SUB BASE IMPROVEMENTS BY STABILIZATION TECHNIQUES USING WASTE MATERIALS

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Degree of Master of Engineering in Highway and Traffic Engineering

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Dr.H.R.Pasindu Date

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Abstract

Improvements of rural roads are active socio-economic passageways to a high quality of life for most of the Srilankan people living in rural areas. The fund allocated for low volume road project is limited, thus it is important to use existing resources for economic advantages. Also, adverse environmental impact can be reduced. Roads are designed for low-volume traffic and are constructed of local soils containing high percentages of fines and high indices of plasticity. These type of soils may not have certain properties pertinent for the sub base in the construction of flexible pavement in rural roads. Thus, it is necessary to modify or stabilize this kind of soil to make it suitable for construction. The soil modification process can be effectively used to meet the challenges of sustainability of the environment, to minimize the adverse effect of industrial wastes such as plastic, glass, paddy husks, etc. Wastes are multiplying day by day leading to diverse environmental concerns. On the account, the disposal of those wastes without causing any environment hazards is a real challenge. Therefore, using plastic waste, glass waste & paddy husk ash stabilizing agents is an economical utilization since there are demand and shortage of well graded soil for sub-base. This research involves a comprehensive study on the feasible use of the waste products for soil stabilization for the sub-base material in the North Central Province I-Road Project in Sri Lanka.

A series of field and laboratory tests were carried out for collected sub-base materials to identify the deficiency of sub base material properties. CIDA specification for the roads was referred and confirmed to the specification for the road projects in Sri Lanka. The specification says that Liquid Limit should be less than 40 (LL<40) and Plasticity Index should be lesser than 15 (PI<15). Three different borrow pits Sub-base materials from Polonnaruwa area were stabilized with different percentage of paddy husk ash, plastic waste and glass waste with weight-based mix proportions. But the experimental study of two sub base borrow pits samples such as Mahadamana source and Sooriyaweva source demonstrated that with a 8% and 10% of optimum paddy husk ash. At the same time, the two composite samples from Mahadamana source and Sooriyaweva source were reduced the Liquid Limit by 20%, 26% and reduced the Plastic Index by 26%, 36 % accordingly. Similarly, California Bearing Ratio of the Mahadamana and Sooriyaweva composite samples were improved by 10% and 14.7% respectively. Finally, it was concluded that the stabilized composite soil can be used for the construction of flexible pavement in rural areas with low volume traffic.

Keywords: Sub-base, Stabilization, Liquid Limit, Plastic Index, Wastes, Paddy Husk Ash

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Description
AASHTO	American Association for Highways and Transportation Officials
ABC	Aggregate Base Course
ASTM	American Society for Testing and Materials
BS	British Standards
CIDA	Construction Institute Development Authority
CL	Center Line
EL	Edge Line
I-Road	Integrated Road
LL	Liquid Limit
MDD	Maximum Dry Density
NAASRA	National Association of Australian State Road Authority
NS	Natural Soil
OMC	Optimum Moisture Content
PHA	Paddy Husk Ash
PI	Plastic Index
PL	Plastic Limit
RDA	Road Development Authority
SL	Shrinkage Limit

TRL	Transport Road Laboratory
UCS	Unconfined Compressive Strength
USC	Unified Soil Classification System

List of Appendices

1 Introduction

Sri Lanka has a land area capacity of about 65,612 square km and a population of above 20 million (Geography of Srilanka, 2019). The country has a huge road capacity compared to other countries in the South Asian region (World Data Atlas). In Sri Lanka, large numbers of road rehabilitation and improvement projects are currently going on to improve the road network. The major part of that construction drive is in the arterial roads. Indeed, the road development projects can be categorized into two: new constructions and rehabilitating of existing roads to both arterials and collector roads.

The rural area’s roads are mainly categorized into two groups. One is low traffic volume roads where social use is more essential. Most of these roads are in very bad condition. The second category is high traffic volume roads where economic use is very high. When considering the road user’s needs, their priority is to have safe and reliable access. This can be obtained by rehabilitating those roads, if the access has been lost, is at risk or is damaged.

In Sri Lanka, the Integrated Road Investment Program (I-Road) has been implemented to increase the road network and their connectivity between rural areas and towns through improving the traffic safety and transport efficiency of the identified arterial roads, collector roads and local roads. Remote areas with lack of unrestricted access to the socioeconomic centers have rendered an oversized portion of the agricultural population with poor agricultural productivity, restricted employment opportunities and slow economic process.

The road project is a qualitative and quantitative task, locally obtained materials mostly used in the construction activities to the improvement of existing roads in Srilanka. Additionally to the economic advantages, the utilization of regionally out there material reduces the adverse environmental impacts. However, using such locally available materials create a number of problems including cracks, settlement, and outward movement.

The scarcity of soil not meeting current speciation used in Sri Lanka, the use of marginal soil because of minor deviation of the specifications are critical issues in road construction project. It is observed that the bad quality of the construction soil, especially the classy soil or cohesion-less soil found within the locality may be the most conducive issue for the on top of failures. Thus, the present construction technique and methodology need to be reviewed by means of any improvements to enhance its strength and workability. Therefore, it is very essential to increase the quality of the locally available soil by suitable soil modification technique. Research on this type of soil is essential to determine its performance under different compositions for road construction.

1.1 Problem Statement

In Srilanka, the main problem is most of the roads fail before their service life mainly because of the load accounted for the road, if design is poor than ground real conditions. The structural strength of the pavement is predicated on the number of stress that's functioning on the bottom layer (subgrade layer). Other than that, damage due to moisture is also significant. Therefore, mainly high temperature deformation, fatigue cracking and moisture damage of Sri Lankan road pavements should be improved. For the low value of subgrade impressions, pavement life is long.

The road typically consists of subgrade, sub-base, mixture base course and carrying course. The subgrade, which is created of existing soil, is a very important part of flexible pavement system. However, if the subgrade is constructed by weak and extremely expansive soil, like black cotton, that particular section must be removed or whole soil must be treated. Due to the scarcity of good quality material, it is worth to fill the knowledge gap of how to use marginal materials for sustainable development in the road industry. If the chosen soil is not available within the close locations and it should be imported from very faraway, then there is a rise in price and time of construction. So, it should be improved by using soil modification techniques.

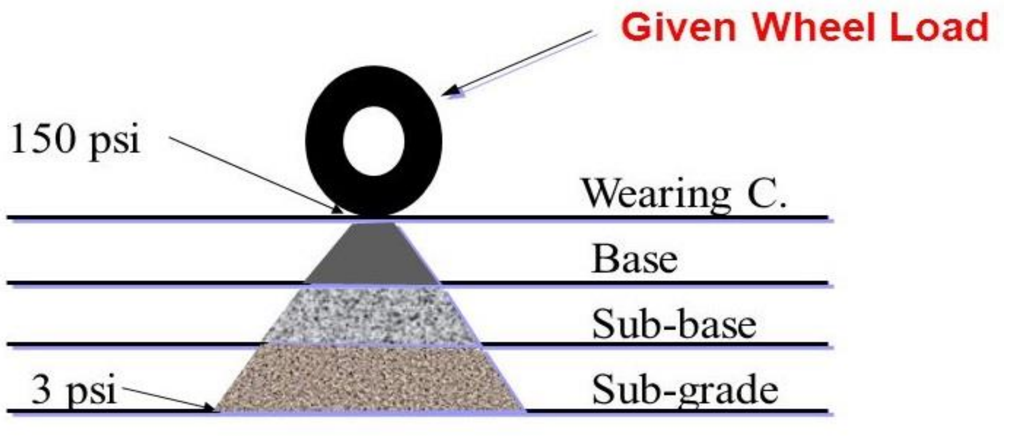

Figure 1: Load distribution in flexible pavement

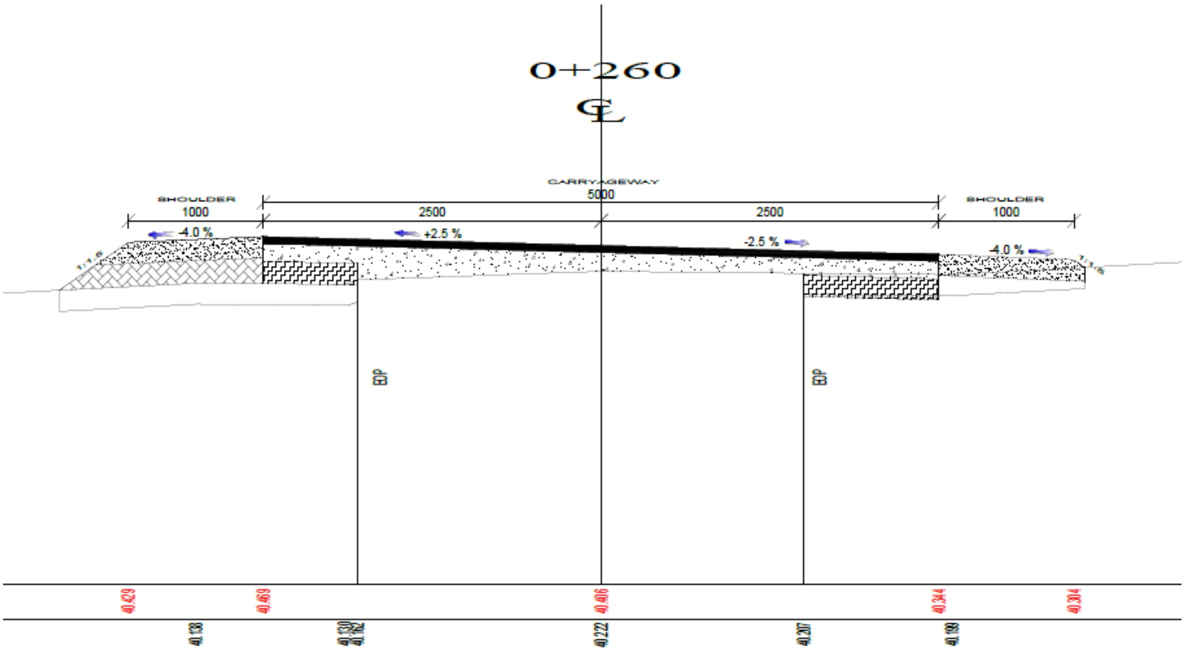

Figure 2: I Road typical cross section (Road NO 64-Polannaruwa)

The sub base layer is a secondary load functioning within the pavement system and functions as a further platform to the road base. The sub-base ought to be free from the excessive settlement, cracks, and outward movements and will have good bearing strength for the effective functioning of the paved surface. Road Development Authority, Srilanka specification allows clay soil to be used as sub-base construction material within the specified limits. Although it is defined that this type of soil has more clay and used for the sub base layer, it is very difficult to get the required compaction and bearing strength.

Figure 3: Some problematic area due to Sub base fail in I road Polonnaruwa

It was determined that when compacting the layer, maintaining water content may be a very difficult task. Because of the lack of shear and high plastic property of the particular soil. Therefore, sub-bases construction having higher plastic index soil found to be vulnerable. Even though the use of higher PI soil for the sub-base construction should be limited or modified using soil stabilization techniques. On the other hand, this paper considers the effectiveness of clay particles on the plastic property of soils and additionally considers cases within which particle size distribution, particle form, bearing characteristic and compaction.

Plasticity is the most distinguishing feature of clay soil. It is measured by routine tests on nearly all soils before they are utilized in an engineering structure and provides a better general indication of their different engineering properties. An understanding of the factors that confirm the plastic property of soils can aid within the interpretation of test data, and result in an improved understanding of the performance of clay soils in engineering use. The factors that have an effect on the plastic property of soil seem to have an effect on most of its different properties and alter the behavior of soil.

In several construction activities, the importance of a sub-base layer is ruled by its unique capability to support the vehicle traffic while not normal buckling and twisting or outward movements. A better-quality sub-base is so needed wherever adverse traffic or weather conditions are severe throughout construction. If the requirements of the properties of the material are unavailable, alternative materials should be selected under typical site conditions.

Transporting soil from out locations create the social and environmental issues. Nowadays, getting the mining licenses for barrow pit and transport licenses are very difficult task. There are lots of procedures to be taken to get those licenses. These procedures have taken more time and caused project delay and affected the contractor's cash flow. Because without enough material stock, it is difficult to commence the civil work.

1.1.1 Research Questions

The flowing questions could be imagined at the beginning of the project.

1. What results we should look for in an experiment?

There is a need for preliminary research about the feasibility of soil stabilization and stabilizer for Sri Lanka. Such research should address the questions such as what are the important properties of soil that need to be checked and what are the practices to be followed to improve the key properties of soil and its behaviors etc. Furthermore, testing and quality control issues also should be addressed.

2. What are the procedures to be followed to increase the potency and accuracy of the study?

It's observed that only the variability of the soil properties that are should be considered as an alternative factors and controlled by means of specifications. However specifications have to be compelled and to be supported easily quantifiable element of the soil. Also, this properties might not correlated well with the behavioral of materials and there physical properties. Still, it's the task of the researchers to estimate likely changes within the soil behavior and soil key properties.

3. How this research is going to be successful and unique from other researches?

Another intension of this study is to find out the gaps among the previous researches. Most of the previous research studies have been carried out with two or more stabilizer to enhance the properties of soil. But this research considered only one type of stabilizer to improve the soil properties with the minimum amount of stabilizer.

It should be mentioned that, lot of researchers have been used the PHA as stabilizer for improve the expansive soil, black cotton soil and soft ground treatment. No body used the PHA for improve the pavement material like sub base. Therefore, improvement of pavement material is not an easy task. So, specific properties of that kind of materials to be considered in this study. For an example, drainage potential for the sub base stabilized layer has not been analyzed by previous researchers. Here, drainage potential of the stabilized soil during the sub base construction has been analyzed in this research. Hence, it can be stated that this research provides some new solution for soil stabilization compared to other researches.

Most of the previous research studies regarding the soil stabilization did not consider the field trial. Those are concluded at the stage of laboratory conditions. Therefore, the field trial is very important to make the model study of the research in the field. Thus, this research is going to be done in both laboratory and field. Therefore, construction of sub base layer using stabilized materials will be done to prove the success of research.

1.2 Practical Constrains & Limitation

According to the current practice in I-road project, most of the contractors use the Aggregate Base Course as a sub-base construction material instead of sub-base soil for emerging situations. The soil stabilization techniques are not commonly practiced in the road construction mainly because the selection of a suitable stabilizer and its success within a short period of time is very difficult procedures to do. It mostly depends on several factors such as finding the suitable stabilizer, soil mix design, layer thickness of stabilized soil, compaction criteria and time consumption etc. The best stabilization method must be chosen to achieve desired soil properties. But choosing appropriate technology is challenging job to make it better. It depends on various factors such as:

- Type of the soil which is going to be stabilized
- Stabilizing Availability
- Surrounding environment and Climate conditions
- Pavement system
- Traffic volume and distribution
- Project period
- Project budget

The proper mix design for soil stabilization should satisfy the pavement design of particular layers. As well as it should meet the stability and durability requirements too. To attain those requirements some admixtures need to be added to the mix. Sometimes, it might be difficult if those admixtures or stabilizing agents are lacking and unserviceable or effect the overall cost of the project.

On the other hand, the technique for blend configuration will also play an important role to accomplish the required strength of the soil mix. Most standard design procedures must be done for each stabilized soil by providing appropriate strength values to each mix. These qualities might be as CBR esteem, the compressive quality of the blend. These strength qualities can likewise be utilized in the plan for the thickness of the stabilized soil layer.

The design thickness of the stabilized soil layer is one of the important parameters of the pavement design. Generally, the thickness of a stabilized soil layer is calculated either as equal to the thickness of the base-course provided in the pavement design. Hence, the total depth of the stabilized layer is kept equivalent to the sub base component of the pavement design when considering the following factors:

- Mix proportion and properties of the agents
- Whether conditions & Environmental Factor
- Traffic count and traffic survey
- Pavement is designed for which period

In most of the stabilization method, above factors will not affect the stability and sustainability requirements. However, it is not recommended to follow the above-mentioned considerations if the stabilized mix is weaker than the requirements. So, the stabilization method should be done again separately using another good stabilizer.

Therefore, this research study considered the above benefits, limitations to give the suitable solutions through the soil stabilization techniques. This soil modification gives roadways that perform as well as typical road surfaces. Further it is successfully challenging the field's empirical reliance on the pavement for constructing and maintaining low-volume roads by using locally available soils and environmentally friendly products.

1.3 Cost & Benefits

There are lots of benefits in soil stabilization techniques. Such as:

- ✓ Money-Saving – No need to replace the Aggregate base course for sub base (and associated hauling).
- ✓ Time-Saving – Very quick stabilization process. Also, waiting time associated with natural soil transporting also will be stopped.
- ✓ Less Environmental Impact - Fewer costs, Dispersion of pollutants is lower.
- ✓ Utilization of Wastes - Recycling wastes with this process make reduce the environmental impact and use of existing available soil.

1.4 Objectives

- ✓ To provide the alternative solutions to shortages of sub-base materials in the rural road project and to reduce the demand for natural quality sub-base material.
- ✓ To identify the limitations of soil stabilization used in Sri Lankan pavements and find the applicability of waste materials as a solution by investigating how waste materials minimizes the current pavement distresses.
- ✓ To provide the set of quality requirement of the blended material at different compositions of Paddy Husk Ash, Plastic Waste, Glass Waste to use as a sub-base soil to do the road construction activities in the rural road project in Polonnaruwa District.

1.5 Study Area

Suitable locations where road constructions are taken place were selected. Also, these places must be suitable for future actions. The research study was carried out in North Central Province in part of the I-road project mainly because the data and records could be easily gathered from these places. An area of 7179km^2 is covered under Anuradhapura and 3,403 km^2 under Polonnaruwa district bringing the total area to about 10,582 km^2 in NCP land area (Wikipedia). NCP is the largest land area capacity compared to other provinces and it is about 16% of the Srilanka (Wikipedia).

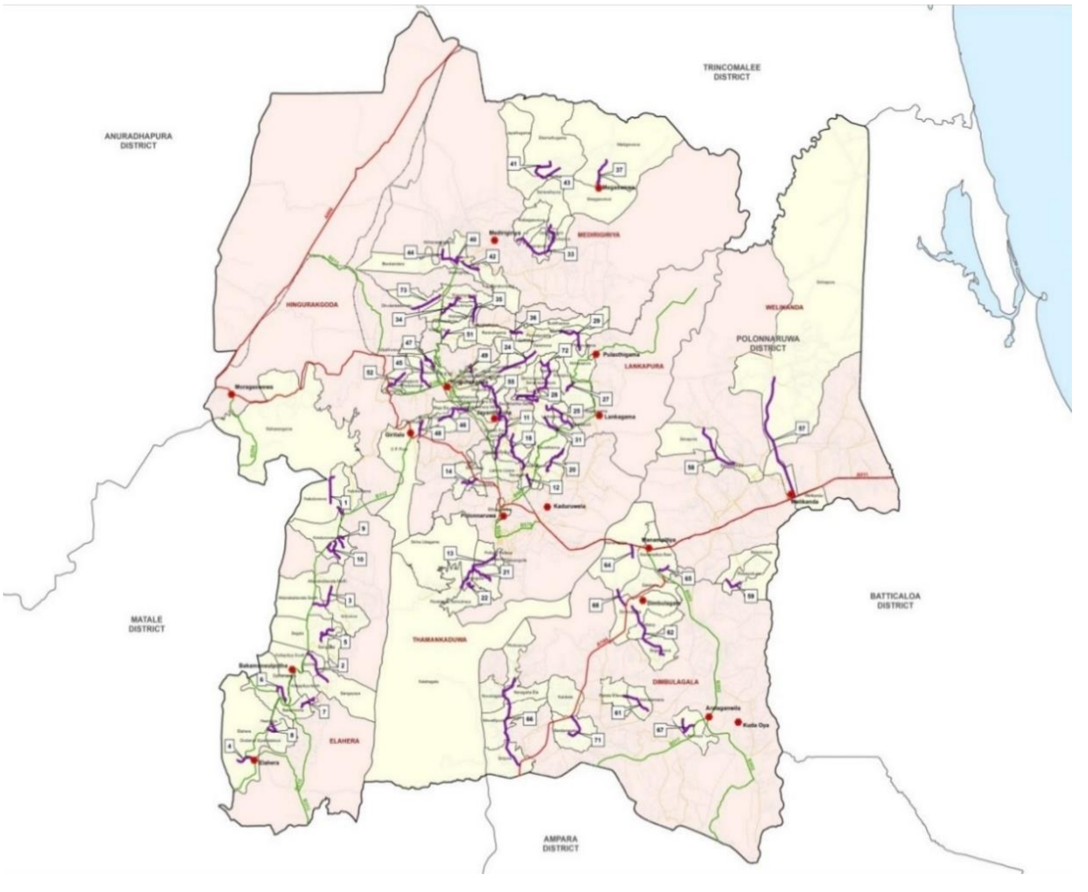

Figure 4: Study Area (Polonnaruwa I road key maps)

When it comes to Polonnaruwa district, during the past six years, most of road construction activities and other infrastructure developments have been undertaken to provide access to the community. The rural road network improvement is very essential to get socio-economic benefits to the community. Within the province irrigation system have been implemented well with a lot of artificial and ancient tanks. Each districts embrace historical cities that relate to the primary kingdoms of Democratic Socialist Republic of Sri Lanka. More care must be taken to avoid any accidental damages to forest, wild life reservation, archeological site and common properties such as paddy fields, water wells, statue located close to selected roads.

Hence, it can be said that most of the lands could not be used for soil mining and other purposes. Thus, locally available quality road construction materials are scarce in these areas. That creates more transport costs involving more travel time, distance and hinders the road development badly in Polonnaruwa area. Therefore contractor could be found out the soil source in the limited location for mining & borrowing purposes.

1.6 Research Approach

In order to satisfy the research study, the following approaches will be considered:

- A brief literature survey of previous and current researches in the areas pf soil stabilization are going to be conducted at the start of the project.
- Identification of suitable stabilization method will be done through reviewing the information available in literature. Laboratory testing also will be used to verify the findings of literature.
- This reviewed literature aiming on the specific properties of both traditional and non-traditional stabilizers, as relevant to this research.
- Material properties and stabilizing agent are going to be examined in every type of materials stabilization. To identify the limitations of soil modification and how waste products become feasible for current conditions of soil stabilization, a laboratory test procedure will be used. The inputs from literature survey will help to identify the relevant test methods.
- The literature survey will contribute to influencing the laboratory test procedures and helped for this research to find out the properties of behavior changes in soil.
- Development of a field trial based on empirical test methods will be done by studying the features of currently available specifications of different countries. The most effective test procedures will be identified and it is

expected to set the requirements according to literature findings and laboratory test results.

2 Theoretical Framework

Fundamental ideas and theories are developed by researchers to explain phenomena, draw connection and create prediction. In this chapter theoretical frame work is used to explain, discuss and evaluate theoretical ideas relevant to this research study. It conjointly provides a transparent basis for interpreting and understanding the relative ideas of research finding. By preparing an extended literature review, it can be identified how other researchers have found and drawn connection between these research studies.

During the literature for this work, quite lots of book on soil and technical research papers from different national and international journals have been referred. This part focuses on the theoretical concept of the improvement of clay soil using various stabilizer agents in the soil stabilization.

2.1 General

Literature survey regarding the soil stabilization were conducted in many areas for identify the stabilizer and materials property. These theories were contributed in determinant the relevance of different mineral dressing ability for different materials. Therefore it is very important for the development of specific guidelines and criteria for productive utilization of the various mineral dressing approaches. Direct and indirect guidance regarding the specific guidelines and research publications on soil stabilization were summarized for a comprehensive review. Direct publications are recommending the stabilization technique for a particular activity. Indirect publications that delivered the use of the stabilizing agent for a particular deficiency in the engineering properties for an available soil material.

2.2 Clayey Soil

The term “clayey soil” is used for soils that have the potential to compress and swell when the water content changes. Some type of saturated clay soils are influencing the water molecules and indicate the changes in volume. Unsaturated expansive clays are another type of soil. Due to its mineralogical composition, it is commonly experiences the large swelling stresses when moistened, Also Large swellings are observed when unloading the soil if the clay is in a saturated condition. (Yesilbas, 2004)

In the literature, these soils are also known as active soils and swell allowable cleats. But although the sidewalks and the roadways sections are generally not sensitive to vertical activities, high maintenance costs must be overcome if they are built on massive soil. Moisture may be due to rainfall, floods, water or sewerage lines or total debris when the area is built over the structure or sidewalk. Generally, above mentioned problem is mostly occurring due to the mineral composition of these soils.

2.2.1 Clay Mineralogy

According to the physical and chemical properties, there are different terms of clays may be categorized. To recognize the clay behavior, first must pay attention to their microstructure.

Most of the clay minerals structure containing alumina octahedron and silica tetrahedron. Aluminum and silicon can partly replace other elements in these units, also known as isomeric substitutes. Silicon-oxygen tetrahedron (silica-tetrahedron) contains four oxygen’s inhabiting a silicon atom.

Combination of both silicon-oxygen tetrahedrons and alumina octahedrons are formed in the silica sheet and alumina sheet.

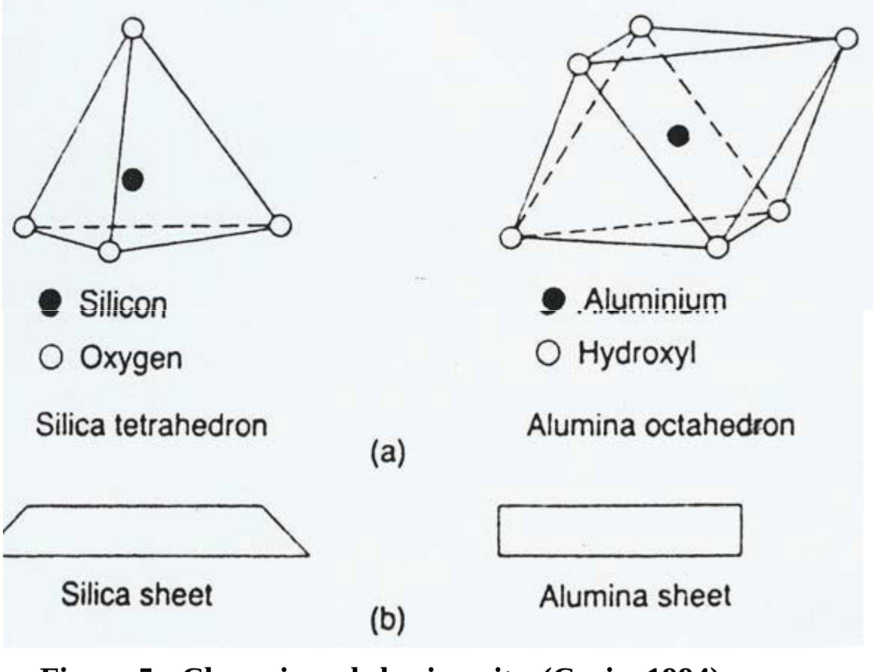

Figure 5 : Clay minerals basic units. (Craig, 1994)

2.2.2 Swelling Mechanism of Clayey Soil

There is a basic mechanism involved in swelling phenomena. Inter particle or inter crystalline swelling, seen in Figure 6 that is suitable for all the clay type minerals. Mostly in the dry clay deposit, the particles hold by relict water and along underneath tension from the capillary action. The capillary force can be relaxed and also the particles will expands if moisturizing clay is present. Whether or not the clay has the shape of particles as shown. The top part of the crystals as shown within the middle part of the figure. There are tiny rushes within the connected layers of the clay crystals. The molecular forces the implying the clay crystals and secured the layer powerfully.

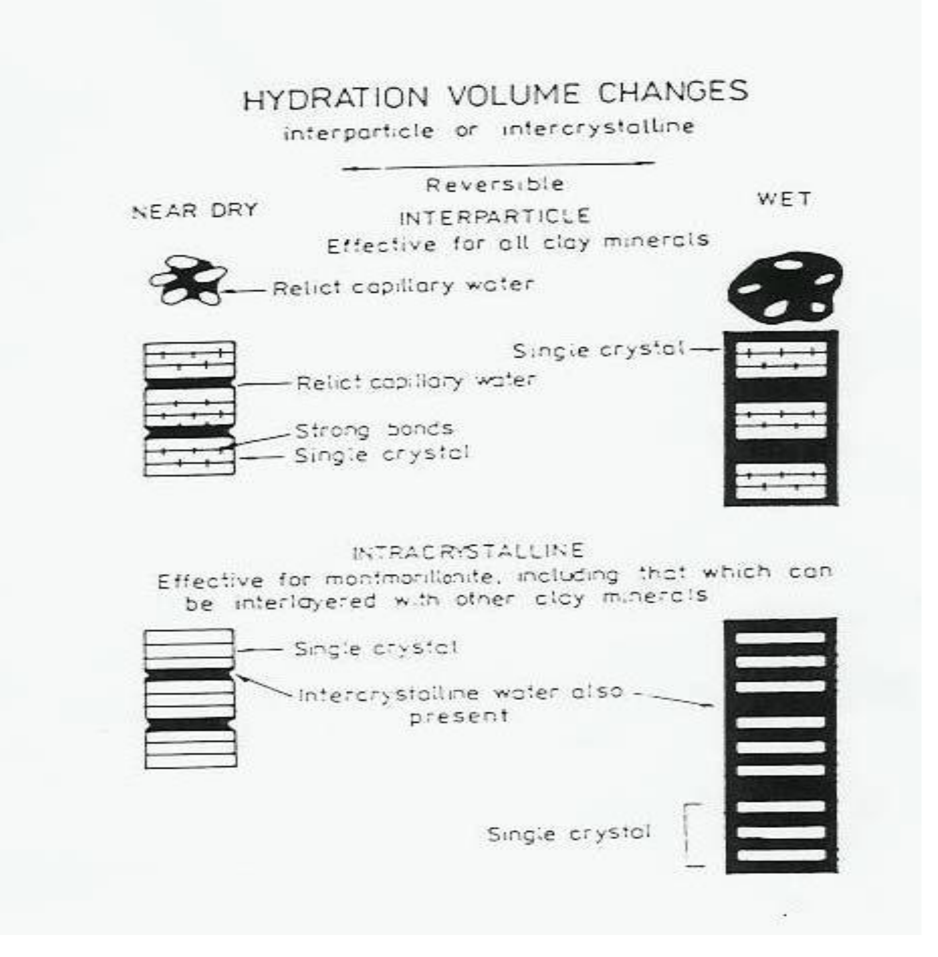

Figure 6 : Mechanism of swelling (After Popescu, 1986)

The potential of swell of soil is the meaning of can presence of enlarging clay minerals. The cations can hydrate on clay surfaces and releasing native strain, that are due to the over consolidation or dehydration of soils. Following soil characteristic such as, mineralogy of the soil, fluid pressure, dry density, voids, permeability and soil structure, primarily confirm the swell potential where environmental consideration like climate, water intrusion, vegetation and field permeableness confirm the particular quantity and swelling rate.

Influencing factor of the swell potential such as environmental conditions and soil properties are categorized in Table 1 and Table 2. (Nesson & Miller, 1992)

Table 1 : Environmental conditions and influences of swelling potential. (Nelson and Miller, 1992)

FACTOR	DESCRIPTION
CLIMATE	Arid climates promote desiccation while humid climates promote wet soil properties.
GROUNDWATER	Fluctuating and shallow water tables provide a source of moisture for heave.
DRAINAGE	Poor surface drainage leads to moisture accumulation or ponding.
VEGETATIVE COVER	Vegetation (trees, shrubs, etc.) deplete moisture from soil through transpiration and cause accumulation of moisture areas denuded of vegetation.
CONFINEMENT	Larger confining pressures reduce swell; cut areas are more likely to swell; lateral pressures may not equal vertical overburden pressures.
FIELD PERMEABILITY	Fissures can significantly increase permeability and promote faster rates of swell.

Table 2: Soil Properties that influences of swelling potential. (Nelson and Miller, 1992)

FACTOR	DESCRIPTION
INITIAL WATER CONTENT	As the initial water content increases, initial degree of saturation will increase, affinity of soil to absorb water will decrease and the amount of swelling will decrease.
INITIAL DRY DENSITY	The higher values of initial dry densities cause closer particle spacing, greater repulsive force between particles, larger swelling potential and pressure.
CLAY CONTENT & MINERALOGY	Clay minerals which have swell potential are montmorillonites, vermiculates, and some mixed layer minerals. As the percentage of clay increases swelling potential increases.
COARSE GRAINED FRACTION	The more the amount of fine particles the higher the swell potential and swell percent.
COMPOSITION OF SOLIDS	Active clay minerals are composed of montmorillonites and mixed layer combinations of montmorillonites and other clay minerals.
CONCENTRATION OF PORE FLUID SALTS	High concentration of cations in the pore fluid tends to reduce magnitude of volume change.
COMPOSITION OF PORE FLUID	Prevalence of monovalent cations increases shrink-swell potential; divalent and trivalent cations inhibit shrink swell.
SOIL STRUCTURE & FABRIC	Flocculated clays are more expansive than dispersive clays. By compacting at higher water content or by remolding, fabric and structure are changed. Kneading compaction create dispersive structures with lower swell potential than statically compacted soils.

2.3 Atterberg Limit

Initially, Atterberg limits criteria were developed by Hogentogler and Willis (1936). This is the basis of AASHTO M147 and ASTM D1241 specifications for the quality control of unbound base and sub base materials. The Atterberg limit is the essential nature of fine-grained soil when water content are changing with in the soil, it's going to seem in following four states.

1. Liquid State

2. Plastic State

3. Semi-Solid State

4. Solid State

Figure 5 shown four consistency stage, with the relevant consistency limits. (Swedish Agriculturist Atterberg, 1911)

In every stage, the consistency, behavior and properties of a soil are completely varying.

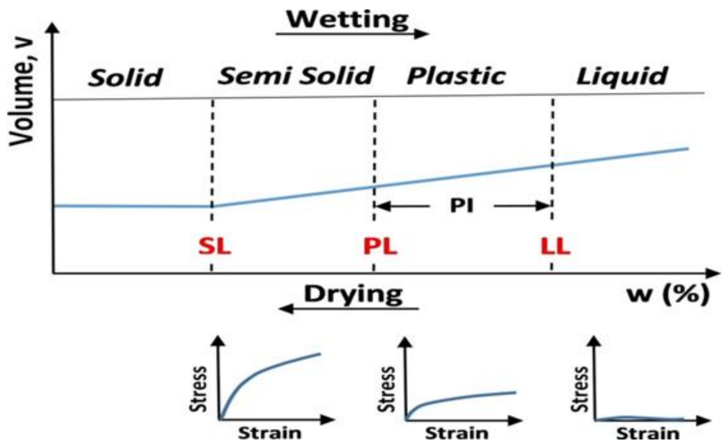

Figure 7 : Soil consistency limit graph

2.3.1 Liquid Limit

Liquid limit is the minimum wetness content at that a soil undergone the application of a smaller shear force (GTM, 2015). The exact concept of the liquid limit is based on the ASTM International D4318 test procedures. Liquid Limit may be determined victimization of the Casagrande cup methodology or a cone penetrometer.

