Engineering Properties of Soil Stabilize with Cement

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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TRONOH, PERAK

September 2013

CERTIFICATION OF ORIGINALITY

This is to 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 persons.

LAM'AH BINTI HAJI FAKHRURROZY

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ABSTRACT

Soils often cause difficulties in subgrade performance with their low stiffness nature. However, the engineering properties of these soils can be enhanced by soil stabilize with cement. This research was carried out to study the potential of Ordinary Portland Cement (OPC) stabilization in soil around the area of Taiping, Perak. The objectives of this research are determine the maximum dry density and optimum moisture content as well as CBR value for undisturbed soil and soil added with cement (Soil Cement Mixture). Compaction Test was applied to determine the maximum dry unit weight and the optimum moisture content of the soils. From this testing, the maximum dry unit was obtained for undisturbed sample are 1.863Mg/m^3 and the optimum mosture content are 11.4%. However, optimum moisture content for soil cement mixture are slightly higher which is 14.1% and the maximum dry density are 1.791Mg/m^3. The result shows that, changes in optimum moisture content and dry density with addition of cement are not always predictable. Flocculation of soil particles by cement can cause an increase in optimum moisture content and decrease in maximum dry density. Secondly, to obtain the CBR value by performing the CBR Test for both sample of soil under soaked conditions. Based on the result obtained, it is possible to conclude that 2.5% of cement as chemically additive would provide the optimum moisture content at maximum CBR value. The CBR value for undisturbed soil are 74% compare to soil cement mixture which is 93%. The results indicate that as cement amount in the mixture are added, the optimum moiture content and CBR values also increased. Overall, 2.5% are the effective amount should be added in existing soil for subgrade preaparation. A new method for strenghthening the subgrade performance are now can be introduced and the objective of this research was achieved.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Subgrade performance is a function of a soil's strength and its behaviour under traffic loading. The subgrade should be sufficiently stable to prevent excessive rutting and shoving during construction, provide good support for placement and compaction of pavement layers, limit pavement rebound deflections to acceptable limits, restrict the development of excessive permanent deformation (rutting) in the subgrade during the service life of the pavement and minimise effect of changes in moisture level.

Soil with characteristics of low strength and compressible exist all over the world. One of the most significant problems arises because such soils have difficulties in supporting loads on such foundation. Soil stabilization by addition of 2.5% cementation material using Ordinary Portland Cement (OPC) are applied for the soil to compare the engineering properties of undisturbed soil and soil cement mixture. OPC is comprised of calcium-silicates and calcium-aluminates that hydrate toform cementitious products. This cementitious reaction is the primary mode of strength gain in soil cement. Cement hydration is rapid and causes immediate strength gain in stabilized layers. Therefore, a mellowing period is not typically allowed between mixing and compaction.

For the aforementioned reason, a comprehensive laboratory testing programme which is Compaction Test and California Bearing Ratio Soaked (CBR Soaked) Test was carried out in order to study the effect of 2.5% addition of cement on the physical and engineering behaviour of the soil samples. The effectiveness of using cement in stabilizing the weak soil was investigated in the laboratory.

1.2 Problem Statement

The adverse effect of increase in moisture content on the soil behavior has been a major concern among the geotechnical as well as pavement engineers. When constructing new roads over virgin ground, the performance of the completed road depends not only on the pavement structural design, but probably more importantly on the subgrade support conditions. Subgrades that change their volumetric and/or stiffness properties significantly during the life of the road lead to deformation and cracking of the road surface, a deterioration in the performance and the service provided by the pavement frequently leading to premature failure. The ability of structures to sustain the applied load depend on the soil under the surface. Without a proper design, problems such as cracking, settlement of pavement may occur and even to extent, the whole pavement structures may collapse within its design life. The author has recently been involved with a problem on highly expansive clay, where despite severe deformation and cracking of the existing road, the road was reconstructed with significant widening, and yet no countermeasures were implemented until cracking of the new road and the added shoulder was noted. Nowadays, many geotechnical engineers faced the problem of soil where the soil cannot reach the required specification to support load above it. The existing soil may not always be totally suitable for supporting pavement design. Due to that, the understanding and knowledge of engineering properties should be investigated and improved.

1.3 Significance of Study

Many studies and researches had been carried out on soil stabilization. Demonstrating cement stabilized soil has a significant enhancement in strength and other soil engineering properties. With this resarch, tests are carried to investigate whether the cement tested soil has enough strength to withstand the increasing load rather than not using any stabilizer. It provides a reference for the behaviour of compressive strength on cement stabilized. Soil cement has been proven in all of these uses to be cost effective, aesthetically pleasing, have good performance and time tested. When it comes to cement soil stabilization, OPC is the most common choice for paving projects. Although these conventional stabilizers can help make soil stronger, studies have shown that OPC can prolong the strength even more.

1.4 Objectives

The main objectives of the project are:-

1. To determine the optimum moisture content and maximum dry density of soil due to stabilization process before and after stabilization with cement.
2. To determine the optimum moisture content at california bearing ratio value of soil before and after stabilization with cement.

1.5 Scope of Study

The scope of the study included the determination of optimum moisture content, maximum dry density and CBR value of undisturbed sample and soil cement mixture. The soil samples which are from Taiping, Perak respectively will be used in this project. For this project, soil properties at subgrade level are required because this is considered appropriate for design purpose. Ordinary Portland Cement (OPC) was used in this project. OPC had proven to be a very method of subgrade stabilization by decrease the liquid limit and increase the plasticity index and workability of weak soil. The laboratory testing scope included performing the Compaction Test and California Bearing Ratio Soaked (CBR Soaked) Test as per British Standard (BS 1377). There are two types of sample that will be tested which is undisturbed soil and soil added with cement.

Laboratory testing was conducted in accordance BS Standard. The following BS Standards were used in this study:-

1. BS 1377 Part 4:1990 (Section 3.0) - Compaction Test (Proctor Test)
   Determination Maximum Dry Density/Moisture Content Relationship

2. BS 1377 Part 4:1990 (Section 7.0) - California Bearing Ratio Soaked Test (CBR Soaked)
   Determination California Bearing Ratio

1.6 Relevancy of the Project

The reason behind the idea is to identify the problems that rise up from the beginning of the project until the project completed as well as performing the laboratory test as per British Standard.

1.7 Feasibility of the Project

Up to this moment, the project has been conducted in accordant with the plan showed in the Gantt Chart. The investigation of the interaction behaviour and engineering properties of undisturbed and soil cement mixture as well as the design procedures for soil stablization has been undergoing. The important materials such as cement will be prepared to add it to soil. Generally, any type of cement may be used for soil stabilization but OPC is most widely used. In order to evaluate the different engineering properties of the subgrade soils found in Taiping, Perak, laboratory testing will be conducted to compare the result between two type of soil as mentioned above due to the soil stabilization before and after adding the ceme

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction to Soil Stabilization

A land -based structures of any type is only as strong as its foundation. For that reason, soil is a critical element influencing the success of a construction project. (Aydogmus, 2009). Soil is either part of the foundation or one of the raw materials used in the construction process. (Aydogmus, 2009). Therefore, understanding the engineering properties of soil is crucial to obtain strength and economic permanence. (Aydogmus, 2009). Soil stabilization is the process of maximizing the suitability of soil for a given construction purpose. (Aydogmus, 2009).

The necessity of improving the engineering properties of soil has been recognized for as long as construction has existed. (Aydogmus, 2009). Many ancient cultures, including the Chinese, Romans and Incas, Utilized various techniques to improve soil stability, some of which were so effective that many of the buldings and roadways they constructed still exist today. Some are still in use. (Aydogmus, 2009).

In the United States, the modern era of soil stabilization began during the 1960s and ‘70s, when general shortages of aggregates and petroleum resources forced engineers to consider alternatives to the conventional technique of replacing poor soils at building sites with shipped-in aggregates that possessed more favorable engineering characteristics. (Aydogmus, 2009). Soil stabilization then fell out of favor, mainly due to faulty application techniques and misunderstanding. (Aydogmus, 2009). More recently, soil stabilization has once again become a popular trend as global demand for a raw materials, fuel and infrastructure has increased. (Aydogmus, 2009). This time, however, soil stablization is benefiting from better research, materials and equipment. (Aydogmus, 2009).

2.2 Defining Soil Stabilization

Soil is one of nature's most abundant construction materials. Almost all construction is built with or upon soil. (Alexiew & Klapperich, 2000). When unsuitable construction conditions are encountered, a contractor has four option:-

1. Find a new construction site
2. Redesign the structure so it can be cosntructed on the poor soil
3. Remove the poor soil and replace it with good soil
4. Improve the engineering properties of the site soils

In general, options 1 and 2 tend to be impractical today, while in the past, option 3 has been the most commonly used method. (Alexiew & Klapperich, 2000). However, due to improvement in technology coupled with increased transportation costs, option 4 is being used more often today and is expected to dramatically increase in the future. (Alexiew & Klapperich, 2000).

Improving an on-site (in situ) soil's engineering properties is referred to as either 'soil modification' or 'soil stabilization'. (Alexiew & Klapperich, 2000). The term 'modification' implies a minor change in the properties of a soil, while stabilization means that the engineering properties of the soil have been changed enough to allow field construction to take place. (Alexiew & Klapperich, 2000).

There are two primary methods of soil stabilization used today:-

- Mechanical Soil Stabilization
- Chemical Soil Stabilization

2.3 Mechanical Soil Stabilization

Mechanical soil stabilization refers to either compaction or introduction of fibrous and other non-biodegradable reinforcement to the soil. (Alexiew & Klapperich, 2000). This practice does not require chemical change of the soil, although it is common to use both mechanical and chemical means to achieve specified stabilization. There are several methods used to achieve mechanical stabilization. (Alexiew & Klapperich, 2000).

