**UNIVERSITI PUTRA MALAYSIA**

# *FABRICATION OF STRENGTHENING TREATMENT METHOD FOR MARINE CLAY*

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# FABRICATION OF STRENGTHENING TREATMENT METHOD FOR MARINE CLAY

**By**

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

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**Chairman : Assoc. Prof. Haslinda Nahazanan, PhD**

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Development of road traffic on marine clay poses a serious problem when this type of soil is being used. In order to solve the problem, the soil would need to be treated to improve its condition. Lime and alkaline activation (AA) are binder techniques that can be used to improve soil strength. However, treating soil with only binder would lead to brittle failure for the soil treatment. Therefore, to improve the mechanical properties of the treated soils to ductile, the inclusion of treated natural coir fibre with randomly distributed soil reinforcement is required.

This research is focused on investigating the performance of treated coir fibre with two different stabilizers by using lime and alkaline activation subjected to static and dynamic loading. The surface of the fibre was treated with calcium chloride ($CaCl_2$), which was proven effective in increasing the tensile strength and improving the fibre adhesion. For the laboratory work, 165 samples (for main tests-range of 3 duplicate tests each) were tested according to the British Standard (BS) and American Society for Testing and Materials (ASTM). The specimens were prepared by using the remoulded method and were cured for 7, 28 and 90 day curing periods before the testing was conducted. There were seven major tests carried out on untreated soils, treated soil with lime, and treated soil with alkaline activation, which were physical properties, compaction test, unconfined compressive strength

(UCS) test, flexural strength (FS) test, indirect tensile strength test (ITS), consolidated isotropic undrained (CIU) test (static load), and dynamic loading test. For the determination of soil behaviour on the CIU test, two types of parameters, which are maximum deviator stress and axial strain, were obtained and analyzed. The results were then used for the further investigation in the dynamic loading test. Besides that, for fundamental research on dynamic loading, the main parameters were comprised of the damping ratio (D) and shear modulus (G). The parameters were defined based on the equation from the stress-strain curve that is generated through AutoCAD software to calculate the area that is produced by the hysteresis loop.

The results of this study show that for a 7 day curing period up to a 90 day curing period, the compressive strength, flexural strength, and indirect tensile strength tests of treated soil with alkaline activation showed higher increments than treated soil with lime. The increments observed were up to 46 % and 71 % for the unconfined compressive strength test, 35 % and 81 % for flexural strength, and 53 % and 69 % for the indirect tensile strength test for both treated lime and alkaline activation, respectively. Other than that, the strength of the increment can be summarized up to 87 % and 98 % for both treated with lime and alkaline activation compared to the untreated soil specimens for the three tests. Moreover, for the dynamic loading test, it can be concluded that the value of G was increased with the addition of stabilizer in the soil, which can be interpreted by the decrease of strength as the curing periods increase between 60 to 40 kPa (lime) and 760 kPa to 210 kPa (AA). Meanwhile, for the value of D, the result showed a decrease as the curing periods increase from 23 % to 32 %, 15 % to 25 % and 5 % to 9 % for untreated soil, treated soil with lime, and treated soil with alkaline activation, respectively. These results show that the addition of the stabilizer to the soil had different effects on the dynamic loading parameter behaviour. The test can be confirmed with the field emission scanning electron microscopy (FESEM) and energy-dispersive X-ray spectroscopy (EDX) tests where there is an interaction between treated soil and fibre as filler, thus strengthening the soil. Therefore, it can be concluded that this research is important as it contributes to proving that the inclusion of fibre as one of the admixtures in the stabilizer not only helps in improving the mechanical interactions between the soil, fibre and the stabilizer but it also results in increasing the performance of the soils as it could be used for the development of light traffic loading in the area of marine clay.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

**FABRIKASI KAEDAH RAWATAN PENGUKUHAN UNTUK TANAH LIAT MARIN**

Oleh

**FATIN AMIRAH BINTI KAMARUDDIN**

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Pembangunan lalu lintas jalan raya di tanah liat marin menimbulkan masalah serius apabila tanah jenis ini digunakan. Untuk menyelesaikan masalah ini, tanah perlu dirawat untuk memperbaiki keadaannya. Kapur dan pengaktifan alkali (AA) adalah teknik pengikat yang boleh digunakan untuk meningkatkan kekuatan tanah. Walau bagaimanapun, merawat tanah dengan hanya menggunakan pengikat akan menyebabkan kegagalan rapuh untuk rawatan tanah. Oleh itu, untuk memperbaiki sifat mekanikal tanah yang dirawat kepada mulur, kemasukan gentian sabut asli yang dirawat dengan tetulang tanah teragih secara rawak diperlukan.

