UNIVERSITI PUTRA MALAYSIA

REINFORCEMENT EFFECTS OF NANO-MODIFIED COIR FIBRES ON LIME-TREATED MARINE CLAY

VIVI ANGGRAINI

FK 2015 92
REINFORCEMENT EFFECTS OF NANO-MODIFIED COIR FIBRES ON LIME-TREATED MARINE CLAY

By

VIVI ANGGRAINI

Thesis Submitted to the School of Graduate Studies Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2015
COPYRIGHT

All material contained within the thesis, including without limitation text, logos, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia
DEDICATED

Mum and Dad, *Hj. Rasiha* and *Ir. H. Abdullah*

And

Beloved sons, *Athar* and *Tariq*
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

REINFORCEMENT EFFECTS OF NANO-MODIFIED COIR FIBRES ON LIME-TREATED MARINE CLAY

By

VIVI ANGGRAINI

November 2015

Chairman: Professor Bujang Bin Kim Huat, PhD
Faculty: Engineering

Marine clay soils under land-based structures develop shrinkage cracks due to the uneven distribution of moisture. Treatment of marine clay soils with lime is one of the widely used methods. However, the soils treated with lime will cause brittle failure. Therefore, to improve the mechanical properties of treated soil, the lime treatment technique combined with inclusion of randomly distributed tensile reinforcement elements such as natural fibres (e.g., coir fibre) were used. However, the mechanical performance of the treated soil depends not only on the nature of the soil, moreover on the mechanical properties of the fibre as well the interaction between the fibre and the lime-treated soil.

This research was developed to further increase the performance of coir fibre in lime-treated soil as pile-supported earth platform. A nano impregnation method was applied through chemical treatment with different chemicals including CaCl₂, MgCl₂, AlCl₃ and FeCl₃ in order to impregnate fibres with nano-particles. To confirm the alteration of morphology in the fibres and understand the underlying mechanisms of chemically treated fibres, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) tests were performed. Furthermore, the mechanical properties of the composites were assessed. Unconfined compressive strength tests, indirect tensile strength tests, flexural strength tests, and triaxial compressive strength tests were carried out on original soil, lime-treated soil, and lime-treated soil reinforced with nano-treated and untreated fibre. Moreover, a durability test was conducted to scrutinize the change in the strength of the reinforced soil. Finally, the experimental results were used in a numerical analysis using commercially available software (ABAQUS CAE) to investigate the performance of the proposed treatment as pile supported earth platform. The physical model experiments were performed to validate numerical model.

The results revealed that the nano impregnation of fibres increased the tensile strength up to 200% compared with untreated fibres. The fibres modified with Ca(OH)₂ showed higher mechanical performance compared with the fibres modified by Mg(OH)₂, Al(OH)₃, and Fe(OH)₃. The SEM/EDX results showed that cellulosic pores of the fibres
were filled with Ca nano-sized crystals ranging from 25 to 150 nm. The mechanical performance of the treated soil increased when chemically treated fibres were used. The compressive strength, indirect tensile strength, and flexural strength of the treated soil increased by 66, 122, and 60% when Ca(OH)$_2$-treated fibres were used compared with those of limed soil reinforced with untreated fibres. Moreover, the addition of nano impregnated fibres using Ca(OH)$_2$ increased the shear strength parameters of marine clay soil with increases in the level of confining pressure and consequently led to a more ductile behaviour. The numerical analyses show the importance of the mechanical properties of the treated soils are effective in reducing the differential settlement up to 50% when the height of the earth platform used is 0.3 m. The research is important in that it confirms that the nano modification technique can not only increase the mechanical performance of the coir fibres but also improve the interfacial mechanical interactions between the fibre surface and soil particles, resulting in a higher performance of the composites used as a pile-supported earth platform.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai mementuh keperluan untuk Ijazah Doktor Falsafah.

KESAN PENETULANGAN OLEH SABUT KELAPA TERUBAH SUAI NANO TERHADAP TANAH LIAT MARINE YANG TERAWAT KAPUR

Oleh

VIVI ANGGRAINI

November 2015

Pengerusi : Profesor Bujang Bin Kim Huat, PhD
Fakulti : Kejuruteraan

Tanah liat marin di bawah struktur berasaskan tanah membangunkan retak pengecutan disebabkan oleh pengagihan kelembapan yang tidak sama rata. Rawatan tanah liat marin dengan kapur adalah salah satu kaedah yang digunakan secara meluas. Walaubagaimanapun, tanah yang dirawat dengan kapur akan menyebabkan kegagalan rapuh. Oleh itu, untuk menambahbaik prestasi mekanikal tanah dirawat, teknik rawatan kapur digabungkan dengan kemasukan secara rawak elemen tetulang tegangan seperti gentian semula jadi (contohnya, gentian sabut kelapa) di dalam tanah telah digunakan. Walaubagaimanapun, prestasi mekanikal tanah yang dirawat bukan sahaja bergantung kepada jenis tanah tetapi juga sifat-sifat mekanik gentian dan interaksi antara gentian dan tanah kapur yang dirawat itu.

