Multi-blend soil stabilizer

by

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September, 2012

CERTIFICATION OF ORIGINALITY

This is certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

____
(MAHWASANE VHANGANI)

ABSTRACT

The effect of fly ash on the strength and deformation characteristics of soft clay is discussed in the paper. Lime or cement has been added as secondary constituents to further enhance self-hardening of the blended mix. For example, unconfined compression tests reveal that after two weeks of curing, a 18% fly ash and a 5% lime treated soft Clay attains a compressive strength 2-3 times greater than that of the natural clay. However, if lime is replaced by cement, the initial rate of strength development increases significantly. Excessive fly ash contents (greater than 25%) cause tensile splitting of unconfined specimens. The compressibility of fly ash--cement treated soil is considerably less than that of the natural clay. As the fly ash content exceeds 10% for a constant cement content of 5%, the increase of the equivalent yield pressure becomes significant. The reduction in compressibility is also associated with a corresponding increase in the coefficient of consolidation. The main aim of this paper is to determine the performance of PFA,OPC and lime as soil stabilizers when combined together.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The growth in Malaysian economy and population means that there are a lot of construction projects at hand. Because of these large scale developments in Malaysia there is a greater need for the use of soil stabilizers. Also it should be noted that when a country develops the road construction also intensifies. In road constructions it would be very costly to use granite as a road sub-grade for every road construction undertake, since in some areas granite is not available closer to the construction site.

Soil is used as a construction material in various civil engineering projects for example as foundation of the road or pavement. Soil, known as sub grade, is a very crucial component as it functions to withstand the loading from traffic and transfer it to the earth. However, weak sub grade will affect the strength of the road structure. Therefore, it is important to have a good sub base layer by modifying and improving its properties and characteristics.

1.2 Problem Statement

Soil stabilization is important in Malaysia as the country is abundance of weak soil (clay) lying underneath which is not fit for the construction of civil engineering structures. Normally, clayey soil will exhibit poor engineering characteristics. High swelling potential shows that the soil is able to absorb large amount water when it gets wets. It is possibly also has high shrinkage potential at which the soil will be easily shrunk when it gets dries. This shrink/swell potential is relative changes of volume with changes of moisture content. The climate that we own here where the rainfall is considered a lot which can increase the moisture and weakening the soil by affecting its properties. Excessive rainfall also caused a lot of other problems such as landslide and erosion. Low bearing capacity and strength of soil can cause a lot of soil problems such as extreme settlement.

Therefore, the method of chemical soil modification by stabilizing soil using lime,PFA and OPC is essential in treating the soft soil up to considerable strength for the purpose to overcome and avoid the possible consequences.

1.3 Objective

The purpose of this research is to determine the effectiveness PFA,OPC and Lime to be as single additive as well as in combination for soil stabilization. This is to be done by evaluating the rate of performance of the varying mixture of the treated soil samples. These are the related objectives of the research:

1) To determine basic properties of the control soil (untreated samples).
2) To determine the optimum design mix for OPC-treated, PFA-treated and Lime-treated samples.
3) To evaluate the effectiveness of PFA,OPC and Lime when mix together.

1.4 Scope of Study

In this study of the soil improvement by using PFA,OPC and Lime, it is focusing to obtain the accurate result to fulfill the aim and objectives of the study. This preliminary study is focusing on literature review to gain information how the project is going to be carried out. The main material is soil that taken in UTP campus. The samples that will be prepared consist of control sample (untreated soil), PFA-treated soil samples, OPC-treated soil samples and Lime-treated soil samples. The optimum mixture of OPC-soil,soil-PFA and soil-lime will be determined after getting the results. Then, a new sample with combination of OPC,PFA and lime content will be prepared and tested. All the methods of tests are chosen that follow are as stated in British Standard (BS 1337: Part 2). The result should be discussed in term how effective the stabilizer improve the engineering properties of the soil and the optimum mixing design will be determined.

1.5 Significance of the Project

In the past, civil engineers have been obliged to use soft soil sites with low bearing capacities, low shear strengths and high settlements. In order to improve the behavior of such soils, attempts have been made to utilize low- cost local materials including waste products. This study deals with lime-fly ash and cement-fly ash stabilization as an effective alternative in the ground modification of soft compressible clays, such as Bangkok Clay. Construction since decades ago, in Malaysia normally will use materials such as granite (for Road construction) as sub base materials when there is problem with the soil (sub grade) underlying the designated pavement layers. Generally this involve when the road to be constructed on the soft soil or clayey soil. Granite will function to protect the sub grade from excessive loading which could lead to excessive deformation that able to cause strength and serviceability failure of the road structure.

With this project, hopefully it will help civil engineering society in Malaysia especially to understand more about chemical stabilization. Power station such as in Manjung, Perak produced a lot of by-product, PFA day to day and it becomes waste material as being dumped into landfill. As the result, it pollutes the environment. With the understanding in this project, Malaysia could utilize the benefit of PFA in road construction industry and reduce the dependency on mass amount the granite. Besides, it also will contribute to the green the environmental as more waste material being reuse in future.

1.6 Feasibility and Limitation

This project covers only short term performance of the treated soil in such a way that the samples will be tested only after it being mixed with the stabilizers. It is feasible to be carried out in the laboratory testing because the result will show the improvement of properties which would be useful to predict the actual enhancement for in-situ stabilization process. However, the treated mixture will demonstrate there is either improvement or unaffected engineering properties. Although there is possibility that the properties will not changed, it is hope that at least the mixture is become beneficial in utilizing the waste materials. Due to short time frame given, long term performance such as durability of the soil sample could not be determine as it requires longer period of time.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 Characteristic of Soil in Malaysia

The soils in Malaysia are best classified into two groups; (1) the sedentary soils and (2) the soils of the coastal alluvial plains [3]. Each group is then further can be categorized into several main types of soils as following:

1. Kaolinitic clay materials
2. Fine-textured clay and clay loam soils
3. Peat and organic soils
4. Acid sulphate soils
5. Sandy soils (bris soils)

2.2 Stabilization Mechanisms

According to Bujang and Kalatari (2008) in their article on "Peat Soil Stabilization using OPC, Polypropylene Fibers, and Air Curing Technique" [2] :

Portland cement is composed of calcium-silicates and calcium-aluminates that, when combined with water, hydrate to form the cementing compounds of calcium-silicatehydrate and calcium-aluminate-hydrate, as well as excess calcium hydroxide. Because of the cementitious material, as well as the calcium hydroxide (lime) formed, portland cement may be successful in stabilizing both granular and fine-grained soils, as well as aggregates and miscellaneous materials. A pozzolanic reaction between the calcium hydroxide released during hydration and soil alumina and soil silica occurs in fine-grained clay soils and is an important aspect of the stabilization of these soils. The permeability of cement stabilized material is greatly reduced. The result is a moisture-resistant material that is highly durable and resistant to leaching over the long term.

Little and Barry (2000) in "Cementitious Stabilization" and Little(1999) " Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates" [3,4] stated that :

Stabilization occurs when the proper amount of lime is added to a reactive soil. Stabilization differs from modification in that a significant level of long-term strength gain is developed through a long-term pozzolanic reaction. This reaction can begin quickly and is responsible for some of the effects of modification. However, research has shown that the full term pozzolanic reaction can continue for a very long period of time - even many years - as long as enough lime is present and the pH remains high (above about 10). The results of stabilization can be very substantial increases in resilient modulus values (by a factor of 10 or more in many cases), very substantial improvements in shear strength (by a factor of 20 or more in some cases), continued strength gain with time even after periods of environmental or load damage (autogenous healing) and long-term durability over decades of service even under severe environmental conditions.

From these papers, it was clearly stated that proper amount of stabilizers are needed for an optimum strength of soil gained from the modification. These amount and proportion of stabilizers in combination is the main factor to the resulting engineering properties of soil. Therefore it is crucial to find the optimum content of OPC,PFA-Lime in this project.

2.3 Mixing and Testing Methods

Indianapolis Office of Geotechnical Engineering (Jan,2008) set the guidelines of "Design Procedures for Modifications and Stabilization" [5] for selecting the amount of stabilizer according to certain criteria.

> ...When the chemical stabilization or modification of sub-grade soils is considered as the most economical or feasible alternate, the following criteria should be considered for chemical selection based on index properties of the soils.
>
> 1. Chemical Selection for Stabilization.
>   a) Lime: If PI > 10 and clay content (2μ) > 10%.
>   b) Cement: If PI ≤ 10 and < 20% passing No. 200.
>
>   Note: Lime shall be quicklime only.
>
> 2. Chemical Selection for Modification
>   a) Lime: PI ≥ 5 and > 35 % Passing No. 200
>   b) Fly ash and lime fly ash blends: 5 < PI < 20 and > 35 % passing No. 200
>   c) Cement and/ or Fly ash: PI < 5 and ≤ 35 % Passing No. 200...(p. 5)

[6]Faisal Ali (2012), in his paper "Stabilization of Residual Soil" line up the testing method can be followed from the British Standard (BS) Code :

> Soil classification tests were being performed based on a combined sieving-sedimentation analysis with wet sieving and followed with a determination of fines particles by the hydrometer procedure as in accordance with BS 1377: Part 2. (p. 117)

and UCS Test can also be based on the BS Code:

> UCS specimens were prepared by static compaction after the respective MDD and OMC of the stabilized soils had been determined through standard compaction test earlier. The specimens were prepared in a 50 mm diameter by 100 mm height cylinder mould conforming to BS1924: Part 2 (p. 119)**.**

2.4 Testing Method

The laboratory tests are chosen and will be conducted to achieve the objectives of this study. As suggested by some researchers, two types of tests will involve in the laboratory tests: (1) Soil Classification Tests which are Atterberg Limit, Specific Gravity, Proctor Test, and Moisture Content test and (2) Soil Strength Test consists of California Bearing Ratio (CBR) and Unconfined Compression Test (UCT) [12].

2.5 Soil Classification

In general, there are two soil classification system; (1) AASHTO Classification System and (2) Unified Classification System. This project focusing to use the AASHTO Classification System, shows in Table 2.2, in classifying type of soil which to be used as sample.

Table 2.2: AASHTO Classification System [13]

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			*A-2*			
Group classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*
Sieve analysis (percent passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand			
General subgrade rating	Excellent to good						

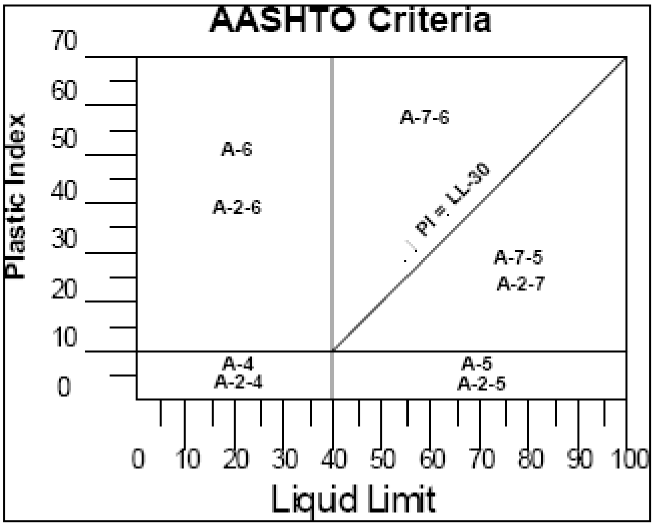


Figure 2.2: AASHTO Classification System [14]

To classify a soil according to the table, we must apply the test data from left to right. By process of elimination, the first group from the left into which test data fit is the correct classification. In addition, Figure 2.2 shows a plot of the range of the liquid limit and plasticity index for soils that fall in each group [13].

This classification system is based on the following criteria:

1. Grain size

a. Gravel: fraction passing the 75-mm sieve and retained on the No. 10 (2mm) US sieve.
b. Sand: fraction passing the No. 20 (2mm) U.S. sieve and retained on the No. 200 (0.075mm) U.S. sieve
c. Silt and clay: fraction passing the No. 200 U.S. sieve

2. Plasticity: the term silty applied when the fine fractions of the soil have a plasticity index of 10 or less. The term clayey is applied when the fine fractions have a plasticity index of 11 or more.

Liquid limit and plasticity index are two factors that are useful to know the swelling potential of the soil for large clay content. The various degrees of swelling capacities and the corresponding range of plasticity index are described in the Table 2.3 [15].