Penyelidikan ini tertumpu kepada penyiasatan prestasi gentian serat yang dirawat dengan dua penstabil yang berbeza dengan menggunakan kapur dan pengaktifan alkali yang tertakluk kepada beban statik dan dinamik. Permukaan gentian serat dirawat dengan kalsium klorida ($CaCl_2$) yang terbukti berkesan dalam meningkatkan kekuatan tegangan dan memperbaiki lekatan gentian serat. Untuk kerja makmal, 165 sampel (untuk ujikaji utama, julat 3 kali ujian setiap satu) telah diuji mengikut piawaian *British Standard (BS)* dan *American Society for Testing and Materials (ASTM)*. Spesimen telah disediakan dengan menggunakan kaedah *remoulded* dan diawetkan selama 7, 28 dan 90 hari tempoh pengawetan sebelum ujikaji dijalankan. Terdapat tujuh ujikaji utama yang dijalankan ke atas tanah yang tidak

dirawat, tanah yang dirawat dengan kapur dan tanah yang dirawat dengan pengaktifan alkali iaitu ujian sifat fizikal, ujian pemadatan, ujian kekuatan mampatan tidak terkurung (UCS), ujian lenturan (FS), ujian kekuatan tegangan tidak langsung (ITS*), consolidated isotropic undrained test (CIU)* (beban statik), dan ujian beban dinamik. Bagi penentuan kelakuan tanah pada ujian CIU, dua jenis parameter, iaitu tegasan penyimpang maksimum dan terikan paksi, diperoleh dan dianalisis. Hasilnya kemudian digunakan untuk penyiasatan lanjut dalam ujian beban dinamik. Selain itu, untuk penyelidikan asas mengenai beban dinamik, parameter utama terdiri daripada nisbah redaman (D) dan modulus ricih kitaran (G). Parameter tersebut ditakrifkan berdasarkan persamaan dari lengkung tekanan ketegangan- keterikan yang dihasilkan melalui perisian AutoCAD bagi mengira kawasan yang dihasilkan oleh gelung histeresis.

Keputusan kajian ini menunjukkan bahawa untuk tempoh pengawetan 7 hari sehingga tempoh pengawetan 90 hari, ujian kekuatan mampatan, kekuatan lenturan dan kekuatan tegangan tidak langsung tanah yang dirawat dengan pengaktifan alkali menunjukkan kenaikan yang lebih tinggi daripada tanah yang dirawat dengan kapur. Kenaikan yang diperhatikan adalah sehingga 46 % dan 71% untuk ujian kekuatan mampatan yang tidak terkurung, 35 % dan 81% untuk kekuatan lenturan dan 53 % dan 69 % untuk ujian kekuatan tegangan tidak langsung masing-masing untuk kedua- duanya dirawat dengan kapur dan pengaktifan alkali. Selain itu, kekuatan kenaikan boleh diringkaskan sehingga 87 % dan 98 % untuk kedua-duanya dirawat dengan kapur dan pengaktifan alkali dibandingkan dengan spesimen tanah yang tidak dirawat untuk ketiga-tiga ujian. Selain itu, bagi ujian beban dinamik, dapat disimpulkan bahawa nilai G meningkat dengan penambahan penstabil di dalam tanah, yang dapat ditafsirkan dengan penurunan kekuatan apabila tempoh pengawetan meningkat antara 60 hingga 40 kPa (kapur) dan 760 kPa hingga 210 kPa (AA). Manakala, untuk nilai D, keputusan menunjukkan penurunan apabila tempoh pengawetan meningkat dari 23 % kepada 32 %, 15 % kepada 25 % dan 5 % kepada 9 % bagi tanah yang tidak dirawat, tanah yang dirawat dengan kapur dan tanah yang dirawat dengan pengaktifan alkali. Keputusan ini menunjukkan bahawa penambahan penstabil ke dalam tanah telah mempunyai kesan yang berbeza pada tingkah laku parameter pemuatan dinamik. Ujian ini dapat disahkan dengan ujian mikroskopi elektron pengimbasan pelepasan medan (FESEM) dan ujian spektroskopi sinar-X penyebaran tenaga (EDX) di mana terdapat interaksi antara tanah yang dirawat dan serat sebagai pengisi, sekaligus mengukuhkan tanah. Oleh itu, dapat disimpulkan bahawa penyelidikan ini penting kerana ia menyumbang untuk membuktikan kemasukan serat sebagai salah satu bahan tambah dalam penstabil bukan sahaja hanya membantu dalam meningkatkan interaksi mekanik antara tanah, gentian serat dan penstabil tetapi juga ia juga meningkatkan prestasi tanah kerana ia boleh digunakan untuk pembangunan pemuatan trafik ringan di kawasan tanah liat marin.