If the water is added to dry soil, its stability changes. If the water is added to fine-grained soil, its consistency changes from hard to semi-solid. Again, continuously water is added to the soil, which can change its state from semi-hard to plastic consistency and eventually reach the liquid consistency stage. Once the soil reached liquid consistency, it failed to maintain a coherent resistance to stay its shape as the same and it'll begin to distort its shape. Therefore, the amount of water is chargeable for this state of soil consistency is called the maximum liquid limit of soil. In alternative words, that will outline the boundary of a liquid as "the minimum quantity of moisture in that is remains during a liquid stage, however incorporates a small shear resistance against flow".

2.3.2 Plastic Limit

The Plastic Limit, which is called as a lower plastic limit, is that the soil moisture changes from the plastic stage to a semisolid stage. The Plastic limit test is carried out by hand and rolling of a sphere shape by deforming of soil mass on a non-porous surface. Then the sample to be remolded and therefore the test will be repeated. Once the suitable size rolls are created, their wetness content is assessed using the procedure delineate previously. (ASTMD4318)

If the wetness content is increase, soil can changed from semi-solid to plastically. Plastic Limit (PL) is that the amount of moisture, expressed as a percentage of the mass of the oven-dried soil at that the soil will be rolled into threads of 3mm in diameter while not the threads crumbling. (ASTMD4318)

Plastic Limit, PL= (Mass of Water / Mass of Oven Dried Soil) *100

2.3.3 Shrinkage Limit

The shrinkage limit (SL) is described as at which stage, the soil moisture changes from a semi-solid to a solid stage. At that stage of moisture content, the volume of the soil mass will change with further drying. The shrinkage limit is less frequently follows up in laboratory testing activities than the liquid and plastic limits. ASTM International D4943 method is used to determine the shrinkage Limit.

The determination of shrinkage limit as follows.

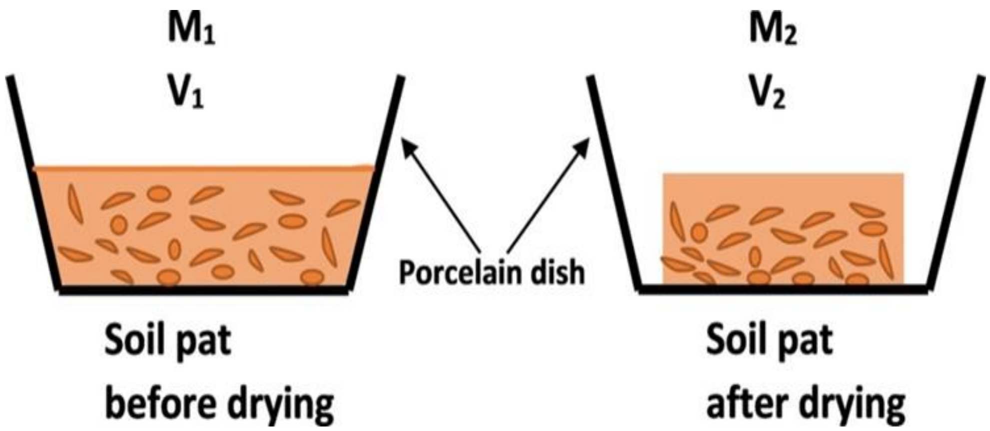

Figure 8 : Soil shrinkage limit diagraph

The shrinkage limit is calculated from:

SL = (W1 - W2) - (V1 - V2) * ρw) / W2

Here,

W1 = Wet weight of soil at beginning

W2 = Dry weight of soil at final

V1 = Volume of soil at beginning

V2 = Volume of dry soil at final

2.3.4 Plasticity

It is described that the cohesive property of the soil has the power to vary form while not tearing or resizing. Conforming to Goldschmidt's theory, plasticity is caused by the occurrence of fine clay minerals. Within the variety of scales, that can carry an electromagnetic charge on their surface. The water molecules are dipole and are oriented like a small magnet within the magnetic field next to the surface of the soil particles. If the water molecules becomes terribly viscous and close to the particles, the space will increase and the viscosity of the water reduces until there is normal water at a certain distance.

When there's enough water (relating to the stage of plastic consistency), the particles are released with molasses water. Thus, that enables the molecules to slip between them to new locations with none tendency to come back to their previous positions, while not ever-changing the dimensions of the holes and while not weakening cohesion.

2.3.5 Plastic Index

The meaning term of Plastic Index can state that the range of water content over that soil particle act as plastic. Thus, the range calls up value of plastic index of the soil. If the soils has higher plastic index are subject to more compressible. The plastic index is also a determination of cohesiveness of soil. The higher value of Plastic index stipulates a higher value of cohesion.

PI is calculated from the difference of the liquid limit and the plastic limit. If there a greater difference, the plasticity of the soil is high. If the soils has higher Plastic index, it can say soil has more clay content. If the soils has lower Plastic index, it can say soil has more silt content. In case of sandy soils, there is not necessary to determine the plastic limit. If the plastic limit shall not determine, the plasticity index is called as NP (non-plastic). (GTM, 2015) The normal equation as follows,

PI = LL – PL.

2.4 Impact on PI, LL on Performance of the Sub base Materials

2.4.1 During Construction

In the road flexible pavement system, the sub base layer shall provide a very good stable platform and give the uniform base support. Another more important function is changing the layer stiffness gradually from bottom of the base layer to top of the subgrade layer. In this regard instantaneous changes can induce the shear stress. These shear stress mostly affect the pavement edges and along the corner as well. The stiff sub bases haven't the fully interaction between the base, environmentally induced failure might happen in the base. Thus, cause shorting the fatigue life of the pavement system.

If the stabilized soils has more fines and gravel or granular material has more fine than fifteen percentages 75micron sieve are impermeable themselves. Therefore, these kinds of substance materials not affected by water penetration without delay from the top. In some situations layer can drain freely, if the sub-grade itself is permeable. So, it is now not essential to furnish vertical drainage. If this turns into viable with the aid of making sure that every layer of the pavement is greater permeable than the layer above it, then an extra drainage layer thru the shoulders will no longer be required. (Croft.j, 1967) It is well understood that, if the sub base layer soil has low permeability that could reduce erosion. But, if any erosion that will happening, the loose material will be highly contribute to liquefaction and transportation. High permeability of sub base limits the development of pore pressure and liquefaction. (Youn su Jung, 2012)

However, excessive amounts of water cause lubrication between the particles and decrease the effective stress and aggregate strength (Abdolreza Osouli, 2018). Also, higher moisture content softens the sharp edges of the angular particles, which ultimately accelerates the rutting process. Since the base and sub base layers may be compacted with moisture contents other than optimum, it is critically important to identify the strength of the aggregates within a range of moisture contents.

The decreasing plasticity would consequently result in decreasing swell ability of the soil samples. All the resulting blends had liquid limit less than 50%, evidence of lower plasticity. Such blends are suitable for road base construction (Samuel Jjuuko, 2011)

Materials having liquid limit greater than 50% are indicative of high plasticity soils. This type of soil very sensitive to water content, more focus should be placed on the compaction methods used. If the soil has more LL, easily to absorb more water and react faster with soil. Thus, the soil becomes liquid stage quickly and the compaction process becomes more difficult. Therefore, workability of the soil is less during the construction.

2.4.2 For Sub-Base Strength Characteristics

Plastic properties of soil such as, plastic limit, liquid limit and plastic index are strongly affect the soil strength (Faiz, 1971). The bad influence of the excessive plasticity index on material strength was once discovered to be aggravated through which include extra fines content to the soil (Tutumluer Erol, 2016).

The sub base layer functions as prevent the pumping, reduce the draining, preventing to the change volume of bottom layer. Hence, it will increase the strength and undertaking the construction activities. A soil that contains sufficient fines to fill up air voids among the soil particles and increase the grain-to-grain contact increase the shear resistance and gain its strength as well. If the material has more density and less permeability, it may be difficult to compact but is ideally has more stability.

A soil that contains more than enough fine particles to fill up air voids among the soil particles, there is no grain to grain contact. Also, the particle will slip and float when water added in the soil. So, this type of soil has low density, it is practically impervious in addition to that this type of soil is quickly distrusted by heavy weather conditions due to lack of stability.

McDowell (1966) differentiated the AASHO and Texas specs for sub base soil and concluded that the AASHO limits on PI and LL are restrictive for Texas and that for Texas, these soil constants confirmed no relationship with the overall performance of roads. He counseled that the limits on PI and LL be raised to 12 percentage and 35 percentage respectively. This would preserve specifically for materials with low portions of fines. Other outcomes received in the research propose that the impact of plasticity on the stability of a soil-aggregate mix relies upon to a great degree on the quantity of fines in the mix. When the quantity of fines is small, the impact of plasticity turns into insignificant. As a long way as omit grading the material, between the No. 30 and No. 200 sieves used to be concerned, the soil-gravel mixes confirmed sufficient strength characteristics even though the plasticity index and liquid limit had been above these specified by way of AASHO.

2.5 Principles of soil stabilization

Most important factors should be considered in the soil stabilization are type of stabilizer, amount of stabilizer, and degree of pulverization, mixing time, and mixing method. In addition to those factors compacting time (time difference between mixing and compaction) is an important factor to achieve target strength in the stabilized samples.

There are many situations where the strength and other properties of the soil have to be improved by ground improvement techniques. Many techniques of soil improvement to be discussed in the literature review. Mainly, there are two types of stabilization; Mechanical stabilization (granular stabilization) and admixture stabilization (blend with cementing materials such as cement, lime fly ash etc. Further, greater attention is now being paid to use other low-cost stabilizers (Quarry dust, Plastic waste, Glass waste, Building waste, Paddy Husk Ash etc.).

Both the advantages and disadvantages are together with each type of stabilization techniques. Through the soil stabilization following advantages might be achieved such as improvements in gradation, plasticity decreases, potential for swell decreases, long term durability, and increases in strength.

2.6 Soil Stabilization by Waste Materials

The great problem in Srilanka is disposal of wastes. The components of solid wastes in Srilanka mostly consist of polypropylene product, building waste, clothes, food cans, paper based product, glass materials and paddy husk ash. These disposals can be a hazard full to the surroundings due to the fact they can end result in pollution in the close by society considering that they are normally non-biodegradable. Many industrial wastes comprise a massive quantity of silica which is the fundamental element of cement altering materials. Despite this quantity of silica content, tremendously has been executed to observe the potential of this waste for soil stabilization.

A stabilizing agent is the mechanical or chemical additive used to increase the strength, durability and stability, decrease moisture sensitivity, or otherwise increase the soil properties. In typically soil, stone aggregates, sand, bitumen, cement amongst others are used for road construction. However, the economy of sourcing for and processing such materials in sufficient volume and satisfactory is on the increase. In presently many of researches are on-going to become aware of and increase alternative materials sources for road construction. The industrial waste products are one of such alternatives.

Finding a proper room for the utilization of these wastes in sustainable manner would be an effective way of getting free of them. Many studies emphasized that successful waste utilization could result in large financial savings in construction expenses. The most related environment pollution and disposal issues can also be considerably reduced, if these materials can be developed and suitably utilized in road construction. (Kamon & Nontananandh, 1991)

2.7 Mechanical stabilization

Properly proportioned materials when sufficiently compact to get a mechanically stable layer, the technique is referred to as mechanical stabilization. Thusly, the two primary concepts in this approach of stabilization are:-

1. Proportioning.

2. Compacting.

Mechanical stabilization commonly used for the construction of sub-base, base, and also for improving the subgrade soils of low bearing capacity and highly expansive soils. It has been used as a surface course for low-cost roads such as forest roads when the traffic and mechanical stabilization is probably the cheapest and the simplest method of soil stabilization. In the mechanical stabilization method, compaction process is improve the soil density by bonding the particles much closer and reduces the air voids. When a load is applied on the soil, if water is presence in the soil that acting as a lubricant and increasing compaction.

2.7.1 Glass Waste Stabilization

Glass pieces is brittle and non-biodegradable. It deteriorates chemically like natural rock. Despite as a chemically inactive construction material, it can be used to improve the strength of various road construction materials. The known type glass that consists of approximately 75% silicon dioxide (Si02), Na2O, CaO, and several additives.

The clay soil stabilization done by waste powdered glass. (J.Olufowobi, 2014) It can be concluded primarily based on the effects observed that powdered glass can be successfully used as a soil stabilizer for the reason that it was once capable to produce substantial enhancements in the soil properties. Such upgrade changes covered an increase in the MDD value from 25.37 KN/m3 for the manage sample up to 25.90 KN/m3 for the sample containing 5% powdered glass. As well as success of the higher CBR values of 14.90% and 112.91% gained at 5% powdered glass content material for each the unsoaked and soaked modified samples respectively. In addition, fulfillment of the most values of cohesion and angle of inner friction of 15.0 and 17.0 respectively gained at 10% powdered glass content.

(Jinu Rose Benny, 2017), revealed that the use of waste glass powder in geotechnical purposes and to consider the consequences of waste glass powder on shear strength, compressibility and CBR values of clayey soil via carrying out direct shear tests, unconfined compression tests, standard proctor test, and CBR test.

The literature review was identifying the waste glass materials to be used to the soil as a stabilizing agent by assess its ability to react on clay soil. However, the previous studies mentioned that the determination of specific quantities of the glass powder or broken glass pieces required for adequate stabilization of the clay soil.

2.7.2 Plastic Waste Stabilization

Plastic by products have grown to be a necessary part of our daily life activities in various stages and also in various forms. However, the disposal and dumping of the used and undesirable plastic waste have come to be the predominant issues for the community as well as government. The manufacturing and utilization of new plastic by products are not in balance with its recycling plastic product status. Using raw plastic bottles in the soil stabilization is another approach for the improvement of the subgrade strength of the flexible pavement. It can enhance the load bearing ability and durability of the subgrade soil used in the road construction. Results exhibit a greater and longer-lasting road with extended loading ability and decreased soil permeability. (Anas Ashraf, 2011)

A sequence of California Bearing Ratio (CBR) tests had been carried out on the soil via various proportions of plastic strips proportions at random. CBR tests end result proven that the inclusion of waste plastic strips were increased the strength and deformation behavior of subgrade soils substantially with optimum amount of plastic waste. (Arpitha G C, 2017) From this study, it can be concluded that the CBR value can be accomplished at weight of two percentages of plastic strips were used in the composite mix. Later it is observed that, the additional amount of plastic decreased the CBR value.

2.7.3 Paddy Husk Ash Stabilization

Paddy husk is an agricultural waste obtained from milling of rice. Ash has been categorized under pozzolana, with about 67 – 70 % silica, about 4.9% aluminum oxide and 0.95% iron oxides respectively (E.B.Oyetolo & Abdullahi, 2016).

Table 3-Geotechnical properties of PHA (NAARA, 1986)

Paddy Husk Ash (PHA)	Values
Liquid Limit (%)	94
Plastic Limit (%)	Non-Plastic
Specific Gravity	2.04
Maximum Dry Density (KN/m3)	6.97
Optimum Moisture Content (%)	45.5
California Bearing Ratio (%)	15

The PHA is not suitable for cattle feeding. It is non-biodegradable, it is also be taken in to consideration as an inexpensive stabilizing agent. Bulk amount of availability as well as the properties of PHA have led many researchers to investigate PHA as an alternative for soil stabilization.

Choobbasti A. J, 2011 showed that PHA was an effective stabilizer for reduction of the plasticity of soil. As well as it was one of the most appropriate stabilizers in the low-volume roads and that it was economically effective. Alhassan, 2008 reported that the Unconfined Compressive Strength (UCS) of the soil could be improved together with the optimum amount of 6–8% PHA.

Optimum Utilization of Paddy Husk Ash for Stabilization of Sub-base Materials in Construction and Repair Projects of Roads. (Mehran Nasiri, 2016) The outcomes of above study confirmed that the maximum dry density (MDD) value decreased and optimum moisture content (OMC) increased up to 21.9% with an increase in PHA content. The liquid limit (LL) and plasticity index (PI) also decreased up to 13.3% at the ratio of 9% PHA. The heights unconfined compressive strength (UCS) values had been obtained at optimum of 9% PHA. Their final results concluded that the combination of soil, 9% PHA and 4% of mixture was the good proportion for the better stabilized sub-base layer in the forest road construction. However, this enhancing impact is not as much as the influence of lime.

2.8 Chemical stabilization

This technique is mainly about improving the technical properties of the soil with combination of chemical compounds or different materials and it is commonly cost-effective and low consuming stabilization technique. These components react with the soil slowly. Generally clay minerals contain successive precipitation of insoluble minerals, which bind the soil particle easier. There are a different categories of these chemical admixtures particularly emulsion, modifiers, waterproofing agents, water-retaining agents, water retarding agents and other reactive chemicals.

Taking the cementing agents into account, the materials that are widely used are sodium silicate, cement, bitumen, lime and fly ash. The most important of these are bituminous materials that are used to cover the soil granules to delay or completely stop. Bituminous stabilization is adopted for non-plastic soils or aggregate base course materials (S. M. Lim, 2004)

2.8.1 Lime Stabilization

The stabilization of clayey soil utilize lime has many successful record in several urban and rural area of other country. (Mallela.J, 2004). In order to understand the properties of lime and its reaction with materials, this literature is help to highlight.

Lime is an excellent chemical additive for clayey soils. Commonly lime use to moderate to excessive plasticity soil. (Plasticity index higher than 15). Lime does not work properly with silts and granular materials due to the pozzolanic reaction does not take place. Because, lack of adequate aluminates and silicates in these materials (S. M. Lim, 2004). This reaction happens right away the lime is dissolve in the soil. Clays will lose plasticity and become more friable due to the change in the soil properties. Compaction characteristics, moisture content value, plastic limits and bearing capability are all modified significantly in this reaction. Plasticity and particle size distribution of the material should be taken in to account when selecting stabilizer as lime or cement. The criteria shown in Table 3 adapted from NAASRA (1986) for choose an appropriate stabilizer.

2.8.2 Cement Stabilization

Cement is mainly used to increase the bearing potential of soil through the soil stabilization technique. Due to hydration reaction, moisture content of the soil will be decrease significantly. The soil stabilization of susceptible granular subgrades and sub base material using cement has a long and successful records in some areas of Sri Lankan roads especially for I Road program. Considering the long-life of the roads to limit future maintenance costs, this is a cost effective. (Technical Note Volume One, 2008)

Soil cement provided strength and durability which is outstanding value as a sub-base material. Also, OMC and UCS of stabilized increased with the cement content (Anil Pandey, June 2017).

The gradation envelope is given in Figure 9 which is required for the cement stabilization and Atterberg Limit given in Table 2 (Overseas Road Note 31, 1993)

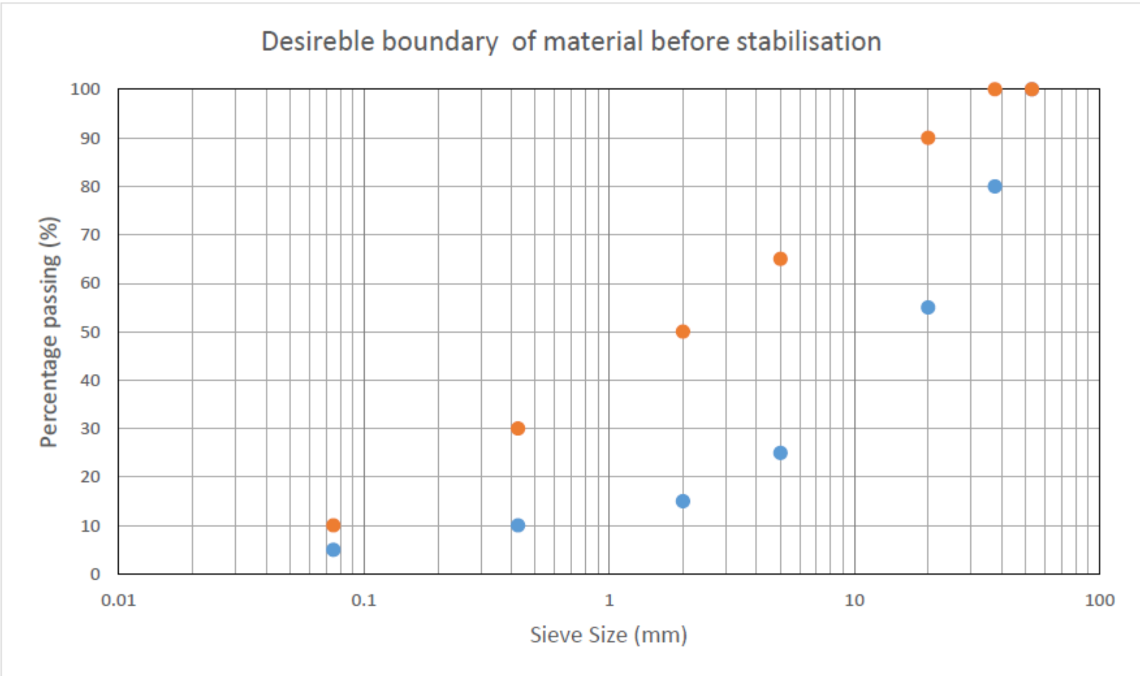

Figure 9: Gradation envelop for material to be stabilized with Cement

Table 4: Material property limit for Cement & Lime Stabilization

Material Property	Limit
Liquid Limit (%)	< 40
Plasticity Index (%)	< 20

2.8.3 Fly Ash Stabilization

Fly ash is the waste material produced from the thermal power plant and usually has a lot of silica and alumina. The fly ash shows some pozzolanic properties, which depends upon its chemical composition. It has the capacity to bind with the soil. The properties of bottom ash and its specific gravity varies according to the own chemical composition which is used in electricity plants. The ash may has greater specific gravity values due to the higher iron contents. An expansive soil contains the silica content; it will react to the fly ash and elevated the stability and strength of the soil. (K Mahendhiran, 2017)

S.Bhuvaneshwari, 2005 published that the soil maximum dry density is obtained for 25% fly ash when present in the soil mix. A.Srirama Rao, 2008 observed that the maximum dry density will increase and optimum moisture content decreases up to the optimum fly ash content. Laboratory Study on Soil Stabilization Using Fly ash mixtures. (Gyanen Takhelmayum, 2013) The above study concluded that the heights strength obtained when fine ash content was 25% more than the coarse fly ash content.

2.8.4 Bitumen Stabilizations

Bituminous stabilization is commonly done with using cutback bitumen, emulsion type bitumen or foamed bitumen. This type soil stabilization techniques are widely use to improve the cohesion of the soil. At the same time it also function as a waterproofing medium. The bituminous material is mainly use to increase the cohesive strength in non plastic and coarse grained materials.

Elifas Bunga, 2011 analyzed the effect of soil stabilization with emulsified asphalt on soil characteristics that can increase its strength. R.D. Linsha, 2016 has used the bitumen emulsifier with laterite soil and kerosene for improve the soil properties.

The height strength was obtained at the ratio of 10 % bitumen emulsion was present in the soil mix.

2.9 Specification and Guidelines

The literature review conducted on the characterization soil in sub base construction and their impact on structural pavement system performance. There are lots of specifications manual give the guidance, requirements, limits and acceptable values for key properties of sub base soil. Such as:

- Construction and Maintenance of Roads and Bridges, Second Edition June 2009, published by the Construction Institution Development Authority (CIDA)
- TRL Overseas Road Note 31
- Technical Notes - Volume 1, Integrated Road Investment Program, Road Development Authority
- AASHTO Classification

According to the specifications the Sub base construction material shall comply with the following requirement.

Table 5: Requirement of Sub base material (CIDA specification (Second Edition June 2009)

PROPERTY	TEST METHOD (AASHTO)	UPPER SUB-BASE		
			Flexible	Rigid
Liquid Limit (LL)	T-90	Not to exceed	40%	25%
Plasticity Index (PI)	T-90	Not to exceed	15%	6%
Maximum Dry Density (Modified)	T-180	Not less than 1,750 kg/m³		
4-day soaked CBR at 98% MDD (Modified)	T-193	Not less than 30%		

Table 1708-3 - Grading Requirements for Upper Sub-base (Section 401 and others)

SIEVE SIZE mm	SIEVE SIZE µm	PERCENTAGE BY WEIGHT PASSING SIEVE
50		100
37.5		80 – 100
20		60 – 100
5		30 – 100
1.18		17 – 75
	300	9 – 50
	75	5 – 25

The stabilizer selection is depend on the plasticity and particle size of the treated soil. Then the selection criteria shown in Table 5 adapted from NAASRA (1986).

Table 6 : Guideline for the type of stabilization (NAASRA 1986)

Type of stabilisation	Soil properties					
	More than 25% passing the 0.075 mm sieve			*Less than 25% passing the 0.075 mm sieve*		
	PI≤10	10<PI≤20	PI>20	PI≤6 PP≤60	PI≤10	PI > 10
Cement	Yes	Yes	*	Yes	Yes	Yes
Lime	*	Yes	Yes	No	*	Yes
Lime-Pozzolan	Yes	*	No	Yes	Yes	*

Notes. 1. * Indicates that the agent will have marginal effectiveness
2. PP = Plasticity Product (see Chapter 6).

2.10 Summary of the Chapter

Many research papers exhibit that the use of PHA with Lime and Cement in clayey soil stabilization is proven to extensively enhance strength and soundness properties of the soil. In engineering practice, the natural soil after stabilization is typically in an unsaturated state, such as excavation filling, embankment filling of road, and earth bund filling. With the exchange in climate and exterior conditions, the water content in the soil changes constantly, which leads to a wider vary of poor pore water pressure (suction) and makes the engineering overall performance more complicated than for saturated soil. Therefore, in addition to reading the curing impact of PHA on natural soil, it is essential to obtain a higher understanding of the soil water character and behavior of PHA with lime and cement stabilized soil.

Mostly in India and Nigeria lots of studies has been carried out using PHA with Lime or Cement in the soil stabilization. But, those are mostly in the expansive clay soils for the sub grade treatment or soft ground treatment. None of researches were carried out to improve the marginal sub base soil using PHA. Even though PHA can produce a strong transition zone and very low permeability with the Cement or Lime if present. Because of the Hydration and pozzolanic reaction of the PHA is higher with Lime or Cement. So, that must be affect the drainage potential of the sub base payment. Therefor Cement and Lime not be suitable in the sub base soil stabilization using PHA.

CIDA (Second Edition June 2009), TRL Overseas Road Note 31(Forth Edition 1993) & I ROAD Technical Note –RDA (Volume 1 April 2018), which are recommend the lime as a stabilizing agent for the soil stabilization based on the plasticity. But there are some draw backs found out from case studies.

- Pure Lime not an environmentally friendly.
- Risk from cracking and carbonation increasing.
- Skill manpower & sophisticated machinery required.
- In Srilanka lime is produced small scale & increase in cost

In general, lime is not a good stabilizer for whole soils. Certain soil elements, such as sulfates, phosphates, organic compounds, etc., may severely affect soil lime inter connection and can lead to obtain poor results using this test method. In most times, it is preferable to get exporter ideas when use it as a stabilizer agent.

However, the cost is increased in recent years to of introducing this stabilizer in the road construction project. In order to mitigate the problems, many scholars have studied new types of stabilizers, which mainly include the industrial and agricultural waste resources in the region where the soil stabilization project has large engineering volume and high environmental protection requirements. So, the door has been widely opened for the development and introduction of other types of soil admixtures, like as building waste, plastic, bamboo, glass, rice husk, etc.

The qualitative analysis carried out using the existing literature shown in the analysis indicates that most industrial waste will be suitable for soil stabilizing to improve the engineering properties of the sub base materials. The literature survey analysis also indicate use of waste as a stabilizing agent. Therefore, it may be wise to choose at least one agent from three stabilizers for a research study.

The alternative selection decision discussed above was based on observations made during the review. A well-designed investigation is necessary to choose and determine the stabilizing factor and its proportion according to soil characteristics and behaviors. Stabilizer agent selection for available material in this study area should consider required bulk quantity, quality, transport, workability, complexity and current practice as decision criteria.

The aim of this analysis is to study the improvement of sub base properties and see if any soil modification techniques is possible. In addition, the study focuses on finding an accurate percentage effect on the sub base soil properties and detecting the relationship among CBR and other important soil factors. In addition, it is important to discover any possible relationship between these properties.

- Check the effect of the exact weight proportion of stabilizer on the sub base material properties.
- Find the important correlations among the soil properties and find fraction of finer particles in a soil.

In this paper, improvements of sub-base material properties given in the specification of Road Development Authority (RDA) referred to the CIDA specification, Sri Lanka and utilization of locally available classy soil as a sub-base construction material have been discussed.

3 Methodology

This chapter gives an overall view of the present study. The approaches used to plan, identify, select, process and analyze the data for a feasible research study are given in a flow chart in Figure 10. The plan of action acknowledge the researchers to evaluate the overall validity and reliability of the research. The following two procedures give some ideas to carry out the methodology.

- Data collection and record review
- Data analysis

After the problem identification, overall research objectives were set. Then literature survey was carried out to identify the current practice of soil stabilization, types of stabilizing agent. Also, several laboratory testing in a samples and their advantages for ongoing construction were analyzed. The ongoing I-road project in the Polonnaruwa area was used as the study area. Available soil sample, Barrow pit, and source approval test reports, frequency test report, Field density test report were collected for the project study area. All the tests were carried out using methods such as BS, ASTM Standards and AASHTO Classification as currently practiced in i-road project.

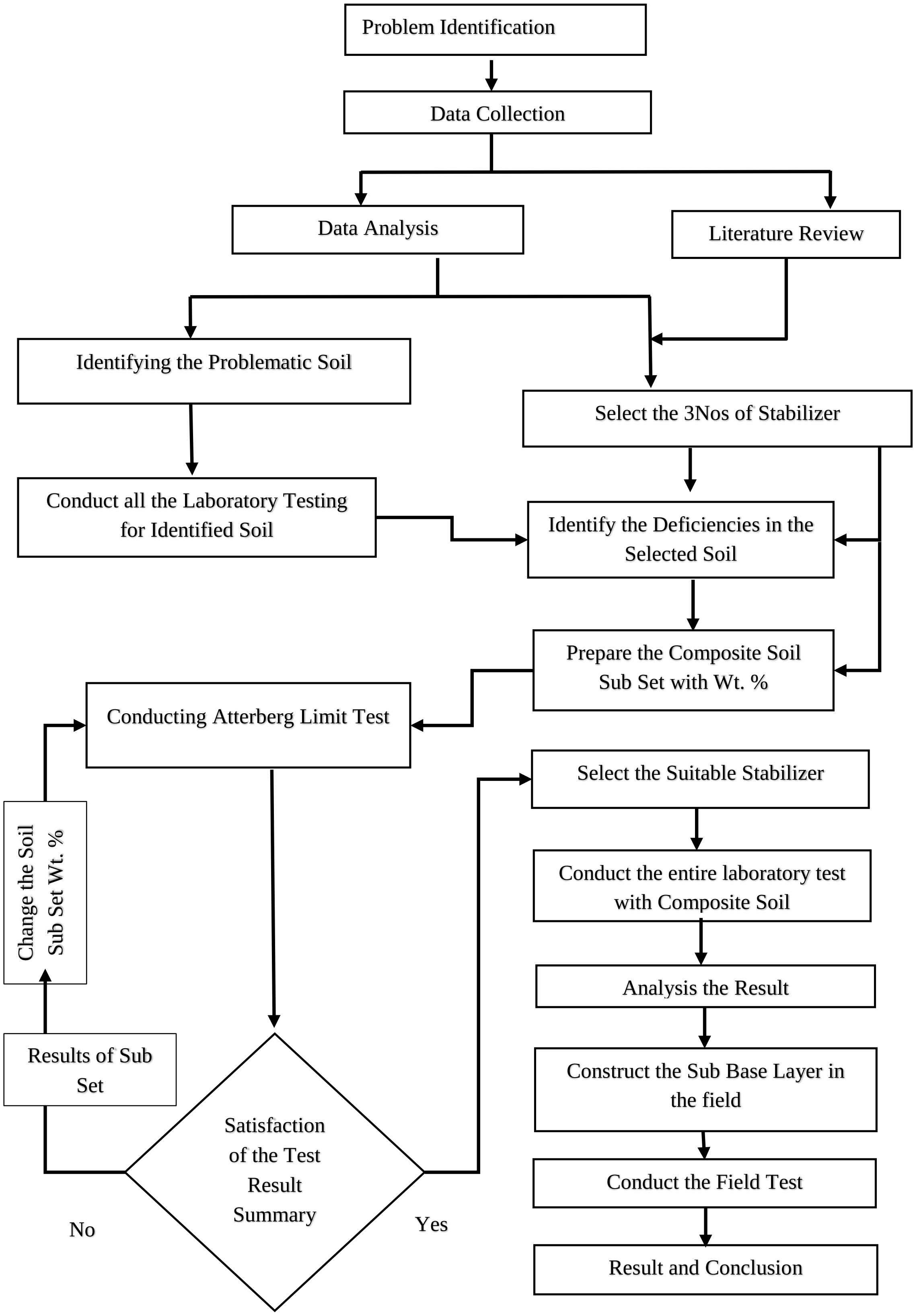

Figure 10: Methodology flow chart

3.1 Method of Data collection

Data collection is a very essential aspect of this research. Faulty data collection can badly impact the results of the research. The qualitative data collection method was used for this study. The qualitative data collection technique is an essential function in having an impact on assessment through giving useful data to recognize the things to do behind the research results. The statistics series techniques need to look at the ethical perception of research. Site visit was carried out to identify the problematic soil section in the study area. During the soil survey, a large amount of soil data of various types and in various formats were commonly collected.

3.1.1 Record Review

Record review is a structural evaluation of information for collected data. The review activities usually consist of a research problem, identification of relevant data sources, drawing up a data extraction plan, checking errors, and distribution of findings.

In this research, review of record was an important process in the investigation of fail locations and identifying the problematic area during the data collection. It helps to identify any deficiencies in the construction of the sub base or any factors that might have influenced the compaction fail locations. A detailed records review was conducted for various data sources with the help of the contractor to obtain the following information;

1. Source details and approval test report.
2. Stock pile details and approval test report.
3. Laboratory test results.
4. Field density test reports of sub base (Compaction fail).
5. Geotechnical information related to Sub base, moisture during the construction.
6. Layer and thickness
7. Time duration for the compaction
8. Machinery status detail.
9. Supervisions and Manpower records.
10. Compaction activity details.
11. No of roller passes details.

