SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH POLYPROPYLENE COLUMN

ANAS MOHAMAD HUSIAN KASSIM

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

_____

Full Name : DR. MUZAMIR BIN HASAN

Position : Director Center for Earth Resources and Management (CERRM)

Date :

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.

_____

Full Name : ANAS MOHAMAD HUSIAN KASSIM

ID Number : MAC15002

Date :

SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH POLYPROPYLENE COLUMN

ANAS MOHAMAD HUSIAN KASSIM

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

MARCH 2017

ACKNOWLEDGEMENTS

Alhamdulillah. Thanks to Allah SWT, whom with His willing giving me the opportunity to complete this master study.

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Muzamir Bin Hasan for the continuous support of my master study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my master study.

Besides my supervisor, I would like to thank the rest of my thesis committee: Dr. Doh Shu Ing, Dr. Ngien Su Kong and Dr. Edriyana Binti A.Aziz for their encouragement, insightful comments, and hard questions.

My sincere thanks also goes to Miss Norhaiza Binti Ghazali and Miss Norhayani Binti Pangee@ Mohd Nor for offering me the inspirational spirit and the encouragement to work harder.

I thank my fellow labmate and close friend in University Malaysia Pahang: Ali Jamal Alrubaye, for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last two years. Also I thank my friends in University Malaysia Pahang: Ahmed Alabasi, Mahmood Hasan for their support all the time.

Last but not the least; I would like to thank my family: my parents for supporting me spiritually throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol	Description
PP	Polypropylene
R^2	Cohesion value
$^\circ C$	Degree Celsius
ρ_d	Dry density
k	Hydraulic conductivity
pH	Hydrogen Number
ϕ	Internal friction angle
kN	Kilo Newton
kPa	Kilo Pascal
w_L	Liquid limit
q_{max}	Maximum deviator stress
$\rho_{d(max)}$	Maximum dry density
Mg	Mega Gram
MN	Mega Newton
m/s	Metre per Second
μm	Micrometre
mm	Milimetre
w	Moisture content
w_{opt}	Optimum moisture content
$\%$	Percent
w_P	Plastic limit
I_P	Plasticity index

G_s	Specific gravity
ϕ_u	Undrained angle of internal friction
c_u	Undrained shear strength

LIST OF ABBREVIATIONS

c_v	Coefficient of Consolidation
ASSHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
A	Area of specimen
BSCS	British Soil Classification System
BS	British Standard
CBR	California Bearing Ratio
C_c	Compression Index
K	Kaolin
LL	Liquid Limit
OL	Low Plasticity Organic Clay
PI	Plastic Index
PL	Plastic Limit
SEM	Scanning Electron Microscope
STP	Standard Penetration Test
SL	Shrinkage Limit
UCT	Unconfined Compression Test
UU	Unconsolidated Undrained Triaxial Test
USCS	Unified Soil Classification System
US	United States
USA	United States of America

SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH POLYPROPYLENE COLUMN

ANAS MOHAMAD HUSIAN KASSIM

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

MARCH 2017

ABSTRAK

Tiang berbutir adalah satu teknik yang mempunyai sifat-sifat penambahbaikan daya dukung, mempercepatkan pelesapan lebihan tekanan air liang dan mengurangkan mendapan di dalam tanah lembut yang lemah. Penyelidikan ini bertujuan untuk mengenalpasti peranan tiang Polipropilena dalam penambahbaikan kekuatan ricih dan kebolehmampatan tanah liat lembut kaolin yang telah disusun semula dengan menentukan akibat-akibat daripada nisbah penggantian kawasan, nisbah tinggi penembusan dan nisbah penggantian isipadu bagi sesebatang tiang Polipropilena ke atas ciri-ciri kekuatan. Sampel-sampel kaolin yang telah diperkuatkan (bertelulang) adalah tertakluk kepada Mampatan Tak Terkurung (UCT) dan Tidak Disatukan Taktersalir (UU) ujian-ujian tiga paksi. Sampel-sampel kaolin berukuran 50mm diameter dan 100mm tinggi. Menggunakan tiang PP bertelulang, dengan nisbah penggantian kawasan sebanyak 0.3, 0.5 dan 0.8, sampel-sampel tanpa tiang PP adalah sample yang dikawal, yang mempunyai kekuatan ricih maksimum sebanyak 6.035-7.223 kPa. Manakala, bagi 10.24% nisbah penggantian kawasan dengan nisbah tinggi penembusan 0.3, kekuatan ricih maksimum adalah 8.422-11.231 kPa, yang membawa peningkatan maksimum purata kekuatan ricih, 55.65% berbanding dengan sampel-sampel yang dikawal. Adapun, tiang yang mempunyai nisbah tinggi penembusan 0.5 dan 0.8 dengan nisbah penggantian kawasan sebanyak 10.24%, masing-masing menunjukkan bacaan kekuatan ricih maksimum sebanyak 8.047-10.462 kPa dan 8.048-10.396 kPa, yang menjadikan peningkatan bagi purata kekuatan ricih untuk kedua-dua adalah 45.073% dan 46.494%. Sementara itu, bagi sample-sampel yang mempunyai 25% nisbah penggantian kawasan dan 0.3 nisbah tinggi penembusan, kekuatan ricih maksimum adalah 10.427-13.595 kPa, yang menandakan satu peningkatan sebanyak 88.095% bagi purata kekuatan ricih maksimum. Bagi nisbah tinggi penembusan 0.5 dan 0.8 untuk 25% nisbah penggantian kawasan, kekuatan ricih maksimum masing-masing adalah 8.432-9.627 dan 7.640-8.427 kPa. Ini membawa peningkatan kepada purata kekuatan ricih sebanyak 40.346% dan 23.247%. Ujian Tidak Disatukan Taktersalir (UU) menunjukkan peningkatan sudut geseran, φ kepada 17.2% daripada 1.5%, yang menunjukkan satu perubahan yang ketara dalam penambahbaikan. Ini dapat dijelaskan dengan ciri-ciri fizikal partikel PP dan keadaan permukaannya. Sementara itu, kejelekitan, c menunjukkan satu peningkatan yang memberangsangkan daripada 25.9% kepada 142.9% berikutan kelancaran dan ketiadaan lompang pada permukaan partikel PP. Tekanan deviasi berbanding dengan terikan paksi pada kegagalan bagi 70, 140 dan 280 kPa tekanan sel telah diuji, mempunyai julat peningkatan daripada 14.7 kPa kepada 67.9 kPa. Kesimpulannya, tiang Polipropilena banyak meningkatkan kekuatan ricih; oleh itu akan dilaksanakan dalam usaha mengurangkan kos bagi pembaikan tanah sebagai ganti kepada bahan-bahan yang tidak boleh diperbaharui.

Kata kunci—Polipropilena, UCT, UU, Pembaikan Tanah, kaolin.

ABSTRACT

Granular columns is a technique that has the properties of improving bearing capacity, accelerating the dissipation of excess pore water pressure and reducing settlement in a weak soft soil. This research aims to investigate the role of Polypropylene (PP) column in improving the shear strength and compressibility of soft reconstituted kaolin clay by determining the effects of area replacement ratio, height penetrating ratio and volume replacement ratio of a singular Polypropylene column on the strength characteristics. Reinforced kaolin samples were subjected to Unconfined Compression (UCT) and Unconsolidated Undrained (UU) triaxial tests. The kaolin samples were 50 mm in diameter and 100 mm in height. Using the Polypropylene column reinforcement, with an area replacement ratio of 0.3, 0.5 and 0.8. Samples without the Polypropylene column are the controlled sample, which is having maximum shear strengths of 6.035-7.223 kPa. While for 10.24% area replacement ratio with height penetration ratio of 0.3, the maximum shear strengths are 8.422-11.231 kPa which brings the average maximum improvement of shear strengths of 55.65% compared to that of the controlled samples. As for the column with height penetration ratio of 0.5 and 0.8 with 10.24% area replacement ratio, The maximum shear strengths indicates the values of 8.047-10.462 kPa and 8.048-10.396 kPa respectively which makes the improvement of average maximum shear strengths for both set are 45.073% and 46.494%. Meanwhile, for the samples having 25% area replacement ratio and 0.3 height penetration ratio, the maximum shear strengths are 10.427-13.595 kPa, which indicates an improvement of 88.095% for the average maximum shear strengths. As for height penetrating ratio of 0.5 and 0.8 for 25% area replacement ratio, the maximum shear strengths are 8.432-9.627 and 7.640-8.427 kPa respectively. This brings the of average maximum improvements of shear strengths to 40.346% and 23.247%. UU testing showed that Friction angle φ improvement recorded to be from 1.5 to 17.2 % which shows a noticeable change in improvement.This can be explained by the physical properties of the PP particle and its surface. Cohesion c in the other hand shows a remarkable improvement of 25.9 to 142.9 % due to the smoothness and the unavailability of voids at the surface of PP particles. Deviator stress versus axial strain at failure for 70, 140 and 280 kPa cell pressure were tested to have the range of improvement from 14.7 kPa to 67.9 kPa.In conclusion, Polypropylene column greatly improved the shear strength; and could therefore be implemented in reducing the cost of soil improvement as a replacement for non-renewable materials**.**

