IMPROVEMENT OF COASTAL SANDY SOIL BY BLENDING LOCAL UOORI CLAY FOR SUBGRADE/ EMBANKMENT AND SUB BASE CONSTRUCTION

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ABSTRACT

Improvement of Coastal Sandy Soil by Blending Local Uoori Clay for Subgrade/ Embankment and Sub Base Construction: An Experimental Study

Use of locally available material for road construction is emphasized in the present context of potential environmental issues and the restriction on transport imposed by the state. Budgetary constraint for coastal road construction is yet another aspect meriting the use of local materials. The situation in the Northern Province of Sri Lanka is particularly severe compared to other provinces because of the scarcity of materials, which instigate long distance transport from adjacent provinces.

The research aims to carry out studies on the engineering properties of the locally available materials in the Northern Province and to adopt an appropriate technique to stabilize and use for low cost coastal roads construction. The material; Uoori clay (CH, Clay of high plasticity) and coastal sand are commonly available in the Northern coastal belts. It is proposed to blend the local Uoori clay material with the coastal sand and explore the use of the blended material for sub grade/embankment and sub base construction. Sieve Analysis, Atterberg Limits, Modified Proctor Compaction, and California Bearing Ratio (CBR) have been performed for the parent material (control sample) and the blended material with various compositions of local Uoori clay and coastal sand.

The blended materials were analyzed with the specified requirement under "Standard Specifications for Construction and Maintenance of Roads and Bridges (SSCM) (iCTAD, 2009)" in Sri Lanka. Accordingly it was found that the composite materials 50:50, 60:40, 70:30 and 80:20 shall be used as embankment materials in road construction works while composite material 60:40 shall only be used for sub base construction.

Key Words: Uoori clay, coastal sand and composite/blended material.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AASHTO	American Association of State Highway and Transportation Officials
BS	British Standards
CBR	California Bearing Ratio
CC	Cement Content
CEA	Central Environmental Authority
CSB	Cement Stabilized Soil Base
GSMB	Geological Survey and Mines Bureau
ICTAD	Institute for Construction Training and Development
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
SFRB	Steel Fibre Reinforced Bases
SSCM	Standard Specifications for Construction and Maintenance of Roads and Bridges
UCS	Unconfined Compressive Strength
UK	United Kingdom
USA	United States of America

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CHAPTER 1
INTRODUCTION

1.1 Background

Majority of the Northern Province of Sri Lanka is surrounded by the sea and is connected to the mainland by several lagoons. The terrain of the province is almost flat and of low elevation. Road development activities in the coastal line of the province have been intensified in the recent past to provide access to the community and enable other infrastructure development. Establishment of the coastal road network is predicted to lead to the achievement of the socio economic benefits to the community. However, materials needed for road construction being scarce, pauses as a hindrance to the road development and causes heavy transport costs involving long haul distance. Borrowing materials from outstations also acts as an invitation to social and environmental issues.

1.2 Problem Statement

Usually the traditional method of placing Palmyra leaves to reinforce the subgrade with adequate cover of locally available Uoori clay (***Figure 1.1***) is being used for road formation/construction in the coastal areas. However, the above construction method has shown signs of failure within a short period despite the low traffic on the road. This happens due to the inadequate blending of materials by mechanical means, the improper moisture content and the uneven layer thickness of the clay layer.

Figure 1.1: A traditional method of road construction in Northern Province

It is prudent to explore the use of locally available materials by improving its quality by a suitable stabilization technique. Coastal sandy soil and local Uoori clay are freely available in bulk quantities in coastal areas. ***Figure 1.2*** and ***Figure 1.3*** shows a source of Uoori clay and a coastal sand dune respectively.

Figure 1.2: Source of Uoori clay

Figure 1.3: Coastal sand dune

1.3 Objectives

The objective of this research is to investigate properties of Uoori clay and coastal sand together with the blended material. Different compositions of local Uoori clay and coastal sandy soil were used to check their compatibility to utilize as a subgrade/embankment and sub base material for road construction.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A previous research on the construction of rural roads, revealed how geographic limitations interrupted the progress of the development. It has also exposed the fact that construction of rural roads can often be costly and energy inefficient *(Lim, et al, 2014)*. Moreover, it causes an adverse impact on the environment. Majority of the roads in the Sri Lankan road network belong to the low volume traffic category and are managed by the provincial authorities with limited funding *(Mampearachchi, 2012)*. Thus, it is economical to use locally available material for road construction since it will reduce the cost and lessen environmental issues that occur due to the removal of low quality soil and being replaced with imported good quality material from long hauling distances. Locally available materials can be improved by a proper soil stabilization technique. Soil stabilization is helpful in improving material properties and strengthening the existing road base and sub base materials for extended life and heavier traffic loads.

Previous studies concluded that California Bearing Ratio (CBR) of subgrade/ embankment material is a key factor in the design of flexible pavements *(Reddy, 2013)*. CBR is a measure of resistance of a material under loading at controlled moisture content and dry density. In areas with moderate to heavy rainfall, a sample is soaked in water for four days to determine the four days soaked CBR value of the sample. Majority of materials used in road construction projects have varying percentages of fines as a result of the varied plasticity index values *(Reddy, 2013)*.

Bio Grout is a new soil reinforcement technique based on microbial induced carbonate precipitation. Bacteria and reactants are flushed through the soil, resulting in precipitation of Calcium carbonate, then consequent soil reinforcement is done to improve engineering properties of soil *(Lim, et al, 2014)*. In this study, Uoori particles in Uoori clay which also contain Calcium carbonate have shown significant improvement in engineering properties of composite blended material.

2.2 Review/ Study the past Research on Mixing various Materials to Improve their Properties for Road Construction

2.2.1 Influence of Sand and fly ash on Clayey Soil Stabilization (Sharma, 2014).

Clayey soils often exhibit undesirable engineering properties, and the common method followed to improve these qualities is stabilization. The above research was carried out to assess the effectiveness of clayey soil blended with Beas sand and fly ash for soil stabilization, by studying the subgrade characteristics.

This study had been undertaken to explore the possibility of stabilizing clay by using a combination of fly ash in combination with sand. The basic engineering properties of the composite material (clay: sand: fly ash) and their compaction and strength characteristics have been studied. The results have been discussed to bring out the possibility of using the composite in the construction of subgrades for roads. The materials used in the study were locally available clayey soil with medium plasticity, sand from Beas river bed and the fly ash obtained as residue left after the electronic precipitation of the burnt gases. The particle size distribution curves for soil, sand and fly ash are shown in ***Figure 2.1***. The geotechnical properties of various materials used in the study are shown in ***Table 2.1.***

Table 2.1: Physical properties of materials used

Property	Clay	Sand	Fly ash
Specific gravity	2.627	2.637	1.947
Maximum dry density, MDD (g/cc)	1.91	1.592	1.159
Optimum moisture content, OMC (%)	12.6	7.3	31.8
Liquid limit (%)	43.6	-	41.6
Plastic limit (%)	23.4	-	-
Plasticity index (%)	20.2	-	-
Uniformity coefficient, Cu	-	1.73	-
Coefficient of curvature, Cc	-	1.02	-
Soaked CBR (%)	2.47	9.17	2.04

All laboratory tests were conducted in accordance with Indian standards. The particle size distribution, specific gravity tests, consistency limit tests and California bearing ratio (CBR) for the soaked and unsoaked condition were conducted. The swelling was measured after 4 days soaking, and from that the expansion ratio was calculated.

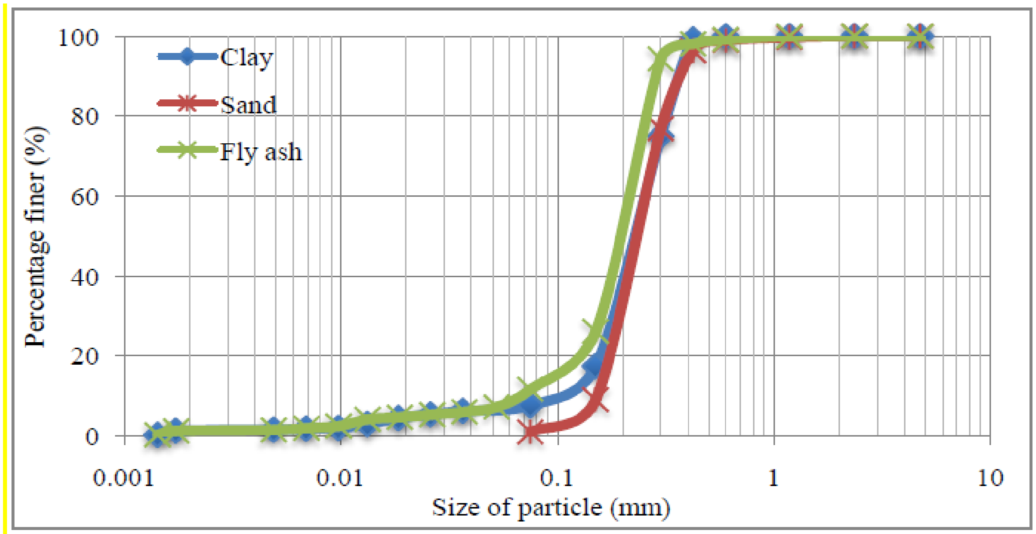

Figure 2.1: Particle size distribution of clay, sand and fly ash

Figure 2.2 shows the water content-dry density curves of clayey soil mixed with sand content varying from 10% to 40%, and the graph shows that the optimum moisture content of clay decreases with the addition of sand. ***Figure 2.3*** shows the water content-dry density curves of the clay-sand composite with fly ash content increasing from 10% to 25%. The maximum dry density, achieved after the addition of fly ash is lesser compared with that of the clay-sand mix.