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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:

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**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.

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## TABLE OF CONTENTS

## LIST OF TABLES

**LIST OF FIGURES**

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AA | Alkaline activation |
| Al | Aluminium |
| $Al_2O_3$ | Aluminium oxide/ Aluminous |
| $A_P$ | Average cross-sectional area |
| A-S-H | Aluminium silicate hydrate |
| ASTM | American Society for Testing and Materials |
| AutoCAD | Auto computer aided design software |
| BS | British standard |
| c | Cohesion |
| C | Clay |
| Ca | Calcium |
| CaO | Calcium oxide/ lime |
| $CaCl_2$ | Calcium chloride |
| C-A-H | Calcium aluminate hydrate |
| C-A-S-H | Calcium aluminosilicate hydrate |
| CIU | Consolidated isotropic undrained |
| cm | Centimeter |
| $cm^3$ | Centimeter cube |
| $CCl_4$ | Carbon tetrachloride |
| CNC | Clay nanocomposites |
| CNCr | Clay nanocomposites with addition of rubber |

| | |
|---|---|
| CL | Clay + Lime |
| CLF | Clay + Lime + Fibre |
| CFA | Clay + Fly ash + Activator (KOH) |
| CFAF60 | Clay + Fly ash (60%) + KOH +Fibre |
| $CO_2$ | Carbon dioxide |
| C-S-H | Calcium silicate hydrate |
| CIU | Consolidated isotropic undrained |
| D | Damping ratio |
| *D* | Diameter of sample |
| DS | Direct shear |
| E | Young modulus |
| EDX | Energy dispersive X-ray spectroscopy |
| ELDYN | Enterprise Level Dynamic Triaxial Testing System |
| F | Fibre |
| FA | Fly ash |
| Fe | Iron |
| $Fe_2O_3$ | Ferric oxide |
| FESEM | Field emission scanning electron microscopy |
| FLEX | Flexural |
| g | Gram |
| $g/cm^3$ | Gram per centimeter cube |
| g/mol | Gram per molar |
| G | Shear modulus |

| | |
|---|---|
| $G_s$ | Specific gravity |
| GDS | Geotechnical Digital System Instruments |
| GGBS | Ground granulated blast furnace slag (GGBS) |
| h | Height |
| Hz | Hertz |
| ITS | Indirect tensile strength |
| K | Potassium |
| kN | Kilonewton |
| KOH | Potassium hydroxide |
| kV | Kilovolt |
| L | Length of sample |
| LL/ $w_L$ | Liquid limit |
| LOI | Loss of ignition |
| MDD/ $\gamma_{dmax}$ | Maximum dry density |
| m | Meter |
| *m* | Mass |
| ml | Milliliter |
| mm | Millimeter |
| mm/min | Millimeter per minutes |
| M | Molar |
| MPa | Megapascal |
| N | North |
| Na | Sodium |