Kajian ini telah dibangunkan untuk meningkatkan lagi prestasi sabut kelapa di dalam tanah yang telah dirawat dengan kapur sebagai sokongan cerucuk platform bumi. Satu kaedah pengisitepuan nano telah diaplikasikan melalui rawatan kimia dengan bahan kimia yang berbeza termasuk CaCl₂, MgCl₂, AlCl₃ dan FeCl₃ untuk mengisitepukan serat dengan zarah-zarah nano. Untuk mengesahkan perubahan morfologi dalam gentian dan memahami mekanisme asas sabut kelapa yang telah dirawat secara kimia, Ujian Mikroskop Imbasan Elektron (SEM) dan X-ray Serakan Tenaga Spektroskop (EDX) telah dijalankan. Tambah pula, sifat-sifat mekanikal komposit adalah dikaji. Ujian Mampatan Tak Terkurung, Ujian Mampatan Tiga Paksi telah dijalankan ke atas tanah asli, tanah yang dirawat dengan kapur, dan tanah yang dirawat dengan kapur yang diperkukuhkan lagi dengan gentian yang dirawat dan tidak dirawat oleh nano . Selain itu, ujian ketahanan telah dijalankan untuk meneliti perubahan dalam kekuatan tanah yang bertetulang. Akhirnya, keputusan eksperimen telah digunakan di dalam analisis berangka dengan menggunakan perisian yang tersedia secara komersil (ABAQUS CAE) untuk menyiasat prestasi rawatan yang dicadangkan sebagai longgokan disokong platform bumi sebagai sokongan cerucuk platform bumi. Eksperimen model fizikal telah dijalankan untuk mengesahkan model berangka.
Keputusan menunjukkan bahawa pengisitepuan nano di dalam sabut kelapa telah meningkatkan kekuatan tegangan gentian sehingga 200% berbanding dengan gentian yang tidak dirawat. Gentian yang diubahsuai dengan Ca(OH)\(_2\) menunjukkan prestasi mekanikal yang lebih tinggi berbanding dengan gentian diubahsuai oleh Mg(OH)\(_2\), Al(OH)\(_3\), dan Fe(OH)\(_3\). Keputusan SEM / EDX menunjukkan bahawa liang berselulos sabut kelapa dipenuhi dengan Ca bersaiz nano Kristal antara 25-150 nm. Prestasi dari sifat-sifat mekanik tanah tanah yang dirawat adalah meningkat apabila gentian yang dirawat secara kimia telah digunakan. Kekuatan mampatan, kekuatan tegangan tidak langsung, dan kekuatan lenturan tanah yang dirawat didapati meningkat sebanyak 66, 122, dan 60 % apabila gentian yang dirawat dengan Ca(OH)\(_2\) digunakan berbanding dengan tanah yang dirawat oleh kapur diperkukuh dengan gentian yang tidak dirawat.

Selain itu, penambahan pengisitepuan nano di dalam gentian menggunakan Ca(OH)\(_2\) meningkatkan parameter kekuatan rich tanah liat marin dengan peningkatan dalam tahap tekanan mengurung dan seterusnya menjadikan kepada tingkah laku yang lebih anjau. Analisis berangka menunjukkan kepentingan sifat-sifat mekanik tanah dirawat bagi keberkesanaan dalam pengurangan penyelesaian pengkamiran platform bumi. Nilai keberkesanaan untuk tanah yang dirawat dengan kapur serta diperkukuhkan dengan semua jenis pengisitepuan nano gentian sabut kelapa adalah sehingga 50% di bawah pelbagai beban struktur apabila ketinggian efektif platform bumi adalah 0.3 m. Penyelesaian pengkamiran pada ketinggian kepala cerucuk semakin berkurang sehingga 100%.

Kajian ini adalah penting kerana ia mengesahkan bahawa teknik pengubahsuaian nano bukan sahaja boleh meningkatkan prestasi mekanik gentian tetapi juga meningkatkan interaksi mekanikal antara muka di antara permukaan gentian dengan zarah tanah, menyebabkan prestasi yang lebih tinggi bagi komposit yang digunakan sebagai sokongan cerucuk platform bumi.
ACKNOWLEDGEMENTS

The author’s gratitude goes to Allah SWT for all the blessings and graces that provided health and wisdom to complete her study. The author is immensely indebted to her academic supervisors, Professor Bujang Bin Kim Huat, Dr. Afshin Asadi and Dr. Haslinda Nahazanan, for their guidance and support through the research degree.

The financial support of the Research Management Centre (RMC) Project No. 05-02-12-1890RU and the Universiti Putra Malaysia Geotechnical and Geological Research Committee are gratefully acknowledged. The author is thankful to Faculty of Engineering Universiti Putra Malaysia for the use of school and lab facilities. The technical support of Mr. Razali, Mr. Sukheri, Mr. Azri, Mr. Wildan, Mr. Haffis and Mr. Mustaqim is gratefully acknowledged. Special thanks to Dr. Hossein Jahangirian and Dr. Nima Farzadnia for their generous contributions to the research. The author is grateful to the anonymous referees for their respective valuable comments on the manuscripts of journal papers. In addition, the author is thankful to her colleagues for their advice and assistance.