2.3.1 Compaction

Compaction typically employs a heavy weight to increse soil density by applying pressure from above. (Alexiew & Klapperich, 2000). Machines are often used for this purpose; large soil compactors with vibrating steel drums efficiently apply pressure to the soil, increasing its density to meet engineering requirements. (Alexiew & Klapperich, 2000). Operators of the machines must be careful not to over-compact the soil, for too much pressure can result in crushed aggregates that lose their engineering properties. (Alexiew & Klapperich, 2000).

2.3.2 Soil Reinforcement

Soil problems are sometimes remedied by utilizing engineered or non engineered mechanical solutions. (Alexiew & Klapperich, 2000). Geo-textiles and engineered plastic mesh are designed to trap soils and help control erosion, moisture conditions and soil permeability. (Alexiew & Klapperich, 2000). Larger aggregates, such as gravel, stones and boulders are often employed where additional mass and rigidity can prevent unwanted soil migration or improve load-bearing properties. (Alexiew & Klapperich, 2000).

2.3.3 Addition of Graded Aggregate Materials

A common method of improving the engineering characteristics of a soil is to add certain aggregates that lend desirable attributes to the soil such as increased strength or decreased plasticity. (Alexiew & Klapperich, 2000). This method provides material economy, improves support capabilities of the subgrade and furnishes a working platform for the remaining structure. (Alexiew & Klapperich, 2000).

2.3.4 Mechanical Remediation

Traditionally, mechanical remediation has been the accepted practice for dealing with soil contamination. (Alexiew & Klapperich, 2000).This is a technique where contaminated soil is physically removed and relocated to a designated hazardous waste facility far from centers of human population. (Alexiew & Klapperich, 2000). In recent times, however chemical and bio remediation have proven to be a better solution, both economically and environmentally. (Alexiew & Klapperich, 2000). It is often cheaper to solve the problem where it exists rather than relocate the problem somewhere else and possibly need to need to deal with it again in the future. (Alexiew & Klapperich, 2000)

2.4 Chemical Soil Stabilization

One method of improving the engineering properties of soil is by adding chemicals or other materials to improve the existing soil. (Bahar, Benazzoug & Kenai, 2004). This technique is generally cost effective: for example, the cost, transportation and processing of a stabilizing agent or additive such as soil cement or lime to treat an in-place soil material will probably be more economical than importing aggregate for the same thickness of base course. (Bahar, Benazzoug & Kenai, 2004).

Additives can be mechanical, meaning that upon addition to the parent soil their own load-bearing properties bolster the engineering characteristics of the parent soil. (Bahar, Benazzoug & Kenai, 2004). Additives can also be chemical, meaning that the additive reacts with or changes the chemical properties of the soil, thereby upgrading its engineering. (Bahar, Benazzoug & Kenai, 2004). Placing the wrong kind or wrong amount of additive or improperly incorporating the additive into the soil can have devastating results on the success of the project. (Bahar, Benazzoug & Kenai, 2004). So, in order to properly implement this technique, an engineer must have:

1. A clear idea of the desired result
2. An understanding of the type of soil and their characteristics on site.
3. An understanding of the use of the additive how they react with the soil type and other additives and how they interact with the surrounding environment.
4. An understanding of and means of incorporating (mixing) the additive
5. An understanding of how the resulting engineered soil will perform.

Combining the additives with the soil is typically done with various machines. (Bahar, Benazzoug & Kenai, 2004).The method used is usually based on three factors: what machines are available, the location (urban or rural), and the additives that are being used. The mixing should be as uniform as possible. (Bahar, Benazzoug & Kenai, 2004).

The most economic and time-efficient method is to use a rotary mixer, a large machine that incorporates additives with the soil by tumbling them in a large mixing chamber equipped with a rotor designed to break up and mix the materials. (Bahar, Benazzoug & Kenai, 2004). It is capable of uniformly introdusing additives and water while breaking up the soil into an optimal homogenous grade. The rotary mixer does all mixing in place and is unrivaled in production by other methods. (Bahar, Benazzoug & Kenai, 2004).

For some applications that require more precision a pugmill is used. A pugmill is essentially a large mixing chamber that is similar to a cement mixer. (Bahar, Benazzoug & Kenai, 2004). Measured pre-graded aggregates, additives and usually water are mixed in the pigmill and then applied to uniform thickness. Pugmills produce high quality stabilization but a higher costs and slower production. (Bahar, Benazzoug & Kenai, 2004).

Blade mixing is done with the use of a motor grader. (Bahar, Benazzoug & Kenai, 2004). Blade mixing is not nearly as efficient as the previously described systems but it is far less complex. (Bahar, Benazzoug & Kenai, 2004). Essentially, the additive is placed in flat windrows and the of the grader mixes the additive with the soil in a series of turning and tumbling actions. (Bahar, Benazzoug & Kenai, 2004). Other machines are similarly used for mixing as well including scarifiers, plows and disks. It is very difficult to uniformly control mixing percentages and mixing depth using this technique. (Bahar, Benazzoug & Kenai, 2004).

2.4.1 Additives

There are many kinds of additives available. Not all additives work for all soil types and a s single additive will perform quite differently with different soil types. (Kolias, Kasselouri & Karahalios, 2005). Generally, an additive may be used to act as a binder alter the effect of moisture, increase the soil density or neutralize the harmful effects of a substance in the soil. (Kolias, Kasselouri & Karahalios, 2005). Followings are some of the most widely used additives and their applications:-

1. **Portland Cement**

   Portland cement is a mechanical additive that can be used for soil modification (to improve soil quality) or soil stabilization. (Kolias, Kasselouri & Karahalios, 2005). The amount of cement used will dictate whether modification or stabilzation has occurred. (Kolias, Kasselouri & Karahalios, 2005). Nearly all types of soil can benefit from the strength gained by cement stabilization. (Kolias, Kasselouri & Karahalios, 2005). However, the best results have occurred when used with well graded fines that possess enough fines to produce a floating aggregate matrix. (Kolias, Kasselouri & Karahalios, 2005).

2. **Quicklime/Hydrated Lime**

   Lime is a chemical additive that has been utilized as a stabilizing agent in soils for centuries. (Kolias, Kasselouri & Karahalios, 2005). Experience has shown that lime will react well with medium, moderately fine and fine-grained clay soils. (Kolias, Kasselouri & Karahalios, 2005). In clay soils, the main benefit from lime stabilization is the reduction of the soil’s plasticity: by reducing the soil’s water content, it becomes more rigid. (Kolias, Kasselouri & Karahalios, 2005). It also increases the strength and workability o the soil and reduces the soil’s ability to swell. (Kolias, Kasselouri & Karahalios, 2005).

It is very important to achieve proper gradation when applying line to clay soils. (Kolias, Kasselouri & Karahalios, 2005). By breaking up the clay into small-properly react with the clay. (Kolias, Kasselouri & Karahalios, 2005). Lime can be applied dry to the soil but if blowing dust is concern or the work is being done in a populated area the lime can be mixed with water to form slurry. (Kolias, Kasselouri & Karahalios, 2005). A curing time of 3 to 7 days is normal to allow the lime to react with the soil during which the surface of the stabilized soil should be wetted periodically. (Kolias, Kasselouri & Karahalios, 2005).

3. Fly Ash

Fly ash a chemical additive consisting mainly of silicon and aluminium compounds is a by product of the combustion of coal. (Kolias, Kasselouri & Karahalios, 2005). Fly ash can be mixed with lime and water to stabilize granular materials with few fines producing a hard cement- like mass. (Kolias, Kasselouri & Karahalios, 2005). Its role in the stabilization process is to act as a pozzolan and/or as a filler product to reduce air voids. (Kolias, Kasselouri & Karahalios, 2005). A common application is part of a lime/cementy/fly ash mixture (LCF) to stabilize coarse-grained soils that possess little or no fine grains because it is essentially a waste product, it can be obtained rather inexpensively. (Kolias, Kasselouri & Karahalios, 2005).

4. Calcium Chloride

Calcium chloride is a chemical additive that has the ability to absorb moisture from the air until it liquifies into a solution. (Kolias, Kasselouri & Karahalios, 2005). The presence of calcium chloride in the moisture of a soil lowers the freezing temperature of that moisture. (Kolias, Kasselouri & Karahalios, 2005). For this reason, calcium chloride is aproven stabilizing additive for cold-climate applications. (Kolias, Kasselouri & Karahalios, 2005).

If the water in the soil can’t freeze there is less soil movement (i.e., frost heaves) maing it much more stable. Calcium chloride also works well as a binder maing the soil easier to compact and reducing dust. (Kolias, Kasselouri & Karahalios, 2005).

5. **Bitumen**

   Bitumen is a mechanical additive that occurs naturally or as a by-product of petroleum distillation. (Kolias, Kasselouri & Karahalios, 2005). It is the black pitch used to make asphalt. Asphalt cement, cutback asphalt, tar and asphalt emulsions are all used to achieved bituminous soil stabiliztation. (Kolias, Kasselouri & Karahalios, 2005). Soil type construction method and weather are all factors in choosing which itumen to use. Bitumen makes soil stronger and resitant to water and frost. (Kolias, Kasselouri & Karahalios, 2005). The use of bitumen can lead to fewer weather-related delays during construction and makes compaction easier and moere consistent. (Kolias, Kasselouri & Karahalios, 2005).

2.4.2 Chemical or Bio Remediation

Our industrial society produces many benefits but occasionally there are unintentional accidental or criminal problems that occur. (Shenbaga & Vasant, 2010). Petroleum hydrocarbons, lead, PCBs, solvents, pesticides and other hazardous natural and man-made substances often contaminate soil because even contaminated soil to an acceptable condition for human habitation. (Shenbaga & Vasant, 2010).

