THE CEMENT STABILIZED SOIL
AS A ROAD BASE MATERIAL FOR SRI LANKAN ROADS

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(2010/2011)

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February 2014

DECLARATION

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ACKNOWLEDGMENT

I wish to pay my sincere gratitude to Dr. W. K. Mampearachchi who supervised and guided me to complete a successful research. Also I would like to thank him for supporting and expending his valuable time throughout the study.

All material tests were conducted in A32 and A35 project laboratories and immeasurable support given by Mr. Athula (MAGA Engineering Pvt Ltd), Mr. Nimal (China Harbour Engineering Company Ltd) and their staff is gratefully acknowledged.

I would like to thank all engineers who contributed their valuable time for sharing knowledge and experience with me.

I thank the organizer of Transport Research Forum, University of Moratuwa, 2011, for giving me a great opportunity to present my research.

I am also grateful to all staff members and post graduate students in the University of Moratuwa who supported and taught me during my post graduate study.

ABSTRACT

Soils that can be stabilized are Granular, Sandy, Salty and Clayey materials. In Sri Lanka, lower quality coarse–grained and sandy materials are available which give higher elastic modulus than fine–grained material (Salty and Clayed materials).

In order to control shrinkage cracks, Unconfined Compressive Strength (UCS) at seven days should be limited. According to the findings, it was revealed that the most practical thickness of the cement stabilized base is 200mm and the most practical UCS at seven days is 3-4MPa to achieve compaction and the decided life with economical pavement thickness.

When the strength is measured in terms of CBR (California Bearing Ratio) and UCS, different cement contents arise from these two measuring methods. Therefore this study was performed to identify correct strength measure. The correct strength measure is UCS only and no relationship was found between UCS and CBR.

For road pavements with stabilized base, critical tensile stress or strain is located at the bottom of the stabilized layer. To control the fatigue cracking for required number of axial load repetitions, this tensile stress should be limited.

Above mentioned limitations cannot be analyzed using the conventional pavement design based on Structural Number principle. Hence a Mechanistic–Empirical Method is used to analyze pavements with a stabilized base which is difficult to carryout in general practice.

Therefore, through this study, pavement design charts for pavements having 200mm thickness of a Cement Stabilized soil Base (CSB) were developed by a Mechanistic–Empirical Method for various sub grade and traffic classes. According to the developed pavement design chart, it was revealed that CSB can be used for roads with traffic less than $1.5x10^6$ standard axial load repetitions.

Key words: Cement Stabilized soil Base, Unconfined Compressive Strength (CUS), California Bearing Ratio (CBR), Mechanistic Empirical Method

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1.0 INTRODUCTION

1.1 General

Aggregate Base has been used for road construction work in Sri Lanka for many years. Rocks that are used to produce aggregate are not available throughout the island. For instance, it is difficult to find suitable rocks in Northern part of Sri Lanka. Furthermore, the available rocks are gradually decreasing due to the usage, ownership and ecological issues. Therefore, cement stabilized soil can be used as an economically viable alternative material for the road base. Soils that can be stabilized are Granular, Sandy, Salty and Clayey materials.

Engineering behavior of a Stabilized Base and a Granular Base under traffic loading is not same. Therefore, achieving required engineering properties of a Stabilized Base is very important than a Granular Base. This will be discussed in detail under literature review section.

1.2 Problem Statement

Road Development Authority (RDA), Sri Lanka, has proposed to rehabilitate gravel roads given in Table 1-1 with a Cement Stabilized soil Base (CSB) made from available soil which is of lower quality coarse-grained and sandy material. Figure 1-1 shows Navakkuli - Kerativu – Mannar road that had to be rehabilitated with CSB. Construction of CSB in B424 is illustrated in Figure 1-2. Only B60 and B424 roads displayed in Figure 1-3 were completed.

However, performance of these two roads were unsatisfactory due to several failures occurred during construction and road maintenance. The contractor had also encountered some technical problems during construction. Therefore it was decided that other roads to be rehabilitated using conventional Aggregate Base. All contractors have carried out soil investigations and designs for proposed roads given in Table1-1.

Table 1-1: Proposed Rehabilitation Road Projects with CSB

Road No.	Road Name
A32	Navakkuli - Kerativu - Mannar
A35	Paranthan - Kachchai - Mullaitivu
B379	Puttalam - Marichchikadai
B403	South Coast Road (Thallady - Arrippu - Marrichchkadai)
B60	Bogahawewa - Pulmoddai
B424	Trincomalee - Pulmoddai
B297	Mullaitivu-Kokilai-Pulmoddai

Figure 1-1: Proposed A32 Road Project with CSB

Figure 1-2: Construction of CSB in B424 road

Figure 1-3: B424 and B60 roads after rehabilitation

1.2.1 General observations

B60 and B424 roads were observed during field visits. Severe distresses as shown on Figure 1-4 and 1-5 were observed in the Pulmoddai end of B424 road. The surface of this road section (Pulmoddai end of B424 road) was of 50mm asphalt layer which was placed immediately following failure of Double Bituminous Surface Treatment (DBST). In addition, some distresses as shown on Figure 1-6 and Figure 1-7 were observed in other sections of B424 and B60 road.

Figure 1-4: Severe distresses in the Pulmoddai end of B424 road

Figure 1-5: Distresses in the Pulmoddai end of B424 road

Figure 1-6: Distresses in B424 road

Figure 1-7: Distresses in B60 road

1.2.2 Engineers' concern

Outcome of the discussions I had with engineers who worked in B60 and B424 projects about distresses is summarized below.

Contractor's Engineer view on B60 Project

According to the bill of quantities (BOQ) and mix design, cement content to be used for CSB are 5% and 2.8% respectively. However, it was used at 2.8% for B60 project, where no severe distresses were observed after construction.

According to Standard Specifications for Construction and Maintenance of Roads and Bridges published by RDA (SSCM, 1989), required strength is 80% CBR. This was achieved by adding 1% cement. Therefore contractor in the B424 project has used 1% cement for construction of Pulmoddai end. However, severe distresses were observed just after construction. Thereafter, 2.8% cement was used for construction of other sections.

Consultant's Engineer view on B60 and B424 Projects

Distresses of B60 and B424 roads occurred due to improper mixing of soil and cement. Mixing of cement and soil for Pulmoddai end of B424 road base was carried out by in situ mixing method while other sections and B60 road were carried out by a plant (a pug mill) mixing method. Therefore severe distresses were observed in Pulmoddai end of B424 road.

Summary of further discussions I had with engineers who did mix designs and trial sections for A32 and A35 projects is given below.