Finally, the author offers her gratitude to her parents, siblings and friends who have supported and encouraged her throughout this work. In particular, the author is thankful to her husband (Dr. Agusril) and her beloved sons (Athar and Tariq) for their unconditional love and support at all times.
I certify that a Thesis Examination Committee has met on 5 November 2015 to conduct the final examination of Vivi Anggraini on her thesis entitled "Reinforcement Effects of Nano-Modified Coir Fibres on Lime-Treated Marine Clay" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Abdul Halim bin Ghazali, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Thamer Ahmad Mohammad Ali, PhD**  
Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Faisal Hj. Ali, PhD**  
Professor  
Universiti Pertahanan Nasional Malaysia  
Malaysia  
(Internal Examiner)

**Hadi Khabbaz, PhD**  
Associate Professor  
University of Technology Sydney  
Australia  
(External Examiner)

---

**ZULKARNAIN ZAINAL, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia  

Date: 12 January 2016
This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Bujang Bin Kim Huat, PhD  
Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

Afshin Asadi, PhD  
Research Fellow  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

Haslinda Nahazanan, PhD  
Senior Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

BUJANG BIN KIM HUAT, PhD  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia  

Date:
Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the University Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification /fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: __________________ Date: __________________

Name and Matric No.: Vivi Anggraini (GS 33125)
Declaration by Members of Supervisory Committee

This is to confirm that:
the research conducted and the writing of this thesis was under our supervision;
supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ____________________________
Name of Chairman of Supervisory Committee: Prof. Dr. Bujang Bin Kim Huat

Signature: ____________________________
Name of Member of Supervisory Committee: Dr. Afshin Asadi

Signature: ____________________________
Name of Member of Supervisory Committee: Dr. Haslinda Nahazanan
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRAK</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>vi</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xviii</td>
</tr>
</tbody>
</table>

## CHAPTER

1 INTRODUCTION

1.1 Introduction

1.2 Problem of Statement

1.3 Objectives of Thesis

1.4 Scope of Study

1.5 Thesis Organisation

2 LITERATURE REVIEW

2.1 Introduction

2.2 Marine clay soil

2.2.1 Peninsular Malaysia marine clay soil

2.2.2 Characteristics of Klang marine clay soil

2.2.3 Marine clay soil problem

2.3 Soil stabilisation

2.4 Soil reinforcement

2.4.1 Coir fibres as soil reinforcement

2.4.2 Coir fibre structure

2.4.3 Natural fibre treatment

2.5 Potential application of lime and fibre reinforcement

2.6 Pile supported earth platform

2.6.1 Load transfer mechanism of pile supported load transfer platform

2.6.2 Numerical modelling

2.6.3 Physical modelling

2.6.4 Potential of lime and fibre as earth platform material

2.7 Summary

3 METHODOLOGY

3.1 Introduction

3.2 Sampling location

3.3 Material preparation

3.4 Original soil investigation

3.4.1 XRF analysis

3.4.2 XRD analysis

3.4.3 Salinity measurement

3.4.4 pH test
3.4.5 Organic content test
3.4.6 Plasticity index test

3.5 Fibre treatment
3.5.1 Quick precipitation method
3.5.2 Scanning electron microscope (SEM)/Energy dispersive X-Ray spectrometer
3.5.3 X-Ray diffractometry
3.5.4 Single fibre tensile strength test

3.6 Performance of coir fibre reinforced limed soil
3.6.1 Preparation of specimens
3.6.2 Unconfined compression strength test
3.6.3 Indirect tensile strength test
3.6.4 Flexural strength test
3.6.5 Triaxial compression strength test
3.6.6 Durability
3.6.7 Scanning electron microscopy test (SEM)

3.7 Use of lime and treated coir fibre reinforced soils as pile supported load transfer platform
3.7.1 Physical model
3.7.2 Numerical model

4 RESULTS AND DISCUSSION
4.1 Introduction
4.2 Results organization
4.3 Geotechnical properties of Klang marine clay soil
4.4 Morphological and mechanical characteristics of nano modified coir fibre through chemical treatment
4.4.1 Nanoparticles impregnate coir fibre mechanism
4.4.2 Morphological changes
4.4.3 Material characterization for untreated and treated fibres
4.4.4 Tensile strength of untreated and treated single coir fibre

4.5 Influence of lime and different amount of coir fibre on mechanical properties
4.5.1 Moisture density relations
4.5.2 Plasticity index
4.5.3 Unconfined compression strength
4.5.3.1 Effect of lime and various percentage of unmodified coir fibres
4.5.3.2 Effect of lime and nano modified coir fibres
4.5.4 Indirect tensile strength
4.5.4.1 Effect of lime and various percentage of unmodified coir fibres
4.5.4.2 Effect of lime and nano modified coir fibres
4.5.5 Flexural strength
4.5.5.1 Effect of lime and various percentage of unmodified coir fibres
4.5.5.2 Effect of lime and nano modified coir fibres
4.5.6 Triaxial compression test
4.5.7 Effect of repetitive wetting
4.5.8 Microstructural study
4.5.9 Pattern of failure 87
4.6 Physical and numerical model of earth platform 92
   4.6.1 Comparison between experimental and finite element analysis (FEA) 92
   4.6.2 Parametric studies 93
   4.6.3 Settlement 93
   4.6.4 Vertical stress 94
   4.6.5 Efficacy 95
   4.6.6 Bending performance of earth platform 97

