COMPRESSIBILITY BEHAVIOUR OF MAGNESIUM PHOSPHOGYPSUM AMENDED LATERITE

NURUL NABILA BINTI ADENAN

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : NURUL NABILA BINTI ADENAN

Date of Birth : 20th AUGUST 1995

Title : COMPRESSIBILITY BEHAVIOUR OF MAGNESIUM PHOSPHOGYPSUM AMENDED LATERITE

Academic Session : 2017/2018

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)*
☑	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

SIGNATURE	SIGNATURE OF SUPERVISOR
(950820-14-5328)	(DR. HJ. MOHD YUHYI BIN MOHD TADZA)
Date: 12th June 2018	Date: 12th June 2018

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

THESIS DECLARATION LETTER (OPTIONAL)

Librarian,
Perpustakaan Universiti Malaysia Pahang,
Universiti Malaysia Pahang,
Lebuhraya Tun Razak,
26300, Gambang, Kuantan.

Dear Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

Please be informed that the following thesis is classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are as listed below.

Author's Name
Thesis Title

Reasons (i)

(ii)

(iii)

Thank you.

Yours faithfully,

____
(Supervisor's Signature)

Date:

Stamp:

Note: This letter should be written by the supervisor, addressed to the Librarian, *Perpustakaan Universiti Malaysia Pahang* with its copy attached to the thesis.

(Please take out if not related)

SUPERVISOR'S DECLARATION

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

____

(Supervisor's Signature)

Full Name : Dr. Hj. Mohd Yuhyi Bin Mohd Tadza
Position : Senior Lecturer
Date : 12th June 2018

STUDENT’S DECLARATION

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

____

(Student’s Signature)

Full Name : NURUL NABILA BINTI ADENAN

ID Number : AA14142

Date : 12th June 2018

COMPRESSIBILITY BEHAVIOUR OF MAGNESIUM PHOSPHOGYPSUM AMENDED LATERITE

NURUL NABILA BINTI ADENAN

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

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Hj. Mohd Yuhyi Bin Hj. Mohd Tadza for his invaluable guidance, continuous encouragement and constant support in making this research possible. I really appreciate his guidance from the initial to the final level enable me to develop an understanding of this research. Without his advice and assistance it would be tough to complete tis research. I also sincerely thanks for the time spent proofreading and correcting my mistakes.

My sincere thanks go to all lecturers and members of the staff of the Soil and Geotechnical Department, UMP, who help me in many ways and made my education journey at UMP pleasant and unforgettable. Many thanks go to my PSM group member for their excellent co-operation, inspiration and supports during study. I also would like to express special thanks to the staff out Soil and Geotechnical Laboratory for their support and encouragement.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and supports throughout my entire study and life. I am really thankful for their supports, patient, and understanding that were inevitable to make this work possible.

Lastly, I would like to thanks any person which contributes to my final year project directly or indirectly. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRAK

Perlombongan laterit bukan aktiviti ekonomi baru untuk Malaysia. Perlombongan laterit telah berlaku di negeri Johor sejak awal tahun 2000. Laterit dianggap sebagai tanah bermasalah kerana ia merupakan produk sisa. Terdapat beberapa sebab mengapa perlombongan laterit boleh menyebabkan masalah jika isu itu tidak diselesaikan atau dikawal. Kajian ini memberi tumpuan kepada tingkah laku mampatan Magnesium Phospogypsum berkenaan dengan ujian oedometer. Hasilnya berguna untuk dilaksanakan di industri untuk menyediakan pelupusan sisa yang efisien atau menggunakan bahan buangan dalam konteks masalah sisa industri. Hasil dari ujian oedometer mendedahkan bahawa magnitud dan kadar pengurangan isipadu spesimen tanah berkurang jika mengalami tekanan menegak yang berbeza. Ini disebabkan oleh ubah bentuk zarah tanah, penempatan semula zarah-zarah tanah dan pengusiran air atau udara dari ruang kosong. Tiga sampel yang berbeza digunakan dalam kajian ini. Kandungan air sebelum ujian untuk sampel 1, sampel 2 dan sampel 3 masing-masing adalah 38.3%, 49.1% dan 47.5%. Selepas eksperimen, kandungan air untuk setiap beban menurun apabila tekanan meningkat. Untuk sampel 1, kandungan air menurun dari 34.54 hingga 22.74, sampel 2 menurun dari 44.4% kepada 31.00% dan sampel 3 menurun daripada 38.1 kepada 25.3 masing-masing. Nisbah kekosongan awal sebelum ujian untuk sampel 1, sampel 2 dan sampel 3 masing-masing adalah 1.0131%, 1.3039% dan 1.2472%. Selepas percubaan, nisbah kebarangkalian untuk setiap beban menurun apabila tekanan meningkat. Nisbah kekosongan selepas kebolehmampatan untuk sampel 1 menurun dari 0.9725 kepada 0.3364, sampel 2 dari 1.2623 hingga 0.8088 dan sampel 3 dari 1.2342 kepada 0.7586 masing-masing Temuan ini menunjukkan bahawa tingkah laku mampatan Magnesium Phosphogypsum berkaitan dengan tekanan yang dikenakan ke sampel tanah.

ABSTRACT

Laterite mining is not a new economic activity for Malaysia. The mining of laterite has taken place in the state of Johor since early 2000. Laterite is considered as problematic soil because it is a waste product. There are a number of reasons why laterite mining can cause problem which will subsequently propagate to problems if the issue is not resolved or controlled. This research focused on the compressibility behaviour of Magnesium Phospogypsum with respect to oedometer test. The result is useful to be implemented in industry to provide efficient waste disposal or reuse the waste materials in the context of industrial waste issues. Result from the oedometer test reveal that the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. This is caused by deformation of soil particles, relocations of soil particles and expulsion of water or air from the void spaces. Three different sample is used in this research. The water content before test for sample 1, sample 2 and sample 3 are 38.3%, 49.1% and 47.5% respectively. After the experiment, water content for each loading decreases as the pressure increases. For sample 1, water content decrease from 34.54 to 22.74, sample 2 decrease from 44.4% to 31,00% and sample 3 decrease from 38.1 to 25.3 respectively. The initial void ratio before test for sample 1, sample 2 and sample 3 are 1.0131%, 1.3039% and 1.2472% respectively. After the experiment, void ratio for each loading decreases as the pressure increases. The void ratio after compressibility for sample 1 decrease from 0.9725 to 0.3364, sample 2 from 1.2623 to 0.8088 and sample 3 from 1.2342 to 0.7586 respectively This finding implies that the compressibility behaviour of Magnesium Phosphogypsum relate to the pressure impose to the soil sample.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Al	Aluminium
Al_2O_3	Alumina
AlOH	Aluminium Hydoxide
Al(OH)3	Gibbsite
AlO(OH)	Boehmite
C	Carbon
Ca	Calcium
Cr	Chromium
Cu	Copper
Fe	Iron
Ga	Galium
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
P	Phosphorus
S	Sulphur
Si	Silicon
Ti	Titanium
V	Vanadium
Zn	Zinc

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Standard Testing Method
BRDA	Bauxite Residue Disposal Areas
BS	British Standard
BSCS	British Soil Classification System
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit
PM	Particular Matter

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, this becomes a common issue which happen every day in all over the world. Mineral resources are very crucial for country's mining sector development and Malaysia's national economy during the 20th century. In Malaysia, mineral resources such as iron, tin, gold, coal, silica sand, laterite, antimony, barite, clays, copper, lead and limestone have played important roles in country's mineral production, although exploitation of some minerals had decreased significantly (Kusin, Azani, Hasan, & Sulong, 2018). Environmental pollution which faced in Malaysia has a long history and is becoming serious issue since this few years due to the economic development and increased in industrialization activities. It leads to the degradation of quality of life by consuming food and water contaminated with chemical, biological and radioactive materials, either directly or indirectly. Pollution is the introduction of a noxious waste emitted into the environment and caused instability and harm to the ecosystem which will be dangerous to humans and creature.

Laterite mining is not known to most Malaysian. Potential impacts are expected to go beyond physical environment and physical illness if the situation is not controlled. Loss of economic potentials, and the presence of unpleasant red dust causing mental distress, anger and community outrage (Abdullah, Mohamed, Sulaiman, Zakaria, & Abdul Rahim, 2016). Mining offers some exciting economic opportunities for various parties including individual land owners. Nevertheless, the extensive and uncontrolled mining activities have great potentials to cause adverse impacts on the environment, health and quality of life of the people living in the affected areas (Abdullah, Mohamed, Sulaiman, Zakaria, & Abdul Rahim, 2016). Laterite mining is not a new economic activity for Malaysia. The mining of laterite has taken place in the state of Johor since early 2000 (Anak Ginung & Abdullah, 2015). Whilst mining operation in Teluk Ramunia Johor has been operating for more than 15 years without much controversy, it has created a different scenario within a short period of time. Extensive and aggressive mining which include transporting and stockpiling of laterite in huge quantities cause environmental problems to emerge within a short period of time leading to community outrage (Abdullah et al., 2016).

New adaption for the waste management planning should be considered to provide efficient use of laterite or reuse the materials in the context of industrial laterite issue. Related to this issue, health of people and health of planet that we live should be protected. Aggressive uncontrolled mining, if sustained over time will cause irreversible changes to the state of the environment that threatens the ecosystems. The polluted ecosystems have great potential to create chronic and unpredictable exposures, leading to direct or indirect, immediate and long-term potential impacts on health. A number of physical, chemical, biological, ergonomic, and psychosocial hazards exist throughout the mining process, as described in the article by Donoghue and Olney (Donoghue, Frisch, & Olney, 2014). There are a number of reasons why laterite mining can cause problem which will subsequently propagate to problems if the issue is not resolved or controlled. One of the reasons is related to its location which is close to the human settlement area. Other reason is associated with unsustainable mining processes that lead to very extensive and aggressive mining activities.