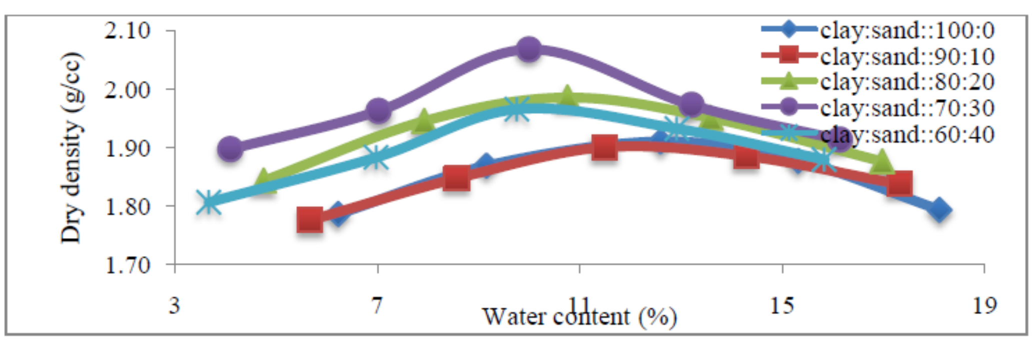

Figure 2.2: Compaction characteristics of clay-sand mixes

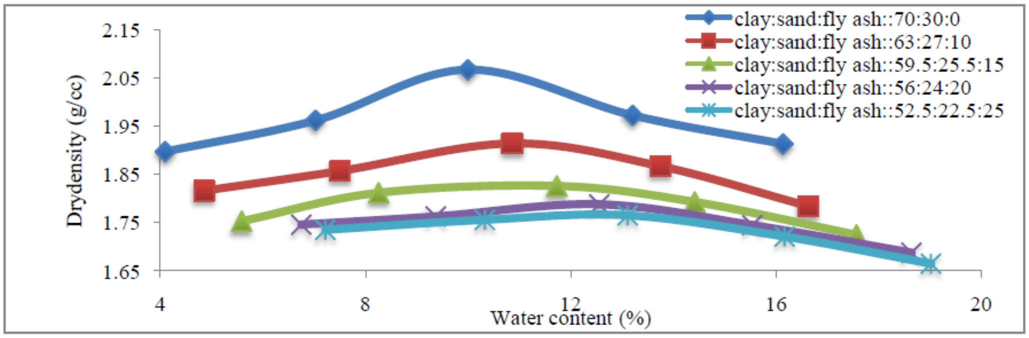

Figure 2.3: Compaction characteristics of clay-sand mixes

The results of California bearing ratio (CBR) tests on clayey soil treated with sand and fly ash are shown in ***Figure 2.4***. It is observed that the soaked CBR value of clayey soil increased with the addition of sand and fly ash. ***Figure 2.5*** shows the variation of the expansion ratio with the addition of sand and fly ash to the clay, which shows that the stabilization decreased the swelling characteristics of clay. Thus, the clayey soil blended with sand and fly ash can be effectively used in the construction of subgrades for roads with low traffic volume.

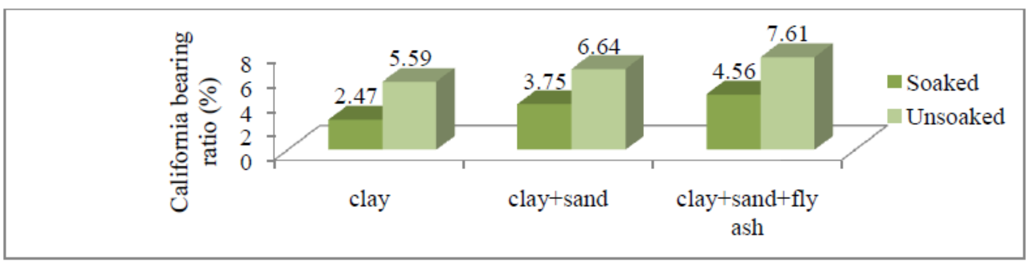

Figure 2.4: Variation of soaked CBR and unsoaked CBR values for various optimum mixes

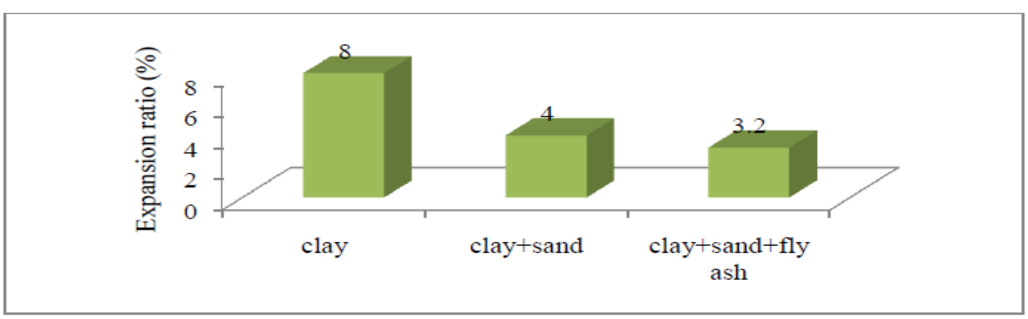

Figure 2.5: Variation of expansion ratio in CBR samples after 4 days soaking for optimum mixes

The results concluded the substantial improvement in compaction and California bearing ratio of the composite containing clay, sand and fly ash (70: 30: 10). The swelling nature of the clay also reduced up to 60% after stabilization. Thus, the stabilized composite can be used for the construction of flexible pavements in rural areas with low traffic.

2.2.2 Compaction and Subgrade Characteristics of Clayey Soil Blended with Beas Sand, Fly Ash and Waste Plastic Strips (Sharma, 2013).

The research is made to study how fly ash and waste plastic strips may be effectively utilized in combination with the clayey soil, local sand and fly ash, to get an improved soil material which may be used in various soil structures. Waste plastic packing strips wasted from the packaging of materials in cardboard boxes etc. have been used as reinforcement.

When adding the waste plastic strips (0.1% to 0.5%) in to the optimum composition of Clay: Sand: Fly ash (60: 40: 10%), the maximum dry density of the mix slightly decreases (about 0.25% to 0.75%) compared to the maximum dry density for the mix without plastic strips, which is shown in ***Figure 2.5***. The dry density is reduced due to the fact that plastic is a lightweight material. The maximum dry density increases slightly with the increase in the plastic strip content up to 0.3%, thereafter it decreases. This can be attributed to the reason that up to a certain percentage the plastic strips tend to facilitate the orientation of the particles in the clay-sand mix after which the greater percentage of the strips tend to disperse them.

Figure 2.6 shows the effect of plastic strips on the California Bearing Ratio (CBR) values of clay-sand- fly ash- plastic strip mixes. It is observed that unsoaked and soaked CBR value of the mix initially increases and then decreases with the addition of plastic strips. The maximum CBR value of the clay-sand fly ash-plastic strip mix is achieved at a plastic strip content of 0.3%. The increase in the CBR value is due to the reinforcing characteristics of the plastic strips. It prevents the formation of cracks in the sample, and binds the soil particles together, leading to an increase in CBR values of the stabilized soil.

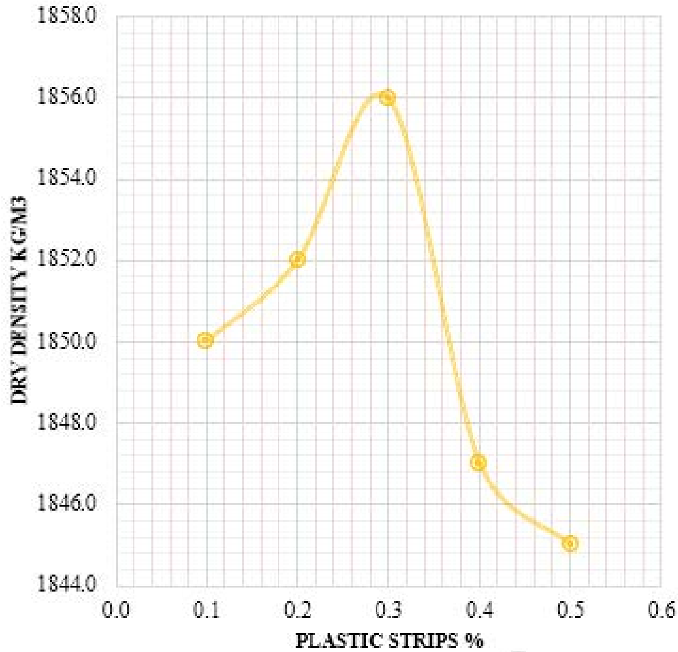

Figure 2.6: Effect of Plastic Strip Content on Maximum Dry Density of (Clay: Sand: Fly Ash: 54:36:10) Mix

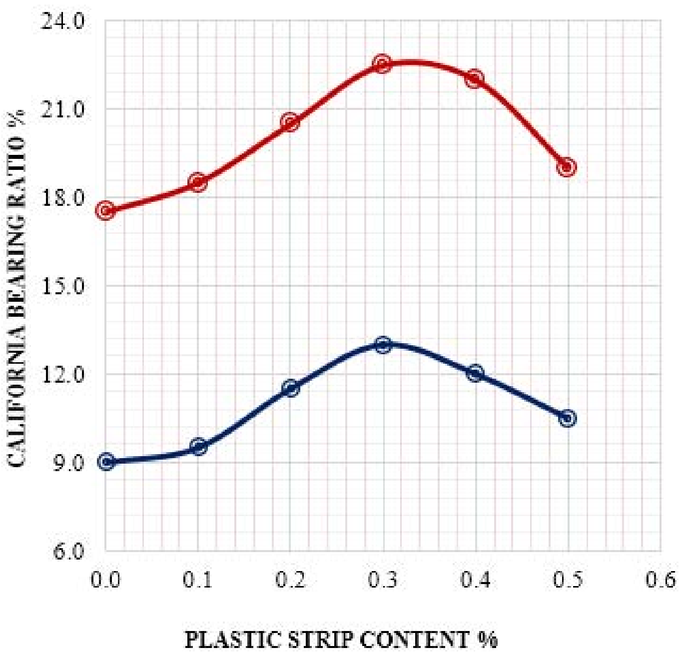

Figure 2.7: Variation of California Bearing Ratio with Plastic Strip for (Clay: Sand: Fly Ash: 54:36:10) Mix

Figure 2.7 shows the variation in the coefficient of permeability (k) of various composites with the increase in the plastic strip content. The permeability of the composite base increases with the increase in the strip content, hence leading to an increase in the number of micro paths in the composite material. The coefficient of permeability corresponding to the optimum strip content i.e. 0.3% plastic strips, is more than six times the coefficient of permeability of the mix without any strips.

