The path for achieving sustainable construction	38
Figure 3.1	Flowchart of research methodology process	40
Figure 3.2	All sizes of sieve under British Standard	44
Figure 3.3	Soil Hydrometer	45
Figure 3.4	Falling head permeability test apparatus	47
Figure 3.5	British Standard rammer and compaction mould	48
Figure 3.6	Customized mould set for 50mm diameter and 100mm height specimen	49
Figure 3.7	Penetration length of crushed brick column	50
Figure 3.8	Detail column arrangement	51
Figure 3.9	Clay specimen reinforced with single crushed brick column	52
Figure 4.1	Kaolin S300 in the plasticity chart	55
Figure 4.2	Particle size distribution curve of kaolin S300	57
Figure 4.3	Particle size distribution curve of crushed brick	57

Figure 4.4	Compaction curve of kaolin S300	59
Figure 4.5	Compaction curve of crushed brick	59
Figure 4.6	Deviator stress versus axial strain at failure for 4.00% and 10.24% area replacement of lime bottom ash column at different penetration ratio	62
Figure 4.7	Shear strength versus height penetration ratio for single crushed brick column with diameter 10mm and 16mm	65
Figure 4.8	Improvement shear strength with height penetration ratio for single crushed brick column with diameter 10mm and 16mm	66
Figure 4.9	Correlation graph of shear strength with height penetration ratio for single crushed brick column with diameter 10mm and 16mm	67
Figure 4.10	Correlation graph of improvement of shear strength with height penetration ratio for single crushed brick column with diameter 10mm and 16mm	67
Figure 4.11	Shear strength versus height over diameter of column ratio for single crushed brick column with diameter 10mm and 16mm	69
Figure 4.12	Improvement of shear strength versus height over diameter of column ratio for single crushed brick column with diameter 10mm and 16mm	69
Figure 4.13	Correlation of shear strength versus height over diameter of column ratio for single crushed brick column with diameter 10mm and 16mm	70
Figure 4.14	Correlation of improvement of shear strength versus height over diameter of column for single crushed brick column with diameter 10mm and 16mm	71
Figure 4.15	Shear strength versus volume replacement ratio for single crushed brick column with diameter 10mm and 16mm	72
Figure 4.16	Improvement of shear strength versus volume penetration ratio for single crushed brick column with diameter 10mm and 16mm	72
Figure 4.17	Correlation of shear strength versus volume replacement ratio for single crushed brick column with diameter 10mm and 16mm	73
Figure 4.18	Correlation of improvement of shear strength versus volume replacement ratio for single crushed brick column with diameter 10mm and 16mm	74

LIST OF SYMBOLS

A_c	Area of crushed brick column
A_s	Area of kaolin clay sample
c'	Apparent cohesion
C_c	Compression index
D_c	Diameter of crushed brick column
e	Void ratio
G_s	Specific gravity
H_c	Height of crushed brick column
H_s	Height of kaolin clay sample
V_c	Volume of crushed brick column
V_s	Volume of kaolin clay sample
kN	Kilo Newton
kPa	Kilo Pascal
M_g	Mega Gram
MN	Mega Newton
m/s	Metre per second
mm	Millimetre
μm	Micrometre
W_L	Liquid limit
W_P	Plastic limit
w_{opt}	Optimum moisture content
γ	Unit weight
γ_{max}	Maximum unit weight
q_u	Deviator stress
s_u	Undrained shear strength
ΔS_u	Improvement of shear strength
ρ_d	Dry density
R^2	Correlation cohesion
%	Percent
°	Degree

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
C	Controlled Sample
CIDB	Construction Industry Development Board
C&D	Construction and demolition
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit
S	Single Column
UCT	Unconfined Compression Test
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Soft clay is often known to be a problematic soil due to its low strength and high compressibility characteristic. Construction on soft soil is a great challenge for geotechnical engineers. Site investigation needs to be conducted and ground improvement technique needs to be applied. Ground improvement is the modification of existing site foundation soils to provide better performance under design and/or operational loading conditions. Ground improvement techniques are used increasingly for new projects to allow utilization of sites with poor subsurface conditions. Ground improvement is executed to increase the bearing capacity, reduce the magnitude of settlements and the time in which it occurs, retard seepage, accelerate the rate at which drainage occurs, increase the stability of slopes, mitigation of liquefaction potential, etc. (Hirkane *et al.*, 2014). The final choice of ground improvement techniques used depend on the economic feasibility, time frame, type of soil, availability of equipment and skills required and environmental conditions such as erosion and water pollution. Engineers must consider all the factors carefully to choose the best method to be used.