Table 2.3: Swelling Potential and Plasticity Index

Swelling potential	Plasticity index
Low	0-15
Medium	10-35
High	35-55
Very high	55 and above

2.6 Summary of Journals

NO	TITLE	AUTHOR	OBJECTIVE	REMARK
1	Soil stabilization for Pavements	Department of The Army, The Navy and The Air Force (October, 1994)	To understand the method of stabilizing using various stabilizers especially lime ad cement	Factors to be considered in choosing stabilizers discussed in this manual.
2	Peat Soil Stabilization, using Ordinary Portland Cement, Polypropylene Fibers, and Air Curing Technique	Behzad Kalatari and Bujang B.K. Huat (2008)	To understand the the stabilization mechanisms.	Stabilization using cement and lime. Mechanisms of Stabilizations, Structural Properties, UCS and CBR achieved discussed in these journals.
3	Cementitious Stabilization	Dallas N. Little, and Barry Stewart (2000)	To understand stabilization method using cement, reaction mechanisms, mix design and performance consideration.	
4	Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates.	Dallas Little (1999)	To understand Structural properties of the soil treated using lime.	
5	Design Procedures for Modification or Stabilization	Indianapolis Office of Geotechnical Engineering (2008)	To determine the mix design and selection of stabilizer in accordance to soil characteristics.	Method of classification of soil in order to find soil that meet the stabilizer (lime, OPC) suitability.

6	Stabilization of Residual Soil using Liquid Chemical	Ali Faisal (2012)	To understand testing method for soil classification and soil strength	Testing method according to BS Code and others.
7	Stabilization of Soil with Self-Cementing Coal Ashes	Scott M. Mackiewicz and Glen Ferguson (April, 2005)	To understand the possibility of improvement on sub-grade through stabilization	The Optimum range of lime and cement in stabilization, 3-7 % are stated in this journal.
8	Laboratory Manual			Testing will be done based on laboratory manual provided.

Table 2.1 summarized the journal and references on the literature review of this project.

Literature review includes the classification of soil, factors to be considered in stabilization, stabilization mechanisms, previous study on stabilization especially using lime and cement.

Mix Design, Testing Methods and Manual for chemical stabilization using lime and cement are also explained in these journals.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology of the research. The literature study was carried out in the early stage of the study to enhance the understanding in the scope of work. The summary of the literature review had been presented in chapter 2.

3.2 Flowchart of the Project

Figure 3.1, shows the process of the whole project until the project is completed.

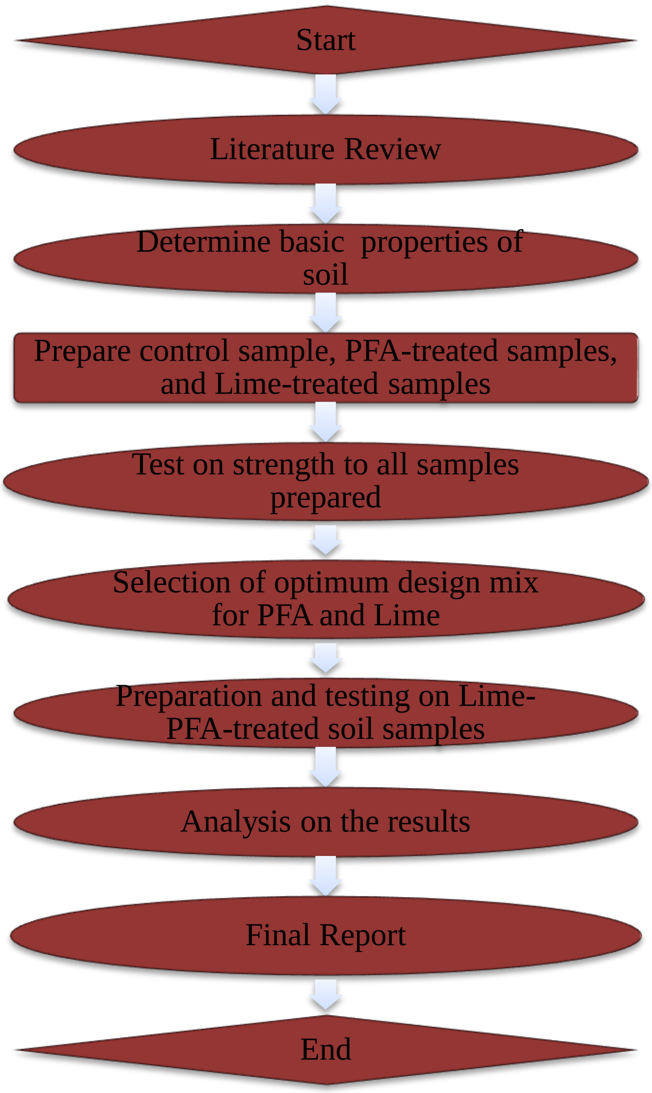


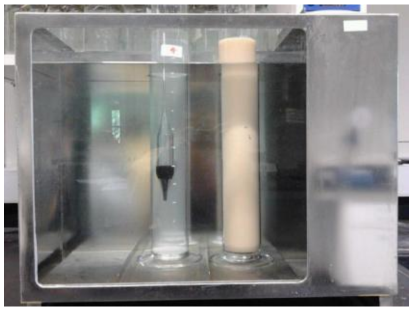
Figure 3.1: Overall methodology of the project

The process is mainly consists of two main parts: (1) paperwork which starting on the project title selection and literature review and (2) experimental and testing that are going to be involved by samples preparation and testing. These all process will be further explained in the next section.

3.3 Required Tests and Method of Experiment

TEST	PURPOSE	EQUIPMENT
Moisture Content	To determine the quantity of water contained in the soil samples.	• Drying oven • Moisture content tin(container) • Electronic balance  
Specific Gravity	The ratio of the density of soil to the density of water.	• Drying oven • A set of pycnometer • A glass rod • Electronic balance • A thermometer 

Atterberg Limit	To determine the Plasticity Index, PI (difference between Liquid Limit and Plastic Limit) PI = LL-PL	Plastic Limit • A flat glass plate • A spatula • A small bowl Liquid limit • A flat glass plate • A spatula • A big bowl • Metal cup • Cone Penetrometer 
pH Test	To determine the pH of the soil	• Soil Solution • pH meter (calibrated) 
Proctor Test	To determine Optimum Moisture Content at where soil is most dense and achieve its Maximum Dry Density.	• Proctor hammer • Proctor mould  

Sieve Analysis	To assess the particle size distribution (gradation) of the soil samples.	• Sieve with various opening sizes (63µm - 2 mm) • Sieve shaker • Electronic balance 
Hydrometer Test	To determine the particle size distribution of finer soil particles (size < 63 µm)	• Hydrometer • Measuring cylinder • Container • Stopwatch  
California Bearing Ratio (CBR Test)	To determine CBR value of soil which is the load-bearing capacity of a soil.	• CBR Apparatus • CBR mould 

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

In this chapter, all the results of the soil samples; control sample,OPC-treated, PFA-treated samples, Lime-treated samples and OPC-PFA-Lime-treated sample; were collected. Each of results is presented in brief and various form, either in table, chart or graph.

4.2 Basic Engineering Properties of Soil

There are some tests were carried out on the control soil sample. Table 4.1 summarized all the engineering properties obtained according to the tests.

Table 4.1: Summary of basic engineering properties for the control sample

No	Properties	Value
1	Moisture content	31.08%
2	Specific Gravity	2.77 Mg/m^3
3	pH	8.44
4	Atterberg Limit:	
	Plastic Limit	28.87 %
	Liquid Limit	48.50 %
	Plasticity Index	19.63 %
5	Particle distribution (BS sieve size)	Percentage passing (%)
	2.00mm	99.45
	1.18mm	97.41
	600µm	92.01
	425µm	87.77
	300 µm	78.85

	212 µm 150 µm 63 µm Pan	65.72 53.69 31.19 0
6	Soil Classification ASSHTO	A-7-6 (clayey soils)
7	Maximum dry density at optimum moisture content	1.72 g/cm^3 at 20.0% of water content

Based the result obtained, it is confirmed that the soil is under group of clayey soil as more than 50% of the soils of soil pass 150 µm. This describes how fine the soil is which fall under A-7-6 type of clay. Referring to the moisture content and plasticity index, the result of the test shows that the soil sample contains high plasticity as it have high amount of water. Referring to the Table 2.3, the result indicates that the soil is having medium swelling potential.

Other than that, based on the requirement stated in the literature review section 2.7, the properties of the soil confirm that it is suitable for the stabilization process. The PI obtained is more that the PI required. In addition, the pH value obtained shows that the soil is in alkalinity side which suitable for soil stabilization using PFA and Lime. If the soil is acidic, the acid content might damage the calcium content thus retard the stabilization process.

4.3 Results for Single Additive Mixture

4.3.1 Samples Treated with PFA

Proctor tests have been carried out to each of samples to determine the optimum moisture content at maximum dry density. The graph of moisture content-dry density relationship for each of PFA contents are plotted and attached in appendices. Table 4.2 summarizes the result of proctor tests that has been carried out for each design mix.

Table 4.2: Maximum dry density and optimum moisture content at different percentage of PFA

Percentage of PFA content in mixture (%)	Maximum dry density (g/cm^3)	Optimum moisture content (%)
14	1.72	13.3
15	1.75	16.0
16	1.77	16.5
17	1.82	14.0

From the range of combination of PFA content tried as in table above, it was found that the dry density of has been increased linearly with the percentage of PFA added. Besides, the dry density is greater than the untreated soil. In this case, it could be assumed that the PFA had probably filled air voids within soil. As more PFA content added, more voids are being filled with PFA and this had reduced the volume of void inside the soil body subsequently increased the dry density. Other than that, the results show that, in overall, the moisture content of treated soils is lesser than the treated soil. This can be explained, possibly, in term of the hydration rate of PFA which it serves as a drying agent. Although it has slower hydration rate compared to other materials such as lime, small amount of heat always generated during mixture of PFA content in soil sample resulted in immediate drop on moisture content.

For unsoaked condition, the test was carried out immediately after compaction. The graph, Figure 4.1, describes the result of the CBR number obtained for mixtures with PFA contents.

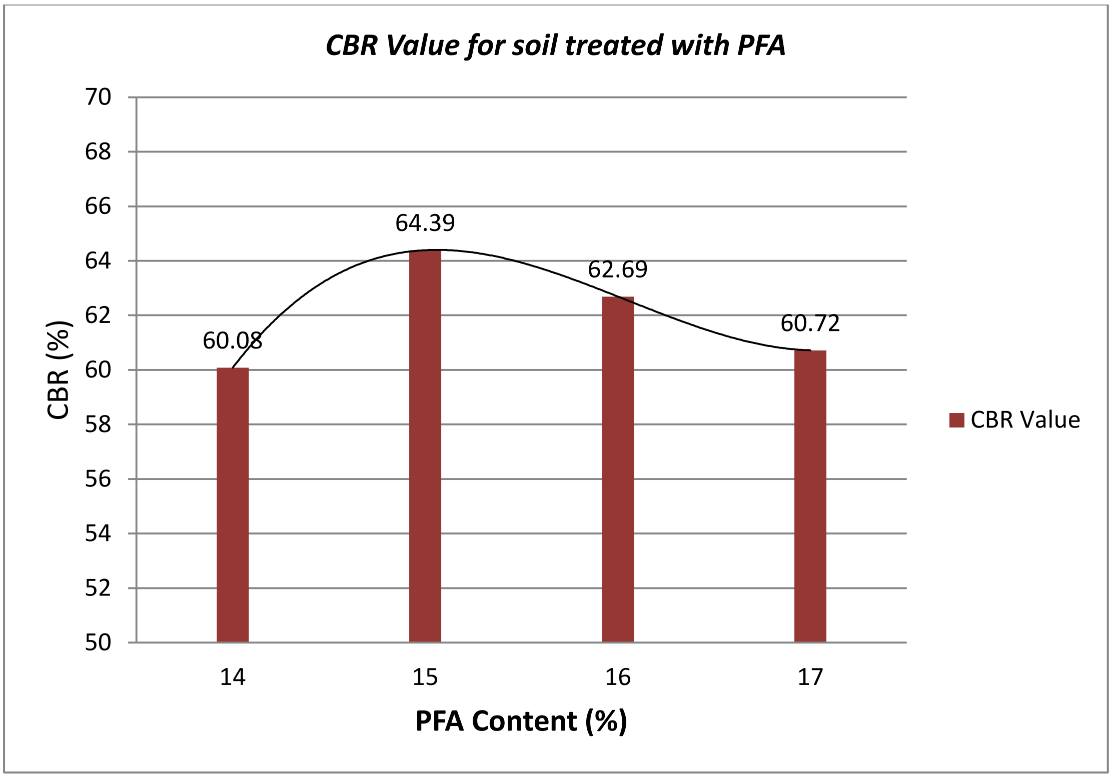


Figure 4.1: Graph of CBR test for PFA content

In general, PFA does improve the strength of the mixture. The significant increment is about 9-15% of the original strength from parent soil. However, as the PFA content increased, the strength of the mixture decreased. The excess content of PFA might have affected the cementation process or the flocculation of the soil particles therefore caused the decline of the performance. The results show that PFA content of 13% has the greatest strength than the others percentage. Meaning that, 15% is the optimum design mix for PFA content.

