EFFECT OF FINE PERCENTAGE ON PROPERTIES OF SUBBASE MATERIAL

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Master of Engineering in Highway and Traffic Engineering

Department of Civil Engineering

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Effect of Fine Percentage on Properties of Subbase Material

Abstract

With the huge infrastructure development in Sri Lanka, road construction plays a vital role. Massive quantities of construction materials are required for these highway and expressway constructions. Finding Subbase material as per specification is a major issue in most part of the country. Therefore, in some road construction projects, crushed stone is used as an alternative material to replace Subbase material. Due to the scarcity of good quality material, there is a need of research to use marginal materials for sustainable development in the highway industry.

Standard Specification for Construction and Maintenance of Roads and Bridges(SCA/5) (SSCM) (ICTAD,2009) is used as a road construction specification in Sri Lanka. Liquid limit(LL), plastic limit(PL), maximum dry density(MDD), California Bearing Ratio (CBR), and sieve analysis are specified in selection of gravel Subbase material. According to sieve analysis requirements in SSCM, percentage of passing 75µm sieve should be 5-25% by weight. This grading limit for Subbase material was adapted to the specification in second edition of SSCM in 2009.Questionnaire survey conducted among senior engineers has expressed that one of the least important parameters in material selections was grading (84% of the participants) and 16% of the engineers have expressed grading as the most difficult parameter to meet. This study was conducted to evaluate the possibility of relaxing the passing percentage of fine fraction.

Experimental study was conducted by altering the fine fraction of soils, varying from 0-40%. Properties of those samples were tested and it revealed a linear relationship with high correlation factor between fine fraction of the material and its properties (CBR, MDD, OMC). Only three samples out of ten samples were within the grading band requirement and nine samples out of ten samples satisfied CBR requirements. By scrutinizing the findings and available literature, it can be recommended that grading band of No.200 sieve passing can be relaxed up to 35% if soil sample satisfy the specified CBR requirement (30), PI value is less than or equal to 10, and swell percentage is less than 2%. Further, linear regression models were fitted to assess the CBR of material with reference to fine fraction(Percentage passing of 425µm, 300µm, 75µm sieves). Statistical analysis explained that material passing 425µm and retained on 300µm, and 75µm passing percentage are the significant parameters when predicting CBR of the selected soil in this study.

Key words: Subbase Material, Grading Band, Fine Fraction

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LIST OF ABBREVIATIONS

AASTHO	American Association of State Highway and Transportation Officials
CBR	California Bearing Ratio
CEA	Central Environmental Authority
EPL	Environmental Protection License
GI	Group Index
GSMB	Geological Survey and Mines Bureau
ICTAD	Institute for Construction Training and Development
IML	Industrial Mining License
LL	Liquid Limit
MDD	Maximum Dry Density
NP	Non-Plastic
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
RDA	Road Development Authority
SSCM	Standard Specification for Construction and Maintains of Highways and Bridges
TRL	Transport Research Laboratory
USCS	Unified Soil Classification System

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CHAPTER 1

INTRODUCTION

1.1. Introduction

In Sri Lanka, construction of roads rapidly increased during the last decade. New expressways were introduced to the country and improvement and rehabilitation work of main arterial roads started. Even rural roads improvement and rehabilitation work occurring throughout the country. Out of the total expenditure, government allocation for road sector from the budget has increased over 10%.

Massive quantity of soil is in need for road construction work for embankment construction, capping layer construction, Subbase construction, and shoulder construction. Even aggregate and soil can use for Subbase construction, soil is mostly used in Sri Lanka.

Subbase material should fulfill more and higher requirements than some other construction materials. Standard Specification for Construction and Maintenance of Roads and Bridges (SCA/5) (SSCM), published by Institute for Construction Training and Development (ICTAD) in June 2009 [1], is widely used for construction purposes in Sri Lanka.

Finding gravel pit for construction purposes is a big issue and must satisfy several environmental requirements.

Acts related to soil extraction are,

- Soil Conservation Act, No. 25 of 1951, Amended in 24 of 1996
- Geological Survey and Mines Bureau Act No. 33 of 1992

Permits related to soil extraction are,

- Industrial Mining License (IML) from Geological Survey and Mining Bureau (GSMB)
- Environmental Protection License (EPL) from Central Environmental Authority(CEA)

Further, finding quality soils that satisfy all SSCM requirements is an important concern. Tests performed to assess the quality of soil and selection:

- Liquid Limit Test (LL Test)
- Plastic Limit Test (PL Test)
- Maximum Dry Density (Modified)
- California Bearing Ratio Test (CBR)
- Sieve Analysis Test

Sieve analysis test finds particle size distribution of soil. When LL and PI are set up for a selected stockpile using fines, percentage of passing may vary for 300µm sieve from 9-50, and 75µm sieve from 5-25, by weight percentage. Properties of sub base can vary according to these fraction changes in fine particles. Therefore, forming a correlation between Subbase material properties and fine particles is vital.

1.2 Problem Statement

Finding Subbase materials that satisfy specification SSCM 2009 [1] requirement is difficult. The difficulty to satisfy required properties varies according to the area.

Even though LL, PI, MDD, CBR, and Sieve Analysis results should satisfy according to [1], only LL, PI, and CBR values in SSCM 2002[2] were considered for selecting Subbase materials and some projects in the country still carryout according to SSCM 2002.

Therefore, it is essential to find the importance of these material properties and find whether any relaxation is possible. Further, it is important to discover any possible relationships between these properties.

1.3 Objective

The objectives of this study are,

1. To find the effect of fine percentage on properties of Subbase material
2. To find the correlations between properties of Subbase material and fine particle fraction in a selected sample
3. To find the proper method of relaxation for the materials in marginal values of Grading Band (Fine fraction) to use as the Subbase materials for construction work.

CHAPTER 2

LITERATURE SURVEY

2.1 Selection of soil for road construction

The term soil is preferred to earth or dirt. It refers to naturally occurring, uncemented, unconsolidated, and/or loose material found above bedrock. Soils composed of particles formed by the physical disintegration of rock are usually called as granular (or mineral or inorganic) soils. Soils formed from the chemical decomposition of rock are usually clays, and soils formed from living material are known as organic. Most soils include particles of both rock and organic material. When considering soils for road making, it is necessary to adhere to the following key steps.

Soils should be:

a) Classified so that the characteristics and past performance of other similar soils can be considered
b) Tested for compactibility
c) Assessed for strength, stiffness, and swell potential
d) Tested for permeability

2.1.1 Soil classification - Method of formation

Soils can classify by their method of formation as:

a) Residual (or eluvial)- Formed in-place from the weathering of parent rock
b) Alluvial - Deposited from running water
c) Lacustrine - Deposited from lake water
d) Marine- Deposited from sea water
e) Glacial- Remains of glacial action
f) Aeolian- Deposited by the wind
g) Colluvial- Deposited by gravity (e.g. landslides)

h) Cumulose (or organic or histostol) - Formed from decaying vegetable or other organic or fibrous matter (or humus). Typical examples are peats, bogs, marshes, moors, and muskegs. They occur predominantly in thick layers in wet areas. They often emit an odour and retain large amounts of water, with moisture contents often exceeding 100%. Organic soils are usually unsuitable under load and are rarely used in road making, unless contained by geofabrics.

i) Leached- Deposited from natural salts in solution in ground water. Presence of such salts can cause problems for spray and chip seal surfaces. Sodium chloride (NaCl), sodium carbonate ($NaCO_3$) from limestone, sodium sulfate (Na_2SO_4), and gypsum ($CaSO_4$) are the most commonly encountered and may occur either in the soil itself or in groundwater (although gypsum is relatively insoluble). The problems associated with their use can be lowered by using an impermeable layer to prevent the migration of salts to the surface via the evaporation of groundwater at the surface.

j) Scalpic- Previous human activity has removed the original soil and left the bedrock exposed, possibly covered by recent landfills or refuse disposal.

2.1.2 Soil classification- Gradation

Major soil groups are defined by their grading variation as:

a) Uniform Soils composed of particles of the same size; they are often sands or heavy, expansive clays.

b) Gradational Soils containing a well-graded range of particle sizes makes them potentially useful for road making.

c) Duplex Soils are sharply contrasted with respect to the size, shape, and arrangement of the component particles. A typical duplex soil is sand over clay. Duplex soils often have the presence of salinity when a heavy clay is below a silty layer.

The common engineering subdivision of soils depends on grading and particle size. The soil ranges from boulders (or floaters) to the fine-grained clays. Actual soils are, usually mixtures of sizes. Sand-clays are one such obviously named mixture in which neither of the two components constitutes more than approximately two-thirds of the mixture. Road making loams are usually mixtures of fine sand and clay and are thus both friable and coherent. They are usually distinguished from sand-clays, which have a coarser sand fraction. The term loam does not imply the richness in humus associated with gardening terminology.

Gravel is a potentially confusing term. This text uses the civil engineering usage, which applies it only to naturally occurring rock particles. However, the soil literature uses it for all rock particles, which this text calls stones. Occasionally, gravel includes sand and/or clay particles.

2.2 Fine grained soil- Clays

The commonest and most demanding fine-grained soils are those with a high clay content and thus clays deserve special attention.

2.2.1 Formation

Clays are commonly formed from the by-products of rock-weathering (called secondary minerals), where further breakdown is prevented by the presence of cations and ionised water. Large varieties of geological depositional processes have then lead the creation of a clay layer. Other geological layers then frequently cover the layer, and a degree of pre-consolidation of the clay layer occurs. Pre-consolidation increases the inherent stiffness of the clay and is usually associated with a fissured and heterogeneous layer.

2.2.2 Clay components and particles

Clay components are usually chemically complex hydrated alumino-silicates. They differ markedly from the other soil components in that the resulting particles (grains, in the context of other soils) are very small, plate-like, and carry ionic electrical charges, which are negative over the plate surfaces and positive around its edges. Their surface chemistry means that the resulting materials are inherently unstable.

The particles attract soil cations and come together edge-to-side, as opposite charges attract through ionic bonding. An open, flocculent, loosely packed structure is produced. In many circumstances, these electrical charges produce inter-particle forces that are far more significant than any gravitational forces. This electrical surface-activity explains the role of clays in the Atterberg limits. The inter-particle attachment also leads to clays being plastic, sticky, smooth to touch, cohesive, strong when dry, weak when very wet, and sometimes prone to major volume changes. The plasticity arises because the edge-to-side clay structure can be forced into new, but still strong, inter-particle arrangements.

The total ion exchange capacity of a clay is an indicator of its reactivity. The capacity is occasionally measured by a methylene blue test in which, exchangeable cations on the clay surfaces are replaced by methylene blue cations. At times, the test acts as an indirect measure for the presence of clays.

If water is present, the water ions can preferentially attach to the plates and thus weaken the clay by preventing inter-particle linking. Thus, wet clays have a low resistance to deformation, are difficult to compact, and are almost impermeable. The low permeability means that the other changes may not directly coincide with climatic conditions. Similarly, laboratory measures of the swell potential of clays can be misleading if the impermeability of clay shields it from the effect of changes in moisture content. Some clays can accept large amounts of water.

Presence of external cations can alter many of the above properties by adhering to the charges on clay plates. In addition, the cations can leave the balance of the inter-particle forces repulsive, with the particle sides repelling each and the plates becoming parallel. The clay is then in a dispersed state. The presence of an electrolyte can counteract this repulsive effect and lead to flocculation.

2.2.3 Kaolinite

Kaolinite forms when sodium, potassium, calcium, magnesium, and iron are commonly present as feldspar and are leached away in an acidic environment, typical of many tropical areas. It has a relatively inactive surface and is composed of single sheets of gibbsite and sub-sheets of silica. Gibbsite is a sheet of hydroxyl ions surrounding aluminium (and occasionally iron or magnesium) atoms in an octahedral pattern. The silica sheets have a silicon atom at the centre of a tetrahedron of oxygen atoms with a hydroxyl layer balancing the oxygen layer formed by the tetrapod bases. Each sheet is about 300nm thick and the actual particle consists of many such layers. The sheets join together by strong hydrogen bonds so the structure is stable and non-expansive and water is unable to penetrate. Halloysite is similar to kaolinite except that a layer of water molecules separates each sub-sheet.

2.2.4 Illite and montmorillonite

Illite and montmorillonite develop in an alkaline, poorly drained environment where sodium, potassium, calcium, magnesium, and iron do not leach away but remain to be part of the crystal structure. The structure of illite and montmorillonite is a plate composed of a gibbsite sheet between two silica sheets. The plates can have thicknesses from 1 nm to 10 nm and lengths about 100 times their thickness. The silicon cations sometimes (more commonly in illite) exchange with aluminium of lesser valency. This exchange results in a net negative charge on the plate surface, which attracts cations such as Na+, Ca++, Mg++, and (in illite) K+ in the soil water and leaves the water highly ionised. Na+ causes the most swelling. The montmorillonite plates have no K+ to bond them together, being dependent on the lesser cation exchanges. They are thus bonded together weakly, and can be easily separated by ionised water.

2.2.5 Swelling and expansion

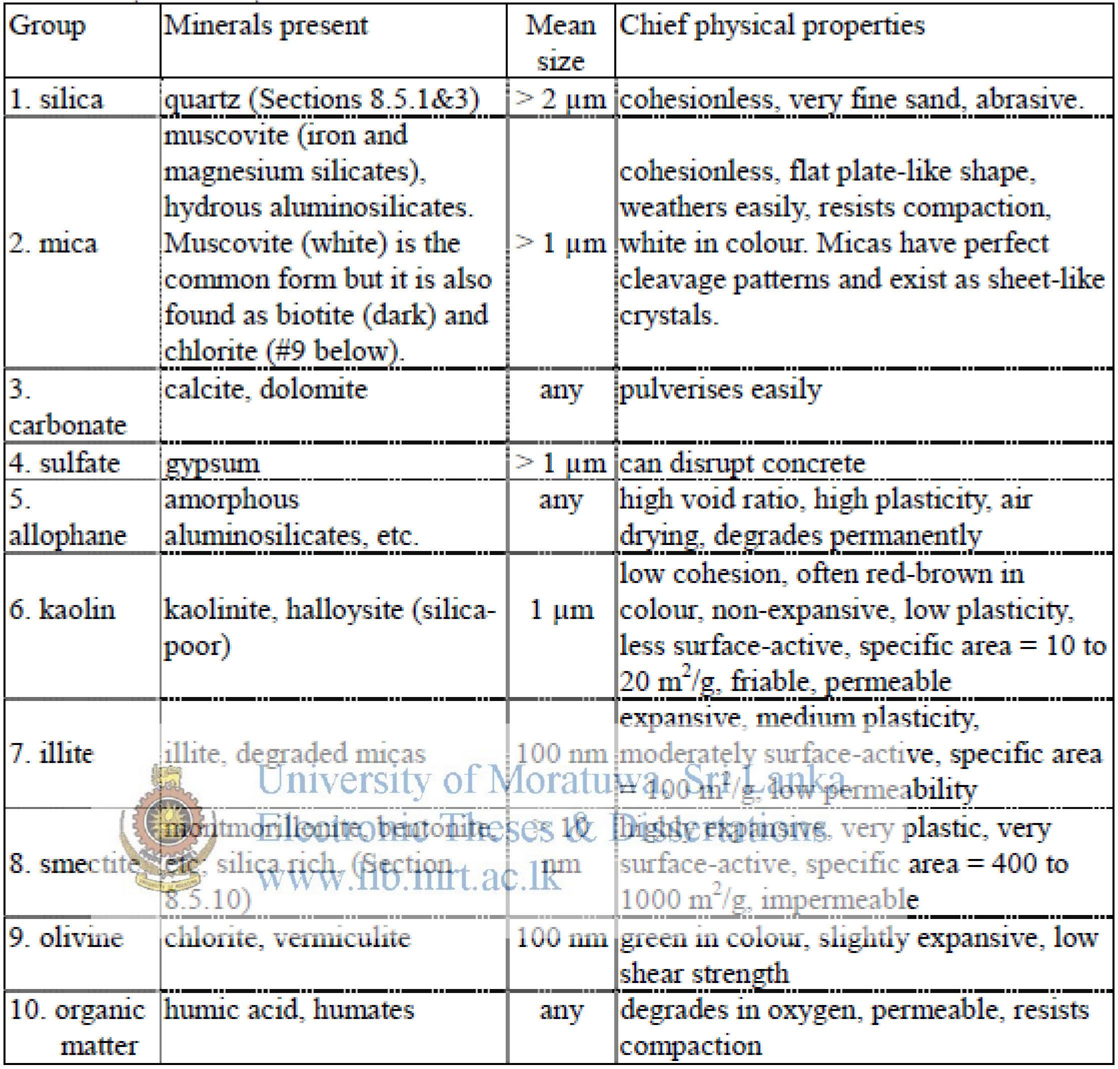
The attachment of ionised water discussed in sub sections 2.2.2 - 2.2.4 can result in the volume of absorbed water being many times the volume of the actual clay particle. This volume change can cause significant swelling (or expansion) of the piece of clay. When the water disappears, there is consequential shrinkage and cracking. Clays can also swell when water entry reduces high internal suction stresses.