Oedometer test is a fundamental property in soil physics and soil mechanics (Heshmati & Motahari, 2012). Oedometer is a geotechnical investigation performed in geotechnical engineering that measures a soil's consolidation properties. Equipment and procedures have been developed at NGI for handling very soft clays or other difficult materials to obtain as reliable and credible parameters as possible (Equipment, 1986). Oedometer tests are performed by applying different loads to a soil sample and measuring the deformation response. It defines the relationship between moisture content and compressibility of soil. Besides, oedometer test contains a lot of importance information such as pressure (kPa) and void ratio (e) on the computer simultaneously.

1.2 Problem Statement

Laterite is the principal ore of alumina (Al_2O_3), which is used to produce aluminum (Al). It is composed of hydrated aluminum oxides, hydrated aluminosilicates, iron oxides, hydrated iron oxides, titanium oxide, and silica. Laterite is a residual rock formed from the weathering of various igneous, sedimentary, and metamorphic rocks. These parent rocks have been exposed to long periods (millions of years) of weathering under tropical, subtropical, or very wet temperate conditions. Open mining involves substantial clearing and removal of land. The processes of excavating, removal of top soil and vegetation, transportation of laterite and unwanted elements and stockpiling of laterite cause degradation of air quality mainly related to dust pollution. Dust is a solid particulate matter, in the size range of 1 to 75 microns in diameter. Dust smaller than 10 micrometer in diameter, known as particulate matter PM10 and PM2.5 are of great health concern because it can be inhaled deep into the respiratory system. Data collected by researcher in December 2015, revealed that 24-hour PM10 level ($\mu g/m^3$) ranged from 164 to 277$\mu g/m^3$ which exceeded the Malaysian National Ambient Air Quality Standard 2015. The impact may persist if there is no proper rehabilitation plan done to the exploited area. It is important to emphasize on sustainable mining practices such as rehabilitation in order to avoid other serious laterite issues in the future. Furthermore, application of magnesium phosphpgypsum in an effective ways, laterite problem can be reduced as well as make benefits on laterite.

1.3 Research Objectives

The aim of this research is to investigate the compressibility behaviour of magnesium phosphogypsum amended laterite:

i. To determine the geotechnical properties of magnesium phosphogypsum amended laterite.

ii. To establish the pressure-water content and pressure-void ratio relationships.

1.4 Scope of Study

The study focused on the development of comparison between pressure-void ratio and pressure-water content curve consists of moisture content in the context of compressibility of magnesium phosphogupsum amended laterite. Oedometer test was applied to investigate the compressibility variation of magnesium phosphogypsum amended laterite. In this study, the raw laterite and magnesium phophogypsum were taken from the site and transported back to the laboratory in seal plastic containers. Several tests were carried out in Soil and Geotechnical Laboratory in University Malaysia Pahang (UMP).

1.5 Significant of Proposed Research

This study enables people to understand magnesium phopshogypsum amended laterite much deeper hence it brings benefits to research purpose. The result from this study can be used for future researchers to get clear information about laterite. In this case, laterite should be investigated in order to find out more applications of laterite to the world. Thus, this investigation about laterite is needed. From the compressibility as it is the fundamental geotechnical properties of soil, this research might be a great exploration of laterite.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the definition of laterite and Bayer process were first presented. The previous study on the laterite residue and geochemicals laws of laterite deposit formation were presented first, followed by geotechnical properties of laterite residue was also discussed. Compaction characteristics, void ratio, and consolidation were also presented. A review on rehabilitation is presented towards the end of the chapter.

2.2 Laterite

First discovered in 1821 by the French geologist Pierre Berthier, laterite was named after the town of Les Baux in France and was noted for having high levels of aluminum (Authier-Martin, Forte, Ostap, & See, 2001). Laterite is known as the primary raw material of aluminum, and is commonly formed as a result of intense chemical weathering in hot and humid zones, representing a typical exogenous type of mineral resource (Zhang et al., 2017). It is an iron-rich tropical lateritic ore typically consisting of the minerals gibbsite, boehmite, and/or diaspore along with the iron oxides goethite and hematite, the clay mineral kaolinite, and trace levels of several metals that include cadmium and titanium. Laterite is non-hazardous (Edition, 2018). Laterite is an aluminum and iron oxide rich lateritic ore found in the tropics between 30 degrees north and 30 degrees south latitude from the equator. The alumina is extracted from laterite using the Bayer process, in which sodium hydroxide is mixed with the ore and heated to 150 °C to 200 °C in a pressure chamber until the alumina is dissolved and filtered out. The waste by product from this process is laterite residue (or red mud), a highly alkaline, heavy metal laden slurry that can, at times, contain naturally occurring radionuclides (Gore, 2015).

2.2.1 Definition

Laterite as it is commonly known is a principal ore of aluminium. It is a large rock composed of a mixture of hydrous aluminium oxides. Laterite vary physically according to the origin and geologic history of their deposits. Some deposits are soft, easily crushed, and structureless while some are hard, dense, and pisolitic. Commonly, laterite type are pisolitic and mottled, with pisolites ranging in size from about 2.5 mm (0.10 inch) to 25 cm (10 inches) or more in diameter. Laterite is a mineral found mostly in a belt around the equator. Laterite, containing 15-25 percent aluminium, is the only ore that is used for commercial extraction of aluminium today. The laterite occurs mostly in the tropics, in horizontal layers normally beneath a few meters of overburden. The layers are usually mixed with various clay minerals, iron oxides and titanium dioxide. It is the iron that gives laterite a deep red colour (Hydro, 2012).

2.2.2 Bayer Process

The Bayer process was invented by the Austrian chemist Carl Josef Bayer in St. Petersburg, Russia in 1887 while trying to develop a method for using alumina in the 15 textile industry as a substance for setting dyes in fabric (Power, Gräfe, & Klauber, 2011). Bayer discovered that, in a cold sodium aluminate solution (alkaline in nature), aluminum hydroxide precipitated into crystalline form if a seed of aluminum hydroxide (AlOH) was used. The aluminum hydroxide could be filtered, washed, and then easily used later to make aluminum sheets. Shortly after his initial discovery, Bayer also discovered that the required sodium aluminate solution could be prepared by heating laterite ore under pressure in concentrated caustic soda solution. Eventually, the potential of combining the two processes was brought to fruition, leading to the process of extracting alumina from laterite and the manufacturing of aluminum. The Bayer Process led to the modern day alumina industry and the accelerated use of aluminum (Gore, 2015). The success of the Bayer process is demonstrated by the fact that, despite enormous technological advances and the need to process a wide range of ore types, the basic chemistry and operational steps of a modern Bayer plant are fundamentally the same as originally described in Bayer's patents (Power et al., 2011).

2.2.3 Laterite Residue

Laterite residue is the largest waste fraction generated in the alumina industry. According to the recent online statistics of World Aluminium, the amount of laterite residue generated annually has increased mainly in China, and the total amount was approximately 150 million tons in 2015 (Kinnarinen, Huhtanen, Holliday, & Häkkinen, 2018). The total inventory of the residue disposed of during the past decades has been estimated to be over 4 billion tons. Laterite residue or red mud is the waste product left from the filtering and washing of the aluminum hydroxide crystals. The residue can vary in color but is typically a reddish brown color and is high in iron (20-45%), aluminum (10-22%), and silica (5-30%) content (IAI 2013), with a specific gravity of 3.0 to 3.6. Laterite residue is produced as a slurry that is highly alkaline (pH as high as 13), laden with heavy metals and fine grained (can exceed 95% finer than 200 sieve/0.075 mm) (Gore, 2015).

Laterite residue is also a highly alkaline solid hazardous waste produced from laterite processing for alumina production. Alkaline transformation appears to reduce the environmental risk of laterite residue disposal areas (BRDAs) whilst potentially providing opportunities for the sustainable reuse and on-going management of laterite residue (Kong et al., 2017). The residue is highly caustic (Clark, Johnston, & Reichelt-Brushett, 2015) has a fine particle size distribution (Johnston, Clark, McMahon, & Ward, 2010) and it contains a wide variety of metals, including both environmentally problematic metals, such as Cd, Cu, Ni and Zn (Ghosh et al., 2011). Laterite residue has a high buffering capacity, which is largely associated with its alkaline solids content. For example, a variety of hydroxides, carbonates, aluminates and aluminosilicates (Gräfe, Power, & Klauber, 2011).