5 CONCLUSIONS AND RECOMMENDATIONS 99
   5.1 Summary 99
   5.2 Conclusions 100
   5.3 Recommendations 101

REFERENCES 102
APPENDICES 110
BIODATA OF STUDENT 119
LIST OF PUBLICATIONS 120
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>15</td>
</tr>
<tr>
<td>3.1</td>
<td>36</td>
</tr>
<tr>
<td>3.2</td>
<td>37</td>
</tr>
<tr>
<td>3.3</td>
<td>40</td>
</tr>
<tr>
<td>3.4</td>
<td>44</td>
</tr>
<tr>
<td>3.5</td>
<td>44</td>
</tr>
<tr>
<td>3.6</td>
<td>54</td>
</tr>
<tr>
<td>4.1</td>
<td>57</td>
</tr>
<tr>
<td>4.2</td>
<td>58</td>
</tr>
<tr>
<td>4.3</td>
<td>67</td>
</tr>
<tr>
<td>4.4</td>
<td>85</td>
</tr>
<tr>
<td>4.5</td>
<td>91</td>
</tr>
<tr>
<td>4.6</td>
<td>98</td>
</tr>
</tbody>
</table>

Materials investigated in some previous studies

The chemical and physical analysis of lime (Cao Industries Sdn BhD)

The chemical and physical analysis of coir fibre

Concentration and composition of chemical used for treatment of coir fibre

Mixture of the tested materials of untreated coir fibres

Mixture of the tested materials of treated coir fibres

Model parameters of the unreinforced and reinforced soils

Basic Properties of Klang Marine soil used in this study

Chemical Composition of Klang Marine Clay

Atterberg limits of lime reinforced soil

Unconfined compressive strength after wetting and drying

Summary of the results at 90-day curing

Deflection of earth platform and vertical stress on soft soil ground midway
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Quaternary Sediments in Peninsular Malaysia (after Stauffer, 1974)</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Depth profile, specific gravity (Gs) and Atterberg’s limit of the Klang clay deposit (Taha, 2000)</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Fibre orientation in composites</td>
<td>13</td>
</tr>
<tr>
<td>2.4</td>
<td>Mechanism of fibre-reinforced soil (after Gray and Ohashi, 1983)</td>
<td>13</td>
</tr>
<tr>
<td>2.5</td>
<td>Structure of natural fibre (John and Anandjiwala, 2008)</td>
<td>17</td>
</tr>
<tr>
<td>2.6</td>
<td>Mechanism of alkali treatment of natural fibre (After Chowdhury et al.2013)</td>
<td>20</td>
</tr>
<tr>
<td>2.7</td>
<td>Rigid inclusion execution (Okyay and Dias, 2012)</td>
<td>22</td>
</tr>
<tr>
<td>2.8</td>
<td>Treated soil as pile supported load transfer platform</td>
<td>23</td>
</tr>
<tr>
<td>2.9</td>
<td>Analytical Model: Semi-cylindrical Earth Platform arches (after Low et al., 1994)</td>
<td>24</td>
</tr>
<tr>
<td>2.10</td>
<td>Geotextile overlying Cap Beams and Soft Ground (after Abusharar, 2012)</td>
<td>25</td>
</tr>
<tr>
<td>2.11</td>
<td>Numerical model grid (Jenk et al 2007)</td>
<td>26</td>
</tr>
<tr>
<td>2.12</td>
<td>Finite element model of geosynthetic reinforced piled embankment (a) and vertical stress (S22) on pile and soil layers (Bhasi &amp; Rajagopal, 2007)</td>
<td>27</td>
</tr>
<tr>
<td>2.13</td>
<td>Finite element model that showing soil arching with 45° angle</td>
<td>28</td>
</tr>
<tr>
<td>2.14</td>
<td>The simulated zone and mesh distribution (Okyay &amp; Dias, 2010)</td>
<td>28</td>
</tr>
<tr>
<td>2.15</td>
<td>Typical Scheebeli small-scale model test</td>
<td>29</td>
</tr>
<tr>
<td>3.1</td>
<td>Overall schematic presentation of the study</td>
<td>33</td>
</tr>
<tr>
<td>3.2</td>
<td>(a) The location of the sampling point of the marine clay at Port Klang, Malaysia</td>
<td>34</td>
</tr>
<tr>
<td>3.3</td>
<td>Grinding of marine clay soil</td>
<td>35</td>
</tr>
<tr>
<td>3.4</td>
<td>Homogenization of marine clay particles</td>
<td>35</td>
</tr>
<tr>
<td>3.5</td>
<td>Short coir fibre as reinforcement</td>
<td>36</td>
</tr>
</tbody>
</table>
3.6 Salinity test of Klang marine clay
3.7 Digital Calibrated pH Probes
3.8 Organic content test of Klang marine clay
3.9 Index plasticity test
3.10 Schematic diagram of the system used in the modification of coir fibre
3.11 SEM/EDX sample preparation
3.12 Sputter/coater samples
3.13 Chopped coir fibres
3.14 Compaction test of Klang marine clay
3.15 Unconfined compression strength test
3.16 Indirect tensile strength test
3.17 Three point bending test
3.18 Triaxial compression test
3.19 Soil submerged
3.20 Schematic diagram of earth platform model
3.21 Test setup and instrumentation detail of the physical model of an earth platform
3.22 Schema of the simulated zone and mesh distribution
4.1 Particle size distribution
4.2 Chemical Structure of (a) Ca(OH)₂ modified coir fibre (b) Mg(OH)₂ modified coir fibre (c) Fe(OH)₃ modified coir fibre (d) Al(OH)₃ modified coir fibre
4.3 Natural coir fibre (a) untreated (b) Mg(OH)₂ treated fibres (c) Ca(OH)₂ treated fibres (d) Fe(OH)₃ treated fibres (e) Al(OH)₃ treated fibres
4.4 Surface structure (a) unmodified (b-c) modified coir fibre
4.5 SEM images (a) cross-section of Mg(OH)₂ impregnated fibre, nano average size 25 ± 4 nm (b) Ca(OH)₂ nano impregnated fibre, nano average size 149 ± 19 nm (c) cross-section of Fe(OH)₃ modified coir
fibre, nano average size 109 ± 15 nm (d) Al(OH)₃ nano impregnated fibre, nano average size 119 ± 19 nm