4.3.2 Samples Treated with Lime

Proctor tests have been carried out to each lime-treated sample to determine the optimum moisture content at maximum dry density. The graphs of moisture content-dry density relationship each of lime contents are plotted and attached in appendices. Table 4.3 summarizes the result of proctor tests that has been carried out for each design mix.

Table 4.3: Maximum dry density and optimum moisture content at different percentage of Lime

Percentage of Lime	Maximum dry density (g/cm^3)	Optimum moisture content (%)
3	1.64	17.6
5	1.66	16.7
7	1.66	19.7

It is observed from Table 7 that the increment of Lime content in the soil samples resulted in maximum density to be decreased in average or 1.66g/cm^3 which lesser compared to dry density of the untreated soil. We could assume that the lime content was not only filled up air voids within the soils body but it also replaces some part of the soil aggregates. Because of lime has lesser specific gravity value, it thereby decreased the dry density of the total mixture. On the other hand, values of optimum moisture content also decreased in overall with the additional of Lime content. This happened probably because of hydration process occurred during the pozzolanic reaction when the lime content being mixed with water contrasted with untreated soil with no heat generated during mixing. The heat produced consequently consumed small amount of water before the mixture get stabilized.

For unsoaked condition, the test was carried out immediately after compaction. The next graph, Figure 4.2, describes the result of the CBR number obtained for mixtures with lime contents.

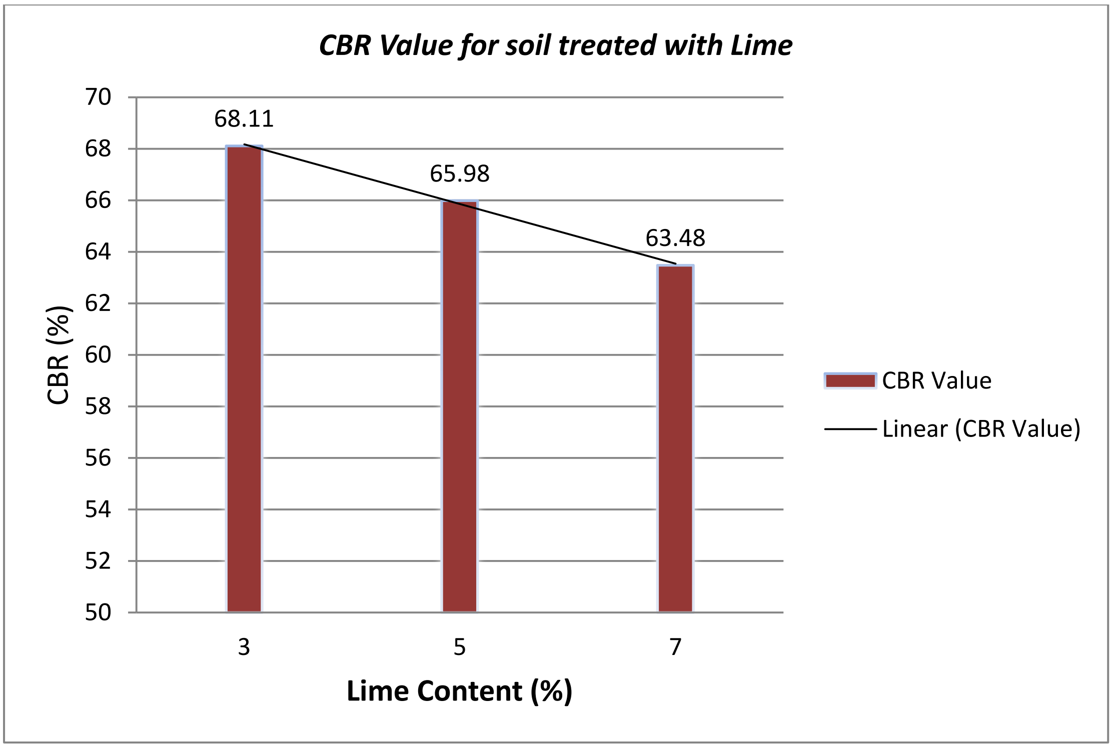


Figure 4.2: Graph of CBR test for lime content

In general, lime does improve the strength of the mixture. From those three mixes, the significant increment is about 14-23% of the original strength from parent soil. It is quite good improvement in comparison with PFA which has lower increment. However, as the lime content increased, more than 3%, the strength of the mixture decreased. The excess content of lime might have affected the cementation process or the flocculation of the soil particles therefore caused the decline of the performance. The results show that PFA content of 3% has the greatest strength than the others percentage. Meaning that, 3% is the optimum design mix for PFA content.

4.3.2 Samples Treated with OPC

Proctor tests have been carried out to each OPC-treated sample to determine the optimum moisture content at maximum dry density. The graphs of moisture content-dry density relationship each of lime contents are plotted and attached in appendices. Table 4.3 summarizes the result of proctor tests that has been carried out for each design mix.

Table 4.2: Maximum dry density and optimum moisture content at different percentage of PFA

Percentage of PFA content in mixture (%)	Maximum dry density (g/cm^3)	Optimum moisture content (%)
11	1.71	13.9
12	1.75	17.1
13	1.78	16.2
15	1.80	13.9

For OPC, the percentage of OPC used in mix is ranged from 11% to 15% and same test will be done to obtain the optimum percentage

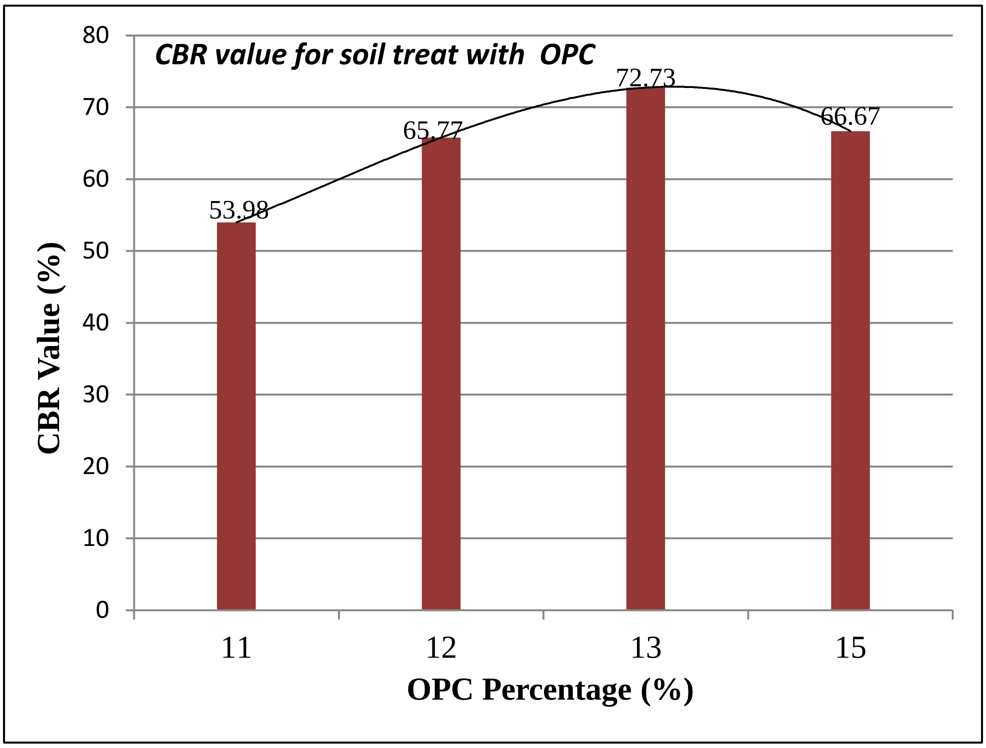


Figure 4.2: Graph of CBR test for OPC content

4.3.3 Selection for Optimum Design Mix

Optimum design mix is selected based on the percentage content of the additive which gives the highest strength or the highest rate of performance under CBR test. Based on the data obtained, it is convinced that the optimum design mix for OPC,PFA and lime are 13%,15% and 3% respectively. This data then been used for the sample preparation of OPC-PFA-lime-treated sample.

4.4 Results for Combination Additive Mixture

4.4.1 Unsoaked CBR Test

For unsoaked condition, the test was carried out immediately after compaction. Table 4.4 explains the result of the CBR number obtained for mixtures of both stabilizers.

Table 4.4: Result of CBR test for combination additive mixture (unsoaked)

Mixture	CBR (%)	Dry Density (g/cm^3)
Control sample	55.98	1.72
13%OPC+15% PFA + 3% Lime	62.88	1.58

The result shows that combination of OPC, PFA and lime does increase the strength of mixture compared to the soil without any treatment. However, by referring to single additive mixture, the strength is lower compared to those mixtures with treatment of any additive. This happened might be due to incorrect composition of additives which then affected the performance of the mixture when it was measured immediately after compacting effort. On top of that, the combination is still successful and effective in stabilizing the soil.

4.4.1 Soaked CBR Test

Soaked condition had been performed to determine the effect of moisture content on the performance of the mixture prepared. As the sample were immersed in water, it is thought that the moisture content of the mixture will increased and this would lead to reduction of the mixture performance. Table 4.5 shows the result for both control and combination sample (PFA-Lime treated).

Table 4.5: Results of CBR test for combination additive mixture (soaked)

Mixture	CBR (%)
Control sample	25.5
13%OPC+15% PFA + 3% Lime	89.8

For control sample, the strength is far lesser than what is obtained in unsoaking condition. The strength is 25.5% which is half of the strength at optimum moisture content. This result shows that the moisture content is really affecting the performance of the soil. Without any treatment, the soil would likely to fall under poor performance when large amount of water being soaked up. On top of that, this might also signifies that the soil is able to absorb large quantities of water which characteristic is not good to be used as construction material.

On the other hand, OPC-PFA-lime-treated sample demonstrates that large increment of strength which in contrast with the mixture measured without soaking. It is assumed that, after 4 of soaking, pozzolanic reactivity and cementation process most likely caused considerable improvement in interlocking of particles thus increased the performance of the mixture.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, it is confirm that the soil sample to be used in this project is clayey soil based on the classification according to ASSHTO. The soil is also fit for chemical stabilization using OPC, lime and OPC based on the PI requirements and particle size distribution of the soil sample.

The optimum percentage of lime obtained is 3% and the optimum percentage OPC is 13% and that for PFA is 15%. Both PFA, lime and OPC are able to improve the strength of the soil however the performance of the combination in term of strength is not as good as the performance of single additive. Even though, the combination is still able improve the strength of the soil in term of strength. There might be improvement to soil other than the CBR strength and in other to determine it, this project can be subjected to further research.

Therefore, it can be conclude that it is suitable or compatible to use the combination of stabilizers in soil stabilization.

5.2 Recommendation

I recommend that further research regarding soil stabilization, appropriate curing time must be provided after mixing before running the tests in order to make sure that the stabilizations is given enough time to take part.

I also recommend that different amounts of each stabilizer be used in a combination blend, one way of achieving this is by trial and error. This will help in making sure that the blend is performing at it best with the right amounts of each soil stabilizer.