Contractor's Material Engineer view on A35 Project: section 0 to 30km

According to pavement design, required strength to be achieved is 3.0MPa. In order to get this strength, 3.5% cement content had to be used. One field trial was conducted for a section of road. During the trial the required compaction (98% of modified proctor density) was hardly achieved. In this trial, curing was carried out for a period of 3 days. Just after curing, severe deep cracks perpendicular to road direction were observed in an interval of 4 to 5m distance. Therefore the proposal to construct CSB pavement was changed to conventional aggregate base pavement. Material Engineer revealed that these cracks occurred due to high cement content, poor-graded soil and less period of curing.

Contractor's Material Engineer view on A35 Project: section 30 to 52km

Material engineer has conducted three trial sections with 3.0% cement content for graded soil and found no cracks. Here, the main issue was to obtain the required compaction.

1.3 Objectives

Based on all the above factors, the study was conducted to fulfill following objectives.

- Develop a relationships between cement content, CBR and UCS of CSB made with available soil (lower quality coarse-grained and sandy material)
- Strength of CSB is measured in terms of CBR and UCS. The present study will aim at identifying correct strength measure.
- This study will check the feasibility of reducing pavement thickness under optimum cement content which is required to achieve 3MPa.
- The study will also cover the analysis of number of standard axial (80kN) load repetitions for CSB pavements made with available soil. The analysis will lead to develop a pavement design chart for different traffic and sub grade classes. This chart can be used in general practice to determine required material layer thicknesses of a CSB pavement. In addition, the chart will help to specify maximum number of standard axial load repetitions that can be achieved from CSB pavements made with available soil.

2.0 LITERATURE REVIEW

2.1 General

Soil stabilization is the alteration of property of locally available soil to improve or change its engineering performance, such as strength, stiffness, fatigue, shear, compressibility, shrinkage, permeability and workability. Methods of soil stabilization are mechanical, cement, lime, bituminous, chemical and electrical.

2.2 Soil-Cement Stabilization

Soil can be stabilized by pulverizing natural soil or borrowed material, mix with cement and thoroughly compact the mixture. Cement is a binding material which forms a soft or low-strength concrete, when mixed with soil.

For stabilizing soils with cement, nearly all soil types can be used, from gravelly and sandy to fine-grained silts and clays. In road construction, stabilized soil can be used as sub base layer or/and base layer with or without surface depending upon type of soil and cement content.

2.3 Engineering Properties and Behaviour of Soil and Stabilized Soil Layer

<u>Soil layer</u>

Granular material and sub grade soil are nonlinear with an elastic modulus varying with the level of stresses. The elastic modulus to be used with the layered systems is the resilient modulus obtained from repeated unconfined or triaxial test. The resilient modulus of granular materials increasing with the increase in stress intensity; that of fine grained soil decreases with the increase in stress intensity (Yang H. Huang, 2004).

Most granular materials cannot take any tension. Unfortunately, when they are used as a base or sub base on a weaker sub grade, the horizontal stresses due to applied loads are most likely to be in tension. However, these materials can still take tensile if the tension is smaller than the pre-compression caused by geostatic or other in situ stresses. But it is not possible to that combine horizontal stress will become negative, because, when it is reduced to zero, the particles separate and no stress will exist.

The strength of road sub grades, soil bases and soil sub bases are commonly assessed in terms of California Bearing Ratio (CBR) and it depends on the type of soil, the degree of compaction, and the moisture content.

Stabilized soil layer

After stabilizing soil layer, it acts as a soft low-strength concrete having linear elastic properties (Yang H. Huang, 2004). Therefore behaviour of the stabilized soil layer is totally different from an unstabilized soil layer.

In road structures with stabilized base or sub base, the most critical tensile stress or strain is located at the bottom of the stabilized layer. Therefore the tensile stress at the bottom of cement-treated layers cause fatigue cracking. Elastic modulus and tensile strain at the bottom of cement-treated layers are considered for detail analysis of stabilized layers. The strength of stabilized base and sub base is commonly assessed in terms of Unconfined Compressive Strength (UCS). Relationship shown in Eq.2.1, Eq.2.2 and Eq.2.3 between elastic modulus and compressive strength varies with type of material to be stabilized. These relationships given in Arellano and Thompson (1998) will be used for pavement analysis.

For lean concrete and high quality coarse-grained material:

$$E = 57{,}500\ (CS)^{1/2} \quad \text{.............................Eq.2.1}$$

For lower quality coarse-grained and sandy material:

$$E = 1200\ CS \quad \text{.............................Eq.2.2}$$

For silty and clayey fine-grained material:

$$E = 440\ CS + 0.28\ (CS)^2 \quad \text{.........................Eq.2.3}$$

where:

E = the modulus of elasticity in psi

CS = compressive strength in psi.

2.4 Damage Analysis

Damage analysis is being performed for both fatigue cracking and permanent deformation (rutting). Fatigue analysis is based on horizontal tensile strain at the bottom of specified layers, usually the hot-mix asphalt (HMA) or cemented layers while rutting analysis is based on the vertical tensile strain at the top of specified layers, usually the sub grade or lowest layer.

<u>Fatigue analysis of cemented material layer</u>

The failure criterion for fatigue cracking is expressed as the allowable number of load repetition (N) to prevent fatigue cracking.

Allowable number of load repetition (N) for Cemented Material layer is given in AP T33-Technical Basis of Austroads Pavement Design Guide (2004) as below:

$$N = (K/\mu\epsilon)^{12}$$ Eq.2.4

and the parameter K depends on the stiffness of the material as follows:

Modulus of Cemented Material (MPa)	Value of K
2,000	440
3,500	350
5,000	310
10,000	260
15,000	240

<u>Rutting analysis of sub grade</u>

The failure criterion for permanent deformation (rutting) is expressed as:

$$N_d = f_4(\epsilon_c)^{-f_5}$$ Eq.2.5

Where N_d is the allowable number of load repetitions to limit permanent deformation, ε_c is the compressive strain on the top of sub grade, and f_4 and f_5 are constants determined from road tests or field performance. Values of f_4 and f_5 are suggested as 1.365×10^{-9} and 4.477 respectively by the Asphalt Institute (AI, 1982).

2.5 Mechanistic-Empirical Pavement Design

A mechanistic approach seeks to explain phenomena by reference to physical causes. In pavement design, the phenomena are the stresses, strains and deflections within a pavement structure and the physical causes are the loads and material properties of the pavement structure. The relationship between these phenomena and their physical causes is described using a mathematical model. A layered elastic model is commonly used for pavement analysis (Yang H. Huang, 2004).

The relationship between physical phenomena and pavement failure is described by empirically derived equations as given in section 2.4 that compute the allowable number of loading repetitions to failure a pavement structure due to fatigue or rutting.