4.6 EDX spectrum of (a) unmodified coir fibre (b) Mg(OH)₂ modified coir fibre (c) Ca(OH)₂ modified coir fibre (d) Fe(OH)₃ modified coir fibre (e) Al(OH)₃ modified coir fibre

4.7 X -ray diffractograms of the coir fibre particles (a) unmodified (b) Mg(OH)₂ treated fibre (c) Fe(OH)₃ treated fibre (d) Al(OH)₃ treated fibre (e) Ca(OH)₂ treated fibre

4.8 Tensile strength of the treated and untreated coir fibres

4.9 Dry unit weight vs water content

4.10 The values of compressive strength of specimen tested at 7, 28 and 90-day curing

4.11 Compressive stress-strain curves of reinforced soils after (a) 7 days (b) 28 days and (c) 90 days

4.12 Evolution of compressive strength

4.13 The values of indirect tensile strength of specimen tested at 7,28 and 90 days

4.14 Load-displacement curves of unreinforced soil and reinforced soils after (a) 7 (b) 28 and (c) 90 days

4.15 Evolution of tensile strength

4.16 The values of flexural strength of specimen tested at 7, 28 and 90-day curing

4.17 The values of Young’s modulus of specimen tested at 7, 28 and 90-day curing

4.18 Load-displacement curves of reinforced soils after 7, 28 and 90- day curing

4.19 Evolution of flexural strength

4.20 Evolution of Young’s modulus

4.21 Stress-strain relationship obtained from CU triaxial test at various confining stresses (a) 50 kPa; (b) 100 kPa; (c) 150kPa

4.22 Pore pressure in terms of effective strain in unreinforced and reinforced soil under triaxial compression shearing stage at different confining stresses (a) 50 kPa, (b) 100 kPa and (c) 150 kPa
4.23 Mohr circles in the case of total stress and effective stress for (a) S (b) SL (c) SLF (d) SLMF (e) SLFF (g) SLCF

4.24 Effect of wetting/ drying cycles on the compressive strength of the stabilized and fibre reinforced soil

4.25 SEM of fibres in soil

4.26 Failure characteristic of unreinforced and reinforced soil of compressive strength test

4.27 Failure characteristic of unreinforced and reinforced soil of indirect tensile strength test

4.28 Failure characteristic of unreinforced and reinforced soil of three point bending test

4.29 Failure characteristic of unreinforced and reinforced soil of triaxial compression test

4.30 Experimental observation of the settlements due to surcharge

4.31 Effect of height of earth platform on settlement from surcharge load

4.32 Effect of the earth platform’s mechanical properties on settlement at various surcharge loads of the earth platform’s height of 0.05 m

4.33 The vertical stress on soft soil ground midway between the pile heads for various earth platform materials

4.34 Performance of the material characteristics on the efficacy

4.35 The vertical stress on soft soil ground midway between the pile heads at 0.05 m height of earth platform
LIST OF ABBREVIATIONS

