EVALUATION OF COHESION AND FRICTION ANGLE OF KUANTAN CLAYEY SOIL STABILISED BY RECYCLED AND REUSED MATERIALS MIXED WITH LIME

SOLOMON EUGENE PHANG

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Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

This thesis deals with assessment for the cohesion and friction angle of Kuantan soils using variable reused and recycled materials. The objective of this thesis is to evaluate the value of cohesion and friction angle of Kuantan soils and also to determine the optimum percentage content of materials and stabiliser for soil improvement. Soil classification is to be done under USCS soil classification methods. Atterberg limits are tested by Casagrande's method. The thesis describes the triaxial tests done to assess the cohesion and friction angle, and identify the critical amount of stabiliser used. Powdered lime, crushed glass, shredded carpet fibres, fly ash, and shredded high density polyethylene plastic materials were used in this research. The values of cohesion and friction angle of Kuantan soils were done using a semi automatic triaxial machine under unconsolidated undrained conditions. Finally, the cohesion and friction angle of the samples obtained are employed as input to find the shear strength of Kuantan soil. From the results, it is observed that the analysis of using fly ash and crushed glass yields more conservative increment in cohesion and friction angle. The acquired results utilizing high density polyethylene and carpet fibres indicate that when the stabiliser is used at a higher percentage, it gives lower cohesion and friction angle than that the results obtained using crushed glass and fly ash. The obtained results indicate that the fly ash blend produces the highest shear strength.

ABSTRAK

Tesis ini membincangkan penilaian untuk perpaduan dan geseran sudut tanah Kuantan menggunakan bahan-bahan yang boleh diubah dan dikitar semula. Objektif projek ini adalah untuk menilai perpaduan dan geseran sudut tanah Kuantan dan juga untuk menentukan jumlah penstabil yang sesuai ditambah untuk penambahbaikan. Klasifikasi tanah dilakukan di bawah standard. Had-had Atterberg diuji dengan kaedah Casagrande. Tesis ini menerangkan ujian tiga paksi dilakukan untuk menilai peningkatan perpaduan dan sudut geseran, dan mengenal pasti jumlah kritikal penstabil yang digunakan. Serbuk kapur, kaca hancur, serat permaidani, abu terbang, dan polietilena berketumpatan tinggi dikaji dalam tesis ini biasanya digunakan semula dan dikitar semula. Nilai perpaduan dan geseran sudut tanah Kuantan telah dilakukan menggunakan mesin tiga paksi semi automatik. Akhirnya, perpaduan dan sudut geseran sampel yang diperolehi digunakan sebagai input untuk mencari kekuatan ricih tanah di Kuantan. Daripada hasil kajian, didapati bahawa analisis menggunakan abu terbang dan kaca hancur menghasilkan kenaikan lebih konservatif dalam perpaduan dan sudut geseran. Keputusan yang diperolehi menggunakan polietilena berketumpatan tinggi dan serat permaidani menunjukkan bahawa apabila penstabil digunakan pada peratusan yang lebih tinggi, ia memberikan perpaduan yang lebih rendah daripada sudut geseran daripada keputusan yang diperolehi menggunakan kaca hancur dan abu terbang. Keputusan yang diperolehi menunjukkan bahawa campuran abu terbang menghasilkan kekuatan ricih tertinggi.

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LIST OF SYMBOLS

c	Cohesion
σ	Effective stress
ϕ	Friction angle
σ_1	Major principle stress
σ_3	Minor principle stress
τ	Shear strength
Cu	Undrained shear strength

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
CF	Carpet fibre
CG	Crushed glass
FA	Fly ash
HDPE	High density polyethylene
L	Lime
L-CF	Lime and carpet fibre blend
L-CG	Lime and crushed glass blend
L-FA	Lime and fly ash blend
L-HDPE	Lime and high density polyethylene blend
USCS	Unified Soil Classification System
UU	Unconsolidated Undrained

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The field of slope stability evaluates the analysis of static and dynamic stability of slopes of earth, rock-fill dams, excavated slopes, and natural slopes in soil and soft rock. Instability of natural and man-made slopes is a significant engineering problem in Kuantan, Pahang. Geotechnical engineers continue to look for improvement alternatives to reduce slope failures especially sliding of soil (sloughing). Consequently, there is a need to conduct research on alternative slope stabilization of soft soil for the improvement of soil stability. Geotechnical engineering has been critical to highway construction since engineers realized that successful civil works depended on the strength and integrity of the foundation material and embankments.