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APPENDICES

APPENDIX A:

Details of Lab Testing for Soil Basic Properties

Appendix A1: Moisture Content

Container (sample)No.	**1**	**2**	**3**
Mass of wet soil + Container (g)	55.67	53.39	57.34
Mass of dry soil + container (g)	46.78	45.69	48.69
Mass of container (g)	18.55	20.50	20.52
Mass of moisture (g)	8.89	7.79	8.65
Mass of dry soil (g)	28.23	25.10	28.17
Moisture content (%)	31.49	31.04	30.71
Average moisture content (%)		**31.08**	

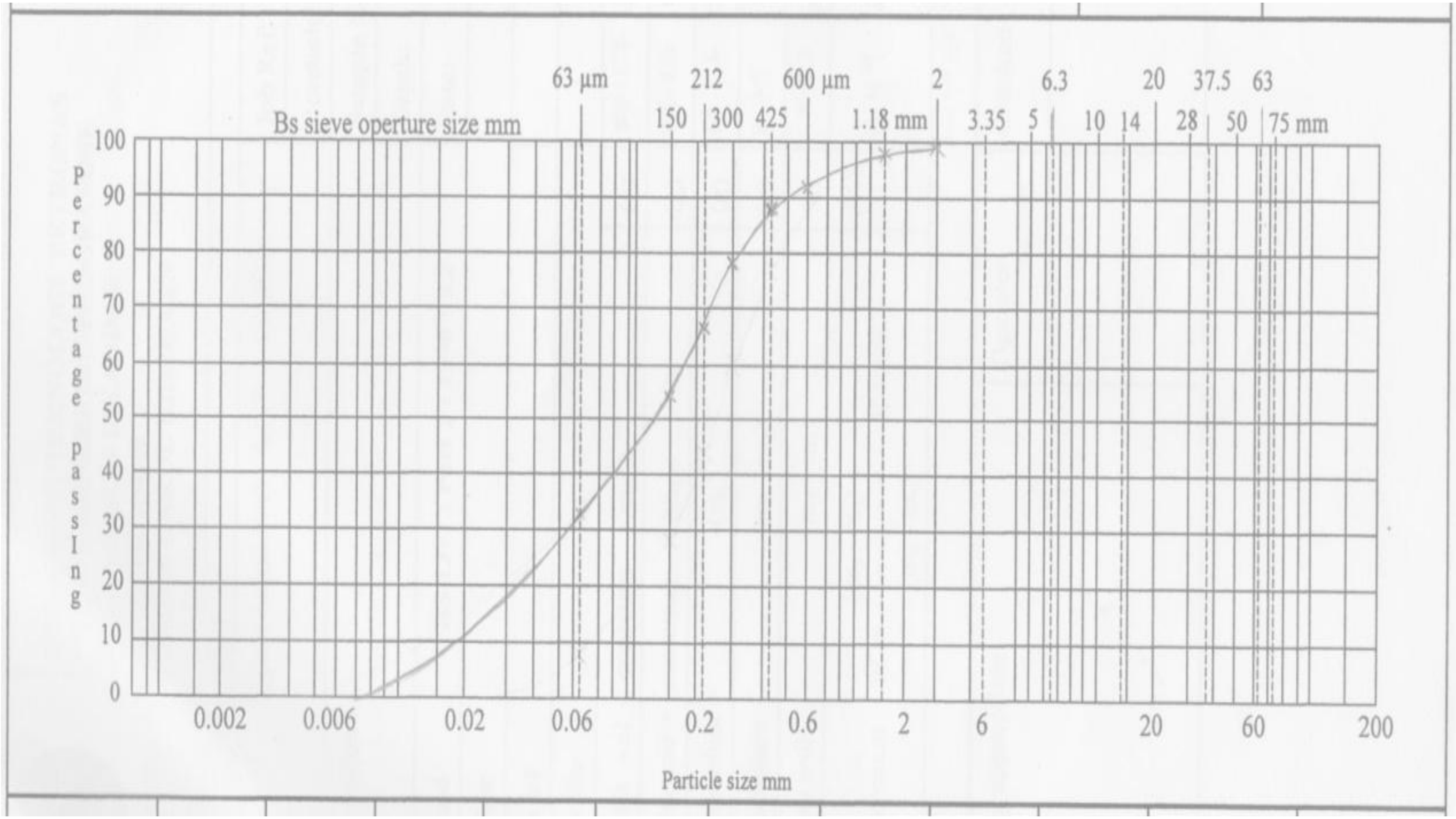
Appendix A2: Sieve Analysis Test

Sieve No	**Opening (mm)**	**Mass Retained (g)**	**% retained**	**Cummulative % Retained**	**% passing**
10	2.00	0.82	0.55	0.55	99.45
16	1.18	3.01	2.04	2.59	97.41
30	0.600	7.96	5.40	7.99	92.01
40	0.425	6.25	4.24	12.23	87.77
50	0.300	13.13	8.92	21.15	78.85
70	0.212	19.34	13.13	34.28	65.72
100	0.150	17.72	12.03	46.31	53.69
	0.063	33.13	22.50	68.81	31.19
Pan		46.21	31.39	100.00	0
Total		**147.57**	**100.0**		

Percentage of loss = [(150.0g - 147.57g) / 150.0g] * 100%

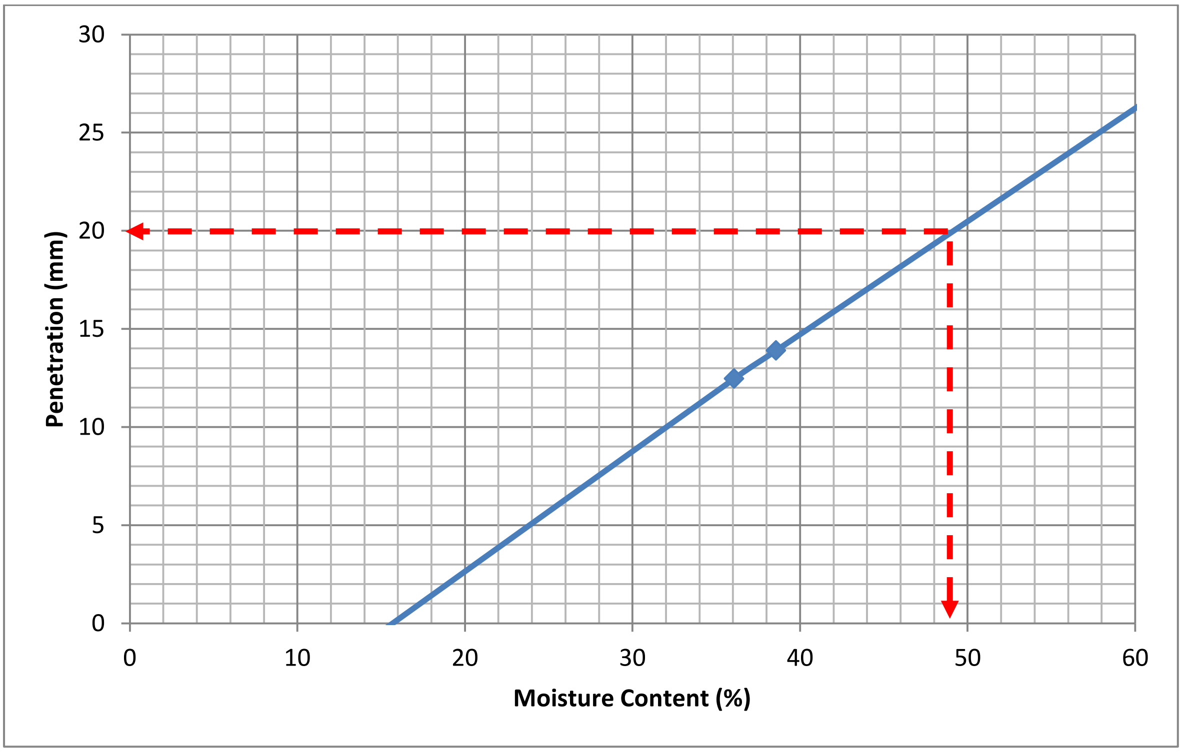
= **1.62%** therefore acceptable.

Appendix A3: Particle Size Distribution Chart



Appendix A4: Atterberg's Limit Test

Test No	1	2
Average Penetration (mm)	12.47	13.9
Container No.	1	2
Mass of wet soil + Container (g)	44.38	55.63
Mass of dry soil + container (g)	38.02	46.63
Mass of container (g)	20.39	23.30
Mass of moisture (g)	6.36	9.00
Mass of dry soil (g)	17.63	23.33
Moisture content (%)	36.08	38.58



Liquid Limit (LL) = 48.5% (at 20mm penertration)

Appendix A5: Plastic Limit and Plasticity Index

Test No	1	2	3	4
Mass of wet soil + Container (g)	28.63	28.58	28.29	28.91
Mass of dry soil + container (g)	28.90	26.89	26.49	27.15
Mass of container (g)	20.48	21.09	20.57	21.08
Mass of moisture (g)	1.73	1.69	1.80	1.76
Mass of dry soil (g)	6.42	5.80	5.92	6.07
Moisture content (%)	26.95	29.14	30.41	28.99
Average of moisture content (%)	**28.87**			

Liquid Limit (LL) = 48.5%

Plastic Limit (PL) = 28.87%

Plasticity Index (PI) = LL – PL = 19.63% ##

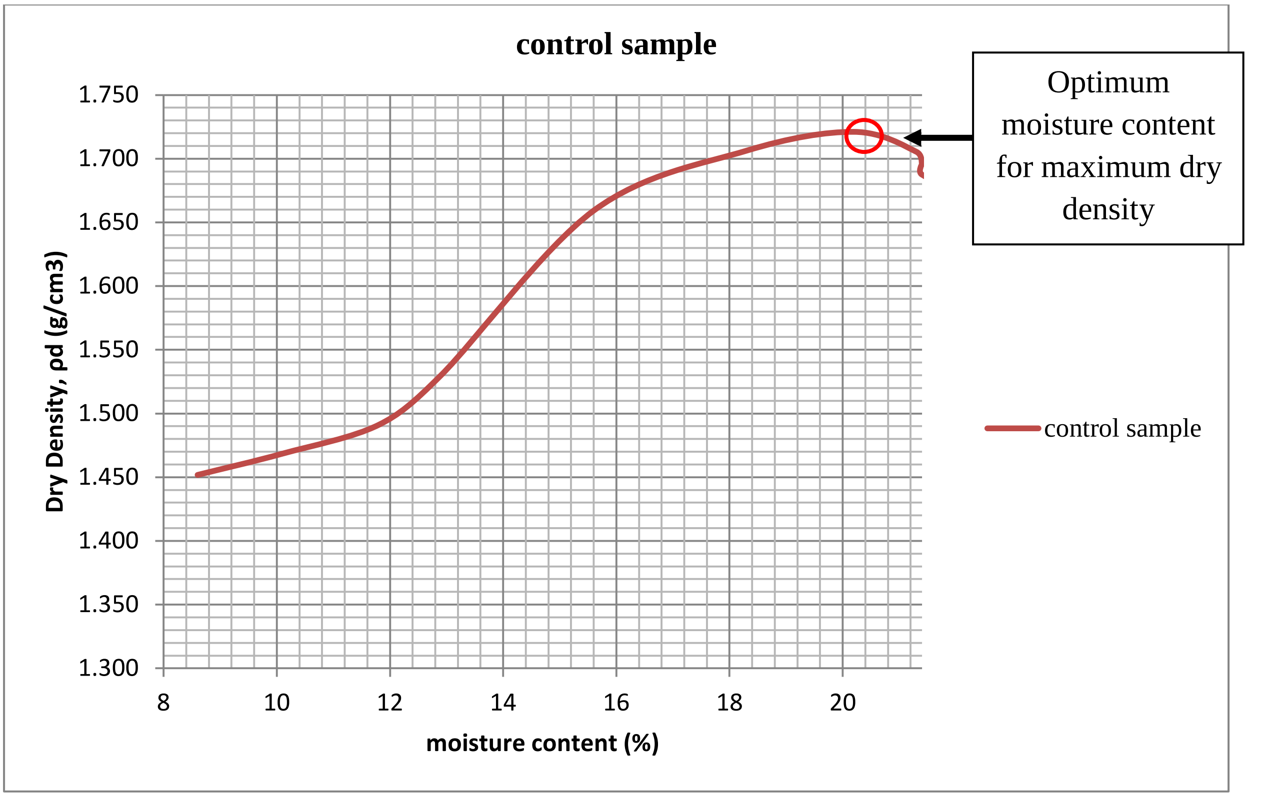
Appendix A6: Specific Gravity of Soil

Jar No.	Unit	1	2
Mass of jar + gas jar + plate + soil + water (m3)	(g)	1718.9	1722.1
Mass of jar + gas jar + plate + soil (m2)	(g)	934.5	936.2
Mass of jar + gas jar + plate + water (m4)	(g)	1464.7	1464.7
Mass of jar + gas jar + plate (m1)	(g)	534.5	536.2
Mass of soil (m2-m1)	(g)	400.0	400.0
Mass of water in full jar (m4-m1)	(g)	930.2	928.5
Mass of water used (m3-m2)	(g)	784.4	785.9
Volume of soil particles (m4-m1)-(m3-m2	ML	145.8	142.6
Particle density, Ps	Mg/m^3	2.74	2.81
Average value	**Mg/m^3**	**2.77**	

APPENDIX B:

Details Result of Proctor Tests

Appendix B1: Moisture content and dry density relationship for control sample.