One of the ground improvement techniques adopted for soft cohesive soils is the stone columns technique. It is a reinforcement of the soft soil with granular column which is then be compacted and normally used in clayey soft soils. The aim of the stone column techniques is to increase the soil bearing capacity and minimize the post construction settlement and consolidation. Because of the stone column is a type of granular column, therefore an alternative granular material can be considered to replace the stone to reduce the cost of project and reduce excavation of stone from quarry which will eventually help in reducing environmental impacts of stone mining.

Environmental issues is the major issue being discussed nowadays on a global scale and people are concerns about the impacts of human activities towards the environment. The environmental awareness level has been increasing since decades ago. The waste products generated in every human and industrial activity certainly bring disastrous impact to quality of living of human. Construction industry is one of the largest waste contributor. Construction waste generation is becoming a pressing issue in Malaysia (Begum *et al.*, 2007; Begum *et al.*, 2010). With the increasing demands for construction projects, large amount of waste is being generated annually. Malaysia generates 26,000 tonnes of wastes from construction and demolition (C&D) daily that further congest the already over-flowing landfills (Zulzaha, 2014). The common principles used in the reduction of C&D waste are reduce, reuse and recycle (3R) (Lu and Yuan, 2010). For sustainable and green construction, approaches have to be taken by adopting new method in construction technologies by reusing the waste as alternative construction material and recycling the material to minimize the waste generation.

Construction waste materials	Amount of waste generated by weight (tonnes 100 m ⁻² floor space)	
	Fully prefabricated	Conventional
Soil and sand	1.01	14.700
Brick and blocks	0.04	0.6300
Concrete and aggregate	0.27	36.000
Tiles	0.02	2.7200
Scrap metal	0.01	0.4500
Wood	0.04	0.1100
Plastic materials	0.01	0.0300
Packaging products	0.07	0.0020
Total	1.47	54.642

Figure 1.1 Waste generation and composition

Source: Begum et al. (2010)

According to Begum *et al.*, (2010), 0.63 tonnes of brick and blocks are generated every 100m² of floor space in conventional building system. Since there are huge amount of bricks waste being produced, these waste can be reused and recycled as substitute material for stone column used in ground improvement. Brick has a good compressive strength varies from 3 N/mm² to 40 N/mm² which depends on the raw material, manufacturing process and size of the brick. It can be compared to stone with that properties since crushed brick has same properties as granular material. The brick waste is crushed into granular form and inserted into ground just like stone. This method greatly reduces the mining and usage of natural resources. It reduces the construction waste by

recycling the waste which is more environmental friendly and providing a cheaper and sustainable construction method.

1.2 Problem Statement

Soft clay being an expansive soil, also known as shrink-swell soil is a fine-grained soils which always brings problems to soil stability and settlement of soil. Expansive soil will increase in volume when water content increases and causes the soil to lose strength and becomes unstable which eventually brings problems to foundation of building. On the other hand, the soil will shrink when dry. The shrinkage will remove support from the foundation and cause structural failures. The expansion and contraction of soil will cause severe damage on the structure. Soft clay also known as problematic soil with low bearing capacity and high compressive strength which is known to has high chance of failure due to its weakness when compared to other type of soils. Malaysia's climate is hot and humid throughout the year, with heavy rainfall during monsoon seasons. The drastic change in temperature and moisture cause the soil likely to fail if the soil is not treated especially at Malaysia coastal areas that are covered with soft soil deposits. Therefore, engineers need to carry out ground improvement technique which will improve the properties of soft soil so that building structure can be built on top. Besides, stone column is an effective and economic ground improvement technique that is being used widely in construction. However, the material used which is stone involving quarrying. The mining of stone will cause environmental impact such as permanently disfigure of the surrounding. The natural resources have been depleting and it is considered not very environmental friendly in using stone column. The best alternative is to use recycle material from waste material or industrial by-products. Due to the increasing demand in housing projects, more waste material are being produced daily in construction industry. The waste are leftovers material and wastage. That include huge amount of bricks that are thrown away. Since the use of brick in construction is unavoidable, but we can definitely reduce the waste generated. Instead of dumping the brick waste into landfill which will pollute the ground, the brick waste should be reused in other construction activity. In the era that highlight on green building process and sustainable construction and rising of environmental issue, alternative material that is environmental friendly should be used for the column. Therefore, the use of crushed brick