***Keywords*—**Polypropylene (PP), UCT, UU, Ground improvement, kaolin.

REFERENCES

Abbawi, Z. W. (2010). *Proposed Techniques for Improving Soft Soil underneath a Ballasted Track*. Ph.D. Thesis. University of Technology, Iraq

Abdelmalak, M., Bulois, C., Mourgues, R., Galland, O., Legland, J. and Gruber, C. (2016). Description of new dry granular materials of variable cohesion and friction coefficient: Implications for laboratory modeling of the brittle crust. Tectonophysics. doi. 10.101. 2016.03.003.

Abdullah, A. and Chandra, P. (1987). Engineering properties for coastal subsoils in Peninsula Malaysia. *Proceedings of the 9th South East Asia Geotechnical Conference*, pp. 127-138

Abdullah, C.H. and Edil, T.B. (2007). Behaviour of geogrid-reinforced load transfer platforms for embankment on rammed aggregate piers. *Geosynthetics Int*. 14(3): 141–153.

Alamgir, M., Miura, N. and Madhav, M. R. (1994). Analysis of granular column reinforced ground-II: stress transfer from granular column to soil. *Reports of the Faculty of Science and Engineering, Saga University, 23*(1), 81-94.

Ambily, a. P., and Gandhi, S. R. (2007). Behavior of Stone Columns Based on Experimental and FEM Analysis. Journal of Geotechnical and Geoenvironmental Engineering, 133(4), 405–415.

Amin, J. M., Taha, M. R., Ahmed, J. and Kassim, A. A. (1997). Prediction and Determination of Undrained Shear Strength of Soft Clay at Bukit Raja, Pertanika Journal of Science & Technology, 5(1), 111–126.

Ariffin, K.S., Rahman, H.A., Hussin, H. and Abdul Hadi, K.A. (2008). The genesis and characteristics of primary kaolinitic clay occurrence at Bukit Lampas, Simpang Pulai, Ipoh. *Journal of Geological Society of Malaysia.* 54: 9-16.

Attom, M. F., & Al-Tamimi, A. K. (2010). Effects of polypropylene fibers on the shear strength of sandy soil. *International Journal of Geosciences*, *1*(01), 44.

Balaam, N.P., Brown, P.T., and Poulos, H.G. (1977). Settlement analysis of soft clays reinforced with granular piles. Paper presented at the 5th Southeast Asian Conference on Soil Engineering, Bangkok. pp. 81–91.

Bauer, G. E., Fatani, M. N., & Al-Joulani, N. (1991). Reinforcing soil with aligned and randomly oriented metallic fibers.

Bell, A. and Kirsch, K. (2013). *Ground Improvement*. Boca Raton, LA: CRC Press.

Black, J., Sivakumar, V. and McKinley, J. (2007). Performance of clay samples reinforced with vertical granular columns. Canadian Geotechnical Journal, 44 (1), 89–95.

Botsis, J., Oerter, G., Friedrich, K., (1996). Fatigue Fracture in Polypropylene with Different Spherulitic Sizes, Paper presented at the ANTEC – Society of Plastics Engineers.

Brand, E. W., & Brenner, R. P. (1981). *Soft clay engineering*, 1st ed Vol. 20. Elsevier. Amsterdam: Elsevier Scientific Publishing Company.

British Standard B.S: C.P. 8004 (1986). *Code of Practice for Foundations*, British Standard Institution, London.

British Standard Institution, (1990). *Method of Testing Soils for Civil Engineering Purposes*, B.S. 1377.

Broms, B. (1987). Stabilization of soft clay in southeast Asia. *Proceedings of the 5th International Geotechnical Seminar on Case Histories in Soft Clay*. 163-198

Burke, P. E. H. (1999). *The tensile deformation process of polypropylene at high pressure* (Doctoral dissertation, University of Toronto).