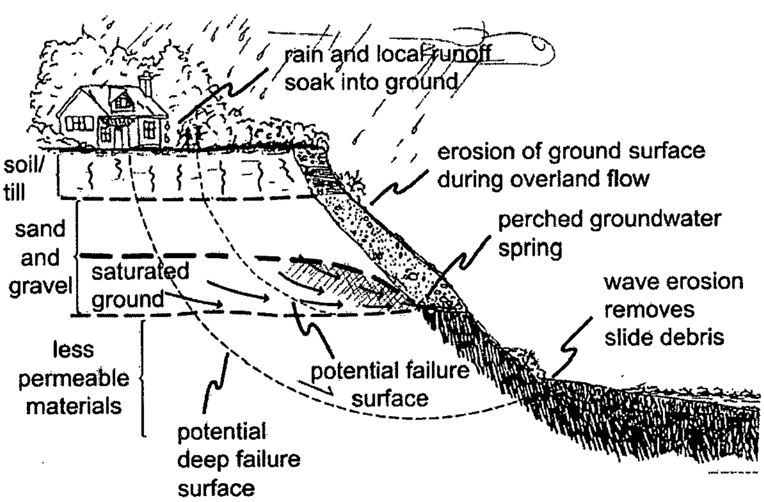

Fig. 1.1 An illustration of slope instability

Road design and construction over and around soft ground especially over very soft soils are engineering challenges. Roads connecting towns and states are constructed based on the shortest route possible and this will eventually go over ever changing terrains. This does not apply on roads but on buildings constructed on and around soft soils. The state of Pahang is in fact, prone to recurring landslides namely at Genting Highlands, Bukit Tinggi, Fraser's Hill, and Cameron Highlands. Soft soils and landslides are not only a problem in Pahang but across Malaysia along the Peninsular and East Malaysia, where it has caused many casualties. To just study an affected slope in Malaysia, it will take around RM 4 million not to include mending and maintaining (Fazaniza, 2013). Despite the fact that engineering slope stability in Malaysia is expensive, many geotechnical options are available from engineers' consideration on slope stability.

Lime stabilization is one of the methods used in soil stabilisation. It was used in many fields around the world including agriculture and geotechnical field to change and improve soil characteristics around Kuantan, Pahang. Hence, this study is mainly for the evaluation of cohesion and friction angle of Kuantan clay to improve its properties by adding lime with reused and recycled materials. This study also investigates the shear strength and the effective stress of the soil sample.

1.2 PROBLEM STATEMENT

In Kuantan, Pahang, there is always a frequent problem of slope instability. This slope instability is causing many slope failures such as sloughing or mass wasting of soil. The sliding slope failure depends on a variety of factors including the influence of gravity, effect of friction on sliding surface, cohesiveness between soil grains, and the presence of water in soil. When the slope gradient becomes steep enough, the driving downslope force exceeds the frictional resistance to sliding and the block slides causes slope failure. On the other hand, economy plays a major role in any construction. Recurring slope failures in Malaysia is charging the country millions and also landfills are getting filled with more waste products from the industrial sector. Hence, this brings in two new problems, the cost for commonly practised soil stabilisation methods and waste disposal.

1.3 SCOPE OF STUDY

The present study is to increase the value of cohesion and friction angle by adding lime with reused and recycled materials into Kuantan soft soil. Lime can be used to treat soils in order to improve their workability and load-bearing characteristics. A significant use of lime is in the modification and stabilization of soil to reduce the sliding action of soil. In this research, reusable materials (CG, FA) and recyclable materials (HDPE, CF) are used extensively to increase cohesion and friction angle of Kuantan soft soil. Soil preparation is done by drying the sample and breaking off lumps of hardened clay into finer particles and the sieving the dried sample with a 5mm sieve. The sample will then be mixed with lime together with recycled and reused materials. Samples are mixed with different water content and compacted. A triaxial test will be carried out to analyse the results yielded from adding the stabilisers. The test requires using unconsolidated undrained (UU) conditions with a constant rate of compression. Data collected will be analysed and recorded upon completion. The area of study includes;

i. Investigating the effects of materials and stabilisers when added to Kuantan soil.
ii. Investigate shear strength from obtained cohesion and friction angle values.
iii. Study the optimum concentration of materials and stabilisers added.