3.1.2 Data Analysis

Data analysis is that the aggregation and organizing of knowledge, so a researcher will come back to decide. After the collection of data from various sources, it was cleaned to get error free data sets. Then the collected data was processed and organized for analysis. Because, based on that, the data analysis became closer to the expected outcome. Table 7 below shows the summary of data analysis.

Table 7: Sub base source approval summary form I road Polonnaruwa

S/No	Source / Barrow pit Location	Test Result Summary						Remarks
		Sieve 0.075mm Passing (%)	LL	PI	CBR	MDD	OMC	
1	Hinguragoda1	13.2	28	13	52	2.2	10.2	Accepted
2	Medirigiriya 1	15.4	30	12	40	2.1	10.8	Accepted
3	Mahulthamana	17.2	43	19	34.5	2.01	9.6	Rejected
4	Gravel kantha 1	16.7	41	17	33	2.0	7.8	Rejected
5	Mahasenpura	15.2	40	16	40	2.13	6.8	Rejected
6	Piparathwewa	14.7	35	15	36	2.05	9.2	Accepted
7	Magathamana	15.3	42	19	33	2.01	9.4	Rejected
8	Sinhapura	16.1	48	23	28	1.94	7.9	Rejected
9	Damminna	15.4	43	16	36	1.84	9.0	Rejected
10	Methagampitiya	16.7	45	19	26.6	1.97	9.4	Rejected
11	Meewathpura 1	15.8	46	22	27	2.02	8.3	Rejected
12	Meewathpura 2	15.5	36	13	36.3	2.1	7.6	Accepted
13	Nawagahaella	14.8	30	10	40	2.135	7.7	Accepted
14	Sripura	14.4	35	12	37.7	2.14	8.6	Accepted
15	Bandanagala	16.1	42	17	38	2.02	9.8	Rejected
16	Karappalai	15.9	43	19	34	2.04	10.3	Rejected
17	Singapura	16.8	44	19	36	2.06	9.7	Rejected
18	Muthugala	16.5	42	18	33	2.1	10.6	Rejected
19	Soruvila	17.2	41	22	32	2.08	9.9	Rejected
20	Nawamillana	15.4	31	8	38.5	2.07	8.4	Accepted

21	Sevanapittiya	17.0	42	16	40	1.98	10.4	Rejected
22	Senapuara	14.8	35	12	42	1.95	9.2	Accepted
23	Samanala	15.1	28	14	35.8	2.09	6.9	Accepted
24	Hinguragoda 2	15.6	34	13	40	2.13	7.8	Accepted
25	Medirigiriya 2	15.3	30	13	37	2.17	6.5	Accepted
26	Aluthoya	16.8	40	18	27.7	1.925	12.7	Rejected
27	Sooriyaweva	17.4	46	22	28.5	1.94	10.4	Rejected
28	Welikanda	17.7	48	26	24.5	1.88	10.2	Rejected

Table 8- Rejected Sub base sources approval list from I road Polonnaruwa

S/No	Source / Barrow pit Location	Test Result Summary						Remarks
		Sieve 0.075mm Passing (%)	LL	PI	CBR	MDD	OMC	
1	Mahulthamana	17.2	43	19	34.5	2.01	9.6	Rejected
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13	Soruvila	17.2	41	22	32	2.08	9.9	Rejected
14	Sevanapitiya	17.0	42	16	40	1.98	10.4	Rejected
15	Aluthoya	16.8	40	18	27.7	1.925	12.7	Rejected

16	Sooriyaweva	17.4	46	22	28.5	1.98	10.4	Rejected
17	Welikanda	17.7	48	26	24.5	1.88	10.2	Rejected

The rejected sub base source approval list shows that, most of the sub base soil has been rejected because the Liquid Limit and Plastic Index exceeded from the required specified value. Table 9 illustrates how the rejected key properties vary within the range.

Table 9: Range of the key properties of rejected Sub base

Test Type	Sieve 0.075mm Passing (%)	LL	PI	CBR	MDD	OMC
Range	13.2 to 23.4	40 to 48	16 to 22	30 to 40	1.78 to 2.13	6.8 to 11.2

3.2 Soil Considered

The first exercise was carried out to find a suitable soil source from problematic areas with available materials database. According to database, the undisturbed soil samples were collected in three different borrow pits located at Magadamana, Sooriyaweva and Welikanda in Polonnaruwa. Sampling was done by excavating up to 0.7 m depth after the top soil is removed.

According to Table 9, three-soil samples (PI values ranging from 16 to 22, Liquid Limit ranging from 40 to 47 and CBR value ranging from 24.4 to 28.5) were obtained from Mahadamana, Sooriyaweva and Welikanda borrow pits in different locations. Several properties, including physical properties, engineering characteristic and behavioral change were investigated. The following common observation could be made based upon the investigation performed. Naturally occurring sub base soil was considered for this study. Hence investigation of available soil characteristics was made to comply with specification requirements.

So, the collected sample was prepared and studied using tests such as CBR, CBR Swell, Proctor Compaction, Atterberg Limit and Sieve Analysis. To get more accuracy, the number of tests were conducted repeatedly for at least 3 times (for each sample). Based on these tests, the deficiency of collected soil was determined.

3.3 Selection of Suitable Stabilizer

The stabilized soil layer design factors include bond, stiffness, friction behavior, traffic factor and thickness of layer. Totally, it was considered the sustainability of the stabilized sub-base layer to provide the overall support to the pavement structure. Some other factors such as workability, transferring loads, joint sealing capability, and drain-ability must be encountered during the design stage to avoid the damages due to the erosion.

Based on the result of the natural soil and its deficiencies, the next exercise was carried out to find a suitable stabilizing agent among the selected stabilizer agents. From the literature review summary and considering the project area, the suitable stabilizing agents were selected, which are Glass waste, Plastic Waste & Paddy Husk Ash (PHA). The glass bottles and waste plastic used for this study were obtained from waste collecting center, Polonnaruwa. The PHA was collected from the rice mill Aralaganwilla, Polonnaruwa. After that, it was washed, dried, ground manually into finer particles and screened through 425micron sieve to get the wastes as powder.

The selection process begins with the soil properties including plasticity and sieve analysis, strength and compaction requirements. The first composite sample for each stabilizer was prepared randomly to identify the weight proportion range and how it reacts with when changing the mix proportion. Then the composite sample was well prepared according to the Weight mix proportion range for all three types of stabilizer. From Atterberg limit test method, the plasticity potential was tested to identify the suitability and effectiveness of the stabilizer agents. As well as CBR also was tested in those three materials to confirm the bearing capacity of three selected stabilizing agents.

The aim of this study is to investigate above there stabilizer and its stabilizing effect on the plasticity of clayey soil as well as effectiveness of the CBR value. For determining limits of smoothness, plasticity and contraction on soil sample, the various percentage (weight proportion) of glass, plastic and PHA samples were added into the clayey soil. According to the result, they were compared and the most suitable one was selected.

3.4 Stabilization Process

From the Atterberg Limit test, the most appropriate stabilizer was selected with the limit and its minimal proportion. According to that result, the study has moved on to the next stage of the experiment. Then the composite sample was well prepared with the satisfying weight proportion to find the other engineering properties where its mix proportion will satisfy or not. Even though finer particles than 75 microns size fine are taken into consideration to possess an advantage of varied plasticity, the percent passing 425 microns is taken into consideration to vary the fines. After that, the passing percentages of 425 microns for the clayey soil is calculated from the natural soil sieve analysis distribution. According to that calculation, the required soil weight and PHA weight were used to prepare the composite mixture.

Testing was carried out for Sieve Analysis, Atterberg Limits, and Modified Proctor Compaction, California Bearing Ratio (CBR) and CBR Swell for prepared composite sample. Thus, it was performed to satisfy the minimum standards set out in the specifications for road construction in Sri Lanka and the effectiveness of the research. For more accuracy and to verify the results, the number of replications for every test was considered 2 times.

4 Laboratory Test Results and Discussion

4.1 Test on Natural Soil sample

The determination of the physical properties of soil was carried out through the testing program at their natural state. Following testing program was conducted on soil samples from different three borrow pits soil, which included USC, sieve analysis, Atterberg limits, proctor compaction, CBR and sell percentage.

4.1.1 Particle Size Distribution Analysis

The soil samples were first underwent 24 hours soaking and oven drying and then allowed for air cooling. The sieve analysis test expresses the weight percentage of soil particle passing through each sieve size. The sieves were equipped in apparatus based on the sieve size and then the soil in each sieve was reweighed after being run into the sieves set while shaking them for ten minutes continuously.

The wet sieve analysis was experimented to find the presence of silt, clay and other fine particles. The soil mass is weighed and recorded on the test sheet. Then the soil sample to be placed in a large bowel and saturated with water.

The sample is then washed through the seventy five mm (No. 200) sieve with a protective mesh on the top. Washing is most simply done by the decantation methodology. Using the methodology, water is slowly added to the bowl and therefore the impurities from solid are smartly removed. The surplus water is carefully drained over the side of the bowl through the two mm sieve and into the seventy five mm sieve, ensuring all the water passes through the seventy five mm sieve before running to waste.

After decantation process is completed, the entire sample placed into a 110°F oven for drying to get the sample weight. Once dried, the method continued as a dry sieve testing process.

The above oven dried soil sample weight was calculated and recorded the weight of each sieve. The sieves need to be cleaned and then all sieves are to be assembled in the reducing order of sieve numbers while the pan was put down below #200 sieves.

Then the soil samples were safely put into the upper sieve and the protective cap was put down over it. The apparatus with sieve stack was placed in the physical shaker sets and was shook until the best screening was obtained. Then the sieves were removed from the apparatus and each sieve size mass was noted. Refer appendix A, B & C to see the test report of Sieve analysis for three different Natural Soil sample.

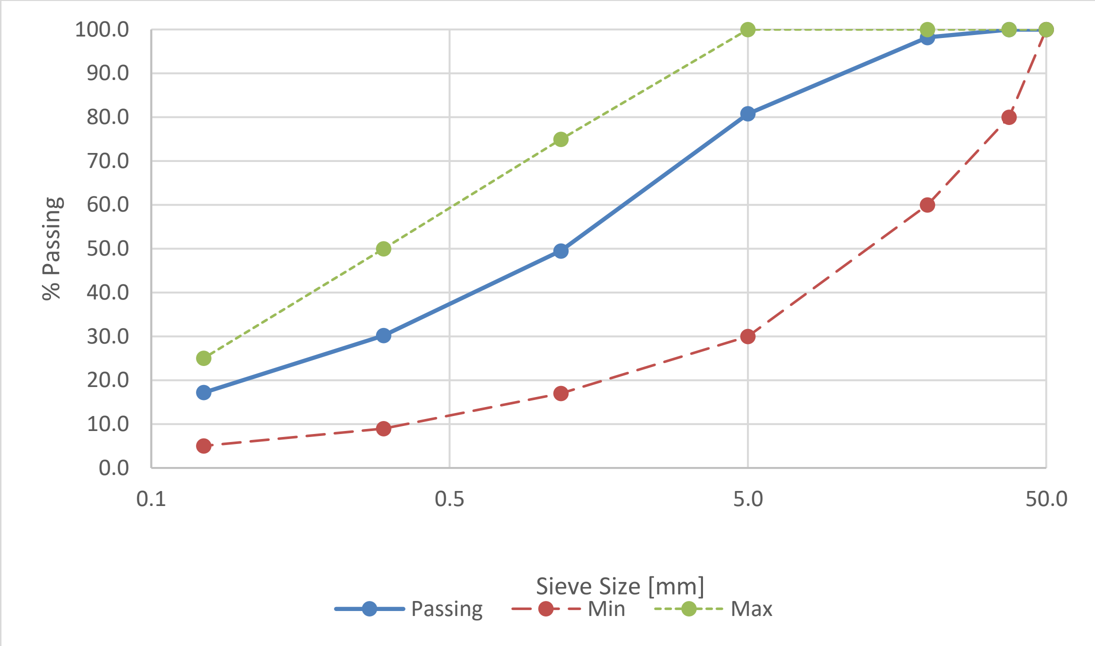

Figure 11: Sieve analysis graph of Mahadamana borrow pit natural soil sample

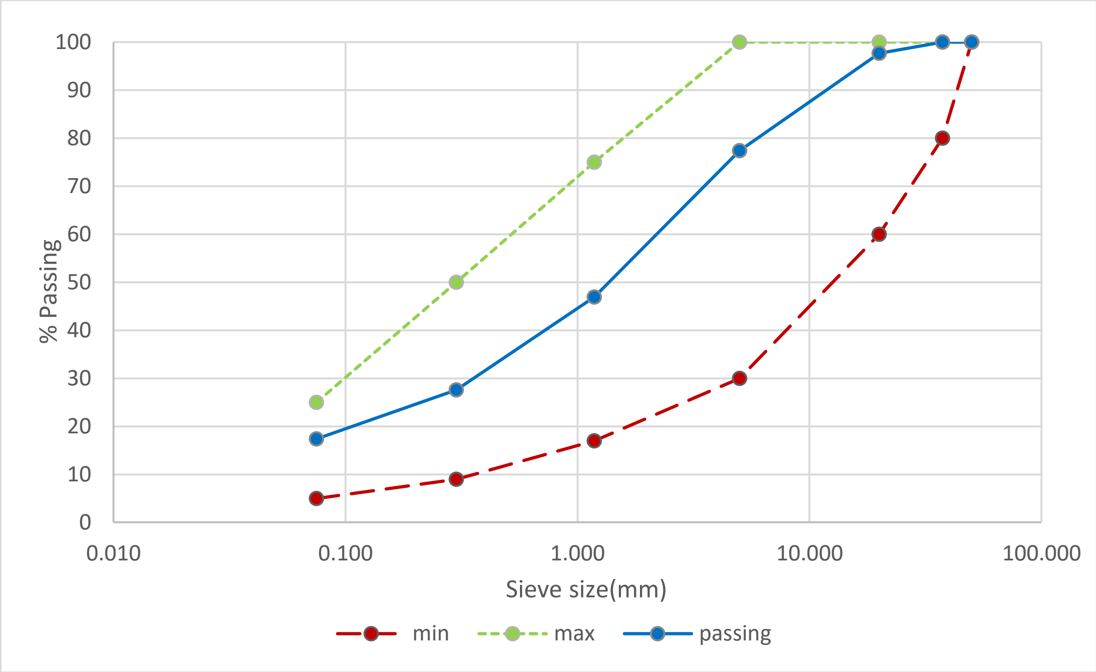

Figure 12: Sieve Analysis graph for Sooriyaweva borrow pit natural soil sample

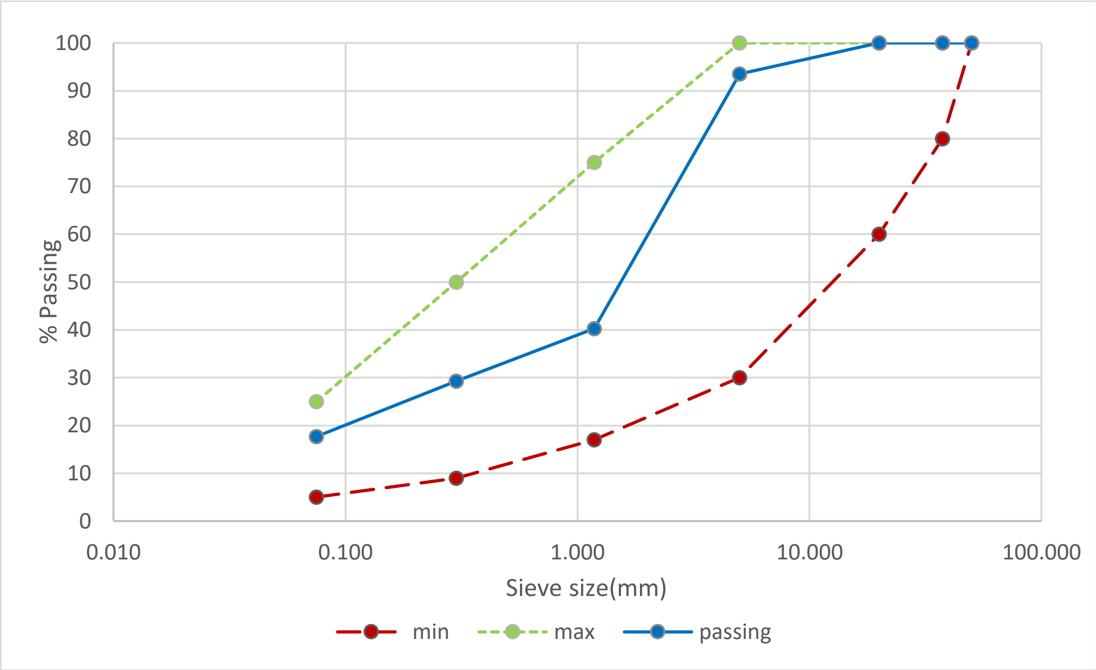

Figure 13: Sieve Analysis graph for Welikanda borrow pit natural soil sample

4.1.2 Atterberg Limits Tests

The Atterberg Limit test is used to find the liquid limit and plastic index of clay soil. The following procedures have been involved for calculating the LL and PI as well.

- The soil sample passing in to the 42µm BS test sieve and its weight measured on the aluminum trays.
- Add on a small amount of water to the soil and mix it well to get the soil paste while making sure that it is not too thick nor too watery.
- After that, the soil paste was placed on the Casagrande's cup and then leveled and grooved using the tool.
- The number of blows was recorded until the separated soil portion became closed.

To determine the moisture content, portion of soil paste was separated. The test was repeated adding different amount of distilled water until the number of blows was equal to the subjected number. Then, moisture content relationship diagram was plotted against the corresponding number of blows. Refer appendix A, B & C to see the test report of Atterberg limit for three different natural soil samples.

The plastic limit (PL) testing procedure carried out with the molding and rolling the mixed composite samples with the 3mm diameter stick shape. The amount of moisture that can indicate the plastic limit at which point, the rolled stick first crumbled.

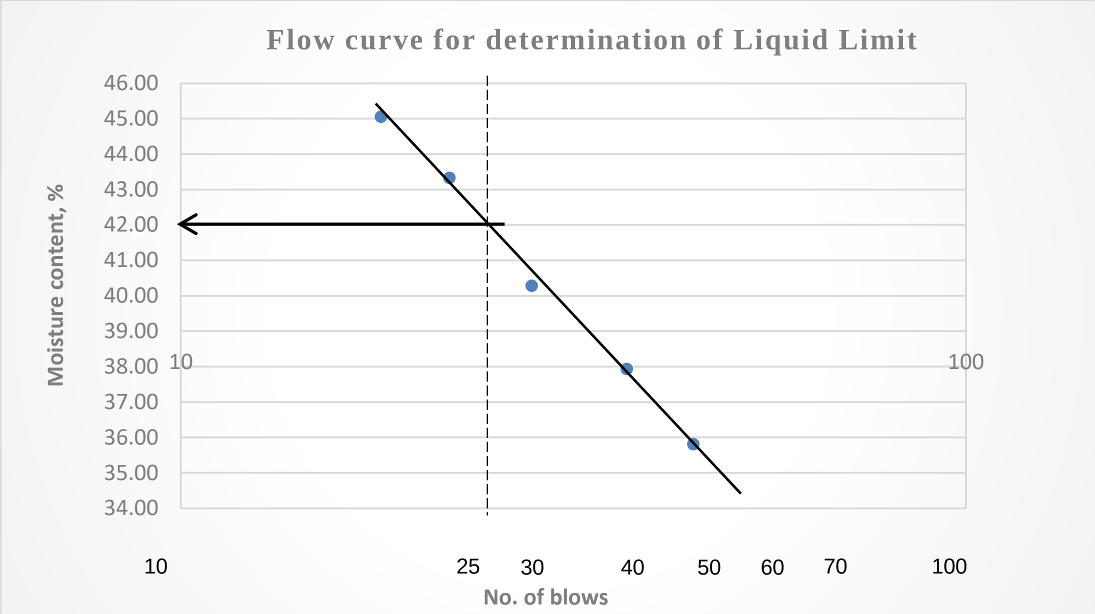

Figure 14: Flow curve for determination of Liquid limit of Mahadamana borrow pit sample AASHTO T-89 /T – 90

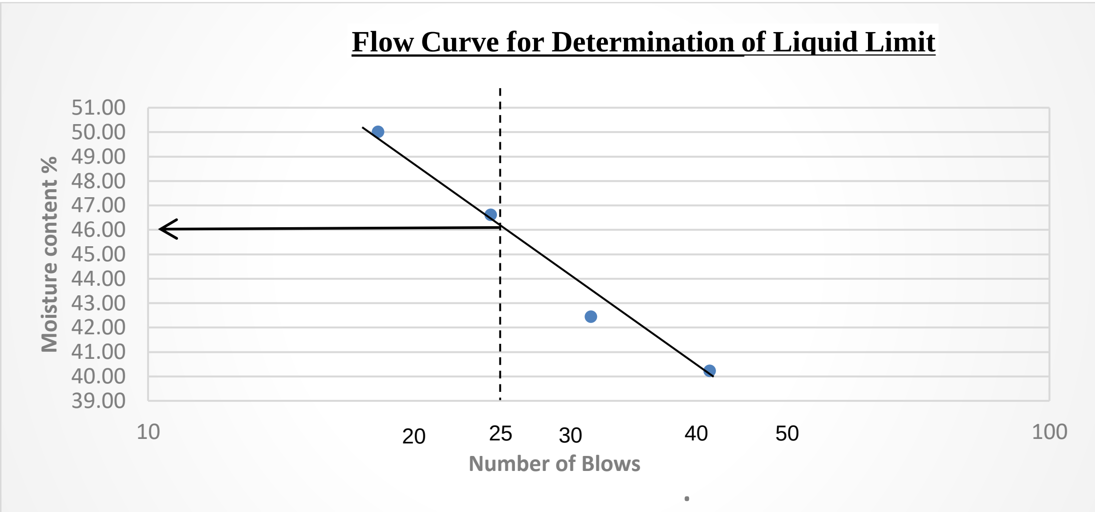

Figure 15: Flow curve for determination of Liquid limit of Sooriyaweva borrow pit sample AASHTO T-89 /T - 90

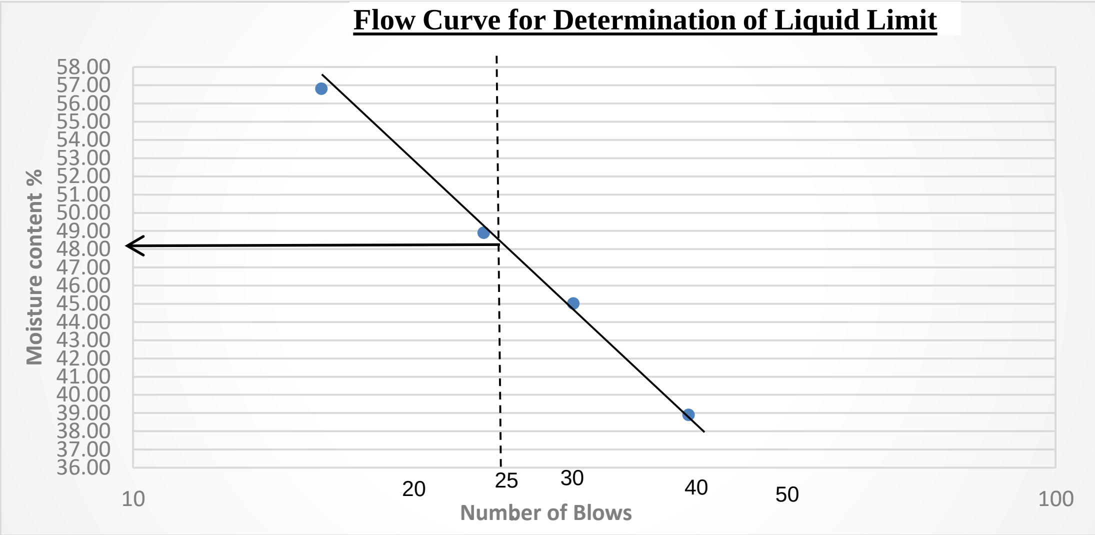

Figure 16: Flow curve for determination of Liquid limit of Welikanda borrow pit sample AASHTO T-89 /T - 90

Similarly, the PI was calculated by using following equation.

PI = LL-PL (1)

4.1.3 Unified Soil Classification

The USC System is used to classify the soils for engineering purposes. The USC system basically classifies the particle-size characteristics, liquid limit, and plasticity. Basically, there are three major soil divisions according to ASTM D2487-17 namely coarse grained soils, fine grained soils, and highly organic soils. Further, those are divided into 15 basic groups, each has its own group symbol (e.g. GW).

Coarse grained soils are primarily categorized into gravels (coarse particles more than 50%) and sands (course particles less than 50%). These soils are similarly sub divided into the following groups: well graded gravel (GW), poor graded gravel (GP), silty gravel (GM), clayey gravel (GC), well-graded sand (SW), poorly graded sand (SP), silty sand (SM), and clayey sand (SC). These are described commonly through the attribute of having 50% or more exceeded the passing of No. 200 sieve.

Fine-grained soils are categorized as silts or clays of a liquid limit both less than 50 or 50 or more. Fine-grained soil groups encompass lean clay (CL), silt (ML), organic clay/organic silt with liquid limit less than 50 (OL), fats clay (CH), elastic silt (MH), and organic clay/organic silt with liquid limit 50 or more (OH). These are principally organic matter, dark in color, and have an organic odor. The only group classification for exceedingly organic soils is peat (PT).

MAJOR DIVISIONS				GROUP SYMBOL	TYPICAL NAMES
COARSE – GRAINED SOILS (Less than 50% passes No. 200 sieve)	GRAVELS (50% or less of coarse fraction passes No. 4 sieve)	CLEAN GRAVELS (Less than 5% passes No. 200 sieve)		GW	Well graded gravels, gravel–sand mixtures, or sand–gravel–cobble mixtures.
				GP	Poorly graded gravels, gravel–sand mixtures, or sand–gravel–cobble mixtures.
		GRAVELS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below the "A" line & hatched zone on plasticity chart	GM	Silty gravels, gravel–sand–silt mixtures.
			Limits plot above the "A" line & hatched zone on plasticity chart	GC	Clayey gravels, gravel–sand–clay mixtures.
	SANDS (More than 50% of coarse fraction passes No. 4 sieve)	CLEAN SANDS (Less than 5% passes No. 200 sieve)		SW	Well graded sands, gravelly sands.
				SP	Poorly graded sands, gravelly sands.
		SANDS WITH FINES (More than 12% passes No. 200 sieve)	Limits plot below the "A" line & hatched zone on plasticity chart	SM	Silty sands, sand–silt mixtures.
			Limits plot above the "A" line & hatched zone on plasticity chart	SC	Clayey sands, sand–clay mixtures.
FINE – GRAINED SOILS (50% or more passes No. 200 sieve)	SILTS (Limits Plot Below "A" Line & hatched Zone on Plasticity Chart)	SILTS OF LOW PLASTICITY (Liquid Limit Less Than 50)		ML	Inorganic silts, non–plastic or slightly plastic.
		SILTS OF HIGH PLASTICITY (Liquid Limit More Than 50)		MH	Inorganic silts, micaceous or diatomaceous silty soils, elastic silts.
	CLAYS (Limits Plot Above "A" Line & hatched Zone on Plasticity Chart)	CLAYS OF LOW PLASTICITY (Liquid Limit Less Than 50)		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
		CLAYS OF HIGH PLASTICITY (Liquid Limit More Than 50)		CH	Inorganic clays of high plasticity, fat clays, sandy clays of high plasticity.

Figure 17: Unified soil classification chart

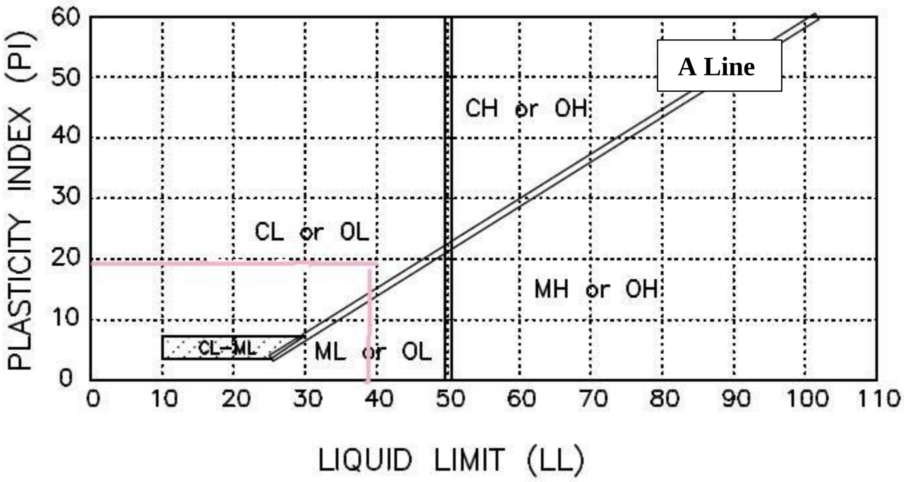

Figure 18: Plasticity chart of Natural Soil

According to the UCS chart, the selected three borrow pits soil samples fall under the Clayey Gravel (GC) category. This soil contains significant amounts of Gravel.

4.1.4 Proctor Compaction Test

Proctor compaction test was carried out to get the "MDD' and "OMC" relationship using the graph of compaction curve. From the graph, MDD and OMC values could be identified.

The dried soils were screening it through 20mm and 4.7mm sieve. Then, 20mm retained percentage and 4.75mm passing percentage were calculated. The 4.75mm sieve passing and retained mixed according to the weight percentage to get nearly 1600g to 1800g of soil. Then enough amount of water was added to the soil and mixed well. The moulds prepared in five layers of approximately equal mass to do the compaction. 25 blows were given by using 4.9 kg rammer to each layer. The blows distributed uniformly from 450mm height over the surface of each layer.

Then the moulds with the compacted soil was weighted and recorded this weight as W2. The amount of water in the sample was determined and the wet content was recorded as 'M'. Then retained soil was broken up and above steps were repeated while adding on suitable amount of water to the soil.

Bulk Density, Ym in g/cm3 of every compacted specimen is derived from the subsequent equation.

Ym = (W2-W1)/Vm Bulk Density (Ym) in g/cm3 is derived from the bellow equation.

Ym = (W2-W1)/Vm

Here,

W1 = mass of the mould + base plate

W2 = mould weight + base plate + soil

Vm = Mold Volume i.e. 1000 cm3.

Dry density (Yd) in g/cm3 is derived from the bellow equation.

Yd = 100 Ym/ (100+M)

Here,

Ym = Bulk Density of soil in g/cm3.

M = Soil Moisture Content

During a series of determinations the dry density, Yd is planned in case of related moisture content ‘M’. An easy curve is then dragged through the ensuing points and therefore the position of the maximum on this curve is decided, that is named maximum dry density (MDD). Therefore the corresponding wet content is named optimum moisture content (OMC). Refer appendix A, B & C to see the test report of Proctor compaction for three different Natural Soil samples.

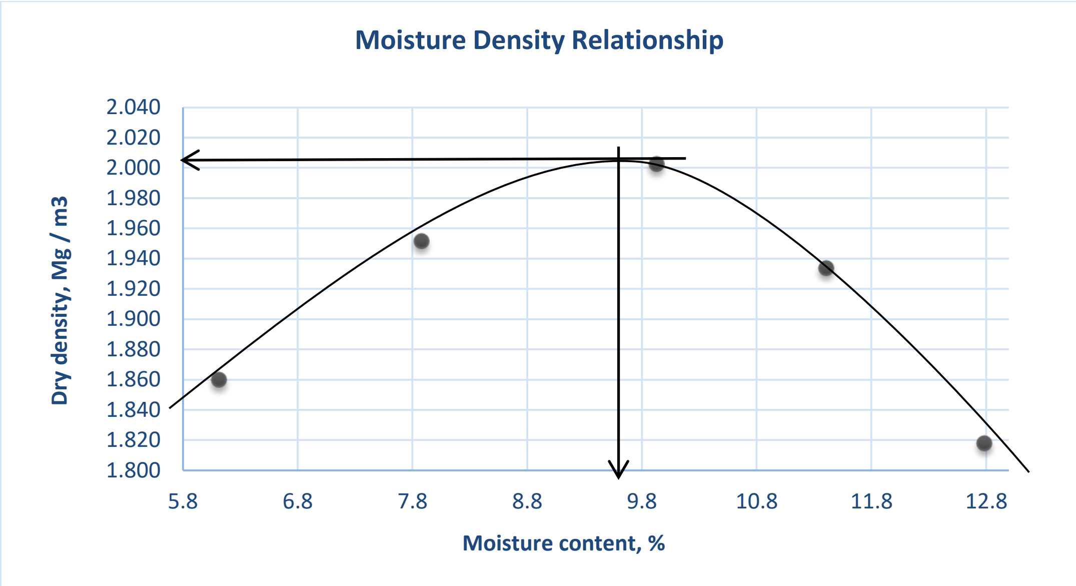

Figure 19: Moisture content and dry density graph for Mahadamana natural soil sample

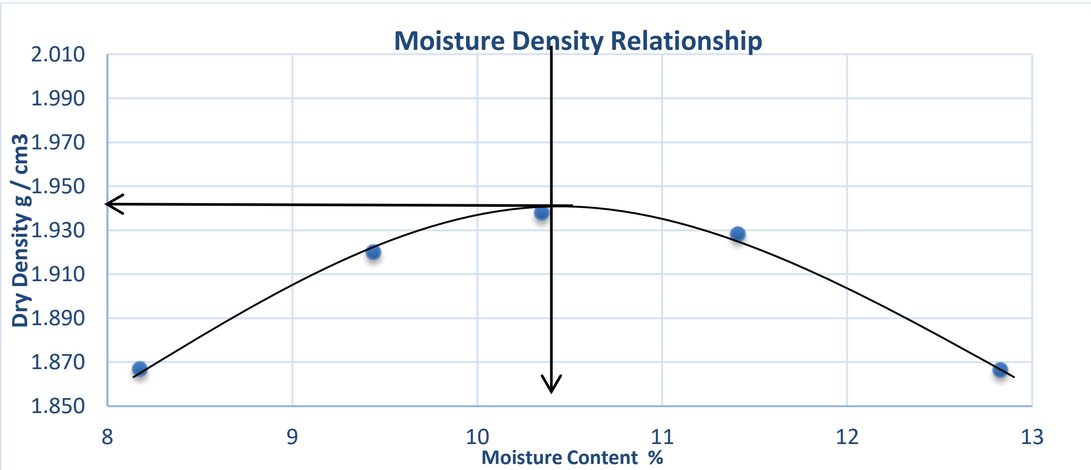

Figure 20: Moisture content and dry density graph for Sooriyaweva barrow pit natural soil sample

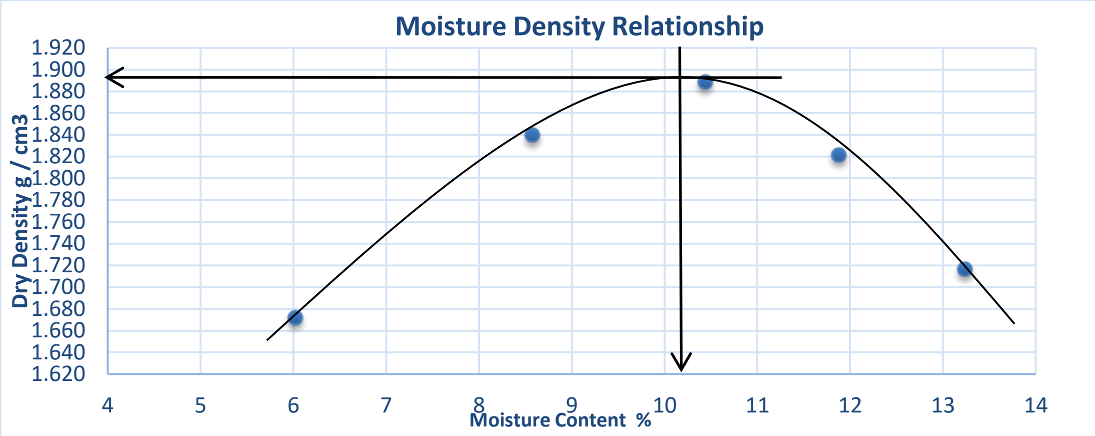

Figure 21: Moisture content and dry density graph for Welikanda barrow pit natural soil sample

4.1.5 California Bearing Ratio Test

The test on penetration is called California bearing ratio which helps to determine the capacity of the bearing of the soil for pavement system. This test should be carried out under the soaked or un-soaked conditions.