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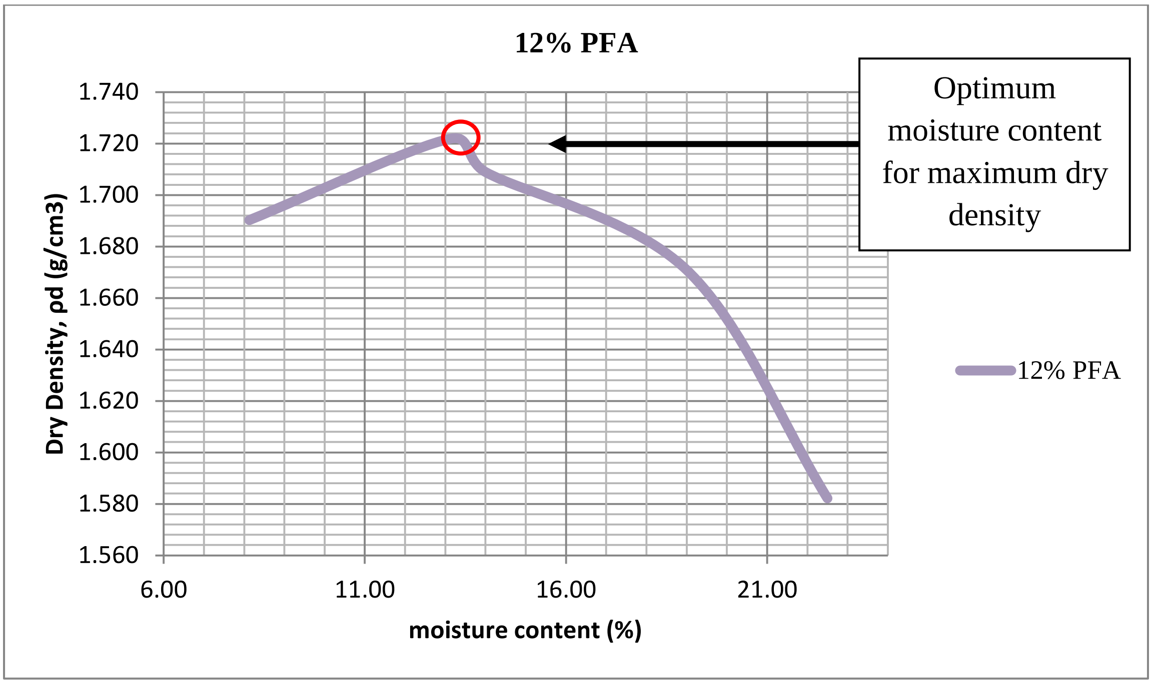
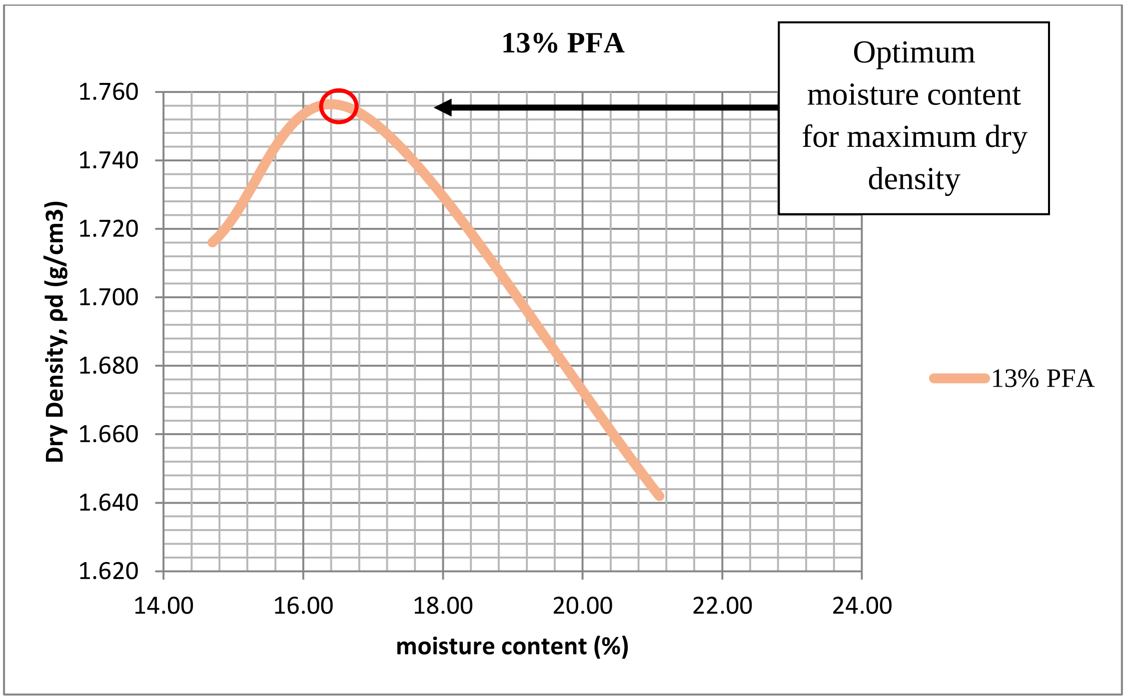
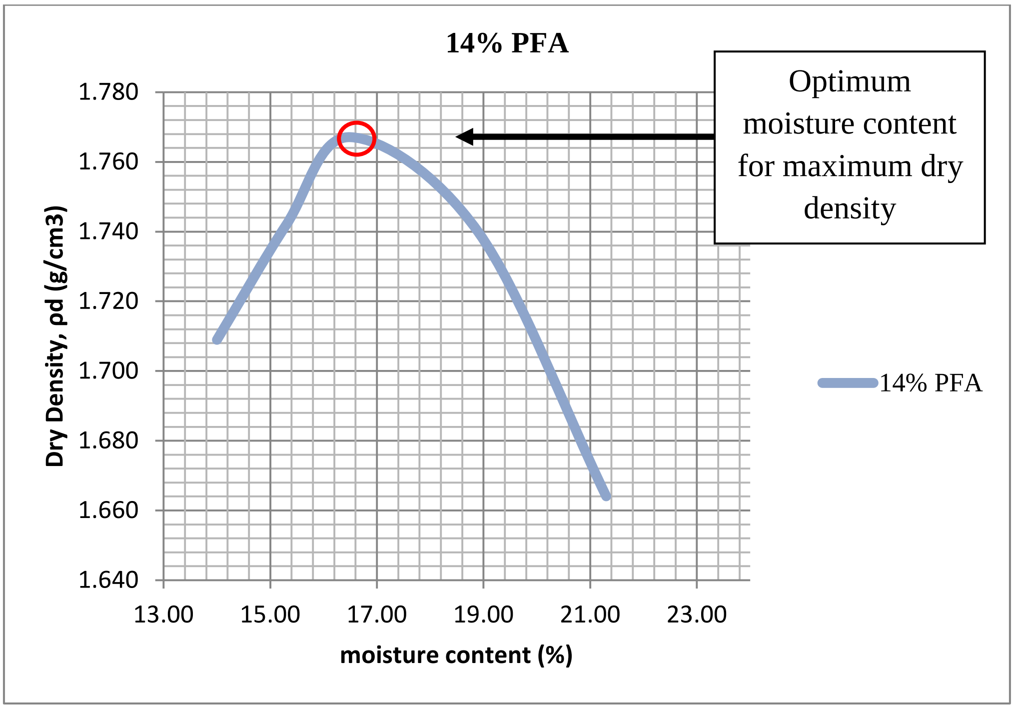
Appendix B2: Moisture content and dry density relationship for 12% PFA content.



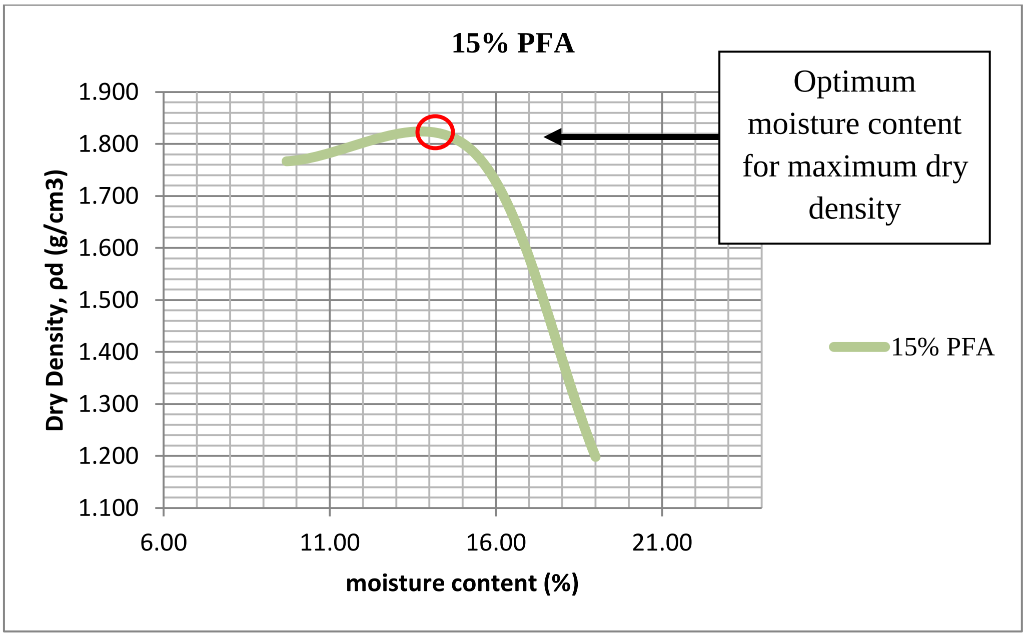
Appendix B3: Moisture content and dry density relationship for 13% PFA .content



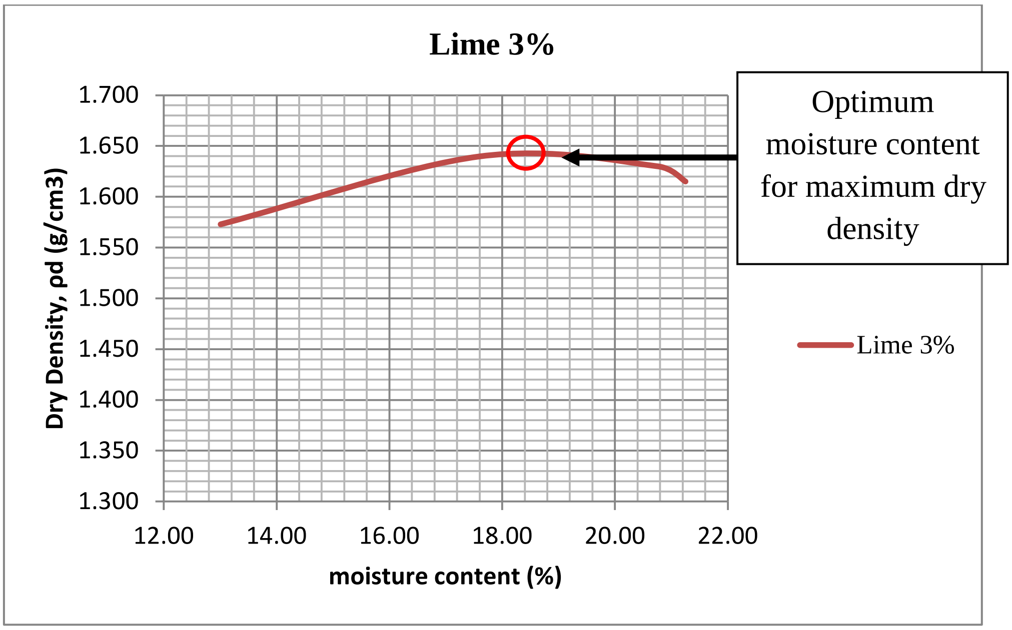
Appendix B4: Moisture content and dry density relationship for 14% PFA .content