1.4 OBJECTIVES OF STUDY

i. To evaluate the shear strength of Kuantan soil by adding lime with reused and recycled materials.
ii. To determine the optimum percentage content of materials and stabiliser for Kuantan soil improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

The theory to increase soil stability from sloughing problems is to engineer them into a more stabilised soil so that they can last for a very long term. To engineer soil on slopes around Kuantan, soil has to be mixed with certain materials to increase the engineering properties. In this research, Kuantan soil will be mixed with stabilisers which are waste products such as lime, HDPE, carpet fibres, fly ash, and crushed glass. Journals and research papers have stated that the use of such materials exist and will help increase the strength of Kuantan soils. Under several researches, it is noted that there is a difference in the amount of stabilisers used for each blends.

2.2 STABILITY OF SLOPES

Kuantan, Pahang has experienced natural disasters such as landslides and slope failures due to sloughing. Demand for engineered cut and fill slopes on construction projects has only increased the need to understand analytical methods, investigative tools, and stabilisation methods to solve slope stability problems since man-made slope has disrupted the delicate balance of natural soil slopes (Arumogam, 2011). This is due to the lack of planning in dealing with sloping ground. Stability of slopes is usually controlled by several factors mainly regarding groundwater levels and seepage. The use of lime, reused and recycled materials have been used in the past to increase the cohesion factor of the soil and friction angle.

All the materials may increase or decrease the effect of shearing resistance on Kuantan soft soil. If shearing resistance of soil is adequate, the slope is stable. Otherwise, slope tends to move and this causes instability conditions in soil (Arumogam, 2011).

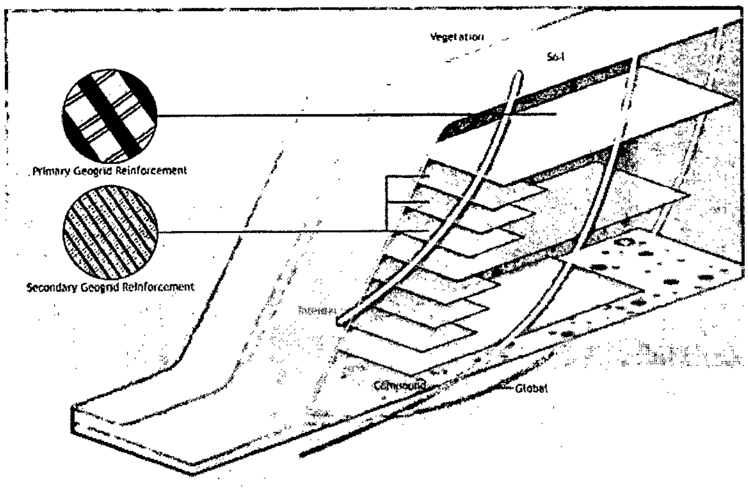

Fig. 2.1 Reinforced soil to increase slope stability

There are many stabilisation techniques applied in soils especially by mechanical means as shown in Fig. 2.1. However, soil stabilisation by soil modification is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material (Indiana Department of Transportation, 2008). To treat soils and stabilising them requires the use of lime as a factor to improve workability and load bearing characteristics.

2.3 SOIL MODIFICATION

2.3.1 Lime as a Stabiliser

Lime is an excellent choice for short-term modification of soil properties. Lime can modify almost all fine-grained soils, but the most dramatic improvement occurs in clay soils of moderate to high plasticity. Combination with lime in specific chemical compositions has self-cementing characteristics similar to ordinary Portland Cement.

It can be added to loam soil containing a high moisture content and organic matter, for sub grade stabilization purposes (Kamon & Nontananandh, 1991). Modification occurs because calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. Thus, the clay surface mineralogy is altered, producing plasticity reduction, reduction in moisture-holding capacity (drying), swell reduction, improved stability, and the ability to construct a solid working platform (Little, 2001). Soil modification is a short term improvement but soil stabilisation is a long term improvement. Soil stabilization occurs when lime is added to a reactive soil to generate long term strength gain through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrate (C-S-H) gels as the calcium from the lime reacts with the aluminates and silicates solubilised from the clay. The full-term pozzolanic reaction can continue for a very long period of time, even decades (Little, 2001). With the addition of lime to soil samples, the benefits can be easily known such as the increase in resiliency of soil, shear strength, and durability.