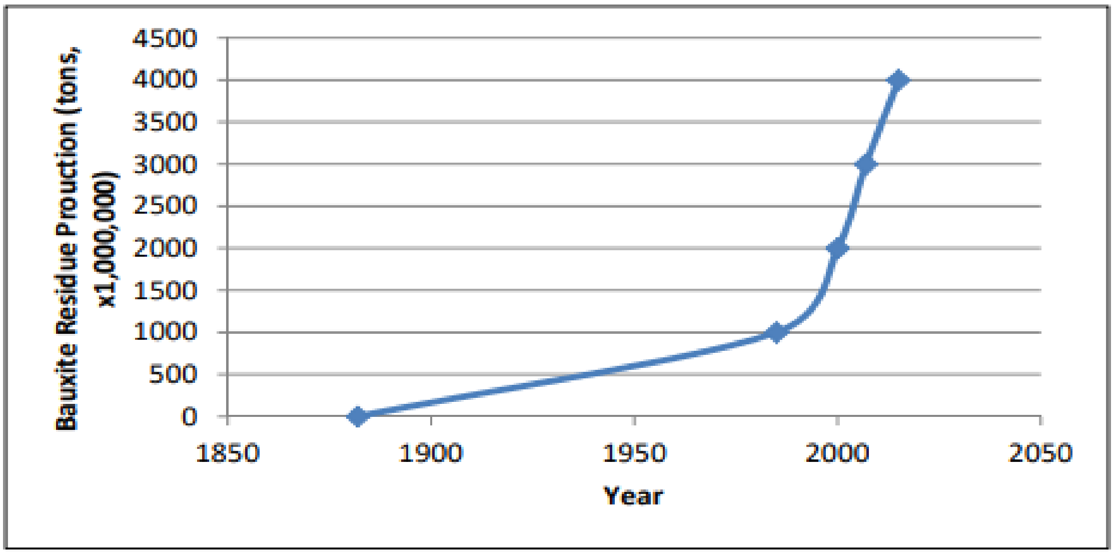


Figure 2-1: Worldwide Laterite Residue Production

2.3 Geochemical Laws of Laterite Deposit Formation

Laterite does not have a specific composition. It is a mixture of hydrous aluminum oxides, aluminum hydroxides, clay minerals, and insoluble materials such as quartz, hematite, magnetite, siderite, and goethite. The aluminum minerals in laterite can include gibbsite Al(OH)3, boehmite AlO(OH), and, diaspore, AlO(OH).The aluminum minerals in laterite can include gibbsite Al(OH)3, boehmite AlO(OH), and diaspore, AlO(OH).The important elements in laterite genesis are Si, Al and Fe. Extensive deposits exclusively or partly formed by the removal of silica, resulting in relative enrichment of Al and Fe. These laterites are characterized by the Al to Fe ratios corresponding to those of the source rocks. Such ferrallites are certain horizons of laterites on igneous rocks and most of the karst deposits. Siallites, which is rocks rich in silica develop if iron is removed faster than silica. They form the saprolite zone on igneous rocks and develop highly aluminous clays and transitional stages to flint clay on sediments. Allite formation occurs by relative enrichment of aluminium through the selective removal of silica and iron.

Besides relative enrichment, absolute enrichment impregnations may occur, resulting from colloidal or ionic transport of Fe, A1 and Si in ground water over long distances vertically and horizontally, followed by reprecipitation (“the Amounts of Specific Elements in the Source Rock; (2) the Chemical Association of Specific Elements With Stable or Unstable Minerals During Weathering; (3) the Intensity of Drainage

During Weathering:," n.d.). The relative enrichment of trace elements in laterite with respect to the earth's crust is shown in Table 2.1.

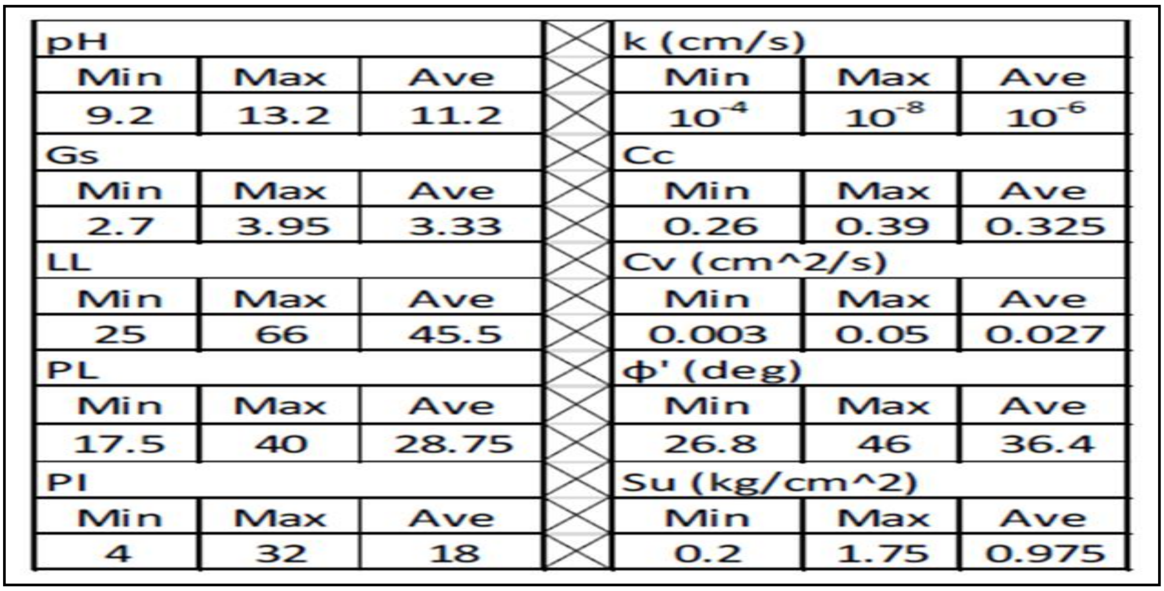
Table 2-1: Concentration of Element in the Earth's Crust an in Laterite

Elements	Laterites	Earth's crust	Concentration
Aluminium	30.16	7.45	4.05
Ferum	9.99	4.20	2.38
Silica	3.8	26.0	0.15
Titanium	1.64	0.64	2.56
Calcium	0.81	3.25	0.25
Carbon	0.515	0.35	-
Sulphur	0.50	0.10	5.00
Potassium	0.36	2.35	0.15
Phosphorus	0.13	0.12	1.08
Magnesium	0.09	2.35	0.038
Sodium	0.08	2.40	0.03
Manganese	0.076	0.10	0.76
Vanadium	0.062	0.02	3.10
Chromium	0.055	0.03	1.83
Copper	0.023	0.01	2.30
Zinc	0.021	0.02	1.05
Galium	0.0035	-	-

2.4 Geotechnical Properties of Laterite Residue

2.4.1 Introduction

Publicly available geotechnical data on laterite residue is presented to illustrate the variability found throughout the related research papers. Many papers lack enough information to conclude reasons for the variability. Never the less, the information is presented to provide an overview of the available data and demonstrate the starting point one finds in studying laterite residue.



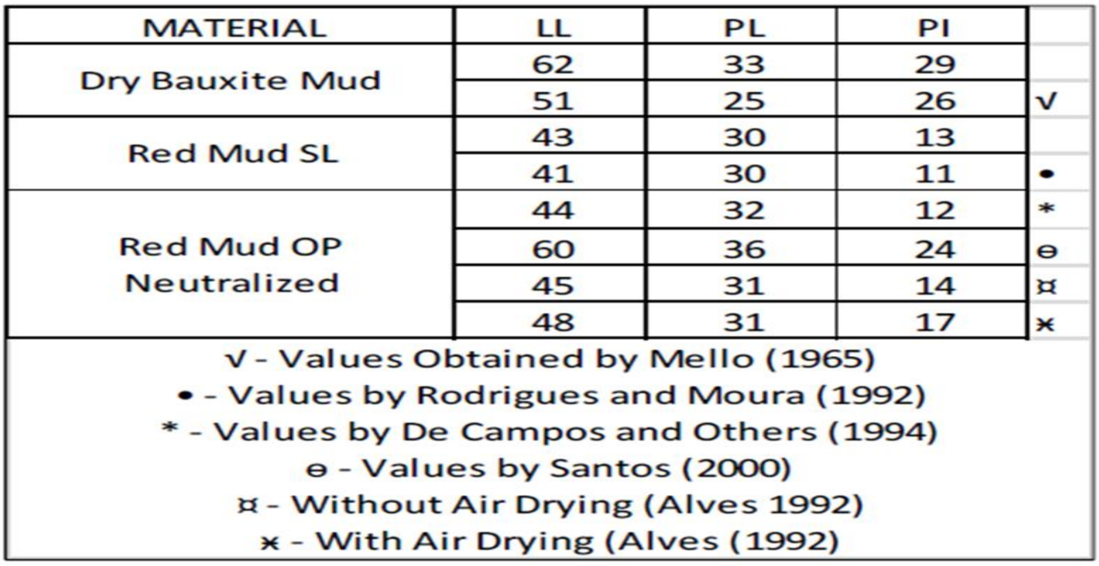
pH				k (cm/s)		
Min	Max	Ave		Min	Max	Ave
9.2	13.2	11.2		10^{-4}	10^{-8}	10^{-6}
Gs				Cc		
Min	Max	Ave		Min	Max	Ave
2.7	3.95	3.33		0.26	0.39	0.325
LL				Cv (cm^2/s)		
Min	Max	Ave		Min	Max	Ave
25	66	45.5		0.003	0.05	0.027
PL				ϕ' (deg)		
Min	Max	Ave		Min	Max	Ave
17.5	40	28.75		26.8	46	36.4
PI				Su (kg/cm^2)		
Min	Max	Ave		Min	Max	Ave
4	32	18		0.2	1.75	0.975

Figure 2-2: Data Presented for Geotechnical Properties of Laterite Residue

Laterite residue contains typically 10% - 30% sand and 70% - 90% particles finer than 2 µm (with breakdown being 20% - 30% clay size and 50% - 60% silt size). Notice that it was not stated that the breakdown includes clay. Researchers have shown that laterite residue is completely absent of quartz or clay minerals (Gore, 2015). Specific gravity values for laterite residue ranged from 2.7 to 3.95 (Somogyi 1976; Cooling 1985, Consoli 1997, Newson 2006; Wagh 1987; Kirkpatrick 1996; Srivastava 2002, Deelwal et al. 2014, Kehagia 2014). The liquid limit (LL), plasticity, limit (PL), and plasticity index (PI) ranges were 25 to 66, 17.5 to 40, and 4 to 32, respectively (O'Kelly, 2015). Figure 2.3, figure 2.4 and figure 2.5 provides considerable information about Atterberg Limit.