REFERENCES

- Aliabdo, A. A., Abd-Elmoaty, A. E. M., & Hassan, H. H. (2014). Utilization of crushed clay brick in concrete industry. *Alexandria Engineering Journal*, 53(1), 151–168. <https://doi.org/10.1016/j.aej.2013.12.003>
- Alrubaye, A. J., Hasan, M., & Fattah, M. Y. (2017). Stabilization of soft kaolin clay with silica fume and lime. *International Journal of Geotechnical Engineering*, 11(1), 90–96. <https://doi.org/10.1080/19386362.2016.1187884>
- Amin, J. M., Taha, M. R., Ahmed, J., & Kassim, A. A. (1997). Prediction and Determination of Undrained Shear Strength of Soft Clay at Bukit Raja. *Pertanika Journal Science & Technology*, 5(1), 111–126.
- Begum, R. A., Satari, S. K., & Pereira, J. J. (2010). Waste Generation and Recycling: Comparison of Conventional and Industrialized Building Systems. *American Journal of Environmental Sciences*, 6(4), 383–388. <https://doi.org/10.3844/ajessp.2010.383.388>
- Black, J., Sivakumar, V., & McKinley, J. D. (2007). Performance of clay samples reinforced with vertical granular columns. *Canadian Geotechnical Journal*. <https://doi.org/10.1139/t06-081>
- Das, B. M., & Sobhan, K. (2014). *Principles of Geotechnical Engineering* (8th ed.). Stamford: Cengage Learning.
- Fakher, A., Jones, C. J. F. P., & Clarke, B. G. (1999). Yield Stress of Super Soft Clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 2(October), 499–509. [https://doi.org/10.1061/\(ASCE\)1090-0241\(2001\)127:10\(893\)](https://doi.org/10.1061/(ASCE)1090-0241(2001)127:10(893))
- Fernandes, F. M., Lourenço, P. B., & Castro, F. (2010). Materials, Technologies and Practice in Historic Heritage Structures. <https://doi.org/10.1007/978-90-481-2684-2>
- Frikha, W., Bouassida, M., & Canou, J. (2013). Observed Behaviour of Laterally Expanded Stone Column in Soft Soil. *Geotechnical and Geological Engineering*, 31(2), 739–752. <https://doi.org/10.1007/s10706-013-9624-8>
- Gregory, A. S., Whalley, W. R., Watts, C. W., Bird, N. R. A., Hallett, P. D., & Whitmore, A. P. (2006). Calculation of the compression index and precompression stress from soil compression test data. *Soil and Tillage Research*, 89(1), 45–57. <https://doi.org/10.1016/j.still.2005.06.012>
- Hammam, A. H., Abel-Salam, A. I., & Yousf, M. A. (2017). On the evaluation of pre-consolidation pressure of undisturbed saturated clays. *HBRC Journal*, 13(1), 47–53. <https://doi.org/10.1016/j.hbrcj.2015.02.003>