The test measures the pressure which is needed to penetrate a soil sample using plunger of normal area.. Half dozen kilo of dry sample was blended totally with a planned amount of water to get moisture of soil with the desired wetness percentage. The three totally different CBR molds were used for the soil compaction. All three layers were subjected to twenty five blows using 4.5kg standard rammer (4.5 kg weighted hammer falling from 300mm).

Then the weight was continuously applied at a constant rate of 1.25 mm per minute. The Lord readings were marked at the successive penetrations for every upper and lower layers. Finally, filter paper was kept on the compacted surface. Then the paper should be shut with polythene cover to avoid the direct impact of water. To get the four days soaked CBR value, the apparatus will be placed within the soaking tank.

Finally, the CBR mould was removed from the tank and therefore the exact soaked CBR value were taken. The similar procedure also used for the un-soaked condition.

Then the graph was plotted with the load intensity readings against the penetration values. According to the plotted values smooth curve was drawn through the points. Refer appendix A, B & C to see the test report of CBR for three different Natural Soil samples.

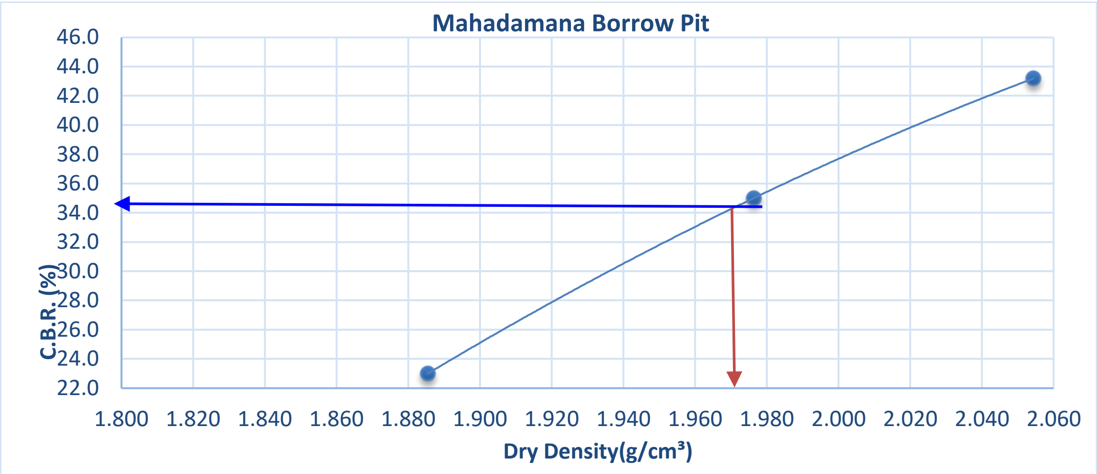

Figure 22: CBR versus Dry Density diagram for Mahadamana borrow pit sample

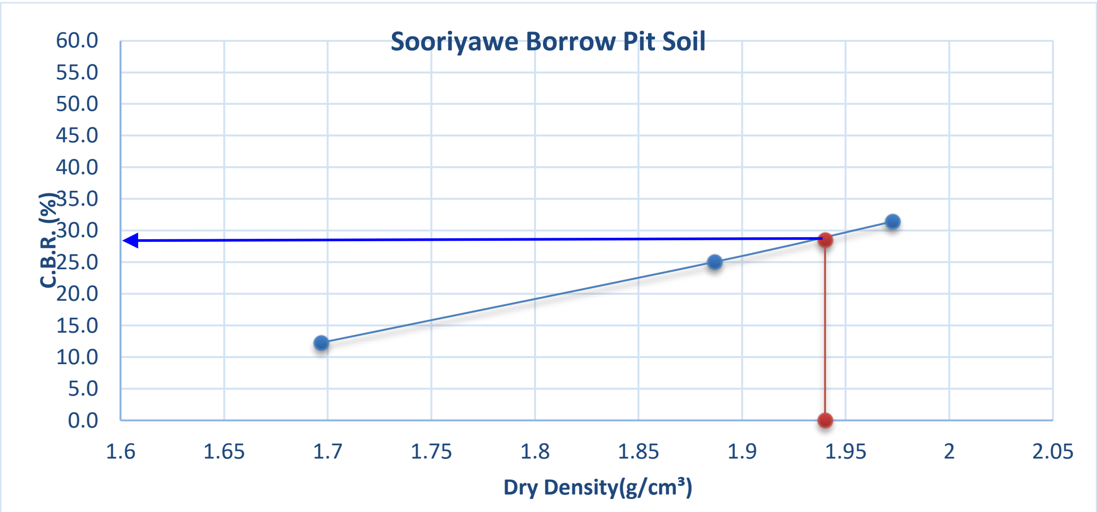

Figure 23 : CBR versus Dry Density diagram for Sooriyaweva borrow pit sample

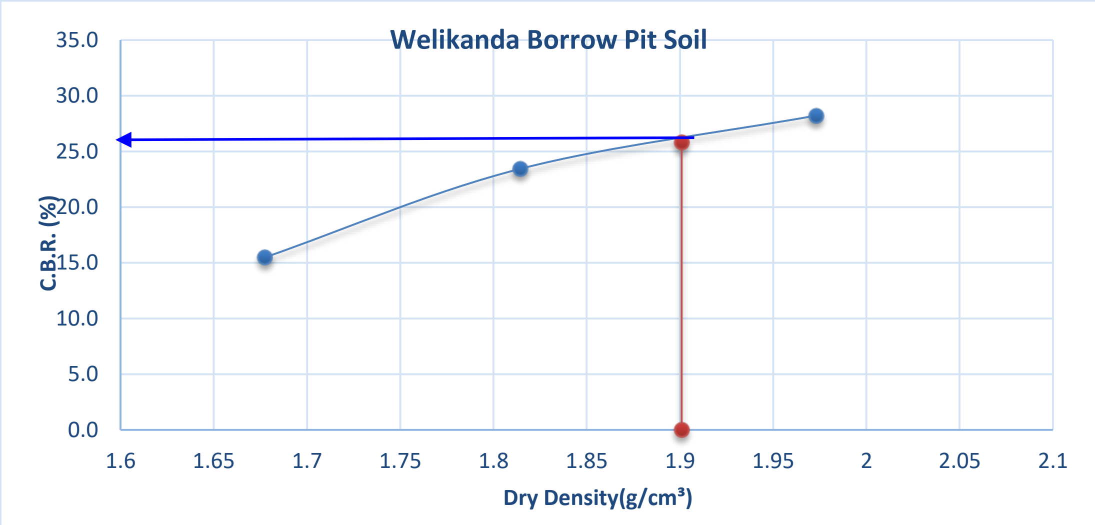

Figure 24: CBR versus Dry Density diagram for Welikanda borrow pit sample

4.1.6 CBR Swell Test

The swelling and shrinking properties of soil could be an excellent identity of its behavioral change in volume. The poor swelling and shrinking behaviors are typically dangerous and tough to manage. The properties of swelling at the beginning stage of saturation may be determined using the CBR swell test. The contraction and swelling properties of soil are mainly controlled by different factors as given below:

- Clay type and quantity in soil constituents
- Moisture Content
- Dry Density

In this experimental study, a CBR swell test was tested to check the soil swelling characteristic. The swell percentage for different barrow pits soil samples were calculated for four days soaked in water. Finally, it was nearly 2%-2.2% in each sample and then it was recorded.

4.1.7 Test Results Analysis

The first exercise was carried out to find a soil source in a problematic area or project test report data base. Hence investigation of available soil characteristics was made to comply with specification requirement. To determine the deficiency of sleeted natural soil sample, the whole laboratory tests were done. Additionally, one of the good quality natural sub-base material's key properties also used to compare with the natural soil to get some ideas and how they vary from quality soil.

The Unified Soil Classification system indicate that the available soil falls into the group of GC (Clayey Gravel, Gravel-Sand-Clay Mixture) adopted by ASTM D-2487-98. Normally this type of soil has more fine grains. Also, these types of soil have more water absorption capability in order that they absorb the water and their volume will increase.

Table 10- Natural soil test result summary comparison with quality Sub base

S/No	Test Type	Specification Requirements	Result Summary		
			Natural Soil (Mahadamana barrow pit)	Natural Soil (Sooriyaweva borrow pit)	Natural Soil (Welikanda barrow pit)
1	Sieve Analysis (Passing % 0.075 mm for wet test)	5% -25%	17.2%	17.4%	17.7%
2	MDD (g cm3)	≥1.75	2.01	1.94	1.881
3	OMC (%)		9.6	10.4	10.2
4	LL	≤40	42	46	48
5	PI	≤15	19	22	26
6	CBR (%) (98% of MDD)	≥30	34.5	28.5	24.5
7	CBR Swell (%)		2%	2.2%	2.2%

From the summary of test results as given in Table 12, the Atterberg limit couldn’t satisfy the requirements for all the three types of soil. Further, CBR was also not satisfied for the soil samples collected from Sooriyaweva and Welikanda borrow pits. The required limit was compared with CIDA specification which is currently practiced in i-road project. According to the above soil behavior with the water, it clearly showed that water reaction time is less. Hence, the stabilizing agent should react with water slowly.

The test summary clearly showed that there was a deficiency in Atterberg Limit as well as CBR. According to that result, the study has moved on to the next stage of an experiment to find out the suitable stabilizer and its minimum proportion to satisfy the required limits.

4.2 Atterberg Limit Test for Selected Stabilizer Agents

4.2.1 Power Glass Composite Soil

Three sets of composite soil samples were prepared for Atterberg limit test. In each sets with subsets to get the varied plasticity index. The powder class composite sample with 8 subsets and its subsets has the soil passing on 425 micron with the varied percentage of 425 microns glass powder (0% to 30%).

Figure 25: Preparation for glass composite sample for Atterberg limit test

Table 14 indicates the results of experiments with various percentages of glass powder. This includes 0, 2 5, 10, 15, 20, 25 and 30 percentages of glass powder added to soils.

When adding glass to composite soil, it gives improvement in the soil Atterberg limits. But, it can be said that, glass has minimum impact on the liquid limit as well as the plastic index for all three borrow pit samples. Figures 26, 27 & 28 shows that when the glass percentage added to the soil, there was an improvement on the plastic index as well as the liquid limit.

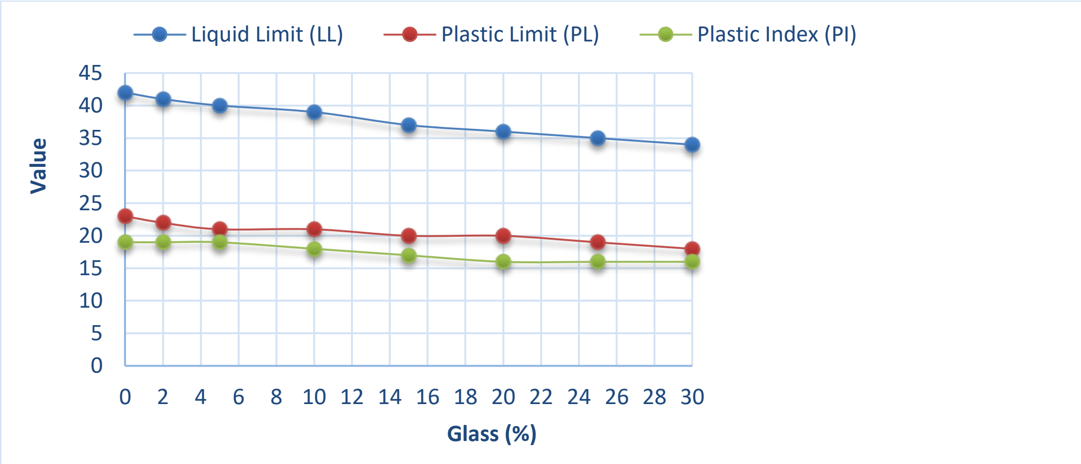

Figure 26: Atterberg limit graph for Mahadamana barrow and pit glass composite soil

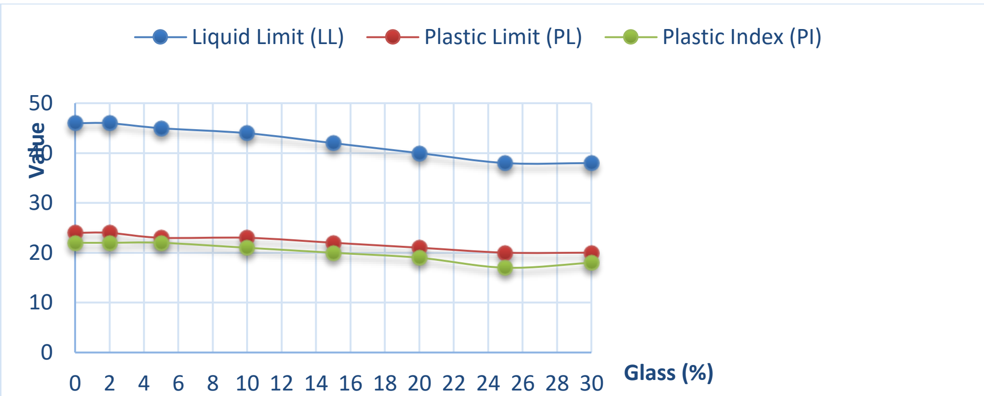

Figure 27: Atterberg limit graph for Sooriyaweva barrow and pit glass Composite soil

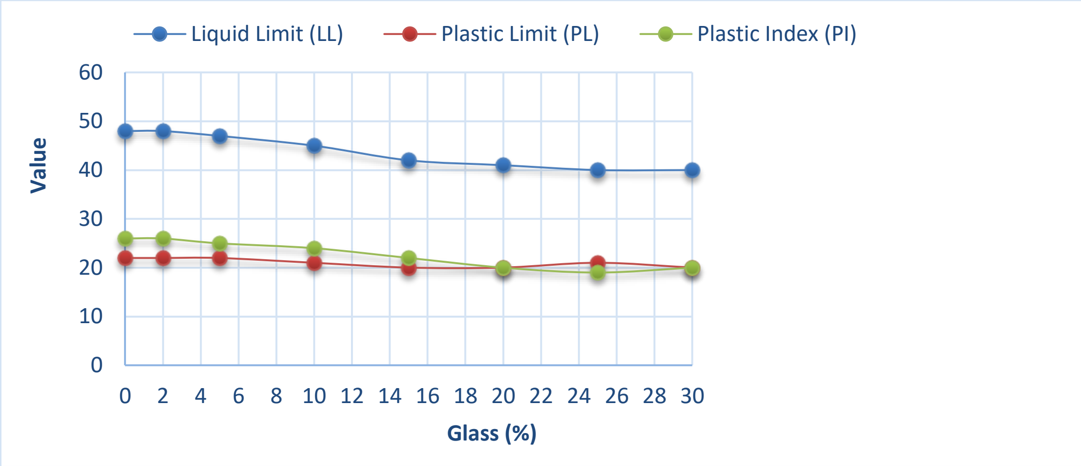

Figure 28: Atterberg limit graph for Welikanda barrow and pit glass composite soil

4.2.2 Plastic Powered Composite Soil

The three plastic powdered composite samples also with 8 subsets and its subsets has the soil passing on 425 micron with the varied percentage of 425 microns plastic powder (0% to 14%).

Figure 29: Atterberg limit test for plastic composite sample

When adding plastic powder to composite soil, it gives improvement in the soil Atterberg limits similar to glass powder. Figures 31, 32 & 33 shows that when increasing the plastic percentage to the soil, there was an improvement on the plastic index as well as the liquid limit. But, it can be said that plastic powder has minimum effect on the plastic limit of each soils. Refer Appendix-E to see the Atterberg limit test report of three different Natural Soil samples with Plastic waste.

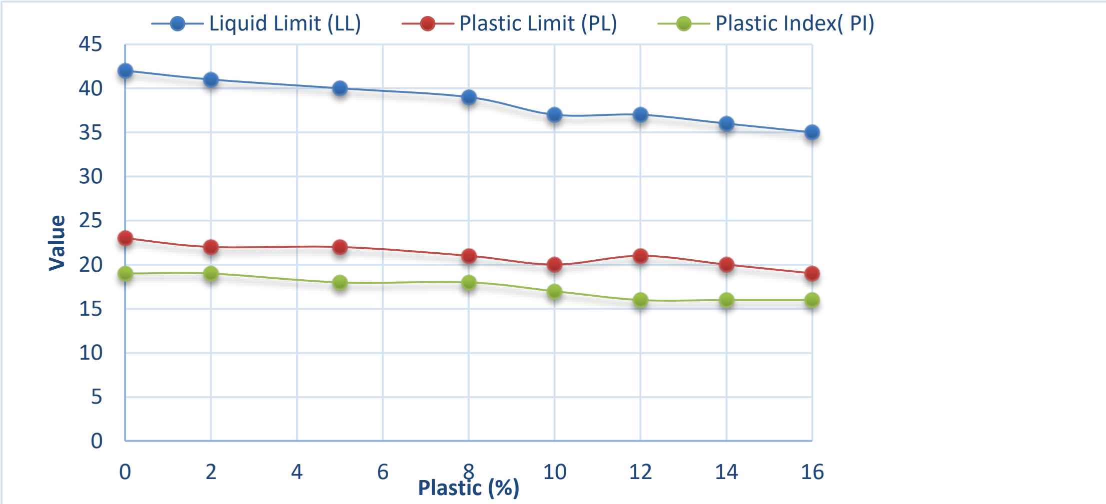

Figure 30: Atterberg limit graph for Mahadamana borrow pit soil and plastic composite sample

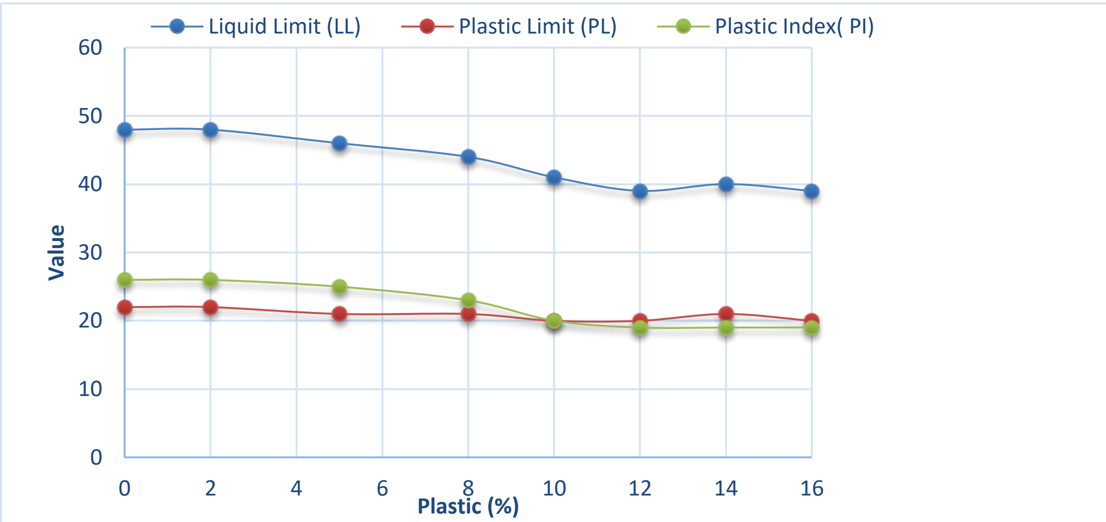

Figure 31: Atterberg limit graph for Sooriyaweva borrow pit soil and plastic composite sample

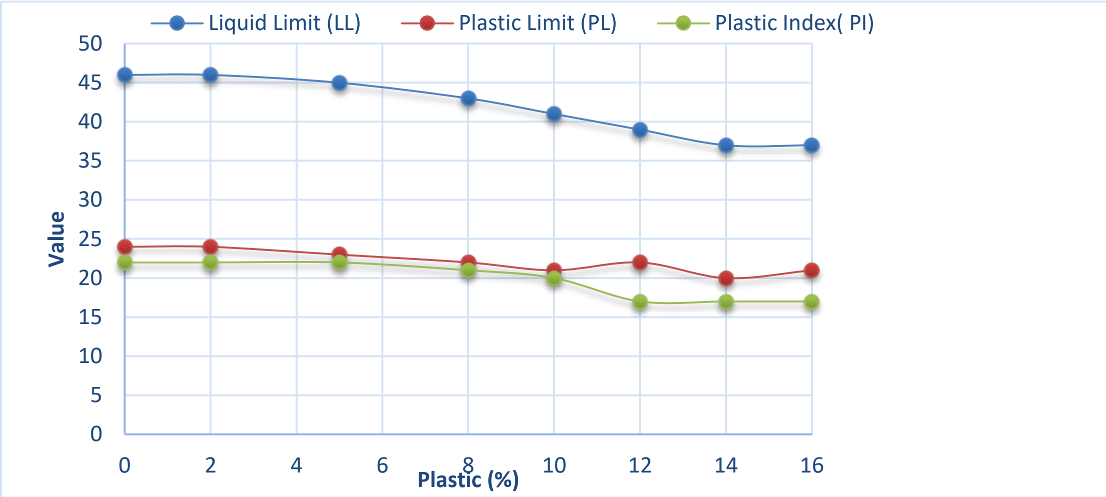

Figure 32: Atterberg limit graph for Welikanda borrow pit soil and plastic composite sample

4.2.3 PHA Composite Soil

The three paddy husk ash composite sample also with 8 subsets and its subsets has the soil passing on 425 micron with the varied percentage of 425 microns PHA (0% to 14%).

Figure 33: Atterberg limit laboratory test for PHA composite sample

When adding PHA to composite soil that improves the soil Atterberg limits similar to previous two stabilizers. Figures 34, 35 & 36 shows that when the PHA content to the soil is increased, there was an improvement on the plastic index as well as the liquid limit. Refer Appendix-D, E &F to see the Atterberg limit test report of three different Natural Soil samples with Plastic waste.

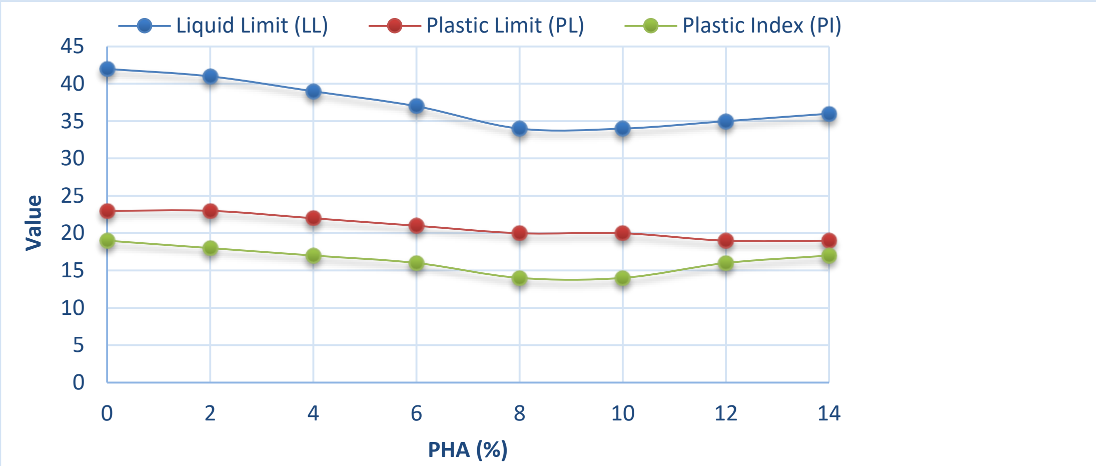

Figure 34: Atterberg limit graph for Mahadamana borrow pit soil and PHA composite sample

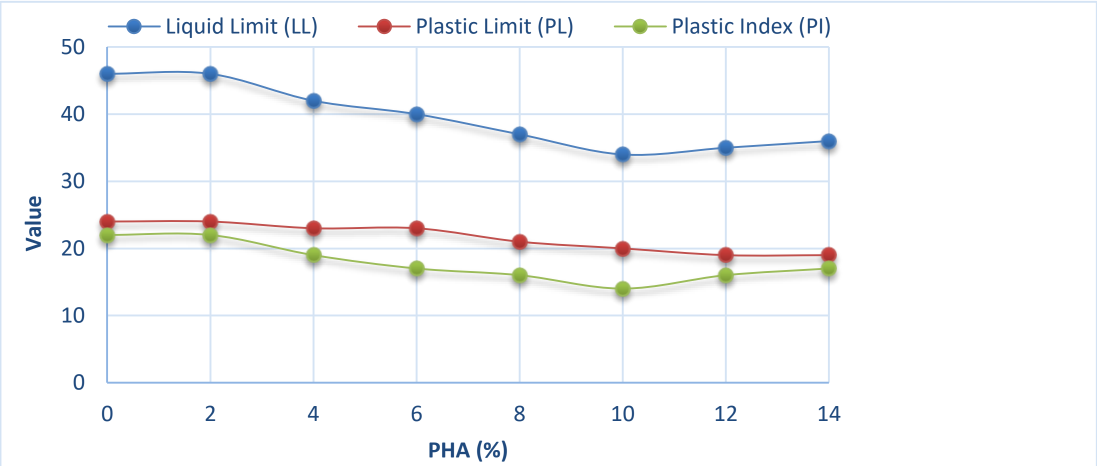

Figure 35: Atterberg limit graph for Sooriyaweva borrow pit soil and PHA composite sample

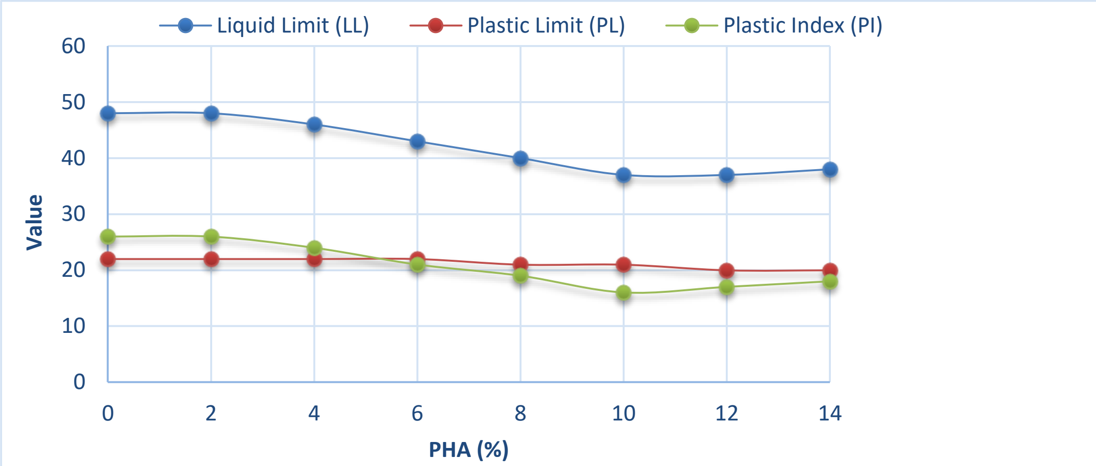

Figure 36: Atterberg limit graph for Welikanda borrow pit soil and PHA composite sample

4.2.4 Effect on Atterberg Limits

Soil samples from three different borrow pits have been examined by using three types of stabilizer. According to the results of laboratory tests, the required weight proportion of mixtures could be selected for each soil sample to determine the optimum content of stabilizer among three different stabilizer agents. Except PHA, Glass waste and plastic waste did not satisfy the specification requirement for the soil samples of all the three borrow pits. It is said that PHA is the effective stabilizer for lower PI compared to other stabilizers such as Plastic & Glass.

Plastic powder & Glass powder could also be used to reduce the Liquid Limits & Plastic index up to some extent, but the reduced amount is not enough to meet the requirements of soil with its optimum percentage. Figures 34, 35 & 36 showed that the Plastic Index value of composite samples decreased when the amount of PHA was increased up to optimum value. Therefore, PHA had improved plastic properties and satisfied the specification requirement for Mahadamana source and Sooriyaweva source. At the same time PHA could not satisfy the specification requirement of Welikanda source. However, above conducted test results show the stabilizer agent's behavior and its reaction with soil particles. According to that result, the above satisfied stabilizer agent and tow borrow pit soil sources were selected for further experimental studies.

4.3 CBR Test for Selected Stabilizer Agent

Next exercise was carried out in the Sooriyaweva soil source. Because it has another deficiency in the CBR properties. A series of CBR test have been carried using PHA on the Sooriyaweva source in order to find the optimum value of the PHA. In case of Sooriyaweva borrow pit source, two different optimum PHA amounts might be observed from the Atterberg limit test and CBR test. Anyhow compared to above two values, the minimum value should be selected. At the same time, that value must satisfy the both properties as well.

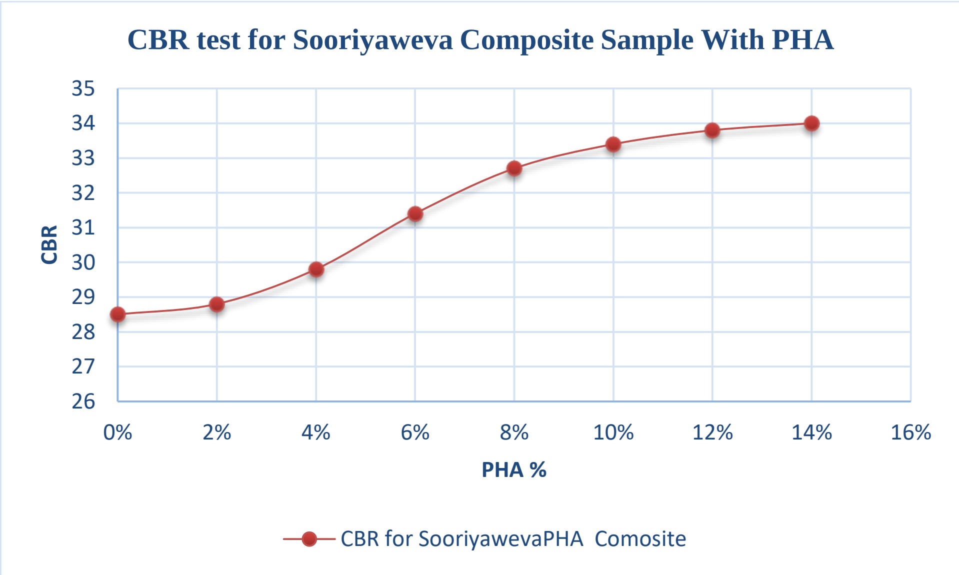

Figure 37 : CBR graph for Sooriyaweva borrow pit soil and PHA composite sample

4.4 Laboratory Test on PHA Composite Soil

4.4.1 Particle Size Distribution

After the composite sample was well prepared, the first exercise was carried out on testing for Sieve Analysis. This test was performed at optimum amount of PHA of the Mahadamana and Sooriyaweva soil sources in order to study with specification and its overall improvements. The wet sieve analysis test was carried out for composite soil to determine the fines influenced by above mentioned agents.

Figure 38: Laboratory Sieve analysis test composite sample preparation for PHA composite sample

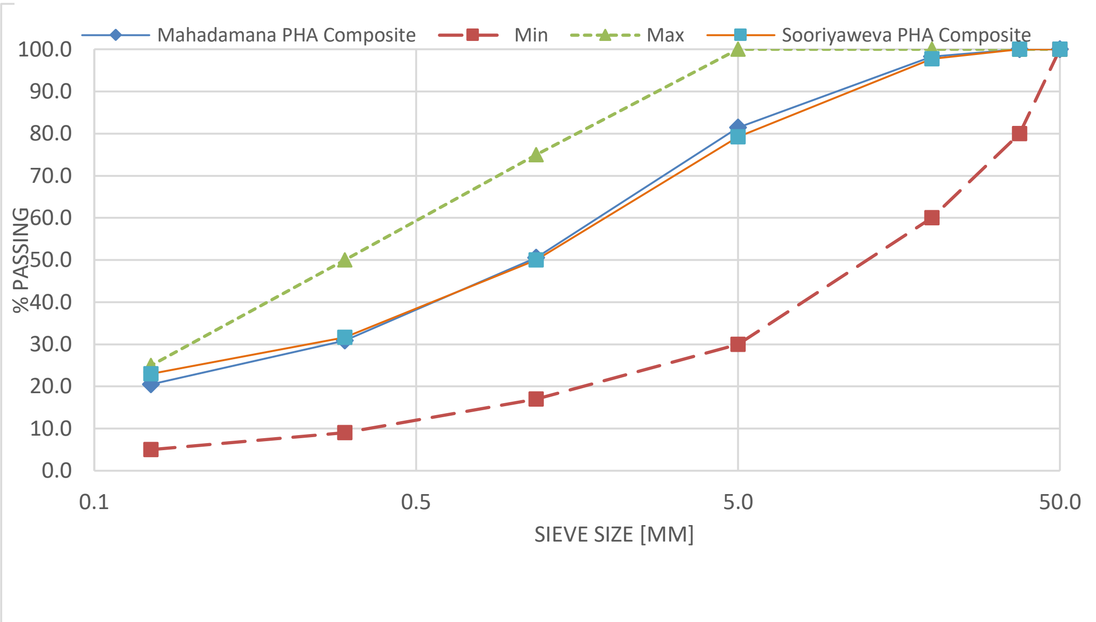

Figure 39: Sieve Analysis for PHA Composite Samples

From the above graph fine (0.075mm passing) % increased from 17.2 % to 20.5% and 17.4% to 23%

4.4.2 Proctor Compaction

Similarly Modified Proctor test was also conducted on specified composite materials in different moisture levels to find out the MDD and OMC. The aim of this test was to determine the optimum moisture content and maximum dry density in all the soil subsets.