Based on classification criteria, laterite residue would be characterized as a clayey silt. Laterite residue contains typically 10% - 30% sand and 70% - 90% particles finer than 2 µm (with breakdown being (20% -30% clay and 50% - 60% silt). Based on classification criteria, Somogyi (1979) defined laterite residue as an inorganic or clayey silt with a Unified Classification System distinction of ML (i.e. – low plasticity, clayey, sandy and sandy, clayey silts, respectively). RARE (EPA 2008) determined that red mud was a lean clay or a Unified Classification System distinction of CL. So, it can be seen just with these two reports that classifying laterite residue in terms of current geotechnical parameters has been and may continue to be difficult. As stated by Somogyi, designers and engineers must be very careful with classification because the material may behave in some ways like a clay but, in fact, may not have any clay minerals within the material structure.

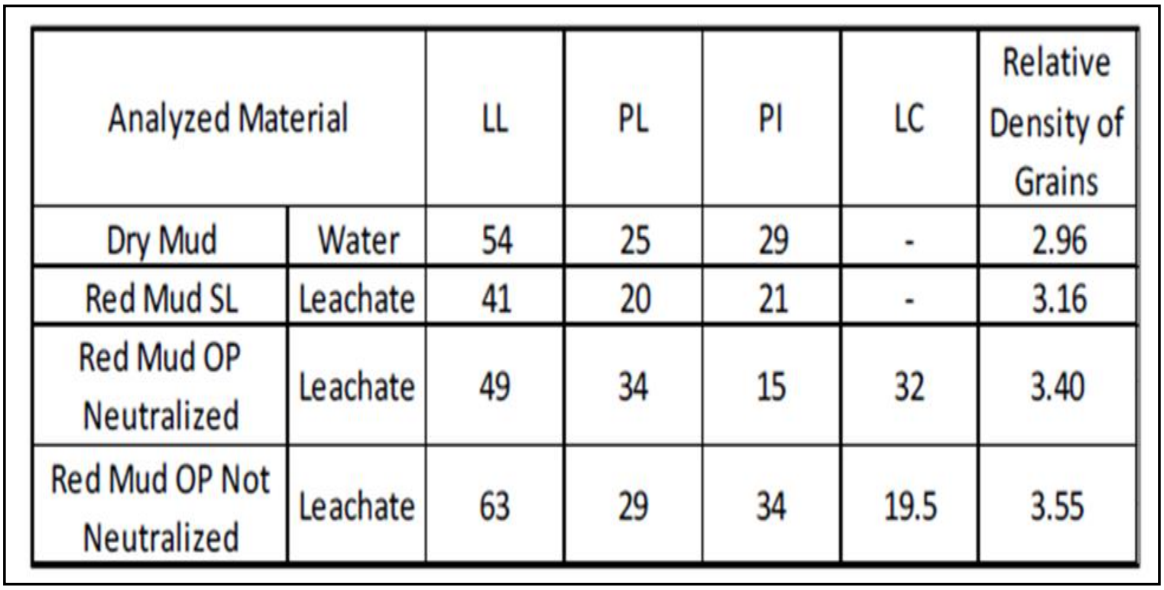
A conclusive reason for the wide range of variability cannot be provided due to lack of information among the publicly available papers. There could be several possible contributing factors that include the source of the laterite residue (different levels of iron and other heavy minerals), the particle segregation of laterite residue (sample source location within containment facilities), sample preparation techniques and processing of the residue before testing, and the effects of salts on specific gravity and its relation to how the material was treated prior to testing in the laboratory (Gore, 2015).



MATERIAL	LL	PL	PI	
Dry Bauxite Mud	62	33	29	
	51	25	26	√
Red Mud SL	43	30	13	
	41	30	11	•
Red Mud OP Neutralized	44	32	12	*
	60	36	24	ɵ
	45	31	14	¤
	48	31	17	ӿ

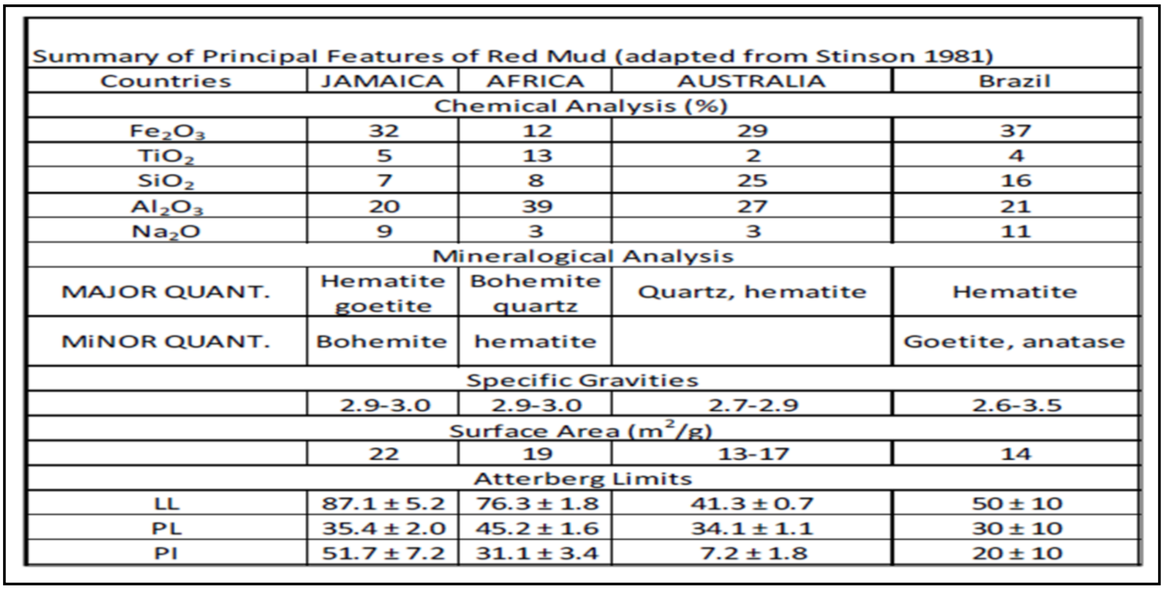
√ - Values Obtained by Mello (1965)
• - Values by Rodrigues and Moura (1992)
* - Values by De Campos and Others (1994)
ɵ - Values by Santos (2000)
¤ - Without Air Drying (Alves 1992)
ӿ - With Air Drying (Alves (1992)

Figure 2-3: Review of Atterberg Limit Values in Brazillian



Analyzed Material		LL	PL	PI	LC	Relative Density of Grains
Dry Mud	Water	54	25	29	-	2.96
Red Mud SL	Leachate	41	20	21	-	3.16
Red Mud OP Neutralized	Leachate	49	34	15	32	3.40
Red Mud OP Not Neutralized	Leachate	63	29	34	19.5	3.55

Figure 2-4: Atterberg Limits in Villar Dissertation Work



Summary of Principal Features of Red Mud (adapted from Stinson 1981)

Countries	JAMAICA	AFRICA	AUSTRALIA	Brazil
Chemical Analysis (%)				
Fe_2O_3	32	12	29	37
TiO_2	5	13	2	4
SiO_2	7	8	25	16
Al_2O_3	20	39	27	21
Na_2O	9	3	3	11
Mineralogical Analysis				
MAJOR QUANT.	Hematite goetite	Bohemite quartz	Quartz, hematite	Hematite
MiNOR QUANT.	Bohemite	hematite		Goetite, anatase
Specific Gravities				
	2.9-3.0	2.9-3.0	2.7-2.9	2.6-3.5
Surface Area (m^2/g)				
	22	19	13-17	14
Atterberg Limits				
LL	87.1 ± 5.2	76.3 ± 1.8	41.3 ± 0.7	50 ± 10
PL	35.4 ± 2.0	45.2 ± 1.6	34.1 ± 1.1	30 ± 10
PI	51.7 ± 7.2	31.1 ± 3.4	7.2 ± 1.8	20 ± 10

Figure 2-5: Atterberg Limits for Laterite Regions by Stinson 1981

2.4.2 Compaction Characteristics

(Matsumura & Tatsuoka, 2018) performed compaction tests using a Harvard miniature mold using an impact hammer that imparted a compaction effort similar to the modified AASHTO test. His results were optimum moisture contents of 28% and 31%

for two laterite residue refineries in Alabama and Texas, respectively, with dry densities of 97 to 98 lb/ft3. (Phillips & Chen, 2010) stated data for modified and standard proctor tests on laterite residue from Louisiana. For the standard proctor test, optimum moisture content was 32.2 % and maximum dry density was 100 lb/ft3. For the modified proctor test, optimum moisture content was 21% and maximum dry density was 125.4 lb/ft3. Method of preparation of the laterite residue and age of the material are unknown for both studies and these characteristics may have significant effects on the behaviour of the soil (Meehan, Cacciola, Tehrani, & Baker, 2017). (Xenidis & Boufounos, 2008) provided a standard proctor optimum moisture content of 28.4% and max dry density of 94 lb/ft3. (Shahin, Mardesic, & Nikraz, 2011) provided an optimum moisture content of 17.8%. (Clayton, 2014) provided an optimum moisture content of 18.8 %, and dry density of 122.4 lb/ft3. (Deelwal, Dharavath, & Kulshreshtha, 2014) provided a maximum dry density 95.5 lb/ft3 and optimum moisture content of 33.5%.

2.4.3 Void Ratio and Consolidation

(Gökçe & Andiç-Çakır, 2018) performed consolidation testing procedures described in ASTM D2435-70 standards, with some modifications. The testing program sought the parameters of compression index, coefficient of consolidation, and pre-consolidation pressure. This testing program was investigating the effects of laterite residue : sand ratio, stress history, dissolved solids content, and pH on the consolidation behaviour (Giger, Ewy, Favero, Stankovic, & Keller, 2018). Two separate facilities for Alcoa were used for samples (Point Comfort, TX and Mobile, AL). Samples for consolidation were prepared using the slurry method.