- Hasan, M., Marto, A., & Hyodo, M. (2014). Shear of Soft Clay Reinforced with Single and Group Bottom Ash Columns. *Arabian Journal for Science and Engineering*, 39(4), 2641–2654. <https://doi.org/10.1007/s13369-013-0933-2>
- Hasan, M., Norhayani, P., & Nurul Aina, H. (2016). Strength Of Soft Clay Reinforced With Square And Triangular Pattern Encapsulated Bottom Ash Columns. *Second International Conference on Science, Engineering & Environment*, (November). <https://doi.org/https://www.researchgate.net/publication/311715583>
- Head, K. H. (2006). *Manual of Soil Laboratory Testing* (3rd ed.). Dunbeath: Whittles Publishing.
- Hirkane, S. P., Gore, N. G., & Salunke, P. J. (2014). Ground Improvement Techniques. *International Journal of Inventive Engineering and Sciences (IJIES)*, 2(2), 11–13.
- Horpibulsuk, S., Yangsukkaseam, N., Chinkulkijniwat, A., & Du, Y. J. (2011). Compressibility and permeability of Bangkok clay compared with kaolinite and bentonite. *Applied Clay Science*, 52(1–2), 150–159. <https://doi.org/10.1016/j.clay.2011.02.014>
- Jamo, H. U., & Abdu, S. G. (2014). Structural Analysis and Surface Morphology Kaolin. *Science World Journal*, 9(3), 29–30.
- Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression. *Journal of Materials in Civil Engineering*, 19(9), 728–739. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2007\)19:9\(728\)](https://doi.org/10.1061/(ASCE)0899-1561(2007)19:9(728))
- Khalid, N., Arshad, M. F., Mukri, M., Mohamad, K., & Kamarudin, F. (2014). The properties of Nano-kaolin mixed with kaolin. *Electronic Journal of Geotechnical Engineering*, 19(Q), 4247–4255.
- Ling, F. N. L., Kassim, K. A., & Abdul Karim, A. P. D. A. T. (2012). Size Distribution Analysis of Kaolin using Laser Diffraction Technique. *Advanced Materials Research*, 342, 341–342. <https://doi.org/10.4028/www.scientificnet/AMR341-342.108>
- Lu, W., & Yuan, H. (2010). Exploring critical success factors for waste management in construction projects of China. *Resources, Conservation and Recycling*, 55(2), 201–208. <https://doi.org/10.1016/j.resconrec.2010.09.010>
- Lynch, G. C. J. (1994). Bricks : Properties and Classifications. *Structural Survey*, 12(4), 15–20.
- McKelvey, D., Sivakumar, V., Bell, A., & Graham, J. (2004). Modelling vibrated stone columns in soft clay. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering*, 157(3), 137–149. <https://doi.org/10.1680/geng.2004.157.3.137>

- Mousavi, S., & Wong, L. S. (2015). Mechanical behavior of compacted and stabilized clay with kaolin and cement. *Jordan Journal of Civil Engineering*, 9(4), 477–486. <https://doi.org/10.7508/cej.2016.01.011>
- Muhmed, A., & Wanatowski, D. (2013). Effect of Lime Stabilisation on the Strength and Microstructure of Clay. *IOSR Journal of Mechanical and Civil Engineering*, 6(3), 2320–334. <https://doi.org/10.6088/ijes.2013030600005>
- Muntohar, A. (2010). Mechanical Behavior of The Bentonite Mixed-Kaolin and Sand. *Civil Engineering Journal*, (December 2010).
- Nagarajan, T., Viswanathan, S., Ravi, S., & Srinivas, V. (2014). Experimental Approach to Investigate the Behaviour of Brick Masonry for Different Mortar Ratios, 586–592.
- Sree, D., Ajitha, A. R., & Evangeline, Y. S. (2011). Study on the Shrinkage , Swelling and Strength Characteristics of Clay Soils Under Different Environmental Conditions, (L), 2–5.
- Sridharan, a, & Nagaraj, H. B. (2000). Compressibility behaviour of remoulded, fine-grained soils and correlation with index properties. *Canadian Geotechnical Journal*, 37(JANUARY), 712–722. <https://doi.org/10.1139/t99-128>
- Tan, Y. C., Gue, S. S., Ng, H. B., & Lee, P. T. (2004). SOME GEOTECHNICAL PROPERTIES OF KLANG CLAY. Retrieved from http://gnpgeo.com.my/download/publication/2004_01.pdf
- Wood, D. M., Hu, W., & Nash, D. F. T. (2000). Group effects in stone column foundations: model tests. *Géotechnique*, 50(6), 689–698. <https://doi.org/10.1680/geot.2000.50.6.689>
- Yahaya, S., Jikan, S. S., Badarulzaman, N. A., & Adamu, A. D. A. (2017). Chemical Composition and Particle Size Analysis of Kaolin. *Path of Science*, 3(10), 1001--1004. <https://doi.org/10.22178/pos.27-1>
- Zainul Abidin, N. (2010). Investigating the awareness and application of sustainable construction concept by Malaysian developers. *Habitat International*, 34(4), 421–426. <https://doi.org/10.1016/j.habitatint.2009.11.011>