A  Area of cross-section of sample
Al  Aluminium
Al(OH)$_3$  Aluminium hydroxide
AlCl$_3$  Aluminium chloride
ASTM  American society for testing and material
BS  British Standard
C  Clay
c  Apparent cohesion
CEC  Cation exchange capacity
Ca  Calcium
CaCl$_2$  Calcium chloride
Ca(OH)$_2$  Calcium hydroxide
CU  Consolidated-undrained triaxial test
CD  Consolidated-drained triaxial test
D  Diameter of sample
D  Constrained modulus
D  Depth of soft ground
E  Young's modulus of elasticity
E  Efficacy
E’  Drained modulus
EDX  Energy dispersive X-ray spectrometer
F  Applied force
Fe  Iron
FeCl$_3$  Ferric chloride
Fe(OH)$_3$  Iron (III) hydroxide
G  Shear modulus
Gs  Spesific gravity
H  Height of sample
H$_2$O  Water
L  Length of sample
LL  Liquid limit
Mg  Magnesium
MgCl$_2$  Magnesium chloride
Mg(OH)$_2$  Magnesium hydroxide
NaOH  Sodium hydroxide
NaCl  Sodium Chloride
OH  Hydroxide
OC  Overconsolidated
OCR  Overconsolidated ratio
OMC  Optimum moisture content
P    Applied force
PL   Plastic limit
PI   Plasticity Index
Rc   Compressive strength
Rt   Tensile strength
Rb   Bending strength
SEM  Scanning Electron Microscopy
UU   Unconsolidated-Undrained triaxial test
XRD  X-ray Diffraction
XRF  X-ray Fluorescence
$E_s$ Elastic modulus of soft ground
$E_s$ Secant modulus
$E_t$ Tangent modulus
$ESP$ Effective stress path
$e$   Voids ratio
$n$   Porosity
$r$   Radius of soil sample
$R$   Radius of circular arc of geosynthetic
$u$   Pore pressure
$\varepsilon$  Strain
$v$   Poisson’s ratio
$v_u$ Poisson’s ratio (undrained)
v'   Poisson’s ratio (drained)
$\gamma_d$ Dry density
$\sigma$ Normal stress
$\sigma'$ Normal effective stress
$\sigma_1, \sigma_2, \sigma_3$ Principal stresses
$\sigma'_1, \sigma'_2, \sigma'_3$ Principal effective stresses
$\sigma_v, \sigma_h$ Vertical and horizontal stresses
$\sigma'_v, \sigma'_h$ Vertical and horizontal effective stresses
$\sigma_n$ Stress normal to surface of failure
$\sigma_1$ Axial stress
$\sigma_3, \sigma_c$ Confining pressure
$\sigma'_3, \sigma'_c$ Effective confining pressure
$(\sigma_1 - \sigma_3)$ Deviator stress
$(\sigma_1 - \sigma_3)_f$ Deviator stress at failure
$\phi'$ Angle of shear resistance based on effective stresses
Vertical stress acting on top of soft ground midway between pile head

\( \sigma_s \)

Unit weight of earth platform

\( \gamma \)

Angle of shearing resistance of earth platform

\( \theta \)

Center to center spacing of piles

\( s \)

Clear spacing between piles, \( s' = s - b(m) \)

\( s' \)

Rankine passive earth pressure coefficient \( K_p = (1 + \sin \theta_s)/(1 - \sin \theta_s) \)

\( K_p \)

Half angle subtended by geosynthetic circular arc (degree)

\( \theta \)

maximum displacement of soft ground midway between pile heads

\( t \)

Axial tension force in geosynthetic

\( T \)
CHAPTER 1

INTRODUCTION

1.1 Introduction

Marine clay soils under land based structures develop shrinkage cracks due to uneven moistures distribution. Consequently, they exhibit considerable variation of shear strength, compressibility and tensile strength which cause differential movement, severe damage in foundations, buildings, roads, embankments, retaining structures, canal lining and etc. (Sivakumar Babu et al., 2008; Ramesh et al., 2010). The problems associated with marine clay soils can be controlled by different techniques such as isolating the soil using geo-membranes or providing an adequate thickness of cohesive non-swelling soil specially given in large-scale projects (Miller, 1997). However, they are expensive in small scale projects such as construction of bunds of smaller height.

One possible solution to this problem is addition of lime in order to immobilize water in marine clay by its chemical reactions and reduce plasticity index of the clay. A reduction in plasticity is usually accompanied by reduction of potential for swelling. Rajasekaran and Rao (1997) reported that lime is commonly used to change properties of soils due to its more stable performance, lower prices, and abundance. Lime is most effective for treating soils capable of holding large amounts of water (Locat et al., 1990; Bell, 1996; Rajasekaran et al., 1997; Rajasekaran and Rao, 2002; Dash and Hussain, 2011). However, soils treated with lime are subjected to a brittle failure (Ninov and Donchev, 2008). Therefore, it is better to amend it with a technique of reinforcement (Ranjan et al., 1994; Ziegler et al., 1998; Yetimoglu and Salbas, 2003; Ninov and Donchev, 2008). So, a possible solution involves inclusion of randomly distributed tensile reinforcement elements in the marine clay. Adding fibres can effectively reduce the number and width of shrinkage cracks and help to obstruct them (Ziegler et al., 1998; Estabragh et al., 2012).