| | |
|---|---|
| NaOH | Sodium hydroxide |
| N-A-S-H | Sodium aluminosilicate hydrate |
| OMC/ $w_{opt}$ | Optimum moisture content |
| OPEFB | Oil palm empty fruit bunches |
| P | Maximum load applied |
| PI/ $I_p$ | Plasticity index |
| PL/ $w_p$ | Plastic limit |
| POFA | Palm oil fuel ash (POFA) |
| R | Radius of specimen |
| RHA | Rice husk ash |
| Si | Silicon |
| $SiO_2$ | Silicon dioxide/ Siliceous |
| UCS | Unconfined compressive strength |
| USCS | Unified soil classification system |
| *v* | Volume of cylinder |
| XRD | X-ray diffraction |
| XRF | X-ray fluorescence |
| USCS | Unified soil classification system |
| $SiO_2$ | Silicon dioxide/ Siliceous |
| μ | Poisson ratio |
| π | *Pi* |
| ε | Cyclic shear strain |
| Δσd | Cyclic deviator stress |

| | |
|---|---|
| % | Percentage |
| $\sigma_s$ | Deviator stress |
| ∘ | Degree |
| ’ | Minutes |
| ’’ | Second |
| °C | Degree Celsius |
| *P* | Dry density |
| *T* | Thickness of soil specimen |
| *P ult* | Ultimate load at which the soil occurred |
| $\Delta u$ | Changes in pore pressure |
| $\delta\sigma_3$ | Changes in cell pressure |
| $\sigma_1$ | Major principal stress |
| $\sigma_3$ | Minor principal stress |
| θ | Theta |
| µm | Micrometer |
| Ø | Angle of internal friction |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of study

Marine clay is generally recognized as a soil with high water content, high compressibility, low permeability, and low shear strength which mostly found along the coastal area. It can be characterized as sensitive clays since it has poor engineering properties. Problems on dealing with this kind of soft soil usually attract researchers to deal with the soil stabilization. Many studies conducted in the past concerning on the strength enhancement of the soil for future development. Due to rapid industrialization and population growth nowadays, the increasing number of constructions of traffic infrastructures have been highly demand including on construction on soft clay soil. Since then, it becomes a necessity although these kinds of soils have some problems to be overcome when the constructions to be built on it. The properties of the soil that is considered as poor have become major influence in pavement design due to the uncertainty that related with the performance.

Soil reinforcement/stabilization is one of the method/techniques that mostly effective and well- engineered as it is a fundamental for the geotechnical practice on problem solving for works such as slope stabilizing, foundations, bearing capacity, and embankment (Cui et al., 2018; and Kumar et al., 2015). Abundances of method regarding the soil stabilization have been recognized in these past few decades in matter of dealing with the problematic soil (Emmanueal et al., 2019a; Jafer et al., 2018; and Hanuma and Prasad, 2017). Enhancement through application by using chemical agent and additive have been widely used as soil stabilization for the construction building and pavement construction. This was supported by Al Bared et al., (2018) in their statement were workability, economical approaches and environmental aspects are an important thing needed to be taken care for the method of selection on the soil stabilization where chemical stabilization was found to be the most applicable method to be used to increase soil strength when it comes to dealing with problematic soil in which enforcement through the engineering and physical properties of soil were done. Many researches have been using chemical stabilizers on various types of soil. The treatment used includes new and traditional techniques such as ground granulated blast furnace, lime, gypsum, cement, fly ash and etc. The utilization of different types of material on soil stabilization and its proven ability to increase the strength of the soil have attracted many researches to explore more on its usage. As for marine clay soil, stabilizing agents such as using the cement, gypsum, waste rubber tires, lime, activators, and etc have been utilized. (Emmanuel et al., 2019a; and Yadav and Tiwari, 2017. The stabilizing agents are used to bind the soil particles together through chemical reactions. It was well documented that the addition of those agents on clay soil have increased its brittleness and stiffness (Yadav and Tiwari, 2016; Kumar and Gupta 2016; and Nguyen and Fatahi, 2016).