This soil stabilisation will be able to sustain environmental damage under severe environmental conditions over decades. Benefits of using lime for soil stabilisation also come in the form of economy. In the short-term, the structural contribution of lime stabilised layers in pavement design can create more cost-effective design alternatives. A recent interstate project in Pennsylvania, for example, began with a $29.3 million traditional design approach. An alternate design using lime stabilization, consistent with AASHTO mechanistic-empirical designs, cost only $21.6 million—more than 25 percent savings. The savings came from treating the existing sub grade material with lime rather than removing the material and replacing it with granular material. In the longer term, lime stabilization provides performance benefits that reduce maintenance costs.

To illustrate, stabilizing an 8-inch native clay sub grade with lime as part of an asphalt pavement project can reduce 30-year life cycle costs from $24.49 to $22.47 per square yard (National Lime Association, 2005). In many ways, the usage of lime can help reduce the cost for engineered slopes.

2.3.2 Crushed Glass to Increase Soil Stability

The usage of reusable materials such as glass also has an effect of increasing soil stability to reduce soil sliding. The result will be measured in the direct sliding resistance of soil due to the addition of crushed glass. An investigation is done which includes evaluation of properties such as consistency limits, index properties, shear strength parameters, Unconfined Compressive Strength, California Bearing Ratio, permeability and potential volume change of the soil with up to 20% glass content (Eberemu, Amadi, & Lawal, 2004). The results obtained showed that the liquid limit and plastic limit decreased with an increase in glass cullet content. The optimum moisture content from the compaction test was used to prepare the samples used in Unconfined Compressive Strength test. From the test, cohesion was found to be decreasing with increase in glass cullet content and the angle of internal friction increases as the glass cullet content increased. The unconfined compressive strength test increases as glass cullet content increased.

2.3.3 Addition of Fly Ash as a Stabiliser

Known today, fly ash is generated as a by-product or waste from coal combustion and is used as a replacement for cement in concrete. It comes from the process of combusting coal for electricity and comprises the fine particles that rise upon combustion. However, ash which does not rise during combustion is called bottom ash. In an industrial environment, fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before it reaches the chimneys of coal-fired power plants.

Fly ash properties are unusual among engineering materials. Unlike soils typically used for embankment construction, fly ash has a large uniformity coefficient and it consists of clay-sized particles. Engineering properties that affect the use of fly ash in embankments include grain size distribution, compaction characteristics, shear strength, compressibility, permeability, and frost susceptibility. Nearly all the types of fly ash used in embankments are Class F. The addition of fly ash has also been proven to reduce soil instability.

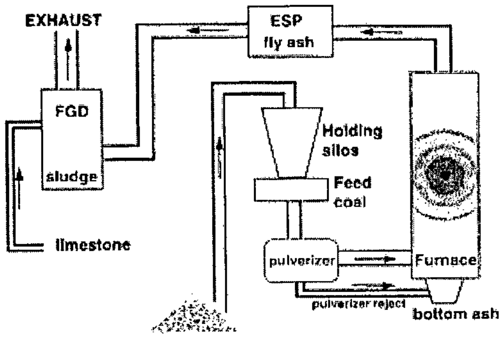

Fig. 2.2 Process of obtaining fly ash from coal combustion

Soil failure that causes sliding depends on the ability of soil to flow especially on soft soil. Fly ash is a non recyclable material and the engineering properties are similar to lime. Tests indicate that fly ash treatment decreases the clay size fraction of the soils and causes the clay particles to amass by cementation (Nalbantoglu, 2003). The cementation properties of fly ash between soil particles is a major factor in limiting volume increase of clays on swelling. Fly ash treatment reduced the swell pressures of both control soils by approximately 67% whereas bottom ash treatment reduced swell pressures of control soils by approximately 56% (Puppala, Punthutaecha, & Vanapalli, 2006). These additions of fly ash to cohesive expansive soils has been shown to making slopes much more stable and limiting the rate of which the soils swell and break off causing soil sliding.