Thus, clays containing illite and/or montmorillonite (sub-section 2.2.4) are called expansive (or active referring to their micro-surface activity cracking or swelling) clays. Illite does not swell as much as montmorillonite as it attracts K+ ions in a non-exchange mode that links the plates together. In practice, both illite and montmorillonite are prone to swell and shrink significantly with changes in moisture content.

Table 2.1 presents that in soil group kaolin, which contains clay mineral kaolinite and halloysite, is non-expansive, low in plasticity, less surface-active, and permeable. Nevertheless, soil group illite, which contains clay mineral illite and degraded micas, is expansive, medium in plasticity, moderately surface-active and low permeable. Further, soil group smectite, which has clay mineral montmorillonite and bentonite, is highly expansive, very plastic, very surface-active, and impermeable.

Swelling is typically measured by an odometer, or consolidation machine. A disc of soil is placed in a mold between two discs of porous stone. The sample is saturated via the porous stones and its expansion normal to the stones is measured. The swell potential is this expansion divided by the original distance between the two stone discs and usually quoted as a percentage. The swelling/contraction occurring in expansive clays will depend on the clay type and the amount of change in moisture content.

Table 2.1: Ten fine-grained soil components



Group	Minerals present	Mean size	Chief physical properties
1. silica	quartz (Sections 8.5.1&3)	> 2 µm	cohesionless, very fine sand, abrasive.
2. mica	muscovite (iron and magnesium silicates), hydrous aluminosilicates. Muscovite (white) is the common form but it is also found as biotite (dark) and chlorite (#9 below).	> 1 µm	cohesionless, flat plate-like shape, weathers easily, resists compaction, white in colour. Micas have perfect cleavage patterns and exist as sheet-like crystals.
3. carbonate	calcite, dolomite	any	pulverises easily
4. sulfate	gypsum	> 1 µm	can disrupt concrete
5. allophane	amorphous aluminosilicates, etc.	any	high void ratio, high plasticity, air drying, degrades permanently
6. kaolin	kaolinite, halloysite (silica-poor)	1 µm	low cohesion, often red-brown in colour, non-expansive, low plasticity, less surface-active, specific area = 10 to 20 m^2/g, friable, permeable
7. illite	illite, degraded micas	100 nm	expansive, medium plasticity, moderately surface-active, specific area = 100 m^2/g, low permeability
8. smectite	montmorillonite, bentonite, etc; silica rich. (Section 8.5.10)	< 10 nm	highly expansive, very plastic, very surface-active, specific area = 400 to 1000 m^2/g, impermeable
9. olivine	chlorite, vermiculite	100 nm	green in colour, slightly expansive, low shear strength
10. organic matter	humic acid, humates	any	degrades in oxygen, permeable, resists compaction

Note: specific area = surface area/mass.
Source: [3]

Materials that swell by more than 2 percent when saturated can cause problems within a pavement. Soils are called expansive if they swell by above 2.5 percent. However, the swelling of some clays can be of the order of 20 percent and can lead to fissures opening in the soil in dry weather. If resisted, the expansion can create large swelling pressures (e.g. 100kPa) which can disrupt road surfaces, tilt poles, and break utility pipes. Seasonal vertical movements (heaves) can be up to 65mm, with diminishing effects to a depth of 2 m [4].

Such volume changes can overcome by preventing changes in moisture content by using several techniques:

Material placement: Usually, material is best placed at OMC to minimize air voids by compacting expansive clays in critical areas at their equilibrium moisture content, rather than at OMC. In practice, systematic testing will usually show that there is a combination of density and moisture content that minimizes the swell potential of a clay in a particular environment.

Moisture control: The expansive material can be protected from moisture. A specific method is to cover the expansive material with an impermeable layer of non-swelling material. This capping layer should be at least 150 mm thick. Roots of roadside trees can be a particular problem by drying out a soil.

Material removal: If the above measures are unsuitable, or fail, it may be necessary to replace the expansive clays to depths of about 2 m with an alternative material having greater volume stability and to ensure that the remaining expansive material is protected from moisture change.

2.2.6 Clay classification

Clays can be classified by their:

a) Particle/component type (sub-sections 2.2.2, 2.2.3 & 2.2.4)

b) Expansion potential (sub-section 2.2.5)

c) Behaviour with hand moulding

According to this, clay can categorize as stiff (cannot be hand-moulded), firm (can be hand-moulded with difficulty) and soft (easily to hand-mould).

d) Clay content

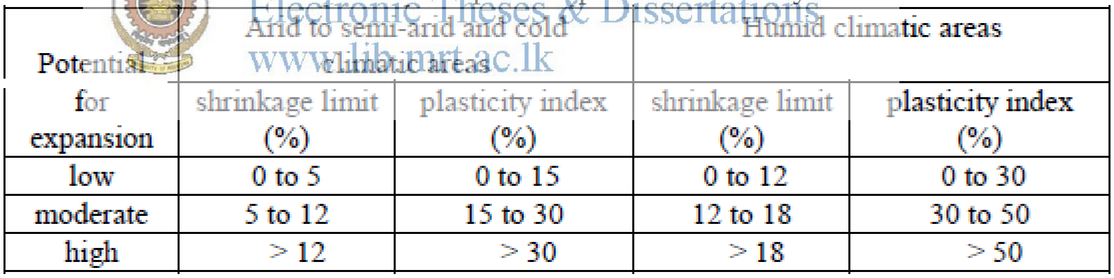
Refer to this clay can be classified as heavy or lean clay.

Heavy (or fat) clays: The term ‘heavy’ originally referred, not to density, but to the difficulty encountered when digging the clay. Heavy clays can readily rolled into thin strings and are highly compressible when moist. They are now considered as clays having plasticity indices over 20 percent and liquid limits over 50 percent. They are thus likely to be expansive clays. Heavy clays often make poor Subgrade material, but unfortunately, commonly occur in areas where useable natural rock for road making is scarce.

Lean clays: High plasticity indexes in any soil indicate the presence of clays. Presence of some clay in a material is desirable, as small amounts of clay will increase strength and wear resistance. Further, as the clay content of a soil increases, its surface activity increases, and hence more and more water can incorporate in to a material with poor cohesive strength without destroying its (low) shear strength. A clay content of over 20 percent means that clay properties will dominate.

The expansive potential of clay in various climatic conditions is presented in Table 2.2.

Table 2.2: Expansive potential of a clay



Potential for expansion	Arid to semi-arid and cold climatic areas		Humid climatic areas	
	shrinkage limit (%)	plasticity index (%)	shrinkage limit (%)	plasticity index (%)
low	0 to 5	0 to 15	0 to 12	0 to 30
moderate	5 to 12	15 to 30	12 to 18	30 to 50
high	> 12	> 30	> 18	> 50

Source: [5]

2.3 Soil Classification Systems

The most commonly used classification systems for highway purposes are American Association of State Highway and Transportation Officials (AASHTO) Classification System and Unified Soil Classification System (USCS).

2.3.1 AASHTO Soil Classification System

In AASHTO Classification System, soils are classified into seven groups, A-1 throughA-7, with several subgroups, as shown in Table 2.3. The classification of a given soil base on its particle size distribution, LL, and PI. Soils are evaluated within each group by using an empirical formula to determine the group index (GI) of the soils. GI is given as,

$$GI = (F- 35) [0.2 +0.005(LL - 40)] +0.01(F - 15) (PI -10) \text{ ------------------ Eq.2.1}$$

Where,

GI = group index

F= percent of soil particles passing 0.075 mm (No. 200) sieve in whole number based on material passing 75 mm (3 in.) sieve

LL = liquid limit expressed in whole number

PI = plasticity index expressed in whole number

The GI is determined to the nearest whole number. A value of zero should be recorded when a negative value is obtained for the GI. In addition, in determining the GI for A-2-6 and A-2-7 subgroups, the LL part of Eq.2.1 is not used. That is, only the second term of the equation is used. Generally, rating for a pavement Subgrade or Subbase is inversely proportional to the group index. A soil with a GI of zero (an indication of a good material) will be better as a Subbase or Subbase material, than one with a GI of 20 (an indication of a poor material) [6].

Under the AASHTO system, granular soils fall into classes A-1 to A-3. The A-1 soils consist of well-graded granular materials, A-2 soils contain significant amounts of silts and clays, and A-3 soils are clean but poorly graded sands.

Classifying soils under the AASHTO system will consist of determining the particle size distribution and Atterberg limits of the soil at first followed by reading Table 2.3

from left to right to locate the correct group. The correct group is the first one from the left that fits the particle size distribution and Atterberg limits and should be expressed in terms of group designation and the GI. Examples are A-2-6(4) and A-6(10).

Soils classified as A-1-a, A-1-b, A-2-4, A-2-5, and A-3 can satisfactorily use as Subgrade or Subbase material, if properly drained [6].

Table 2.3: AASHTO Classification of soils and soil aggregate mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5,* *A-7-6*
Sieve analysis											
Percent passing											
No. 10	−50 max.	—	—	—	—	—	—	—	—	—	
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit			—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

*Plasticity index of A-7-5 subgroup ≤ LL - 30; Plasticity index of A-7-6 subgroup >LL - 30.

Source: Adapted from [7]

2.3.2 USCS Soil Classification System

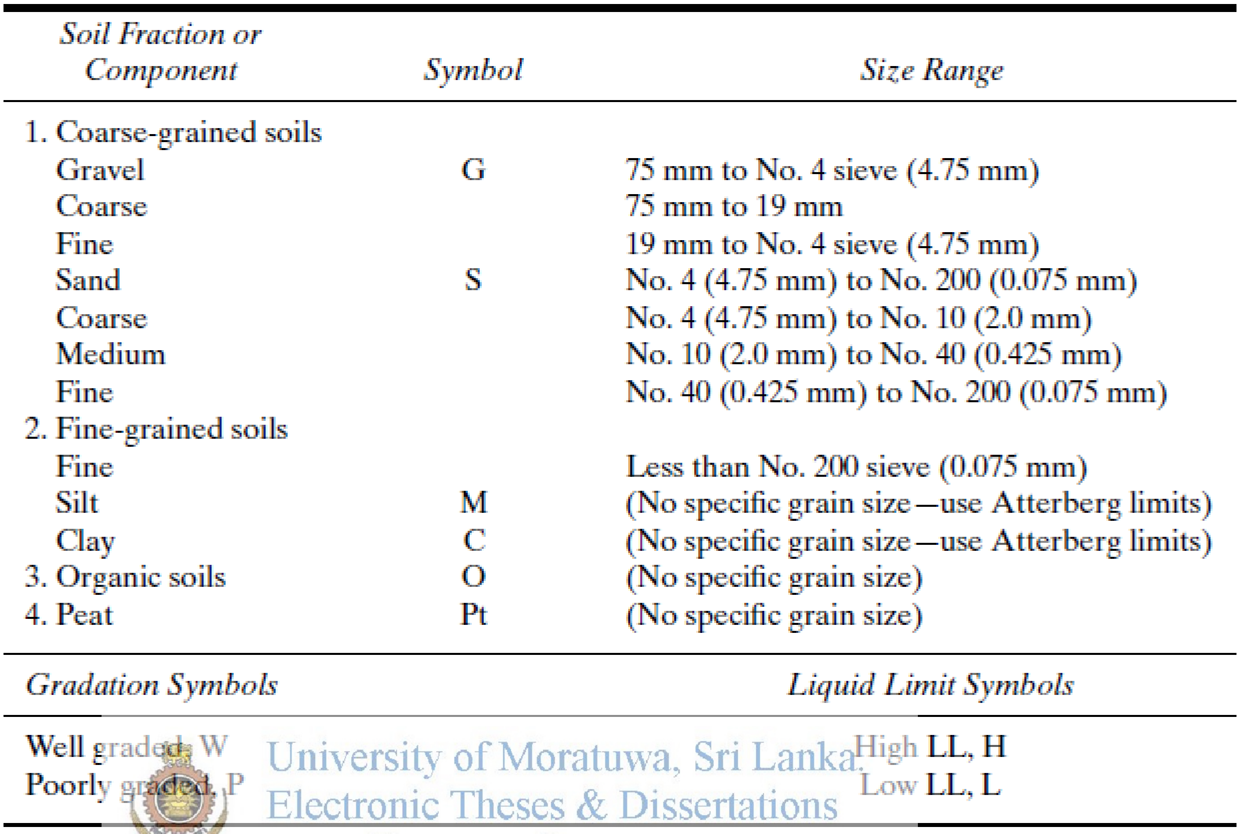
The fundamental premise used in the USCS system is that the engineering properties of any coarse-grained soil depend on its particle size distribution, whereas those for a fine-grained soil depend on its plasticity. Thus, the system classifies coarse-grained soils based on grain size characteristics and fine-grained soils according to plasticity characteristics.

Table 2.4 lists the USCS definitions for the four major groups of material, consisting of coarse-grained soils, fine-grained soils, organic soils, and peat. Material that is retained in the 75 mm (3 in.) sieve is recorded, but only that passes is used for sample classification. Soils with over 50 percent of their particles being retained in No. 200 sieve are coarse-grained, and those with less than 50 percent of their particles retained are fine-grained (Table 2.5).

Coarse-grained soils can subdivide into gravels (G) and sands (S). Soils containing over 50percent of their particles larger than 75 mm, that is, retained in No. 4 sieve, are gravels and those with more than 50 percent of their particles smaller than 75 mm, which passes through No. 4 sieve, are sands.

The gravels and sands are further divided into four subgroups, each based on grain-size distribution and the nature of fine particles in them. Thus, they can be classified as either well-graded (W), poorly graded (P), silty (M), or clayey (C). Gravels can be described as either well-graded gravel (GW), poorly graded gravel (GP), silty gravel (GM), or clayey gravels (GC), and sands can be described as well-graded sand (SW), poorly graded sand (SP), silty sand (SM), or clayey sand (SC).

Table 2.4: USCS Definition of Particle Sizes



Soil Fraction or Component	*Symbol*	*Size Range*
1. Coarse-grained soils		
Gravel	G	75 mm to No. 4 sieve (4.75 mm)
Coarse		75 mm to 19 mm
Fine		19 mm to No. 4 sieve (4.75 mm)
Sand	S	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse		No. 4 (4.75 mm) to No. 10 (2.0 mm)
Medium		No. 10 (2.0 mm) to No. 40 (0.425 mm)
Fine		No. 40 (0.425 mm) to No. 200 (0.075 mm)
2. Fine-grained soils		
Fine		Less than No. 200 sieve (0.075 mm)
Silt	M	(No specific grain size—use Atterberg limits)
Clay	C	(No specific grain size—use Atterberg limits)
3. Organic soils	O	(No specific grain size)
4. Peat	Pt	(No specific grain size)

Gradation Symbols	*Liquid Limit Symbols*
Well graded, W	High LL, H
Poorly graded, P	Low LL, L

Source: Adapted from [8]

A gravel or sandy soil is described as well-graded or poorly graded, depending on the values of two shape parameters known as the coefficient of uniformity, *Cu*, and the coefficient of curvature, *Cc*, given as,

$$D_u = \frac{D_{60}}{D_{10}} \qquad \text{---------------------------- Eq. 2.2}$$

and

$$C_c = \frac{(D_{30})^2}{D_{10} \text{x} D_{60}} \qquad \text{---------------------------- Eq. 2.3}$$

Where,

D_{60}= grain diameter at 60% passing

D_{30}= grain diameter at 30% passing

D_{10}= grain diameter at 10% passing

Gravels are described as well graded if *Cu* greater than 4 and *Cc* is between 1 and 3. Sands are described as well graded if *Cu* greater than 6 and *Cc* is between1 and 3.