Lime is one of traditional binder that was proven in improving soil strength and other properties of soil due to their robustness and easily mixed towards a different type of soil as it has a capability to immobilize water through soil (Anggraini et al., 2016). It has been well established and reported by many researchers regarding the effectiveness of lime as the soil stabilizer which the materials have reduced swelling of soil and water content. It has the capability of holding large amount of water and hence increased the workability of the soil (Anggraini et al., 2017; and Dash and Hussain, 2011). Maubec et al., (2017) in their research stated that, utilization of lime as stabilizer also exhibits an immediate result in terms of reduction of plasticity, workability, and etc. A sufficient quantity of lime used for stabilization produce a cementitious gel that exhibit a binding between the soil particles and thus produced a reaction either calcium aluminate hydrates (C-A-H) or calcium silicate hydrate (C-S-H) which helps in strengthen the soil.

Alkaline activation (AA) is one of binder that being actively presented these days apart from a traditional binder as a replacement/ soil stabilizer in improving soil; where the activator binder used is commonly an environmental friendly materials which is a reutilized industrial waste (Rios et al., 2018; Cristelo et al., 2015a; and Davidovits, 2008). AA is a formed by a reaction of an amourphous aluminosilicate which is either from calcium (Ca), sodium (Na) or potassium (K) that affiliated in dissolution of mineral aluminosilicates. The reaction were subsequently though a process of condensation and hydrolysis components of alumina and silica which then resulting in a formation of the three dimensional of aluminosilicate gel (Yunsheng et al., 2008; and Weng and Sagoe- Crentsil, 2007). By Pourakbar and Huat (2016), there is a reaction occur when water is mixed together with the effective amount of binder which turn into a development of cementitious gel of either C-S- H or C-A-H. Entirety material that being used as the precursor is mostly contain high of alumina ($Al_2O_3$), silica ($SiO_2$) and ferum ($Fe_2O_3$). Many past researchers have conducted research on the effectiveness and performance at different precursor such as by using olivine, red gypsum (RG), palm oil fuel ash (POFA), ground granulated blast-furnace slag (GGBS) and fly ash (FA) with AA that thus lead in resulting a significant increment of the soil strength (Thomas et al., 2018; Pourakbar and Huat, 2017; and Singhi et al., 2016). From all the alternatives (precursor) in increasing the strength performance of the precursor with AA stabilizers, usage of fly ash (FA) class F with the fibre inclusion is one of the methods should be considered as the soil stabilization.

However, the usage of chemical stabilizing agents as a treatment to the soils has exhibit an excessively brittle performance which affects the stability of structures (Teing et al., 2019; Anggraini et al., 2017; and Pourakbar et al., 2015). This main weakness of the treated soil should be taken care since it would cause a problem in the future and hence increase the cost. Therefore, several solutions have been proposed by some researchers. Inclusion of fibre as soil reinforcement have seen to be effectively increased the ductility behaviour, compressive strength, soil stiffness and tensile strength (Shukla, 2017; and Joy and Thomas, 2017). Utilization of the soil reinforcement is ascertained to be the preferred alternative methods as it has the ability to help in strengthening the soil and lower the water content and compressibility. Henceforth, it is believed that the dynamic properties of marine clay soils can be improved by using lime and alkaline activation treatment with combination of treated fibre.

In this study, marine clay was treated with lime and alkaline activation with the inclusion of fibre as soil reinforcement. The dynamic behaviour of the treated samples was then investigated to be used for light road traffic. As for today, there is no discussion have been made on the comparison of dynamic behaviour of treated soil with inclusion of the fibre. Most of the studies comprises only about the different types of soil, places, variables frequencies used, method and parameters that had been used. Research studies focusses on the typically types of dynamic loading and parameters of the study which focuses on cyclic shear modulus and damping ratio. Therefore, this study aims to compare the lime and alkaline activation modified treated marine clay reinforced with natural modified natural fibre. Behaviour of static and cyclic loading on light traffic were also investigated and evaluated.