The goal of chemical or bio remediation is to convert hazardous substances into inert ones and to prevent hazardous substances from spreading or leaching. (Shenbaga & Vasant, 2010). The type of additive depends on the contaminants and the environment. (Shenbaga & Vasant, 2010). Chemical additives are often proprietry cehmical cocktails but the science is well unedrstood and they are quite effective at neutralizing hazardous substances. (Shenbaga & Vasant, 2010). Bio remediation is typically done by the introduction of natural means: bacteria or insects that eat contaminants and convert them to inert waste or plants that filter out contaminants and convert them to natural substances. (Shenbaga & Vasant, 2010).

2.5 Stabilization Soil with Cement

All soils can be stabilized with portland cement, provided sufficient quantity is added. Some soils with a high organic content do not react well with cement and hardening may be delayed. (Kolias, Kasselouri, & Karaholios, 2005). As clay content inreases, soils become more difficult to pulverize and work and larger quantities of cement must be added to harden them. (Kolias, Kasselouri, & Karaholios, 2005). The thickness of a cement-stabili zed base depends upon the traffic loads and volumes and the stability of the subgrade. (Kolias, Kasselouri, & Karaholios, 2005). Thicknesses greater than 7 inches are built in more than one lift. The thickness of subbase or subgrade stabilization depends upon the nature of the soils and the conditions of the job. (Kolias, Kasselouri, & Karaholios, 2005). Chemical bonds or linkages are developed between adjacent cement grain surfaces and exposed soil particle surfaces. (Kolias, Kasselouri, & Karaholios, 2005). There is also a secondary effect produced when lime, which is formed as the cement hydrates, reacts with the silica and alumina in the clay fraction to produce secondary cementitious material. (Kolias, Kasselouri, & Karaholios, 2005).

The degree of stability is governed by:-

1. The physical and chemical properties of the soil.
2. The proportion of cement.
3. Moisture conditions (content, temperature, duration) during both compaction and curing.
4. Degree of compaction

Soil have been stabilized with cement contents ranging from 4 to 15 percent by weight of the soil. (Kolias, Kasselouri, & Karaholios, 2005). The majority of work, however is completed with a cement content of around 6 to 8 percent. (Kolias, Kasselouri, & Karaholios, 2005). Representative soil samples should be identified and subjected to (Kolias, Kasselouri, & Karaholios, 2005). :-

1. Moisture-density tests to determine optimum moisture content and maximum density.
2. Freeze-thaw and wet-dry test to determine the lowest cement content taht will produce a hard, durable base.

Pulverization is necessary with heavier-type soils to break up the soil particles and ensure intimate contact with the cement. (Kolias, Kasselouri, & Karaholios, 2005). Optimum moisture is necessary to both hydrate the cement and facilitate compaction. As a rule-of- thumb guide, optimum moisture content can be assumed to be the driest condition at which a 2-inch ball of soil, molded in the fingers, retains its shape. (Kolias, Kasselouri, & Karaholios, 2005). As a further aid, the ball should break into only a few pieces when dropped. (Kolias, Kasselouri, & Karaholios, 2005).Traces of moisture on the fingers means that the optimum content has been exceeded. (Kolias, Kasselouri, & Karaholios, 2005). Proper curing for 7 days is essential. The surface must be sealed to prevent evaporation losses. (Kolias, Kasselouri, & Karaholios, 2005).

2.6 The Basic Soil Stabilization Process

Both new construction and rehabilitation projects are candidates for soil stabilization. (Umar & Ali, 2011). While the precise stabilization procedures will vary depending on many factors including location, environment, time requirements, budget, available machinery and weather. (Umar & Ali, 2011). The following process is generally practiced:-

1. **Assesment and Testing**

   The soils of the site are thoroughly tested to determine the existing conditions. (Umar & Ali, 2011). Based on analysis of existing conditions, additives are selected and specified. Generally, a target chemical percentage by weight and a design mix depth are defined for the sub-base contractor. (Umar & Ali, 2011). The selected additves are subsequently mixed with soil samples and allowed to cure. (Umar & Ali, 2011). The cured sample is then tested to ensure that the additives will produce the desired results. (Umar & Ali, 2011).

2. **Site Preparation**

   The existing materials on site, including existing pavement if it is being reclaimed, is pulverized utilizing a rotary mixer. (Umar & Ali, 2011). Any additional aggregates or base materials are introduced at this time. (Umar & Ali, 2011). The material is brought to the optimal moisture content by drying overly wet soil or adding water to overly dry soil. (Umar & Ali, 2011). The grade is shaped if necessary to obtain the specified material depth. (Umar & Ali, 2011).

3. **Introduce Additives**

   Cement, lime or fly ash can be applied dry or wet. When applied dry, it is typically spread at a required amount per square yard (meter) or station utilizing a cyclone spreader or other device. (Umar & Ali, 2011). When lime is applied as slurry, it is either spread with a tanker truck or trough the rotary mixer’s on board water spray system. (Umar & Ali, 2011). Calcium chloride is usually applied by a tanker truck equipped with a spray bar. (Umar & Ali, 2011).

Bituminous additives are typically added utilizing an on-board emulsion spray system on rotary mixer. (Umar & Ali, 2011). It can also be srayed on the surface btu this method requires several applications and additional mixing. (Umar & Ali, 2011).

4. **Mixing**

   To fully incorporate the additives with the soil, a rotary mixer makes several mixing passes untill the materials are homogenous and well graded. (Umar & Ali, 2011). It is crucial that the rotary mixer maintains optimal mixing depth as mixing too shallow or too deep will create undesirable proportions of soil and additive. (Umar & Ali, 2011). Inappropriate proportions of soil and additive will decrease the load bearing properties of the cured layer. Some projects require multiple layers of treated and compacted soil. (Umar & Ali, 2011).

   When applying cement and fly ash it is important to finish mixing as soon as possible due to the quick-setting characteristic of the additives. (Umar & Ali, 2011).

5. **Compaction and Shaping/Trimming**

   Compaction usually follows immediately after mixing especially when the additive is cement or fly ash. (Umar & Ali, 2011). Some bituminous additive require a delay between mixing and compaction to allow for certain chemical changes to occur. (Umar & Ali, 2011).

   Compaction is accomplished through several passes using different machines. (Umar & Ali, 2011). Initial compaction is begun utilizing a vibratory padfoot compactor. (Umar & Ali, 2011). The surface is then shaped and trimmed to remove pad marks and provide a more suitable profile. (Umar & Ali, 2011). Intermediate compaction follows utilizing pneaumatic compactor, which provides a certain kneading action that further increases soil density. (Umar & Ali, 2011). A tandem drum roller is used on the finishing pass to provide a smooth surface. A final shaping gives the material a smooth surface. (Umar & Ali, 2011). A final shaping gives the material a smooth finish and a proper crown and grade. (Umar & Ali, 2011).

6. Curing

Sufficient curing will allow the additve to fully achieve its engineering potential. (Umar & Ali, 2011). For cement, lime and fly ash stablilization weather and moisture are critical factors as the curing can have a direct bearing on the strength of the stabilized base. (Umar & Ali, 2011). Bituminous-stabilized bases often require a final membrane of medium-curing cutback asphalt or slow-curing emulsified asphalt as a moisture seal. (Umar & Ali, 2011). Generally, a minimum of seven days are required to ensure proper curing. (Umar & Ali, 2011). During the curing period samples taken from the stabilized base will reveal when the moisture content is appropriate for surface. (Umar & Ali, 2011).

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Throughout the project, some systematic procedures are complied to ensure that the project is accomplished successfully and orderly. The first step is identifying the problem statement through discussion and analysis. Studies were done to get the ideas of the problems. Each criteria of the problem is important to narrow down the scope of the problems. The problem was divided into smaller scopes so that the problems can be analyzed systematically. The next step is to define the meaning of soil stabilization through some research and revision as well as the procedures soil stabilization added with cement. Generally, cement is the chemical agent that was chosen as the stabilizer for the soil taken. The possible information identified was analyzed to this project. Soil sampling are required for pavement design. This is considered appropriate for design purpose. At subgrade level, when the soil is likely to be affected by water added during drilling or excavating operation, the top 150 mm of the subgrade material should be removed and not be tested. After preparing the soil, a suggested tested will be conducted. Based on the information gathered, the tools and hardware will be justified to test the soil. There are two types of sample of soil will be tested that is undisturbed soil and soil added with 2.5% cement. Based on the investigation through research, the soil added cementation will be prepared followed by the equipment for the laboratory testing. In the case of stabilization, the Compaction Test (Proctor Test) and California Bearing Ratio Soaked Test (CBR Soaked) shall be performed in accordance to British Standard. The results are evaluated and compared to determine the maximum dry density and moisture content as well as optimum moisture content at a certain CBR value towards the situation.