2.3.4 Incorporation of HDPE and Carpet Fibres to Soil

Recyclable materials such as high density polyethylene (HDPE) and carpet fibres are also added to Kuantan soil to improve the engineering properties and stop soil from sloughing. Newman and White has done test sections of high-early strength (Type III) Portland cement and polypropylene monofilament fibres which is similar to carpet fibres were done at the Bradshaw Field Training Area in the Northern Territory, Australia as part of a Joint Rapid Airfield Construction project. Aprons, taxiways, and a helipad were constructed on to top of the soil using the materials in combination. Their purpose of the test section was to evaluate the resulting properties for different stabilization dosage rates.

The soil stabilization technique used a combination of polypropylene fibres and high-early strength (Type III) cement to quickly increase soil load-bearing properties and improve durability (Newman & White, 2008). The use of HDPE and carpet fibres can help to reduce the increase in waste disposal from homes and industries. By applying those on soil, it may be possible to stabilise slopes from constantly failing. From a research done in China, it was found that fibre content had a significant influence on the engineering properties of the fibre treated soil. Cai et al., 2006 stated that an increase in lime content on the fibre treated soil resulted in an initial increase followed by a slight decrease in unconfined compressive strength, cohesion and angle of internal friction of the clayey soil.

2.4 SHEAR STRENGTH

The nature of shearing resistance of Kuantan soil is needed to be understood in order to analyze soil stability problems such as shear strength and slope stability on earth retaining structures such as an embankment. To understand the parameters of this research, the triaxial test is done under UU conditions. This test is usually conducted on clay specimens and depends on a very important strength concept for cohesive soils if the soil is fully saturated. This test is important as it registers the shear strength of each blend over S2 and S24 soils based on cohesion and friction angle of the soil. The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it (Das, 2010). However, the stress-strain relationship of soils, and therefore the shearing strength, is affected by soil composition, soil state, structure of soil, and loading conditions (Poulos, 1988). The soil composition depends on the mineralogy, grain size and grain size distribution, shape of particles, pore fluid type and content. Whereas the state of soil is defined by the initial void ratio, effective normal stress and shear stress. State can be described by terms such as loose, dense, over consolidated, normally consolidated, stiff, or soft soil. However, the soil structure refers to the arrangement of particles within the soil and the manner the particles are packed or distributed internally. Structure of soils is described by terms such as undisturbed, disturbed, compacted, or stratified.

Finally, for loading conditions is dependent on the effective stress path of drained or undrained and type of loading, such as the magnitude of soil. When testing under UU conditions, the undrained strength is taken into account. Undrained strength describes a type of shear strength as different from drained strength where drained shear strength is the shear strength of the soil when pore fluid pressures, generated during the course of shearing the soil, are able to dissipate during shearing. Undrained strength of a soil depends on a number of factors, the main ones being the orientation of stresses, stress path, and rate of shearing. Undrained strength is typically defined by Tresca theory, based on Mohr's circle as following;

$$\sigma_1 - \sigma_3 = 2\,C_u \qquad (2.1)$$

Where σ_1 is the major principal stress, σ_3 is the minor principal stress, and C_u is the shear strength. However, when running under UU conditions, value of cohesion and friction angle can be directly determined from the Mohr's circle. By using the determined values of cohesion and friction angle, shear strength can also be calculated from the following formula (Das, 2010);

$$\tau = c + \sigma \tan \phi \qquad (2.2)$$

The values in the equation are symbolised where c is cohesion, σ is the effective stress, ϕ as the friction angle, and τ as the calculated shear strength of soil.

CHAPTER 3

METHODOLOGY

3.1 MATERIALS AND EQUIPMENTS

This research studies and evaluates the shear strength parameters of soil which are cohesion and friction angle of Kuantan soil. It is then stabilized by recycled and reused materials mixed with powdered lime. The sources of soil sample are obtained from 2 places in Kuantan, Pahang. The two types of soil used in this research study, was obtained from Panching in Kuantan which is recorded as S24 and the other one obtained from Lepar Hilir, in Kuantan which is then recorded as S2. Four recycled and reusable materials in which to be used are mixed with lime for stabilization of Kuantan soil. All five materials used are crushed glass (CG), fly ash (FA), carpet fibre (CF), high-density polyethylene (HDPE), and lime (L). Containers are needed to store extruded samples to proceed to triaxial tests. The machines needed to analyse the soil are cone penetrometer, semi-automatic triaxial machine, proctor compaction machine, and hydraulic extruder.