Castro-Fresno, D., Movilla-Quesada, D., Vega-Zamanillo, Á. and Calzada-Pérez, M. A. (2011). Lime stabilization of bentonite sludge from tunnel boring. *Applied Clay Science. 51*(3), 250-257.

Chen F.H. and Morris M.D. (2000). Soil engineering: testing, design and remediation. *Engineering Geology Journal*. 87(3-4): 230-240.

Clarke, B. O., Porter, N. A., Symons, R. K., Marriott, P. J., Stevenson, G. J. and Blackbeard, J. R. (2010). Investigating the distribution of polybrominated diphenyl ethers through an Australian wastewater treatment plant. *Science of the Total Environment. 408*(7), 1604-1611.

Craig, R. F. (1983). *Soil Mechanics*, 3rd edition. Berkshire, England: Van Nostrand Reinhold (UK) Co. Ltd. pp1-415.

Craig, R. F. (2013). *Soil mechanics*, 7th edition. Springer science. ISBN 0–415–32703–2, pp1-415.

Demir, S., Mokarram, F. R., & Özener, P. The Sustainable Design of Granular Columns Based on Laboratory Model Tests. In *Geo-Chicago (2016)*(pp. 893-903).

Dutta, S., Nadaf, M. B., Birali, R. R. L., & Mandal, J. N. Encased Stone Columns for Soft Ground Improvement. In *Geo-Chicago (2016*)(pp. 746-755).

Encyclopedia Britannica. 2010. 15th Edition. Encyclopedia Britannica Inc. 32: 675-686

Etezad, M., Hanna, A., and Ayadat, T. (2005). Numerical model for group of stone columns. *Paper presented at the Proc. 73rd Annual Meeting of ICOLD.*

Faruq, M. (2011). Determination of basic soil properties and shear strength of Pekan soft clay. Bachelor. Thesis, University Malaysia Pahang, Malaysia.

Fattah, M. Y., A'amal, A. and Jaber, M. M. (2015a). Characteristics of clays stabilized with lime-silica fume mix. *Italian Journal of Geosciences. 134*(1), 104-113.

Fattah, M. Y., A'amal, A. and Jaber, M. M. (2015b). Improvement of bearing capacity of footing on soft clay grouted with lime-silica fume mix. *Geomechanics and Engineering, 8*(1), 113-132.

Fattah, M. Y., Bushra, S. Z. and Hanan, A. H. (2014). An experimental analysis of embankment on stone columns. *Journal of Engineering and Development, 20*(7), 62-84.

Fleming, K., Weltman, A., Randolph, M., & Elson, K. (2008). Piling engineering. 2nd edition CRC press, pp1-385.

Freeze, R. A., & Cherry, J. A. (1979). *Groundwater* (No. 629.1 F7).

Frikha, W., Bouassida, M., and Canou, J. (2008). Calibration of an elas- toplastic model for the prediction of stone column ultimate bearing capacity. Paper presented at the GeoCongress, ASCE, Reston, VA, 604–611.

Ghosh, A., & Dey, U. (2009). Bearing ratio of reinforced fly ash overlying soft soil and deformation modulus of fly ash. *Geotextiles and Geomembranes. 27*(4), 313-320.

Gniel, J., and Bouazza, A. (2009). *Improvement of Soft Soils Using Geogrid Encased*

Gotsis, A. D., Zeevenhoven, B. L. F., & Tsenoglou, C. (2004). Effect of long branches on the rheology of polypropylene. *Journal of Rheology (1978-present)*, *48*(4), 895-914.

Gue, S. S., & Tan, Y. C. (2005). Failures of ground improvement works in soft ground. *Elsevier Geo-Engineering Book Series*, *3*, 665-680.

Hasan, M. (2013). Strength and Compressibility Of Soft Soil Reinforced With Bottom Ash Columns. Ph.D. Thesis. Universiti Teknologi Malaysia, Malaysia.

Head, K. H. (1992). *Manual of Soil Laboratory Testing*. London: John Wiley & Sons. 2nd ed, pp1-448.

Hemati, Z. (2012). Study on plastic recycling in Petaling Jaya. M.Sc Thesis. University Malaya, Malaysia.