Effects of mud : sand ratio showed increasing sand content resulted in decrease in compression index. The coefficient of consolidation and hydraulic conductivity values appeared to be independent of the mud : sand ratio. Both leaching and pH neutralization caused a decrease in the compression index. Also, it was stated that leaching removed most of the dissolved solids, leading to low void ratios and a generally dispersed structure. Leaching also caused a decrease in compression index and coefficient of consolidation while pH neutralization decreased compression index and increased the coefficient of consolidation. Lastly, horizontal consolidation testing resulted in coefficients of consolidation that were twice that of vertical consolidation. Recently, other researchers have started to report their consolidation data as well.

2.5 Additional Reported Behaviour of Laterite Residue

(Xue et al., 2018) results concluded that laterite residue properties varied between refineries, varied when unleached versus leached by distilled water, varied due to differences source ore, contained no clay minerals (including kaolinite, chlorite, or hydrous mica) despite showing clay-like behaviour for some properties, contained hydrated crystalline compounds in slurry state that became amorphous upon heating, had a brittle behaviour under shearing, and showed limited signs of thixotropy. (Bodley & Associates, 2011) reference the fact that pore pressure build up (through CPTU testing) was significantly influenced by the hydraulic conductivity with the highest pore pressure build up occurring in the lowest permeable laterite residue.

Based on a comparison of their data with that of clays with similar plasticity and moisture content, Newson et al concluded that the laterite residue behaved more like a sensitive, cemented sandy material. The cause of the cementation was attributed to "cementation or aggregation caused by feldspathoid hydroxysodalite". They found that laterite residue appeared to be anisotropic with higher vertical stiffness than horizontal stiffness and no evidence of strain-softening. The second point led to the conclusion that there was little chance of progressive failure possibility. Cubic and prismic shape particles, to a less extent, also contribute to higher strength values. When treated with an acid wash, the laterite residue lost cementation and strength, resulting in a behaviour more consistent with a silty clay material.

2.6 Soil Classification

The last few decades have seen an escalation in the importance and scope of soil science (Shahbazi, Huang, McBratney, & Hughes, 2018). Soil classification is a means of grouping soils into categories according to a shared set of properties or characteristics that will exhibit similar engineering behaviour under loading. Correctly classifying site conditions is an important, costly, and time-consuming process which needs to be carried out at every building site prior to the commencement of construction or the design of foundation systems (Reale, Gavin, Librić, & Jurić-Kaćunić, 2018). Soil classification system is important in geotechnical engineering. It provides a systematic method of categorizing soil according to their probable engineering behaviour. From previous research and experience, engineering properties such as shear strength and compressibility characteristics of soil have been found to correlate quite well with the index properties (water content, density and void ratio) and classification properties (grain size and grain size distribution as well as plasticity) of a given soil deposit. By knowing the classification of the soil, an engineer will have a good idea on how to proceed with detailed site investigation and laboratory testing and subsequently with the design of foundation as well as the engineering situations both during and after construction.

All laboratory test procedures are based on the manual of soil laboratory testing in accordance with the British Standard (BS) and American Standard Testing Methods (ASTM):

i. Coarse-grained soils with up to 50% passing No. 200 ASTM Sieve.

ii. Fine-grained soils with more than 50% pass No. passing No. 200 ASTM Sieve.

iii. Organic soils.

In the British Soil Classification System, soils are classified into named Basic Soil Type groups according to size, and the groups further divided into coarse, medium and fine sub-groups as shown in Table 2.2:

Table 2-2: British Soil Classification System

Very coarse soils	BOULDERS		> 200 mm
	COBBLES		60 - 200 mm
Coarse soils	**G** GRAVEL	coarse	20 - 60 mm
		medium	6 - 20 mm
		fine	2 - 6 mm
	S SAND	coarse	0.6 - 2.0 mm
		medium	0.2 - 0.6 mm
		fine	0.06 - 0.2 mm
Fine soils	**M** SILT	coarse	0.02 - 0.06 mm
		medium	0.006 - 0.02 mm
		fine	0.002 - 0.006 mm
	C CLAY		< 0.002 mm

2.7 Rehabilitation

Specific rehabilitation processes are very much dependent on the mine site and the ecological, social and geological conditions. Assessment of soil biological communities and activity may be a valuable indicator of ecological stress and ecosystem function in rehabilitated laterite residue (Courtney, Feeney, & O'Grady, 2014). Laterite resources are abundant in China, ranking as the fifth major laterite province in the world, next to Guinea, Australia, Brazil, and Jamaica (Zhang et al., 2017).

Besides that, Australia also one of country that has abundant of laterite. A mining and refining of laterite in south-western Australia has been an expanding industry during the past 20 years. Alumina produced from this area is now one over sixth of the supply for the western world. The open- cut laterite mining occurs in a zone of environmental sensitivity, and it has therefore been necessary to develop techniques of mining and rehabilitation which accommodate that sensitivity (Nichols, Carbon, Colquhoun, Croton, & Murray, 1985). The soil in Australia are typically coarse-textured at the surface, but become fine textured with depth. It is close to the scarp, the softs have up to 1 m of surface sand or gravelly-sand, often over cemented laterite. This cemented laterite, and the 1 to 4 m of loam beneath it, is rich in aluminium oxide or iron oxides.

A long-term decision on access to laterite will depend largely on the environmental impacts of mining. It is also a consequence of competition for land use. In order to maintain access to laterite resources, a comprehensive plan of post-mining rehabilitation and an active research programme designed need to be conduct to minimise the environmental impact. The overall objective of rehabilitation is to regenerate a stable forest ecosystem capable of replacing the function of the original forest system. Between 1989 and 2007, leaf areas have increased after mining (CSIRO), even as rainfall has fallen ("Frank batini fifa," n.d.). More than half of the rehabilitated areas are now above the desired tree density (Grigg, 2017).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The study was an experimental research, which concentrate on the evaluation of compressibility behaviour of magnesium phosphogypsum amended laterite. Literature study was made to provide rationale of the research and to gather sufficient information on the compressibility behaviour of magnesium phosphogypsum amended laterite. The physical properties of every soil sample were investigated. Preliminary evaluation of the compressibility characteristics of the soil is based on the standard consolidation test. All laboratory test procedures are based on the manual of soil laboratory testing in accordance with the British Standard (BS) and American Standard Testing Methods (ASTM). The focus of the research was to evaluate the compressibility parameters (moisture content and void ratio) of the magnesium phosphogypsum amended laterite under a range of compressibility pressure. The evaluation is based on the oedometer test (one dimension test) and the compressibility curve obtained from the test.

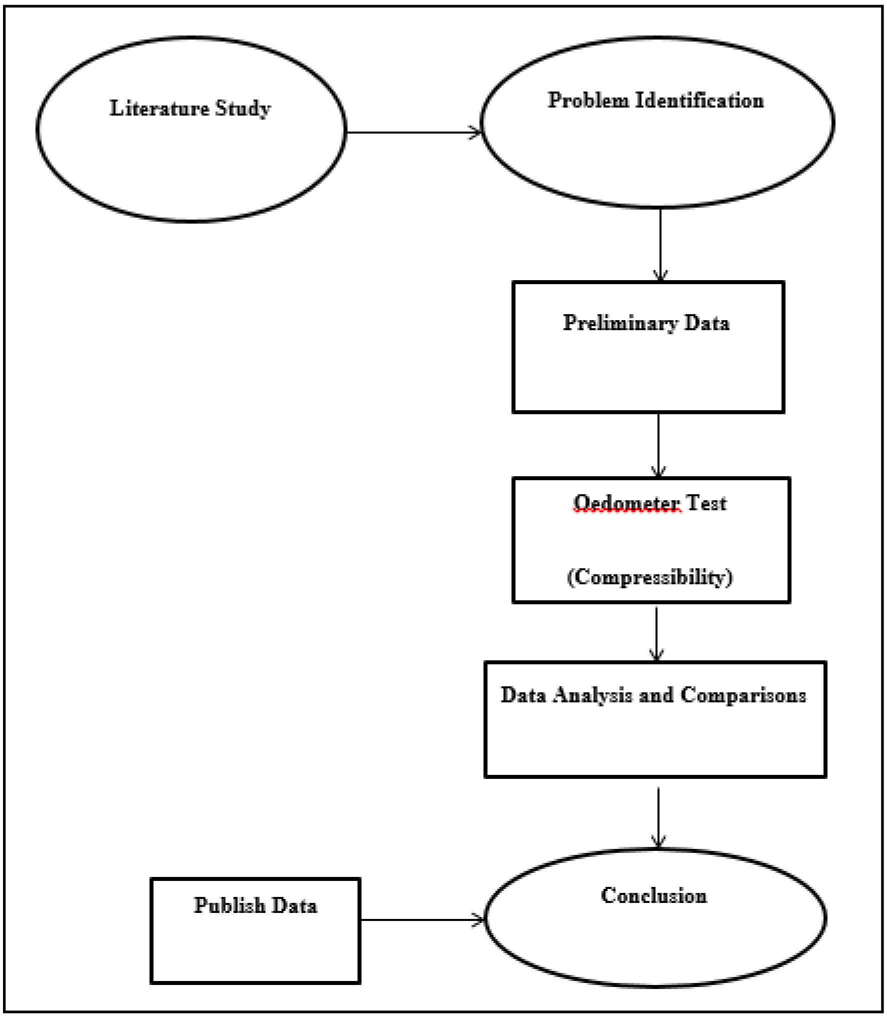


Figure 3-1: Flowchart of Study

3.2 Selection of Materials

The soil samples come with 3 different ratio. Sample 1 is laterite, sample 2 is 1:2:7 and sample 3 is 1:3:6. Table 3.1 shows ratio of soil sample. The sample is the stored in container since it is not so reactive and sensitive to atmospheric exposure. The sample is then preserved and protected from any unwanted exposure to water spillage and extreme temperature change that may cause inaccuracy during testing.