The effectiveness of fibres depends upon the strength of fibre as well as how they interact with soil at normal stresses through adhesion. When a tensile force needs to mobilize in the fibres, as in drying shrinkage and desiccation cracks, adhesion restrains the fibres from pull out and thus allows its tensile resistance to develop. The mechanical properties of fibres reinforced lime treated soil have been investigated by various authors. A number of triaxial tests, unconfined compression tests, california bearing ratio (CBR) tests, direct shear tests, tensile strength tests and flexural strength tests have been conducted on the subject by several researchers in the last few decades (Prabakar and Sridhar, 2002; Yetimoglu and Salbas, 2003; Yetimoglu et al., 2005; Cai et al., 2006b; Tang et al., 2007; Tang et al., 2010; Estabragh et al., 2012; Hejazi et al., 2012; Divya et al., 2013; Estabragh et al., 2013; Hamidi and Hooresfand, 2013). All the previous studies have shown that the addition of fibre-reinforcement caused significant improvement in the strength and increased the stiffness of the soil.
At the same time, there has been a growing environmental consciousness and understanding of the need for sustainable development in recent years, which has raised interests in using natural fibres as reinforcements in soil. The reinforcement of soils with natural fibres such as roots, sisal, coir and palm has recently received a great deal of attention (Ghavami et al., 1999; Prabakar and Sridhar, 2002; Babu and Vasudevan, 2007; Sivakumar Babu et al., 2008; Subaida et al., 2008; Mwasha, 2009; Vinod et al., 2009; Ramesh et al., 2010; Bateni et al., 2011). Of all the natural fibres, coir fibres has the greatest tensile strength and it retains this property even in wet conditions (Eze-Uzomaka, 1991a; Ghavami et al., 1999; Sen and Reddy, 2011b). The reinforcing effectiveness of coir fibre is related to the nature of cellulose and its crystallinity.

Cellulose is a natural polymer consisting of D-anhydro-glucose (C_{6}H_{11}O_{5}) repeating units joined by β-1,4-glycosidic linkages at C1 and C4 position (Nevell and Zeronian, 1985). Each repeating unit contains three hydroxyl groups. These hydroxyl groups and their ability to hydrogen bond play a major role in directing the crystalline packing and also govern the physical properties of cellulose.

Recently, few efforts have been made to enhance the interaction between soil and the coir fibres by modification of the fibres surface. One of the applied methods is the alkali treatment. In this method, a strong sodium hydroxide were used to remove lignin, hemicellulose and other alkali soluble compounds from the surface of the fibres in order to increase the number of reactive hydroxyl groups on the fibre surface to enhance chemical bonding. The removal of these substances also enhanced the surface roughness which increased the unconfined compressive strength of clay soil by 5 to 10% (Dutta et al., 2012). In another study by Ramesh et al. (2011) kerosene, bitumen and varnish were used to coat the coir fibres in order to modify the surface of fibres. It was observed that kerosene increased compression strength by 55% compared to uncoated coir fibre in soil. So far, however, no studies addressed the enhancement of tensile strength in coir fibre to be used in soil.

Nanotechnology has been a recent approach to modify natural fibres by impregnation of nano particles into fibres to improve their mechanical properties as well as introducing a new function onto the surface of fibres. (Chattopadhyay and Patel, 2009; Castellanos et al., 2012; Chowdhury et al., 2013; Khandanlou et al., 2013; Ridzuan et al., 2013).

In this study, the application of using randomly distributed coir fibre as tensile reinforcement elements and lime in the marine clay soil is investigated to be used as pile supported load transfer base layer. Finite element analyses of pile supported load transfer platform are performed using the program ABAQUS CAE 6.11 to investigate the load-transfer mechanism in the piled earth platforms by considering two major factors of influence: the mechanical properties of the earth platform and its height. The differential settlement is used to acquire experimental data for numerical model validation.
1.2 Problem of statement

Marine clays soils are present in many parts of the world and these deposits characterized by poor engineering properties such as high compressibility and very low shear strength. This sediment is mainly deposited along coastal areas of Peninsular Malaysia.

The rapid growth of industrialisation requires and extensive construction of infrastructure in Malaysia. Especially to new projects, the maintenance and upgrading of facilities also provided significant input to the overall developments include the coastal regions where ports and highways are located.

Even though some systematic studies are available on compressibility characteristic and shear strength of marine clay, not much work has been done its tensile strength aspects. Stabilization using lime was successfully done to increase strength and stiffness of marine clay soil. However, this method did not solve brittle problem of treated marine clay. For the utilisation of treated marine clay for the geotechnical structures, care should be taken to ensure that treated soil retains its ductile behaviour after failure.

The idea of reinforcing soil with tensile resisting elements such as synthetic and natural fibre has been commonly recognized in engineering practice. Using coir fibre as soil reinforcement has much advantages due to high tensile strength, good durability, environmentally friendly material and its ability to absorb water. However, the performance of the matrix (lime, fibre and soil) depends not only on fibres strengths but also how they interact with soil. Various techniques have been developed to modify natural fibres such as biological, physical, thermoplastic and nanotechnology. So far, no study addressed the enhancement of tensile strength of the fibres as well as its interaction with soils.