Figure 40: Preparation of PHA Composite Sample for Proctor Compaction Laboratory Testing

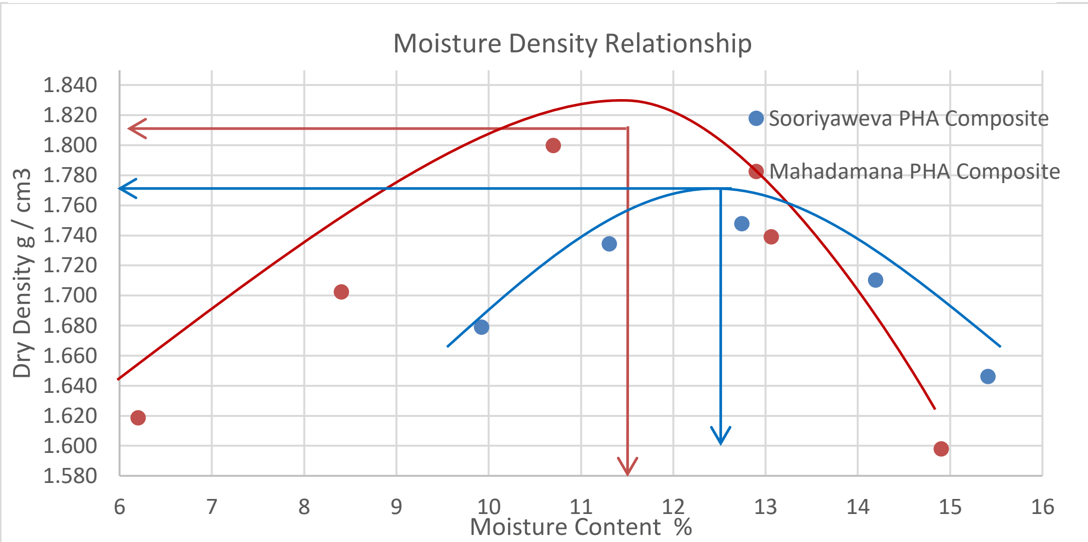

Figure 41: MDD versus Moisture Content for PHA Composite Sample (AASHTO T 180-1)

According to the above plotted graph, maximum dry density and optimum moisture content values could be calculated in the two PHA composite soil sources.

4.4.3 California Bearing ratio (CBR) test for Field Sample

California Bearing ratio (CBR) test was conducted on two specified composite materials. The aim of this test was to determine the bearing capacity and dry density in all the soil subsets under 4 day-soaked condition.

Figure 42: Preparation of PHA composite sample for CBR laboratory testing

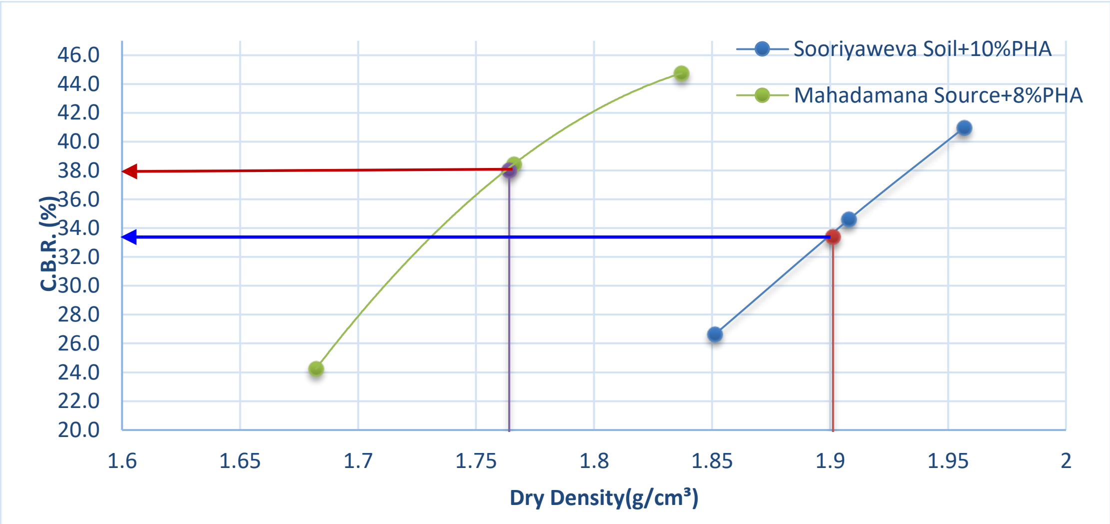

Figure 43: CBR test graph for PHA composite samples with its optimum percentage

4.4.4 CBR swell for Field Sample

Adding PHA to composite soil improves the soil swelling. At the optimum amount of PHA, there was a reduction in swell of the particular soils.

Figure 44: CBR swell observation under the 4 days soaked condition

4.5 Summary of Results and Discussions

Three different kinds of sub base soils with dissimilar soil properties and values have been used for this experimental studies. Those materials were collected from different soil sources. In order to check the validity and accuracy of the stabilizing agent, minimum of three material sources have been examined.

When PHA is added to a natural soil, ash particles replace the clay particles at the saturated conditions. For that, specific amount of PHA particle is required to satisfy these reactions. That is the reason for the variation of the optimum amount of stabilizing agents for different soil sources. However, it mainly depends on the individual specific properties and behavior of the soil sources. This amount was initially determined during the Atterberg limit test. Because, all three problematic soil sources mainly have the deficiency in the Atterberg limit.

From that, Mahadamana, Sooriyaweva and Welikanda borrow pits soil were adopted into 8%, 10%, and 14% of optimum PHA amount respectively. Among the above three cases, Welikanda soil sample could not satisfy the requirement of plastic index. But, the improvement of the property could be observed considerably. Due to the high plastic limit, the optimum amount of PHA was increased up to 14%. That is why ash particles were tried to increase and absorbed more water. The reason was the plastic limit is high beyond the stabilizing capacity limit of the optimum amount of PHA. From the above observation it can be said that if the soil PI or LL is higher than the marginal limit it could be difficult to improve as a sub base material with PHA alone.

In addition, out of three sources, Sooriyaweva and Welikanda borrow pits also had the deficiency in the CBR value. Therefore, series of the CBR tests were carried out in above soil source at the varied amount of PHA in order to find the optimum amount of PHA. Because of the characteristic of behavioral change in the property, the optimum stabilizer amount could be varied for different properties of same soil. It was identified that the cementations reaction was increased dramatically in the Sooriyaweva soil sample when the PHA amount is 10% to 12% due to the solubility reaction of silica and alumina took place in the particular composite soil.

It is observed that, increased amount of PHA decreased the soil MDD. From the Atterberg limit test, it was revealed that increased amount of PHA depends on the Plasticity of the soil. When Mahadamana and Sooriyaweva soil sources are compared, the optimum of 8% PHA and 10% PHA could reduce the MDD 2.01g/cm-3 to 1.81gcm-3 and 1.94gcm-3 to 1.75gcm-3 respectively. The specification limit of sub base martial is 1.75gcm-3. So, the original MMD of the Sooriyaweva source was very sensitive of the PHA stabilization. From the above observation it could be said that if the MMD is less or PI is higher than the marginal limit it would be difficult to improve as a sub base material. Therefore consideration of MMD of the soil is very important at the beginning stage of selection of stabilizer.

The final laboratory test results of PHA composite soil are summarized in the Table11

Table 11: Comparison test result summary of PHA stabilized soil

S/No	Test Type	Specification Requirements	Result Summary				
			Mahadamana Source		Sooriyaweva 2 Source		Remarks
			Natural State	8% PHA Composite	Natural State	10% PHA Composite	
1	Sieve Analysis (Passing % 0.075 mm for wet test)	5% -25%	17.2%	22.3%	17.4	23	
2	MDD (g cm3)	≥1.75	2.01	1.81	1.94	1.75	
3	OMC (%)		9.6	11.4	10.4	12.5	
4	LL	≤40	42	34	46	34	
5	PI	≤15	19	14	22	14	
6	CBR (%) (98% of MDD)	≥30	34.5	38	28.5	32.7	
7	CBR Swell (%)		2	0.3	2.2	0.4	

4.6 Research Finding

Based on the test results of the composite material, PHA fulfills the flowing acceptable qualities at varying weight ratio for two different types of sub base borrow pits soil.

1. The results showed that the LL decreased with the increasing amount of PHA content.
    - LL value of the Mahadamana natural soil was 42. Optimum of 8% PHA could reduce the soil liquid limit to 34 (20%).
    - LL value of the Sooriyaweva natural soil was 46. Optimum of 10% PHA could reduce the soil liquid limit to 34 (26%).

2. Adding PHA to natural soil lowered the plasticity Index.
    - The plastic index value of the Mahadamana natural soil was 19. Optimum of 8% PHA can reduce the soil Plastic index to 14 (26%) and then decreased.
    - The plastic index value of Sooriyaweva the natural soil was 22. Optimum of 10% PHA can reduce the soil Plastic limit to 14 (36%) and then decreased.
3. The soil OMC for combinations of Mahadamana NS +8%PHA had increased up to 18.7% from original value, compared to the natural soil. At the same time Sooriyaweva NS+10% PHA could be increased up to 20.1% from the original value. The reason is larger conducting surface were formed due to the coarse particles bonding. (additional amount of water required for this process)
4. Increasing amount of PHA to lower the soil MDD.
    - The MDD of Mahadamana natural soil was 2.01g cm-3 and when adding 8% PHA to soil, it could decrease the soil MDD up to 1.81 g cm-3.
    - The Sooriyaweva natural soil MDD is 1.94g cm-3 and when adding 10% PHA to soil, it could decrease the soil MDD up to 1.75 g cm-3.

5. In saturated condition, the treatment of Mahadamana NS+8%PHA increased the effectiveness on CBR (an increase of 10%). Similarly Sooriyaweva NS+10% PHA increased the potency on CBR (an increase of 14.7%) The pozzolanic reaction of PHA could increase the stability and minimize change in the clay volume. This reaction occurred quickly and could increase the CBR of PHA composite soil.
6. PHA could decrease the swelling potential which is linked with the reduction on plasticity index of soil. Hence, the swell could be reduced from 2 % to 0.3% and 2.3% to 0.4% respectively for the Mahadamana source and Sooriyaweva source by the addition of 8% and 10% of PHA.
7. The PHA composite sub base layer can used to protect a drainage function from blockage of fine particles or prevent the finer particles migration and the mixing with other layers. Through filter criteria analysis, the amount of material passing the 75-micron sieve should be restricted. From that, it could be said that the fine passing percentage of PHA composite soil has been increased. That means most of clay particles have been replaced by PHA. PHA is mostly non plastic in nature and reacted as a binding agent. Hence, larger surface areas were formed with the considerable air voids. Therefore, porosity of the PHA composite sub base layer will increase.

5 Construction of Sub base Layer using PHA Stabilized Materials

5.1 Construction Procedures

Above conducted series of laboratory tests clearly show the improvements in key engineering properties of soil as well as satisfy the requirements for the specification limits. After the laboratory testing for PHA composite sample, the construction of sub base layer was carried out in one of the road sections. The Mahadamana borrow pit soil was used for the sub base construction. The construction was made on Bandana gala village road tail end (Road No 71-I Road Polonnaruwa). The last 30m section was selected in that road for the construction of sub base layer. Finally, with the help of the contractor, the modified PHA composite soil layer was laid and compacted. The construction of stabilized sub base layers follows the same procedure like normal construction methods statement if the stabilizing agent is PHA.

5.1.1 Blending and Mixing of PHA Stabilized Soil with Proper Gradation

In the case of PHA-stabilization, initially soil and PHA shall be mixed in dry form to get the composite soil with the optimum moisture level. The soil material was obtained from borrow pits with the wet form. Though, natural soil sources must satisfy the requirements for gradation, quality, and consistency. After the blending of the natural soil, the soil was brought to the site. Where blending purpose is required, that should be carried out by uniformly spreading and mixing or by a process of windrowing action as directed. After that, blended sample was pulverized to get the uniform blending.

The stabilizer will be manually spread by using the shovel at frequent interval, and spreading the stabilizer over top of the layer as homogeneously. PHA is a lower density stabilizer compared to other stabilizer. Thus, it can be possible to get a much homogeneous distribution with soil when manually spreading of stabilizer. Mixing of the stabilizer and soil was pulverized using a back hoe loader, rotary tiller, water bowser, motor grader or any suitable machinery until the uniform mix of such soil with the stabilizer is obtained. To get the necessary pulverization, enough water be added on to the soil mix. The enough amount of necessary roller passes are required after the quality of mixing is accepted. Therefore only be considered for quick processing stabilization method because of the greater workability of PHA-stabilized materials. The height and width of layer should be maintained carefully in order to get the uniformity of the stabilized layer.

5.1.2 Placing & Laying

The composite sub-base material prepared in stock shall be placed on the existing subgrade and compacted in a layer according to the specification manuals. The sub base soil shall be spread in a very uniform layer to avoid the segregation. Loose depth of the layer shall be compacted with the required thickness. The stabilized soil was spread by Moto grader or other approved devices.

Before commencing the laying, following things were inspected at the field.

- ✓ Site Safety arrangement in place
- ✓ Approval of design cross section
- ✓ Previous layer levels, dimension checked & accepted
- ✓ Previous layer tested & accepted
- ✓ Surface preparation accepted

After the stabilized material has been placed, the stabilized soil was laid on the existing sub grade and then mixed well. After that, trimming and leveling also to be done in prepared layer. Also stabilized material mixed again with the sufficient water to satisfy the required compaction. After that, trimming and leveling also to be done in prepared layer. Then the constructed layer should be compacted after the curing.

A minimum thickness of any stabilized layer to be maintained and it is not less than 100mm of compacted thickness. Also, maximum compacted thickness shall be 200mm, and it’s should be accepted by the Engineer. The sub base material was constructed in a layer in 150mm of compacted thickness. If more than one layer is needed, the development procedure delineate and shall apply equally to every layer. Careful observation shall be followed to prevent the mixing of either subgrade or shoulder material in to the sub base layer.

5.1.3 Compaction

Commonly compaction will end up in a dense state of compactness if occurred with robust particles bonding or interaction. Sometimes, it may be very effective to the performance of the PHA composite layers due to the following reasons.

(1) Minimizing the deformation and settlements

(2) Providing the very good structural stability by increasing the shear strength

(3) Arising the bearing capacity of sub base layers

(4) Avoiding undesirable volume changes caused due to the shrinkage, frost action, and swell.

The mixture of composite sample was deposited in situ before the compaction shall equally cover the entire area for the layer involved. The required amount of water will be added with the composite soil mixture. Then it should be laid by means that of motor graders or alternative appropriate instrumentality. The amount of water be added continuously until getting the uniform mixture for the compaction purpose.

The Sub-base were spread normally in layers of thickness of 150mm. Ten tone smooth wheeled roller was used for the compaction. The smooth wheeled roller operated in the vibratory mode, and at a speed not exceeding 4 km/h; plus, one of the following:

- ✓ The stabilized soil shall be compacted. In order that, once the whole lift has been spread, a minimum of eight complete roller passes with the required equipment is used compact the particular strip area.
- ✓ Rolling should begin at the edge of the road and work towards the center and be continual by a variety of passes till full compaction has been achieved. The number of passes needed and it can depend upon the type and weight of the roller used. Table nineteen provides a guide to the number of passes to be created to adequately compact a 150mm gravel layer with typical varieties of roller utilized in labor-based construction. Otherwise, water ought to be added as required, throughout the rolling operation.

- ✓ The satisfactory moisture content level should be maintained during the construction of layer to obtain maximum density. If there are minor deficiency or excess of moisture was occurred, that will be corrected by repeated application of water or air drying.
- ✓ After the compaction, top of the Sub-base layer should be trimmed and leveled to get the good finish regarding the engineer’s instruction or shown in the cross-sections.

Thereafter compaction may proceed with finishing roller passes. The compaction must be done at the level of predetermined moisture content (plus or minus 2% of OMC). The compaction activities must be done immediately or sometime later. Otherwise if the layer needed for air drying, compaction to be done after the curing. Required curing is very important for such reasons.

• To obtain the enough water content, the constructed layer is maintained in order to that the stabilizer will allow to achieve the hydration.

• To minimize the shrinkage.

A good curing is very essential in hot and drought seasons. But it is very difficult to avoid the moisture loss during the construction times. Though, alternative procedures have been practicing in dry zone areas. If the layer is sprayed in evening, the excess amount of water applied on the surface and kept it night to allow the surface for air drying. Next day morning that will be observed in the field. Then the moisture content of the layer was checked, whether it will remain stable or not for the compaction. According to the observed decision, compaction was done in the sub base composite layer. Table No. 12 illustrate the compaction details.

Table 12: Detail of roller speed and roller passes

Roller type	Smooth wheeled 10 tone
Number of Roller Passes	08
Speed(km/h)	2.5
Operating width(m)	1.3

5.1.4 Acceptance Sampling and Testing

Quality control measures are very important in this type of construction activities. Quality control measures consider the evaluation of PHA content, sufficient wetness maximum dry density, bearing strength and plasticity measuring. Also, verify the intermixture techniques, timely intermixture, laying techniques and good compaction method of soils. After the compaction has been made on field, the inspection must be made on constructed layer. The following necessary items were checked and they comply with all specified requirements.

- ✓ Safety measures & Traffic control in place
- ✓ Setting Out (CL, EL & Levels marked)
- ✓ Layer levels & dimension checked & accepted
- ✓ Surface preparation accepted
- ✓ Equipment as required & in order

Normally testing process has been carried out on the compacted layer after the field inspection. Engineers give the prior approval for testing if the surface was ready for testing. If it is difficult to find the quality of the compacted layer, the approval and decision will be based on density results. Then test was administered right away once the compaction cured out. The random selection of the sampling locations were determined by the Engineer’s. Finally it will be decided with the contractor. That should be done on a random basis using ASTM D 3665 method.

The field tests were carried on three different locations within 10m interval, because to achieving uniformity of the compaction in the field. Thus, it could be checked whether the material satisfied the requirement in the Technical Specification. Density measurements were taken using one of the sand cone methods. The densities observed during construction were below the maximum Modified Proctor density.

MC (%) = (Water weight/Dry sample weight) *100………… (i)

Dry density = (wet density/ (100 + weight of dry sample) *100………………… (ii)

The following Table 14 shows the field density test result.

Table 13-Field density test summary for PHA stabilized Sub base construction

NO	Location	Test Hole Depth (mm)	Moisture Content (%)	Compaction (%)	Required Compaction (%)	Remarks
1	0+000 to 10+000	146	10.4	98.3	98	Satisfied
2	10+000 to 20+000	155	9.6	97.2	98	Not Satisfied
3	20+000 to 30+000	148	10.2	98.2	98	Satisfied

From the test results, one location out of three gave the less density than required density. Therefore, re-compaction process was applied in the same length by increasing the roller passes and moisture content in the same condition. The PHA stabilized soil layer would be sufficiently watered as required and prior to compaction by using sprinkler attached with water bowser. This procedure shall be followed until the required density is reached. Compaction would be done in lower end to higher end (edge to center) method by using the 10-ton vibrating roller with sufficient roller passes. After a specific number of roller passes, the density was checked again at failure location.

5.2 Discussion on How the Blending Affects the Observed Changes in LL, PI, Etc.

From the field consistency test data, it is observed that addition of PHA decreases LL value and PI value. The liquid limit of the resulting blends decreased with addition of 8% PHA and decreased the PI respectively. The addition of PHA which is non-cohesive and increased the binding ability of the mixture and its capacity to retain moisture. The decreasing plasticity would consequently result in decreasing swell ability of the soil samples.

Further, increasing the percentage of PHA make fines of the gravel soil attained the behavior of PHA. The plastic behavior of the gravel soil are purely controlling on the percentage of particles less than < 425μm and specifically less than 75μm. The percentage of fines are 17 in the given soil composition. The main contribution for the development of plasticity characteristics are clay content and silt content. During the bleeding process, PHA increased the cohesive strength of the soil. As well as retained the shape changes when adding water to composite sample. Therefore, some amount of water is required for liquid consistency stage. When the LL was reduced, the range of consistency and free movements of soil particles within a PHA soil mix also reduced. Hence, PI value was reduced. So, workability of the soil mix was improved due to the decrease of LL and PI.

Compaction test results shown that, there was a rise in the OMC value and also slight decreasing in the MDD value. A steady increase in OMC was observed at early dosages. The increase in optimum Moisture contents are due to replacement of Silt and Clay particles by PHA particles. Thus which is increases the intake of moisture and decreasing dry densities are due to occupation of more PHA solids with respect to soil particles. The percentage of PHA increased the CBR values up to 10%. Attainment of maximum values up to 8% dosage are due to occupation of more solids in the given volume and effective interaction between the PHA particles and fine and coarser particles of gravel soil. In addition which offer more shearing resistance against compression.

The blending process that will help to improves the soil resistance against deformation and durability. As well as decrease the susceptibleness to water molecules. Angular particles provides more interaction and particles bonding with in the particles and influence smaller deformation compared to rounded shape particles. During the blending process ash particles replace the finer particles and then increase the amount of coarse particles in the soil mixture. Hence, contact points between particles will be increased due to the angular shape particles. Therefore, it results should give the better load distribution between the layers. At the beginning stage it's requiring more water for binding and hydration process. So, due to the hydration, lower water content might be predictable and that will develop the capillary action between the particles. Thus, it will create the low volume of voids and this provides more strength.

It is also indicated that the increasing amount of PHA to the composite sample decreased their shrink ability as was expected. Also, it evidence that the resulting blends would be less susceptible to crack when dried. Due to the remarkable improvements made in the bearing strengths of the gravels blended with PHA is easier to compact. Hence, 8% of blended PHA satisfy these specifications and would therefore perform excellently in road construction.

6 Conclusions

Marginal sub-base soils, including fine particles topsoil and organics, are not adequate materials for the construction of road projects. These marginal soil do not possess valuable engineering properties for construction applications. In most cases finding an alternative soil source might be proven uneconomical; hence we can modify or improve the natural soil to meet the required objectives. Such nature of problematic soils are often improved using the wastes materials. This research result shown that, how potential of industrials wastes used for the problematic clay soils and how changes the engineering properties of soil.

In countries with high rice production, Paddy husk and its ash are residues whose final disposition is a big concern, the use of PHA for soil improvement is particularly attractive. Paddy husk ash most widely available in everywhere of Srilanka. Also, it is partially produced from the rice mill and readily available. Weight wise 20% husk can be obtained from the rice. PHA was obtained from burnt paddy husk at a temperature of 400℃ to 700℃, after which the ash was allowed to pass through 425μmm BS sieve size. Most probably, if the soils consist a considerable quantity of clay and its relevant mineralogy, stabilization using PHA could be suitable for improve it. According to the plastic properties of different natural soil, it can be seen that minimum percentage of the Paddy Husk Ash was required to getting the best results. In this experiment, the fraction of Paddy Hush Ash was reduced the clay content, improved the passing through 0.075mm sieve and reduced the Liquid Limits as well as Plastic Index significantly.

Addition of PHA as a stabilizer increased the value of OMC steadily; the initial increase amount could have been as a result of hydration reaction due to the increased demand for water by various cations and the clay mineral particles in that soil mixture. However, addition of PHA was reduced the density of composite soil sample. The reduction in MDD was occurred due to the replacement of soil particles by PHA. The reason was behind this, specific gravity of PHA lesser than the soil specific gravity. When PHA is used as soil stabilizer, soil particles became larger due to the changes occurred in texture. Also, the void ratio might be increase in the composite sample when particle become larger size.

In this experimental research study, PHA was acted as a cementations' material because of its pozzolanic property. Thus, it could reduce the volume changes within the clay fraction. Its high reactivity and pozzolanic properties increased the CBR value as well. . The PHA composite soil mixture was decreased the swell potential up to 0.3%-4%. The tests result for the 8%-10% PHA composite materials indicate acceptable specification limits for sub base construction. The construction of sub base layer with the PHA composite soil also provided the good response in the field. Field Density test results of the sub base layer shown that, there was a good enough compaction and stability in the field.

(Xunli Jiang, 2019) Stated that, the microscopic test analyses disclose that the main motives for strength increase and soil water characteristics alternate with the addition of PHA are the more advantageous cohesion by way of cementation and pore fillings with agglomerated minerals. (Leonardo, 2017) Found following outcomes that UCS will increase with the increase of the PHA quantity till to attain an optimum. The optimum PHA is greater when the lime quantity is less, then again it is feasible to attain greater UCS when is added the least quantity of lime and PHA contents greater than the top of the line corresponding to greater lime contents. A gain of UCS over time is discovered for all studied PHA and lime combinations. Pozzolanic reactions start rapidly and proceed for a very long duration of time, even many years, as long as sufficient free calcium ions and silica are existing and the pH stays high.

Ahmad, 2014 and Rasoul, 2017 published that the PHA properties (silica form, fineness, silica share and loss on ignition) have a strong impact on the improvement of strength at longevity for concrete. Experiments confirmed that concrete has a greater strength, resilience and toughness performance compared to OPC concrete when add with 50% substitute of Ordinary Portland Cement by PHA. This might also be attributed to the truth that increasing percentage of PHA could be lessen the porosity, at the same time rise the strength and durability of concrete.

The Paddy Husk Ash has low organic content and is a non-bio degradable product so, durability of pavement will be improved due to the presence of ass particles. Which acts as cementation, making the soil particles connect better and enhancing the tensile strength. The pavement strength is expected to improve gradually with compaction due to the traffic flow. Because of the constructed of PHA composite layer was adopted with the approved payment design by the consultant of the particular project. However, only the properties were improved using PHA particles match with pavement design. PHA composite sub-base layer could also serve as a drainage layer to eliminate water intrusion from the pavement because of its higher porosity due to the larger particles and air voids. Hence, this layer will solve many problems like collection of drain water on road surface in rainy season, flexibility of a rigid pavement as well.

The experimental study revealed that the Mahadamana, Sooriyaweva and Welikanda borrow pits soil were indicated the optimum PHA amounts such as 8%, 10%, and 14% respectively. Among the above three cases, Welikanda soil sample could not satisfy the requirement of the plastic index. LL value and PI value of the Mahadamana natural soil were 42 and 19 respectively. An optimum of 8% PHA could reduce the soil liquid limit to 34 (20%) and Plastic Index to 19 (26%). LL value and PI value of the Sooriyaweva natural soil were 46 and 22 respectively. An optimum of 10% PHA could reduce the soil liquid limit to 34 (26%) and the Plastic limit to 14 (36%).

Finally, it’s concluded that if the marginal sub base soil has the plastic limit below 46, the plastic index below 22 and the maximum dry density above 1.94g/cm3, it could be improved using PHA as a sub base soil in the soil stabilization. This analysis study has additionally enhanced our understanding of failure roads and how it depends on the structural pavement behavior. Importantly, the properties of road construction materials and also the maintenance strategy must be adopted with the PHA stabilized layer. Therefore utilization and adoption of paddy husk in rural road construction activities is a good technique compared to other development technique used in traditional roads.

7 Recommendation

Based on the study, 8% to 10% Paddy Husk Ash (RHA) content can be recommended as suitable materials for treatment of clay soil to improve its geotechnical properties (in places where they are abundant) before using it as sub base materials in road construction. It can be suggested that further research must be carried out to increase the maximum dry density of the PHA composite soil with addition of suitable and less cost waste products for this composite sample rather than lime and cement. The effect of the Paddy Husk on other type of materials such as subgrade material, shoulder material and base course also to be investigated to find where it will be suitable or not. So, that will use to establish it in future as an overall soil stabilizer agent.

For the present specification guidelines, the supported empirical check strategies should be incorporate with additional tests result and that assess short term and long-run aging procedure. Another good example is the preparation current payment design methods also not include the behavioral character of the soil and long term aging. For that, additional analysis work is important to change the specification limits. This specification needs to be revised from time to time and also the future expertise of Sri Lankan road engineers and designer ought to be taken to develop this specification a lot of effectively.

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Appendix A: Test Reports for Mahadamana borrow pit soil

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

Consultant: **RDC (Pvt.)Ltd.**

Contractor: ***TISSA-AMSK (JV)***

Type of Materil	**: Sub Base**	Date of Sampling :	
Sample No.		Date of Testing :	
Lacation	**Lab**		
Source	**Mahadamana Borrow pit**		

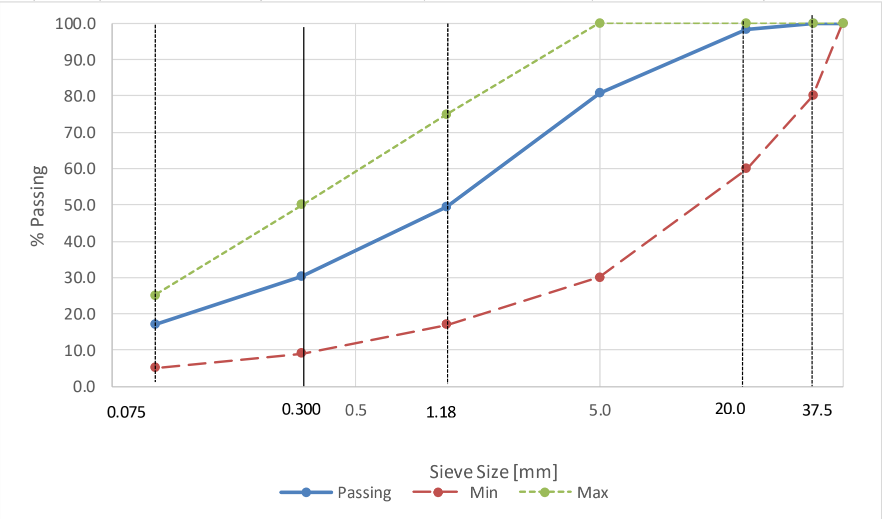
Sieve analysis of Soil

(BS-1377-Part-2-1990)

Wt. of Oven dry Sample before washing (g) : 2,366.0

Wt. of Oven dry sample after washing (g) : 1,896.0

Sieve Size [mm]	Weight retained [g]	% Retained [%]	% Passing [%]	Specified Limits [%][Sec:1705.2]	
				Min	Max
50.0	0.0	0.0	100.0	100	100
37.5	0.0	0.0	100.0	80	100
20.0	43.6	1.8	98.2	60	100
5.0	412.4	17.4	80.8	30	100
1.18	740.0	31.3	49.5	17	75
0.300	456.4	19.3	30.2	9	50
0.075	236.6	13.0	17.2	5	25
Pan	6.3				
Total	1895.3				



Remarks :

	CONTRACTOR			CONSULTANT	
	Tested by:	***Checked by:***	***Approved by:***	***Witnessed by:***	***Reviewed by:***
Name:	A.M.Wasantha	Pubudu Perera	R.R.P.A.S.Kumara	S.S.R.ajapaksha	....
Designation:	MT	ME	QAM	MT	....
Signature:	....	....	....	....	....
Date:	....	....	....	....	....