Table 3-1: Ratio of Sample

Sample	**Ratio (%)**
Sample 1	Laterite
Sample 2	1:2:7
Sample 3	1:3:6

3.3 Sample Preparation

Samples were prepared in powder and slurry condition. To prepare powder sample, soil were crushed and sieved passing 2mm before being placed in sealed bags prior to being tested in the laboratory. Some of each samples were added with deionized water to 1.2 times the liquid limit value to prepare slurry specimens. All the slurry specimens were kept in seal bags before being tested.

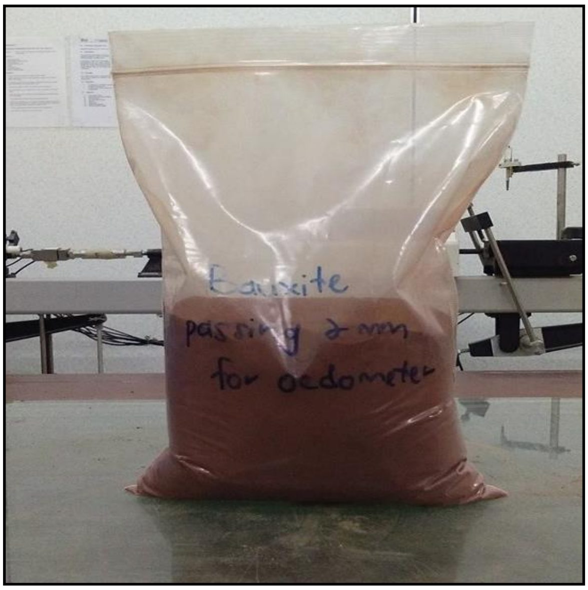


Figure 3-2: Soil Sample in Powder Condition

Figure 3-3: Soil Sample in Slurry Condition

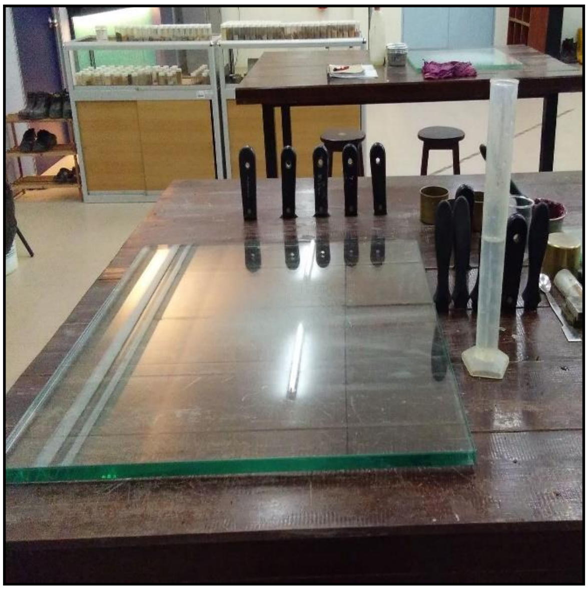


Figure 3-4: Preparation of Sample

Figure 3-5: Mixture of Sample and Water

3.4 Physical Properties of Magnesium Phosphogypsum Amended Laterite

The properties testing that have been conducted was physical properties testing as shown in Table 3.2:

Table 3-2: Physical properties testing method

Physical properties	Testing Method
Specific gravity, G_s	Density Bottle (BS 1377: Part 2 1990: 8.3)
Particle size distribution	(BS 1377: Part 2 1990: 9.3&9.5)
Liquid limit, LL	(BS 1377: Part 2 1990: 4.3)
Plastic limit, PL	(BS 1377: Part 2 1990: 5.3)
Shrinkage limit, SL	(ASTM D4943-08)
Water content, w	(BS 1377: Part 2 1990)

3.4.1 Specific Gravity, Gs

This test followed BS 1377-2 (2012). About 10 g oven dried soil samples were transferred into density bottle. The distilled water was added about half to three-fourth of the density bottle and placed in the vacuum desiccator. The soil samples were left in the desiccator for at least one hour until no further loss of air was apparent. The distilled water was added until the density bottle full and left for an hour in room temperature. Then, the soil and water were removed from the bottle. The density bottle was refilled with water until full and were left for an hour. The test repeated twice for the same soil sample. The specific gravity can be calculated using Eq. 3.1.

$$Gs = \frac{W2 - W1}{(W4 - W1) - (W3 - W2)} \tag{3.1}$$

where W1 = weight of bottle + Stopper

$W2$ = weight of bottle + Stopper + Dry soil

$W3$ = weight of bottle + Stopper + Soil + Water

$W4$ = weight of bottle + Stopper + Water

3.4.2 Particle Size Analysis

Particle Size Analysis of the samples was determined according to (BS 1377: Part 2 1990: 9.3&9.5), hydrometer method will be used to test the particle size distribution. The oven dried sample is sieve using different sizes (5mm, 3.35mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, 0.063mm) and is sieved using mechanical shaker.

Figure 3-6: Mechanical Shaker

3.4.3 Atterberg Limit

Atterberg limit include of liquid limit, plastic limit and shrinkage limit values were determined by (BS 1377: Part 2 1990: 9.3&9.5).

Figure 3-7: Atterberg Limit Test

3.4.4 Liquid Limit

Liquid limit test were conducted using cone penetrometer follows BS 1377-2 (2012). About 250 g oven dried soil passing 425 μm were left air dried for at least 30 minutes. Distilled water was added to the soil sample to form paste and then transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample. The penetrometer was adjusted that the cone point touches the surface of the soil paste. The vertical clamp was released to penetrate into soil paste under its own weight for five seconds. The test was repeated for three times of values of penetration in the range of 13.5 to 27.5 mm. The graph of water content versus cone penetration was plotted. The moisture content corresponding to cone penetration of 20 mm was taken as liquid limit of the soil.

Figure 3-8: Cone Penetrometer

3.4.5 Plastic Limit

Plastic limit test referred BS 1377-2 (2012). Soil paste was rolled out a thread on a flat surface. The plastic limit is defined as the moisture content where the soil paste begin to break apart at diameter 3.2 mm.

3.4.6 Shrinkage Limit

Shrinkage limit test was referred to Standard Test Method for Shrinkage Factors of Soils by the Wax Method (ASTM D4943:2008). Soil sample was added with distilled water until it reaches 1.2 times liquid limit of the soil sample. Weight of empty container is recorded. Then, grease was applied on internal of the container and weight again. The soil sample was transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in the soil sample and the weight is recorded. The soil sample was left air dried until no changes in the soil weight. The weight of metal cup with soil sample after oven dried were recorded. The dry soil sample is tied with thread and coated with wax. The weight of dry soil with thread and weight of dry soil with thread and wax were recorded. The dry soil with thread and wax is weight in air and in water.

The graph of void ratio versus water content was plotted. The moisture content corresponding to void ratio of the soil was taken as shrinkage limit of the soil.

3.4.7 Water Content

Water Content was obtained using (BS 1377: Part 2 1990) as the standard references. The mass of an empty container with its lid before and after placed the sample was recorded.

Figure 3-9: Water Content Test

3.5 Oedometer test

In this study, the oedometer test was conduct using different vertical loadings. The test was performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From measured data, the compressibility curve (pressure-water content and pressure-void ratio) can be plotted. This data is useful to make comparisons between graphs.

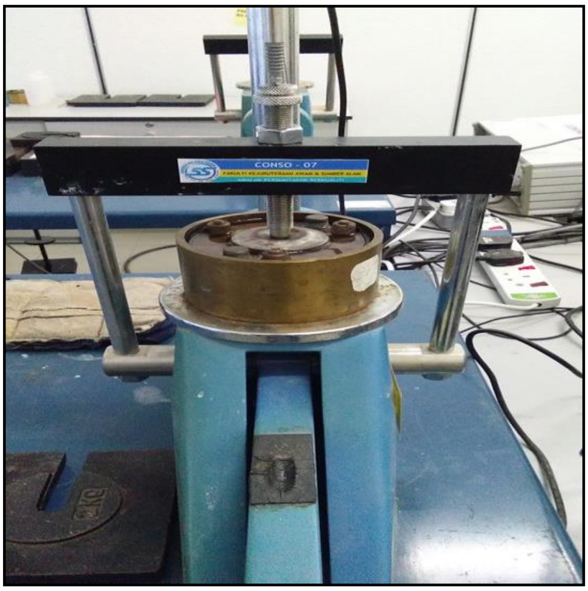


Figure 3-10: Oedometer Test

Table 3-3: Loading and pressure for oedometer test (sample 1)

LOADING (g)	PRESSURE (kPa)
125	6.4
250	12.7
500	25.5
1000	51
2000	101.6
4000	203.9
8000	407.8
16000	815.6
32000	1631.2

Table 3-4: Loading and pressure for oedometer test (sample 2)

LOADING (g)	PRESSURE (kPa)
125	6.5
250	13
500	26
1000	52
2000	104
4000	208.1
8000	416.2
16000	832.4
32000	1664.7

Table 3-5: Loading and pressure for oedometer test (sample 3)

LOADING (g)	PRESSURE (kPa)
125	6.5
250	13
500	26
1000	52
2000	104
4000	208.1
8000	416.2
16000	832.4
32000	1664.7

The soil sample 20mm in height and 50mm in diameter is confined in a steel confining ring and immersed in water bath. The three different samples are subjected to a compressive stress by applying a vertical load, which is assumed to act uniformly over the area of the soil sample. Two way drainage is permitted through porous disks at the top and bottom of the soil ample. The vertical compression of the soil sample is recorded using highly accurate dial gauge.