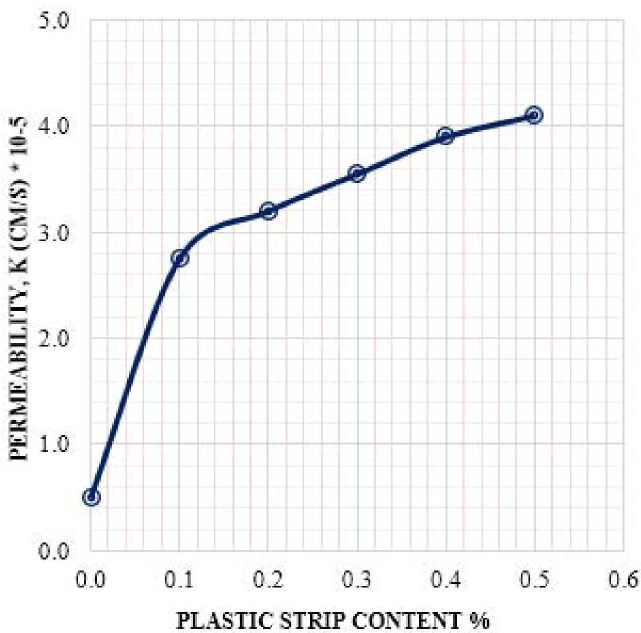

Figure 2.8: Variation of Coefficient of Permeability (k) with Plastic Strip Content.

The above test results concluded that an optimized mix of clay: sand: fly ash: 54: 36:10 with 0.3% plastic strips may be chosen as the suitable composite, which can be considered for applications in the construction of embankments, sub-grade and foundation bases, particularly in rural roads and low cost roads with a lesser traffic volume.

2.2.3 Bamboo as a Subgrade Reinforcement for Low Volume Roads on Soft Soils (Raja, Babu, 2013).

The paper explains the use of bamboo as a subgrade reinforcement in unpaved roads, and focuses on the scope of use of bamboo as a subgrade reinforcement for conventional geogrid and geotextiles in unpaved roads with poor subgrade CBR values. The use of bamboo as a reinforcement in unpaved roads is evaluated in terms of required base course thickness, for poor subgrade CBR values using the design method developed by *(Giroud and Han, 2004a)* for geogrid-reinforced unpaved roads.

The studies conducted on bamboo shows that it is a rough material, and develops sufficient interaction with soil for developing tensile stresses when used as a reinforced material. Strength and deformation characteristics of bamboo compare very favorably with geosynthetics. In fact, with regard to the deformation modulus and creep, natural materials such as bamboo are superior to geosynthetics (Sivakumar, 2006). Due to the higher stiffness of bamboo compared to geogrid, the bamboo grid will have a higher aperture stability modulus than conventional geogrids.

The bamboo grid is placed at the interface due to important reasons,

1. Decreases the rut depth occurring in the base course layer
2. Increases the stiffness of the base courses by interlocking the aggregates in the apertures of the bamboo grid.

In this research, the required base course thickness is determined for allowable rut depths of 50, 60, 70, 80 and 90 mm with the corresponding subgrade CBR values of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5%. A minimum thickness of 0.1 m is adopted for the base course to reduce the disturbance of subgrade soil during trafficking, and to provide sufficient anchorage for the bamboo geogrid.

The research presents the use of bamboo grids in unpaved rural roads as reinforcement materials. The results are presented in terms of the required base course thickness for different subgrade CBR values. As the subgrade CBR value increases, the base course thickness reduces. The percentage reduction of the thickness of the base course for the unreinforced unpaved road section, compared with the reinforced unpaved section is higher for low allowable rut depths. It is shown that bamboo grids serve as an effective reinforcement in soft soils and also result in saving aggregate materials.

2.2.4 Effect of Fine Percentage on the Properties of Sub base Material (Inan 2016).

The objective of the research is studying the importance of sub-base material properties and ascertaining whether any relaxation on the fine aggregate percentage is possible. The study is focused on identifying the effects of the fine percentage on sub-base material properties and on determining the correlation between the CBR and each of the important soil parameters.

Most roads in Sri Lanka have been constructed to fulfil the requirements stipulated in the standard specifications. It is noted that until the time the second edition was published, the grading was not considered in selecting materials for the construction of the sub base. The maximum dry density of the material was also not considered. ***Table 2.2*** elaborates the requirement of the properties for the sub base construction practice in Sri Lanka.

Table 2.2: Requirement of the Material Properties for Sub base Construction Practice in Sri Lanka

Properties Requirement	**SSCM *(iCTAD)* 2002**	**SSCM *(iCTAD)* 2009**
Liquid Limit(LL)	Not to exceed 40%	Not to exceed 40%
Plasticity Index (PI)	Not to exceed 15%	Not to exceed 15%
Maximum Dry Density (Modified)	*Not specified*	Not less than 1,750 kg/m3
4-day soaked CBR at 98% MDD (Modified)	-	Not less than 30%
4-day soaked CBR at 100% MDD (Modified)	Not less than 20%	-

		Sieve Size mm	***Passing %***
Grading Requirements	*Not specified.* But the condition of the LL & PI may relaxed at the discretion of the engineer when the portion of material finer than 75 µm is small	50	100
		37.5	80 - 100
		20.0	60 - 100
		5.0	30 - 100
		1.18	17 - 75
		0.3	9 - 50
		0.075	5 - 25

It is difficult to find sub base materials that satisfy the specifications given in SSCM *(iCTAD)* 2009. The difficulties encountered in satisfying the required properties vary according to the area concerned. Even though LL, PI, MDD, CBR, and sieve analysis results have to satisfy the SSCM *(iCTAD)* 2009 requirements, only LL, PI, and CBR values given in SSCM *(iCTAD)* 2002 have been considered in selecting the sub-base materials, and some projects in the country still work according to SSCM *(iCTAD)* 2002.

Therefore, it is essential to find out the importance of the properties of these materials and whether any relaxation is possible. Furthermore, it is important to ascertain any possible relationships among the properties.

- To investigate the effect of the fine percentage on properties of sub-base material.
- To find out the significant correlations between properties of sub-base material and the fine particle fraction of a selected sample.
- To investigate the proper method of relaxation for the materials in marginal values of the grading band (fine fraction) to be used as sub-base materials in construction work.

The sample was initially prepared to satisfy all the sub base material requirements specified in the SSCM by initially blending two types ***(type 1 and type 2)*** of soil. A stock of fine particles was prepared by sieving soil through a 425 µm sieve. These sieved fines were incrementally added to the prepared sub base material to make 10 different soil samples. Atterberg limit tests were only performed on random samples in order to confirm the soil uniformity since the Atterberg limit has to be unique for all samples having fine fractions separated from ***type 2*** soil.

Table 2.3 illustrates the passing percentages through 425 µm, 300 µm and 75 µm sieves and MDD, OMC, and CBR values of the 10 samples. The MDD values of all samples were each greater than the minimum requirement of 1.75 kg/m3.

Table 2.3: Material Properties of Soil Samples

Sample No.	0.425 sieve (% passing)	0.300 sieve (% Passing)	0.075 sieve (% passing)	MDD (kg/m3)	OMC (%)	CBR 98% at MDD & OMC (%)
1	22.8	17.4	12.5	2.040	8.5	59
2	24.6	22.6	14.1	2.043	8.6	58
3	27.5	25.0	17.2	2.025	8.9	52
4	35.2	33.0	25.9	1.980	9.7	49
5	45.0	41.8	29.8	1.977	9.9	44
6	49.7	42.6	30.1	1.959	10.3	40
7	54.5	49.0	31.2	1.972	11.1	38
8	54.3	49.4	32.4	1.952	11.6	37
9	55.1	46.8	31.9	1.940	11.8	30
10	59.3	52.5	37.2	1.917	12.2	25

Based on the test results, the correlations of the material properties have been studied. Accordingly, the changes of the CBR when different fractions were passed through the 425 µm, 300 µm, and 75 µm sieves were found. In the fitted models, the fine content of the material affected their CBR values. The CBR of the material decreased as the fine content was increased. However, it can be noted that the selected samples, which were outside the grading band recommended by the SSCM, satisfied the CBR requirements specified in the SSCM. The correlation coefficient (R2) of the fitted models was 0.926 for a 425 µm sieve passing, 0.890 for a 300 µm sieve passing and 0.889 for a 75 µm sieve passing. Further, ***Table 2.4*** illustrates the correlation between the material properties of the samples and their effect.