The fine-grained soils, which are defined as those having more than 50 percent of their particles passing No. 200 sieve, are subdivided into clays (C) or silt (M),depending on soil PI and LL. A plasticity chart, presented in Table 2.5, helps to determine whether a soil is silty or clayey. The chart is a plot of PI versus LL, from which a dividing line known as the "A" line, was developed, which generally separates the more clayey materials from the silty materials. Soils with plots of LLs and PIs below the "A" line are silty soils, whereas those with plots above the "A" line are clayey soils. Organic clays are an exception to this general rule, since they plot below the "A" line. Organic clays, however, generally behave similarly to soils of lower plasticity.

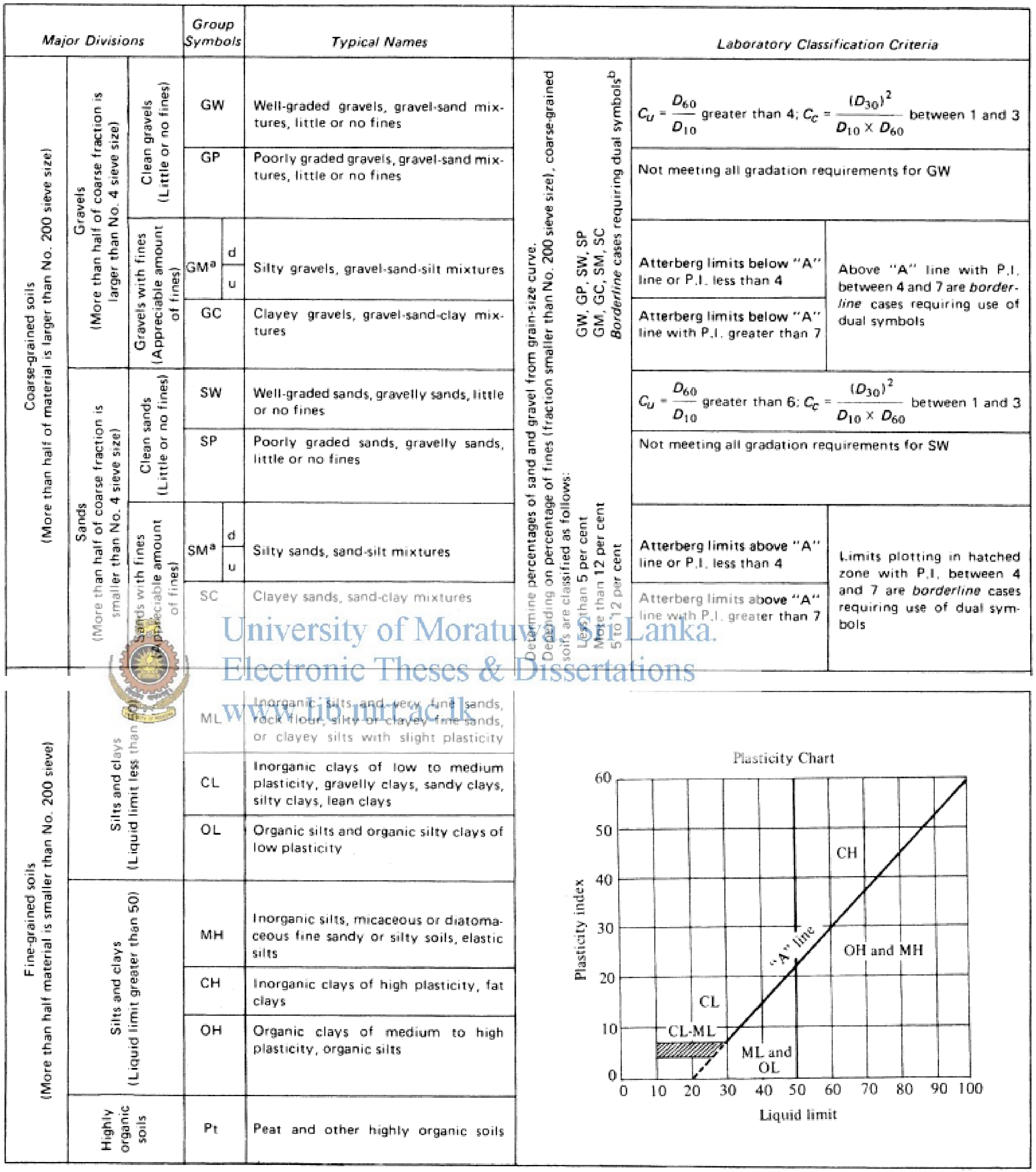
Classification of coarse-grained soils as silty or clayey also depends on their LL plots. Only coarse-grained soils with above 12 percent fines (i.e. passes No. 200 sieve) are so classified. Those soils with plots below the "A" line or with a PI less than four are silty gravel (CM) or silty sand (SM), and those with plots above the "A" line with a PI greater than seven are classified as clayey gravels (GC) or clayey sands (SC).

The organic, silty, and clayey soils are further divided into two groups, one having a relatively low LL (L) and the other having a relatively high LL (H). The dividing line between high LL soils and low LL soils is arbitrarily set at 50 percent.

Fine-grained soils can classify as either silt with low plasticity (ML), silt with high plasticity (MH), clays with high plasticity (CH), clays with low plasticity (CL), or organic silt with high plasticity (OH).

Table 2.5 presents the complete layout of USCS, and Table 2.6 shows an approximate correlation between the AASHTO system and USCS.

Table 2.5: Unified Soil Classification System



Major Divisions			Group Symbols		Typical Names	Laboratory Classification Criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent GW, GP, SW, SP More than 12 per cent GM, GC, SM, SC 5 to 12 per cent *Borderline* cases requiring dual symbols^b	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM^a	d u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-clay mixtures		Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM^a	d u	Silty sands, sand-silt mixtures		Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Plasticity Chart		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

^{a}Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

^{b}Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Source: [8]

Table 2.6: Comparable Soil Groups in the AASHTO and USCS Systems

	Comparable Soil Groups in AASHTO System		
Soil Group in Unified System	*Most Probable*	*Possible*	*Possible but Improbable*
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4 A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4, A-6	A-4, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4, A-5	A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6 A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

Source: Adapted from [9]

2.4 Research Findings

Previous studies reports [10] on the effect of clay content and air drying period on CBR for Sand-Kaolin clay mixture. This research discovered the following results. Change in CBR with Kaoline clay content is illustrated in Figure 2.1.

Content of water have no significant effect on the CBR of 100% sand (0% kaolin clay content), since the CBR values remain around 15-20% at any water content. The increase of kaolin clay content up to 5% decrease in CBR under soaked and unsoaked conditions, but it cause a slight increase in CBR when the specimens were dried up for 1 or 2.5 days. The significant increase in CBR is shown by 10% kaolin clay content (90:10 mixture) when the specimen was dried up. The mixture of 90:10 exhibits the best proportion in term of CBR (even though according to compaction curves, the highest MDD was resulted from 80:20 mixtures). The CBR of 90:10 mixture increases from 18.6% in soaked condition to 28.3% in unsoaked condition. Again, the CBR increases to 41.3% and 48.5%, when the sample was dried up for 1 and 2.5 days respectively. Beyond 10% kaolin clay content, the CBR decreases even though the samples were air-dried.

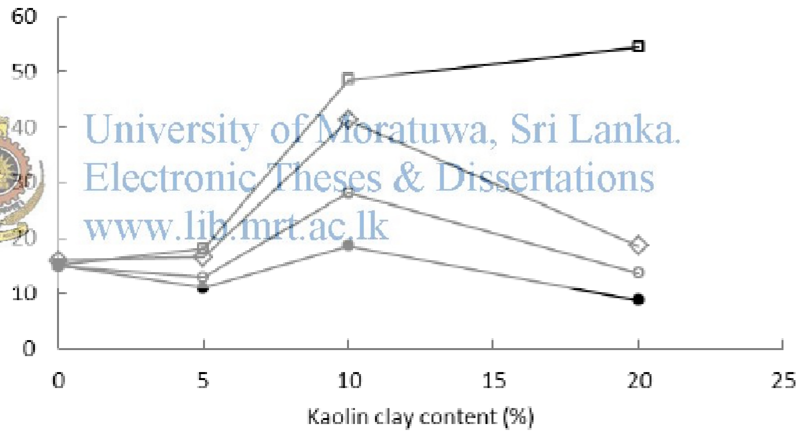


Figure 2.1: The effect of kaolin clay content on CBR

Earlier workers [11] studied the change of CBR with the fine content of Lateritic soil under the two conditions; soaked and unsoaked. They have developed the correlations for the samples, which were obtained from different borrow pits. The results indicate that both Unsoaked CBR (CBRu) and Soaked CBR (CBRs) decrease with the increase of fines content of all the samples as shown in Figure 2.2.

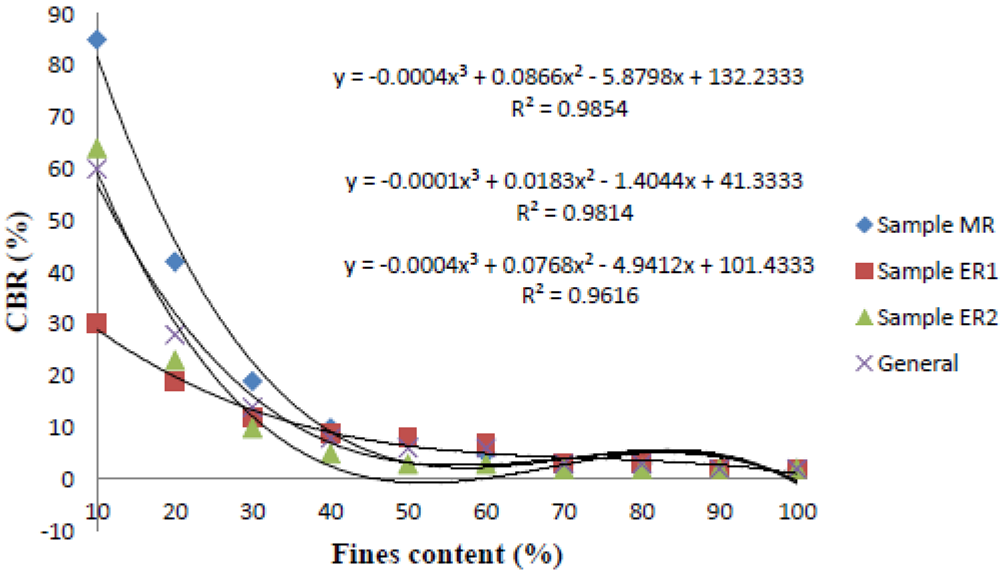


Figure 2.2: Relationship between the CBR and the fines content

A case study [12] investigates the CBR change with the fine content of sub grade soils. CBR was determined using Dynamic Cone Penetration index and a relationship was formed. The relationship is presented in Figure 2.3.

It is observed that with the increase of percentage fines, the CBR percentage increases. The reason may be the increase in affinity to water molecules with increase in fines. With the fines (percentage) increase from 21.81% to 52.41%, CBR increases from 2.62% to 4.15%.

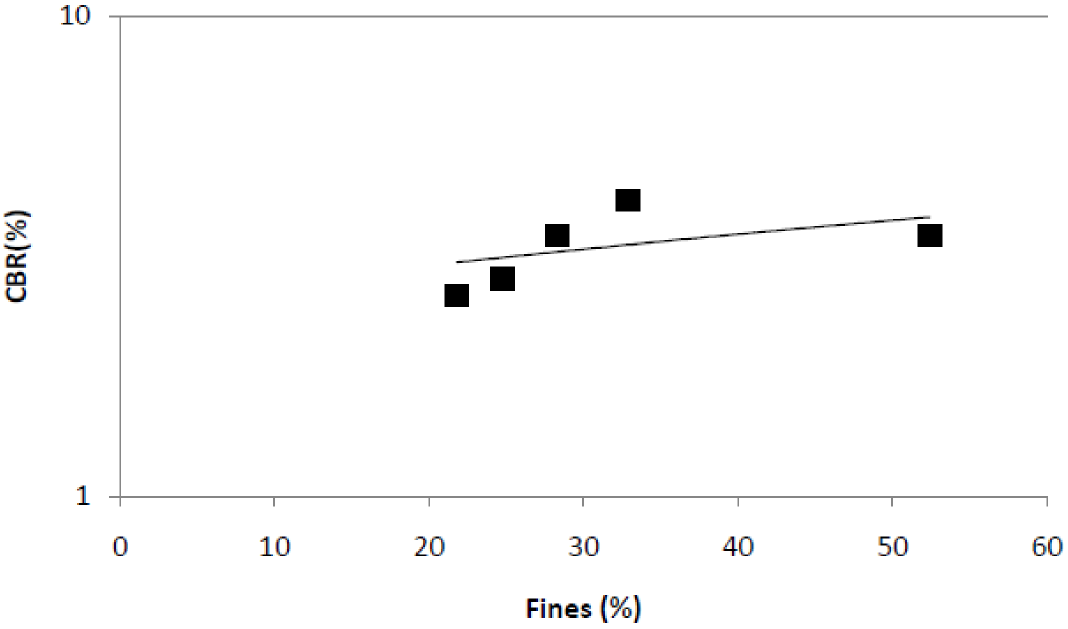


Figure 2.3: Variation of CBR with Fines (%)

A relationship between CBR and fine content of soil is being discovered [13], but, according to Figures 2.4 and 2.5, the R^2 values of the fitted models are not significant.

For the purpose of the study, a database including different materials used for pavement construction projects in the Delta region in Egypt was collected.

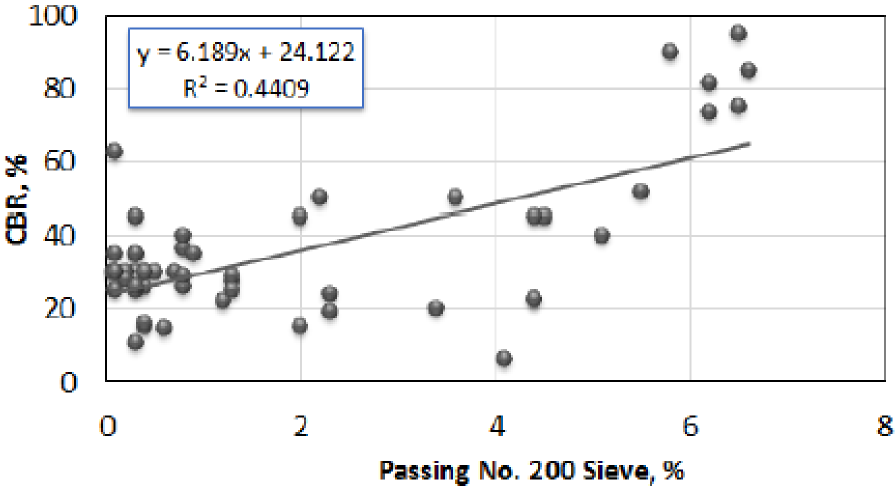


Figure 2.4: Relationship between CBR and percent passing No. 200 sieve

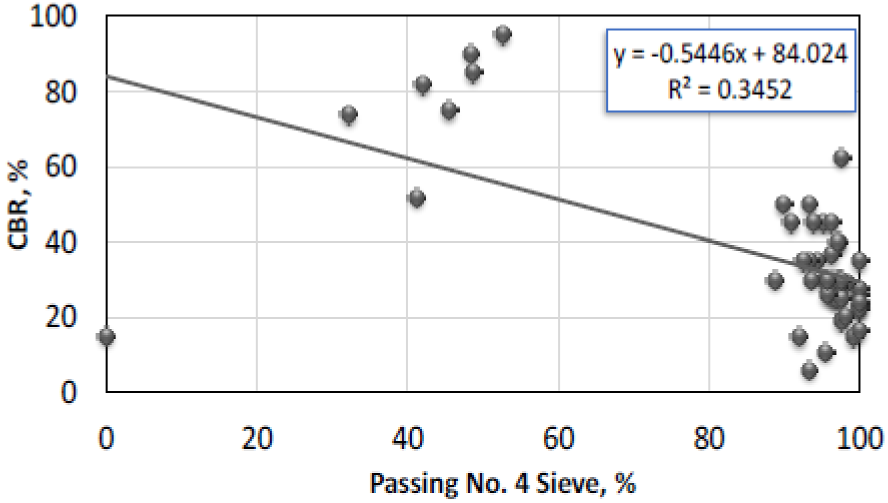


Figure 2.5: Relationship between CBR and percent passing No. 4 sieve

As illustrated in Figure 2.6, it has developed a model for the change of CBR with the Maximum Dry Density. For this model, correlation coefficient is 0.54.