3.2 Project Activities

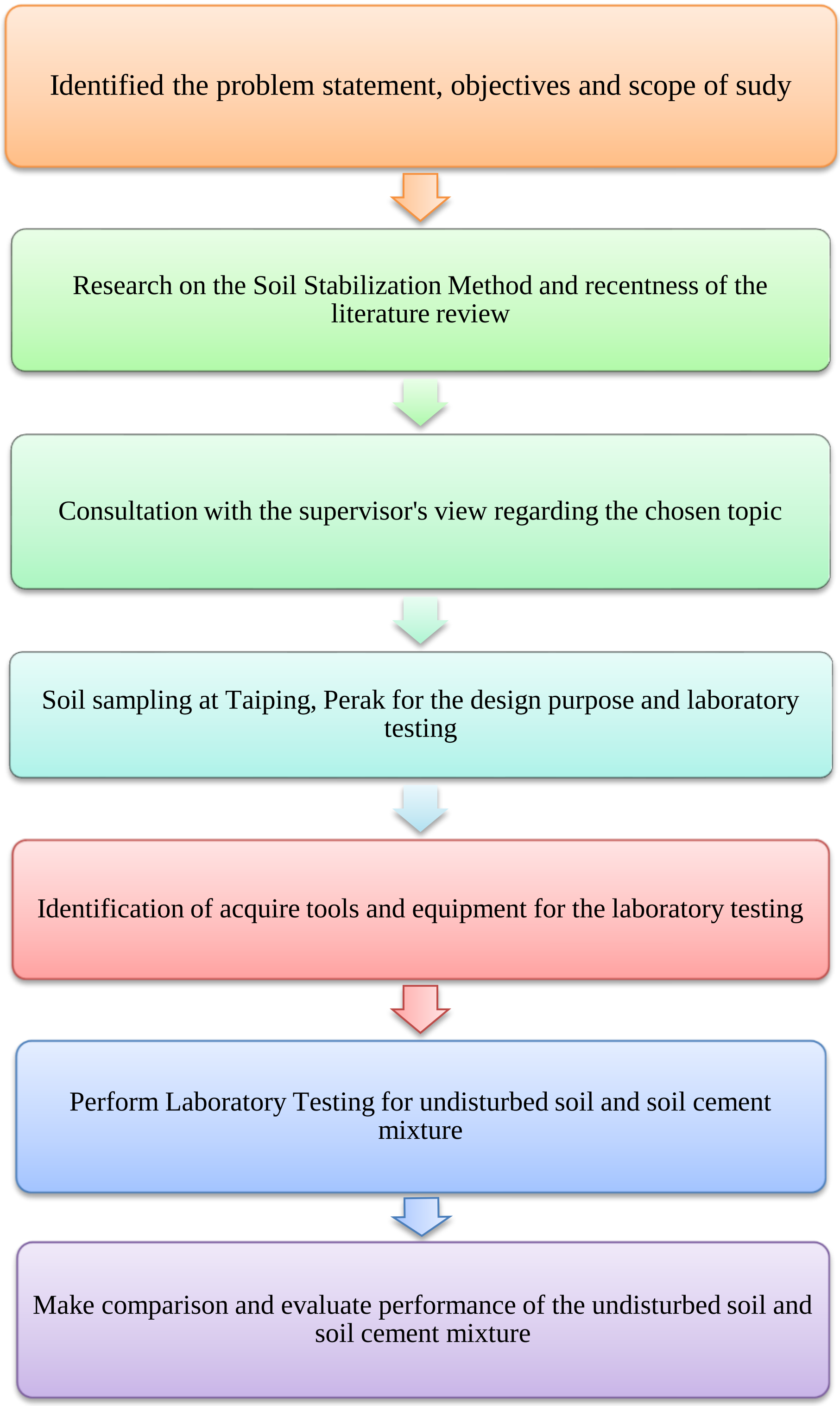


Figure 1: Methodology/Flow of the Project

3.3 Gantt Chart/Schedule FYP I and II

PROJECT FLOW/TASK	WEEK 1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1 BRIEFING	■													
SELECTION OF PROJECT TOPIC ➢ Submission Form 01 ➢ Consultation with supervisor	■	■												
PRELIMINARY RESEARCH WORK ➢ Identification of Problem Statement and the objective of the study ➢ Consultation with supervisor **LITERATURE REVIEW** ➢ Research on topic chosen (Soil Stabilization Method). ➢ Review some journal regarding the Soil Stabilization **METHODOLOGY STUDY** ➢ Research on acquire material material and preparing soil. ➢ Research on Soil Stabilization Process ➢ Make comparison from the research. ➢ Perform project flow activities ➢ Investigation on test that will be conducted.			■	■										
SUBMISSION OF DRAFT EXTENDED PROPOSAL DEFENCE					■									
SUBMISSION OF EXTENDED PROPOSAL DEFENCE						■								
SUBMISSION OF PROPOSAL DEFENCE								■	■					
PROJECT WORK CONTINUES ➢ Prepare acquire material such as Ordinary Cement Portland ➢ Review information about the test that will be conducted **PRESENTATION VIVA** ➢ Prepare slide presentation and Poster ➢ Practicing for the presentation										■	■	■		
SUBMISSION OF INTERIM DRAFT REPORT													■	
SUBMISSION OF INTERIM REPORT														■

Figure 2: Gantt Chart/Schedule of the FYP I

PROJECT FLOW/TASK	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FYP 2 BRIEFING															
PROJECT WORK ➢ Soil Sampling at Taiping, Perak ➢ Perform Compaction Test (Proctor Test) for undisturbed sample. ➢ Perform Compaction Test (Proctor Test) for soil cement mixture.															
SUBMISSION OF PROGRESS REPORT ➢ Consultation with supervisor															
PROJECT WORK ➢ Perform CBR Soaked Test for undisturbed sample. ➢ Perform CBR Soaked Test (for soil cement mixture.															
Pre-SEDEX ➢ Prepare slide presentation															
SUBMISSION OF DRAFT REPORT ➢ Consultation with supervisor															
SUBMISSION OF DISSERTATION (SOFT BOUND) ➢ Consultation with supervisor															
SUBMISSION OF TECHNICAL PAPER ➢ Consultation with supervisor															
PRESENTATION VIVA ➢ Prepare slide presentation and Poster ➢ Practicing for the presentation															
SUBMISSION OF PROJECT DISSERTATION															

Figure 3: Gantt Chart/Schedule of the FYP II

3.4 Experimental Opertional Framework

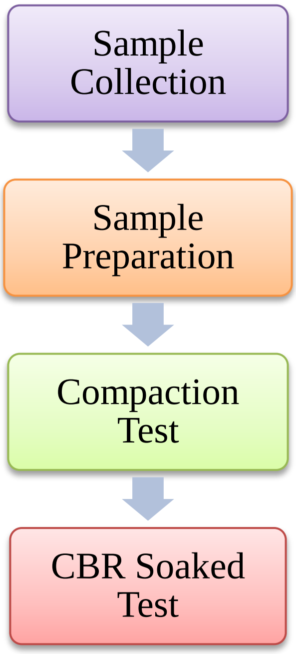


Figure 4: Experimental Framework

3.5 Sample Collection

The samples are taken from Taiping, Perak. From the site, the author took about 20kg of undisturbed soil to be produced as remolded sample. The undisturbed samples are obtained using hand auger. The author hand-auger until around two feet depth to obtain undisturbed sample. The two feet is decided because the upper layer of soil normally comprised of fill soil.

Figure 5: Hand-Auger

3.6 Sample Preparation

After seperating the disturbed soil sample from unnecessary objects such as big sized-gravel and grass root, the sample is removed into a large square steel tray and being put into a oven for 24 hours at 100°c. After 24 hours, the sample is removed from the oven and crushed into very fine pieces using a rubber hammer.

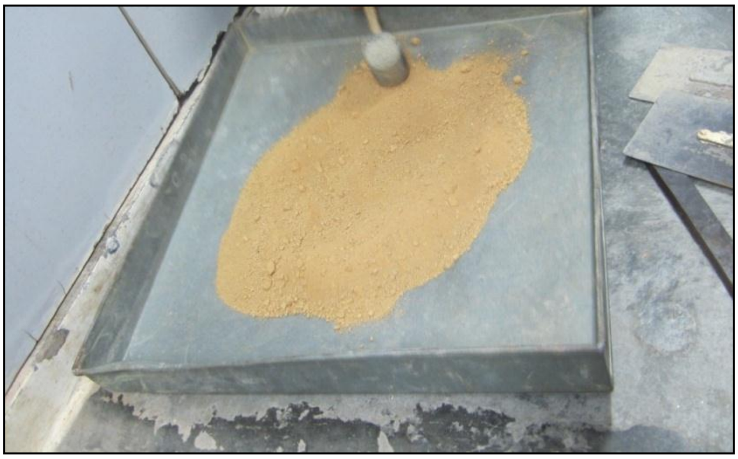


Figure 6: The sample is crushed using a rubber hammer

Figure 7: Soil sample are weighed about 3000g

3.7 Compaction Test

For fill materials, Compaction tests are required to determine the optimum moisture content at which the material should be compacted on site. Compaction of soil is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density which can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value. For cohesionless soils an optimum moisture content might be difficult to define.

The objective of the tests decribed in this clause is to obtain relationships between compacted dry density and soil moisture content, using two magnitudes of manual compactive effort, or compaction by vibration.