KENLAYER computer program provided with 2nd Edition, Pavement Analysis and Design, Yang H. Huang, 2004 can be used to calculate the compressive strain at the top of the sub grade and tensile strain at the bottom of the asphalt layer or stabilized layer under axle loading.

2.6 KENLAYER Computer Program for Flexible Pavement Modeling

The KENLAYER computer program is used to analyze flexible pavements. The KENLAYER give the solution for an elastic multilayer system under a circular loaded area. The solutions are superimposed for multiple wheels, applied iteratively for non-linear layers. As a result, KENLAYER can be applied to layer systems under different axle load arrangements with each layer behaving differently, linear elastic, and nonlinear elastic.

2.7 Traffic and Loading

The traffic and loading to be considered include axle loads, the number of load repetitions, tire-contact areas, and vehicle speeds.

<u>Axle Loads</u>

Single axle with single tire, single axle with dual tires, tandem axle with dual tires and tridem axles with dual tires are four different axle load arrangements. Every vehicle will consist one of four axle load arrangement.

Figure 2-1 demonstrates the wheel spacing for a typical semitrailer consisting of single axle with single tires, single axle with dual tires, and tandem axles with dual tires. For special heavy-duty haul trucks, tridem axles consist of a set of three axles, each spaced at 48 to 54in. (1.22 to 1.37m) apart.

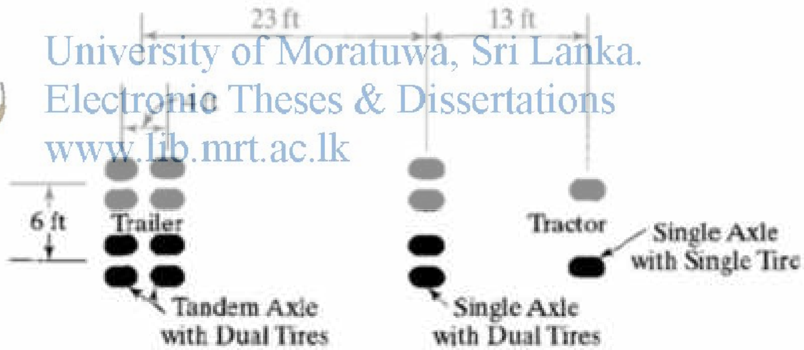

Figure 2 -1: Wheel configuration for a typical semitrailer unit (Huang, Y. H., 2004)

The spacing of 23 and 13ft (7m and 4m) given in Figure 2-1 should have no effect on pavement design because the wheels are so far apart that their effect on stresses and strains should be considered independently. The consideration of multiple axles is not a simple matter. The design may be unsafe if the tandem and tridem axles are treated as a group and considered as one repetition. The design is too conservative if each axle is treated independently and considered as one repetition.

In order to avoid above mentioned issues, the approach of an equivalent single-axle load (ESAL) is used to analyze the pavement. One ESAL is known to cause a quantifiable and standardized amount of damage to the pavement structure equivalent to one pass of a single 80kN, dual-tire axle with another axle load with its arrangement. When considering a vehicle, ESAL is taken as the summation of ESAL of each axle load arrangement of the vehicle.

When designing flexible pavements by layered theory, only the wheels on one side of axle load arrangement are considered. But designing of rigid pavements by plate theory, the wheels on both sides are usually contemplated.

Number of Repetitions

It is not a problem to consider the number of load repetitions for each axle load and evaluate its damage. Instead of analyzing the stresses and strains due to each axle-load arrangement, a simplified and widely accepted procedure is to develop equivalent factors and convert each load group into ESAL.

Contact Area

In the mechanistic method of design, it is necessary to know the contact area between tire and pavement, so the axle load can assume to be uniformly distributed over the contact area.

The contact area shown in Figure 2-2a was used previously by Portland Cement Association (PCA, 1966) for the design of rigid pavements. The current PCA (1984) method is based on the finite element procedure, and a rectangular area is assumed with length of 9.03in (229mm), and a width of 6.22in (158mm) as shown in Figure 2-2b. These contact areas are not asymmetric and cannot be used with the layered theory.

When the layered theory is used for flexible pavement design, it is assumed that each tire has a circular contact area as shown in Figure 2-2c. This assumption was also made by the Asphalt Institute (AI, 1981a) and a tire pressure of 70psi (483kPa) and a contact radius of 4.52in. (115mm) were used for flexible pavement design. These values were used for pavement modeling in this study.

The above-mentioned assumption is not accurate, but the error will be small. To simplify the analysis of flexible pavements, a single circle as shown in Figure 2-2d with the same contact area is used to represent a set of dual tires, instead of using two circular areas. This practice usually results in a more conservative design, but could become un-conservative for thin asphalt surface because the horizontal tensile strain at the bottom of asphalt layer under the larger contact radius of single wheel is smaller than that under the smaller contact radius of dual wheels.

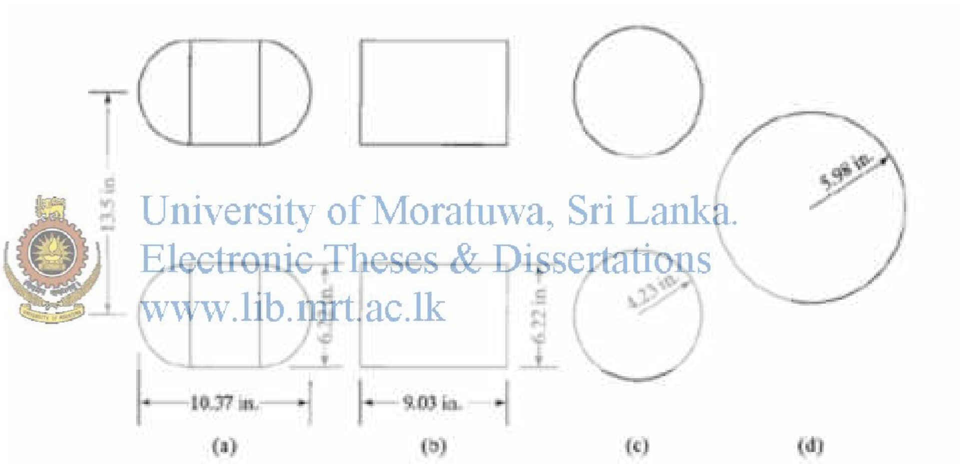

Figure 2-2 (a-d): Configuration of tire contact area (Huang, Y. H., 2004)

2.8 Construction Requirements

Following construction requirements are given in Standard Specifications for Construction and Maintenance of Roads and Bridges published by Institute for Construction Training and Development (ICTAD) (SSCM, 2009). It was revealed that these construction requirements were based on Overseas Road 31 (1993): A Guide to the Structural Design of Bitumen-surfaced Roads in Tropical and Sub-Tropical Countries.