Table 2.4: Correlation between the Material Properties of the Samples

Correlation	Correlation Coefficient (R2) for Sieve			Line Gradient (m)
	425 µm	300 µm	75 µm	
MDD vs % Passing	0.905	0.888	0.952	Negative
OMC vs % Passing	0.930	0.904	0.868	Positive
CBR vs MDD	0.936			Positive
CBR vs OMC	0.953			Negative
MDD vs OMC	0.902			Negative

The study revealed that the fine fraction of a selected material affects the CBR and MDD values of the material. When the fine fraction increases, CBR and MDD values of the soil decrease. Based on the above studies, it can be recommended that the grading band of 75 µm sieve passing can be relaxed up to 35%, if the soil sample satisfies the specified CBR requirement (30) and also if the PI value is less than or equal to 10. Further studies will be required to revise the present grading band by extending this research to different types of soils found in Sri Lanka.

2.2.5 Applicability of Steel Fibers to Improve the Properties of Cement Stabilized Aggregate Bases (Silva 2011).

Stabilized bases are normally designed for the heavy traffic categories or in the absence of base materials which should have the required material properties according to the specifications, so that the higher strength category can be achieved.

Bases can be constructed using soil or aggregates. Those are stabilized with various admixtures such as lime, sand or cement. Among them, cement stabilization is a common practice in the road construction industry and content of cement has to be increased to get a higher strength capacity. The shrinkage cracks may appear with the increased usage of the cement content, and it has a tendency to convert the layer to a rigid pavement. Hence, another feasible technique should be applied to achieve the required higher strength capacities concurrently to diminish shrinkage cracks.

The research was conducted to introduce the usage of a reinforcement type such as steel fibers in Dense Graded Aggregate bases to achieve the above phenomena. The main objective of the research is to find out the strength variation between the flexural and crushing strengths of Steel Fiber Reinforced Bases (SFRB).

The cement contents were carefully selected in the range between 3% and 8% to confine to the flexible pavement type, and Dramix RC-80/60-BN steel fibers were used as manufacturer's practice of 10 - 12 kg/m3 to increase the flexural capacity of the SFRB layer in this research. Accordingly, relevant tests were conducted and results for "Comparison of Flexural Strength of the Beams with and without Steel Fibers" and "Comparison of Crushing Strength of the Cubes with and without Steel Fibers" are presented in the ***Table 2.5*** and ***Table 2.6*** respectively.

Table 2.5: Flexural Strength with/ without steel Fibres

Cement %	Flexural Strength with steel fibres (N/mm2)	Flexural Strength without steel fibres (N/mm2)	Incremental
3	0.8	0.5	1.6
4	1.3	0.7	1.8
5	1.5	0.8	1.8
6	2.0	1.4	1.4
7	2.6	1.4	1.8
8	2.9	2.1	1.4

Table 2.6: Crushing Strength with/ without steel Fibres

Cement %	Crushing Strength with steel fibres (MT)	Crushing Strength with steel fibres (MT)	Incremental
3	13.0	8.8	1.5
4	15.0	9.5	1.6
5	17.0	11.2	1.5
6	22.0	11.3	1.9
7	23.2	11.8	1.9
8	35.8	12.2	2.9

The research concluded that the steel fiber reinforced stabilized beams showed a significant increase in the first crack load over conventional stabilized beams. According to the research outcome, it can be understood that the increase of flexural strength was 1.5 times greater than the conventional stabilized beams. Hence, it can be said that the steel fiber reinforced stabilized beams were more flexible than conventional stabilized beams. The reasons can be the effects of steel fibres, good bonding between steel fibres with the surrounding cementitious materials, which act as a confinement to the stabilized mix and also the energy absorption under flexural loading which was greatly enhanced with steel fibre reinforcement.

Furthermore, according to the study, it was understood that the crushing strength also increased by 1.5 times with the use of steel fibers. Therefore, steel fibres were used in the Cement Stabilized Dense Graded Aggregate to improve the strength in flexible pavement types.

2.2.6 The Cement Stabilized Soil as a Road Base Material for Sri Lankan Roads (Bandara 2017).

Aggregate bases are being used for road construction work in Sri Lanka. However, quarries that produce aggregates are not commonly available in the country. Furthermore, the number of available rocks is also gradually decreasing due to various factors related to their usage and ownership, and also due to ecological reasons. As a result, cement stabilized soil is now being introduced as an economically viable alternative material to be used in road bases.

The main reasons for this study were the failures that occurred in several road rehabilitation projects in the northern part of the country, which had used Cement Stabilized Soil Base (CSB) for the construction of the roads concerned. These are failures which occurred during the early stages of the operation. According to the Consultant's Engineer, the main reasons for those failures were the use of improper cement-soil proportions, unsuitability of the soil used for the stabilization, use of improper mixing methods and the lack of technical guidance.

Thus, there was a need for a study to identify methods and specifications that are appropriate to stabilizing the locally available soils.

The strength of road subgrades, soil bases and sub bases are commonly assessed in terms of the California Bearing Ratio (CBR) which is dependent on the type of soil used, its density and moisture content. Therefore, it is important to use correct test procedures to assess the properties of a cement stabilized road base.

In a road structure with either a stabilized base or a subbase, the most critical tensile stress or strain will be located at the bottom of the stabilized layer. Therefore, the tensile stress at the bottom of cement treated layers can cause fatigue cracking. The elastic modulus and the tensile strain at the bottom of cement treated layers are considered for the detailed analysis of a stabilized layer. The strength of the stabilized base and the subbase are commonly assessed using the Unconfined Compressive Strength (UCS).

The main objectives of the study were to identify and develop a relationship between the cement content, CBR and UCS of a CSB, to identify a suitable method for measuring the strength of a CSB and to develop a pavement design chart for CSB pavements for various traffic and subgrade classes.

The test reports pertaining to borrow pit samples of natural soils that were selected for the CSBs of the proposed rehabilitation road projects were collected and the properties of the soils were determined through standard laboratory tests. Accordingly, the Modified Proctor Test was carried based on the guidelines in Road Note 31, to ascertain the moisture-density relationship of the stabilized soil sample mixed with cement content ranging from 1.5% to 5.0% at 0.5% intervals. Further, the CBR and UCS test specimens of the stabilized soil were prepared as per Road Note 31, and CBR and UCS tests were carried out on the specimens according to AASHTO T-193 and BS 1924 respectively.

The SPSS software was used to develop the relationships among the Cement Content, CBR and UCS. The relevant equations were derived using a fitted model. The KENPAVE mechanistic pavement design software was used to analyze the fatigue cracking and permanent deformation (rutting) for 200mm and 175mm thicknesses of CSB, with 8% CBR of the subgrade. Also mechanistic pavement analysis was performed on various combinations of sub-base, capping layer and subgrade CBR, to estimate the traffic demand on CSB pavements. Accordingly, the pavement design chart was prepared for various subgrades and traffic conditions.

Based on the test results, there was a good relationship between the Cement Content (CC) and the Crushing Strength (UCS) of the CSB. Consequently, a fitted model, UCS = 1.0381(CC) - 1.0488, was developed. It has also been noted that there is no correlation between the Cement Content and CBR. Therefore, the study shows that the strength of a CSB should be measured using the UCS. The CBR is an empirical test (a penetration-based test) which can measure the strength of soil that does not take tension under loading. After the stabilization of the soil, the stabilized soil layer can stand tension. Therefore, the strength of any stabilized layer should not be measured using the CBR.

According to the analysis, it was found that when the CSB thickness is increased from 175 mm to 200 mm, the allowable number of load repetitions for fatigue is increased by five times, and that the allowable number of load repetitions for rutting is increased by two times. Therefore, the pavement design with a 200mm CSB can be considered as the most economical pavement design for a CSB, made from available soils for traffic where standard axle repetitions are less than 1.5x106 in number. Since the allowable number of load repetitions for rutting is always greater than that for fatigue, fatigue cracking would be more critical in a CSB pavement than rutting.

CHAPTER 3

REQUIRED SOIL PROPERTIES FOR ROAD CONSTRUCTION IN SRI LANKA

3.1 Introduction

The road construction methodology/requirement in Sri Lanka is based on the requirement embedded in the "Standard Specification of Construction and Maintenance of Roads and Bridges" - Second Edition 2009 (SSCM) *(iCTAD 2009)*, published by the Institution for Construction Training and Development. According to these specifications, the requirement of soil properties are defined for Embankment, Sub base, Road shoulder and Gravel surfacing work.

3.2 Embankment Material

The soils used as Embankment materials shall be naturally occurring soils and shall not include highly plastic clay, silt, peat or other organic soils or any soil that is contaminated with topsoil vegetable and other deleterious matter. The material used for the top 500 mm of Embankment shall conform to the requirements of type I material, and the material for lower layers of Embankment shall conform to the requirements of type II material as given in ***Table 3.1***.

Table 3.1: Requirement of Embankment

Property	**Embankment**	
	Type I	**Type II**
Liquid Limit (LL)	Not to exceed 50%	Not to exceeded 55%
Plasticity Index (PI)	Not to exceed 25%	Not to exceeded 25%
Maximum Dry Density (Modified)	Not less than 1,600 kg/m3	Not less than 1,500 kg/m3
4-day soaked CBR at 95% MDD (Modified)	Not less than 7%	Not less than 5%

(Table 1708-1, iCTAD 2009)

3.3 Soil for Upper Sub base and Lower Sub base or Selected Subgrade Materials

The materials used for upper sub base and lower Sub base or selected subgrade shall be either naturally occurring or blended gravel and sands or mixtures. They shall not include highly plastic clays, peat, other organic soil or any soil that is contaminated with topsoil, vegetable and other deleterious matter. Specification for upper sub base materials and lower sub base/ select subgrade are given in ***Table 3.2, Table 3.3*** and ***Table 3.4***.