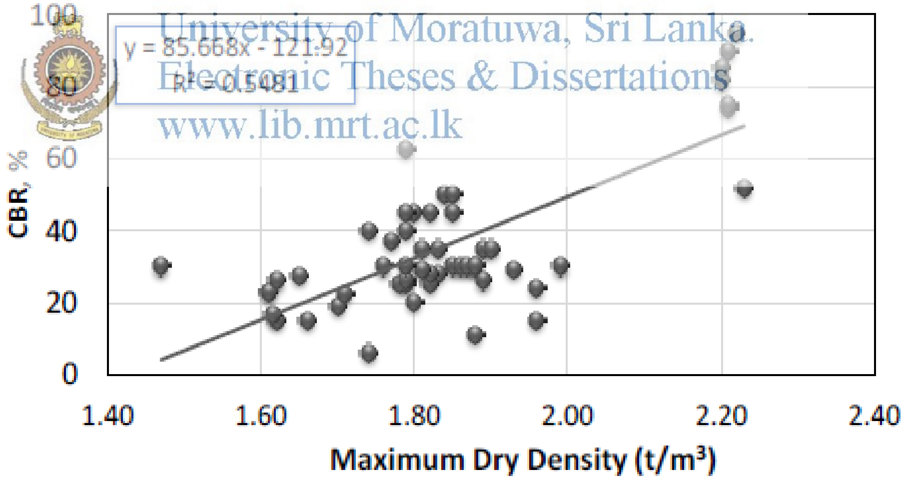


Figure 2.6: Relationship between CBR and maximum dry density

Equation 2.4 was developed to assess the CBR value using the change of fine fraction and MDD.

CBR= 0.025(P200)^4+30.130(MDD)-25.813------------------------ Eq.2.4

Where:

CBR=soaked California Bearing Ratio, %

P200 = passing No. 200 U.S. sieve, %

MDD = maximum dry density according to modified Proctor method, (t/m^3)

This model has an R^2 of 0.785, R^{2}adj of 0.776, and Se/Sy of 0.463.

The National Cooperative Highways Research Program (NCHRP) [14] through the "Guide for mechanical-empirical design of new and rehabilitated pavement structures," suggested some correlations for soil index properties and CBR. Equation 2.5 was developed for soils which contain over 12% fines and exhibit some plasticity, for soil groups such as GM, GC, SM, SC, ML, MH, CL, and CH in Unified Soil Classification System.

The suggested equation is:

$$CBR = \frac{75}{1 + 0.728 \times (\#200) \times (PI)} \qquad \text{---------------------------- Eq. 2.5}$$

Where, #200 = Passing No. 200 US sieve (%)

PI = plasticity index

According to [15], a correlation was developed between MDD and CBR as well as Plasticity Index and CBR for fine-grained soil.

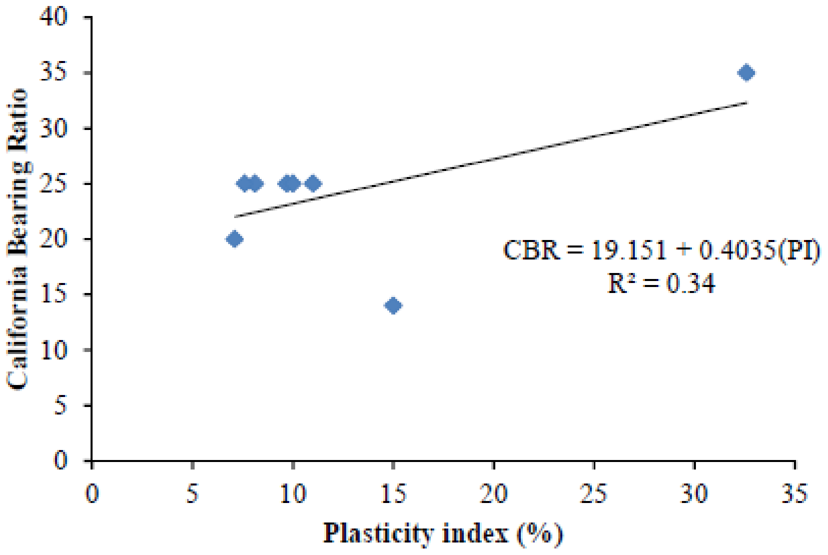


Figure 2.7: Plasticity index vs. CBR for the experimental soil samples at OMC

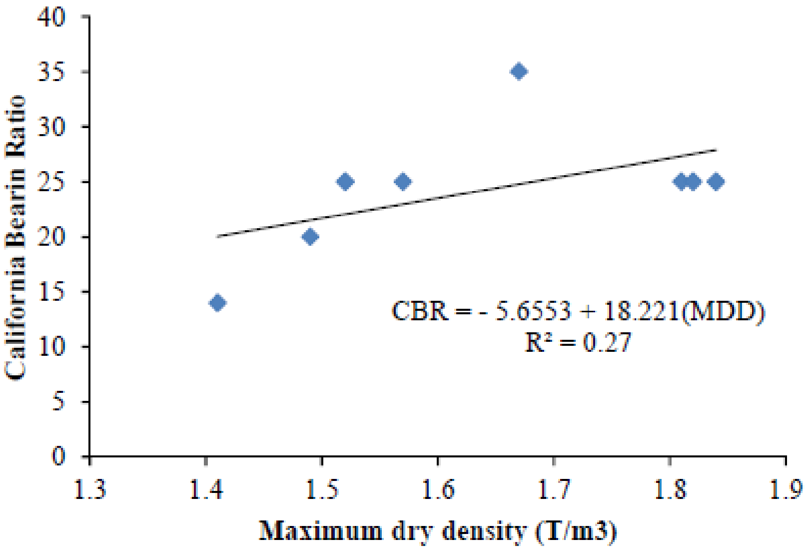
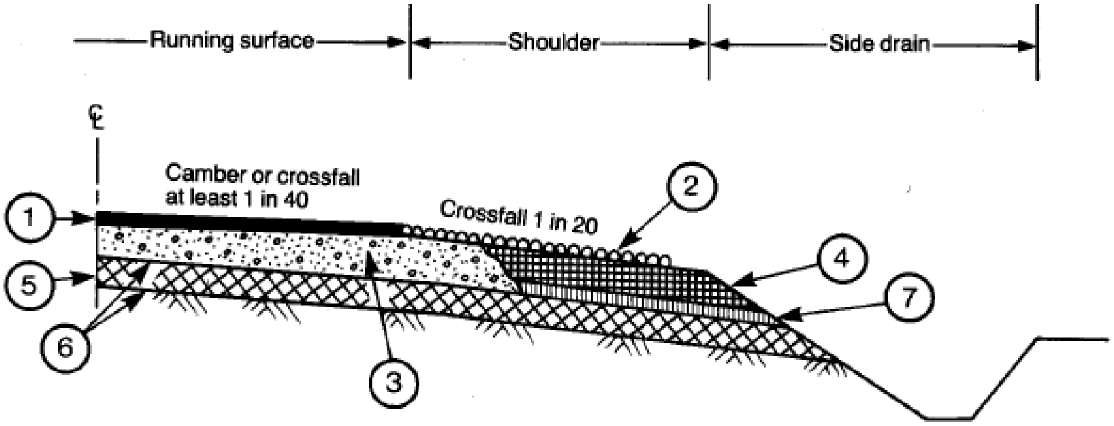


Figure 2.8: Maximum dry density vs. CBR for all experimental soil samples at OMC

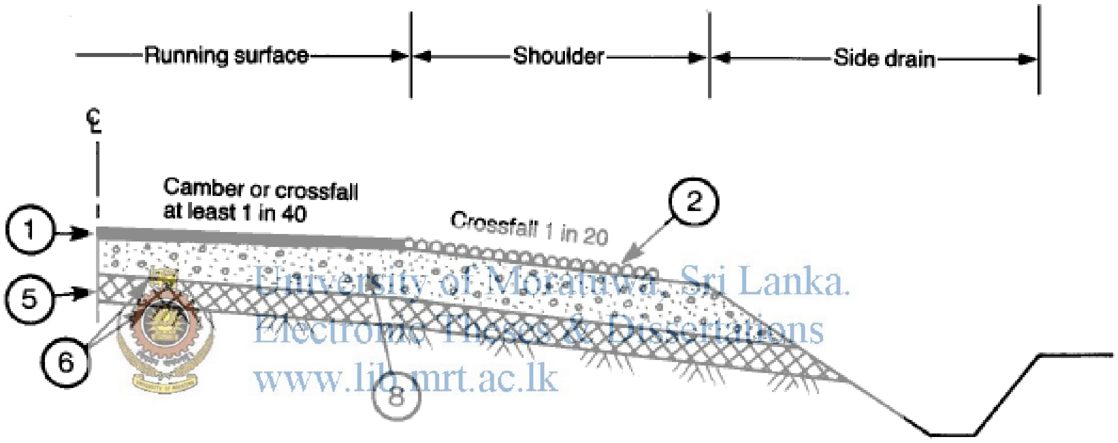
Figures 2.7 and 2.8 displays the developed correlations for both cases where correlation coefficients are not significant.

Overseas Road Note 31 published by the Transport Research Laboratory (TRL) [16] recommends some requirements for pavement construction materials. Especially it discusses the permeability of the material. Accordingly, “Dense bitumen-bound materials, stabilised soils with only very fine cracks, and crushed stone or gravel with more than 15 percent of material finer than the 75 micron sieve are themselves impermeable (permeability less than 10^{-7} metres per second), and therefore Subgrades under road pavements incorporating these materials are unlikely to be influenced by water infiltrating directly from above.”

It has mentioned that, “In circumstances where the Subgrade itself is permeable and can drain freely, it is preferable that vertical drainage is not impeded.” If this is possible by ensuring that each layer of the pavement is more permeable than the layer above, then the additional drainage layer through the shoulders (layer No. 7 in Fig.2.9) is not required. Cross sections proposed for drainage arrangement of roads in Road Note 31 is given in Figure 2.9.



(a) Separate shoulder material



(b) Extended roadbase and sub-base

Figure 2.9: Cross section of road showing drainage arrangements

1 Impervious surfacing

2 Shoulders surface dressed (giving contrasting texture to running surface)

3 Road base extending under shoulder for at least 500mm

4 Shoulder material capable of supporting occasional traffic

5 Impervious Subbase carried across full width of construction

6 Formation and Subbase constructed with crossfall of 1 in 30 (providing drainage path for any water that enters and also a thicker and stronger pavement on the outside wheel track)

7 Drainage layer of pervious material

8 Road base extending through shoulder

CHAPTER 3

SUBBASE CONSTRUCTION PRACTICES IN SRI LANKA

3.1 Introduction

Road construction work in Sri Lanka is normally commented in accordance with the Standard Specification of Construction and Maintenance of Roads and Bridges, published by the Institution for Construction Training and Development. Two editions are available and used for the constructions.

- First edition in year 2002 (Reprinting of SSCM issued under the authority of Road Development Authority in 1989)
- Second edition in year 2009

Comparisons of two specifications are given in section 3.2 and 3.3.

3.2 First Edition of SSCM 2002

First edition of the specification mentions that the Subbase material should meet following requirements:

- Materials used for soil Subbase shall be naturally occurring, or blended gravels and sands, or mixtures thereof, and shall not include highly plastic clays, silts, peat, or other organic soils, or any soil that is contaminated with top soil, vegetable, and other deleterious matter.
- The material used for the top 150 mm of Subbase shall conform to the requirements of Type I material and the material used for the lower layers of Subbase shall conform to the requirements of Type II material.
    1. <u>Type I Subbase Material</u>
        - The 4-day soaked CBR of the soil 100% maximum dry density under standard conditions of compaction shall not be less than 20%.
        - The PI and LL of the soil shall be less than 15% and 40% respectively. This condition may however be relaxed and at

the discretion of the Engineer when the portion of material finer than 75 µm is small.

2. Type II Subbase Material
    - The 4-day soaked CBR of the soil at 100% maximum dry density under standard conditions of compaction shall not be less than 8%.
    - The PI and LL of the soil shall be less than 15% and 40% respectively. This condition may however be relaxed at the discretion of the Engineer if the portion of material finer than 75 µm is small.

These specified values have been revised in certain projects to suite the project requirements by providing a special specification.

3.3 Second Edition of SSCM 2009

Modifications have been proposed for the second edition [1]. The main additional requirements specified are the grading requirement and Maximum Dry Density of the Subbase material. In accordance with second edition, following requirements are essential to satisfy the material used for Subbase construction.

Soils for Upper Subbase

- The materials used for the upper Subbase shall be naturally occurring or blended gravels, and sands or mixtures thereof, and shall not include highly plastic clays, peat, or other organic soils, or any soil that is contaminated with topsoil, vegetable, and other deleterious matter.
- The completed upper Subbase shall contain no aggregate having a maximum dimension exceeding two thirds of the compacted layer thickness.
- The 4-day soaked CBR of the soil 98% maximum dry density under modified conditions of compaction shall not be less than 30%.

- Maximum Dry Density under modified conditions of compaction shall not be less than 1.750 kg/m^3.
- The PI and LL of the soil shall be less than 15% and 40% respectively.
- Grading requirement shall conform to Table 3.2.

Soils Lower Subbase

- Materials used for the lower Subbase shall be naturally occurring or blended gravels, and sands or mixtures thereof, and shall not include highly plastic clays, peat, or other organic soils or any soil that is contaminated with topsoil, vegetable, and other deleterious matter.
- The 4-day soaked CBR of the soil 95% maximum dry density under modified conditions of compaction shall not be less than 15%.
- Maximum Dry Density under modified conditions of compaction shall not be less than 1.650 kg/m^3.
- The PI and LL of the soil shall be less than 15% and 40% respectively.

For lower Subbase, grading requirement has not specified.

3.4 Quality Tests for Subbase

3.4.1 Introduction

Soils that are used as Subbase materials are excavated from borrow pits. To use them as Subbases, these soil materials should satisfy requirements in Table 3.1.

Table 3.1: Requirements of Upper Subbase-Flexible pavement

Property	**Test Method (AASHTO)**	**Upper Sub Base**
Liquid Limit(LL)	T-89	Not to exceed 40%
Plasticity Index (PI)	T-90	Not to exceed 15%
Maximum Dry Density (Modified)	T-180	Not less than 1,750Kg/m3
4-day soaked CBR at 98% MDD (Modified)	T-193	Not less than 30%

Source: [1]

Table 3.2: Grading requirements for Upper Subbase

Sieve Size		Percentage by weight passing sieve
mm	**µm**	
50		100
37.5		80-100
20		60-100
5		30-100
1.18		17-75
	300	9-50
	75	5-25

Source: [1]

Following tests assist to find above requirements for Subbase materials.

1. Liquid Limit Test (LL Test)
2. Plastic Limit Test (PL Test)
3. Maximum Dry Density (Modified)
4. California Bearing Ratio Test (CBR)
5. Sieve Analysis Test

3.4.2 Atterberg Limits of a soil

The Swedish soil scientist Albert Atterberg originally defined seven “limits of consistency” for soils, but in current engineering practice, only two of the limits, the liquid and the plastic limits, are commonly used(Figure 3.1). The third limit, called as the shrinkage limit, is used occasionally. The Atterberg limits base on the moisture content of the soil. Liquid Limit (LL) is used in conjunction with the Plastic Limit to determine the Plasticity Index (PI) of a soil. LL and PI provide an indication of the "clayeyness" of a soil.