Hewaarachchi, S.U. (2014). Rock and minerals. https://prezi.com/pnvu-ztj3ggv/rocks-and-minerals/, (17 October 2014).

Ho, M. H., & Chan, C. M. (2011). Some mechanical properties of cement stabilized Malaysian soft clay. *World Academy of Science, Engineering and Technology, 50*, 24-25.

Huang, W. H. (1990). The Use of Bottom Ash in Highway Embankments, Subgrade and Subbases. Joint Highway Research Project, Final Report, Purdue University, West Lafayette, Indiana.

Huat, B. B., (1994), Behavior of Soft Clay Foundation beneath an Embankment. *Pertanika Journal of Science and Technology*, *2* (2). 215 – 235.

Hughes, C. S. (1996). *Variability in highway pavement construction* (Vol. 232). Transportation Research Board.

Hughes, C. S., & Killingsworth, B. M. (2000). *Quality Assurance Specification Review for Hot Mix Asphalt and Structural Concrete* (No. ME 99-4,).

Hughes, J. M. O., and Withers, N. J. (1974). Reinforcing of Soft Cohesive Soils with Stone Columns. *Ground Engineering. 7* (3), 42-49.

Hussin, J. M., Rahman, I. A., and Memon, A. H. (2013). The way forward in sustainable construction: issues and challenges. *International Journal of Advances in Applied Sciences*, *2*(1), 15-24.

INEOS Olefins and Polymers Europe. 2011

Jiang, H., Cai, Y., & Liu, J. (2010). Engineering properties of soils reinforced by short discrete polypropylene fiber. *Journal of Materials in Civil Engineering*, *22*(12), 1315-1322.

Jordan, J., Jacob, K. I., Tannenbaum, R., Sharaf, M. A., & Jasiuk, I. (2005). Experimental trends in polymer nanocomposites—a review. *Materials science and engineering: A*, *393*(1), 1-11.

Juran, I. and Guermazi, A. (1988). Settlement response of soft soils reinforced by compacted sand columns. *Journal of Geotechnical Engineering. 114*(8), 930-943.

Kamal, M. F. M. (2009). *Reduce, Reuse, Recycle and Recovery Technique in Sustainable Construction Waste Management*. M.Sc Thesis. Universiti Teknologi Malaysia, Malaysia.

Karian, H. (Ed.). (2003). *Handbook of polypropylene and polypropylene composites, revised and expanded*. CRC press.

Karim, H.H., Mahmood, M.M. and Renka, R.G. (2009). Soft Clay Soil Improvement Using Stone Columns and Dynamic Compaction Techniques. *Journal of Engineering and Technology*, 27(14), pp.2546–2565.

Kempfert, H.-G. and Gebreselassie, B. (2006). *Supported excavations in soft soil deposits*. Excavations and Foundations in Soft Soils. Springer-Verlag, pp.117-273.

Kumar, R., Chandrawanshi, M. S., & Jain, M. S. The Behavior of Sand Columns in Soft Expansive Clay: Experimental Study. In *Geo-Chicago 2016*(pp. 698-706).

Kumar, S., & Tabor, E. (2003). Strength characteristics of silty clay reinforced with randomly oriented nylon fibers. *Electronic Journal of Geotechnical Engineering*, *8*, 1.

Kumar, S., and Stewart, J. (2003). Evaluation of Illinois Pulverized Coal Combustion Dry Bottom Ash for Use in Geotechnical Engineering Applications. *Journal of Energy Engineering*. *129* (2), 42 - 55.

Licht, M. A., & Al-Kaisi, M. (2005). Strip-tillage effect on seedbed soil temperature and other soil physical properties. *Soil and Tillage research,80*(1), 233-249.

Ling, F.N., Kassim, K.A. and Abdul Karim, A., (2013). Reaction Products of Lime Zeolite Stabilized Kaolin Humic Acid. *Applied Mechanics and Materials, 372*(1), 88–96.

Liu, C. and Evett, J.B. (2004). Soils and Foundations. *Geotechnical and Geological Engineering*, 29(5): 675-684.

Liu, M. D., Pemberton, S. and Indraratna, B. (2010). A study of the strength of lime treated soft clays. *International Symposium and Exhibition on Geotechnical and Geosynthetics Engineering*, pp.245-251.