Table 3.2: Requirement of Upper Sub base

Property	**Upper Sub base**		
		Flexible	Rigid
Liquid Limit (LL)	Not to exceed	40%	25%
Plasticity Index (PI)	Not to exceed	15%	6%
Maximum Dry Density (Modified)	Not less than 1,750 kg/m^3		
4-day soaked CBR at 98% MDD (Modified)	Not less than 30%		

(Table 1708-2, iCTAD 2009)

Table 3.3: Grading Requirements for Upper Sub base

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

(Table 1708-3, iCTAD 2009)

Table 3.4: Requirements of Lower Sub base or Select Subgrade

Property	Lower Sub base or Select Subgrade
Liquid Limit (LL)	Not to exceed 40%
Plasticity Index (PI)	Not to exceed 15%
Maximum Dry Density (Modified)	Not less than 1,650 kg/m3
4-day soaked CBR at 95% MDD (Modified)	Not less than 15%

(Table 1708-4, iCTAD 2009)

3.4 Soil for Road Shoulders and Gravel Surfacing

The soil used for road Shoulders and gravel surfacing shall consist of naturally occurring gravels, sands and mixtures thereof with sufficient plastic fines to act as binder or such soil obtained by blending two or more soils, that conform to the grading requirement and consistency limits tabulated below. The soil shall also have a 4 day soaked CBR value not less than 15% at 100% maximum dry density under standard conditions of compaction. Specification for road shoulders and gravel surfacing are given in ***Table 3.5*** and ***Table 3.6***.

Table 3.5: Grading Requirements for Road Shoulders and Gravel Surfacing

Sieve Size mm	Sieve Size µm	Percentage by Weight Passing Sieve
37.5		100
20		77 - 100
5		41 - 100
2.36		30 - 80
	600	18 - 50
	75	5 - 25

(Table 1708-1, iCTAD 2009)

Table 3.6: Consistency limits for Earthen Road Shoulders and Gravel Surfacing

Climatic Zone		LL	PI
Wet Zone	Lateritic Gravely Soils	Not to exceed 55%	4 – 25
	Other Gravely Soils	Not to exceed 50%	4 - 20
Dry Zone		Not to exceed 55%	6 – 25

(Table 1708-2, iCTAD 2009)

3.5 Limitation for Burrowing Materials of Uoori clay and Coastal Sand for Road Construction

Permits for borrowing materials of Uoori clay and Coastal Sand are limited after the newly imposed restrictions by the government authorities *(Ministry of Mahaweli Development and Environment, Circular 02/2015)* and because it involves lengthy and tedious procedures. The permits 'A' (>525cube/Moth), 'B' (100-525cube/Moth) and 'C' (<100cube/Moth) are issued by relevant authorities based on the requirements recommended by the Implementing Agencies. The permits shall be approved by the Central Environmental Authority (CEA), Coast Conservation and Coastal Resource Management Department, Geological Survey & Mines Bureau (GSMB), Wild Life Department, Forest Department, Archaeology Department, District Secretariat and Divisional Secretariat after conducting the inspection at mining locations.

The coastal sand dunes available in Manalkadu, Maruthankerny, Alampil, Kalmunai and Kavutharimunai of the Northern part of the Sri Lanka, have formed as a result of the interaction between the wind and soil in the form of sand grains, and by strong currents beneath the water. The improvement/formation of the coastal road network in coastal lines shall be constructed by adding the clayey layer over the sand surfaces of existing subgrade soil. Additional sands from sand dunes shall be brought only for the rising requirement of the embankment section. A loyalty charge of Rs 460.0/Cube shall be applied by the respective Divisional Secretariat to issue the permit to burrow the Coastal sand.

Uoori clay is available in the lagoons of Jaffna, Nanthikadal, Cheddikulam, Vadamarachchi, Maruthankerny, Uppuaru, Kokkilai, Naiaru and Chalai. Uoori is the forming/sediment in the clay layer available in the coastal lagoon beds during the seasonal movement of seawater into the lagoon and mixed with the clayey layer, which shall be burrowed to improve/form the coastal road networks, after getting prior approval from the relevant authorities. The limited quantities of Uoori clay are allowed to be borrowed by the Divisional Secretary without any restriction, after receiving the recommendation from the Implementing Agencies of Road Development Department and Local Government. A loyalty charge of Rs 185.0/Cube shall be applied by the respective Divisional Secretariat to issue the permit for burrowing of the Uoori clay.

CHAPTER 4

METHODOLOGY

4.1 Introduction

Experimental studies for Sieve Analysis, Atterberg Limits, Modified Proctor Compaction and California Bearing Ratio (CBR) were performed following the testing procedures specified by the American Association of State Highway and Transport Officials (AASHTO) and British Standards (BS). Test procedures; ***AASHTO T 88-00, BS 1377-2: 1990, AASHTO T 180-01 and AASHTO: T193-99*** were conducted for different mixture proportions of Uoori clay and coastal sand respectively as 50:50, 60:40, 70:30, 80:20, 90:10 and 100:00. Properties of composite material were compared with standard specifications for the construction of roads and bridges *(iCTAD 2009)*.

Uoori clay and coastal sand were proportionately mixed to obtain 72kgs of samples for each compositions. Accordingly 35kg, 30kg, 5kg and 2kg samples were prepared by Sample divider for CBR, Proctor Compaction, Sieve Analysis and Atterberg Limit tests respectively. Samples collected after conducting the “Proctor Compaction Test” were stored for further tests. Sample preparation is shown in ***figure 4.1***.

Figure 4.1: Preparation of composite material

4.2 Laboratory Testing for Sieve Analysis

Laboratory test for Sieve Analysis was carried out for blended materials in different compositions to assess the particle size distribution of composite material in accordance with AASHTO T 88-00 standard. Dry sieve and wet sieve tests were conducted for blended material by using the mechanical sieve shaker with embedded sieve sizes of 20.0mm, 5.0mm, 2.36mm, 1.18mm, 0.600mm, 0.300mm, 0.075mm and pan in descending order. Approximately 2.5kgs of sample was taken for this test and the weight of the material in each sieves and pan were measured after 10 minutes of mechanical shaking. For the wet sieve test, a retained sample of the material washed on a 0.075mm sieve and washed out material through 0.075mm sieve were oven dried to obtaining wet sieve results. Dry sieve and wet sieve tests readings and the calculation of soil passing percentage through the sieves are enclosed in **Appendix A**. Shaking operation and retain sample in sieves are shown in ***figure 4.2***.

Figure 4.2: Shaking operation and retain sample in sieves

4.3 Laboratory Testing for Atterberg limit test

Laboratory tests on Atterberg Limit were conducted for blended materials in different compositions, which were selected using following ***methods*** to measure the cohesiveness of composite material in accordance with BS 1377-2: 1990.

1. Sample selected prior to the Proctor compaction test for each composite material.
2. Sample selected after conducting the Proctor compaction test at optimum moisture level.

Soil particles passing a 0.425 mm sieve was used for this test and the material collected based on above two methods was naturally dried prior to the preparation for testing to avoid the particles split/ agglomerate.

For the ***Plastic Limit test***, correct quantity of sample was taken to avoid the common error in the results and it was mixed with water in longer period (>5-20min) to obtain the more plastic sample.

For the ***Liquid Limit test***, adding the dry sample in the prepared mixture had avoided since which might cause stirring process.

Readings of both test methods and calculations of Liquid Limit (LL) and Plastic Index (PI) are enclosed in **Appendix B**. Laboratory testing for above tests are shown in ***figure 4.3***.

Figure 4.3: Conduct the Liquid limit and Plastic limit tests

4.4 Laboratory Testing for Modified Proctor Compaction

Laboratory test for modified Proctor compaction was conducted for blended materials in different composition to measure the Maximum Dry Density (MDD) with an Optimum Moisture Content (OMC) of composite material in terms of AASHTO T 180-01 standard. A 30kg of sample of each composition was divided equally to five specimens and each specimen was compacted in different moisture levels.

The prepared sample was placed in a mould to a depth of about 125 mm in five equal layers and each layer was compacted with uniformly distributed blows of 56 Nos by the hammer, dropped from 457 mm height. Accordingly density and moisture content are recorded to find out the MDD with an OMC and the calculations with a graphs are enclosed in **Appendix C**. Further, materials collected after the tests were stored for additional testing. Laboratory testing for above tests are shown in ***figure 4.4***.

Figure 4.4: Compaction of sample and measures

4.5 Laboratory Testing for California Bearing Ratio

Laboratory test for California Bearing Ratio (CBR) was conducted for blended materials in different composition to evaluate the bearing strength of composite material according to AASHTO: T193-99 standard.

Three specimens of each composite material were compacted with density ranging from 95% (or lower) to 100% (or higher) of MDD determined by modified Proctor compaction. Usually 10, 30 and 65 blows per layer were applied to compact the specimens respectively. Each specimen was prepared by adding water to the OMC and placed into the mould in 5 equal layers and each layer was compacted. In each case the total compacted depth was 125mm.

A swell plate and an adjustable stem were placed on the sample in the mould and 4.54kg of surcharge weight was added on immersed mould in water for 96 hours. During soaking, the water level was maintained approximately 25mm above the top of the specimen. Specimens were removed from the soaking tank and allowed to drain out for 15 minutes. Care was taken not to disturb the surface of the specimens.

The surcharge weights and perforated plates were then removed and the wetted mass was measured to determine the density changes arising due to the water absorption during the soaking. Equal surcharge weights used during soaking on the specimen were applied and the specimen was placed on the CBR machine.

The penetration plunger was set on specimen top surface with a load of 44N and both penetration dial and load indicators were set to zero. Load was applied through the penetration increment of 0.25mm and load readings were recorded. Graph was plotted Penetration (X) Vs Load (Y) to determine the four day soaked CBR value. The calculation of CBR values and relevant graphs are enclosed in **Appendix D**. Laboratory testing for CBR is shown in ***figure 4.5***.