General

Stabilized soil sub bases and bases shall be constructed by the mix-in-place method. The plant used for the mix-in-place construction is capable of pulverizing the soil to the full thickness of the layer being processed and of achieving uniformity of the stabilized material on completion of the mixing. Trial runs with the equipment will be carried out to establish its suitability for work.

The material to be stabilized could either be material brought to site or the *in-situ* material or a blend of both materials.

When compacted, the thickness of any layer to be stabilized will not be less than 100mm and the maximum compacted thickness shall be 200mm.

Weather limitations

Soil stabilization is not conducted when the air temperature under shade is less than 10^0C.

Quantity of stabilizer in the mix

The quantity of cement to be added to the soil is based on laboratory tests depending on the strength requirements of the stabilized mixes and shall not exceed 8% respectively.

Strength requirements of stabilized soil

The strength of cement-stabilized soil is measured in terms of Unconfined Compression Strength (UCS) using 150mm cubes. According to Road Note 31 (1993), stabilized material should be compacted to 97% maximum dry density as determined by BS 1377, test 13 (heavy compaction) or AASHTO T-180 (modified). The UCS value and the maximum dry density are determined by the UCS test and the modified compaction test respectively. The samples shall be tested for the UCS value after 7 days of moisture curing and 7 days soaking in water as Road Note 31 (1993) and BS 1924 (1990).

The required UCS value will be specified in the contract or by the engineer depending on whether the stabilized material is used as a sub base (CSB) or a road base. In case of stabilized sub bases, the UCS is between 0.75 – 1.50MPa and in case of stabilized road bases (CB1 and CB2), the UCS is between 1.5 – 3.0 (for CB1) and 3.0 – 6.0MPa (for CB2) as per Road Note 31 (1993).

Depth of scarifying and spreading

The depth of spreading of soil brought to site and the depth of scarifying the existing soil will depend on the machinery available for compaction, pulverization and mixing. When 8 – 10 ton smooth-wheeled rollers are used for compaction and agricultural implements such as rotarvators, disc ploughs and rotary tillers are used for pulverizing and mixing, the depth of loose soil spread or scarified shall not exceed 225mm. Careful control of the depth of spreading and/or scarifying shall be exercised at all times. The depth of spreading or scarifying may be increased using a heavier roller for the compaction.

Mixing of stabilizer and soil

The stabilizer is spread manually or by a suitable spreader uniformly over the entire surface of the pulverized soil. Stabilizer and soil will then be mixed using a rotary tiller, rotarvator or any other approved equipment until such time that the soil mixed with stabilizer is as nearly homogeneous as practicable. Depth of layer shall be carefully controlled so as to maintain a uniform percentage of stabilizers in the mix.

In case of cement-stabilization, soil and cement shall be dry-mixed prior to composing the soil cement to the optimum moisture content.

Compaction of stabilized soil mixture

The stabilized soil mix will be compacted at or near the optimum moisture content using an 8 – 10 ton smooth-wheeled roller or any other roller. The moisture content of the material is checked at the time of compaction.

In the case of cement-stabilized mixes, care shall be taken to complete the rolling within 2 hours on addition of water or such smaller period as found necessary in dry weather.

Degree of compaction of stabilized sub bases and bases

Stabilized soil sub bases are to be compacted to a density not less than 97% of the maximum dry density of the soil mix as determined by the BS 1377 test 13 (heavy) or AASHTO T-180 (modified) test.

Quality control

In order to prevent carbonation and subsequent failure of stabilized soil course/s, the stabilizer is mixed and compacted uniformly to the full depth of the course/s.

Curing and protection

The stabilized sub bases or base shall be cured by covering with sand for 30mm thickness which will be kept moist by sprinkling water at frequent intervals for a period of seven days. Alternatively, the stabilized sub bases or base shall be cured by the application of a thin coat of bitumen. This coat will be applied by lightly spraying water on the stabilized base or sub base followed by either MC 3000 or 10% cut back bitumen or CSS-1 at the rate of 0.51/m^2.

In the alternative method of curing, traffic is not allowed on this membrane for seven days. After this time, any excess bitumen shall be blotted by sanding the surface.

Soil for cement-stabilized sub base and base

The soil used for cement-stabilized sub base or base shall be either naturally-occurring or blended soils. It may not include highly plastic clays, silts or peats or any soil that is contaminated with top soil, vegetation, organic or other deleterious matter which inhibit chemical reaction with the stabilizer. The soil shall also confirm to requirements given in Table 2-1 and Table 2-2.

Table 2-1: Guide to the type of stabilization likely to be effective

Type of Stabilization	**Soil Properties**					
	More than 25% Passing the 0.075mm Sieve			**Less than 25% Passing the 0.075mm 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

Note: *Indicates that the agent will have marginal effectiveness,PP - Plasticity Product,PI - Percentage passing through 75µm sieve

Source: (Road Note 31, 1977)

The soil should have a stable grading with coefficient of uniformity D60/D10 (ratio of percent passing sieve sizes) not less than 5 and will be able to pulverize to an extent that the entire portion will pass through the 25mm sieve and not less than 60% will pass through a 4.75mm sieve.

Table 2-2: The desirable properties of material before stabilization

BS test sieve mm	BS test sieve µm	Percentage by mass of total passing test sieve CB1	CB2	CSB
53		100	100	-
37.5		85 - 100	80 - 100	-
20		60 - 90	55 - 90	-
5		30 - 65	25 - 65	-
2.36		22 - 53	17 - 53	-
	425	10 - 30	10 - 30	-
	75	5 - 15	5 - 15	-
Maximum allowable value				
LL		25	30	-
PI		6	10	20
LS		3	5	-

Note: CB1 - stabilized road base 1, CB2 - stabilized road base 2, CSB - Stabilized sub base

Source: (Road Note 31, 1977)

2.9 Control of Shrinkage and Reflection Cracks

There is no simple method of preventing shrinkage cracks occurring in stabilized layers. However, design and construction techniques can be adopted which may alleviate the problem to some extent.

Shrinkage, particularly in cement-stabilized materials, has been shown by Bofinger et al., (1978) to be influenced by,

- loss of water, particularly during the initial curing period
- cement content
- density of the compacted material
- method of compaction and
- pre-treatment moisture content of the material to be stabilized.

Proper curing is essential not only for maintaining the hydration action but also to reduce volume changes within the layer. When the initial period of moist curing is longer, the shrinkage due to subsequently drying of a stabilized layer is the smaller.