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

Consultant: Contractor:
RDC (Pvt.)Ltd. ***TISSA-AMSK (JV)***

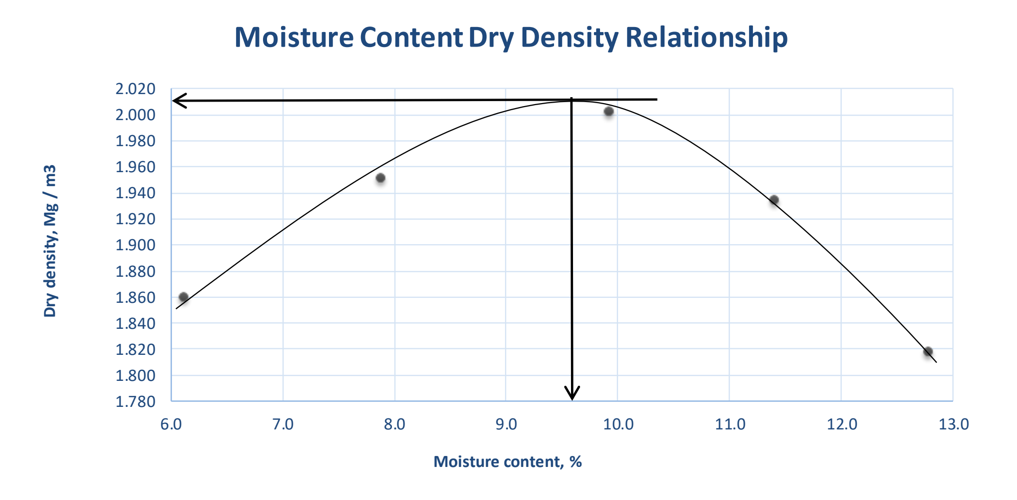
Type of Material	:		Date of Sampling	:
Sample No.	:		Date of Testing	:
Lacation	:	**Lab**		
Source	:	**Mahadamana Borrow Pit**		

DETERMINATION OF DRY DENSITY - MOISTURE CONTENT RELATIONSHIP

Test Method :AASHTO T 180

No. of Layers	Blows per layer	Volume of Mould(cm^3)	Total mass of sample(g)	Weight of Rammer (kg)	Mould ID No:
5	**56**	**2124**	25000	4.5	H

Trial No		**1**	**2**	**3**	**4**	**5**
Volume of water added	ml	100	200	300	400	500
Mass of mould with base plate + compacted soil	g	9682	9962	10166	10066	9845
Mass of mould with base plate	g	5490	5490	5490	5490	5490
Mass of compacted soil	g	4192	4472	4676	4576	4355
Bulk density	Mg / m^3	1.974	2.105	2.202	2.154	2.050
Moisture container no.		**AN**	**ED**	**O**	**6**	**U**
Mass of wet soil + container	g	498.2	422.6	451.9	521.3	487.4
Mass of dry soil + container	g	471.9	394.4	413.3	475.3	436.8
Mass of clean dry container	g	41.6	36.4	24.4	72.0	41.0
Mass of water	g	26.3	28.2	38.6	46.0	50.6
Mass of dry soil	g	430.3	358.0	388.9	403.3	395.8
Moisture content	%	**6.1**	**7.9**	**9.9**	**11.4**	**12.8**
Dry density	Mg / m3	**1.860**	**1.952**	**2.003**	**1.934**	**1.818**



Max. Dry Density,(Mg / m^3) = **2.010** **Optimum Moisture content %** = **9.6**

	CONTRACTOR			CONSULTANT	
	Tested by:	***Checked by:***	***Approved by:***	***Witnessed by:***	***Reviewed by:***
Name:					
Designation:					
Signature:					
Date:					

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

Consultant: **RDC (Pvt.)Ltd.**

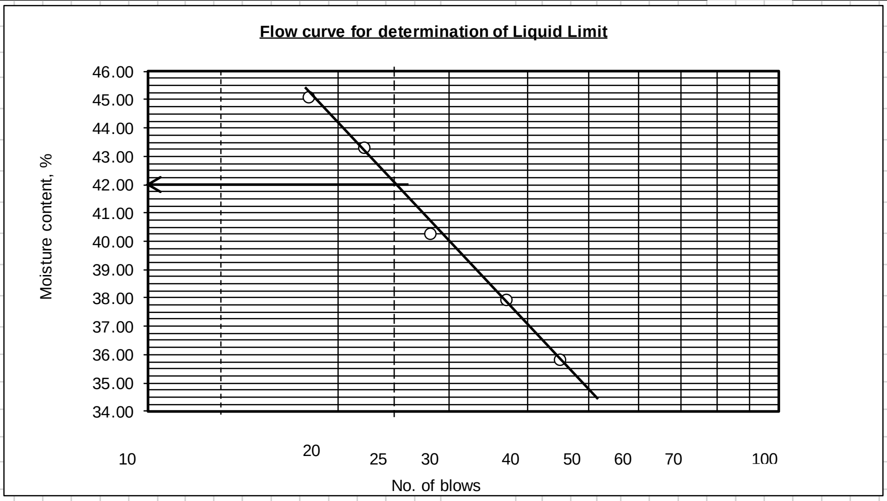
Contractor: **TISSA-AMSK (JV)**

Type of Material	:	**Sub Base**	Date of Sampling	:	
Sample No.	:		Date of Testing	:	
Lacation	:	**Lab**			
Souurse	:	**Mahadamana Borrow pit**			

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL

(AASHTO T - 89 / T - 90)

		Determination of Liquid limit						Determination of Plastic Limit	
Trial No.		**1**	**2**	**3**	**4**	**5**		**1**	**2**
Can No		A	16	51	13	20		12	8
Wt. of wet soil + Can	(g)	59.88	62.11	60.41	58.94	60.22		41.56	40.62
Wt of Dry soil + Can	(g)	**51.76**	**53.28**	**52.04**	**50.28**	**50.85**		**39.26**	**38.70**
Wt. of Can	(g)	29.08	30.00	31.26	30.29	30.05		29.31	30.51
Wt. of Moisture	(g)	**8.12**	**8.83**	**8.37**	**8.66**	**9.37**		**2.30**	**1.92**
Wt. of Dry soil	(g)	**22.68**	**23.28**	**20.78**	**19.99**	**20.80**		**9.95**	**8.19**
Moisture Content %	%	**35.80**	**37.93**	**40.28**	**43.32**	**45.05**	Average	**23.12**	**23.44**
No of blows		45	37	28	22	18	M/C =	**23**	



	TEST RESULT	Specific limit			Remarks
		SUB BASE	SHOULDER	EMBANKMENT-1	
LIQUID LIMID (LL)	**42**	**40**	**50**	**50**	
PLASTIC LIMID (PL)	23	**-**	**-**	**-**	
PLASTICITY INDEX (PI)	**19**	**15**	**Jun-25**	**25**	
FOR USE					

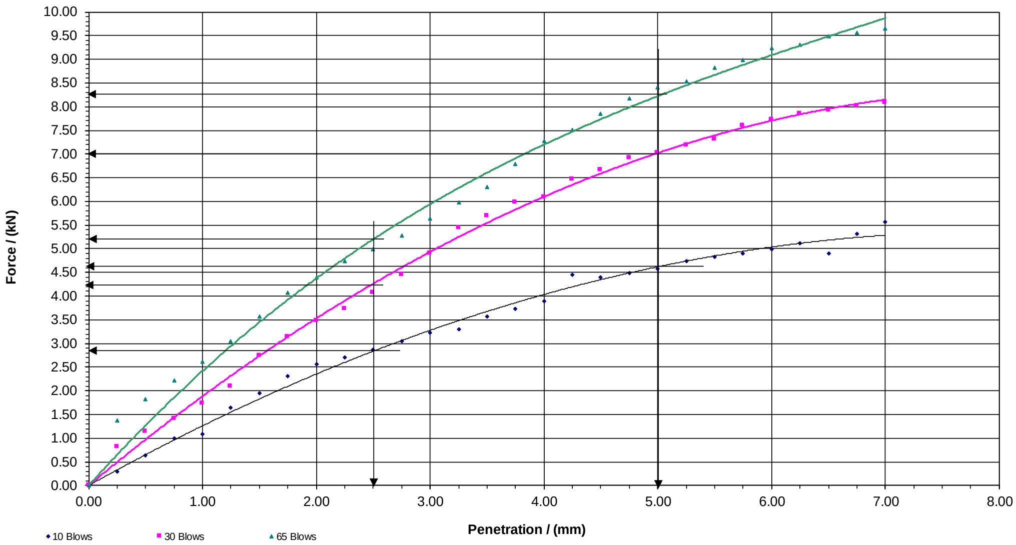
	CONTRACTOR			*CONSULTANT*	
	Tested by:	***Checked by:***	***Approved by:***	***Witnessed by:***	***Reviewed by:***
Name:					
Designation:					
Signature:	....	....	....	....	....
Date:	....	....	....	....	....

Rehabilitation / Improvements of 47 km of Rural Road
in the Polonnaruwa District - Contract 3 including
Performance based Maintenance for 3 years
Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

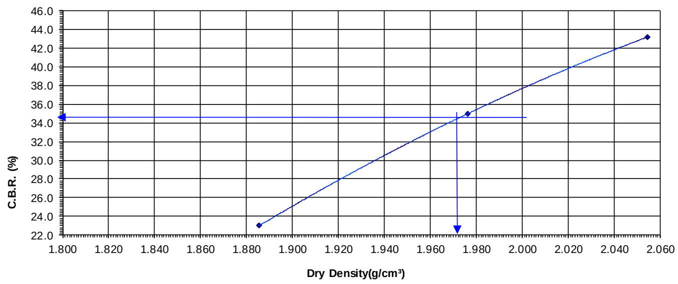
Consultant :
RDC (Pvt.)Ltd.

Contractor :
TISSA-AMSK (JV)

Lab Sample No : Mahadamana
Borrow Pit



Penetration (mm)	Standered Load (kN)	10 Blows		30 Blows		65 Blows	
		Corrected Force	Corrected CBR	Corrected Force	Corrected CBR	Corrected Force	Corrected CBR
2.5	13.20	2.81	21.29	4.25	32.20	5.70	43.18
5.0	20.0	4.60	23.00	7.00	35.00	8.20	41.00
Highest Valuve		23.00		35.00		43.18	
Dry Density		1.885		1.976		2.054	



Dry density (g/cm³)	Dry density % of MDD	C.B.R.(%)
1.970	98	**34.5**

Contractor			Consultant	
.... Tested by MT	.... Checked by ME	.... Approved by QAM	.... Witnessed by MT	.... Reviewed By ME
Date	Date	Date............................	Date............................	Date...............................

Appendix B: Test Reports for Sooriyaweva borrow pit soil

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RDC RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

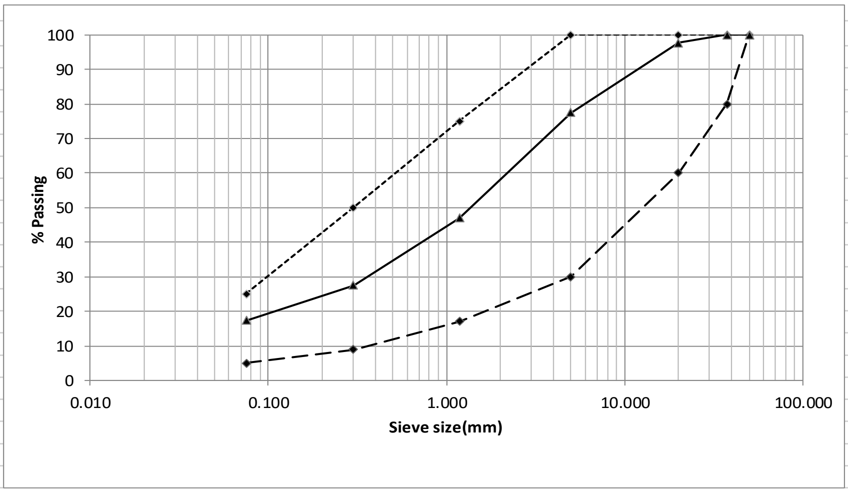
Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

SIEVE ANALYSIS

AASHTO T 88

Sample No.		**Date of Sampling**	
Sample Location	Lab	**Date of Test**	
Source	Sooriyaweva Borrow pit 2	**Before weight**	**2195.0**
Type of Material	Sub base	**After weight**	**1825.0**

Sieve Size (mm)	Weight Retained (g)	% Retained	% Passing	Spec. Limits Table-1708/3
50.0	0.0	0.0	100.0	100 -100
37.5	0.0	0.0	100.0	80 - 100
20.0	51.0	2.3	97.7	60 - 100
5.0	444.6	20.3	77.4	30 - 100
1.18	668.9	30.5	46.9	17 - 75
0.300	425.0	19.4	27.6	9 - 50
0.075	223.6	10.2	17.4	5 - 25
pan	11.1			
Total Weight Of Soil	1824.2			



Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Approved by	Witnees by	Review by
	Contractor			Engineer	

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

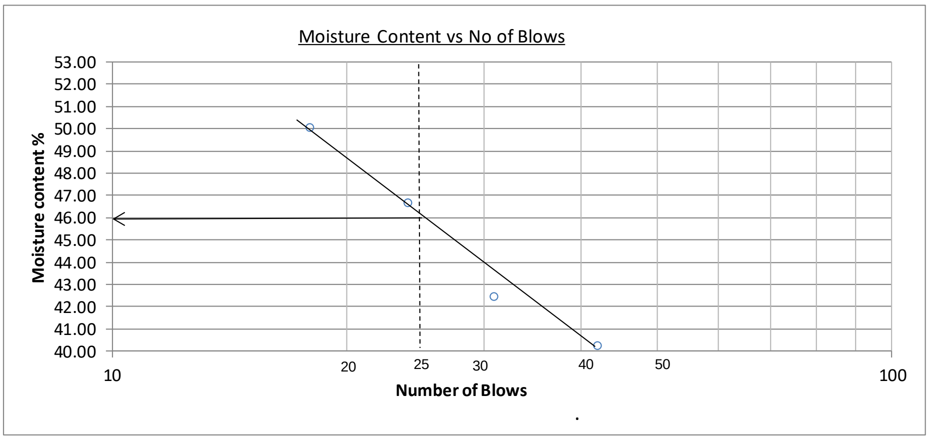
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.		Type Of Material	Embankment
Sample Location	Lab	Date of Sample	
Source	Sooriyawava borrow pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		1	2	3	4			5	6
Wt. of wet soil + Can	(g)	51.23	56.36	60.23	53.62			39.4	35.50
Wt of Dry soil + Can	(g)	43.73	47.13	49.23	44.36			36.69	33.47
Wt. of Can	(g)	25.08	25.38	25.63	25.84			25.03	25.25
Wt. of Moisture	(g)	7.50	9.23	11	9.26			2.71	2.03
Wt. of Dry soil	(g)	18.65	21.75	23.6	18.52			11.66	8.22
Moisture Content %	%	40.21	42.44	46.61	50.00			23.24	24.70
No of Blows		42	31	24	18			24.0	



LIQUID LIMIT % :- **46.0**
PLASTIC LIMIT % :- **24.0**
PLASTICITY INDEX % :- **22**

Remarks :	

Signature					
Name					
Designation					
Date					
	Tested by	*Checked by*	*Approved by*	*Witnees by*	*Review by*
	Contractor			***Engineer***	

Appendix C: Test Reports for Welikanda borrow pit soil

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RDC RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

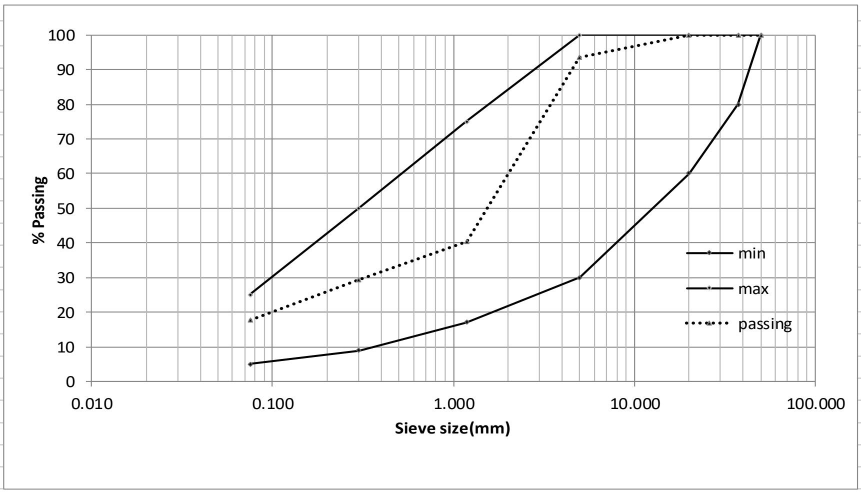
Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

SIEVE ANALYSIS

AASHTO T 88

Sample No.	SOIL - 02	**Date of Sampling**	
Sample Location		**Date of Test**	
Source	Welikanda Borrow pit	**Before weight**	**2700.0**
Type of Material		**After weight**	**2260.0**

Sieve Size (mm)	Weight Retained (g)	% Retained	% Passing	Spec. Limits Table-1708/3
50.0	0.0	0.0	100.0	100 -100
37.5	0.0	0.0	100.0	80 - 100
20.0	0.0	0.0	100.0	60 - 100
5.0	174.4	6.5	93.5	30 - 100
1.18	1438.7	53.3	40.3	17 - 75
0.300	296.0	11.0	29.3	9 - 50
0.075	340.6	11.6	17.7	5 - 25
pan	9.6			
Total Weight Of Soil	2259.3			



	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Approved by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

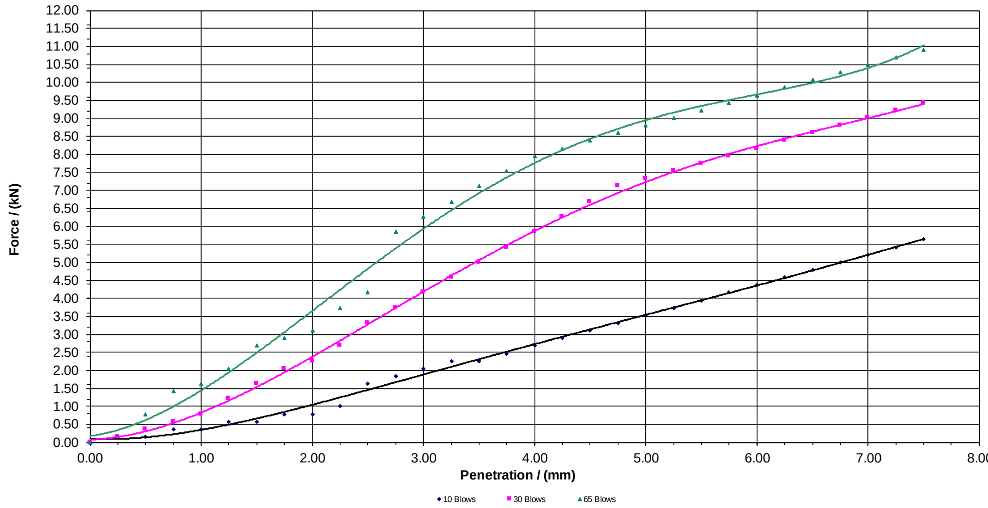
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

CONTRACT PACKAGE:- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

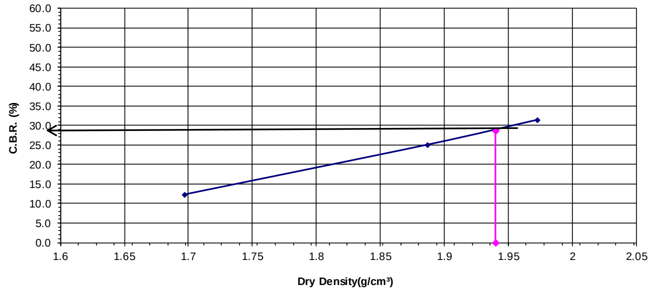
CALIFORNIA BEARING RATIO TEST

(AASHTO / T193 - 99)

Sample No.		Type of Material	
Sample Location		Date of Sampling	
Source	Sooriyaweva Borrow Pit	Date of Testing	



Penetration (mm)	Standered Load (kN)	10 Blows			30 Blows			65 Blows		
		Force	Corrected Force	Corrected CBR	Force	Corrected Force	Corrected CBR	Force	Corrected Force	Corrected CBR
2.5	13.24	1.63	1.63	12	3.32	3.32	25	4.16	4.16	31
5.0	19.96	3.53	3.53	18	7.33	7.33	37	8.80	8.80	44



Dry density (g/cm³)	Dry density %	C.B.R.(%)
1.940	98	28.5

Signature					
Name					
Designation					
Date					
	Contractor			Engineer	

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

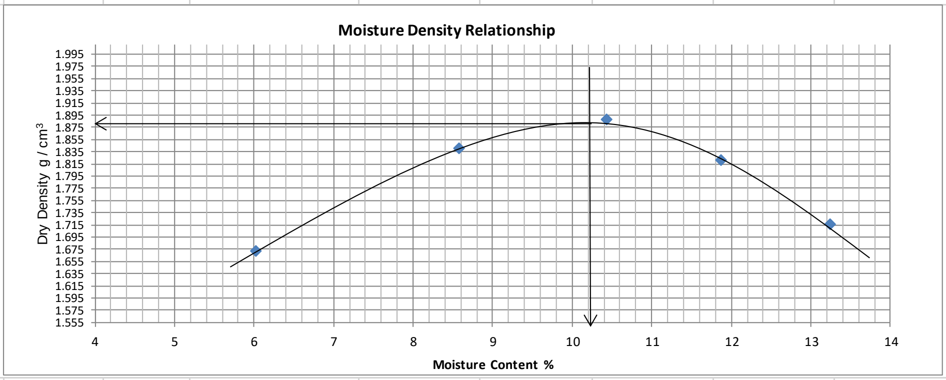
PROCTOR COMPACTION

(Test Method -AASTO T-180)

Sample No.	SOIL - 02	**Date of Sampling**	
Sample Location		**Date of Test**	
Source	Welikand borrow pit 2	**Type of Material**	

Mould No.		2	Weight of Rammer	kg	4.5
Height	cm	11.7	Dropping Height	mm	457
Diameter	cm	15.2	Number of Layers		5
Volume	cm^3	2124	Blows Per Layer		56
Weight	g	6080			

Test No. / Container No.		1	32	58	54	38
Weight of Water	ml	250	350	450	550	650
Weight of wet sample + container	g	385.9	355.0	326.1	343.7	320.9
Weight of dry sample + container	g	365.7	330.2	298.5	311.3	287.7
Weight of container	g	30.2	41.0	34.0	38.5	36.9
Weight of water	g	20.2	24.8	27.6	32.4	33.2
Weight of dry Soil	g	335.5	289.2	264.5	272.8	250.8
Moisture content	%	6.0	8.6	10.4	11.9	13.2
Weight of wet sample + mould	g	9845	10323	10632	10634	10209
Weight of mould	g	6080	6080	6080	6080	6080
Weight of sample	g	3765	4243	4430	4328	4129
Bulk density	g/cm^3	1.773	1.998	2.086	2.038	1.944
Dry density	g/cm^3	1.672	1.840	1.889	1.821	1.717



Maximum dry density	g/cm^3	1.881
Optimum moisture content	%	10.2

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Approved by

0	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

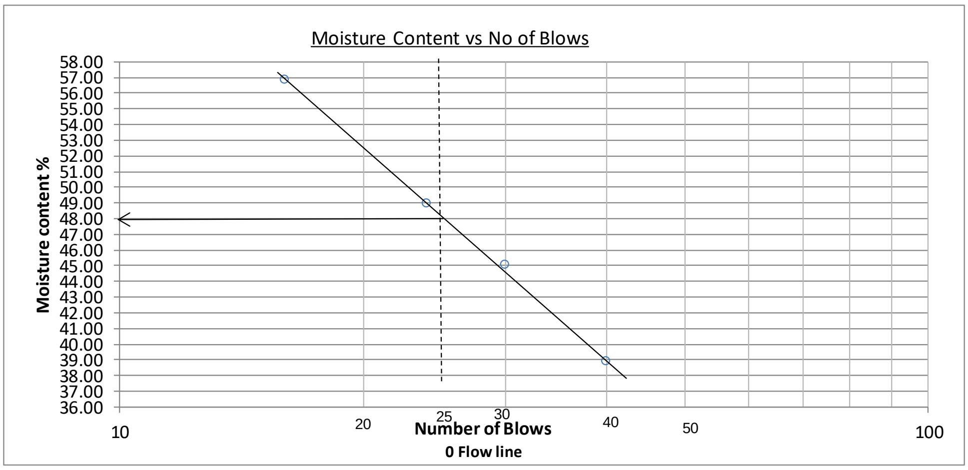
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.		Type Of Material	
Sample Location		Date of Sample	
Source	Welikanda Borrow pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		1	2	3	4			5	6
Wt. of wet soil + Can	(g)	47.36	47.03	45.36	47.26			37.59	39.19
Wt of Dry soil + Can	(g)	41.12	40.31	38.88	39.50			35.32	36.68
Wt. of Can	(g)	25.08	25.38	25.63	25.84			25.03	25.25
Wt. of Moisture	(g)	6.24	6.72	6.48	7.76			2.27	2.51
Wt. of Dry soil	(g)	16.04	14.93	13.25	13.66			10.29	11.43
Moisture Content %	%	38.90	45.01	48.91	56.81			22.1	22.0
No of Blows		40	30	24	16			22.0	



LIQUID LIMIT % :- **48**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **26**

Remarks :	

	Contractor			*Engineer*	
Signature					
Name					
Designation					
Date					
	Tested by	*Checked by*	*Recommended by*	*Witnees by*	*Approved by*

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

CONTRACT PACKAGE:- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

CALIFORNIA BEARING RATIO TEST

(AASHTO / T193 - 99)

Sample No.		Type of Material	
Sample Location		Date of Sampling	
Source	Welikanda borrow pit	Date of Casting	
IMC (%)	2.5	Date of Testing	
MDD (g/cm³)	1.940	OMC (%)	10.4

Mould No.	A	B	C
Mould height mm	116	117	117
Number of Layers	5	5	5
Number of Blows	10	30	65

	Before Sat.	After Sat.	Before Sat.	After Sat.	Before Sat.	After Sat.
Weight of Mould+Soil g	12495	12692	12894	13006	13266	13408
Weight of Mould g	8063	8063	8085	8085	8011	8011
Weight of Wet Soil g	4432	4629	4809	4921	5255	5397
Volume of Mould cm³	2396	2396	2401	2401	2414	2414
Wet Density g/cm³	1.850	1.932	2.003	2.050	2.177	2.236

Moisture Content & Dry Density of Specimen

Container No.	36	59	54	37	15	16	18	17	10	12	57	52
Cont.+Wet Sample g	298.8	382.2	426.1	464.8	264.4	292.1	317.2	312.4	221.9	225.9	401.1	436.3
Cont.+Dry Sample g	274.6	349.8	375.6	409.5	242.6	267.4	284.2	279.3	204.0	207.4	360.5	391.3
Wt.of Water g	24.2	32.4	50.5	55.3	21.8	24.7	33.0	33.1	17.9	18.5	40.6	45.0
Wt.of Cont. g	39.4	34.2	38.5	35.6	30.9	31.9	29.4	27.0	30.5	28.7	36.4	35.5
Wt.of Dry Sample g	235.2	315.6	337.1	373.9	211.7	235.6	254.8	252.3	173.5	178.7	324.1	355.8
Moisture Content %	10.3	10.3	15.0	14.8	10.3	10.5	13.0	13.1	10.3	10.4	12.5	12.6
Ave. Moisture Content %	10.3		14.9		10.4		13.0		10.3		12.6	
Dry Density g/cm³	1.677		1.682		1.814		1.813		1.973		1.986	
Degree of Compaction %	86.5		86.7		93.5		93.5		101.7		102.4	

	Initial swell / (mm)	4 days soak swell / (mm)	Initial swell / (mm)	4 days soak swell (mm)	Initial swell / (mm)	4 days soak swell (mm)
Swell	0	1.60	0	1.02	0	0.50
Percentage of swell	1.38		0.87		0.43	

Signature					
Name					
Designation					
Date					
	Test by	Checked by	Approved by	Witnees by	Review by
	Contractor			Engineer	

Appendix D: Atterberg Limit Test Reports for Mahadamana borrow pit soil with PHA stabilizer

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

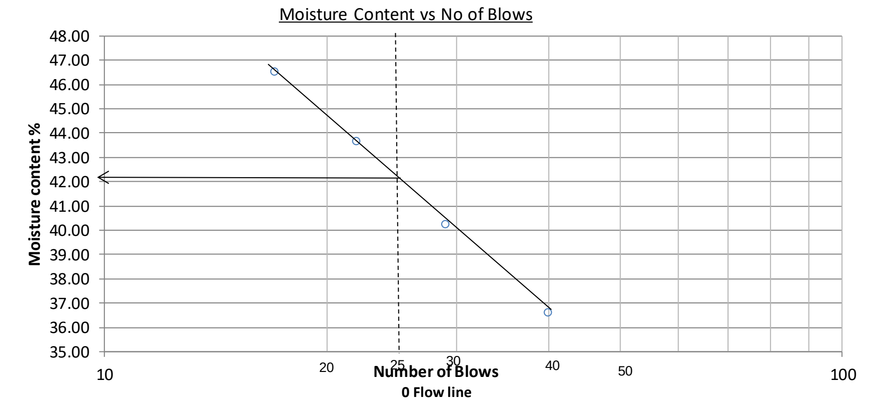
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NILL	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Source	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		14	15	16	17		18	19
Wt. of wet soil + Can	(g)	52.65	54.99	54.87	56.39		39.57	40.13
Wt of Dry soil + Can	(g)	45.39	46.41	45.87	46.57		36.83	37.39
Wt. of Can	(g)	25.54	25.07	25.24	25.45		25.03	25.25
Wt. of Moisture	(g)	7.26	8.58	9	9.82		2.74	2.74
Wt. of Dry soil	(g)	19.85	21.34	20.63	21.12		11.8	12.14
Moisture Content %	%	36.57	40.21	43.63	46.50		23.22	22.57
No of Blows		40	29	22	17		23	



LIQUID LIMIT % :- **42**
PLASTIC LIMIT % :- **23**
PLASTICITY INDEX % :- **19**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

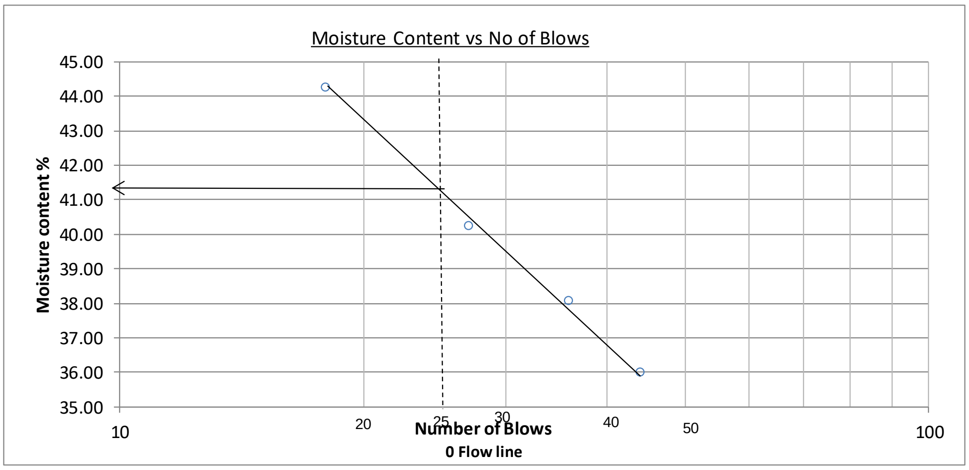
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+2%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		1	2	3	4		5	6
Wt. of wet soil + Can	(g)	52.11	54.89	54.74	56.39		39.44	40.01
Wt of Dry soil + Can	(g)	44.97	46.77	46.44	47.05		36.76	37.31
Wt. of Can	(g)	25.12	25.43	25.81	25.93		25.04	25.31
Wt. of Moisture	(g)	7.14	8.12	8.3	9.34		2.68	2.70
Wt. of Dry soil	(g)	19.85	21.34	20.63	21.12		11.72	12
Moisture Content %	%	35.97	38.05	40.23	44.22		22.87	22.50
No of Blows		44	36	27	18		23	



LIQUID LIMIT % :- **41**
PLASTIC LIMIT % :- **23**
PLASTICITY INDEX % :- **18**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

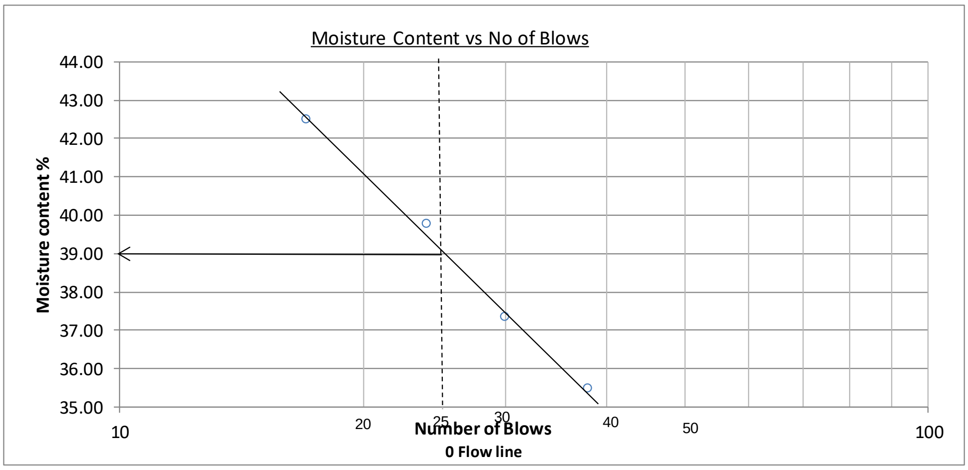
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+4%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		21	22	23	24		25	26
Wt. of wet soil + Can	(g)	52.33	55.47	54.2	55.98		39.99	39.63
Wt of Dry soil + Can	(g)	45.26	47.43	45.98	46.96		37.29	37.34
Wt. of Can	(g)	25.33	25.90	25.3	25.73		25.67	25.96
Wt. of Moisture	(g)	7.07	8.04	8.22	9.02		2.7	2.29
Wt. of Dry soil	(g)	19.93	21.53	20.68	21.23		11.62	11.38
Moisture Content %	%	35.47	37.34	39.75	42.49		23.24	20.12
No of Blows		38	30	24	17		22	



LIQUID LIMIT % :- **39**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **17**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

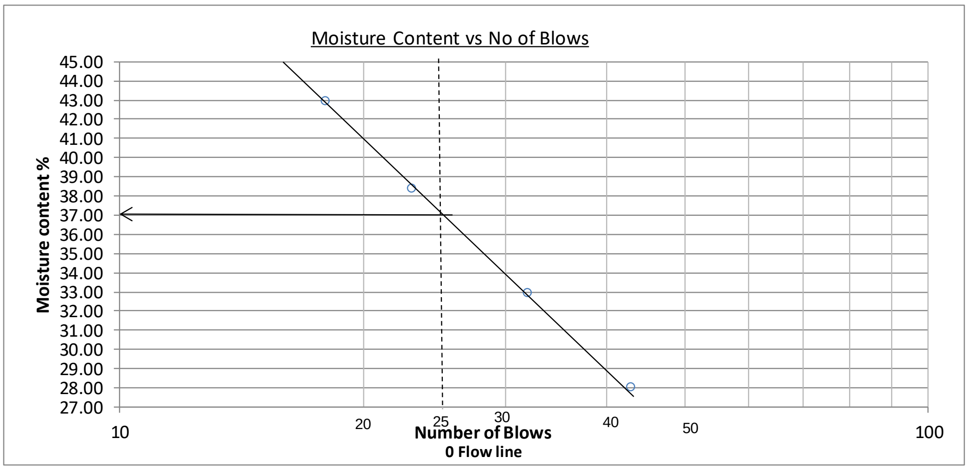
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+6%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		9	10	11	12		13	14
Wt. of wet soil + Can	(g)	51.42	54.43	54.17	56.52		40.35	39.98
Wt of Dry soil + Can	(g)	45.75	47.28	46.15	47.38		37.95	37.39
Wt. of Can	(g)	25.5	25.57	25.25	26.08		26.15	25.54
Wt. of Moisture	(g)	5.67	7.15	8.02	9.14		2.4	2.59
Wt. of Dry soil	(g)	20.25	21.71	20.9	21.3		11.8	11.85
Moisture Content %	%	28.00	32.93	38.37	42.91		20.34	21.86
No of Blows		43	32	23	18		21	



LIQUID LIMIT % :- **37**
PLASTIC LIMIT % :- **21**
PLASTICITY INDEX % :- **16**

Remarks :