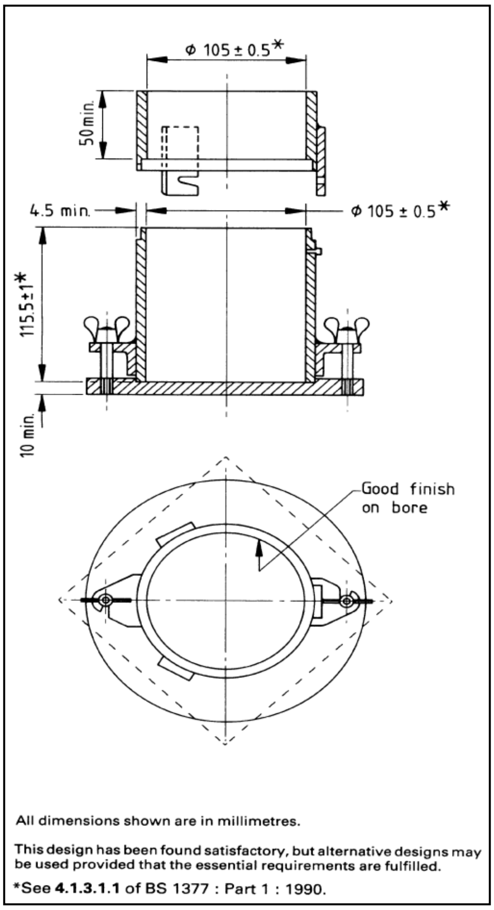


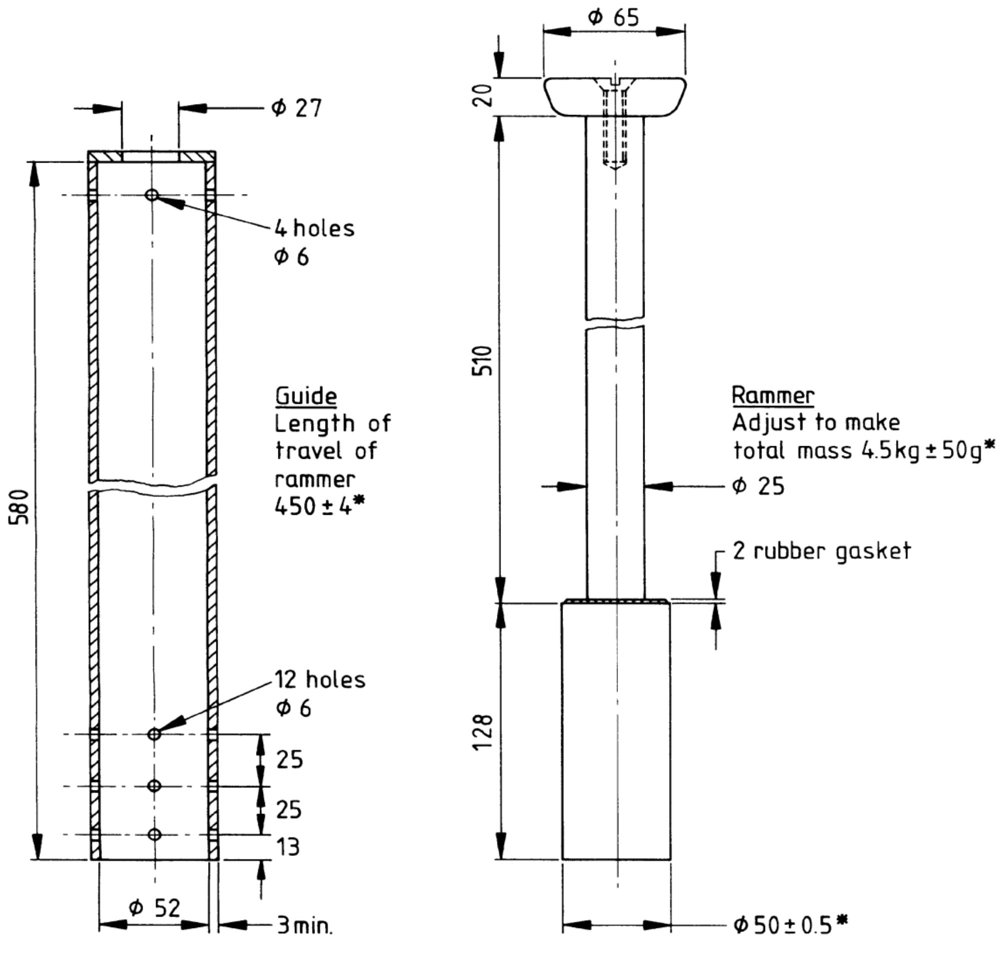
Figure 8: Mould for Compaction Test (1 L mould)

3.7.1 Tools and Equipment Required for Compaction Test

These are the lists of tools and equipements that are required for laboratory testing:-

No.	Tools and Equipment	Description
Compaction Test (Proctor Test)		
1.	A cylindrical	Corrosion-resistant metal mould i.e. the compaction mould, having a nominal internal volume of 1 L. The mould shall be fitted with a detachable baseplate and a removable extension. The internal faces shall be smooth, clean and dry before each use.
2.	Rammer	A metal rammer having a 50.8 mm diameter circular face with a 4.5 kilogram weight which will drop freely for a distance of 450 mm.
3.	Compaction base	A cube of concrete weighing not less than 45 kg.
4.	Straight-edge	A steel straight-edge approximately 300 mm in length
5.	Balance	A balance sensitive to 0.1 g.
6.	A knife or spatula	
7.	Dry apparatus	Oven or stove suitable for drying samples.

Table 1: Tools and Equipment Required for Compaction Test (Proctor Test)



This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 9 : 4.5 kg Rammer for Compaction Test

3.7.2 Procedure of Compaction Test

a. Prepare the undisturbed and soil cement soil and subdivide the initial sample by the procedures to produce a representative sample of about 6kg of the soil.
b. Add suitable amount of water depending on the soil type and mix thoroughly.
c. If the soil initially contains too much water allow it to air dry to the lowest moisture content at which the soil is to be compacted, and mix thoroughly.
d. If the soil is cohesive, seal in an airtight container and store for at least 24 h.
e. Weigh the mould with baseplate attached to 1 g. Measure the internal dimensions to 0.1 mm.
f. Attach the extension to the mould and place the mould assembly on a solid base, e.g. a concrete floor or plinth.
g. Place a quantity of moist soil in the mould such that when compacted it occupies a little over one-fifth of the height of the mould body.
h. Apply 27 blows from the rammer dropped from a height of 450 mm above the soil as controlled by the guide tube. Distribute the blows uniformly over the surface and ensure that the rammer always falls freely and is not obstructed by soil in the guide tube.
i. Repeat (g) and (h) four more times, so that the amount of soil used is sufficient to fill the mould body, with the surface not more than 6 mm proud of the upper edge of the mould body.
j. Remove the extension, strike off the excess soil and level off the surface of the compacted soil carefully to the top of the mould using the straightedge. Replace any coarse particles, removed in the levelling process, by finer material from the sample, well pressed in.
k. Weigh the soil and mould with baseplate to 1 g.

l. Remove the compacted soil from the mould and place it on the large metal tray. Take a representative sample of the soil for determination of its moisture content.

m. Break up the remainder of the soil, rub it through the 20 mm test sieve and mix with the remainder of the prepared test sample.

n. Add a suitable increment of water and mix it thoroughly into the soil.

o. Repeat (g) to (n) to give atotal of at least five determinations. The moisture contents shall be such that the optimum moisture content, at which the maximum dry density occurs, lies near the middle of the range.

3.8 California Bearing Ratio Soaked Test (CBR Soaked)

This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil.The principle is to determine the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is made to penetrate the soil at a given rate. At certain values of penetration, the ratio of the apPrplied force to a standard force, expressed as a percentage, is defined as the CBR.

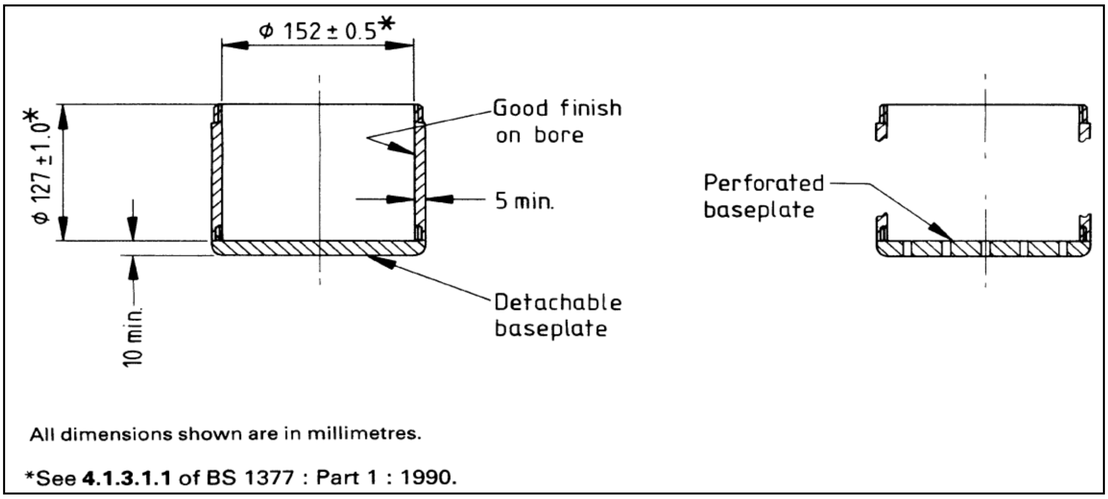


Figure 10 : Cylindrical mould for the determination of the California Bearing Ratio

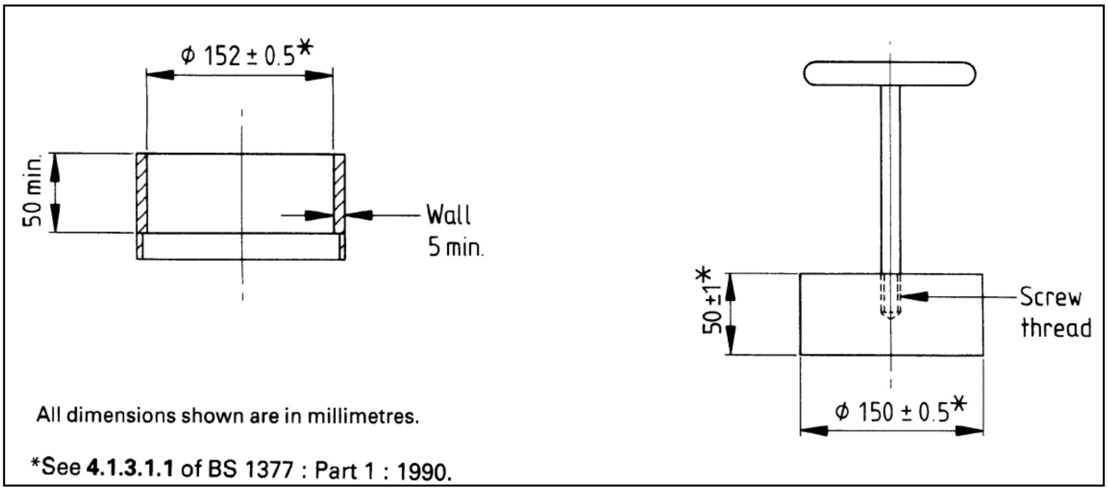


Figure 11 : Plug and collar extension for use with cylindrical mould for the determination of the California Bearing Ratio