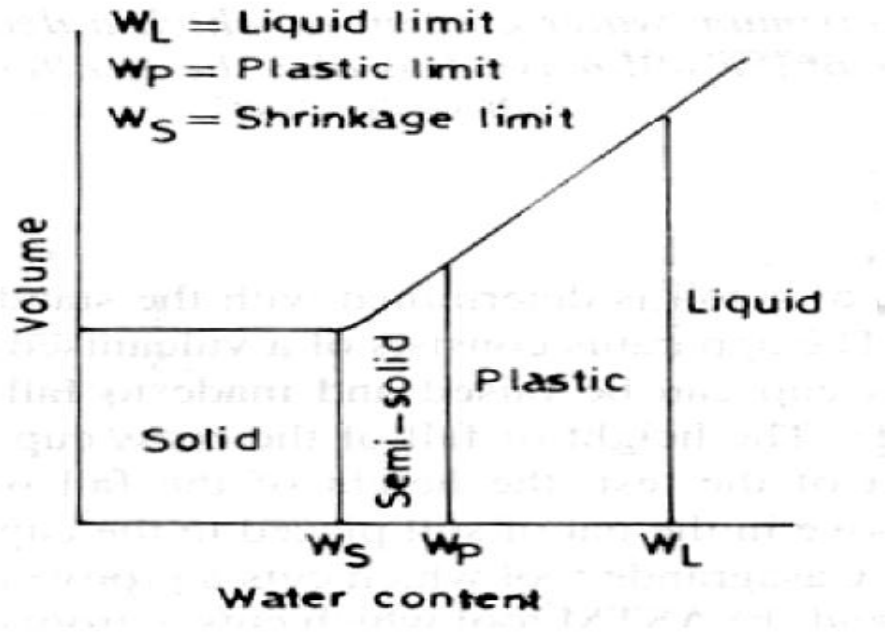


Figure 3.1: Atterberg Limits and soil volume relationships

3.4.2.1 Determination of the Liquid Limit of a soil

The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic states of consistency.

This test is performed in accordance with AASHTO T-89 [17] , and following apparatus are required for the test:

Porcelain (evaporating) dish, Spatula, Liquid limit device, (Flat) Grooving tool, Gauge, Containers, Balance, Oven.

This test needs a minimum of 100g of soil sample passing No. 40 sieve (425µm), which is a thoroughly mixed portion. Four empty moisture cans with their lids are weighed and respective weights recorded. The point on the cup that is in contact with the base should rise to a height of 10mm. Height gauge of 10mm thickness and 50mm length is used for this adjustment.

The soil sample is placed in the porcelain dish and thoroughly mixed using the spatula by adding 15 to 20 ml of distilled water. Water is continually added in increments of 1 to 3 ml and mixed thoroughly until soil turns in to a consistent paste mixture. The initially prepared paste should not contain too much water and grove should closure in the range of 25 to 35 shocks when used in the liquid limit apparatus. Figure 3.2 illustrates the liquid limit test apparatus with prepared sample, before and after the test.

(a) (b)

Figure 3.2: Liquid Limit Test apparatus

(a) Sample ready for the liquid limit test.

(b) Completed liquid limit test with groove closed.

The mixed soil is placed in the cup of the liquid limit apparatus at the point where the cup rests on the base. The soil squeezes down to eliminate air pockets and spread into the cup to a depth of about 10mm at its deepest point. The soil paste should form an approximately horizontal surface.

The grooving tool helps to cut a clean straight groove down the center of the cup carefully. The tool should remain perpendicular to the surface of the cup while making the groove. Extreme care is necessary to prevent sliding the soil relative to the surface of the cup.

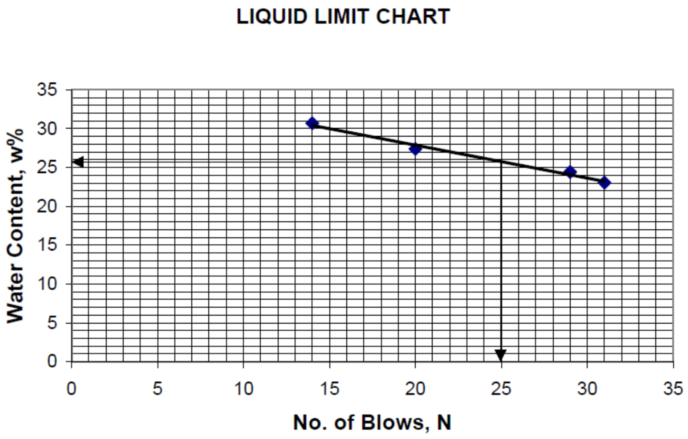
Base of the apparatus below the cup should be clean of soil. The crank of the apparatus is turned at a rate of approximately two drops per second and counted the number of drops, N. It takes a distance of 13 mm (1/2 in.) to make two halves of the soil paste to come into contact at the bottom of the groove.

Using the spatula, a sample is obtained from edge to edge of the soil paste. The sample should include soil on both sides from where the groove came into contact. The soil is placed in a moisture can and covered. Moisture can containing the soil is immediately weighed, mass recorded, lid removed, and placed in the oven. Moisture can is left in the oven for at least 16 hours. Soil remaining in the cup is placed into the porcelain dish. The cup on the apparatus and the grooving tool are cleaned and dried.

The entire soil specimen in the porcelain dish is remixed. A small amount of distilled water is added to increase the water content to reduce the number of drops required to close the groove.

Above mentioned testing steps are repeated for at least two additional trials, producing successively lower number of drops to close the groove. One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring15 to 25 drops. The water content is determined from each trial using the same method mentioned above, using the same balance for all weighing.

Number of drops, N, (on the log scale) is plotted against the water content (w). The best-fit straight line is drown through the plotted points and the liquid limit (LL) is determined as the water content at 25 drops. An example of finding liquid limit is presented in Figure 3.3.



From the above graph, Liquid Limit = 26

Figure 3.3: Finding Liquid Limit- water content percentage at 25 number of Blows

3.4.2.2 Determination of the Plastic Limit of a soil

The plastic limit of a soil is the lowest water content at which the soil remains plastic. Hence, plastic limit (PL) is a measurement of the moisture content where the soil stiffens from a plastic condition to a semi rigid friable state.

This test was performed in accordance with AASHTO T-90 [18]. Following apparatus are required for the test: Mixing dish, Spatula, Rolling Surface, Moisture containers with lids, Balance, and drying oven. All apparatus should be clean, dry, and within specifications.

Weigh the empty moisture cans with their lids, and record the respective weights and can numbers on the data sheet.

Approximately 20 g of material passing the number 40 sieve (425µm) is required for this test. From the 20 g sample, two 8 g samples are used for individual tests. Distilled water is incorporated until the soil is at a consistency where it can be rolled without sticking to the hands. Approximately 1.5-2.0 g of the 8 g sample is used for the test.

Form the soil into an ellipsoidal mass [Figure 3.4(b)]. Roll the mass between the palm or the fingers and the glass plate [Figure 3.4(c)].Use sufficient pressure to roll the mass into a thread of uniform diameter by using about 80-90 strokes per minute (a stroke is one complete motion of the hand forward and back to the starting position). The thread shall de-formed so that its diameter reaches 3 mm (1/8in.), in about two minutes.

When thread reaches the correct diameter, it breaks into several pieces(6 to 8 pieces). These pieces are kneaded and reformed into ellipsoidal masses, and re-rolled. This alternate rolling, gathering together, kneading and re-rolling is continued until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3 mm diameter thread [see Figure 3.4(d)]. This process is continued until the entire 8 g sample is used. Once each 1.5 to 2.0 g samples is at plastic limit, all portions of crumbled thread are gathered into a suitable container, using spatula, and covered immediately. This container is weighed to the nearest 0.01 g when the total 8g sample is collected.

This process is repeated with the other 8 g soil sample and collected into a container and weighed as previously mentioned.

Containers, after removing the covers, are placed in an oven and dried at 110^{0}C until it reaches a constant mass. Constant mass is defined as, after initial drying, the weight decreases by less than 0.1% after a minimum of 10 minutes additional drying. These samples are covered immediately after removing from the oven to determine the constant mass. Cooled containers are weighed to nearest 0.01 g and moisture content is calculated to nearest 0.1%. Plastic limit is calculated using equation 3.1.

$$\text{Plastic Limit} = \frac{\text{Mass of Water}}{\text{Mass of oven dry soil}} \times 100 \qquad \text{---------------------------} \ \text{Eq. 3.1}$$

Average of two water contents is reported to the nearest whole number and it is the Plastic Limit of that soil. It is used in conjunction with the Liquid Limit (AASHTO T-89) [17] to determine the Plasticity Index (PI), which is an indicator of the "clayeyness” of a soil, and calculated using equation 3.2.

Plasticity index, PI=LL-PL ---------------------------- Eq.3.2

Liquid limit, plastic limit, and plasticity index are reported to the nearest whole number, omitting the percent designation.

(a): Apparatus (b): Ellipsoidal soil mass

(c): Rolling (d): Brocken thread

Figure 3.4: Plastic Limit Test

3.4.3 Maximum Dry Density (Modified) test of a soil

Proctor stated in 1933 [19], that compaction is the function of four variables, namely dry density, moisture content, compaction effort, and type of soil. He found that these variables have a strong inter-relationship.

Water act as a lubricant and with an effect allow better packing of soil particles together. However, adding excess water decrease the density of soil. An excellent compaction of soil occurs when the soil achieves at the optimum moisture content and maximum dry density point.

This test is conducted according to AASHTO T-180 [20]. Method D is used even though several test methods are described there.

Two test methods, Multi-Point Moisture Density Relationship Test, and One-Point Moisture Density relationship Test are available to find Maximum Dry Density. However, Multi-Point Moisture Density Relationship Test is recommended and performed.

Apparatus

Compaction equipment including density mold, base and collar, compacting rammer and guide

Balance, readable to 5g (0.01 lbs)
Oven
19 mm sieve
Mixing tools
Moisture sample cans with lids
Straightedge, 250mm (10") long
Knife

Procedure

If the soil is damp upon receipt, it is dried until easily crumbled under a trowel. It can be air-dried or oven dried at a temperature up to 60°C (140°F). The soil chunks are broken up so that the entire sample passes through the 19mm sieve. Natural size of the particles should not be reduced and any individual particle of material retained in the 19mm sieve or any organic material are discarded. A representative sample should have approximately 11 Kg (25 lb) and thoroughly mixed with sufficient water to dampen it to approximately four percentage points below optimum moisture content. An alternative method is the "five bag method.” Five separate and approximately equal representative samples are weighed and placed in a bowl or plastic bag used for mixing purposes. A different percentage of moisture is added to each sample to create the five points required for this test.

A specimen is formed by compacting the prepared soil in a 152.40 mm (6 in.) mold, with collar attached, in five approximately equal layers, to give a compacted depth of about 127 mm (5 in.).

Figure 3.5: Placing loose soil into the mould

The loose soil is placed into the mould and spread into a layer of uniform thickness prior to compaction. The soil is lightly tamped prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or similar device having a face diameter of approximately 50.8 mm. Each layer is compacted by 56 uniformly distributed blows over the surface of the layer from the rammer dropping free from a height of 457.2 mm above the elevation of the soil. The sector face hammer overlaps the hammer surface area for each blow during compaction. The mold should rest firmly on a dense, uniform, rigid, and stable foundation or base during compaction. This base should remain stationary during the compaction process.

Extension collar of mold is removed and the compacted soil carefully trimmed even with the top of the mold, using the steel straightedge. Holes developed on the surface by removal of coarse material are patched with smaller sized material.

Excess material is cleaned from the outside of the mold and base. The mold is weighed with soil to the nearest 0.1 g and recorded.

The compacted specimen is removed from the mold by using a sample extruder. Specimen is vertically sliced through the center and a representative sample is obtained from the entire length of cut faces. This moisture sample is placed in a suitable container, weighed to the nearest 0.1g, and recorded. The weighed moisture sample should not be less than 100 g. The sample is dried in the oven at 110 °C, to a constant mass**.**

If the "Five Bag Method" is not used, the remaining portion of the molded specimen is thoroughly broken up and mixed with remaining quantity of the prepared sample. Same steps are repeated from adding water to dampen the sample, to weighing the dried constant mass in the oven. Water is added in sufficient amounts to increase the moisture content by approximately one to two percentage points from previous test. This series of determinations is continued until there is either a decrease or no change in the wet weight per unit volume of the compacted soil. A minimum of five points should run to determine maximum density and optimum moisture accurately, with three points up and two points down obtained.

The moisture content and the dry weight of the soil are calculated as compacted for each specimen using equation Eq.3.3 and Eq.3.4.

$$\%\text{Moisture Content} = \frac{A-B}{B-C} \times 100 \qquad \text{---------------------------- Eq. 3.3}$$

A = Weight of container and wet soil

B = Weight of container and dry soil

C = Weight of container

$$\text{Dry Weight} = \frac{W1}{\%\ \text{Moisture} + 100} \qquad \text{---------------------------- Eq. 3.4}$$

W1 = Wet weight, in g/cm³ of compacted soil

Calculated data is plotted on appropriate form and graph to determine maximum dry density and optimum moisture content. When the densities and corresponding moistures are plotted, it will reveal that a curve is produced by connecting the points with a smooth line. The moisture content corresponding to the peak of the curve shall be termed as "optimum moisture content" of the soil. The oven-dry density in grams per cubic centimeter of the soil at optimum moisture shall be termed as "maximum dry density". The maximum dry density is expressed in grams per cubic centimeter, to the nearest whole number, and the optimum moisture as a percentage, to the nearest whole number.

3.4.4 California Bearing Ratio (CBR) test of a soil

Definition of CBR:

CBR is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.3 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) in late 1920s for evaluating the bearing capacity of Subgrade, Subbase, or base course materials for designing road pavements.

CBR Tests are performed on natural or compacted soils in water soaked or un-soaked conditions and the results so obtained are compared with the curves of standard test to develop an idea of the soil strength of the Subgrade or selected soil.

Apparatus Used:

- Moulds 3Nos- 152.4mm in diameter and 177.8mm in height with 50mm high extension collar
- Spacer Disk - 150.8mm in diameter and 61.37 mm in height
- Rammer 4.7Kg
- Apparatus for Measuring Expansion
- Indicators - Two dial indicators
- Surcharge Weights - 2.27 Kg in weight
- Penetration Piston - 49.63 mm diameter, area 1935 mm^2
- Loading Device- a uniformly increasing load at a rate of 1.3 mm/min
- Soaking Tank
- Drying Oven -capable of maintaining a temperature of 110 ± 5ºC
- Moisture Content Containers
- Miscellaneous

CBR Test Procedure:

A sample of soil weighing 35 Kg or more is used for testing. Material passes through 19mm sieve is only used for test. If material is retained on 19mm sieve, those should be replaced by an equal amount of soil that passes through 19mm sieve but retain on 4.75mm sieve.

Normally three specimens each of about 6.8Kg must be compacted so that their compacted densities range from 95% to 100% generally with 10, 30, and 65 blows.

First, an empty mould is weighed with the extension collar for nearest 5g. Sufficient water is added to all three portions to obtain the optimum moisture content. First specimen is placed in the mould by five layers and compacted each layer by 10 blows. Moisture content in the specimen is measured by taking samples at the beginning and at the end of the process.

Extension collar is removed and compacted soil is trimmed using straightedge even with the top of the mould. Irregularities in the surface are patched with small-sized material. Coarse filter paper is placed after removing the spacer disk on the perforated base plate. Mould and compacted soil is inverted and placed on the filter paper so as the compacted soil is in contact with the filter paper. The perforated base plate is clamped to the mould and attached the collar. The mass of the mould and specimen is weighed to the nearest 5g.

Other two specimens are also compacted as previous with 30 and 65 blows. Same procedure is repeated until the mass of the moulds and specimens are weighed.