	Contractor			Engineer	
Signature					
Name	M.A.Dharmapriya	C.S.Dahanayaka	M.D.K.N. Samarasekara	K.Vinojan	S.R.A. Anura Gamini
Designation	LT	MT	QAE	RA	Material Engineer
Date	1/0/1900	0	0		
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

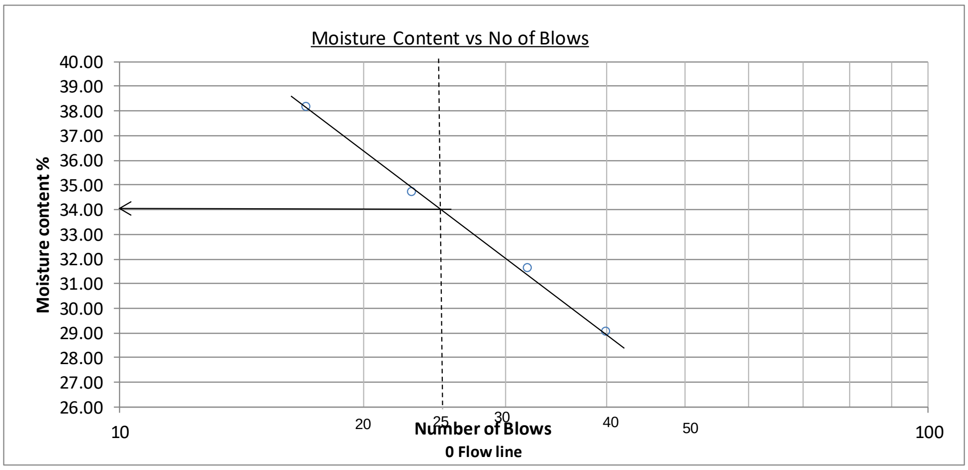
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+8%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		8	9	10	11			12	13
Wt. of wet soil + Can	(g)	53.95	53.58	55.2	57.62			40.42	41.06
Wt of Dry soil + Can	(g)	47.37	46.82	47.57	48.68			38.01	38.57
Wt. of Can	(g)	24.71	25.44	25.59	25.25			26.05	26.16
Wt. of Moisture	(g)	6.58	6.76	7.63	8.94			2.41	2.49
Wt. of Dry soil	(g)	22.66	21.38	21.98	23.43			11.96	12.41
Moisture Content %	%	29.04	31.62	34.71	38.16			20.15	20.06
No of Blows		40	32	23	17			20	



LIQUID LIMIT % :- **34**
PLASTIC LIMIT % :- **20**
PLASTICITY INDEX % :- **14**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

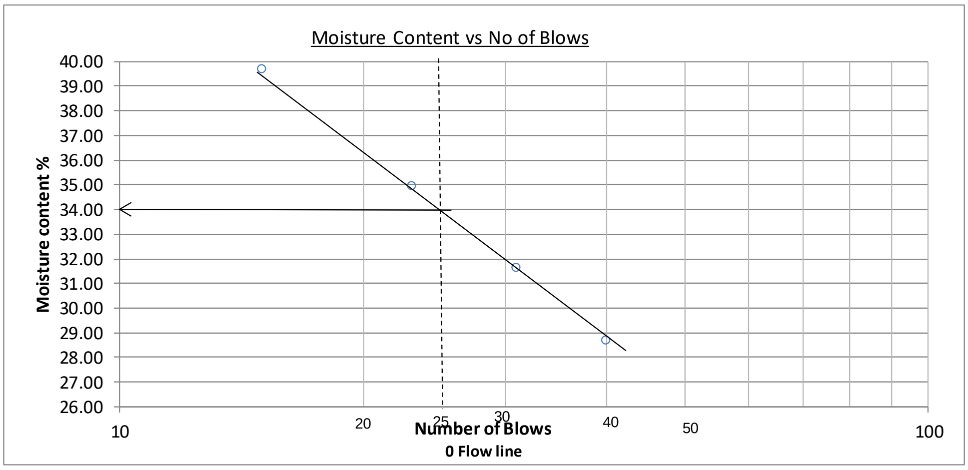
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+10%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pits	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		9	10	11	12		13	14
Wt. of wet soil + Can	(g)	53.32	57.53	56.19	55.13		40.38	40.23
Wt of Dry soil + Can	(g)	47.11	49.86	48.18	46.87		37.98	37.77
Wt. of Can	(g)	25.44	25.59	25.25	26.05		26.16	25.50
Wt. of Moisture	(g)	6.21	7.67	8.01	8.26		2.4	2.46
Wt. of Dry soil	(g)	21.67	24.27	22.93	20.82		11.82	12.27
Moisture Content %	%	28.66	31.60	34.93	39.67		20.30	20.05
No of Blows		40	31	23	15		20	



LIQUID LIMIT % :- **34**

PLASTIC LIMIT % :- **20**

PLASTICITY INDEX % :- **14**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer RDC
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

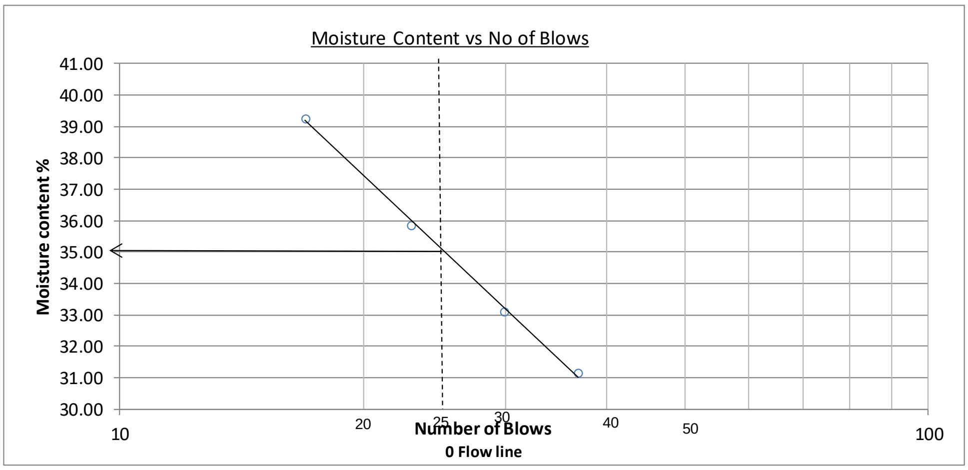
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+12%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		2	3	4	5		6	7
Wt. of wet soil + Can	(g)	54.62	57.03	56.94	58.02		40.48	40.99
Wt of Dry soil + Can	(g)	47.68	49.23	48.74	48.73		38.05	38.47
Wt. of Can	(g)	25.38	25.63	25.84	25.03		25.25	25.27
Wt. of Moisture	(g)	6.94	7.80	8.2	9.29		2.43	2.52
Wt. of Dry soil	(g)	22.3	23.6	22.9	23.7		12.8	13.2
Moisture Content %	%	31.12	33.05	35.81	39.20		18.98	19.09
No of Blows		37	30	23	17		19	



LIQUID LIMIT % :- **35**
PLASTIC LIMIT % :- **19**
PLASTICITY INDEX % :- **16**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

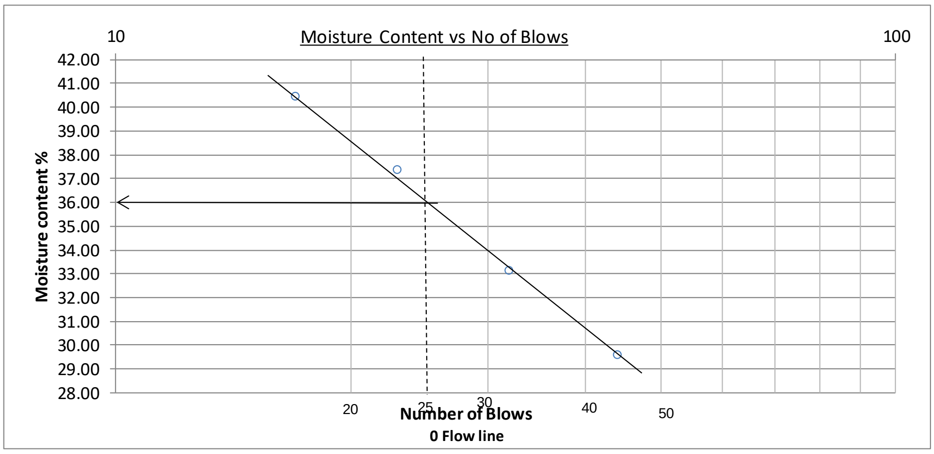
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+14%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		5	6	7	8		11	12
Wt. of wet soil + Can	(g)	58.14	51.82	54	53.05		42.36	41.23
Wt of Dry soil + Can	(g)	50.52	45.22	46.13	45.15		39.68	38.67
Wt. of Can	(g)	24.73	25.27	25.05	25.61		25.25	25.26
Wt. of Moisture	(g)	7.62	6.60	7.87	7.9		2.68	2.56
Wt. of Dry soil	(g)	25.79	19.95	21.08	19.54		14.43	13.41
Moisture Content %	%	29.55	33.08	37.33	40.43		18.57	19.09
No of Blows		44	32	23	17		19	



LIQUID LIMIT % :- **36**
PLASTIC LIMIT % :- **19**
PLASTICITY INDEX % :- **17**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Appendix E: Atterberg Limit Test Reports for Sooriyaweva borrow pit soil with PHA stabilizer

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

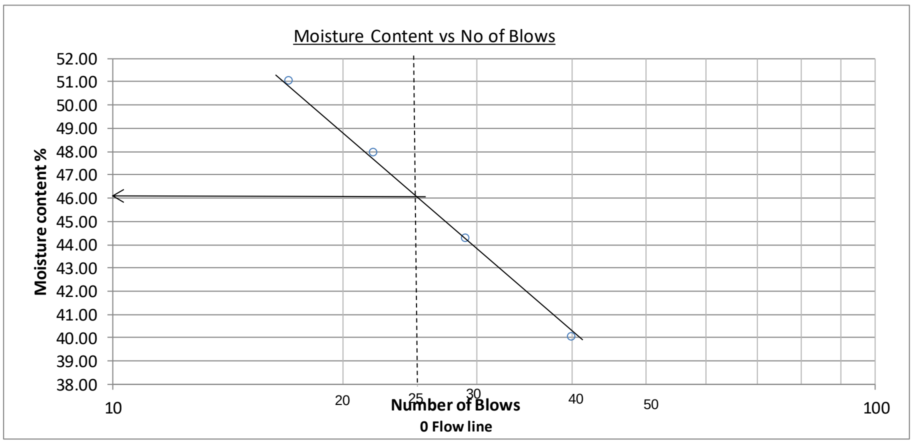
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NILL	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		14	15	16	17			18	19
Wt. of wet soil + Can	(g)	52.65	54.99	54.87	56.39			39.57	40.13
Wt of Dry soil + Can	(g)	44.90	45.81	45.27	45.94			36.76	37.33
Wt. of Can	(g)	25.54	25.07	25.24	25.45			25.03	25.25
Wt. of Moisture	(g)	7.75	9.18	9.6	10.45			2.81	2.80
Wt. of Dry soil	(g)	19.36	20.74	20.03	20.49			11.73	12.08
Moisture Content %	%	40.03	44.26	47.93	51.00			23.96	23.18
No of Blows		40	29	22	17			24	



LIQUID LIMIT % :- **46**
PLASTIC LIMIT % :- **24**
PLASTICITY INDEX % :- **22**

Remarks :					
	Contractor			**Engineer**	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

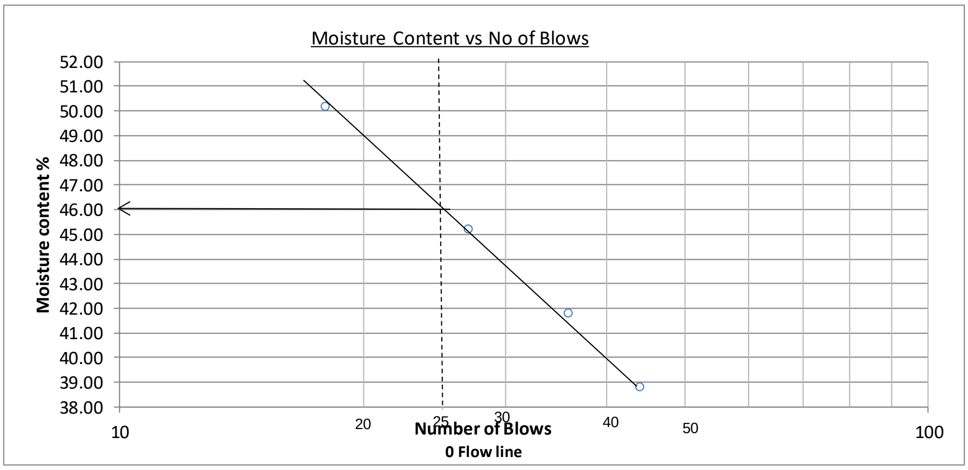
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+2%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		1	2	3	4			5	6
Wt. of wet soil + Can	(g)	52.11	54.89	54.74	56.39			39.44	40.01
Wt of Dry soil + Can	(g)	44.57	46.21	45.74	46.22			36.73	37.18
Wt. of Can	(g)	25.12	25.43	25.81	25.93			25.04	25.31
Wt. of Moisture	(g)	7.54	8.68	9	10.17			2.71	2.83
Wt. of Dry soil	(g)	19.45	20.78	19.93	20.29			11.69	11.87
Moisture Content %	%	38.77	41.77	45.16	50.12			23.18	23.84
No of Blows		44	36	27	18			24	



LIQUID LIMIT % :- **46**
PLASTIC LIMIT % :- **24**
PLASTICITY INDEX % :- **22**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

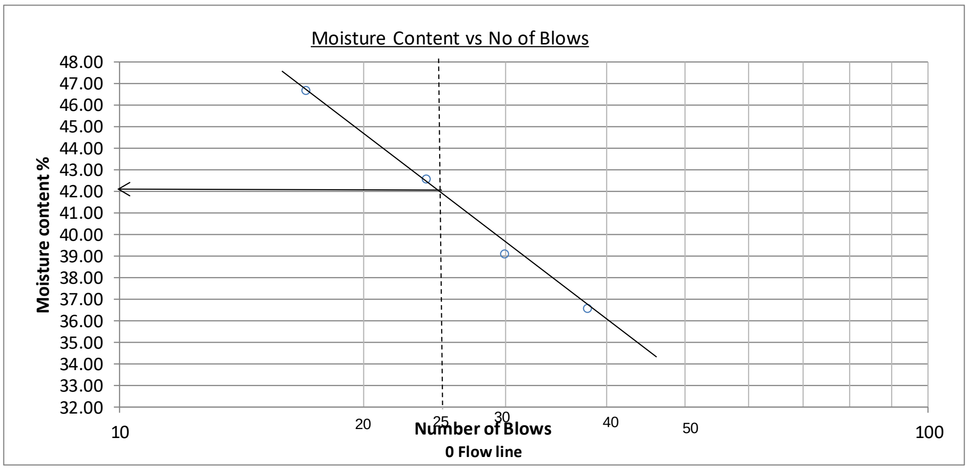
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+4%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		21	22	23	24		25	26
Wt. of wet soil + Can	(g)	52.33	55.47	54.2	55.98		39.99	39.63
Wt of Dry soil + Can	(g)	45.11	47.17	45.58	46.36		37.27	37.18
Wt. of Can	(g)	25.33	25.90	25.3	25.73		25.67	25.96
Wt. of Moisture	(g)	7.22	8.30	8.62	9.62		2.72	2.45
Wt. of Dry soil	(g)	19.78	21.27	20.28	20.63		11.6	11.22
Moisture Content %	%	36.50	39.02	42.50	46.63		23.45	21.84
No of Blows		38	30	24	17		23	



LIQUID LIMIT % :- **42**
PLASTIC LIMIT % :- **23**
PLASTICITY INDEX % :- **19**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

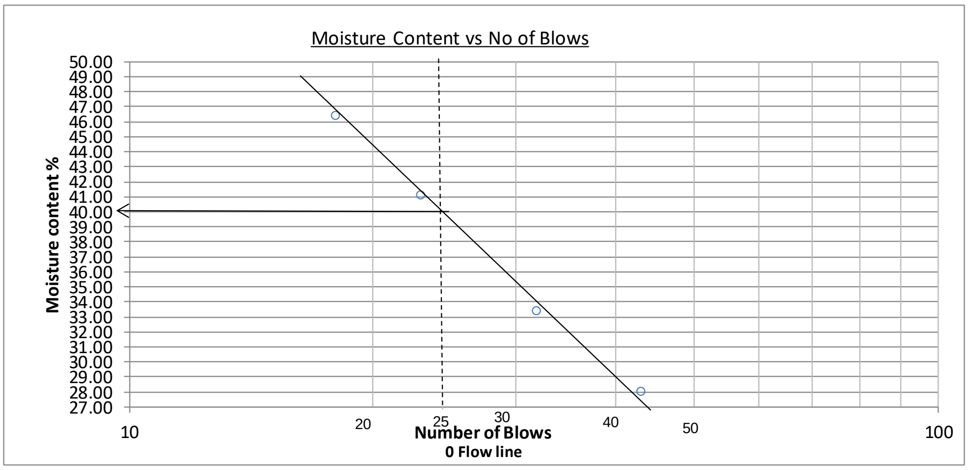
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+6%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		9	10	11	12		13	14
Wt. of wet soil + Can	(g)	51.42	54.43	54.17	56.52		40.35	39.98
Wt of Dry soil + Can	(g)	45.75	47.21	45.75	46.88		37.82	37.26
Wt. of Can	(g)	25.5	25.57	25.25	26.08		26.15	25.54
Wt. of Moisture	(g)	5.67	7.22	8.42	9.64		2.53	2.72
Wt. of Dry soil	(g)	20.25	21.64	20.5	20.8		11.67	11.72
Moisture Content %	%	28.00	33.36	41.07	46.35		21.68	23.21
No of Blows		43	32	23	18		22	



LIQUID LIMIT % :- **40**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **18**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

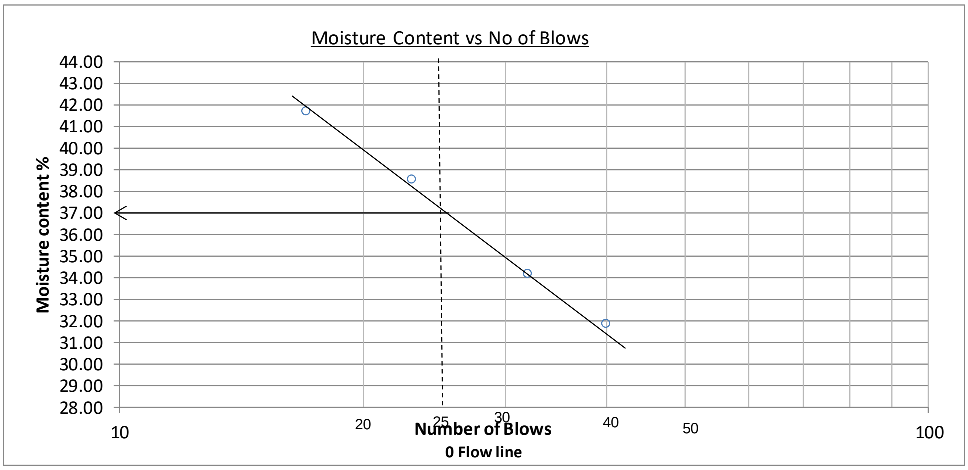
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+8%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow Pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		8	9	10	11			12	13
Wt. of wet soil + Can	(g)	53.95	53.58	55.2	57.62			40.42	41.06
Wt of Dry soil + Can	(g)	46.89	46.42	46.97	48.10			37.96	38.49
Wt. of Can	(g)	24.71	25.44	25.59	25.25			26.05	26.16
Wt. of Moisture	(g)	7.06	7.16	8.23	9.52			2.46	2.57
Wt. of Dry soil	(g)	22.18	20.98	21.38	22.85			11.91	12.33
Moisture Content %	%	31.83	34.13	38.49	41.66			20.65	20.84
No of Blows		40	32	23	17			21	



LIQUID LIMIT % :- **37**

PLASTIC LIMIT % :- **21**

PLASTICITY INDEX % :- **16**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

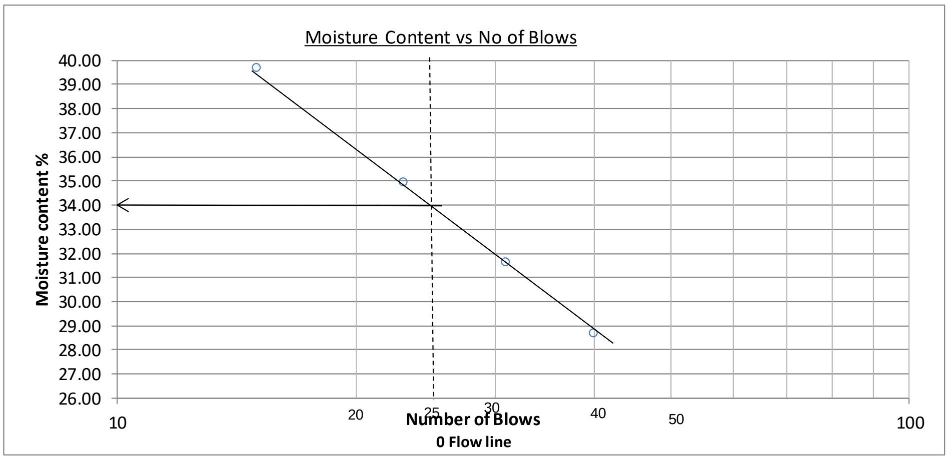
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+10%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow Pits	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		9	10	11	12		13	14
Wt. of wet soil + Can	(g)	53.32	57.53	56.19	55.13		40.38	40.23
Wt of Dry soil + Can	(g)	47.11	49.86	48.18	46.87		37.98	37.77
Wt. of Can	(g)	25.44	25.59	25.25	26.05		26.16	25.50
Wt. of Moisture	(g)	6.21	7.67	8.01	8.26		2.4	2.46
Wt. of Dry soil	(g)	21.67	24.27	22.93	20.82		11.82	12.27
Moisture Content %	%	28.66	31.60	34.93	39.67		20.30	20.05
No of Blows		40	31	23	15		20	



LIQUID LIMIT % :- **34**
PLASTIC LIMIT % :- **20**
PLASTICITY INDEX % :- **14**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

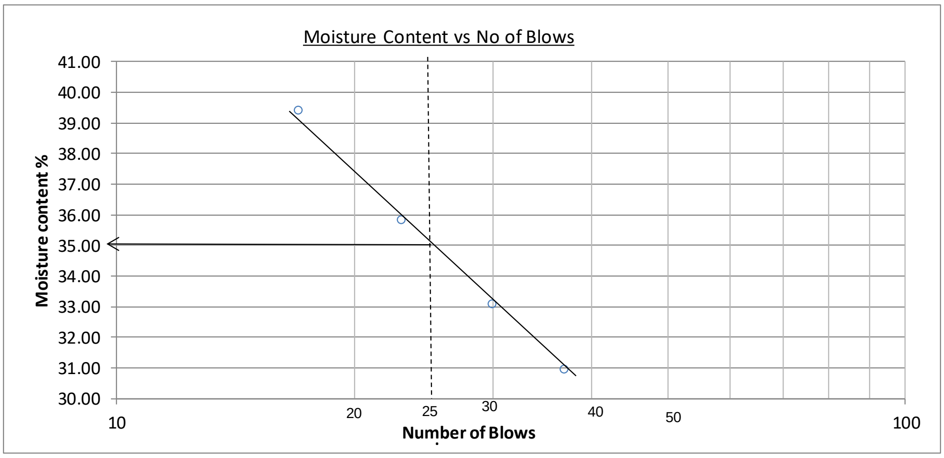
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+12%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		2	3	4	5		6	7
Wt. of wet soil + Can	(g)	54.62	57.03	56.94	58.02		40.48	40.99
Wt of Dry soil + Can	(g)	47.71	49.23	48.74	48.70		38.02	38.42
Wt. of Can	(g)	25.38	25.63	25.84	25.03		25.25	25.27
Wt. of Moisture	(g)	6.91	7.80	8.2	9.32		2.46	2.57
Wt. of Dry soil	(g)	22.3	23.6	22.9	23.67		12.77	13.15
Moisture Content %	%	30.94	33.05	35.81	39.37		19.26	19.54
No of Blows		37	30	23	17		19	



LIQUID LIMIT % :- **35**
PLASTIC LIMIT % :- **19**
PLASTICITY INDEX % :- **16**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

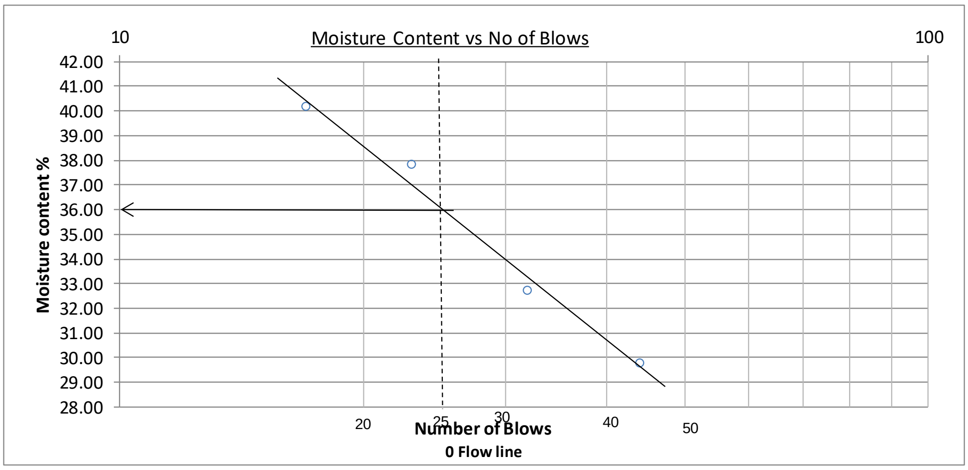
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+14%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		5	6	7	8			11	12
Wt. of wet soil + Can	(g)	58.14	51.82	54	53.05			42.36	41.23
Wt of Dry soil + Can	(g)	50.48	45.28	46.06	45.19			39.63	38.61
Wt. of Can	(g)	24.73	25.27	25.05	25.61			25.25	25.26
Wt. of Moisture	(g)	7.66	6.54	7.94	7.86			2.73	2.62
Wt. of Dry soil	(g)	25.75	20.01	21.01	19.58			14.38	13.35
Moisture Content %	%	29.75	32.68	37.79	40.14			18.98	19.63
No of Blows		44	32	23	17			19	



LIQUID LIMIT % :- **36**
PLASTIC LIMIT % :- **19**
PLASTICITY INDEX % :- **17**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Appendix F: Atterberg Limit Test Reports for Welikanda borrow pit soil with PHA stabilizer

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

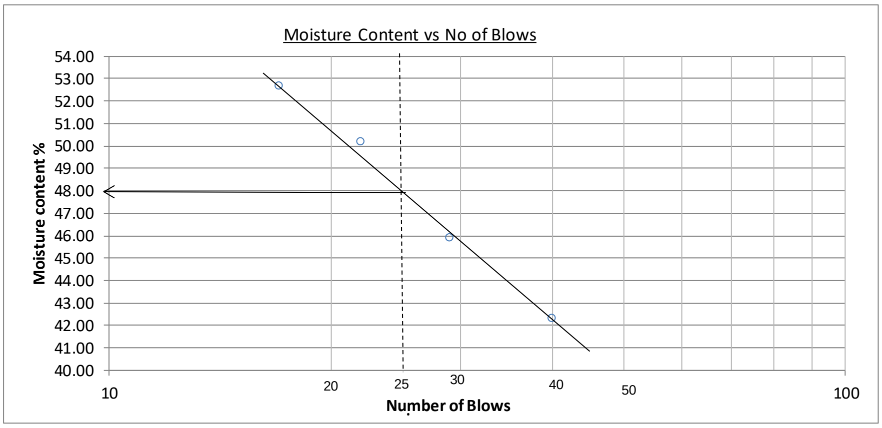
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NILL	Type Of Material	
Sample Location		Date of Sample	
Source	Welikanda borrow pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		14	15	16	17		18	19
Wt. of wet soil + Can	(g)	52.65	54.99	54.87	56.39		39.57	40.13
Wt of Dry soil + Can	(g)	44.59	45.58	44.97	45.72		36.88	37.45
Wt. of Can	(g)	25.54	25.07	25.24	25.45		25.03	25.25
Wt. of Moisture	(g)	8.06	9.41	9.9	10.67		2.69	2.68
Wt. of Dry soil	(g)	19.05	20.51	19.73	20.27		11.85	12.2
Moisture Content %	%	42.31	45.88	50.18	52.64		22.70	21.97
No of Blows		40	29	22	17		22	



LIQUID LIMIT % :- **48**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **26**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

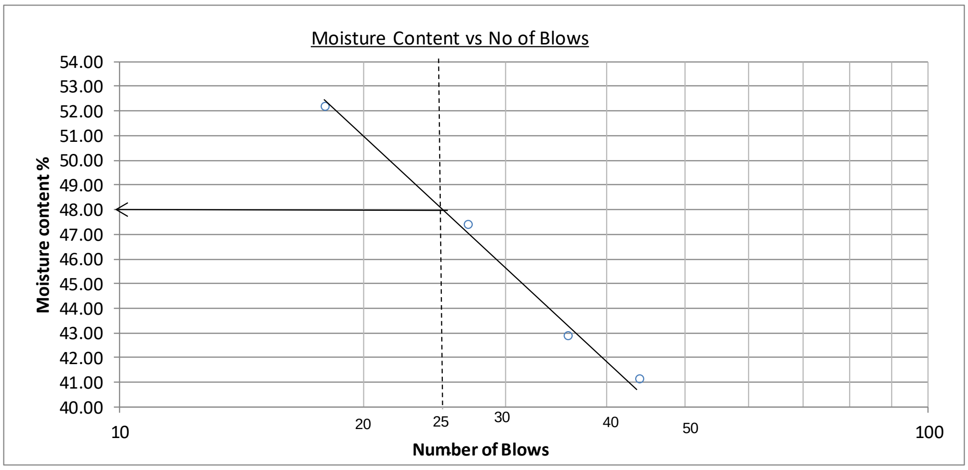
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+2%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Weliksnda Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		1	2	3	4		5	6
Wt. of wet soil + Can	(g)	52.11	54.89	54.74	56.39		39.44	40.01
Wt of Dry soil + Can	(g)	44.25	46.05	45.44	45.95		36.83	37.39
Wt. of Can	(g)	25.12	25.43	25.81	25.93		25.04	25.31
Wt. of Moisture	(g)	7.86	8.84	9.3	10.44		2.61	2.62
Wt. of Dry soil	(g)	19.13	20.62	19.63	20.02		11.79	12.08
Moisture Content %	%	41.09	42.87	47.38	52.15		22.14	21.69
No of Blows		44	36	27	18		22	



LIQUID LIMIT % :- **48**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **26**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

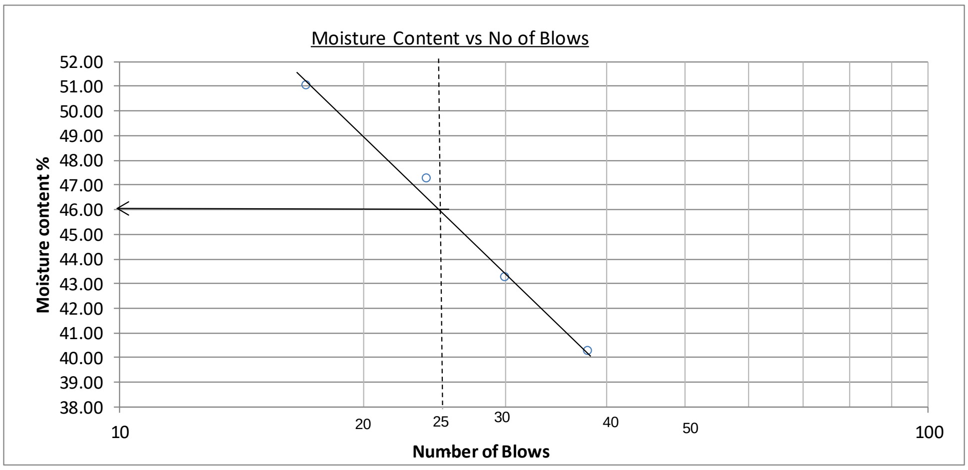
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+5%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		21	22	23	24			25	26
Wt. of wet soil + Can	(g)	52.33	55.47	54.2	55.98			39.99	39.63
Wt of Dry soil + Can	(g)	44.58	46.54	44.93	45.76			37.39	37.26
Wt. of Can	(g)	25.33	25.90	25.3	25.73			25.67	25.96
Wt. of Moisture	(g)	7.75	8.93	9.27	10.22			2.6	2.37
Wt. of Dry soil	(g)	19.25	20.64	19.63	20.03			11.72	11.3
Moisture Content %	%	40.26	43.27	47.22	51.02			22.18	20.97
No of Blows		38	30	24	17			22	



LIQUID LIMIT % :- **46**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **24**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

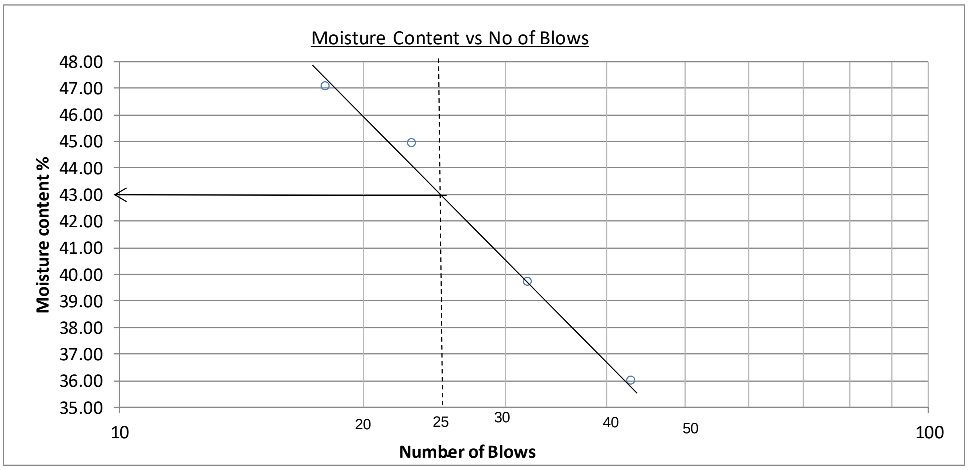
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+8%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Welikanda Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		9	10	11	12		13	14
Wt. of wet soil + Can	(g)	51.42	54.43	54.17	56.52		40.35	39.98
Wt of Dry soil + Can	(g)	44.56	46.23	45.21	46.78		37.90	37.31
Wt. of Can	(g)	25.5	25.57	25.25	26.08		26.15	25.54
Wt. of Moisture	(g)	6.86	8.20	8.96	9.74		2.45	2.67
Wt. of Dry soil	(g)	19.06	20.66	19.96	20.7		11.75	11.77
Moisture Content %	%	35.99	39.69	44.89	47.05		20.85	22.68
No of Blows		43	32	23	18		22	