3.8.1 Tools and Equipment Required for CBR Soaked Test

These are the lists of tools and equipements that are required for laboratory testing:-

No.	Tools and Equipment	Description
California Bearing Ratio Soaked Test (CBR Soaked)		
1.	Test sieves of aperture sizes 20mm and 5mm	Sizes 20mm and 5mm
2.	A cylindrical corrosion-resistant, metal mould	The CBR mould, having a nominal internal diameter of 152 ± 0.5mm. The mould shall be fitted with a detachable baseplate and a removeble extension. The internal faces shall be smooth, clean and dry before each use
3.	A compression device for static compaction	Horizontal platens shall large enough to cover a 150mm diameter circle and capable of a separation of not less than 300mm. The device shall be capable of applying a force of at least 300kN.
4.	Metal Plugs	150 ± 0.5mm in diameter and 50 ± 1.0mm thick for static compaction of a soil specimen. A handle which may be screwed into the plugs facilitates removal after compaction.
5.	A metal Rammer	These shall be 4.5kg rammer depending on the degree of compaction required.
6.	Vibrating Hammer	An electric and tamper
7.	A steel rod	16mm in diameter and 600mm long
8.	A spatula	A steel strip about 300mm long, 25mm wide and 3mm thick with one beveled edge.
9.	A balance	Capable of weighing up to 25kg readable to 5g
10.	Filter Papers	150mm in diameter

11.	A perforated baseplate	Fitted to the CBR mould in place of the normal baseplate.
12.	A perforated swell plate	An adjustable stem to provide a seating for the stem of a dia gauge.
13.	Tripod	Mounting to support the dial gauge.
14.	Dial Gauge	Having a travel of 25 mm and reading to 0.01 mm.
15.	Soaking Tank	Large enough to allow the CBR mould with baseplate to be submerged, preferably supported on an open mesh platform.
16.	Annular Surcharge Discs	Each having a mass known to ± 50 g, an internal diameter of 52 mm to 54 mm and an external diameter of 145 mm to 150 mm. Alternatively half circular segments may be used.

Table 2: Tools and Equipment Required for California Bearing Ratio Soaked Test (CBR Soaked)

3.8.2 Procedure of CBR Soaked Test

1. **Preparation of the Sample**
   a. Prepare the undisturbed and soil cement soil and subdivide the initial sample by the procedures to produce a representative sample of about 15kg of the soil.
   b. Divide the prepared quantity of soil into five portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.
   c. Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.
   d. Place the first portion of soil into the mould and compact it, so that after 62 blows of the appropriate rammer the layer occupies about or a little more than one-third (one-fifth*) of the height of the mould. Ensure that the blows are evenly distributed over the surface. Alternatively the mechanical compacting apparatus may be used.
   e. Repeat **(d)** using the other four portions of soil in turn, so that the final level of the soil surface is not more than 6 mm above the top of the mould body.
   f. Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.
   g. Weigh the mould, soil and baseplate to the nearest 5 g.
   h. Seal and store the sample.

2. **Soaking Procedure**
   a. Remove the baseplate from the mould and replace it with the perforated baseplate.
   b. Fit the collar to the other end of the mould, packing the screw threads with petroleum jelly to obtain a watertight joint.
   c. Place the mould assembly in the empty soaking tank. Place a filter paper on top of the sample, followed by the perforated swell plate. Fit the required number of annular surcharge discs around the stem on the perforated plate.

d. Mount the dial gauge support on top of the extension collar, secure the dial gauge in place and adjust the stem on the perforated plate to give a convenient zero reading.
e. Fill the immersion tank with water to just below the top of the mould extension collar. Start the timer when the water has just covered the baseplate.
f. Record readings of the dial gauge at suitable intervals of time, depending on the rate of movement.
g. Record the time taken for water to appear at the top of the sample. If this has not occurred within 3 days, flood the top of the sample and leave to soak for a further day, giving the normal soaking period of 4 days. A longer period may be necessary to allow swelling to reach completion.
h. Plot a graph of swelling (as indicated by the dial gauge movement) against elapsed time or square-root time. Flattening of the curve indicates when swelling is substantially complete.
i. Take off the dial gauge and its support,remove the mould assembly from the immersion tank and allow the sample to drain for 15 min. If the tank is fitted with a mesh platform leave the mould there to drain after emptying the tank.
j. Remove the surcharge discs, perforated plate and extension collar. Remove the perforated baseplate and refit the original baseplate.
k. Weigh the sample with mould and baseplate to the nearest 5 g if the density after soaking is required.
l. If the sample has swollen, trim it level with the end of the mould and reweigh. The sample is then ready for test in the soaked condition.

3. Penetration Test Procedure

a. Place the mould with baseplate containing the sample, with the top face of the sample exposed, centrallyon the lower platen of the testing machine.
b. Place the appropriate annular surcharge discs on top of the sample.

c. Fit into place the cylindrical plunger and force-measuring device assembly with the face of the plunger resting on the surface of the sample.
d. Apply a seating force to the plunger, depending on the expected CBR value, as follows:-
   i. For CBR value up to 5% apply 50N
   ii. For CBR value from 5% to 30% apply 50N.
   iii. For CBR value above 30% apply 250N.
e. Record the reading of the force-measuring device as the initial zero reading (because the seating force is not taken into account during the test) or reset the force-measuring device to read zero.
f. Secure the penetration dial gauge in position. Record its initial zero reading, or reset it to read zero.
g. Start the test so that the plunger penetrates the sample at a uniform rate of 1 ± 0.2 mm/min, and at the same instant start the timer.
h. Record readings of the force gauge at intervals of penetration of 0.25 mm, to a total npenetration not exceeding 7.5 mm.
i. If a test is to be carried out on both ends of the sample, raise the plunger and level the surface of the sample by filling in the depression left by the plunger and cutting away any projecting material. Check for flatness with the straightedge.
j. Remove the baseplate from the lower end of the mould, fit it securely on the top end and invert the mould. Trim the exposed surface if necessary.
k. Carry out the test on the base by repeating (a) to (j).
l. After completing the penetration test or tests, determine the moisture content of the test sample.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

Soil compaction for undisturbed and soil cement mixture is one of the critical components in this laboratory testing. The durability and stability for both soil tested are related to the achievement of proper compaction. A principal advantage resulting from compaction of soils used is to reduce settlement that might be caused by consolidation of the soil. Increasing density by compaction usually increases shearing resistance. This effect is highly desirable in that it may allow the use of thinner pavement structure over a compacted subgrade. When soil particles are forced together by compaction both the number of voids contained in the soil mass and the size of the individual void spaces are reduced. From the laboratory test, this change in voids has an obvious effect on the movement of water through the soil. Similarly, if the compaction of both soils accomplished with proper moisture control, the movement of capillary water is minimized. Nearly all soils exhibit a similar relationship between moisture content and dry density when subjected to a given compactive effort. From the laboratory testing for both sampel, a maximum dry density develops at an Optimum Moisture Content (OMC) for the compactive effort used. The OMC at which maximum density is obtained is the moisture content at which soil becomes sufficiently workable under a given compactive effort to cause the soil particles to become so closely packed that most soils. When the moisture content is less than optimum, the soil is more difficult to compact. Beyond optimum, most soils are not as dense under agiven effort because the water interferes with the close packing of the soil particles. Beyond optimum and for stated conditions, the air content of most soils remains essentially the same, even though the moisture content increased.

Standard Proctor tests of the raw soil as well as mixture of soil and stabilizers were performed in accordance with standard procedure to evaluate the maximum dry density and the optimum moisture content associated with that density. The compaction energy was applied by dropping 4.5 kg hammer from a height of 450 mm in five different layers with 27 number of blows/layer. The undisturbed soil were compacted in proctor after few hours of mixing to allow the mellowing period, whereas soil cement mixture specimens were compacted immediately after mixing. The detailed results of the standard compaction tests will be presented.

This section presents the compaction characteristics curves determined for the soils used in the experimental work. Compaction Test were performed on undisturbed subgrade soils as well as the treated/stabilized soils that is 2.5% soil cement mixture as described in chapter 3. The compaction curves obtained for the undisturbed subgrade soil sand treated/stabilized soils are presented.

For the pavement design of new roads the subgrade strength needs to be evaluated in terms of CBR value which can be estimated by any of the following methods:-

1. Based on soil classification tests and the table given in IRC:SP:72-2007 which gives typical presumative design CBR values for soil samples compacted to proctor density at optimum moisture content and soaked under water for 4 days.
2. Using nomograph based on wet seive analysis data, for estimating 4 days soaked CBR values on samples compacted to proctor density.
3. Using two sets of equations, based on classification test data, one for plastic soils, for estimating soaked CBR values on samples compacted to proctor density.
4. By conducting actual CBR test in laboratory.

The california bearing ratio, abbreviated as CBR is defined as the ratio of the test load to the standard load, expressed as percentage for a given penetration of the plunger. CBR = (Test Load/Standard Load) X 100.

4.2 Compaction Test Result for Undisturbed Soil and Soil Cement Mixture

The summary of the Compaction Test results of undisturbed soil as compared with the soil cement mixture is presented. There was almost 2.7% different effect of the stabilizers on the compaction characteristics showed significant change in the compaction characteristic after addition of the stabilizers. The maximum change in optimum moisture content (OMC) and maximum dry density (MDD) for the cement-treated soils were observed to be 1.791% and 14.1% for soil cement mixture respectively. However, the OMC of undisturbed soil sample are lower than the soil cement mixture which is 11.4% but the MDD of undisturbed soil are slightly higher than the soil cement mixture which is 1.863% respectively. Changes in optimum moisture content and dry density with addition of cement are not always predictable. Flocculation of soil particles by cement can cause an increase in optimum moisture content and decrease in maximum dry density for cement-soil mixes whereas the higher density of cement relative to soil can result in a higher density for mixes. Therefore, it is appropriate to use the 2.5% cement content as shown for determination of moisture density relationships as the maximum dry density varies only slightly with modest changes in percent cement content. However, as previously discussed, it is expected that acceptable treatment can be achieved with considerably lower cement contents than those in then that cement content should be used to determine the moisture-density relationship. After the required amount of cement is added to the soil, the blend should be mixed thoroughly until the color of the mixture is uniform.