1.3 Objectives of the thesis

This study aims to investigate the mechanical properties of lime treated marine soil reinforced with modified coir fibre as pile supported load transfer platform. A practical approach was developed to impregnate fibres with nano particles of calcium hydroxide, magnesium hydroxide, ferric hydroxide and aluminum hydroxide. The overarching purpose of this study was to increase the tensile strength of fibres and to enhance their interaction with marine clay soil. The following objectives are identified for the successful completion of the aim of this research:

1. To investigate the morphological and mechanical characteristics of nano treated coir fibres as soil reinforcement.
2. To determine the effect of the nano modification of coir fibre and its interaction with lime reinforced marine clay soil.
3. To evaluate the performance of using nano modified coir fibre in lime treated soil as pile supported load transfer platform.

1.4 Scope and limitation of the study

The scope of the study can be presented in a form of three phases and these phases are:

i. Phase one, in order to increase the strength as well as interactions of natural fibres and soil, green nano-impregnation method is applied. To improve the structures of the fibre, chemical treatment of fibre using different chemicals such as calcium chloride, magnesium chloride, aluminium chloride, and sodium hydroxide were carried out. To confirm the alteration of morphology in the fibres and understand the underlying mechanisms of chemically treated coir fibres, Scanning electron microscopy (SEM), X-Ray diffraction (XRD) and Energy-dispersive X-ray spectroscopy (EDX) tests were performed.

ii. Phase two, to identify the applicability of the proposed nano-fibre treatment, the mechanical properties of the composites was assessed. Unconfined compressive strength tests, indirect tensile strength tests, flexural strength tests, and triaxial compressive strength tests were carried out on pure soil, lime-treated soil, and lime-treated soil reinforced with nano-treated and untreated fibres. Microstructure tests were performed to observe the interaction between fibres and soil. Moreover, a durability test was conducted to scrutinize the change in the strength of the reinforced soil due to the excessive moisture content in the soil.

iii. Phase three, the experimental results from phase two were used in a numerical analysis using commercially available software (ABAQUS CAE). The physical model experiments were performed to validate numerical model of pile supported load transfer platform.

The followings are limitations of the present study:

i. Marine clay soil samples are collected from Klang, Peninsular Malaysia.

ii. 5% lime of dry weight of soil is used as additive.

iii. The differential settlement is used to acquire experimental data for numerical model validation.

iv. Two-dimensional numerical model is analysed to perform pile supported load transfer platform.

v. Parametric study is developed based on numerical analysis.
1.5 Thesis organisation

This thesis presents different aspects of the potential of coir fibres as reinforcement in lime treated soft marine clay soil as pile supported earth platform. This thesis was organized into 5 chapters.

Chapter 1 gives a general introduction to the subject, problem statement, scope and limitation of the study and in addition of the objectives and outline of the thesis.

In providing a relevant background for the work described in this thesis, Chapter 2 contains a general literature review on characteristics and problem of Klang marine clay was used in the study. Special attention is given to various methods that have been used in marine clays stabilization for many years with various degrees are described. The gaps are identified and the importance of embarking on the current research work has been justified. In addition, the benefit of soft soil reinforcement for structural application such as pile supported earth platform including computational modelling, design method and lab-scale model are elaborated.

Chapter 3 describes the methodology used to fulfill the designated objectives for the research for reinforcing of marine clay soil. This chapter begins with a flow chart describing the general plan for the study, sampling location and continues with the required laboratory tests on some of the most significant physical, chemical and mechanical properties of natural marine clay soil, continue with coir fibre treatment, identification of the performance of lime and untreated coir fibre and treated coir fibre reinforced soil by performing mechanical tests, durability and microstructural tests. Finally, the numerical and physical models of the proposed composites as pile supported load transfer platform are analyzed.

Chapter 4 presents the results of the testing programs described in chapter three. The mechanical characterisation of untreated/treated single coir fibre as soil reinforcement has been investigated. Mechanisms of nano modified coir fibre and their interaction with soil matrix are also explained. The highest reinforcement potential of nano particles modified coir fibre and lime is exploited for marine clay reinforcement (i.e strength and durability). Attention is also paid to the mode of failure of fibre surface modification mixed with marine clay soil subjected to tensile and flexural loading. Furthermore, the interaction between fibres and limed soils are showed. Finally, numerical modelling is discussed and analysed and experimentally validated to reliably model the behaviour of nano modified coir fibre reinforced marine soil as pile supported load transfer platform over soft soil.

Chapter 5 is devoted to conclusions drawn from this study along with highlights topics for future work.
REFERENCES


Rowell, R.M., Han, J.S., Rowell, J.S., 2000. Characterization and factors effecting fiber properties. Natural Polymers and Agrofibers Bases Composites. Embrapa Instrumentacao Agropecuaria, P. O. Box 741, Sao Carlos, 13560-970 SP, Brazil, 2000., 115-134.