Figure 4.5: CBR sample measures and testing

4.6 Laboratory Testing for Composite Material 60:40

Modified Proctor compaction tests were conducted for composite material 60:40 with incremental compaction efforts obtained by applying a number of blows. Accordingly 56 (standard), 65, 95, 125, 155 and 185 blows were used for the tests and MDDs at corresponding moisture contents, and were recorded to obtain the density of the material in different degree of compactions. The readings and calculations with graphs are enclosed in **Appendix E**.

In addition, the dry sieve tests were performed on the above samples. By selecting the materials after conducting the Proctor compaction at OMC in each degree of compaction. Accordingly retained samples in sieves were recorded for each test and calculations of soil passing percentage with respective sieves are enclosed in **Appendix F.**

CHAPTER 5

LABORATORY TEST RESULTS AND DISCUSSION

5.1 Sieve Analysis (AASHTO T 88-00)

Particle size distribution of soil is not a critical requirement for the construction of the lower layer of embankment, lower sub base or selected sub grade. However, it is one of the most important parameters for the upper sub base and "road shoulders and gravel surfacing" as stated in the SSCM of Sri Lanka. Initially, dry sieve and wet sieve tests were conducted for blended material *prior to* compaction to investigate the influence of Uoori clay on gradation of blended material.

5.1.1 Dry Sieve Test

Dry sieve tests were conducted for selected blended material using sieve sizes of 0.075mm, 0.3mm, 1.18mm, 5.0mm and 20.0mm for upper sub base layer. Sieve sizes of 2.36mm and 0.6mm instead of 1.18mm and 0.3mm were used respectively for "road shoulders and gravel surfacing" as specified by SSCM in Sri Lanka. The ***Table 5.1*** illustrate test results of dry sieve test for composite material.

Table 5.1: Passing percentage in dry sieve test

Sieve size (mm)	Soil passing (%) for dry sieve analysis					
	50-50	60-40	70-30	80-20	90-10	100-0
20.00	100.0	100.0	100.0	100.0	100.0	100.0
5.00	89.33	80.62	73.87	80.29	72.68	64.82
2.36	80.38	67.63	60.64	65.38	55.38	45.28
1.18	69.51	56.71	52.88	56.90	48.26	39.24
0.60	53.20	40.34	41.25	44.17	37.56	30.16
0.300	23.51	17.04	20.41	24.26	20.99	18.91
0.075	0.46	0.88	1.19	0.51	0.72	0.45

Figure 5.1 shows the results of dry sieve test for blended material. Specification limits for "road shoulders and gravel surfacing" and upper sub base materials are depicted in the same figure.

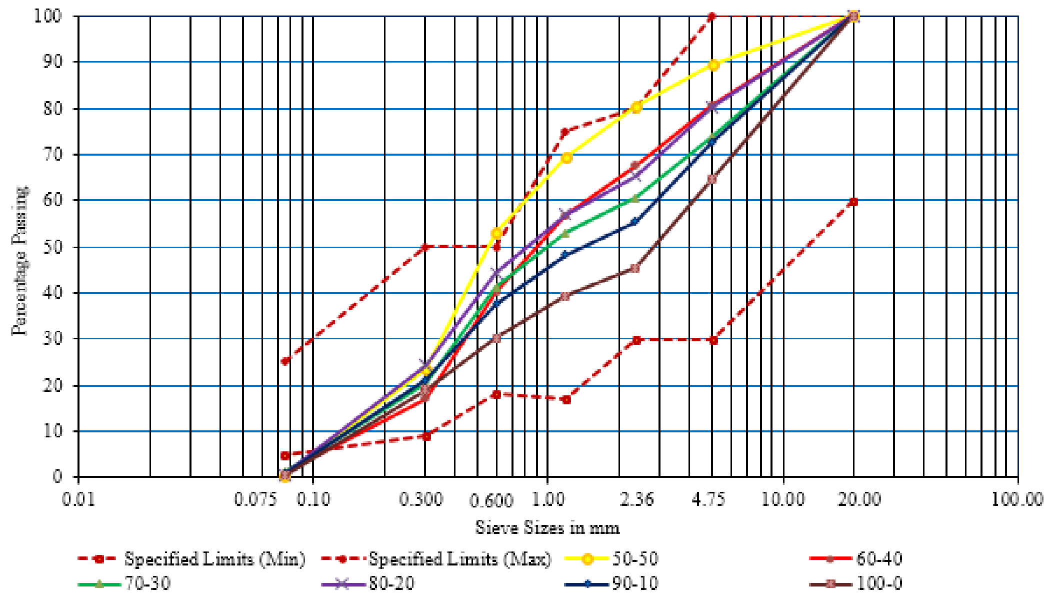

Figure 5.1: Results of dry sieve test for blended materials

Test results show that particles passing thorough the sieve size of 0.075mm do not satisfy even the minimum specifications given by SSCM for all composite materials. Furthermore, it was observed that testing of composite material 50:50 for "road shoulders and gravel surfacing" do not satisfy passing percentages specified for sieves the sizes of 0.60mm and 2.36mm.

5.1.2 Wet Sieve Test

Wet sieve tests were conducted for selected blending proportions and weight percentages of the washed-out material; obtained by air drying the retained sample passing through 0.075mm sieve. Total percentage of the materials that passed through 0.075mm sieve were calculated by adding a percentage of washed-out material in wet sieve test. The ***Table 5.2*** illustrate test results of wet sieve test for composite material.

Table 5.2: Passing percentage in wet sieve test

Sieve size (mm)	Soil passing (%) for wet sieve analysis					
	50-50	60-40	70-30	80-20	90-10	100-0
20.00	100.0	100.0	100.0	100.0	100.0	100.0
5.00	97.41	94.46	94.62	94.27	90.43	91.32
2.36	93.66	87.66	87.59	86.86	82.55	80.91
1.18	84.73	79.78	81.68	81.57	78.48	77.97
0.60	71.39	67.98	72.25	73.65	72.36	73.56
0.300	42.07	43.63	47.08	55.28	58.55	62.55
0.075	14.68	18.28	20.44	24.80	30.62	32.56
Washed	13.92	17.08	19.27	24.15	29.06	32.12

Figure 5.2 shows results of the wet sieve test for the blended material. Specification limits for "road shoulders and gravel surfacing" and upper sub base materials are depicted in the same figure.

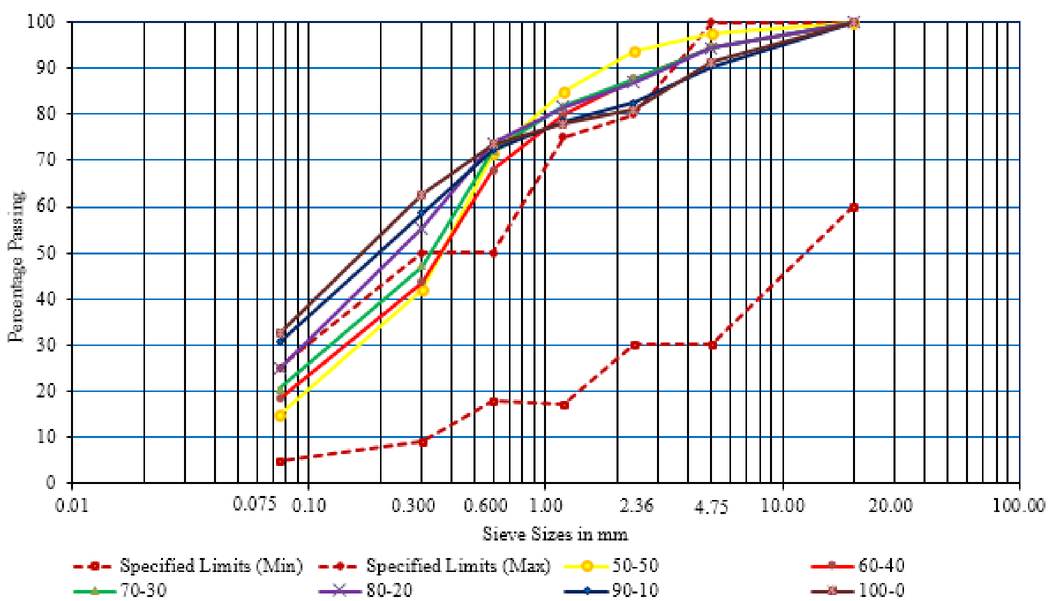

Figure 5.2: Results of wet sieve test for blended materials.

Results show that the percentage of material passing through 0.075mm sieve is less than 1.20% for the initial dry sieve test, and the percentage of materials passing through 0.075mm sieve varies from 14.7% to 32.6% in the wet sieve test depending on the percentage of Uoori clay (i.e., higher passing percentage for samples with higher amount of Uoori clay).

5.2 Atterberg Limits (BS 1377-2: 1990)

Liquid Limit (LL) and Plasticity Index (PI) of samples collected from the blended material *prior to* Proctor compaction test and samples collected at *optimum compaction level* under laboratory conditions (MDD at OMC) were recorded to examine the influence of Uoori particles on the plasticity index of the material. Material passing through 0.425mm sieve were used for the above tests and 34.31% of fresh sand passed through the particular sieve. The ***Table 5.3*** and ***Table 5.4*** respectively shows the results of samples selected *prior to* Proctor compaction test and samples taken at *optimum compaction level* under laboratory conditions.