Figure 3-11: Consolidation Cell

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical Properties of Magnesium Phosphogypsum Amended Laterite

Table 4-1: Physical Properties of Magnesium Phosphogypsum Amended Laterite

Physical Properties	Testing Method		Sample		
			Laterite	1:2:7	1:3:6
Specific Gravity, Gs	BS 1337: PART 2 1990: 8.3		2.75	2.72	2.62
Particle Size Distribution	BS 1337: PART 2 1990: 9.3 & 9.5	Sand	72.0	70	69.2
		Silt	21.5	19.5	18.0
		Clay	6.5	10.5	12.8
Water Content, w	BS 1337: PART 2 1990		7.32	15.88	20.0
Liquid Limit	BS 1337: PART 2 1990: 4.3		34.0	40.5	45.0
Plastic Limit	BS 1337: PART 2 1990: 8.3		21.5	26.6	34.0
Shrinkage Limit	ASTM D4943-08		14.8	18.4	20.0

4.1.1 Oedometer Test

From the oedometer test, we obtained the pressure-water content curve and also pressure-void ratio curve. The result obtained from the oedometer test has been summaries in Table 4.2, Table 4.3 and Table 4.4. Coefficient of Volume Change and Compression Index were also determined.

Table 4-2: Oedometer test results (Sample 1)

Loading (g)	Pressure (kPa)	Water Content (%)	Void Ratio, e
125	6.4	34.54	0.9725
250	12.7	33.26	0.9608
500	25.5	32.18	0.9418
1000	51.0	31.43	0.8295
2000	101.6	28.69	0.7644
4000	203.9	26.73	0.7258
8000	407.8	25.50	0.6284
16000	815.6	24.16	0.4376
32000	1631.2	22.74	0.3364

Table 4-3: Oedometer test results (Sample 2)

Loading (g)	Pressure (kPa)	Water Content (%)	Void Ratio, e
125	6.5	38.1	1.2342
250	13	37.3	1.2108
500	26	36.7	1.1655
1000	52	34.5	1.1490
2000	104	32.5	1.0561
4000	208.1	30.5	1.0454
8000	416.2	29.5	0.8359
16000	832.4	28.1	0.7952
32000	1664.7	25.3	0.7586

Table 4-4: Oedometer test results (Sample 3)

Loading (g)	Pressure (kPa)	Water Content (%)	Void Ratio, e
125	6.5	44.4	1.2623
250	13	43.2	1.2431
500	26	42.0	1.2233
1000	52	41.6	1.2017
2000	104	40.5	1.1075
4000	208.1	37.8	1.0614
8000	416.2	36.9	1.0507
16000	832.4	33.9	0.9251
32000	1664.7	31.0	0.8088

4.1.2 Coefficient of Volume Change and Compression Index

Table 4-5: Coefficient of Volume Change and Compression Index

Sample	m_v	C_c
Sample 1	3.491 x 10^-6	0.168
Sample 2	1.471 x 10^-6	0.214
Sample 3	1.374 x 10^-6	0.215

4.2 Discussion

4.2.1 Comparison between Graph

From the oedometer, both the water content and void ratio been decreased after imposed with loading. This is due to the deformation and relocation of soil particles. Figure 4.1 shows the comparison for water content-pressure curve and Figure 4.2 shows the comparison for void ratio-pressure curve for all three different samples.

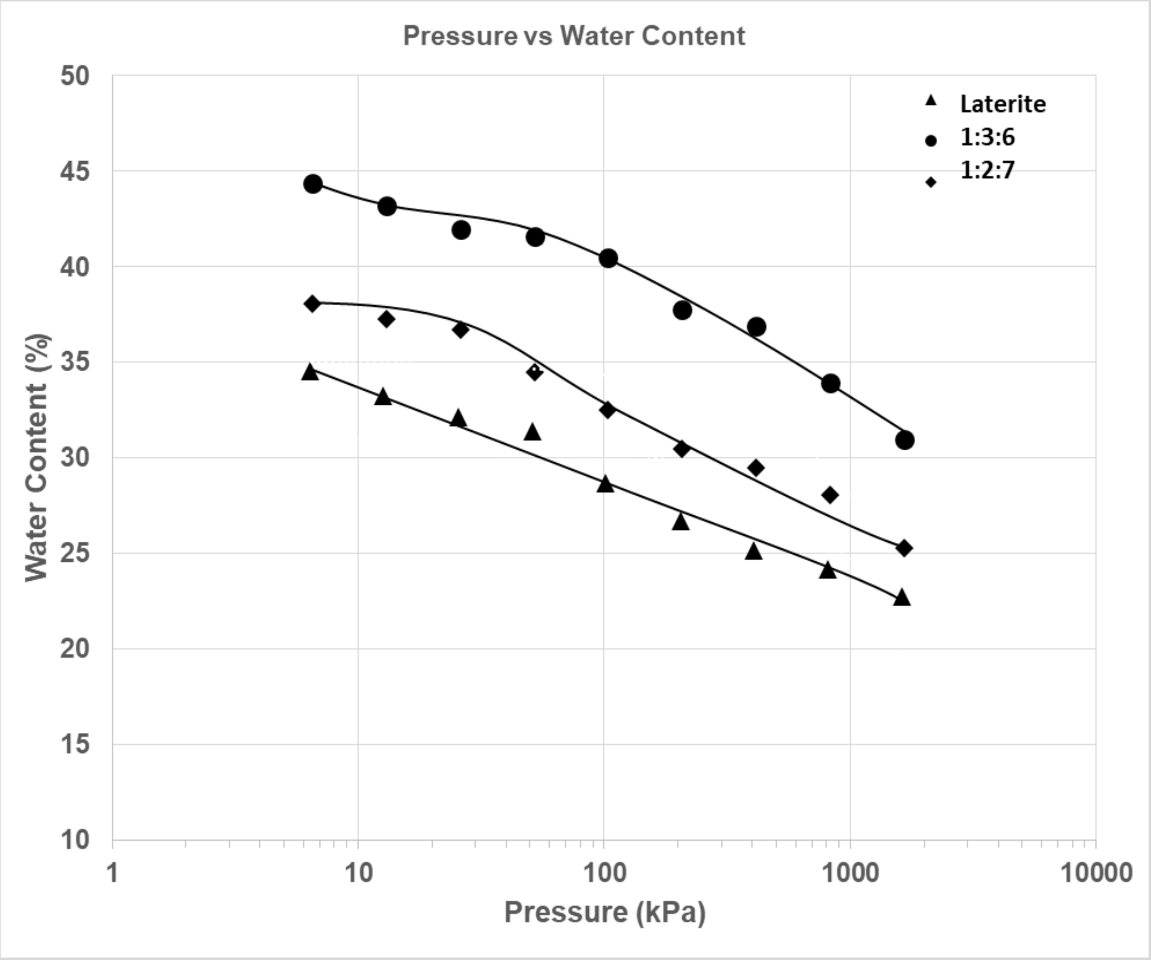


Figure 4-1: Pressure – Water Content Relationship

Figure 4.1 shows that the water content (%) of soil for three sample decreases when the pressure (kPa) increases. The water content before test for sample 1, sample 2 and sample 3 are 38.3%, 49.1% and 47.5% respectively. After the experiment, water content for each loading decreases as the pressure increases. The maximum value of water content after compressibility for sample 1 is 34.54, sample 2 is 44.4 and sample 3 is 38.1 while the maximum value are 22.74, 31.0, and 25.3 respectively