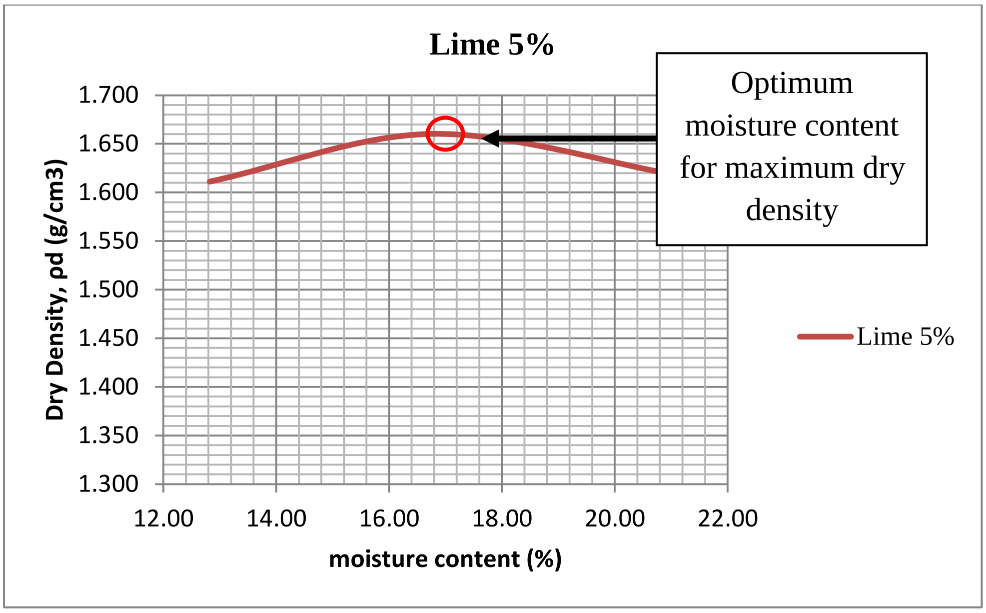
Appendix B5: Moisture content and dry density relationship for 15% PFA .content



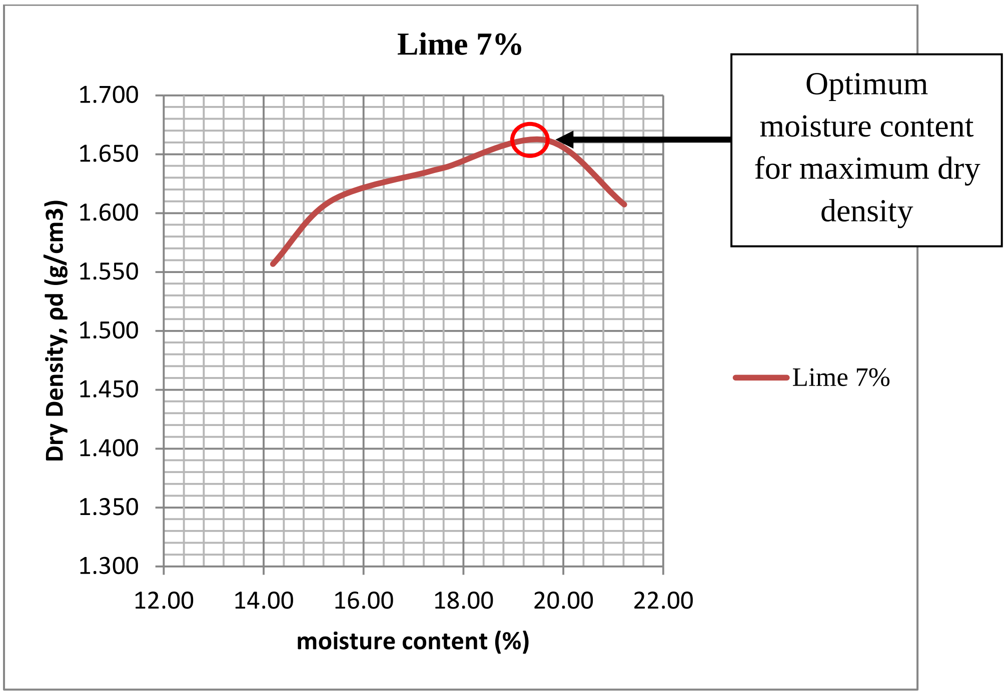
Appendix B6: Moisture content and dry density relationship for 3% Lime .content