## 1.2 Problem statement

Marine clay is known as one of the problematic soils when it is identified in various geotechnical engineering applications such as slope stabilization or as a support for foundations, which are relatively related to low bearing capacity, high settlement, high plasticity, high compression and low shear strength. Most of the problems encountered also are due to the high permeability, unstable or unpredictable soil condition that occurs when a project or construction on the marine clay deposits is constructed (Yunus et al., 2015; and Bushra and Robinson, 2009). Properties of the marine clay soils itself that tend to induce swelling and shrinkage, and with the wet- dry cycles condition due to climate changes (rain and hot) poses an extreme distress towards the structures that being constructed on them (Anggraini et al., 2016). Due to the high demands and rapid developments throughout Malaysia, an extensive construction either building, road pavement and infrastructure which involves this type of soil is required. Therefore, treatment on these soils is needed so that it could fulfil the demand of the construction. Many methods of soil stabilization have been done such as using cement, lime, fly ash, polyurethane and other mixtures materials. The methods not only increase the physical characteristic but also increase the mechanical characteristic of the soil in term of strength and stiffness of the soil. Treatment using soil stabilizer only shows an excessively brittle behaviour which influences the stability of structure, therefore inclusion of fibre in soil is needed to improve the tensile strength of the soil matrix. Due to the problems of surface adhesion and the durability of the fibre, treatment of the fibre itself is needed in this research. This research focused on strength soil of both static load and cyclic load with the suitable frequencies that was chosen based on the simulation that represent from the light traffic road. Problem on road deterioration, cracks, potholes and others damage on the road traffic highway (such as at highway of Central and South West Coast, Peninsular Malaysia) due to a heavy traffic must be taken care before any construction is done. The effects that occur due to unproper planning have contributed in a short-term damage on the road. Thus, a better understanding on the dynamic behaviour of marine clay is a major concern since the construction of light traffic road has become very important due to the rapid developments nowadays. Consideration on the loading subjected to the untreated and treated marine clay is important before any construction be made to avoid any damages. The behaviour of the dynamic loading may give impact towards the road construction planning. To date, no study has been addressed on the dynamic behaviour of soil treated with both stabilizer with lime and alkaline activation with fibre inclusion. The need for soil improvement on the usage of conventional binding materials such as lime is due to the fact that conventional binding materials have proprietary chemical compositions, which makes it difficult to estimate the chemical stabilizing mechanisms that may occur for a given type of soil, and which also makes it difficult to predict their performance for use of the soil stabilizer in practise (Latifi et al., 2016). Hence, improvement on the marine clay behaviour is strictly needed to be done before any construction is made. This is to avoid some problems such as cracking, settlements, etc to happen in future.

## 1.3 Aim and objectives

This research is aimed to enhance both static and dynamic behaviour of treated marine clay with lime and alkaline activation stabilizer with the inclusion of treated fibre to be used for light traffic road construction. The following objectives are identified in order to achieve the aim:

i. To investigate the effect of treated fibre on the lime-treated marine clay subjected to static and dynamic loading
ii. To determine the optimum percentage of fly ash for marine clay stabilization by alkaline activation.
iii. To evaluate the effectiveness of treated fibre with alkaline activation (AA) on the marine clay subjected to static and dynamic loading.
iv. To compare the effect of lime and alkaline activation with the treated fibre on the marine clay subjected to static and dynamic loading.

## 1.4 Significant of study

Generally, this study was conducted to improve the geotechnical properties of marine clay using soil stabilization method. There are many methods that have been employed in soil stabilization either by chemical, physical or biological method. The common and effective method used these days was by using the chemical additives as the stabilizers on the soil. Chemical stabilization is a widely method used for the engineering properties applications needed such as for the treatment towards foundations, erosion control, earthquakes liquefaction mitigation, slope stabilization, embankment, etc. Due to high demand on construction developments all over Malaysia, a deep understanding of this matter is essential. The infrastructure development is including the new housing area, road, railways, township educational area and etc. Currently, limited significant research study, data and information that have been proposed towards the response of the dynamic loading parameters on both lime and alkaline activation stabilized marine clay with fibre inclusion. Previous study on the dynamic loading test were mostly conducted only on untreated soil such as clay, organic soil, and peat soil. (Ozcan et al., 2018; Ashango and Patra, 2013; Li et al., 2011; and Zolkefle, 2019). The comparison on the treatment for the soil stabilization with fibre inclusion on marine clay for the developments of infrastructure is uncommon and rarely being discussed. In this study, utilization of lime and alkaline activation stabilizer with fibre inclusion were conducted to determine the effect of the treatment on marine clay when subjected to both static and dynamic loading. Therefore, this study is important to obtain an effective solution for soil stabilization with marine clay (either between the lime or alkaline activation) that can be used for future developments towards the dynamic loading. Other than that, this study is expected to give a better understanding, guidance and benefit in dealing with the marine clay at site location.