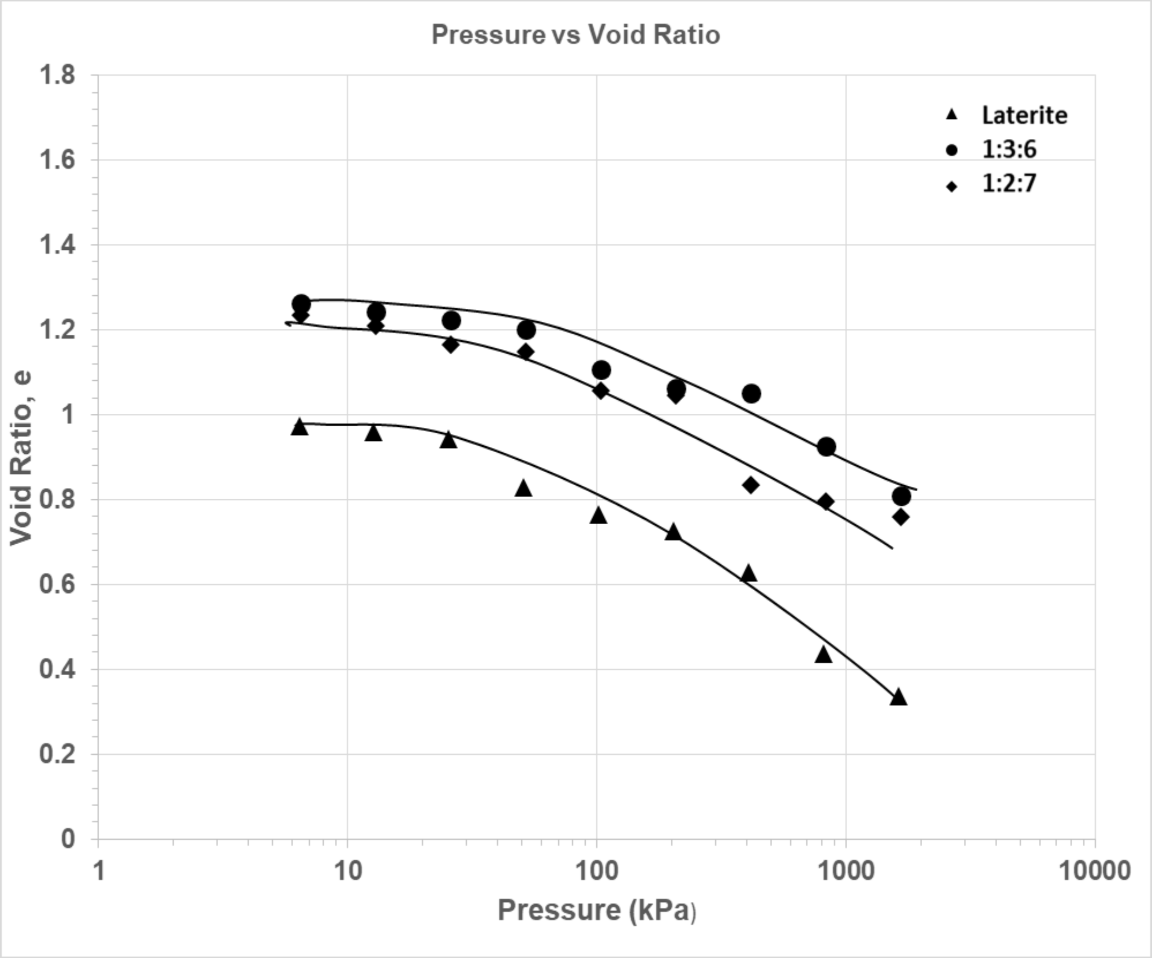


Figure 4-2: Pressure – Void Ratio Relationship

Figure 4.2 shows that the void ratio of soil for three sample decreases when the pressure (kPa) increases. The initial void ratio before test for sample 1, sample 2 and sample 3 are 1.0131%, 1.3039% and 1.2472% respectively. After the experiment, water content for each loading decreases as the pressure increases. The maximum value of void ratio after compressibility for sample 1 is 0.9725, sample 2 is 1.2623 and sample 3 is 1.2342 while the minimum value are 0.3364, 0.8088, and 0.7586 respectively. The water content and void ratio decreases when the load been imposed on the soil for the oedometer test. This prove that the amount of water content affected by loading expose, pressure (kPa) and the void ratio, e inside the soil sample.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The observation made in laboratory show that the curve followed by a soil elements during compressibility depends on pressure been expose to the soil sample. A review of past research on the magnesium phosphogypsum shows that I have progress from initial period of uncertainty and incompetence to a stage at which have gradually reaching a better understanding of the properties of magnesium phosphogypsum amended laterite, and thus are developing an improved ability to take into account the factors responsible for the previous discrepancies between theory and practice. This progress is almost exclusive due to three factors.

First, careful measurements of the behaviour of magnesium phosphogypsum amended laterite have provided an invaluable collection data to guide me in this research. Second, improvement of the technique of taking, handling and testing soil sample has increased my possibility of discovering the true properties of magnesium phosphogypsum amended laterite. The third factor that has greatly contributed a better understanding of the behaviour of magnesium phosphogypsum amended laterite is the incorporation of engineering geology into our way of thinking.

5.2 Recommendation

Futher research is required to verify the use of magnesium phosphogypsum amended laterite to the world as it is not treated as a dangerous waste product. It could give benefits not only to the humans but also to the world as futureresearch can increase the uses of magnesium phosphogypsum in many ways and can reduce the pollution of environment as well as increase the economy

REFERENCES

Abdullah, N. H., Mohamed, N., Sulaiman, L. H., Zakaria, T. A., & Abdul Rahim, D. (2016). Potential health impacts of bauxite mining in Kuantan. *Malaysian Journal of Medical Sciences*, *23*(3), 1–8.

Anak Ginung, G., & Abdullah, A. H. (2015). Malaysian Minerals Yearbook 2014, 116.

Authier-Martin, M., Forte, G., Ostap, S., & See, J. (2001). The mineralogy of bauxite for producing smelter-grade alumina. *Journal of the Minerals, Metals and Materials Society*, *53*(12), 36–40.

Bodley, A., & Associates, H. (2011). Reclamation of a Conventional Tailings Facility for Long Term Dry Stacking Operations in Western Australia.

Clark, M. W., Johnston, M., & Reichelt-Brushett, A. J. (2015). Comparison of several different neutralisations to a bauxite refinery residue: Potential effectiveness environmental ameliorants. *Applied Geochemistry*, *56*, 1–10.

Clayton, S. (2014). Lateral Earth Pressure Problems involved with Cantilever Retaining Structures and Stability of those Structures Bachelor of Engineering October 2014, (October).

Courtney, R., Feeney, E., & O’Grady, A. (2014). An ecological assessment of rehabilitated bauxite residue. *Ecological Engineering*, *73,* 373–379.

Deelwal, K., Dharavath, K., & Kulshreshtha, M. (2014). Evaluation of characteristic properties of red mud for possible use as a geotechnical material in civil construction. *International Journal of Advances in Engineering and Technology*, *7*(3), 1053–1059.

Donoghue, A. M., Frisch, N., & Olney, D. (2014). Bauxite mining and alumina refining: Process description and occupational health risks. *Journal of Occupational and Environmental Medicine*, *56*(5).

Edition, F. (2018). Sustainable Bauxite Mining Guidelines, (May).

Equipment, T. (1986). Oedometer test, *2*(163), 1–22.

Giger, S. B., Ewy, R. T., Favero, V., Stankovic, R., & Keller, L. M. (2018). Consolidated-undrained triaxial testing of Opalinus Clay: Results and method validation. *Geomechanics for Energy and the Environment*, 1–13.

Gökçe, H. S., & Andiç-Çakır, Ö. (2018). A new method for determination of dynamic stability of self-consolidating concrete: 3-Compartment sieve test. *Construction and Building Materials*, *168*, 305–312.

Gore, M. S. (2015). Geotechnical Characterization of Bauxite Residue (Red Mud), (August 2015), 287.

Gräfe, M., Power, G., & Klauber, C. (2011). Bauxite residue issues: III. Alkalinity and associated chemistry. *Hydrometallurgy*, *108*(1–2), 60–79.

Grigg, A. H. (2017). Hydrological response to bauxite mining and rehabilitation in the jarrah forest in south west Australia. *Journal of Hydrology: Regional Studies*, *12*(November 2016), 150–164.

Heshmati, A., & Motahari, M. (2012). Identification of key parameters on Soil Water Characteristic Curve. *Life Science Journal*, *9*(3), 1532–1537.

Hydro. (2012). “Aluminum, environment and society,” 5.

Johnston, M., Clark, M. W., McMahon, P., & Ward, N. (2010). Alkalinity conversion of bauxite refinery residues by neutralization. *Journal of Hazardous Materials*, *182*(1–3), 710–715.

Kinnarinen, T., Huhtanen, M., Holliday, L., & Häkkinen, A. (2018). Challenges related to solute analysis of bauxite residue filter cakes. *Minerals Engineering*, *120*(January), 1–6.

Kong, X., Li, M., Xue, S., Hartley, W., Chen, C., Wu, C., … Li, Y. (2017). Acid transformation of bauxite residue: Conversion of its alkaline characteristics. *Journal of Hazardous Materials*, *324*, 382–390.

Matsumura, S., & Tatsuoka, F. (2018). Effect of compaction conditions and fines content on cyclic undrained strength of saturated soils. *Soil Dynamics and Earthquake Engineering*, *112*(April), 152–161.

Meehan, C. L., Cacciola, D. V., Tehrani, F. S., & Baker, W. J. (2017). Assessing soil compaction using continuous compaction control and location-specific in situ tests. *Automation in Construction*, *73*, 31–44.

Nichols, O. G., Carbon, B. A., Colquhoun, I. J., Croton, J. T., & Murray, N. J. (1985). Rehabilitation after bauxite mining in south-western australia. *Landscape Planning*, *12*(1), 75–92.

O'Kelly, B. C. (2015). Atterberg limits are not appropriate for peat soils. *Geotechnical Research*, *2*(3), 123–134.

Phillips, I. R., & Chen, C. (2010). Surface charge characteristics and sorption properties of bauxite-processing residue sand. *Australian Journal of Soil Research*, *48*(1), 77–87.

Power, G., Gräfe, M., & Klauber, C. (2011). Bauxite residue issues: I. Current management, disposal and storage practices. *Hydrometallurgy*, *108*(1–2), 33–45.

Reale, C., Gavin, K., Librić, L., & Jurić-Kaćunić, D. (2018). Automatic classification of fine grained soils using CPT measurements and Artificial Neural Networks. *Advanced Engineering Informatics*, *In Press*(September 2017), 207–215.

Shahbazi, F., Huang, J., McBratney, A. B., & Hughes, P. (2018). Allocating soil profile descriptions to a novel comprehensive soil classification system. *Geoderma*, *329*(May), 54–60.

Shahin, M. A., Mardesic, T., & Nikraz, H. R. (2011). Geotechnical characteristics of bauxite residue sand mixed with crumbed rubber from recycled car tires. *Journal of GeoEngineering*, *6*(1), 63–72.

The Amounts of Specific Elements in the Source Rock; (2) the Chemical Association of Specific Elements With Stable or Unstable Minerals During Weathering; (3) the Intensity of Drainage During Weathering: (n.d.).

Xenidis, A., & Boufounos, D. (2008). Dry disposal of bauxite residues in abandoned mine open pits. *GeoCongress 2008: Geotechnics of Waste Management and Remediation*, 40–47.

Xue, S., Li, M., Jiang, J., Millar, G. J., Li, C., & Kong, X. (2018). Phosphogypsum stabilization of bauxite residue: Conversion of its alkaline characteristics. *Journal of Environmental Sciences*, 1–10.

Zhang, L., Park, C., Wang, G., Wu, C., Santosh, M., Chung, D., & Song, Y. (2017). Phase transformation processes in karst-type bauxite deposit from Yunnan area, China. *Ore Geology Reviews*, *89*, 407–420.