The swell plate with adjustable stem is placed on the soil sample in the mould and applied sufficient annular weights to produce an intensity of loading equal to mass above the intended layer with minimum of 4.54 kg.

The tripod is placed with dial indicator on top of the mould and an initial reading is taken. All three prepared moulds are immersed in water so as to allow free access of water to top and bottom of the specimens soaked for four days.

Figure 3.6: Immersed Soil Specimens in a water tank

Final dial readings on the soaked specimen are obtained at the end of 4 days (96 hrs) soaking and swell percentage are calculated (Eq.3.5).

$$\text{Percent swell} = \frac{\text{Change in length in mm during soaking}}{116.43\text{ mm}} \times 100 \qquad \text{---------------- Eq.3.5}$$

Specimens are removed from the soaking tank and allowed about 15 minutes to drain water. The surcharge weights and perforated plates are removed after draining. A surcharge of annular and slotted weights equal to the soaking surcharge is placed on the specimen. Penetration piston is seated to the specimen with a 44 N load. Both penetration dial indicator and load indicator are set to zero.

The loads are applied to the penetration piston so that the rate of penetration is uniform at 1.3mm/min. Load is recorded at every 0.25mm penetration up to 7.62mm of total penetration.

Figure 3.7: Data recording in CBR test

The graphs between the penetration (mm) and penetration load (KN) are drawn and CBR values calculated by dividing the load values at 2.54 and 5.08mm penetration by standard loads of 13.35 and 19.93 KN for each specimen. Equation 3.6 determines the CBR value.

$$\mathrm{CBR} = \frac{\text{Corrected load value}}{\text{Standard load}} \times 100 \qquad \text{---------------------------- Eq. 3.6}$$

The graph is plotted between CBR and Dry Density in all three specimens and CBR is acquired at required degree compaction (98% for sub base).

3.4.5 Sieve analysis test of a soil

The procedure of quantitative determination of the distribution of particle sizes in a selected soil is described in this method. The percentages of gravel and sand fractions in a representative soil sample are determined by shaking it through required sieve sizes. The smaller size fractions silt and clay, both of which pass the 75µm (#200) sieve, are determined by hydrometer analysis. However, here the hydrometer test is not considered, since fractions of smaller sizes less than 75µm is not mentioned in SSCM specification requirements.

This test can use either wet sieving or dry sieving. Wet sieving to separate fine grains from coarse grains is carried out by washing the soil specimen on No.200 (75µm) sieve mesh and remaining soil is dried and sieved through a nest of sieves of descending sizes. Dry sieving sample is dried and shaken through a nest of sieves of descending size. Wet sieving is actually the correct way to analyse particles, which contain considerable amount of fine. Washing soil particles is the way to ensure that fine grained are separated from the coarse grained. Therefore, wet sieving method is selected for this research.

Apparatus

- Balance - A balance sensitive to 0.01 g
- Thermometer - A thermometer accurate to 0.5°C (1°F)

- Sieves - Following series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification: 50mm, 37.5mm, 20mm, 5mm, 1.18mm (No.16), 300µm (No. 50) and 75µm (No.200)
- Oven - A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5 °C (230 ± 9 °F) for drying the sieve analysis samples
- Mechanical sieve shaker

Procedure

Soil sample weighing 4 Kg is used for sieve analysis test. The soil chunks are broken up so that the natural sizes of the particles are not reduced. The soil specimen is placed on the No.200 (75µm) sieve mesh and washed properly. The remaining soil particles are dried and weighed. This dried soil should sieve through the set of sieves and this sieving operation consist of 50mm, 37.5mm, 20mm, 5mm, 1.18mm (No.16), 300µm (No.50), and 75µm (No.200) sieves.

The sieving operation is conducted by means of a lateral and vertical motion of sieves, accompanied by a jarring motion. This can be achieved by manual operation, i.e. handshaking or using a mechanical sieve shaker. Fragments in the sample should not be manipulated through the sieve openings by hand. The sieving operation is continued until not more than one percent (1%) of the retained material on the sieve passes that sieve during 1 minute of sieving. The thoroughness of the sieving is checked manually because a mechanical sieve shaker is used.

The masses retained on each sieves are weighed in the balance. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely to the original mass of the quantity sieved.

(a): Mechanical sieve shaker (b): Masses retain on sieves

Figure 3.8: Sieve Analysis Test

To find the percent of aggregate passing through each sieve, first the percent retained in each sieve should be defined. Equation 3.7 fulfills this purpose.

$$\% Retained = \frac{W_{Sieve}}{W_{Total}} \times 100\% \qquad \text{---------------------------- Eq. 3.7}$$

Where W_{Sieve} is the weight of soil fraction in the sieve and W_{Total} is the total soil weight.

The next step is to find the cumulative percent of soil retained in each sieve by adding up the total amount of soil that is retained in each sieve and the amount in the previous sieves. The cumulative percent passing of the soil is obtained by subtracting the percent retained from 100% (Eq3.8).

%Cumulative Passing = 100% - %Cumulative Retained --------------------------- Eq. 3.8

The acquired % cumulative passing is plotted in graph where the upper and lower limits in the SSCM (Second Edition, 2009) are graphed.

3.5 Study on Specification limits and properties of Subbase Material

Most of the roads in Sri Lanka were constructed to fulfill the stipulated requirement in these standard specifications. It is noted that until the second edition publishes, the grading requirement was not considered to select the materials for the construction of Subbase. In addition, the Maximum Dry Density of the material was not considered.

To verify the method of material selection, importance of the required properties for the material, and performance of the already constructed roads in accordance with different specifications, a Questionnaire survey was conducted among the experienced professional engineers who have worked in road sector for over fifteen years.

A questionnaire (Appendix D) was distributed among 60 engineers, out of which 43 responded.

Summary of the questionnaire survey

1) Approximately 49% of the engineers “Strongly agree or Agree” that finding sub base material according to SSCM 2009[1] is extremely difficult.
2) About 65% out of total respondents identified the most important factor for the material selection is CBR and 84% says that lower or least importance should be given to Grading.
3) The most difficult parameter to meet, according to respondents, is PI and the percentage is 51%. Nevertheless, 16% of the respondents mentioned Grading as a most difficult parameter.
4) Nearly 67% recommended giving relaxation for Grading.
5) Around 93% agreed with the limits given in SSCM2009 [1].
6) Nine percent (9%) of the engineers proposed that shrinkage to be added to specifications as an additional property.
7) Almost 35% of the respondents revealed that they have used marginal or substandard material in their road construction projects.

CHAPTER 4

METHODOLOGY

4.1 Introduction

Finding approved Subbase materials with varied percentages of fines is difficult. Therefore, it was decided to prepare soil samples, which satisfy all the SSCM Subbase material requirements by blending two soil types.

First, Subbase material was prepared by blending two soil types. Sieve analysis, CBR, MDD, OMC, LL, and PI values were obtained for this Subbase material. A stock of fine particles was prepared by sieving a soil through 425µm sieve. These sieved fines were incrementally added to the prepared Subbase material to make ten different soil samples. All tests relevant to Subbase materials were performed to each of these prepared samples.

4.2 Preparation of Subbase Material

Different types of soils were used for blending trials until suitable Subbase material was formed.

Table 4.1 depicts the properties and Table 4.2 illustrates sieve analysis results of selected soil for blending.

Table 4.1: Properties of blending soils

Soil Type	LL %	PI %	OMC %	MDD (Kg/m3)	CBR % Soaked
1	NP	NP	9	2.090	46
2	33	8	15.5	1.705	14

Table 4.2: Sieve Analysis details of blending soils

Sieve Size (mm)	**% Passing**		**Spec. Limits Table 1708-3**
	Soil Type 1	**Soil Type 2**	
50.00	100.0	100.0	100
37.50	100.0	100.0	80-100
20.00	98.9	95.2	60-100
5.00	81.0	73.0	30-100
1.180	48.7	27.5	17-75
0.300	34.9	7.5	9-50
0.075	32.7	1.8	5-25

Selected two soils were not suitable to use as Subbase material with reference to SSCM. Therefore, several mixing proportions were made to prepare suitable samples of Subbase material. Finally, blending below-mentioned proportions of the two types of soil satisfied the specification requirements.

- Soil Type 1 - 50% of 5mm sieve retain
- Soil Type 2 - 50% of 5mm sieve passing

(a): Soil Type 1 (b): Soil Type 2

Figure 4.1: Selected soils for blending

4.3 Test Methods to find the properties

The properties of the soil were determined according to following test methods:

Sieve Analysis - AASHTO T88-00 [21]
Atterberg Limits Tests (LL & PI) - AASHTO T89-10 [17] and AASHTO T90-00 [18]
CBR Test - AASHTO T193-99 [22]
MDD and OMC - AASHTO T180-10 [20]

4.4 Properties of prepared Subbase material

Following properties were determined for the prepared Subbase material:

LL (%) = 32
PI (%) = 7
OMC (%) = 8.5
MDD(Kg/m^3) = 2.04
CBR % = 59

Table 4.3: Sieve Analysis Report of Subbase Material

Sieve Size (mm)	% Passing	Spec. Limits- Table 1708-3
50.00	100.0	100
37.50	100.0	80-100
20.00	98.9	60-100
5.00	70.5	30-100
1.180	41.3	17-75
0.300	17.4	9-50
0.075	12.5	5-25

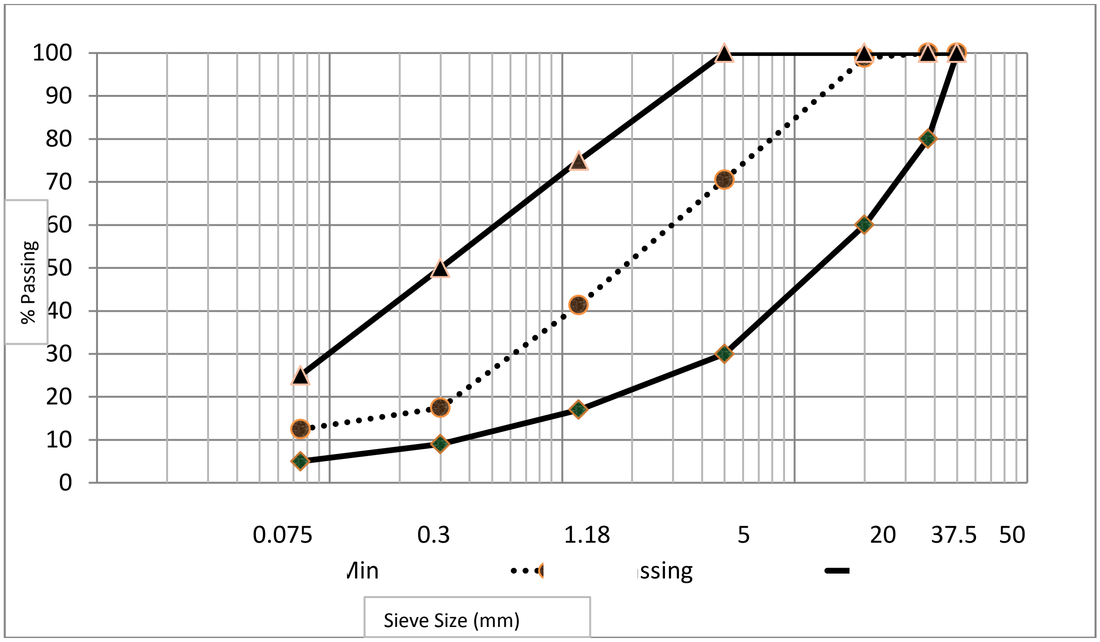


Figure 4.2: Grading details of Subbase sample

4.5 Preparation of 10 soil samples

It was decided to find the change of properties in this prepared Subbase with the variation of fine fraction. A fine material heap was prepared by sieving type 2 soil through 425µm sieve. The sieved fine material was incrementally added to the Subbase material to prepare 10 different soil samples as shown in Table 4.4.

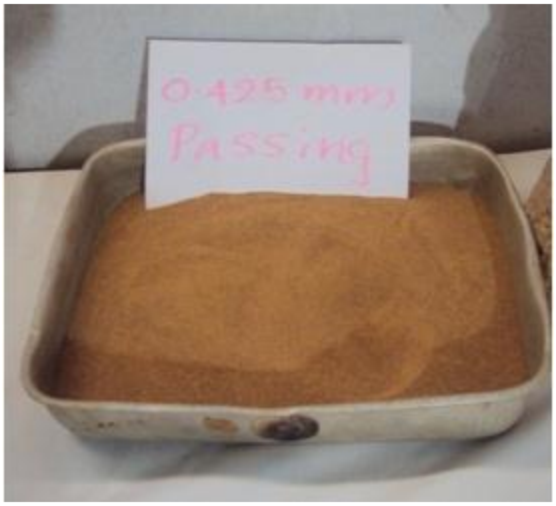


Figure 4.3: No # 40 sieve passing of Type 2 soil

4.6 Properties of prepared 10 samples

The following properties were found for the ten samples which were prepared according to Table 4.4.

a) CBR
b) Maximum Dry Density
c) Optimum moisture content
d) Liquid Limit and Plastic Limit

Sieve analysis was conducted for all ten samples. Test summary is provided in Appendix B.

Atterberg limit tests were only performed with sample numbers 1, 4, and 7 to confirm soil uniformity since Attrberg limit should be unique for all samples as all samples contain fine fraction separated from type 2 soil.

Only three samples were within the SSCM specification limits and all other seven samples were out of grading band, as shown in Table 4.5 and Figure 4.4. The 75µm sieve passing values greater than the maximum SSCM allowing limit of 25% were present in samples 4, 5, 6, 7, 8, 9, and 10 in Table 4.5. However, when considering 300µm sieve passing, only the tenth sample's value exceeded the maximum allowing passing limit of 50%.