LIQUID LIMIT % :- **43**
PLASTIC LIMIT % :- **22**
PLASTICITY INDEX % :- **21**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

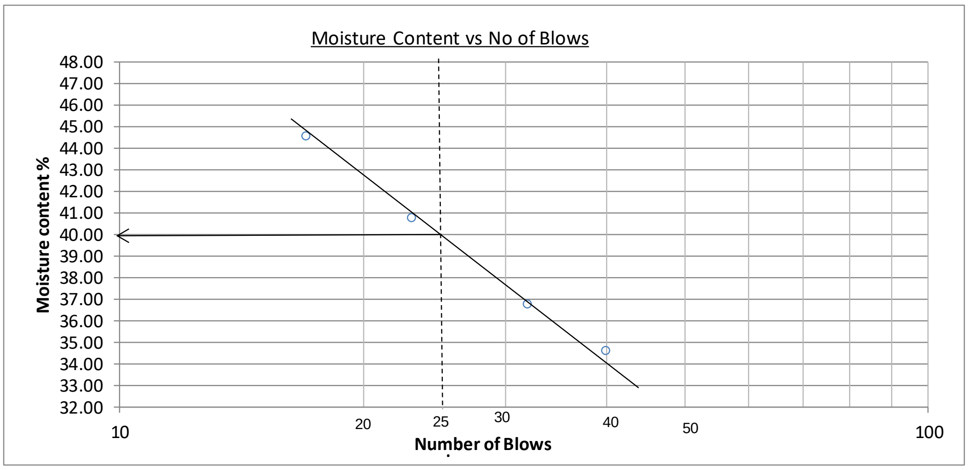
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+10%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		8	9	10	11		12	13
Wt. of wet soil + Can	(g)	53.95	53.58	55.2	57.62		40.42	41.06
Wt of Dry soil + Can	(g)	46.44	46.02	46.63	47.65		37.96	38.53
Wt. of Can	(g)	24.71	25.44	25.59	25.25		26.05	26.16
Wt. of Moisture	(g)	7.51	7.56	8.57	9.97		2.46	2.53
Wt. of Dry soil	(g)	21.73	20.58	21.04	22.4		11.91	12.37
Moisture Content %	%	34.56	36.73	40.73	44.51		20.65	20.45
No of Blows		40	32	23	17		21	



LIQUID LIMIT % :- **40**
PLASTIC LIMIT % :- **21**
PLASTICITY INDEX % :- **19**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

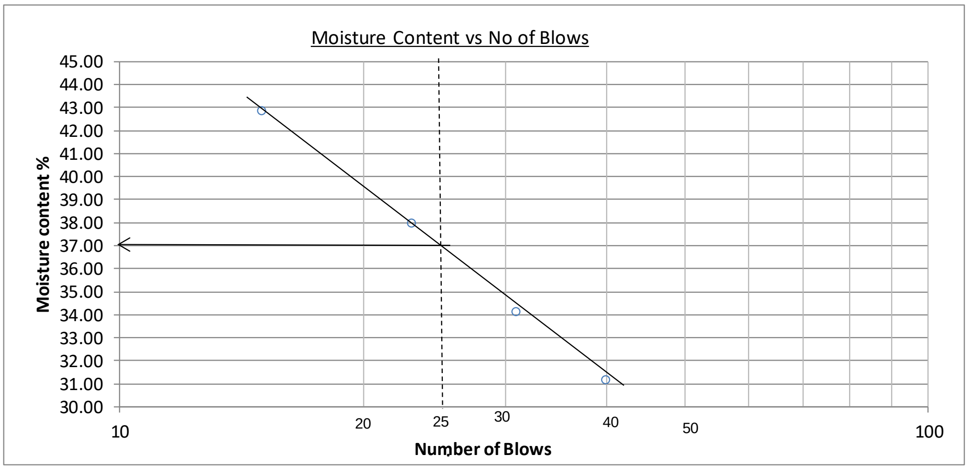
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+12%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Welikanda Borrow Pits	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		9	10	11	12			13	14
Wt. of wet soil + Can	(g)	53.32	57.53	56.19	55.13			40.38	40.23
Wt of Dry soil + Can	(g)	46.70	49.41	47.68	46.41			37.91	37.77
Wt. of Can	(g)	25.44	25.59	25.25	26.05			26.16	25.50
Wt. of Moisture	(g)	6.62	8.12	8.51	8.72			2.47	2.46
Wt. of Dry soil	(g)	21.26	23.82	22.43	20.36			11.75	12.27
Moisture Content %	%	31.14	34.09	37.94	42.83			21.02	20.05
No of Blows		40	31	23	15			21	



LIQUID LIMIT % :- **37**
PLASTIC LIMIT % :- **21**
PLASTICITY INDEX % :- **16**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

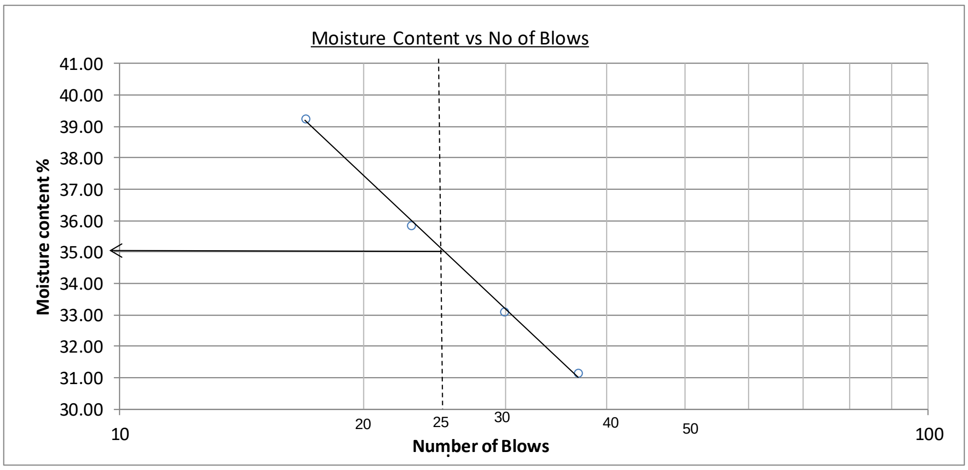
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+12%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Borrow Pit	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		2	3	4	5			6	7
Wt. of wet soil + Can	(g)	54.62	57.03	56.94	58.02			40.48	40.99
Wt of Dry soil + Can	(g)	47.68	49.23	48.74	48.73			38.05	38.47
Wt. of Can	(g)	25.38	25.63	25.84	25.03			25.25	25.27
Wt. of Moisture	(g)	6.94	7.80	8.2	9.29			2.43	2.52
Wt. of Dry soil	(g)	22.3	23.6	22.9	23.7			12.8	13.2
Moisture Content %	%	31.12	33.05	35.81	39.20			18.98	19.09
No of Blows		37	30	23	17			19	



LIQUID LIMIT % :- **35**
PLASTIC LIMIT % :- **19**
PLASTICITY INDEX % :- **16**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

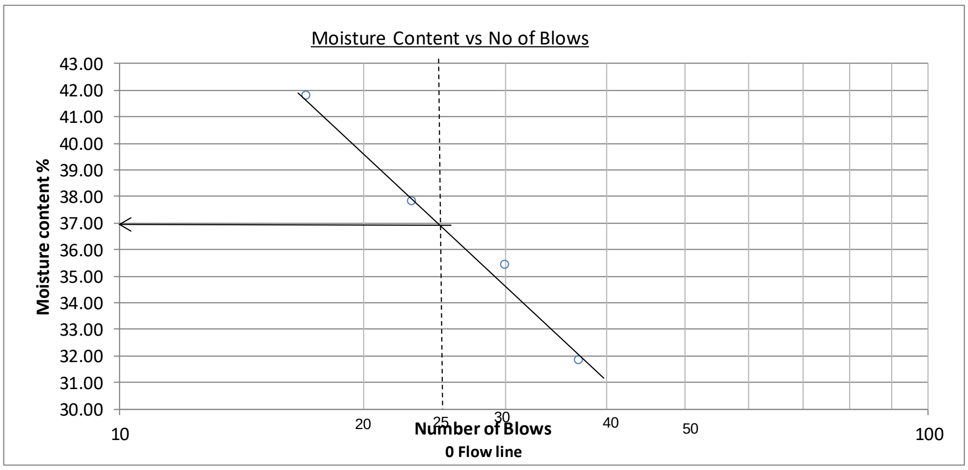
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+14%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Welikanda Borrow Pit	Date of Testing	

		DETERMINATION OF						
		LIQUID LIMIT					PLASTIC LIMIT	
Trial No.		1	2	3	4		1	2
Can No		2	3	4	5		6	7
Wt. of wet soil + Can	(g)	54.62	57.03	56.94	58.02		40.48	40.99
Wt of Dry soil + Can	(g)	47.56	48.82	48.41	48.30		37.96	38.43
Wt. of Can	(g)	25.38	25.63	25.84	25.03		25.25	25.27
Wt. of Moisture	(g)	7.06	8.21	8.53	9.72		2.52	2.56
Wt. of Dry soil	(g)	22.2	23.19	22.57	23.27		12.71	13.16
Moisture Content %	%	31.83	35.40	37.79	41.77		19.83	19.45
No of Blows		37	30	23	17		20	



LIQUID LIMIT % :- **37**
PLASTIC LIMIT % :- **20**
PLASTICITY INDEX % :- **17**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

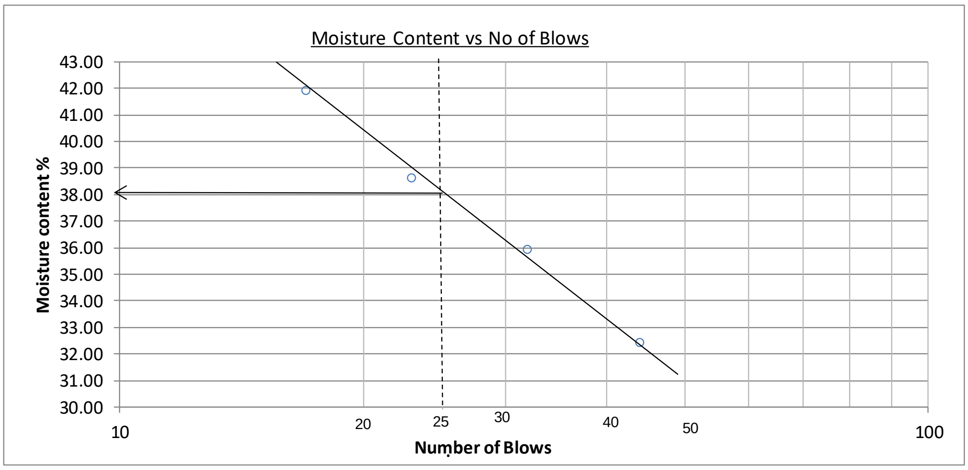
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+16%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Mahadamana Source	Date of Testing	

		DETERMINATION OF							
		LIQUID LIMIT						PLASTIC LIMIT	
Trial No.		1	2	3	4			1	2
Can No		5	6	7	8			11	12
Wt. of wet soil + Can	(g)	58.14	51.82	54	53.05			42.36	41.23
Wt of Dry soil + Can	(g)	49.97	44.81	45.94	44.95			39.57	38.61
Wt. of Can	(g)	24.73	25.27	25.05	25.61			25.25	25.26
Wt. of Moisture	(g)	8.17	7.01	8.06	8.1			2.79	2.62
Wt. of Dry soil	(g)	25.24	19.54	20.89	19.34			14.32	13.35
Moisture Content %	%	32.37	35.88	38.58	41.88			19.48	19.63
No of Blows		44	32	23	17			20	



LIQUID LIMIT % :- **38**
PLASTIC LIMIT % :- **20**
PLASTICITY INDEX % :- **18**

Remarks :	

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Reviwe by

Appendix G: Set of Laboratory Test Reports of constructed Sub base layer with Mahadamana Borrow pit soil and 8%PHA

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

Consultant: **RDC (Pvt.)Ltd.**

Contractor: **TISSA-AMSK (JV)**

Type of Materi	**: Sub Base**	Date of Sampling	:
Sample No.		Date of Testing	:
Lacation			
Source	**:Mahadamana Borrow pit+8% PHA Composite**		

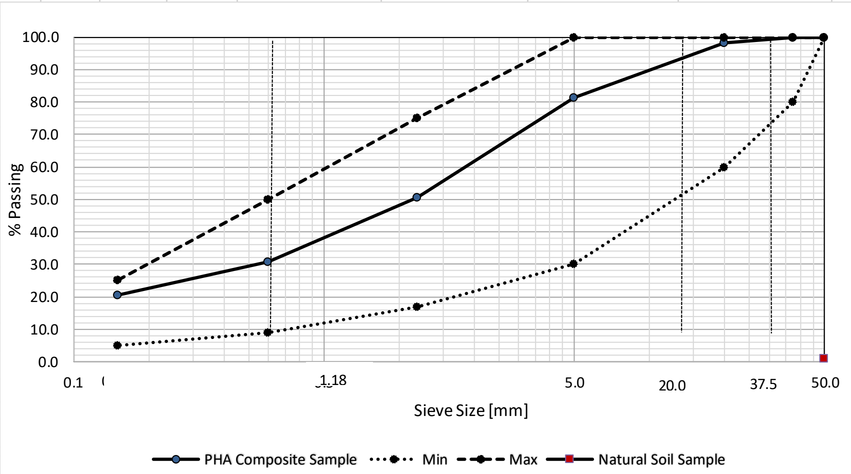
Sieve analysis of Soil

(BS-1377-Part-2-1990)

Wt. of Oven dry Sample before washing (g) :	2450
Wt. of Oven dry Sample before washing (g) :	50
Wt. of Oven dry Sample before washing (g) :	2,500.0
Wt. of Oven dry sample after washing (g) :	2,000.0

50

Sieve Size [mm]	PHA Weight retained (g)	Soil Weight retained [g]	Composite Weight retained [g]	% Retained [%]	% Passing [%]	Specified Limits [%][Sec:1705.2]	
						Min	Max
50.0	0.0	0.0	0.0	0.0	100.0	100	100
37.5	0.0	0.0	0.0	0.0	100.0	80	100
20.0	0.0	43.5	43.5	1.7	98.3	60	100
5.0	0.0	421.6	421.6	16.9	81.4	30	100
1.18	0.00	772.4	772.4	30.9	50.5	17	75
0.300	3.0	485.9	488.9	19.6	30.9	9	50
0.075	6.0	254.7	260.7	10.4	20.5	5	25
Pan	1	6.3	7.3				
Total	10.0	1984.4	1994.4				



	CONTRACTOR			CONSULTANT	
	Tested by:	Checked by:	Approved by:	Witnessed by:	Reviewed by:
Name:					
Designation:					
Signature:					
Date:					

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

Consultant:
RDC (Pvt.)Ltd.

Contractor:
TISSA-AMSK (JV)

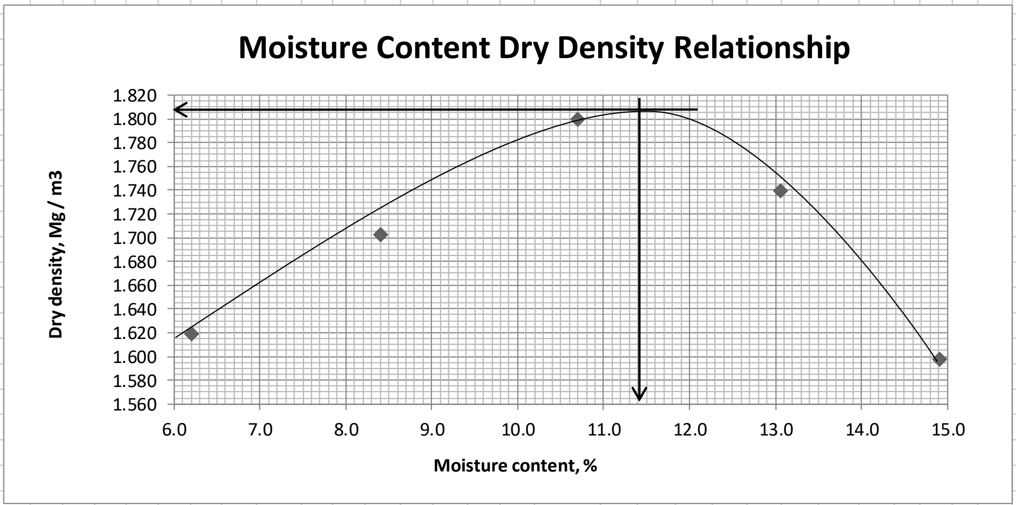
Type of Material	:	**Sub base**	Date of Sampling	:	
Sample No.	:		Date of Testing	:	
Lacation	:				
Source	:	**Mahadamana borrow pit + 8% PHA**			

DETERMINATION OF DRY DENSITY - MOISTURE CONTENT RELATIONSHIP

Test Method :AASHTO T 180

No. of Layers	Blows per layer	Volume of Mould(cm^3)	Total mass of sample(g)	Weight of Rammer (kg)	Mould ID No:
5	**56**	**2124**	25000	4.5	H

Trial No		1	2	3	4	5
Volume of water added	ml	100	200	300	400	500
Mass of mould with base plate + compacted soil	g	9141	9410	9722	9666	9390
Mass of mould with base plate	g	5490	5490	5490	5490	5490
Mass of compacted soil	g	3651	3920	4232	4176	3900
Bulk density	Mg / m^3	1.719	1.846	1.992	1.966	1.836
Moisture container no.		**BH**	**C7**	**U**	**1**	**18**
Mass of wet soil + container	g	525.6	419.6	466.1	474.3	451.9
Mass of dry soil + container	g	497.3	390.3	424.3	426.3	398.6
Mass of clean dry container	g	40.8	41.7	41.4	58.8	41.0
Mass of water	g	28.3	29.3	41.8	48.0	53.3
Mass of dry soil	g	456.5	348.6	382.9	367.5	357.6
Moisture content	%	**6.2**	**8.4**	**10.7**	**13.1**	**14.9**
Dry density	Mg / m3	**1.619**	**1.702**	**1.800**	**1.739**	**1.598**



Max. Dry Density,(Mg / m^3) = **1.810** **Optimum Moisture content %** = **11.4**

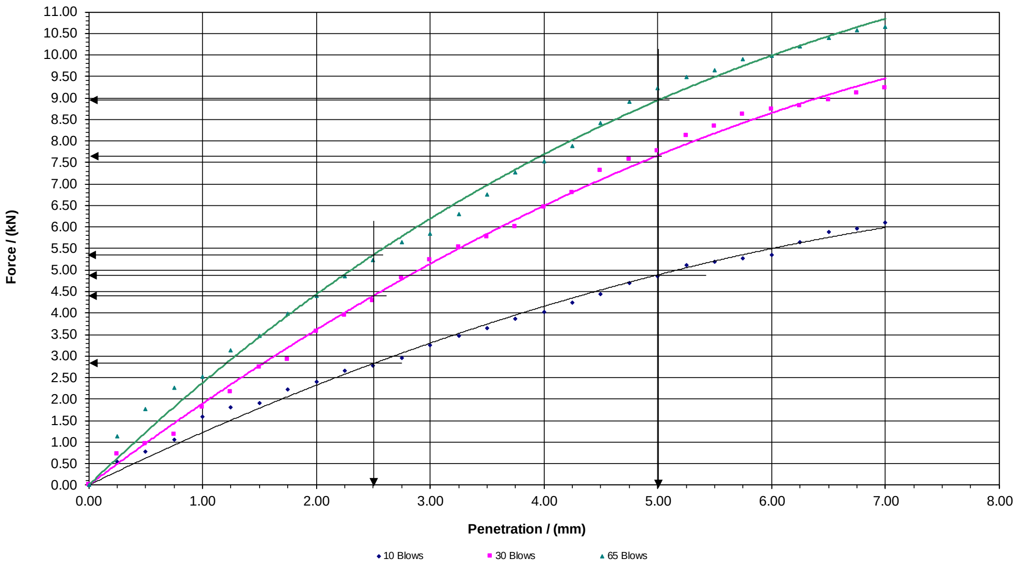
	CONTRACTOR			*CONSULTANT*	
	Tested by:	***Checked by:***	***Approved by:***	***Witnessed by:***	***Reviewed by:***
Name:					
Designation:					
Signature:					
Date:					

Rehabilitation / Improvements of 47 km of Rural Road
in the Polonnaruwa District - Contract 3 including
Performance based Maintenance for 3 years
Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

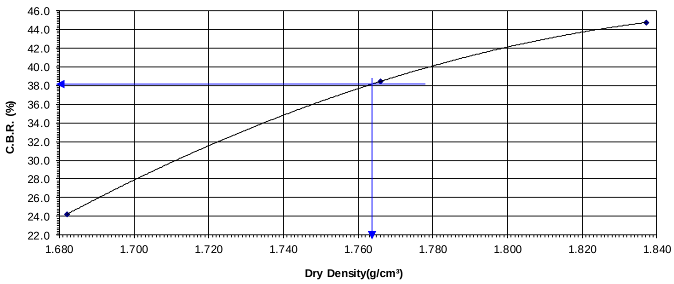
Consultant :
RDC (Pvt.)Ltd.

Contractor :
TISSA-AMSK (JV)

Lab Sample No : 8%PHA



Penetration (mm)	Standered Load (kN)	10 Blows Corrected Force	10 Blows Corrected CBR	30 Blows Corrected Force	30 Blows Corrected CBR	65 Blows Corrected Force	65 Blows Corrected CBR
2.5	13.20	2.80	21.21	4.40	33.33	5.35	40.53
5.0	20.0	4.85	24.25	7.69	38.45	8.95	44.75
Highest Valuve		24.25		38.45		44.75	
Dry Density		1.682		1.766		1.837	



Dry density (g/cm³)	Dry density % of MDD	C.B.R.(%)
1.764	98	**38.0**

Contractor			Consultant	
.... Tested by MT	.... Checked by ME	.... Approved by QAM	.... Witnessed by MT	.... Reviewed By ME
Date	Date	Date..............................	Date..............................	Date..................................

Appendix H: Set of Laboratory Test Reports of constructed Sub base Layer with Sooriyaweva barrow pit soil and optimum of 10%PHA

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RDC RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

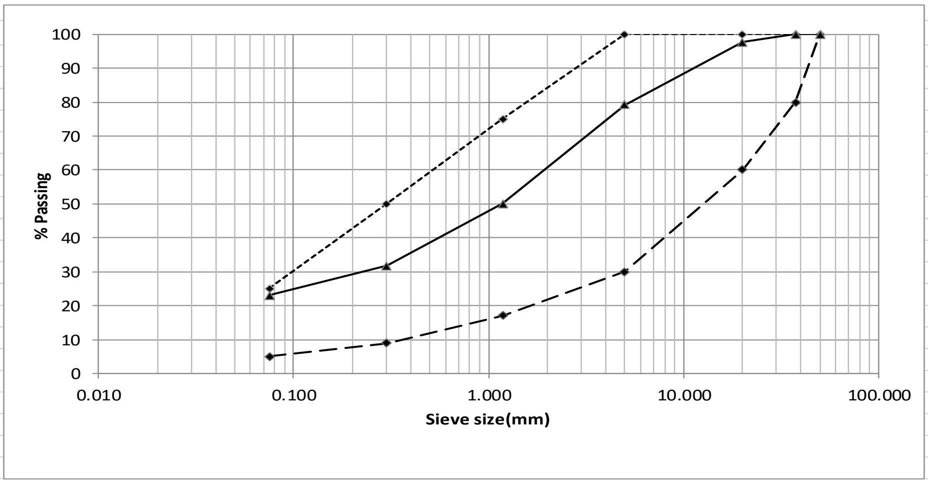
Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

SIEVE ANALYSIS

AASHTO T 88

Sample No.		**Date of Sampling**	
Sample Location		**Date of Test**	
Source		**Before weight**	**2250.0**
Type of Material	Sooriyaweva Borrow pit + 10%	**After weight**	**1750.0**

Sieve Size (mm)	Weight Retained (g)	% Retained	% Passing	Spec. Limits Table-1708/3
50.0	0.0	0.0	100.0	100 -100
37.5	0.0	0.0	100.0	80 - 100
20.0	51.0	2.3	97.7	60 - 100
5.0	415.7	18.5	79.3	30 - 100
1.18	658.5	29.3	50.0	17 - 75
0.300	412.5	18.3	31.7	9 - 50
0.075	195.2	8.7	23.0	5 - 25
pan	11.1			
Total Weight Of Soil	1744.0			



Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Approved by	Witnees by	Review by
	Contractor			Engineer	

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

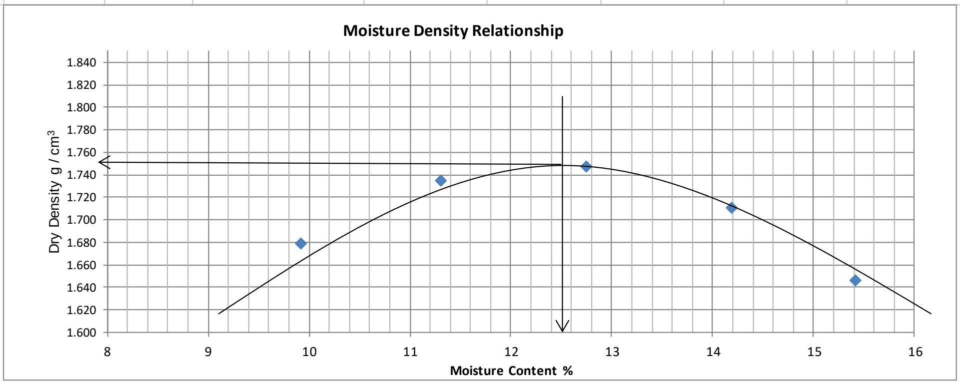
PROCTOR COMPACTION

(Test Method -AASTO T-180)

Sample No.	SOIL - 01	**Date of Sampling**	
Sample Location		**Date of Test**	
Source	Sooriyaweva Borrow pit 2	**Type of Material**	

Mould No.		2	Weight of Rammer	kg	4.5
Height	cm	11.7	Dropping Height	mm	457
Diameter	cm	15.2	Number of Layers		5
Volume	cm^3	2124	Blows Per Layer		56
Weight	g	6080			

Test No. / Container No.		1	2	3	4	5
Weight of Water	ml	200	300	400	500	600
Weight of wet sample + container	g	441.8	434.9	483.2	496.4	491.1
Weight of dry sample + container	g	405.0	394.5	432.7	439.6	430.5
Weight of container	g	34.2	37.2	36.4	39.4	37.3
Weight of water	g	36.8	40.4	50.5	56.8	60.6
Weight of dry Soil	g	370.8	357.3	396.3	400.2	393.2
Moisture content	%	9.9	11.3	12.7	14.2	15.4
Weight of wet sample + mould	g	10000	10180	10265	10228	10115
Weight of mould	g	6080	6080	6080	6080	6080
Weight of sample	g	3920	4100	4185	4148	4035
Bulk density	g/cm^3	1.846	1.930	1.970	1.953	1.900
Dry density	g/cm^3	1.679	1.734	1.748	1.710	1.646



Maximum dry density	g/cm^3	1.750
Optimum moisture content	%	12.5

Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Approved by	Witnees by	Review by
	Contractor			Engineer	

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

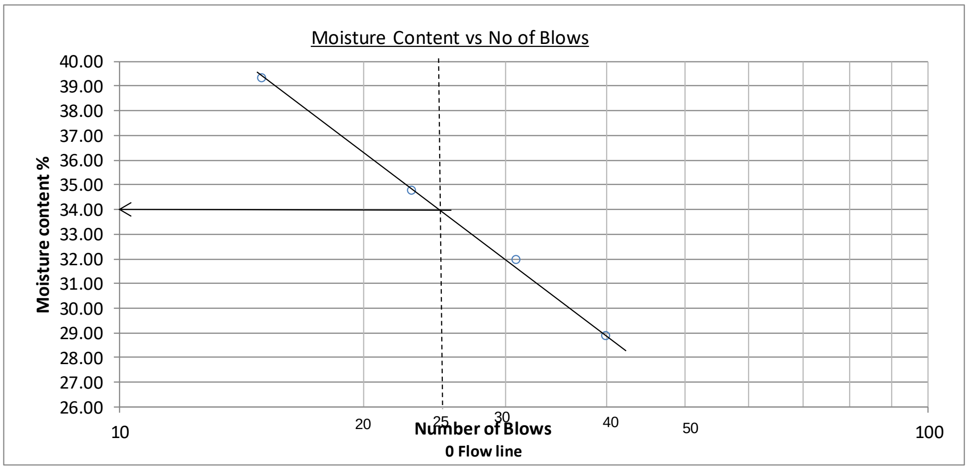
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3

Contract Package :- RDA/ADB/I Road (NC)/NCB/CP - RR (PO3)

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL
AASHTO T89 -T96

Sample No.	NS+10%PHA	Type Of Material	
Sample Location		Date of Sample	
Source	Sooriyaweva Borrow Pits	Date of Testing	

		DETERMINATION OF					
		LIQUID LIMIT				PLASTIC LIMIT	
Trial No.		1	2	3	4	1	2
Can No		9	10	11	12	13	14
Wt. of wet soil + Can	(g)	54.32	58.53	57.16	56.24	41.35	40.28
Wt of Dry soil + Can	(g)	47.85	50.56	48.93	47.72	38.78	37.94
Wt. of Can	(g)	25.44	25.59	25.25	26.05	26.16	25.50
Wt. of Moisture	(g)	6.47	7.97	8.23	8.52	2.57	2.34
Wt. of Dry soil	(g)	22.41	24.97	23.68	21.67	12.62	12.44
Moisture Content %	%	28.87	31.92	34.76	39.32	20.36	18.81
No of Blows		40	31	23	15	20	



LIQUID LIMIT % :- **34**
PLASTIC LIMIT % :- **20**
PLASTICITY INDEX % :- **14**

Remarks :

	Contractor			Engineer	
Signature					
Name					
Designation					
Date					
	Tested by	Checked by	Recommended by	Witnees by	Revive by

Employer	Contractor	Engineer
ROAD DEVELOPMENT AUTHORITY	TISSA BUILDERS & CONTRACTORS	RESOURCES DEVELOPMENT CONSULTANTS (PVT) LTD.

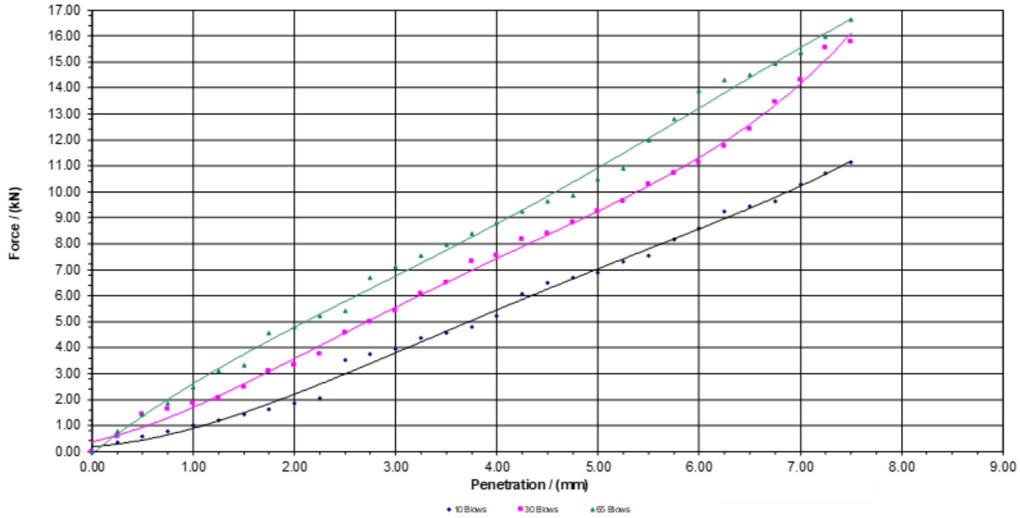
Rehabilitation / Improvements of 47 km of Rural Road in the Polonnaruwa District - Contract 3 including Performance based Maintenance for 3 years

CONTRACT PACKAGE:- RDA/BCRIP/ICB/SFD/01

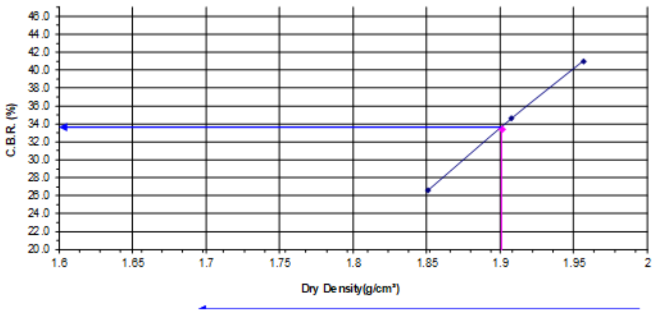
CALIFORNIA BEARING RATIO TEST

(AASHTO / T193 - 99)

Sample No.	Soil+10% PHA	Type of Material	
Sample Location		Date of Sampling	
Source	Sooriyaweva Borrow Pit	Date of Tsting	



Penetration (mm)	Standered Load (kN)	10 Blows			30 Blows			65 Blows		
		Force	Corrected Force	Corrected CBR	Force	Corrected Force	Corrected CBR	Force	Corrected Force	Corrected CBR
2.5	13.24	3.53	3.53	27	4.58	4.58	35	5.43	5.43	41
5.0	19.96	6.90	6.90	35	9.23	9.23	46	10.49	10.49	53



CEC LAB BIBILA R/NO-C2018-10583

$F = A + B.X + C.X^2 + D.X^2$

A = -5.55E-02
B = 2.10E-01
C = 1.50E-05
D = -9.13E-08

Dry density (g/cm³)	Dry density %	C.B.R.(%)
1.901	98	33.4

Signature					
Name					
Designation					
Date					
	Test by	Checked by	Approved by	Witnees by	Review by
	Contractor			Engineer	