Table 5.3: Samples selected prior to proctor compaction

Sieve size (mm)	Passing % of the blended material selected prior to Proctor compaction *(Test Method 1)*					
	50-50	60-40	70-30	80-20	90-10	100-0
0.425	37.03	27.15	30.44	34.31	29.08	25.29
If not considering the Sand component	19.88	13.43	20.15	27.44	25.65	25.29

Table 5.4: Samples taken at optimum compaction level under laboratory conditions

Sieve size (mm)	Passing % of the blended material selected at optimum compaction level under laboratory conditions *(Test Method 2)*					
	50-50	60-40	70-30	80-20	90-10	100-0
0.425	56.06	54.94	58.01	64.82	66.32	69.01
If not considering the Sand component	38.90	41.22	47.72	57.96	62.89	69.01

Material (***Table 5.3-*** Samples selected *prior to* proctor compaction) analysis conducted disregarding the presence of sand shows that there is no significant variation in the passing percentage of Uoori clay with the increase of the percentage of clay in the composite materials. Therefore the results conclude that clay in composite material "twigs" in Uoori particles.

Material (***Table 5.4-*** samples taken at *optimum compaction level* under laboratory conditions) analysis conducted disregarding the presence of sand shows that there is a significant variation in the passing percentage of Uoori clay upon increasing the percentage of clay in the composite materials. Therefore, results indicate that the Uoori particles in Uoori clay were "crushed" during compaction which lead to the increase of the passing percentage of clay.

Tests conducted on Atterberg limits presented in ***Table 5.5*** using two methods, have shown a significant increment in the limits for each composite material due to the fraction of Uoori and clay that escape through 0.425mm sieve. The composite material 60:40 has satisfied recommended specification limits (LL<40% and PI<15%) for sub base material though the specified LL varies between 32.20 and 36.90, and the specified PI varies between 6.59 and 11.31. On a further note, composite materials 50:50, 70:30 and 80:20 have satisfied recommended specification limits (LL<50% and PI<25%) of embankment and composite materials 50:50 and 70:30 have satisfied the recommended specification limits (LL<50% and PI<20%) for "road shoulders and gravel surfacing".

Table 5.5: Limit results for composite material

Atterberg Limits		Limit results for composite material for the Test Methods 1 and 2					
		50-50	60-40	70-30	80-20	90-10	100-0
LL%	*Test Method 1*	-	32.20	35.15	41.5	46.6	51.25
	Test Method 2	31.75	36.9	41.1	48.6	57.75	68.00
PI %	*Test Method 1*	-	6.59	11.11	15.64	23.77	25.01
	Test Method 2	6.88	11.31	16.49	22.43	25.57	32.09

5.3 Proctor Compaction (AASHTO T 180-01)

Modified Proctor compaction tests were performed for composite material to determine the Maximum Dry Density (MDD) with the corresponding Optimum Moisture Content (OMC). ***Figure 5.3*** shows that MDD values for all the available compositions have satisfied the minimum required specification limit of 1750 kgm^{-3} for the upper subbase.

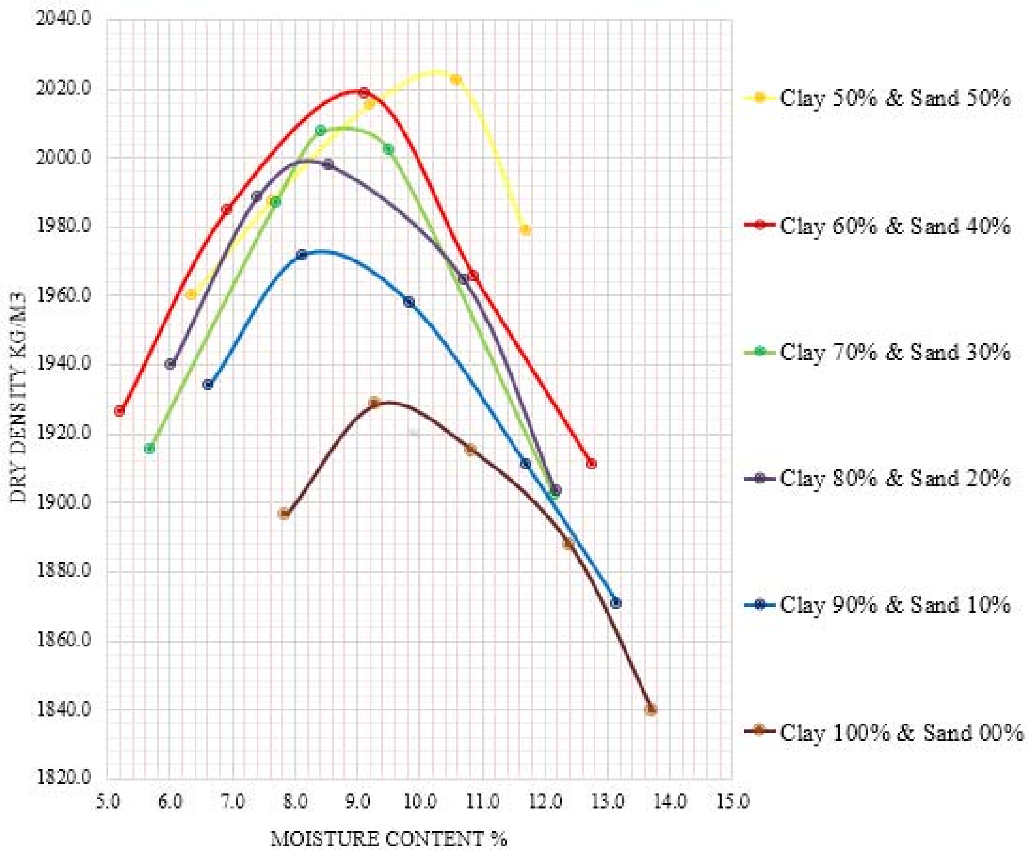

Figure 5.3: Moisture content vs. dry density for blended material

Table 5.6 shows that MDD values are reduced with the increasing of the clay percentage. However, OMC values decreased upon increasing the clay content but increased again with the presence of pure Uoori clay.

Table 5.6: OMC and MDD results for composite material

Clay & Sand %	50-50	60-40	70-30	80-20	90-10	100-0
OMC%	10.59	9.12	8.42	8.54	8.11	9.33
MDD	2022	2018	2007	1997	1971	1928

5.4 California Bearing Ratio Test (AASHTO: T193-99)

California Bearing Ratio (CBR) tests were conducted to examine the bearing capacity of composite material in four day soaked condition. Test results presented in ***Table 5.7*** shows that blended material 60:40 has only satisfied the recommended specification requirement [4-day soaked CBR at 98% MDD (Modified) > 30%] for upper sub base. Nevertheless, all the blended materials except 60:40 have satisfied the recommended specification requirement [4-day soaked CBR at 95/ 100% MDD (Modified) > 7/ 15%] for embankment/ “road shoulders and gravel surfacing”.

Table 5.7: CBR value for composite material in different % of MDD

CBR % at	Clay & Sand %					
	50-50	60-40	70-30	80-20	90-10	100-0
95% of MDD	14.0	28.0	21.0	14.8	12.2	11.0
98% of MDD	18.0	38.0	28.5	19.5	16.5	15.0
MDD	20.0	44.0	33.5	23.0	19.5	17.5

It was observed that in the dry sieve test; composite material 60:40 does not satisfy the recommended gradation criteria though it is a mandatory requirement for the upper sub base. Therefore, it can be recommended to conduct a wet sieve test to separate fines (clay and silts) from the blended mixture.

5.5 Research Findings

Tests results for the composite material 60:40 indicate acceptable specification limits for sub base construction except the initial test results of dry sieve analysis falling outside the band. Therefore, Proctor compaction and sieve analysis tests were conducted for the specified composite material 60:40 with the increment of compaction effort to study the field condition.

5.6 Compaction on Incremental Compaction Effort

A Proctor compaction test was performed by increasing the number of blows to examine the breakage in calcium carbonate particles (sea shells) in Uoori clay, which has an effect on the density of the material. In this study, a higher compaction effort was applied to the selected composite material 60:40. "OMC percentage and MDD for incremental compaction efforts" is presented in ***Table 5.8***.

Table 5.8: OMC percentage and MDD for incremental compaction efforts

Compaction effort	56 Blows (Standard)	65 Blows	95 Blows	125 Blows	155 Blows	185 Blows
OMC%	9.12	9.10	9.05	8.92	8.94	8.78
MDD	2018	2020	2024	2014	2001	1989

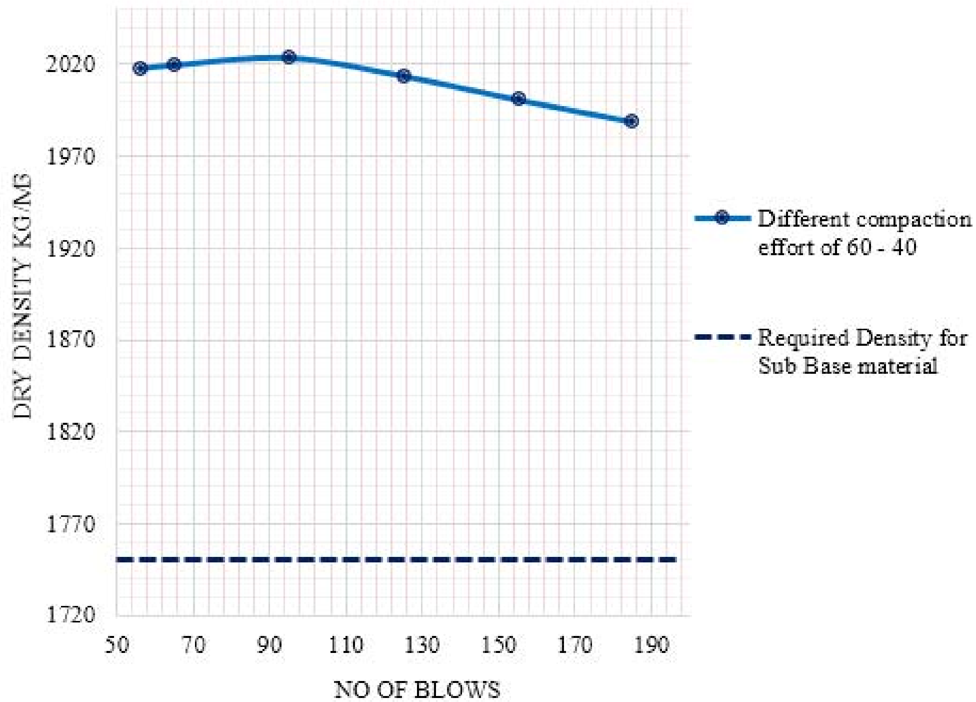

Figure 5.4: Number of blows vs. dry density for 60:40 (with increasing compaction effort)

Figure 5.4 shows that MDD could be achieved at a compaction effort of 95 blows. Furthermore, increase in compaction effort reduces OMC and MDD of the composite material 60:40. However, it was observed that MDD is higher than the specification limit.