Appendix B7: Moisture content and dry density relationship for 5% Lime .content

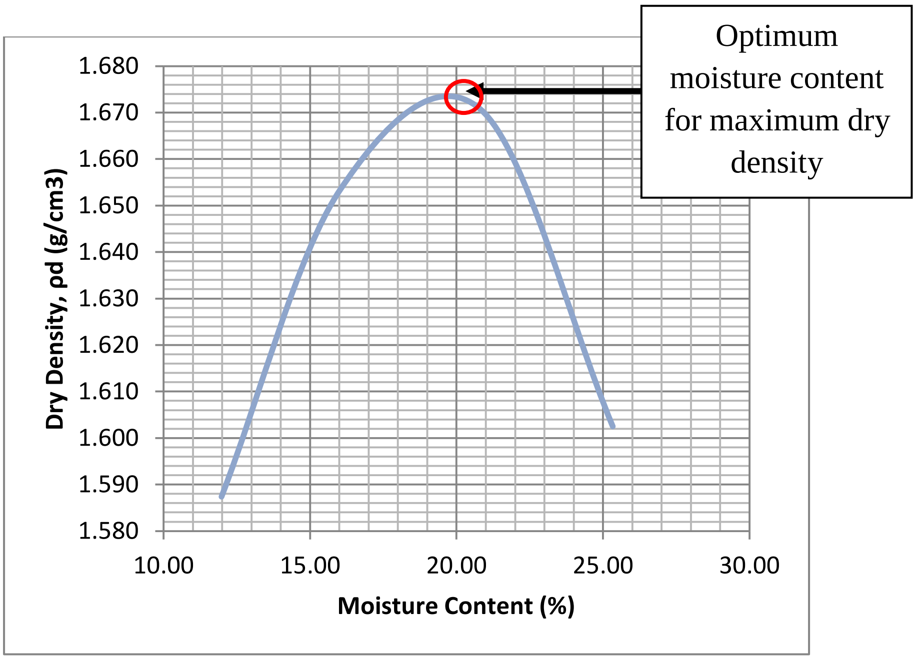


Appendix B8: Moisture content and dry density relationship for 3% Lime .content

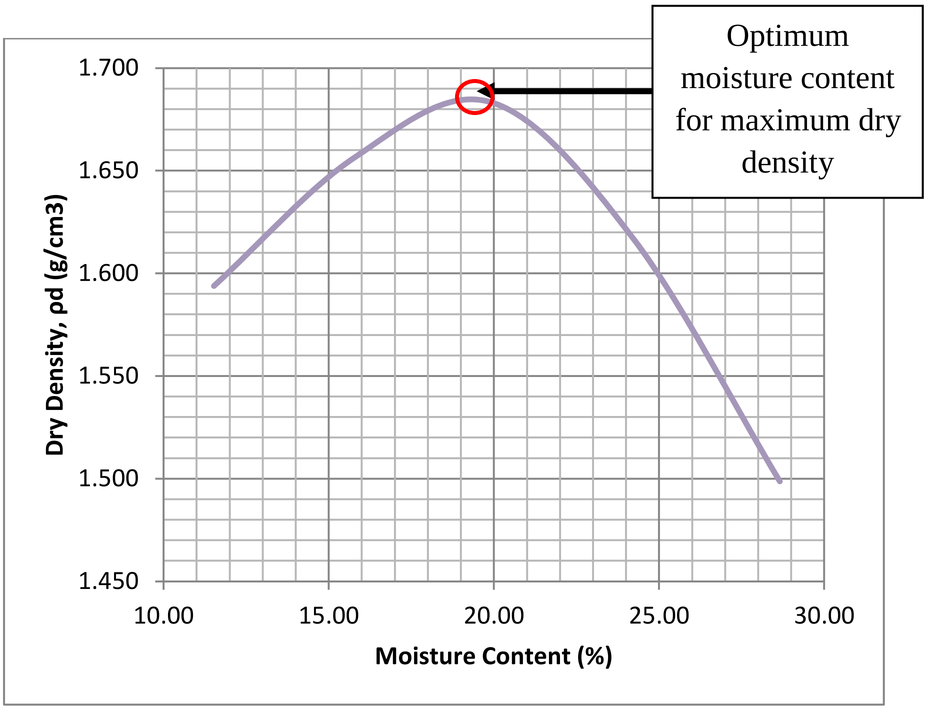


Appendix B2: Optimum Moisture Content of OPC Mix

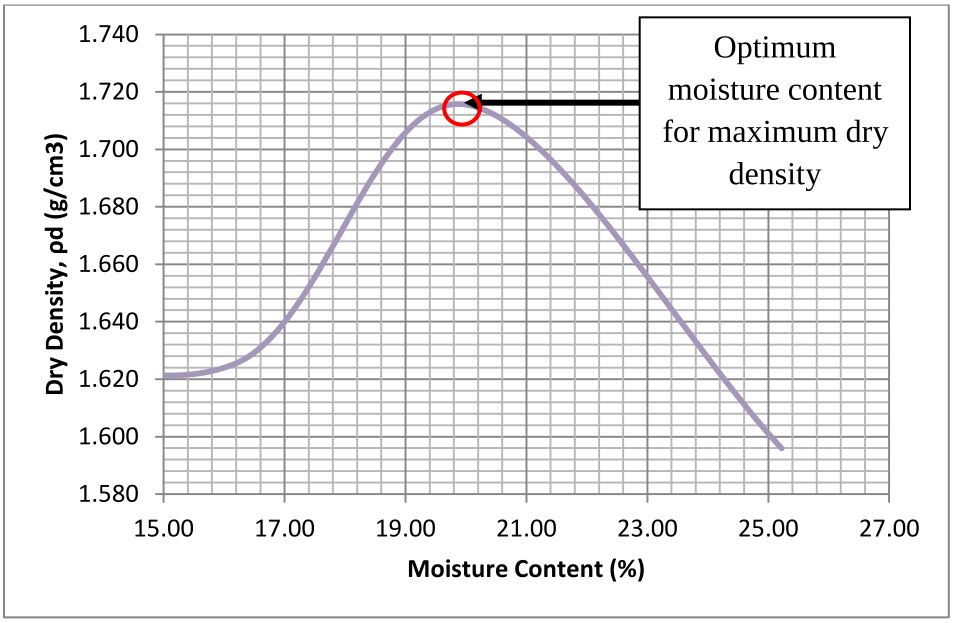
<u>11% Cement</u>



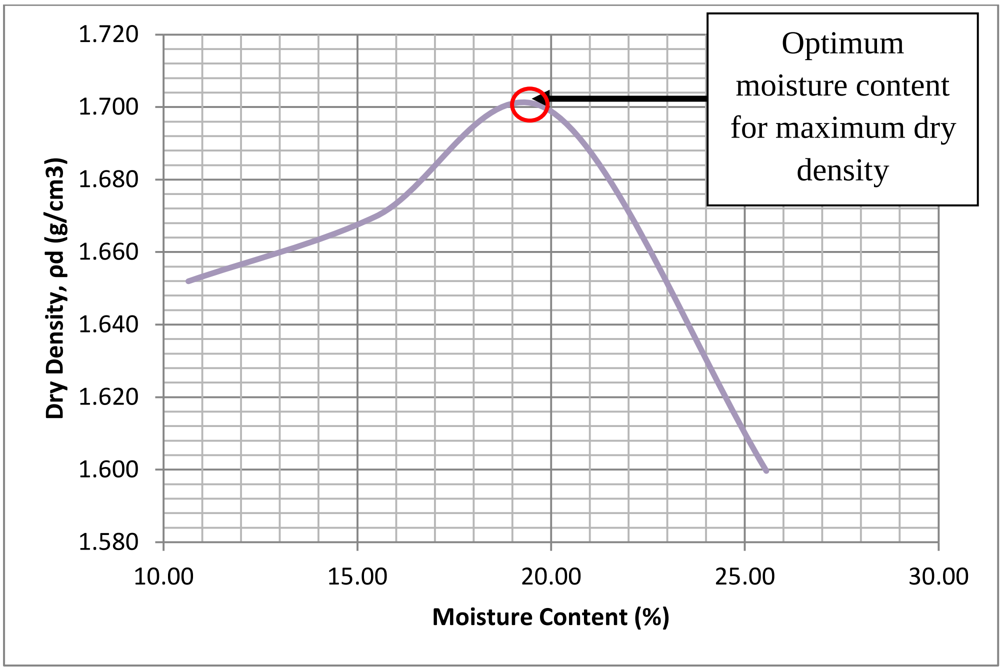
12% Cement



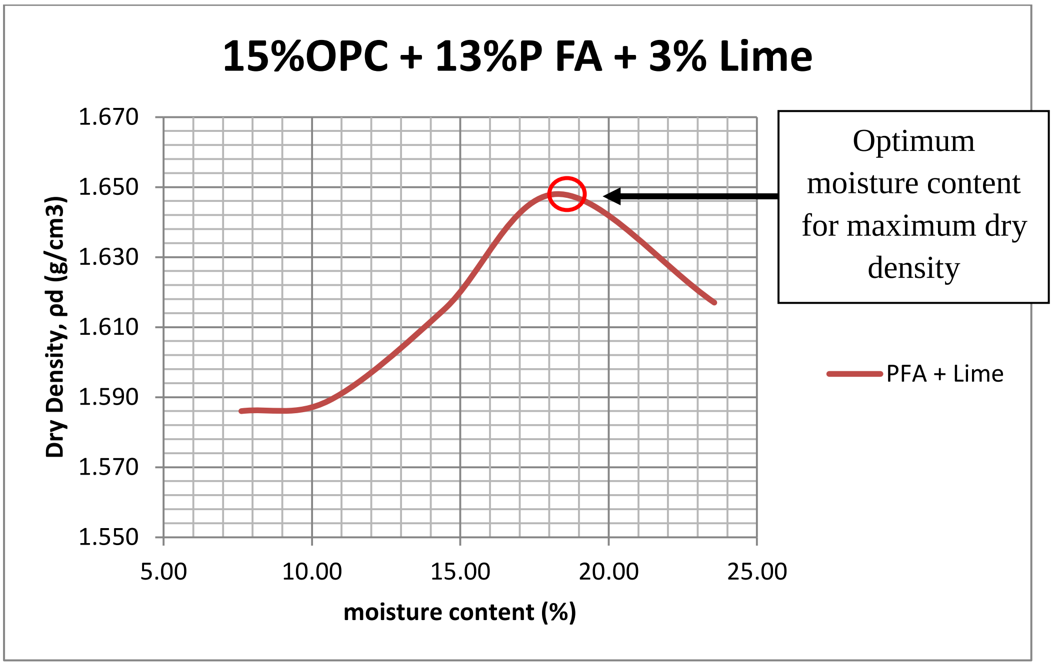
13% Cement



15% Cement

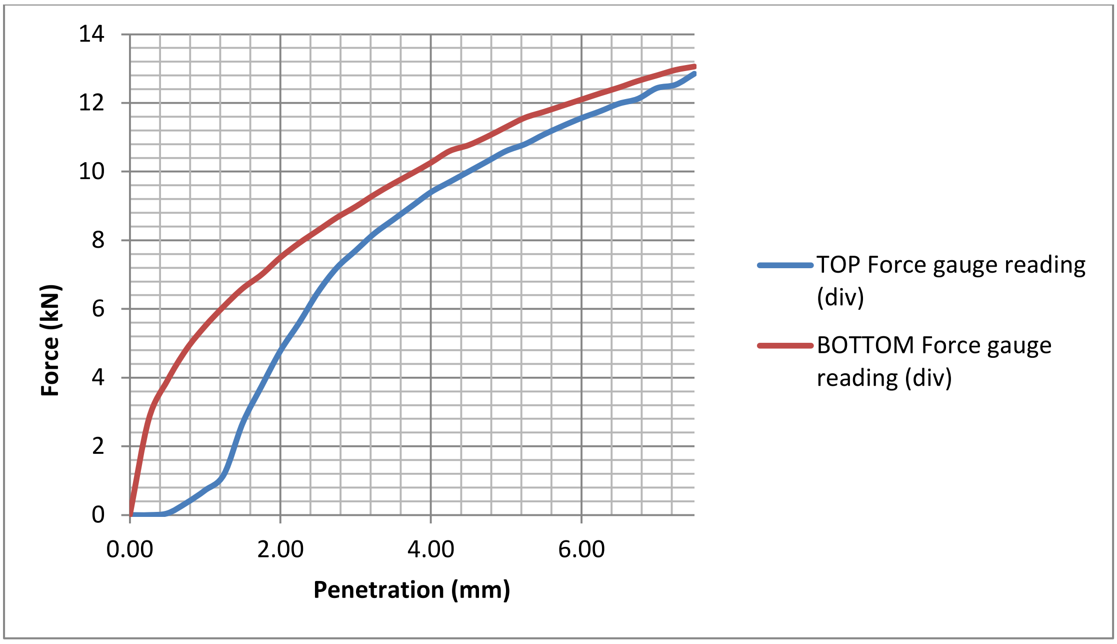


Appendix B9: Moisture content and dry density relationship for Combination additives mixture

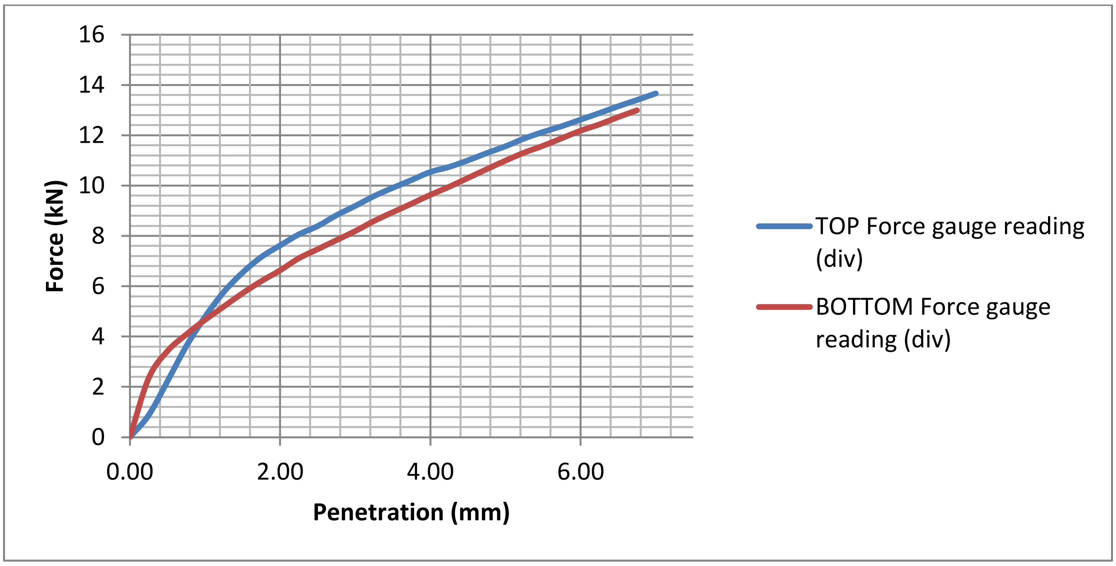


APPENDIX C:
Details Result of CBR Tests

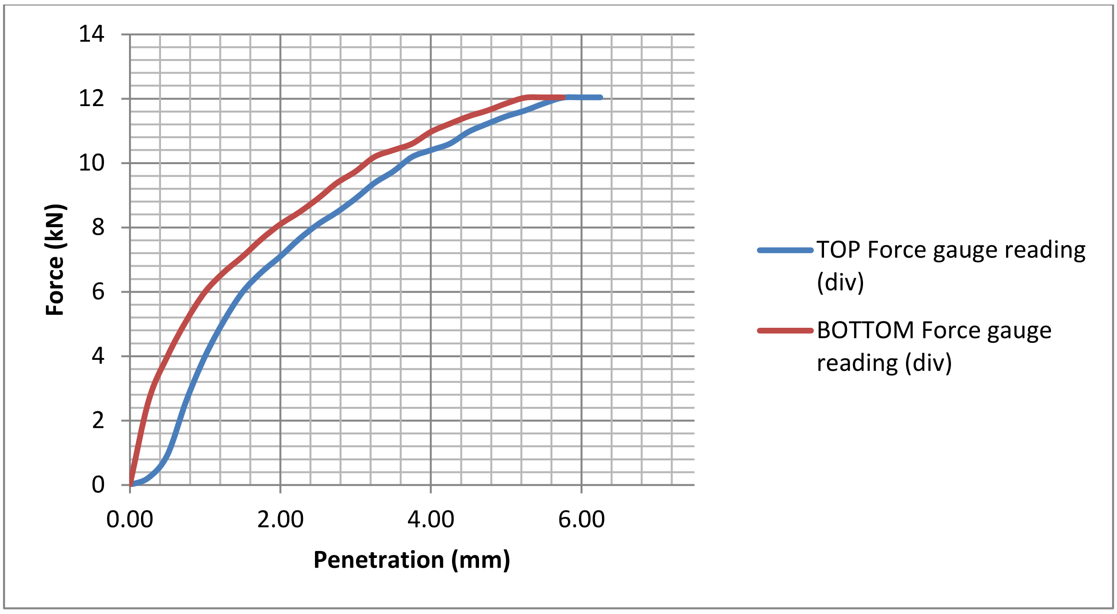
Appendix C1: Performance under unsoaked CBR testing for control sample



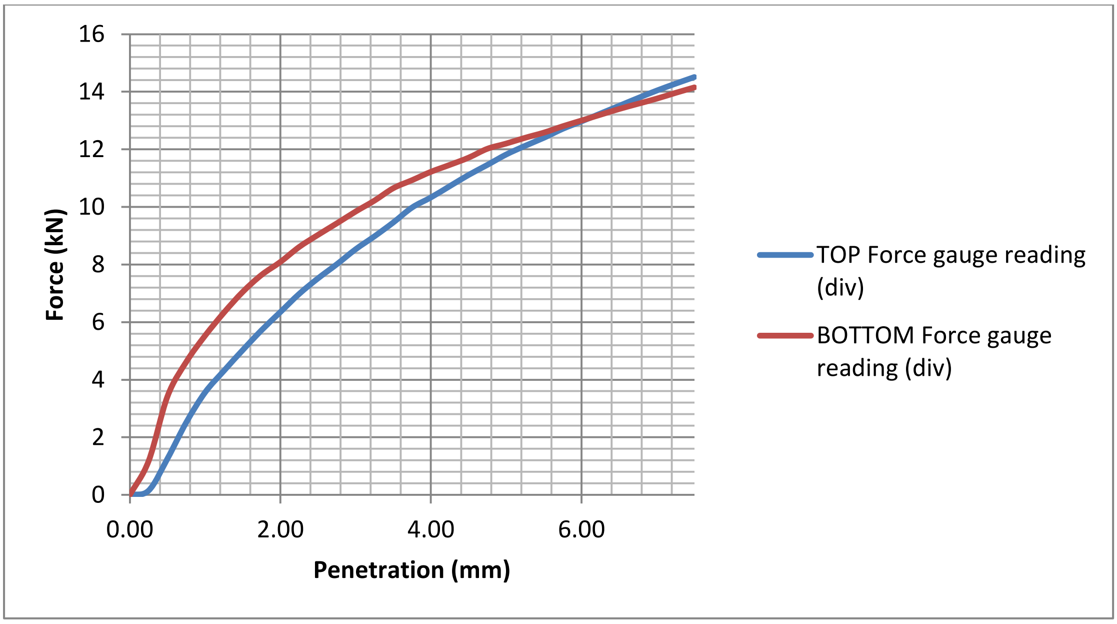
Appendix C2: Performance under unsoaked CBR testing for 12% PFA content.



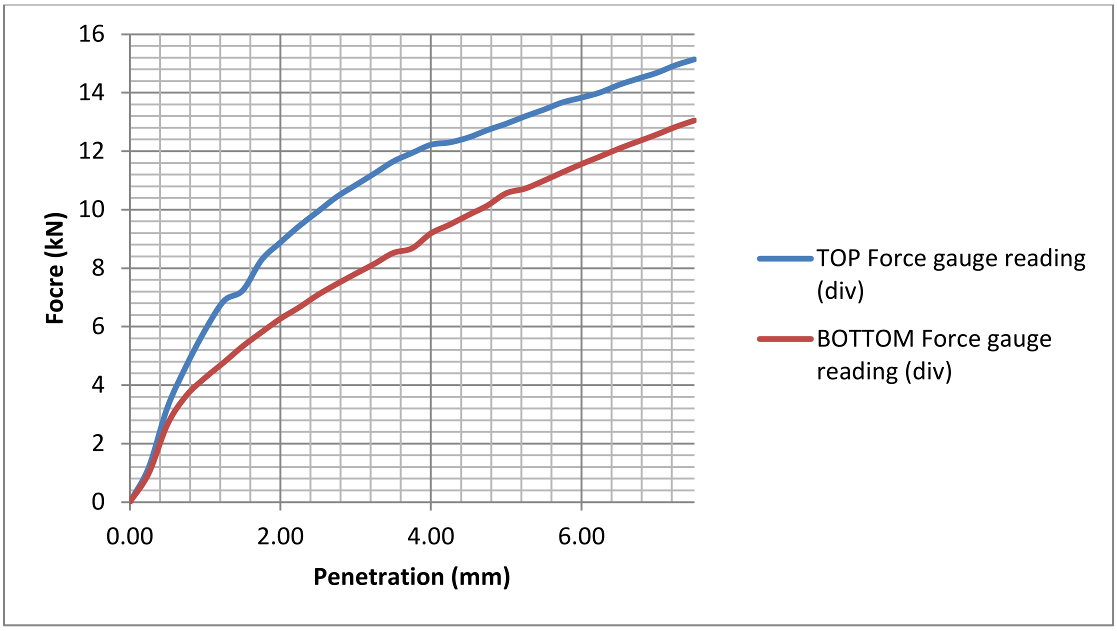
Appendix C3: Performance under unsoaked CBR testing for 13% PFA content.