3.2 PARTICLE SIZE ANALYSIS

A typical sieve analysis involves a nested column of sieves with wire mesh cloth. The equipments for sieve analysis are a sieve set size of No.7, No.14, No.25, No.50, No.100, and No.200. An electronic balance and a mechanical shaker are also used. The first step is writing down the weight of each sieve as well as the bottom pan to be used in the analysis. Then, 3 kg of soil that has already been dried in the oven for 24 hours is prepared. Before stacking the sieves, the sieves are cleaned, and then assembled in descending order by having sieves with the largest opening above, then smaller opening sieves, and the pan at the bottom.

The weighted soil sample is poured into the top sieve which has the largest screen opening. The stack is then placed in a mechanical shaker for 10 minutes. After the shaking is complete, the material on each sieve is weighed. The weight of the sample of each sieve is recorded then divided by the total weight to give a percentage retained on each sieve. The sample retained on the pan is sorted by using sedimentation methods such as pipette method and hydrometer method.

3.3 ATTERBERG LIMITS

3.3.1 Liquid Limit Test

Upon reference standard of BS 1377: Part 2:1990, ASTM D4318 and ASTM D427, the liquid limit test is done by the cone penetrometer method. 200g of soil sample passing through no.200 sieve is mixed with distilled water in successive stages. The wet soil is then pressed against the side of the cup to avoid trapping of air. Soil is also pressed more into the bottom of the cup, without an air pocket. Once the cup is filled, the top surface is finally smoothed off, levelled with the rim using a straightedge. The cup is placed at the base of the penetrometer. The tip of the cone is adjusted by a few millimetres away from the surface of the soil in the cup. The cone is held and the release button is released. The height of the cone is adjusted to that it touches the soil surface. The stem of the dial gauge is lowered to make contact with the top of the cone shaft. Dial gauge reading is recorded. 5 sec is set on the timer, then releasing the cone and record the dial reading. The procedure is repeated with a wetter soil to the cup. 10g of soil is taken from the penetrated area to take the moisture content. It is weighted, oven dried, and weighted again to get the dry weight.

3.3.2 Plastic Limit

The test is performed using about 20g of soil passing sieve no.200. The soil is then mixed with distilled water and spread out on a glass plate. When the soil is plastic enough, it is kneaded and shaped into an ellipsoidal mass. Then the sample is rolled between the fingers or palm of hand against the glass plate with just sufficient pressure. The rate of rolling is between 80 and 90 strokes/min.

When the diameter of the thread becomes 3 mm, the thread is broken into 4 pieces. The pieces are squeezed together between the thumbs and fingers into a uniform mass of roughly ellipsoidal in shape, and rerolled again. The alternate rolling is repeated and continued until the thread crumbles under the pressure required and can no longer be rolled. After crumbling of soil happens, the crumbles are weighted immediately to determine its moisture content. The procedure is repeated on all sample mix.

3.3.3 Plasticity Index

Plasticity index (PI) is the range of water content within which the soil exhibits plastic properties. It is the difference between liquid and plastic limits. To get the value of PI, first we have to complete the liquid limit and plastic limit test. The values taken from the experiment are then used to calculate the plasticity index of the soil. The plasticity index can be calculated once liquid limit and plastic limit are identified, using the following formula;

$$PI = LL - PL \tag{3.1}$$

3.4 STANDARD PROCTOR TEST

To get the optimum moisture content of each specimen, standard proctor test is done. This is because each blend of materials and stabiliser will yield a different dry unit weight. The reference standard for this test is BS 1377:1975, Test 14. The apparatus used are standard compaction mould with base plate and collar, standard mechanical compaction machine, sample extruder, mixing pan, and a trowel. 2.5kg of air dried soil passing 5mm sieve is prepared. The first test is conducted at 5% water content (125mL). Soil is then mixed with materials and stabilisers according to Table 3.1. All percentage of materials, stabilisers, and water is by weight of soil. The compaction mould is weighted and recorded and then fixed to the base plate with its collar. The moist soil is then placed in the compaction mould by 3 layers and 25 blows for each layer.