Table 4.4: Blending details of prepared 10 samples

Sample No.	Type of Material
1	Subbase material
2	Subbase material: 2 units +05% of 0.425mm sieve passing soil from type 2 soil
3	Subbase material: 2 units +15% of 0.425mm sieve passing soil from type 2 soil
4	Subbase material: 2 units +25% of 0.425mm sieve passing soil from type 2 soil
5	Subbase material: 2 units +30% of 0.425mm sieve passing soil from type 2 soil
6	Subbase material: 2 units +40% of 0.425mm sieve passing soil from type 2 soil
7	Subbase material: 2 units +50% of 0.425mm sieve passing soil from type 2 soil
8	Subbase material: 2 units +60% of 0.425mm sieve passing soil from type 2 soil
9	Subbase material: 2 units +75% of 0.425mm sieve passing soil from type 2 soil
10	Subbase material: 2 units +90% of 0.425mm sieve passing soil from type 2 soil

Table 4.5: Particle size analysis of prepared 10 samples

Sample No	**Particle Size Analysis (% Passing)**							
	Sieve size (mm)							
	50.0	**37.5**	**20.0**	**5.0**	**1.180**	**0.425**	**0.300**	**0.075**
1	100.0	100.0	98.9	70.5	41.3	-	17.4	12.5
	100.0	100.0	98.9	70.5	41.3	22.8	17.4	12.5
2	100	100	91.9	65.7	41.4	-	22.6	14.1
	100	100	91.9	65.7	41.4	24.6	22.6	14.1
3	100	100	90.8	56.4	32.0	-	25.0	17.2
	100	100	90.8	56.4	32.0	27.5	25.0	17.2
4	100.0	100.0	90.1	65.7	43.0	-	33.0	25.9*
	100.0	100.0	90.1	65.7	43.0	35.2	33.0	25.9*
5	100	100	90.8	69.3	51.9	-	41.8	29.8*
	100	100.	90.8	69.3	51.9	45.0	41.8	29.8*
6	100	100	95.5	67.1	58.6	-	42.6	30.1*
	100	100	95.5	67.1	58.6	49.7	42.6	30.1*
7	100.0	100.0	91.1	79.6	62.5	-	49.0	31.2*
	100.0	100.0	91.1	79.6	62.5	54.5	49.0	31.2*
8	100	100	93	76.3	60.7	-	49.4	32.4*
	100	100	93	76.3	60.7	54.3	49.4	32.4*
9	100.0	100.0	94.4	74.3	58.1	-	46.8	31.9*
	100.0	100.0	94.4	74.3	58.1	55.1	46.8	31.9*
10	100.0	100.0	93.9	77.6	64.5	-	52.5**	37.2*
	100.0	100.0	93.9	77.6	64.5	59.3	52.5**	37.2*

* exceed the maximum limit (25%) of 0.075mm sieve passing

** exceed the maximum limit (50%) of 0.300mm sieve passing

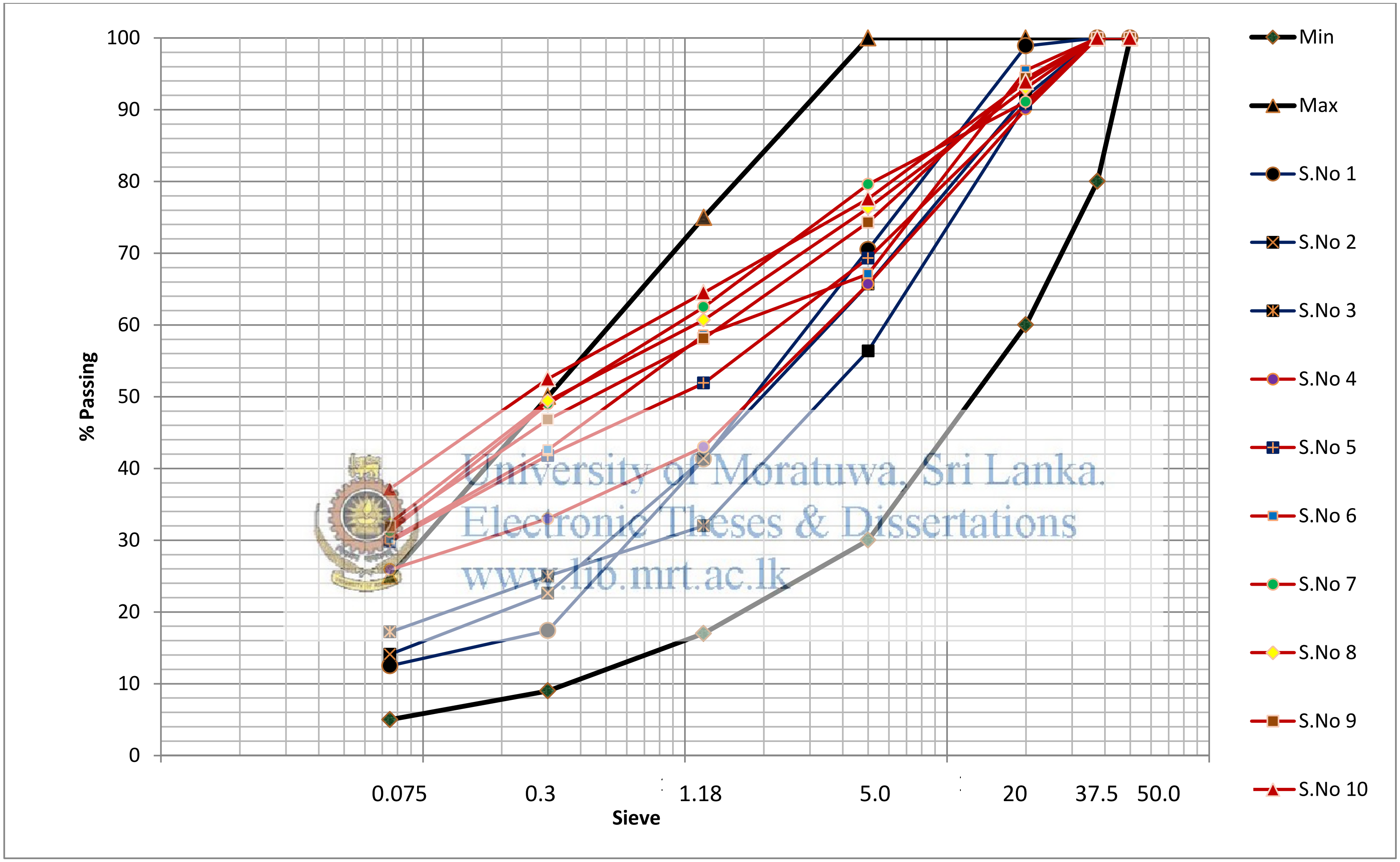


Figure 4.4: Particle size distribution of samples

Table 4.6 demonstrates the passing percentages through 425µm, 300µmand 75µm sieves and MDD, OMC, and CBR values of 10 samples. Only 10th sample's CBR value is less than the minimum requirement of 30. MDD values of all samples are greater than the minimum requirement of 1.75 Mg/m3. Additional details of the prepared samples are given in Appendix B.

Table 4.6: Material properties of prepared 10 samples

Sample No.	**0.425 sieve (% passing)**	**0.300 sieve (% Passing)**	**0.075 sieve (% passing)**	**MDD (Mg/m3)**	**OMC (%)**	**CBR 98% @ 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

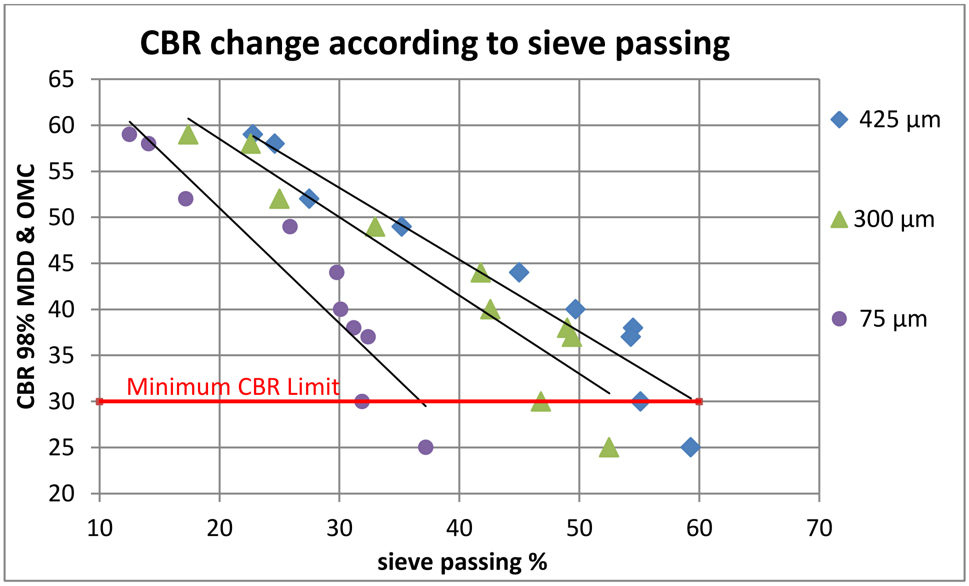


Figure 4.5: CBR change according to sieve passing

CBR change reference to sieve passing through 425µm, 300µm, and 75µm sieves are presented in Figure 4.5. MDD variation reference to sieve passing through 425µm sieve, 300µm sieve, and 75µm sieve is shown in Figure 4.6.

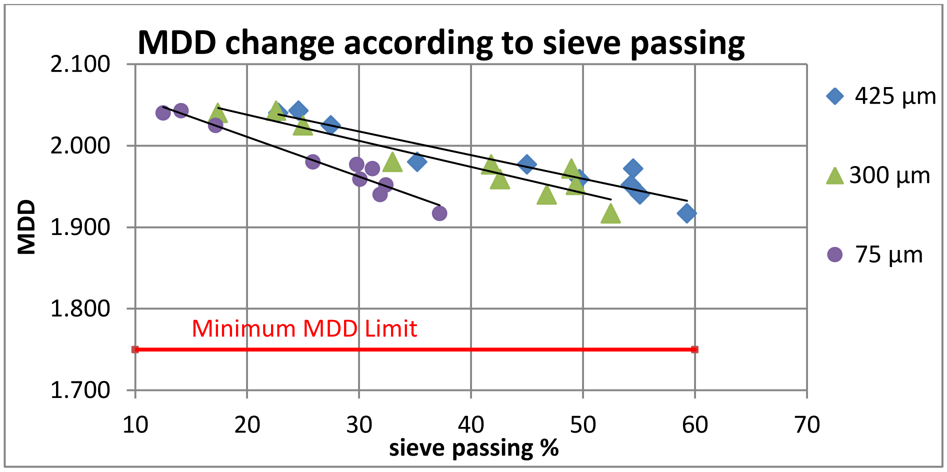


Figure 4.6: MDD change according to sieve passing

Figure 4.7 displays the OMC change according to sieve passing through 425µm sieve, 300µm sieve, and 75µm sieve.

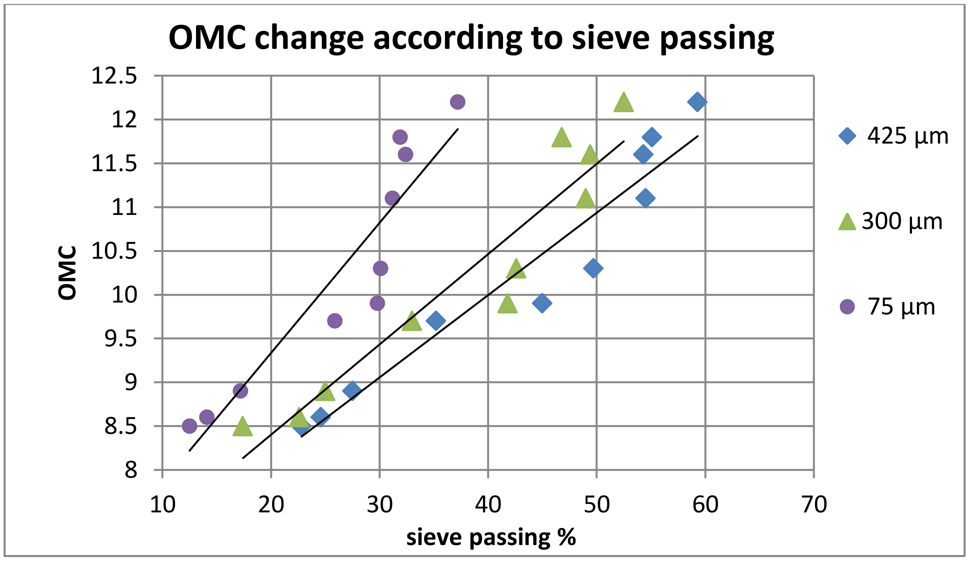


Figure 4.7: OMC change according to sieve passing

CHAPTER 5

ANALYSIS OF TEST RESULTS

5.1 Soil Classification

The results obtained from laboratory testing were used to classify the soil samples according to AASHTO and USCS soil classification systems (Appendix C). A summary of classifications is provided in Table 5.1.

Table 5.1: Summary of soil samples classifications

Sample No.	**AASHTO Classification**				**USCS Classification**	
	Group Classification	**Usual types of significant constituent materials**	**General Rating**	**GI**	**Group Symbol**	**Group Name**
1	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
2	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
3	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	GM	Silty gravel with sand
4	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
5	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
6	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
7	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
8	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
9	A-2-4	Silty or clayey gravel and sand	Excellent to good	0	SM	Silty sand with gravel
10	A-4	Silty Soil	Fair to poor	0	SM	Silty sand with gravel

According to AASHTO classification, group classification of samples 1 to 9 are A-2-4, which is generally rated as ‘excellent to good’ and sample 10 is A-4, where generally rated as ‘fair to poor’. The same result is represented in test summary (Appendix B) where CBR value (25) of sample 10 is less than minimum requirement (30) when No.200 sieve passing is more than 35%. Group Index (GI) values of all samples were 0.

With reference to USCS classification, group symbol of sample number 3 is GM and all others were SM.

It revealed that four-day soaked swell percentages for moulds prepared by 10, 30, and 65 blows were very less than 2% (Appendix B).

5.2 Correlation between material properties

The collected data from the laboratory testing (Appendix B) were used to obtain the correlations between the material properties (Appendix A).

A. CBR vs. passing percentages

a) CBR vs. Passing percentage of 425µm sieve
b) CBR vs. Passing percentage of 300 µm sieve
c) CBR vs. Passing percentage of 75 µm sieve

B. MDD vs. passing percentages

a) MDD vs. Passing percentage of 425µm sieve
b) MDD vs. Passing percentage of 300 µm sieve
c) MDD vs. Passing percentage of 75 µm sieve

C. OMC vs. passing percentages

a) OMC vs. Passing percentage of 425µm sieve
b) OMC vs. Passing percentage of 300 µm sieve
c) OMC vs. Passing percentage of 75 µm sieve

D. CBR vs. MDD

E. CBR vs. OMC

F. MDD vs. OMC

5.2.1 Relationship between CBR vs. passing percentages

Change of CBR with reference to fraction passing through 425µm, 300µm, and 75µm sieves were discovered. Finding relationship between CBR and these fine fractions passing is very important because it represent the Subbase layer bearing strength capacity variation according to percentage of fine fraction change.

Referring the fitted models in Figure 5.1, Figure 5.2, and Figure 5.3, the fine content of the material affected to its CBR value.CBR of the material decreased with the increase of fine content. However, it can be noted that selected samples, which are in out of the grading band recommended by the SSCM, satisfies the CBR requirement of the same specification. Correlation coefficient (R^2) of the fitted models is 0.926 for 425µm sieve passing (Figure 5.1), 0.890 for 300µm sieve passing (Figure 5.2), and 0.889 for 75µm sieve passing (Figure 5.3).Therefore, the fitted models are significant.