Maakaroun , T., Najjar S. S., and Sadek, S. (2009). Effect of Sand Columns on the Load Response of Soft Clays. Paper presented at the International Foundation Congress and Equipment Expo. 217 - 224.

Maier, C., & Calafut, T. (1998). *Polypropylene: the definitive user's guide and databook*. William Andrew.pp1-429.

Malaysian Petrochemicals Association (MPA). (2014). *Malaysia Petrochemical Country Report APIC 2014 Thailand*, 1-49.

Malaysian Plastics Manufacturer Association (MPMA). (2011). *A Study on Plastic Management in Peninsular Malaysia, Golden Ecosystem SDN.BHD.*

McKelvey, D., Sivakumar, V., Bell, A. and Graham, J. (2004). Modelling Vibrated Stone Columns In Soft Clay. *Geotechnical Engineering. 157*(1), 137 – 149.

Mitchell, J. K. (1976). *Fundamentals of Soil Behavior*. New York: John Wiley and Sons, Inc.

Miura, N., & Nagaraj, T. S. (2001). *Soft clay behaviour analysis and assessment*. St. Martin's Press

Mohd Yusof, K.N., Lun, L.C., Guan, P.P., and Ahmad Tajuddin, S.A. 2006. The correlations between chemical and index properties for soft clay of peninsular Malaysia. *Journal of Transportation, Geotechnics and Geomatics Engineering.* 10: 1-7.

Muir Wood, D., Hu, W., and Nash, F.T. (2000). Group effects in stone column foundation: model tests. *Geotechnique*. *50* (6), 689 - 698.

Murugesan, S., and Rajagopal, K. (2010). Studies on the Behavior of Single and Group of Geosynthetic Encased Stone Columns. *Journal of Geotechnical and Geoenvironmental Engineering, 136*(1), 129 – 139.

Nagy, N.M., (2013). Numerical analysis of soft clay performance reinforced by geosynthetics encased stone columns., Paper presented at the 11th International Conference Of Numerical Analysis And Applied Mathematics 1998(1), pp.1995–1998.

Najjar, S. S., Sadek, S., and Makaroun, T. (2010). Effect of Sand Columns on the Undrained Load Response of Soft Clays. *Journal of Geotechnical and Geoenvironmental Engineering, 136* (9), 1263 - 1277.

Nelly Pasquini and Antonio Addeo (2005). *Polypropylene handbook*. 2nd ed. Hanser Gardner Publications.

Ouederni, M. and Phillips, P., (1996). Effect of a Nucleating Agent on the Fracture Toughness of Isotactic Polypropylene, Paper presented at the ANTEC – Society of Plastics Engineers.

Park, T., & Tan, S. A. (2005). Enhanced performance of reinforced soil walls by the inclusion of short fiber. *Geotextiles and Geomembranes, 23*(4), 348-361.

Peacock, A. (2000). *Handbook of polyethylene: structures: properties, and applications*. CRC Press.

Portnoy, R. C. (1994). Polypropylene for Medical Device Application. Medical Plastics and Biomaterials. *Trade Journal*, *2*(4).

Prasad, A., Kazemian, S., Kalantari, B., & Kim Huat, B. (2012). A behavior of reinforced vibrocompacted stone column in peat. *Pertanika Journal of Science & Technology*, *20*(2), 221-241.

Rao, G. V. (1996). *Principles of transportation and highway engineering*. New Delhi, India: Tata Macmillan Press Ltd, pp. 1-517.

Rios, A. D. S. (2015). *Mechanical behavior of recycled polypropylene reinforced by coconut fibers using X-ray tomography and digital image correlation* (Doctoral dissertation, Université Paris-Saclay).

Salih, A. G. (2012). Review on granitic residual soils' geotechnical properties. *Electronic Journal of Geotechnical Engineering*, *17*.

Seco, A., Ramírez, F., Miqueleiz, L., García, B. and Prieto, E. (2011). The use of non-conventional additives in Marls stabilization. *Applied Clay Science. 51*(4), 419-423.

Senol, A., Edil, T. B., Bin-Shafique, M. S., Acosta, H. A. and Benson, C. H. (2006). Soft subgrades' stabilization by using various fly ashes. *Resources, Conservation and Recycling. 46*(4), 365-376.

Senol, A., Etminan, E., Yildirim, H., & Olgun, C. G. (2013). Improvement of High and Low Plasticity Clayey Soils Using Polypropylene Fibers and Fly Ash. In *ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction* (pp. 500-509). ASCE.