When a stabilized layer eventually dries, the increased strength associated with high cement content will cause the shrinkage cracks in closer intervals. With lower cement contents, the shrinkage cracks occur at reduced spacing and the material will crack more readily under traffic because of its reduced strength. The probability of these finer cracks reflecting through the surfacing is reduced, but the stabilized layer itself will be both weaker and less durable.

In order to maximize the strength and durability of the pavement layer, the material is generally compacted to the maximum density possible. However, for some stabilized materials, occasionally it is difficult to achieve normal compaction and any increase in compactive effort to achieve them may have the adverse effect of causing shear planes in the surface of the layer or increasing the subsequent shrinkage of the material as its density is increased. If it proves difficult to achieve the target density, higher stabilizer content should be considered in order that an adequately strong and durable layer can be produced at a lower density.

Laboratory tests have shown that samples compacted by impact loading shrink more considerably, than those compacted by static loading or by kneading compaction. Where reflection cracking is likely to be a problem, it is therefore recommended that the layer should be compacted with pneumatic-typed rollers rather than vibrating types.

Shrinkage problems in plastic gravels can be substantially reduced if air-dry gravel is used and the whole construction is completed within two hours, the water being added as late as possible during the mixing operation. It is generally not possible to use gravel in a completely air-dry condition, but lower the initial moisture content and the quicker it is mixed and compacted, smaller will be the subsequent shrinkage strains.

3.0 DATA COLLECTION AND TESTING

3.1 Properties of Available Soil Used For CSB

Test reports of borrow pit sample of natural soils which were selected to use for CSB of proposed rehabilitation road projects were collected. Properties of these natural soils are summarized in Table 3-1 and a natural soil sample is illustrated in Figure 3-1.

Table 3-1: Properties of natural soil

Project	Sieve Analysis Passing %									Proctor		Limit Test	
	50	37.5	25	20.0	5.0	1.18	0.425	0.300	0.075	MDD	OMC	PI	LL
B297	100	95		87	61	39	29	25	16	2.10	8.9	15	33
A35		100		92	49	41	27		13			15	39
B424			100		58				15	2.14	7.5	18	47

PI-Plastic Index, LL-Liquid Limit

Figure 3-1: Natural soil

3.2 Properties of CSB Made From Available Soil

A sample was collected from Kalmadukulam Borrow pit of A35 project. Modified Proctor test was carried out as per standard given in AASHTO T-180 to derive moisture – density relationship of the stabilized soil sample mixed with cement. A series of test was done to derive moisture – density relationships of stabilized soil having cement contents starting from 1.5% to 5.0% by 0.5%.

According to guide lines given in Road Note 31, stabilized soil should be compacted to 97% of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) to form a stabilized sub base (CSB). MDD (97%) and OMC of the stabilized soil were found out from the moisture–density relationship. CBR and UCS test specimens of stabilized soil were prepared so that 97% compaction is achieved and 7 days period of moisture curing and 7 days period of soaking in water was carried out for prepared specimens as per Road Note 31. After the curing, CBR and UCS tests were performed according to AASHTO T-193 and BS 1924 respectively for the specimens. Figure 3-2 shows testing of UCS and CBR specimens. Summarized test results are presented in Table 3.2.

Figure 3-2: Testing of UCS and CBR Samples

Table 3-2: UCS and CBR Test Results

Mixed Cement content (% by Dry weight of soil)	Unconfined Compressive Strength (MPa)	CBR % (97% compacted)
1.5	0.3	190
2.0	0.6	205
2.5	2.1	235
3.0	2.4	210
3.5	2.7	275
4.0	2.9	235
4.5	3.6	215
5.0	4.0	220

3. 3 Most Practical Thickness and UCS of CSB Made From Available Soil

According to the field trails performed for B297 and A35 projects, it was revealed that the most practical thickness of the cement stabilized base is 200mm to achieve 97% compaction.

Most practical maximum UCS at seven days was 4MPa to control shrinkage cracking and minimum UCS at seven days was selected as 3MPa for economical pavement thickness.

4.0 DATA ANALYSIS

4.1 Comparison of Properties of Available Soil with Specification Limits

SSCM 2009 specification was used for stabilized soil base. In SSCM 2009, CB2 are the finest material used for cement stabilized base. Comparison of properties of natural soils (i.e. selected for CSB) with specification limits of CB2 was carried out and is presented in Table 4.1. According to sieve analysis results, it was understood that finding soil having particles within specification limits is difficult. Figure 4-1 shows that particle size distributions of natural soils are much closer to finer limit (upper limit) and liquid limit (LL) is above the maximum limit of 30.

Material engineers of the studied projects pointed out that soil given in SSCM 2009 and Road Note 31 are not freely available. Even when it is available, it is not found in large quantities. Therefore the study was conducted to use freely available upper sub base material (i.e. given in SSCM 2009) as stabilized soil base. Specified properties of available soil are given in Table 4-2.