4.2.1 Data for Undisturbed Soil

Project	**FINAL YEAR PROJECT**	Ref. Standard	BS 1377 : PART 4 : 1990
		Student	LAM'AH BINTI HAJI FAKHRURROZY
		Test	Compaction Test (Proctor Test)
Source/Location	Taiping, Perak	Method	Determination Max. Dry density/Moisture Content
Sample Description	Undisturbed Soil	Date Sample	17/10/2013 Date Tested 18/10/2013

Cyl. Wt. = 4836 (gm) Test No	**1**	**2**	**3**	**4**	**5**
Cyl. Wt. + Wet Sample (gm)	6798	6849	6903	6922	6925
Wt. Wet Sample (gm)	1962	2013	2067	2086	2089
(1) Wet Density : Wt of Wet Sample / Vol. of Mould (Mg/m^3)	1.970	2.021	2.075	2.094	2.097
Container No.	**71**	**E1**	**T1**	**MI**	**A1**
Wt. Wet Sample + Container (gm)	121.1	145.5	139.0	144.2	161.2
Wt. Dry Sample + Container (gm)	115.2	140.8	128.4	131.1	152.0
Wt. Container (gm)	38.9	90.2	35.7	35.0	90.9
Wt. Water (gm)	5.9	4.6	10.6	13.1	9.2
Wt. Dry Sample	76.3	50.6	92.7	96.1	61.1
(2) Moisture Content	**7.7**	**9.1**	**11.4**	**13.6**	**15.1**
Dry Density : (100 x Wet Density) / (100 + Moisture Content) (Mg/m^3)	**1.829**	**1.852**	**1.863**	**1.843**	**1.822**
Maximum Dry Density (MDD)	**1.863 Mg/m^3**				
Optimum Moisture Content (OMC)	**11.4 %**				
Particle Density	-				
Volume of Mould	996 cm^3				
Rammer Wt.	4.5 kg				
Blows/Layer	27 Blows				
No.of Layer	5 Layers				

Table 3: Compaction Test Result for Undisturbed Soil Sample

4.2.2 Data for Soil Cement Mixture

Project	**FINAL YEAR PROJECT**	Ref. Standard	BS 1377 : PART 4 : 1990		
		Student	LAM'AH BINTI HAJI FAKHRURROZY		
		Test	Compaction Test (Proctor Test)		
Source/Location	Taiping, Perak	Method	Determination Max. Dry Density/Moisture Content		
Sample Description	Soil Cement Mixture	Date Sample	07/11/2013	Date Tested	08/11/2013

Cyl. Wt. = 4836 (gm) Test No	**1**	**2**	**3**	**4**	**5**
Cyl. Wt. + Wet Sample (gm)	6702	6800	6867	6834	6788
Wt. Wet Sample (gm)	1861	1959	2026	1993	1947
(1) Wet Density : Wt of Wet Sample / Vol. of Mould (Mg/m^3)	1.878	1.977	2.044	2.011	1.965
Container No.	**A1**	**D3**	**K1**	**M2**	**JJ**
Wt. Wet Sample + Container (gm)	107.5	106	119.9	116.5	119.3
Wt. Dry Sample + Container (gm)	101.2	98.5	110.2	105.4	106.8
Wt. Container (gm)	39.3	38.4	41.5	36.1	38.4
Wt. Water (gm)	6.3	7.5	9.7	11.1	12.5
Wt. Dry Sample	61.9	60.1	68.7	69.3	68.4
(2) Moisture Content	**10.2**	**12.4**	**14.1**	**16.0**	**18.3**
Dry Density : (100 x Wet Density) / (100 + Moisture Content) (Mg/m^3)	**1.704**	**1.759**	**1.791**	**1.734**	**1.661**
Maximum Dry Density (MDD)	**1.791 Mg/m^3**				
Optimum Moisture Content (OMC)	**14.1%**				
Particle Density	-				
Volume of Mould	991 cm^3				
Rammer Wt.	4.5 kg				
Blows/Layer	27 Blows				
No.of Layer	5 Layers				

Table 4: Compaction Test Result for Soil Cement Mixture

4.2.3 Graph for Undisturbed Soil and Soil Cement Mixture

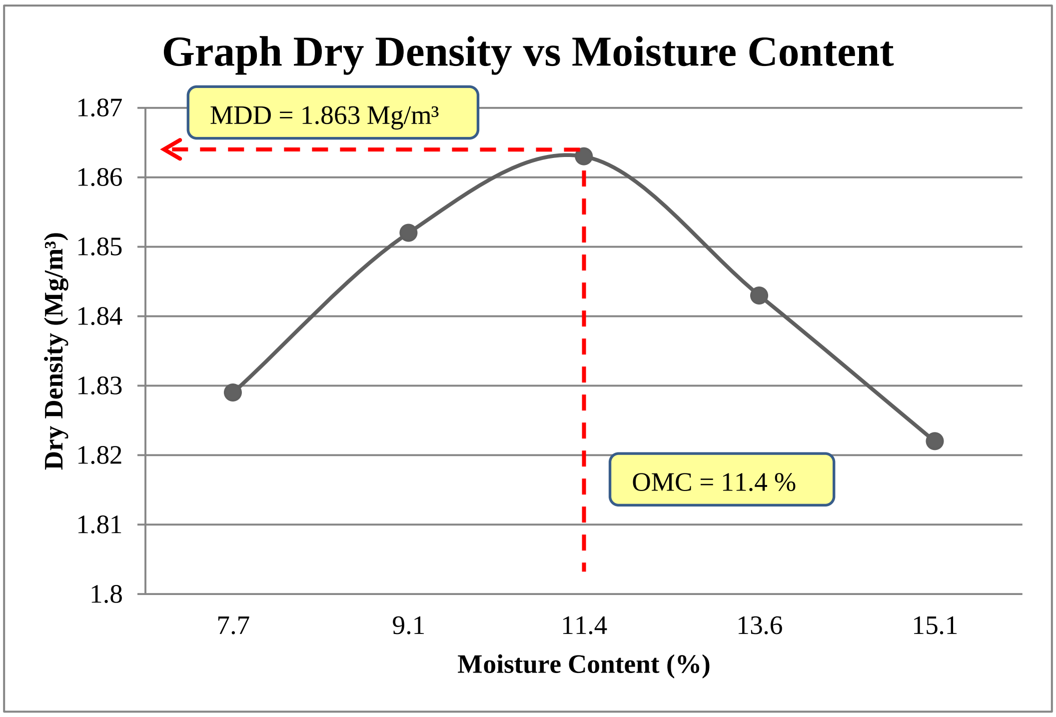


Figure 12: Graph Dry Density vs Moisture Content for Undisturbed Soil

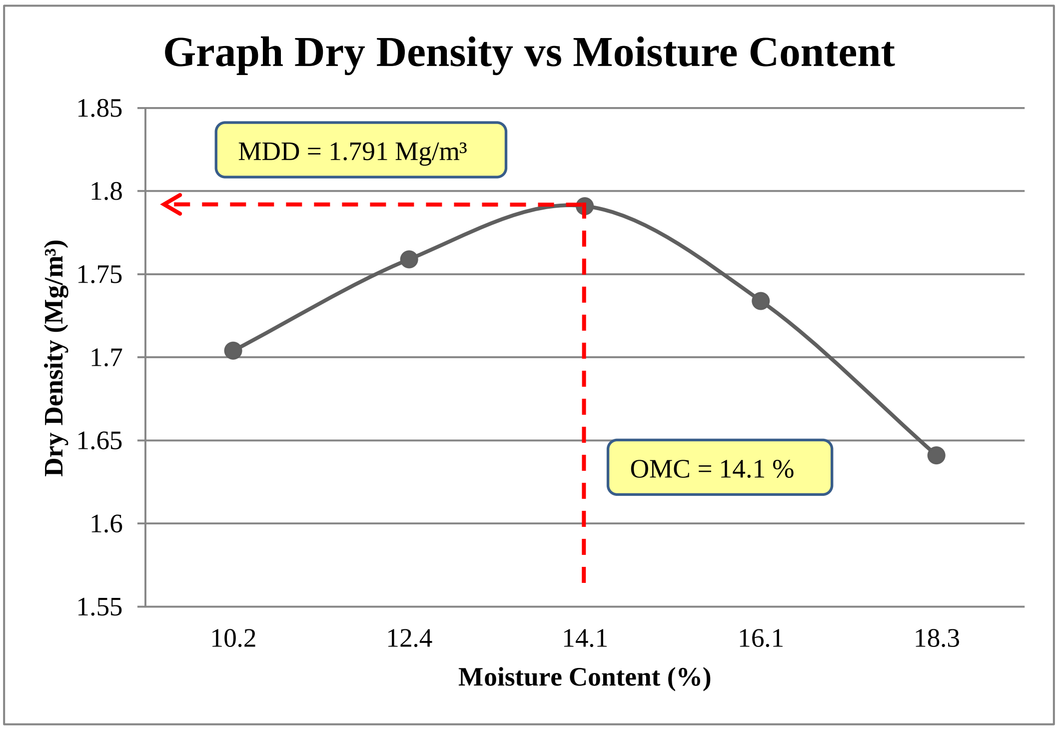


Figure 13: Graph Dry Density vs Moisture Content for Soil Cement Mixture

4.2.4 Sample Calculations

Moisture Content and Dry Density for undisturbed soil and soil cement mixture are calculated. The following example illustrates the method to be used for each specimen:

Undisturbed Soil (Container No. 71)

Wet Density = Weight of Wet Sample /Volume of Mould

= 1962/ 996

= **1.970 Mg/m³**

Moisture Content = (Weight of Water /Weight of Dry Sample) x 100

= (5.9/76.3) x 100

= **7.7%**

Dry Density = (100 x Wet Density)/(100 + Moisture Content)

= (100 x 1.970)/(100 + 7.7)

= **1.829 Mg/m³**

Soil Cement Mixture (Container No. A1)

Wet Density = Weight of Wet Sample /Volume of Mould

= 1861/ 991

= **1.878 Mg/m³**

Moisture Content = (Weight of Water /Weight of Dry Sample) x 100

= (6.3/61.9) x 100

= **10.2%**

Dry Density = (100 x Wet Density)/(100 + Moisture Content)

= (100 x 1.878)/(100 + 10.2)

= **1.704 Mg/m³**

4.3 CBR Soaked Test Result for Undisturbed Soil and Soil Cement Mixture

California Bearing Ratio (CBR) Soaked tests have been conducted on the undisturbed soil as well as soil stabilized with cement (soil cement mixture). 2.5% dosage of cement were mixed well with the peat soil for uniformity and homogenity, before moulding the samples according to the specified standard. CBR test were performed on both samples under soaked conditions. In this study, in order to find the optimum moisture content for undisturbed soil and soil cement mixture, five sample for from both sample were tested to get the optimum moisture content at certain CBR value.