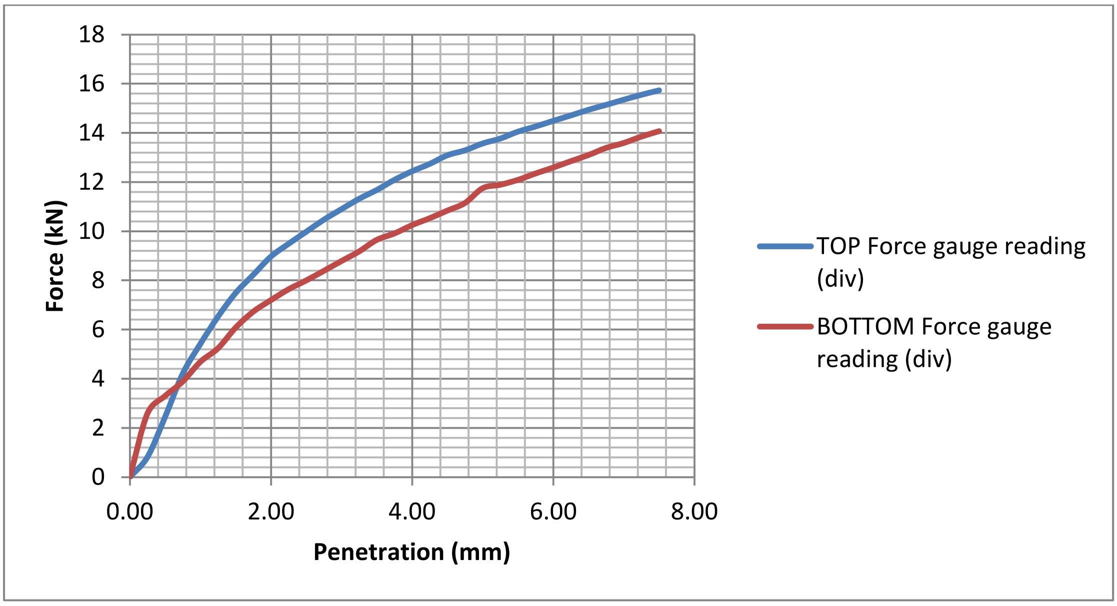
Appendix C4: Performance under unsoaked CBR testing for 14% PFA content.



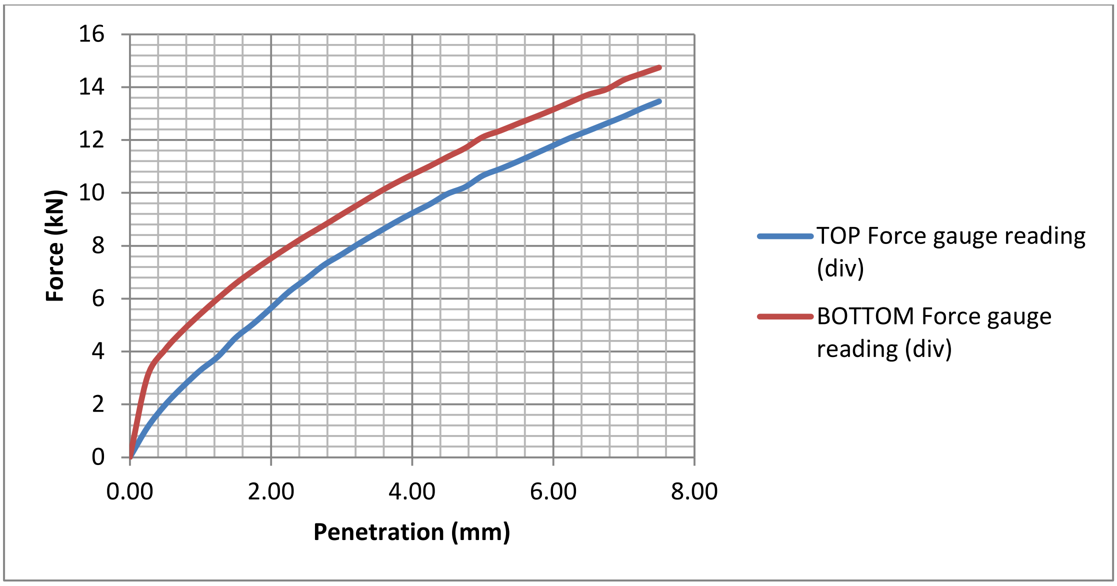
Appendix C5: Performance under unsoaked CBR testing for 15% PFA content.



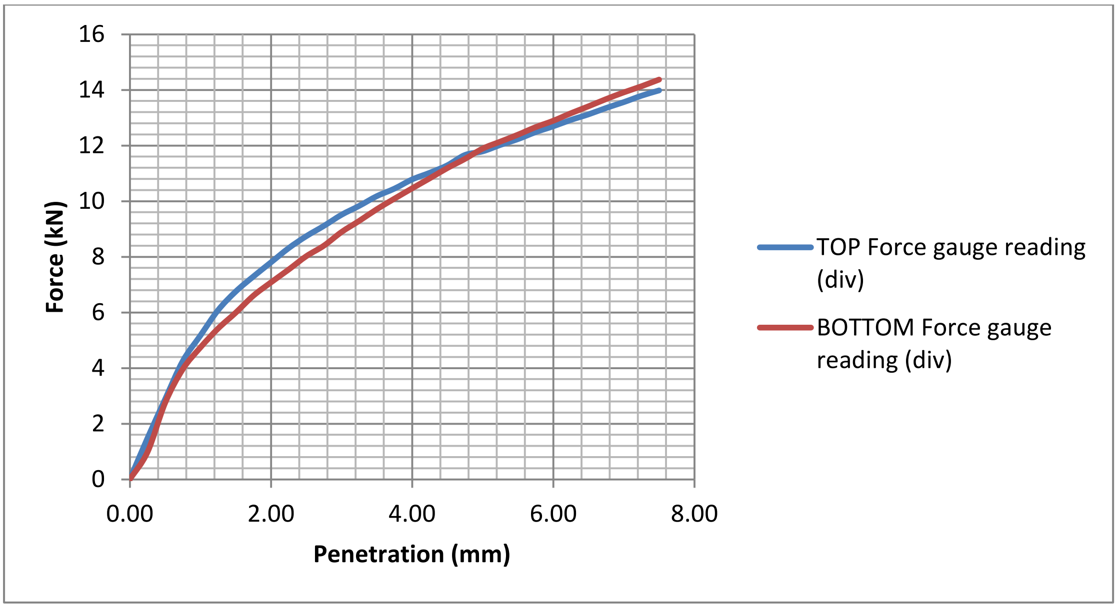
Appendix C6: Performance under unsoaked CBR testing for 3% Lime content.



Appendix C7: Performance under unsoaked CBR testing for 5% Lime content.

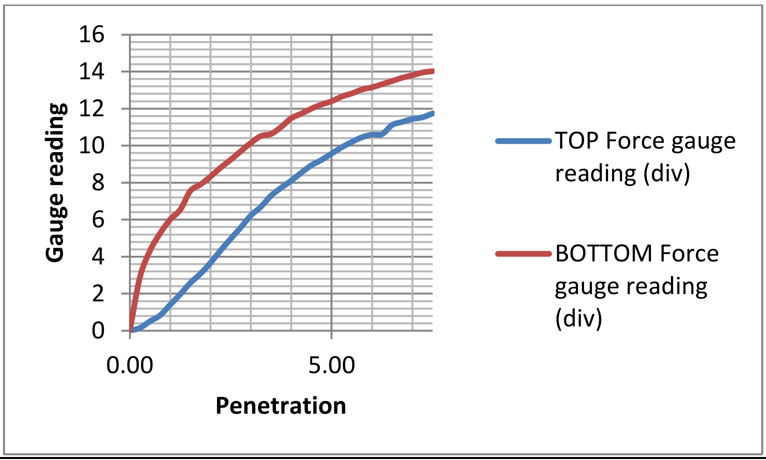


Appendix C8: Performance under unsoaked CBR testing for 7% Lime content.

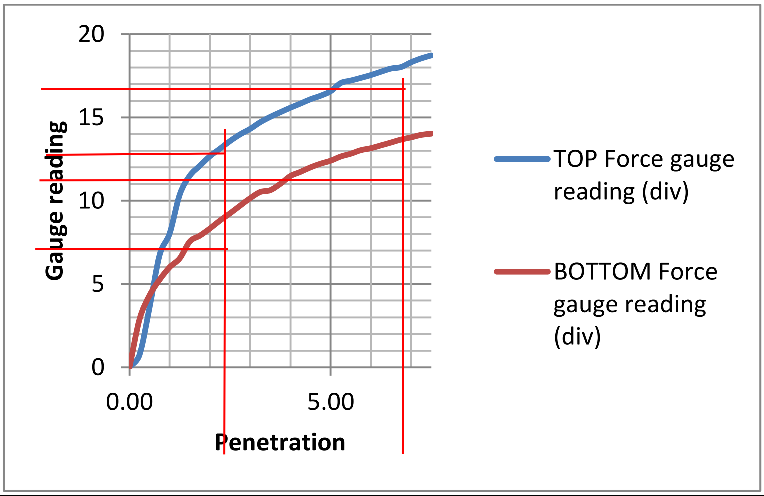


Appendix C2 : CBR of OPC Mix

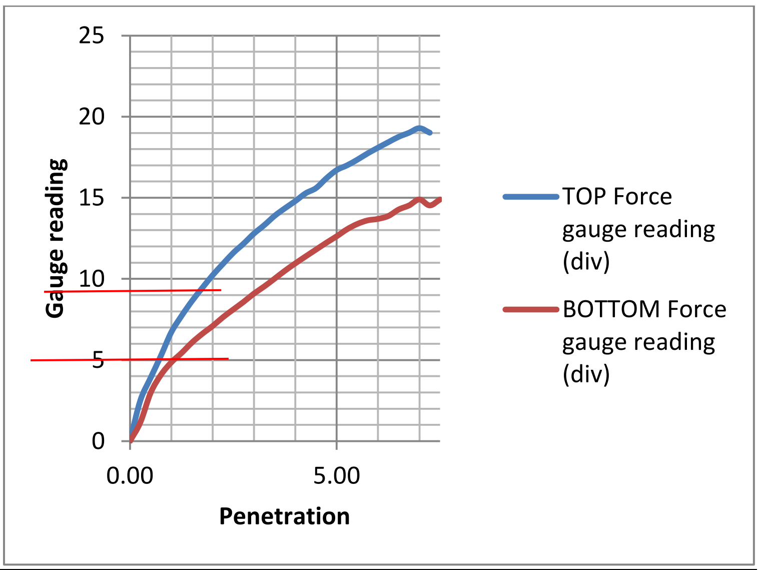
OPC 11%



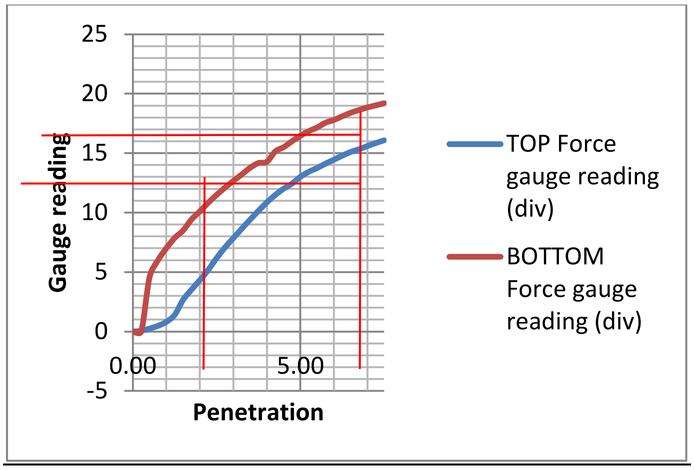
OPC 12%



OPC 13%



<u>OPC 15%</u>


25
20
15
10
5
0
-5
0.00
5.00
Gauge reading
Penetration
TOP Force gauge reading (div)
BOTTOM Force gauge reading (div)