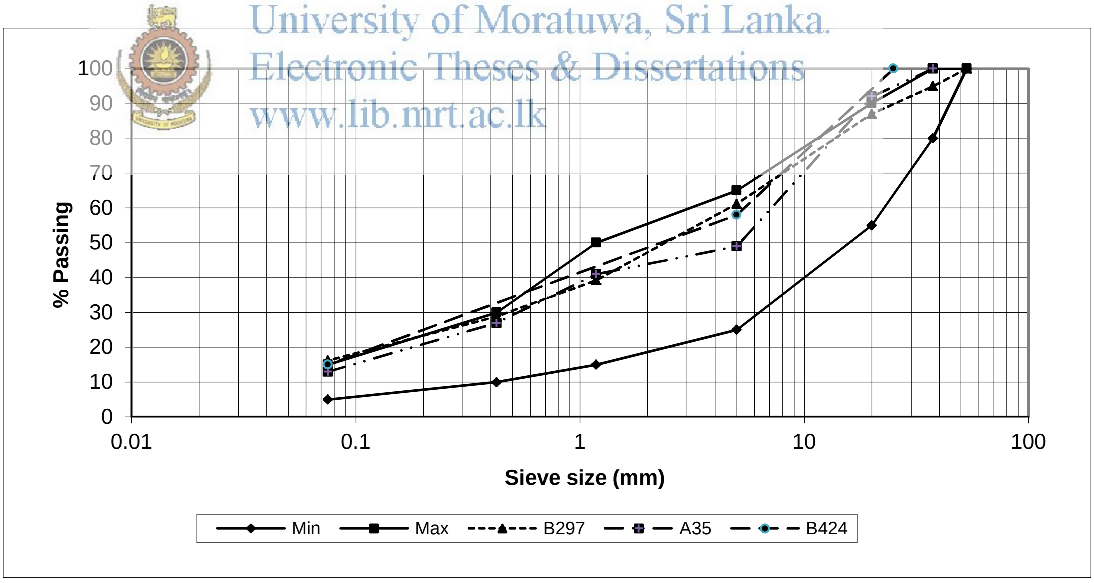

Figure 4-1: Particle Size Distribution of Natural Soils

Table 4-1: Properties of Natural Soils with Specification Limits

Project		Sieve Analysis passing %								Limit Test		D60	D10	D60/D10
		53	37.5	25	20.0	5.0	1.18	0.425	0.075	PI	LL			
B297		100	95		87	61	39	29	16	15	33	5	0.075	67
A35			100		92	49	41	27	13	15	39	7	0.075	93
B424				100		58			15	18	47	5	0.075	67
Specification Limits	Min	100	80		55	25	15	10	5	Max	Max			Min
CB2, SSCM-2009	Max	100	100		90	65	50	30	15	10	30			5

Table 4-2: Specified Properties of Soil before Stabilization

BS Test Sieve Size		Percentage by Mass of Total Passing Test Sieve
mm	**µm**	
53		100
37.5		80 - 100
20		60 - 100
5		30 - 100
1.18		17 - 75
	300	9 - 50
	75	5 - 25
Maximum allowable value		
LL		40
PI		15

4.2 Relationships of CBR and UCS with Cement Content

According to data analysis there is a very good relationship between cement content (CC) and Unconfined Crushing Strength (UCS) of CSB. Among the ten models fitted by SPSS software used for statistical analysis, only three models were not significant because the coefficient of determination (R^2) was less than 0.8. With the other seven models it can be recommended to fit the linear relationship since the model is the bearer of value of R^2=0.9402. Figure 4-2 expresses this linear relationship of UCS–CC.

Fitted model for the CC and the UCS is,

$$UCS = 1.0381(CC) - 1.0188. \quad \text{..........................Eq.4.1}$$

Furthermore, correlation of cement content and CBR is not significant and any of the considered models cannot be fitted. Scattered data shown in Figure 4-3 also confirmed that there is no relationship between CBR and cement content.

Considering the correlation between CBR and UCS, no significant model can be fitted with the ten models concerned. Therefore it can be concluded that no relationship exist between CBR and UCS which was also revealed by scattered data shown in Figure 4-4.

This analysis shows that UCS of CSB increase lineally with increasing Cement Content (CC). This increment is expected in the field. Despite the fact that some engineers and SSCM-1989 expect CBR of CSB to increase with cement content, this study reveals that no such relationship exist between CBR and cement content as well as CBR with USB. Therefore strength of CSB cannot be measured in terms of CBR and should be measured in terms of UCS.