Senol, A., Ikizler, S. B., Etminan, E., & Demir, G. (2014). Improvement of low plasticity clayey soils using polypropylene fibers. *Proceedings of the Pavement Performance Monitoring, Modeling, and Management*, 1-8.

Serridge, C. J. (2006). Some Applications of Ground Improvement Techniques in the Urban Environment. *International Association for Engineering Geology and the Environment. 296*(1).1-14.

Shamshuddin, J. and Anda, M. (2008). Charge properties of soils in Malaysia dominated by kaolinite, gibbsite, goethite and hematite. *Bulletin of the Geological Society of Malaysia. 54*(1), 27-31.

Shirlaw, J. N., Tan, T. S., and Wong, K. S. (2006). *Deep excavations in Singapore marine clay*. London, Taylor and Francis Group, pp. 13-28.

Sivakumar, V., McKelvey, D., Graham, J., and Hughus, D. (2004). Triaxial Tests on Model Sand Columns in Clay. *Canadian Geotechnical Journal, 41*. 299 - 312.

Soleimanbeigi, A., & Edil, T. B. (2015). Compressibility of recycled materials for use as highway embankment fill. *Journal of Geotechnical and Geoenvironmental Engineering*, *141*(5), 04015011.

Tan Y. C. and Gue, S. S., (2005). Innovative Substructures on Soft Ground. *Master Builders Journal, 2* (1), 8-14.

Tan Y. C., Gue, S. S., Ng, S. B. and Lee, P. T., (2004). Some Geotechnical Properties of Klang Clay. Paper presented at the Malaysian Geotechnical Conference, Kuala Lumpur, 179 – 185.

Tan, Y., Gue, S., Ng, H. and Lee, P. (2003). Design parameters of Klang clay, Malaysia. Paper presented at the 12th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Singapore.

Tandel, Y. K., Solanki, C. H. and Desai, A. K. (2012). Numerical Modelling of Encapsulated Stone Column-Reinforced Ground. *International Journal of Civil Structural, Environmental and Infrastructure Engineering*, *2* (1), 82 - 96.

Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. *Geotextiles and Geomembranes*, *25*(3), 194-202.

Terzaghi, K. and Peck, R. (1967). *Settlement of point bearing pile foundation;, settlement of floating pile foundation. Soil mechanics in engineering practice.*2^{ed}, John Wiley and Sons. New York, 540-555.

Terzaghi, K., Peck, R. B. and Mesri, G. (1996). *Soil mechanics in engineering practice*. John Wiley & Sons, pp.1-528.

Thian, S. Y., & Lee, C. Y. (2014). Geotechnical characterisation of high plasticity offshore clay. *Journal of Scientific Research & Reports*, *3*(21), 2745-2756.

Ting, W., Wong, T. and Toh, C. (1988). Design parameters for soft ground in Malaysia. *Geotechnical Engineering. 19*(1), 5.45-5.60.

Wesley, L. D. (2009). *Fundamentals of soil mechanics for sedimentary and residual soils*. John Wiley & Sons, pp. 1-402.

Wilkinson, A., Haque, A., Kodikara, J., Adamson, J. and Christie, D. (2010). Improvement of problematic soils by lime slurry pressure injection: case study. *Journal of Geotechnical and Geoenvironmental Engineering. 136*(10), 1459-1468.

Winterkorn, H. F., & Fang, H. Y. (1975). Foundation engineering handbook. pp.1-751.

Yee, Y. M. (2012). Shear Strength of Soft Soil Reinforced With Singular and a Group Of Bottom Ash Columns. Bachelor. Thesis, University Teknologi Malaysia, Malaysia.

Yilmaz, Y., & Karatas, K. (2011). Effect of Polypropylene Fibre on the Strength Characteristics of Lightly Cemented Clayey Soil Mixtures. In *Geo-Frontiers 2011: Advances in Geotechnical Engineering* (pp. 707-716). ASCE.

Yoo, C. (2010). Performance of geosynthetic-encased stone columns in embankment construction: numerical investigation. *Journal of Geotechnical and Geoenvironmental Engineering. 136*(8), 1148-1160.

Yusof, M. (2012). *Composite foundations on Malaysian soft clay soil: applications of innovative techniques* (Doctoral dissertation, University of Leeds).