5.7 Particle Size Change with Incremental Compaction

A Sieve analysis was conducted separately for the specified composite material 60:40, where the sample was collected after conducting a Proctor compaction test at MDD. In addition, to study possible changes in particle sizes, behavior of the composite material 60:40 was also evaluated by analyzing particle fraction with an increment in compaction effort. “Passing percentage of composite material 60:40 with increasing number of blows” is presented in ***Table 5.9***.

Table 5.9: Passing percentage of composite material 60: 40 with increasing the number of blows

Sieve size (mm)	Soil passing % for composite material 60:40					
	Initial	65 Blows	95 Blows	125 Blows	155 Blows	185 Blows
20.00	100.00	100.00	100.00	100.00	100.00	100.00
5.00	80.62	83.51	86.97	92.28	96.96	99.18
2.36	67.63	69.44	73.11	76.49	78.73	81.58
1.18	56.71	59.44	65.32	68.76	71.57	75.05
0.600	40.34	42.05	44.66	46.65	49.51	52.48
0.300	17.04	22.46	29.32	34.73	42.42	46.84
0.075	0.88	1.89	3.24	4.81	6.45	7.96

It was observed that the passing percentage of blended material has reached a specification limit after 155 blows of compaction under dry condition. It was also observed that wet sieve result for the sample with 155 blows does not exceed the upper limit of the recommended specification. It was identified that possible breakage in Calcium carbonate particles (sea shells) in Uoori clay does not make a significant effect on gradation. ***Figure 5.5*** shows the gradation for composite material 60:40 with various compaction efforts (56 blows are used in standard CBR test).

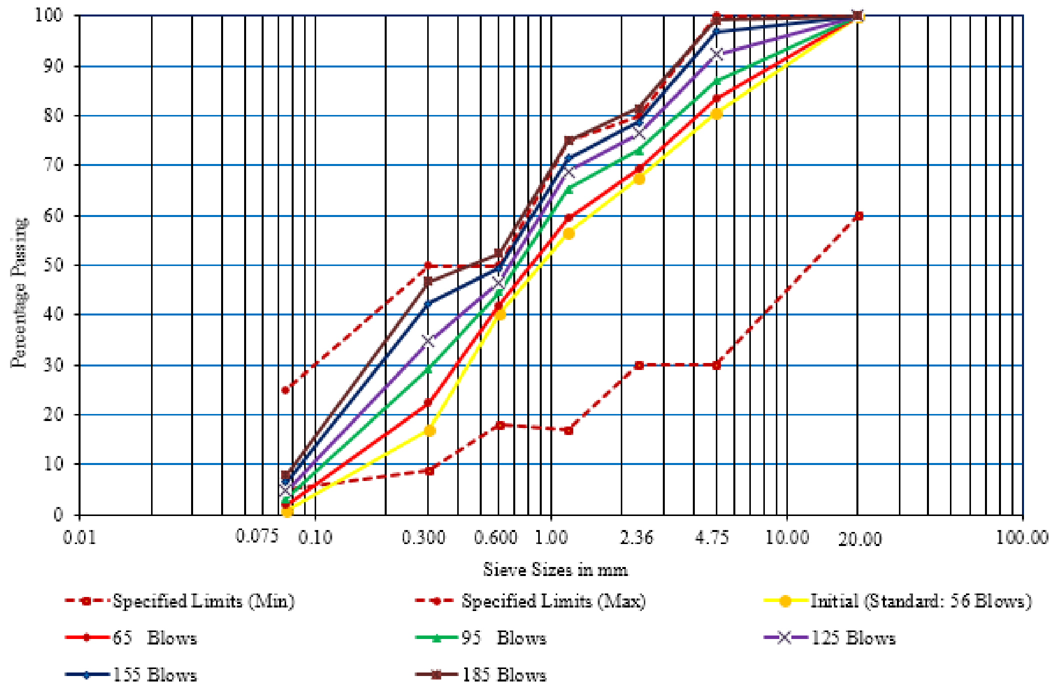

Figure 5.5: Graph for passing percentage of 60:40 with specified limit

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Test results of the composite material 60:40 indicates acceptable specification limits for upper sub base, road shoulders and gravel surfaces. It was noted that the initial test results of the dry sieve analysis falls outside the band and that of the wet sieve falls within the specified limits. In addition to that tests results show that composite material 50:50, 70:30 and 80:20 shall be used for the embankment and composite material 70:30 could be used for "road shoulders and gravel surfacing" in road constructions. Therefore, grading requirement for certain composite materials shall be redefined in SSCM *(iCTAD 2009)*. It is recommended to conduct wet sieve tests for composite material made out of highly plastic soil such as Uoori clay. Further research shall be carried out to improve the SSCM for various compaction efforts and gradation of blended materials. When increasing the compaction effort on composite material, the fine particle fraction of the gradation shifted to the gradation limits. Breakage of Uoori (sea shells) particles with incremental compaction effort satisfies both dry sieve and wet sieve gradation (passing through 0.075mm sieve).

REFERENCE LIST

[1]. AASHTO Designation: T 193-99 (2003). *California Bearing Ratio*, American Association of State Highway and Transportation Officials, USA.

[2]. AASHTO Designation: T 180-01 (2010). *Moisture Density Relations of Soils Using a 4.54 kg Rammer and a 457 mm Drop*, American Association of State Highway and Transportation Officials, USA.

[3]. AASHTO Designation: T 88-00 (2010). *Particle Size Analysis of Soils,* American Association of State Highway and Transportation Officials, USA.

[4]. Babu, S. K. Raja, J. (2013). Bamboo as Subgrade Reinforcement for Low Volume Roads on Soft Soils, *A Review of Road and Road Transport Development*, Volume 41, Indian Highways.

[5]. BS 1377-2 (1990). *Determination of Liquid limit, Plastic limit and Plasticity Index*, Part 2, British Standards, UK.

[6]. Giroud, J. P. Han, J. (2004). Design method for geogrid-reinforced unpaved roads. *Journal of Geotechnical and Geoenvironmental Engineering*, 130 (8), 775–797.

[7]. Lim, S. M. Wijeyesekera, D. C. Lim, A. J. M. S Bakar, I. B, H. (2014). Critical review of Innovative Soil Road Stabilization Techniques, *International Journal of Engineering and Advanced Technology (IJEAT),* Volume 3, Issue 5, June.

[8]. Mampearachchi, W. K. (2012). Towards a Proper Road Classification System for Economic Development of Sri Lanka, *Journal of Economic Review*, People's Bank, April/May, Sri Lanka.

[9]. Ministry of Construction and Engineering Services (2002). *ICTAD Standard Specification for Highway Construction and Maintenance of Roads and Bridges,* Second Edition, Ministry of Construction and Engineering Services, Sri Lanka.

[10]. Ministry of Construction and Engineering Services (2009). *ICTAD Standard Specification for Highway Construction and Maintenance of Roads and Bridges,* Second Edition, Ministry of Construction and Engineering Services, Sri Lanka.

[11]. Reddy, K. V. (2013). Correlation between California bearing ratio and shear strength on artificially prepared soils with varying plasticity index. *International journal of civil engineering and technology (IJCIET)*, Volume 4, Issue 6, November- December, pp. 61-66.

[12]. Sharma, R. K. Bandhu, D. Maheshwari, R. Kumar, S. (2013). Compaction and Subgrade characteristics of Clayey Soil blended with Beas sand, Fly ash and Waste plastic strips, *A Review of Road and Road Transport Development,* Volume 41, Indian Highways.

[13]. Sharma, R. K. Prasad, C.R.V. (2014). Influence of sand and fly ash on clayey soil stabilization, *IOSR Journal of Mechanical and Civil Engineering*, e-ISSN: 2278-1684, p-ISSN: 2320-334X, PP 36-40.

[14]. Sivakumar, G. L. (2006). An introduction to soil reinforcement and geosynthetics. First edition, University Press.

APPENDIX A:

Dry Sieve and Wet Sieve Tests Readings and the Calculation of Soil Passing Percentage through the Sieves for Composite Materials

APPENDIX B:

Test Readings and Calculation of “LL” and “PI” Values for Sample, Selected “Prior to the Proctor Compaction” and “After Conducting the Proctor Compaction at Optimum Moisture Level” of composite materials

APPENDIX C:

Test Readings and Calculations of Dry Density with Respective Moisture Content and Graphs for Composite Materials

APPENDIX D:

Test Readings and Calculation of Four Day Soaked “CBR” Values with Respective Densities (95%, 98% & 100% of “MDD”) and Relevant Graphs for Composite Materials

APPENDIX E:

Test Readings and Calculations of Dry Density with Respective Moisture Content and Graph for Composite Material 60:40 in Different Compaction Efforts

APPENDIX F:

Dry Sieve Test Readings and Calculations of Soil Passing Percentages for Composite Material 60:40, Selected "After Conducting the Proctor Compaction at OMC" in Different Compaction Efforts