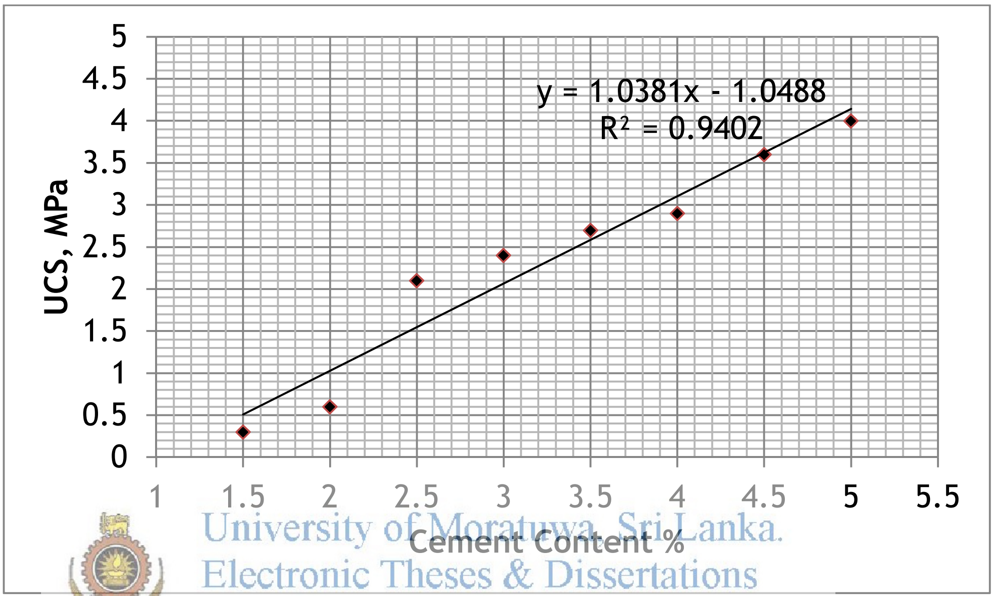

Figure 4-2: Cement Content vs. UCS

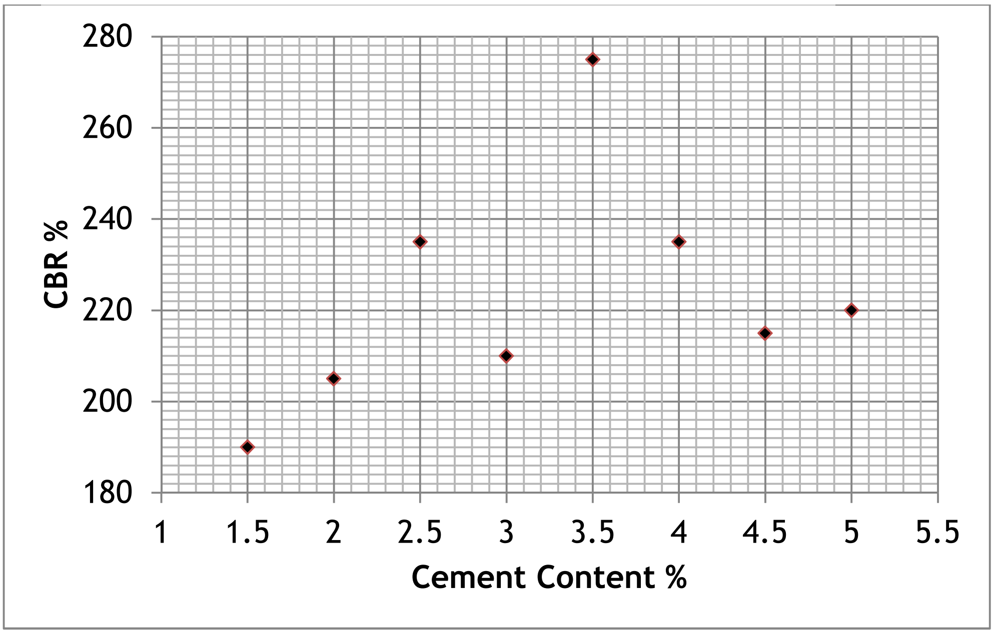

Figure 4-3: Cement Content vs. CBR

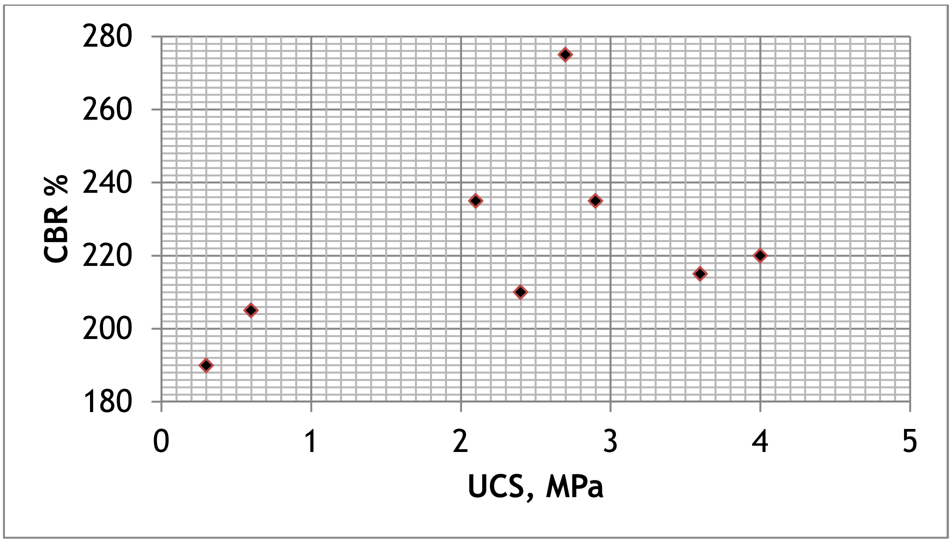

Figure 4-4: UCS vs. CBR

4.3 Traffic Demand for CSB Pavements Made with Available Soil

CSB pavements for stabilized base were modeled and analyzed by KENPAVE mechanistic pavement design software provided with the book, Pavement Analysis and Design (Yang H. Huang, 2nd Edition, 2004).

Modulus of Materials was estimated by formulas given in the literature review. Estimate modulus and other properties used for pavement modeling are summarized in Table 4-3.

Table 4-3: Properties of Materials Used for Pavement Modeling

Layers	**Governing Properties to Estimate Modulus**	**Estimate Modulus**	**Poisson's Ratios**	**Unit Weight (kN/m^3)**
Stabilized Base	UCS at 7 Days Cub – 3.0MPa	5.9E+06 kPa	0.25	21
Soil Sub Base	K1-31Mpa K2-0.53	Estimated by KENPAVE	0.38	19
Capping Layer	CBR = 15%	150MPa	0.40	19
Sub grade	CBR	10xCBR% MPa	0.45	18

80-kN single-axle standard load was applied on molded pavement and allowable number of repetitions for both fatigue cracking and permanent deformation (rutting) were calculated by formulas given in the literature review. This analysis was performed for 200mm and 175mm thicknesses of CSB and 8% CBR of sub grade and summarized in Table 4-4 and Table 4-5.

Table 4-4: Fatigue and Rutting Analysis of 200mm Thickness CSB

Sub Base Thickness	**Tensile Strain at Bottom of CSB**	**Load Repetitions for Fatigue**	**Compressive Strain at Top of Sub Grade**	**Load Repetitions for Rutting**
100	9.888E-05	6.084E+05	2.469E-04	1.931E+07
200	9.256E-05	1.344E+06	2.183E-04	3.351E+07
300	8.862E-05	2.265E+06	1.873E-04	6.652E+07

Table 4-5: Fatigue and Rutting Analysis of 175mm Thickness CSB

Sub Base Thickness	**Tensile Strain at Bottom of CSB**	**Load Repetitions for Fatigue**	**Compressive Strain at Top of Sub Grade**	**Load Repetitions for Rutting**
100	1.154E-04	9.528E+04	2.971E-04	8.432E+06
200	1.064E-04	2.524E+05	2.585E-04	1.572E+07
300	1.013E-04	4.551E+05	2.179E-04	3.379E+07

According to the analysis, it was found that when the CSB thickness is increased from 175mm to 200mm, allowable number of load repetitions for fatigue is increased by five times and allowable number of load repetitions for rutting increased twice. Therefore 200mm CSB is the best economical pavement design thickness for CSB pavement made from available soil. Since allowable number of load repetitions for rutting is always greater than that of fatigue, the fatigue cracking is critical than rutting in CSB pavement.

Considering 200mm as CSB thickness, above analysis was repeated for 100mm, 200mm and 300mm thicknesses of sub base, 200mm, 250mm and 300mm thicknesses of capping layer and 2%, 3%, 5%, 8% and 15% CBR of sub grade as shown in Table 4-6.

Based on the results, a Pavement Design Chart as shown in Figure 4-5 was developed for CSB pavement made with available soil. This can be used in general practice without doing any calculations. The chart shows that CSB is suitable for traffic less than $1.5x10^6$ standard axle repetitions.