## 1.5 Scope and limitation of study

The scope for this study is presented in the following phases which are:

i. In Phase 1, the geotechnical properties of marine clay were examined and investigated through laboratory testing. The inclusion of fibre in the marine clay is taken into consideration for the soil reinforcement. A green and clean process of impregnation method was applied in order to increase the durability, strength parameters, and interfacial interactions. To improve the structure of the fibre, chemical treatment of the fibre was carried out. Natural fibre was soaked in an aqueous solution of calcium chloride, magnesium chloride, and aluminium chloride in order to uniformly fill the internal pores and spaces of the fibre. The tensile strength of the treated fibre was then determined. The effectiveness of fibre reinforced in lime treated marine clay on soils subjected to static and dynamic loading was also evaluated at this stage.
ii. Phase 2, different percentages of fly ash as precursor (40 %, 50 %, 60 % and 70 %) with 10 M KOH were used for the determination of the optimum fly ash to be used for the alkaline activation stabilization method.
iii. Phase 3, determination of the effectiveness of treated fibre with alkaline activation (AA) on the marine clay subjected to static and dynamic loading were carried out.
iv. Phase 4, a comparison between the effect of lime and alkaline activation with the treated fibre on the marine clay subjected to static and dynamic loading were determined and discussed. In addition, the microstructural testing using FESEM, EDX, XRF and XRD both unstabilized and stabilized soils were investigated to assess the effectiveness of this method on peak, post peak, and dynamic behaviour of the matrix.

For the limitations of the study:

i. Marine clay samples were collected at Jeram, Klang Selangor.
ii. Soil sampling cannot be taken during the rainfall condition due to the effects on the water table.
iii. Different soil sampling sites and depths produce different results.
iv. The soil pH on site will differ from the soil pH in the laboratory.
v. Corrosive effects due to the application of stabilized materials in the field conditions were not included in this study.
vi. There are two different treatments for clay soil involved in this study which are by using lime and alkaline activation.
vii. 5 % hydrated lime of dry weight of soil, fly ash class F (precursor) and potassium hydroxide (KOH) as activator are the three additive that been used.
viii. Usage of 1 % of fibre treated with calcium chloride were used as the fibre inclusion in the soil treated.
ix. The effective stress of 50 kPa and frequencies of 1 Hz was used for static and dynamic loading test.

## 1.6 Outline of the study

This section generally discusses about five main chapters. Chapter 1 focuses on the introduction, where this section is a general introduction of the background of the study, problem statement, objectives, research scope, and limitations of the study. Next, Chapter 2 discusses the literature review. The literature review consists of the reviews from the past researchers that were related to this study, including the types of soil, characteristics of soil, types of waste materials and stabilizer used, and parameters used for dynamic loading. Identification of the gaps between the past and current studies was justified. Subsequently, Chapter 3 in the thesis explains the research methodology. In this chapter, the method of being used, materials, equipment, and procedures of the work are described and explained. The following Chapter 4 is on the results and discussion. The data analysis of the test results, the effect of the treated fibre on lime and alkaline activation, and the comparison of the unconfined compression test, tensile test, flexural test, and triaxial test are all discussed in this section. Both static and cyclic results are discussed in detail. Correlations between the parameters are established and compared with the findings of previous researchers. Lastly, Chapter 5 (Conclusions and Recommendations) wraps up the summary of the study and provides detailed recommendations for future work based on the current research project and literature review. The study's recommendation is suggested so that it would help to establish a new method or improvement for further research and long-term applications.

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