The results of increase in CBR values and optimum moisture content are shown in figure 14 and 15. It appears that the samples with 2.5% cement gives the maximum percentage increases in CBR value for optimum moisture content compare to undisturbed sample after soaking for 4 days which is 93% compare to undisturbed soil 74%. Based on the results obtained, it is possible to conclude that 2.5% of cement as chemically additive would provide the maximum CBR values for the existing soil. Also, based on the result of this test, 2.5% of cement have been chosen as an optimum amount for the stabilization of undisturbed soil samples. The CBR value of undisturbed soil at optimum moisture content 17% are 93% compare to undisturbed soil which is 10% and 74%. The results indicate that as cement amount in the mixture are added, the optimum moisture content and CBR values also increased. Cement as additive contributes more strength to the exiting soil samples. It is because the cement acts as a binding agent and is responsible for the increase in the mechanical strength of the samples. When cement and water are mixed together the cement itself will react with the soil and the cement start to hydrate.

4.3.1 Data for Undisturbed Soil and Soil Cement Mixture

These are the summary of data for five sample of undisturbed soil sample. (Refer attachment for detailed test result)

Undisturbed Soil	
Moisture Content(%)	CBR (%)
7.00	20.90
8.10	64.80
11.30	72.10
16.40	54.00
20.40	22.50

Table 5: Data for Undisturbed Soil

Soil Cement Mixture	
Moisture Content(%)	CBR (%)
14.20	32.90
14.82	53.60
16.90	90.00
17.10	87.00
17.85	20.70

Table 6: Data for Soil Cement Mixture

4.3.2 Graph for Undisturbed Soil and Soil Cement Mixture

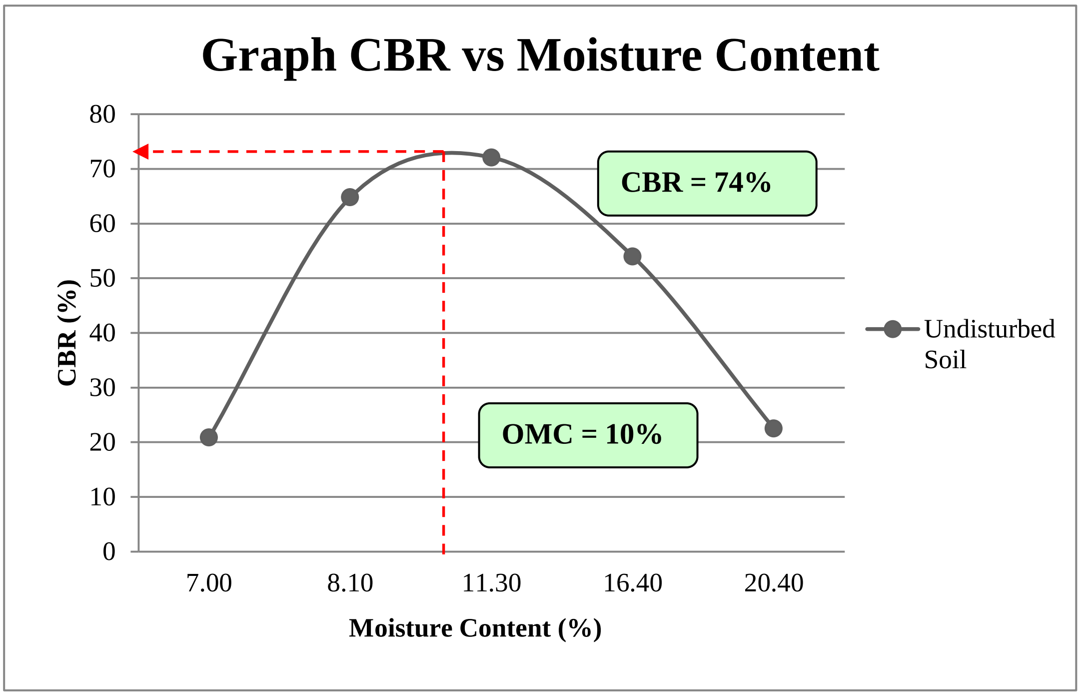


Figure 14: Graph CBR vs Moisture Content for Undisturbed Soil

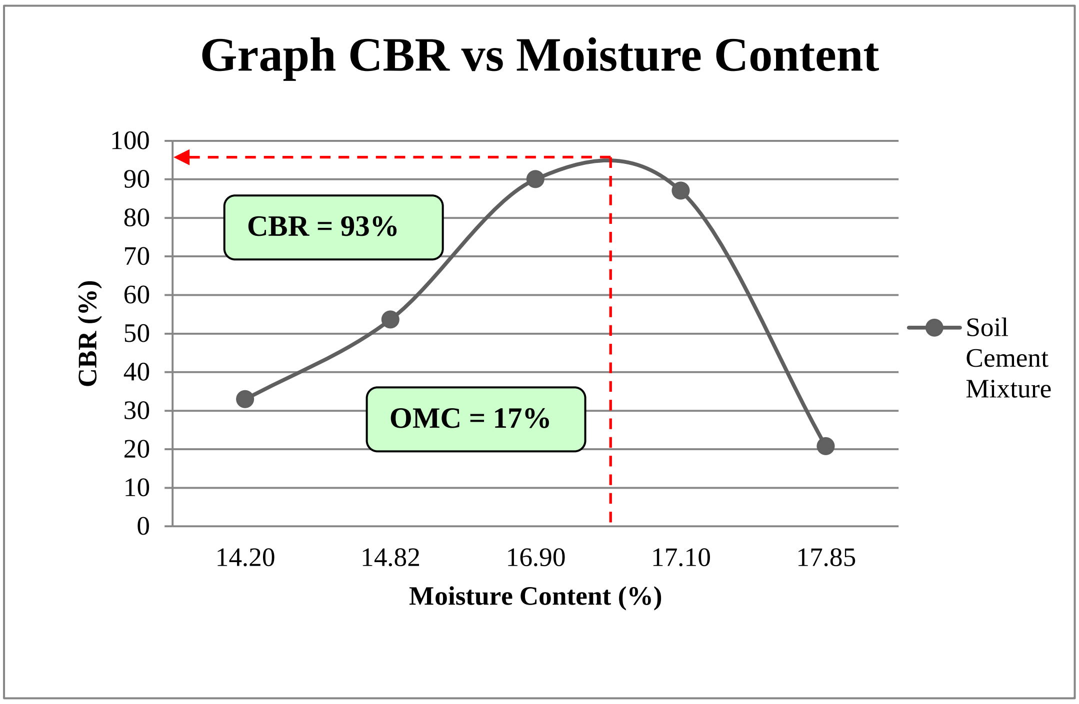


Figure 15: Graph CBR vs Moisture Content for Soil Cement Mixture

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Throughout this research study, the use cement as a chemical stabilizer to stabilize subgrade soils has been recognized, discussed, and analyzed. The research was focused on evaluating and comparing undisturbed sample and soil cement mixturebased on the soil properties and its use to achieve the maxmimum strength. These objectives were determined by conducting the Compaction Test and CBR Soaked Test on different condition of soil specimens. In this study, the comparison of the the undisturbed soil and soil stabilized with cement are investigated as cement act as good binding agent with the existing soil. The result for both test are good and can be applied in the geothchnical engineering as by adding the chemical agent will cause the increases of moisture content and CBR value that can make the soil became more stronger. The soil engineering properties of soil stabilize with cementation have been tested and the quality of the end product also have been compared to the undisturbed sample of soil. Generally, All the test was used for this project because it has been successfully correlated with strength potential of the subgrade, subbase, and base course material for use in road and airfield construction. Overall, the objective for this project was achieved.

5.2 General Recommendations

After completing this research study, the following recommendations are suggested for cementitious stabilization of subgrade soils:

1. Since the moisture contents selected in this study for the laboratory tests beyond the optimum moisture content of raw soils, it was very difficult to compact the soil in the mould manually by dropping the hammer. So, in order to achieve uniform compaction, it is recommended to use automatic compactors.
2. Only one type of cementitious stabilizer, cement, were used as a stabilizing agent in this project. Further research could be done with wide range of chemical stabilizers including quick lime, fly ash, blast furnace slag geopolymers, etc.
3. The study only focused on Compaction Test and CBR Soaked of molded specimens. Further research is recommended to completely characterize the soil stabilization by using various type of laboratory testing such as Unconfined Compressive Strength test, Shear Strength Test, etc.

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