Table 4-6: Fatigue and Rutting Analysis of CSB

Layer Thickness		Subgrade CBR	Tensile Strain at Bottom of CSB	Repetition for Fatigue	Compressive Strain at Top of Sub grade	Repetition for Rutting
Subbase	Capping Layer					
100	-	15	8.524E-05	3.612E+06	1.800E-04	7.948E+07
200	-	15	8.222E-05	5.568E+06	1.550E-04	1.552E+08
300	-	15	8.078E-05	6.883E+06	1.313E-04	3.263E+08
100	-	8	9.888E-05	6.084E+05	2.469E-04	1.931E+07
200	-	8	9.256E-05	1.344E+06	2.183E-04	3.351E+07
300	-	8	8.862E-05	2.265E+06	1.873E-04	6.652E+07
100	200	5	9.804E-05	6.739E+05	2.428E-04	2.081E+07
200	200	5	9.210E-05	1.427E+06	2.092E-04	4.055E+07
300	200	5	8.843E-05	2.324E+06	1.798E-04	7.988E+07
100	250	5	9.615E-05	8.513E+05	2.855E-04	1.008E+07
200	250	5	9.065E-05	1.726E+06	1.942E-04	5.658E+07
300	250	5	8.733E-05	2.701E+06	1.672E-04	1.106E+08
100	300	5	9.456E-05	1.040E+06	2.100E-04	3.986E+07
200	300	5	8.942E-05	2.033E+06	1.805E-04	7.850E+07
300	300	5	8.640E-05	3.071E+06	1.557E-04	1.521E+08
100	200	3	1.050E-04	2.959E+05	3.064E-04	7.345E+06
200	200	3	9.737E-05	7.317E+05	2.641E-04	1.428E+07
300	200	3	9.242E-05	1.369E+06	2.266E-04	2.836E+07
100	250	3	1.021E-04	4.141E+05	2.855E-04	1.008E+07
200	250	3	9.514E-05	9.663E+05	2.453E-04	1.988E+07
300	250	3	9.073E-05	1.708E+06	2.106E-04	3.936E+07
100	300	3	9.964E-05	5.549E+05	2.657E-04	1.390E+07
200	300	3	9.326E-05	1.228E+06	2.279E-04	2.764E+07
300	300	3	8.931E-05	2.064E+06	1.961E-04	5.416E+07
100	200	2	1.107E-04	1.569E+05	3.607E-04	3.538E+06
200	200	2	1.015E-04	4.445E+05	3.106E-04	6.911E+06
300	200	2	9.544E-05	9.304E+05	2.658E-04	1.388E+07
100	250	2	1.069E-04	2.386E+05	3.352E-04	4.913E+06
200	250	2	9.873E-05	6.195E+05	2.885E-04	9.617E+06
300	250	2	9.326E-05	1.228E+06	2.469E-04	1.931E+07
100	300	2	1.037E-04	3.436E+05	3.130E-04	6.677E+06
200	300	2	9.630E-05	8.355E+05	2.679E-04	1.340E+07
300	300	2	9.143E-05	1.557E+06	2.295E-04	2.679E+07

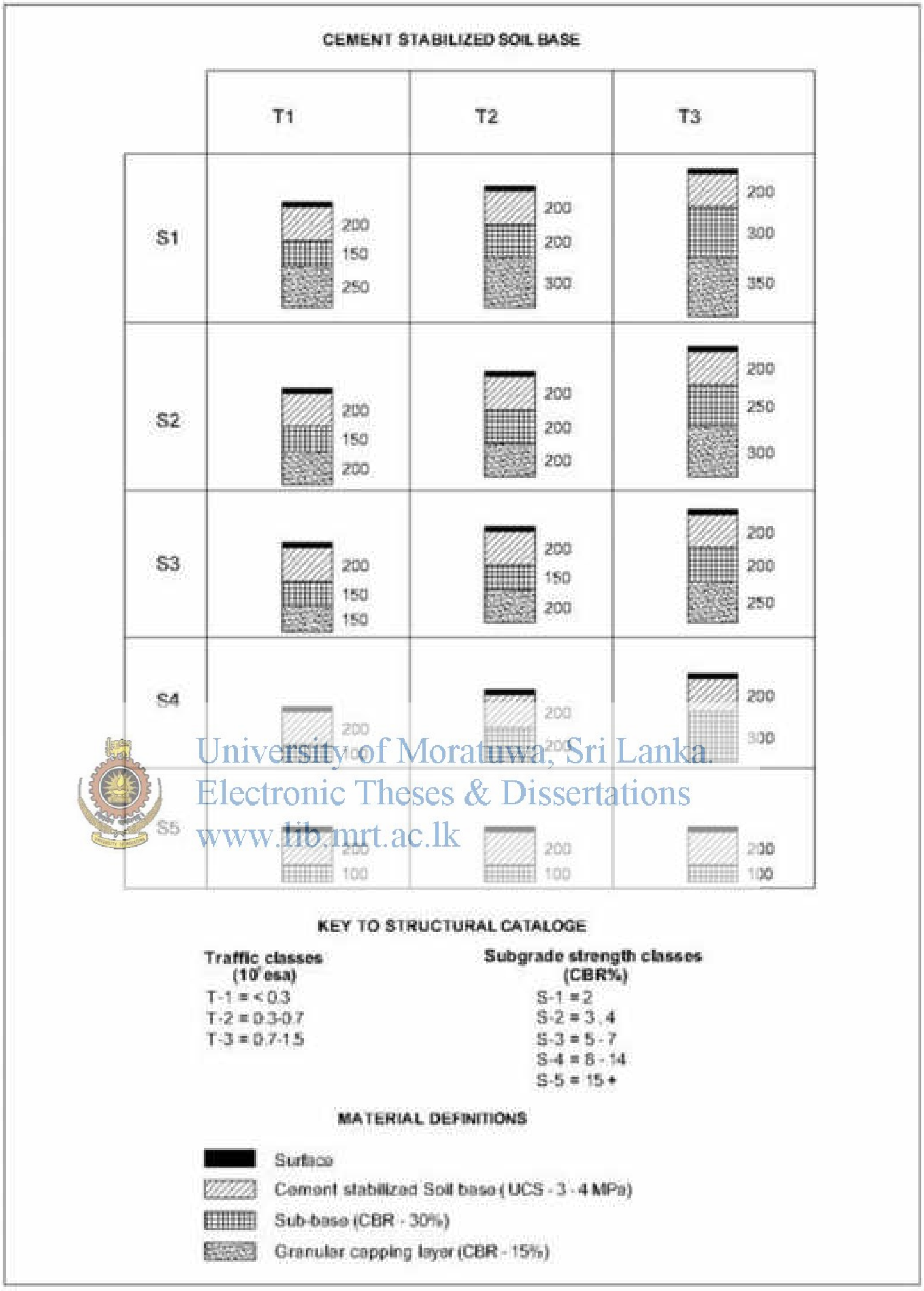

Figure 4-5: Developed chart for CSB Pavement

5.0 CONCLUSION

The present study shows that strength of CSB should be measured in terms of UCS and not in terms of CBR.

CBR is a penetration-based test that can measure strength of soil which does not take tension under loading. After stabilization of soil, the stabilized soil layer can take tension. Therefore strength of any stabilized layer should not be measured in terms of CBR.

The fatigue cracking is critical than rutting in CSB pavement. The required compaction of CSB layer having more than 200mm thickness is difficult to be achieved. When CSB thickness is increased from 175mm to 200mm, allowable number of load repetitions for fatigue is increased by five times. Therefore 200mm thickness is the most practical and economical pavement thickness for CSB pavement made from available soil (lower-quality, coarse-grained and sandy material). CSB pavement made from available soil is suitable for traffic less than 1.5×10^6 standard axle repetitions.

This study provides a guideline to select an appropriate CSB pavement made with available soil in Sri Lanka and properties of materials specified in this report are based on availability, laboratory tests, field trails and literature. After selecting CSB pavement field trails should be carried out to confirm performances during construction, curing and completion of curing.

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