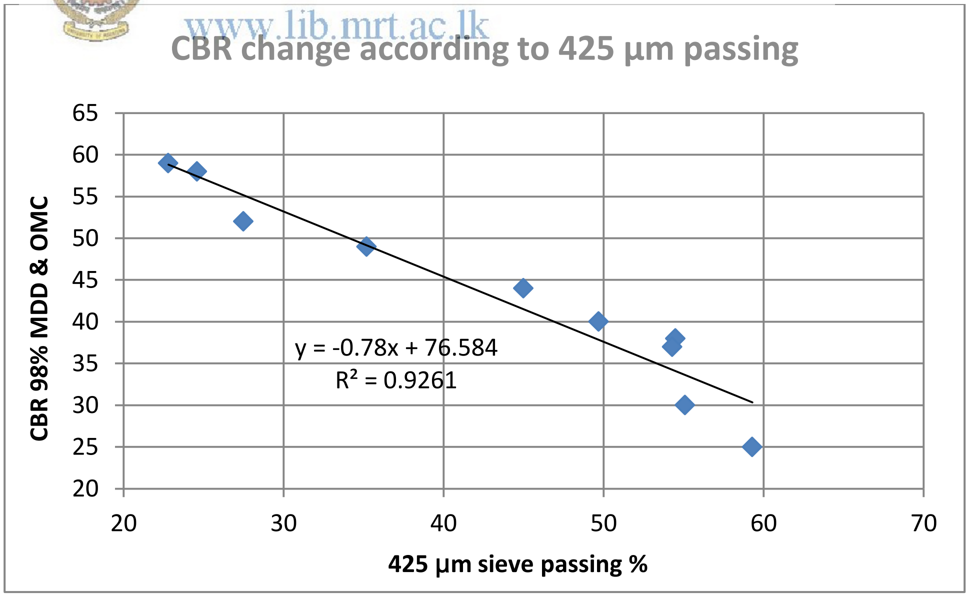


Figure 5.1: Relationship between CBR and percent passing through 425µm sieve

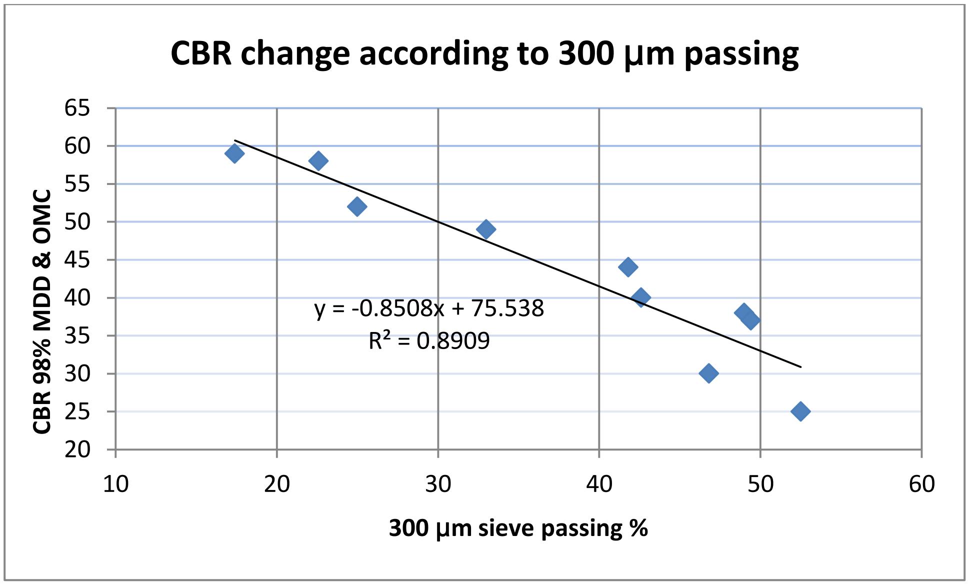


Figure 5.2: Relationship between CBR and percent passing through 300µm sieve

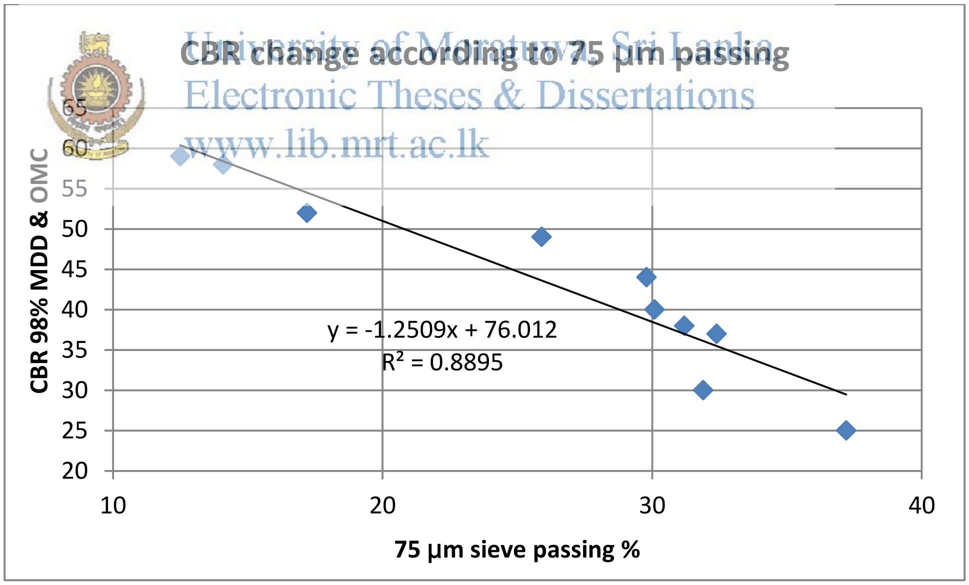


Figure 5.3: Relationship between CBR and percent passing through 75µm sieve

Analysing these results clearly reveals that the fine fraction of the material has a close relationship to the bearing strength of the material.

5.2.2 Relationship between MDD vs. passing percentages

Change of MDD with reference to passing through 425µm, 300µm, and 75µm sieves were found. Fine content of the material affects to the MDD value as shown in Figure 5.4, Figure 5.5, and Figure 5.6. MDD values of the material decrease with the increase of fine content.

Nevertheless, it is notable that selected samples, which are out of the grading band recommended by the SSCM, satisfy the MDD requirement of the same specification. Correlation coefficient (R^2) of the fitted models are 0.905 for 425µm sieve passing (Figure 5.4), 0.888 for 300µm sieve passing (Figure 5.5), and 0.952 for 75µm sieve passing (figure 5.6).Therefore, the fitted models are significant.

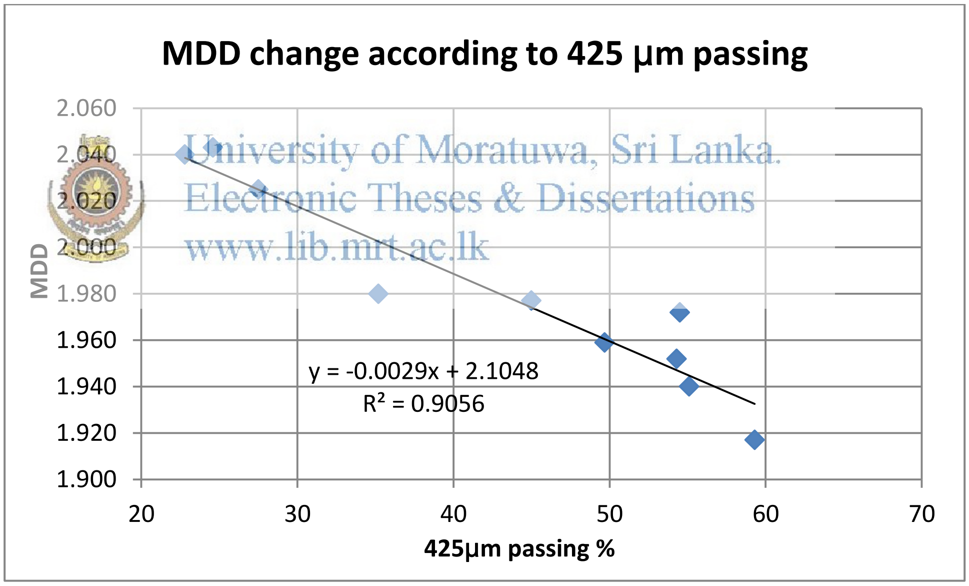


Figure 5.4: Relationship between MDD and percent passing through 425µm sieve

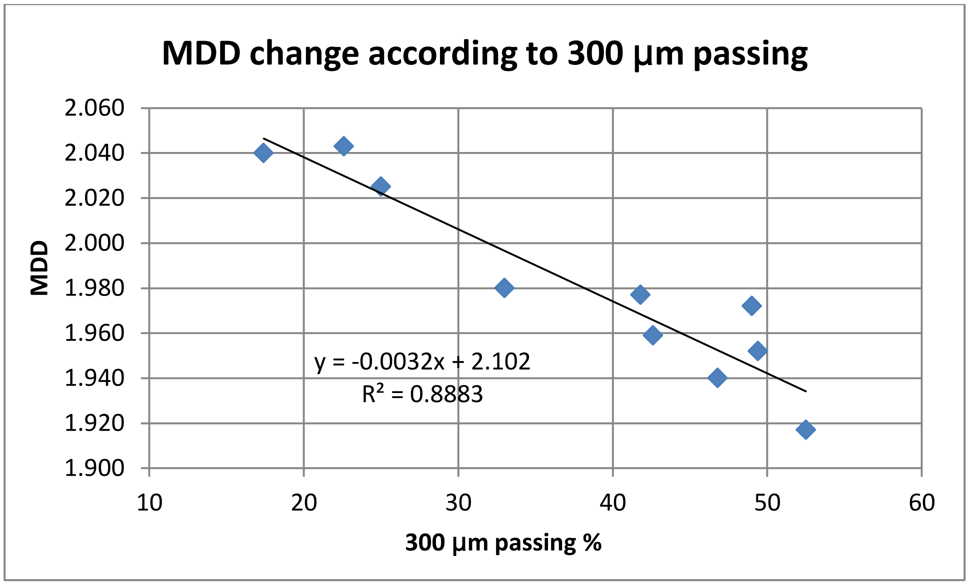


Figure 5.5: Relationship between MDD and percent passing through 300µm sieve

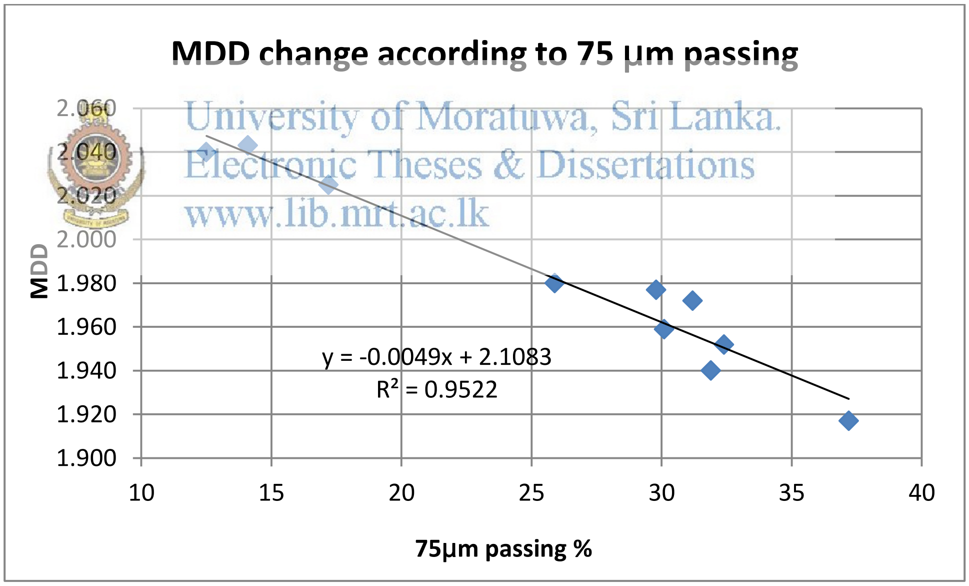


Figure 5.6: Relationship between MDD and percent passing through 75µm sieve

5.2.3 Relationship between OMC vs. passing percentages

Change of OMC with reference to passing through 425µm, 300µm, and 75µm sieves were found. Fine content of the material affected the OMC value as shown in Figures 5.7, 5.8, and 5.9. OMC values of the material increased with the increase of fine content.

Correlation coefficient (R^2) of the fitted models are 0.930 for 425µm sieve passing (Figure 5.7), 0.904 for 300µm sieve passing (Figure 5.8), and 0.868 for 75µm sieve passing (figure 5.9).Therefore, the fitted models are significant.

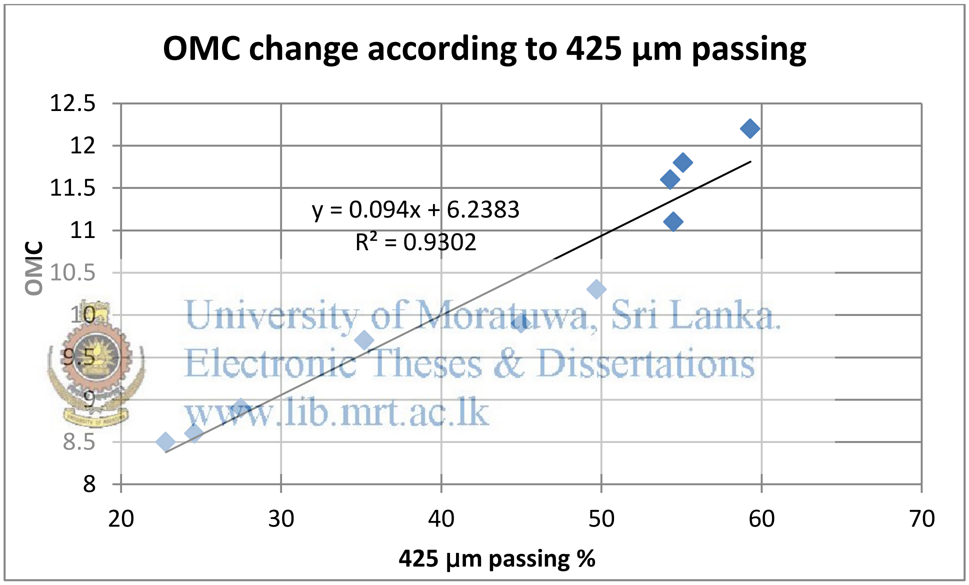


Figure 5.7: Relationship between OMC and percent passing through 425µm sieve

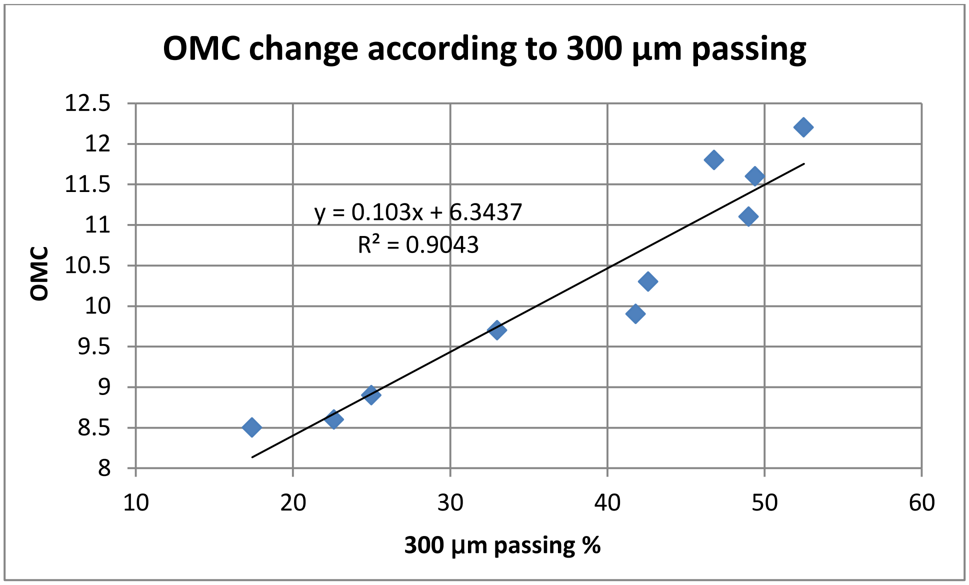


Figure 5.8: Relationship between OMC and percent passing through 300µm sieve

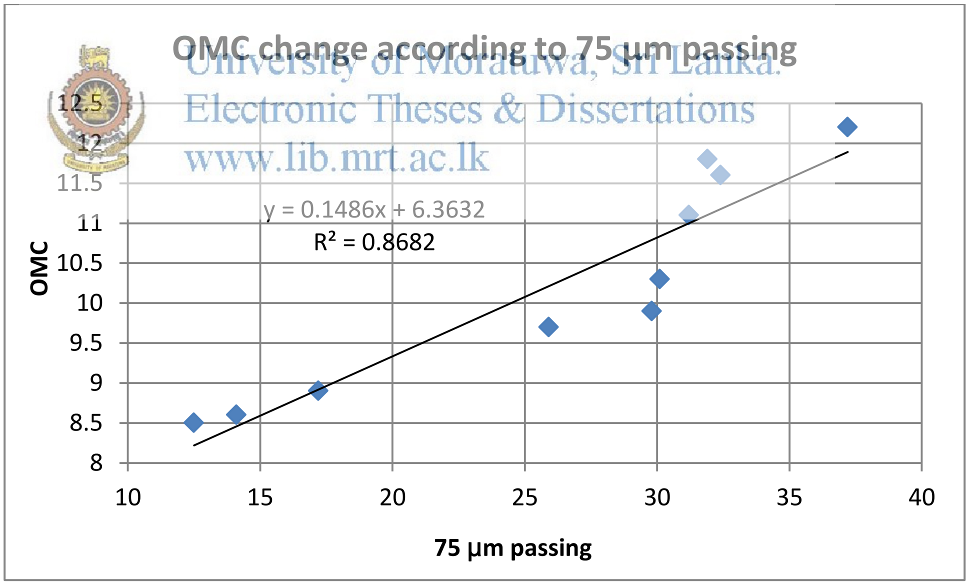


Figure 5.9: Relationship between OMC and percent passing through 75µm sieve

5.2.4 Relationship between CBR vs. MDD

Since the bearing strength under the four-day soaked condition of the Subbase is the most severe condition for the durability of the roads, it is important to obtain a relationship with the CBR and MDD. Therefore, change of CBR according to MDD variation was detected.CBR values of the material increased with the increase of MDD value.

Correlation coefficient (R^2) of the fitted model is 0.936 as shown in Figure 5.10. Thus, the fitted model is significant.

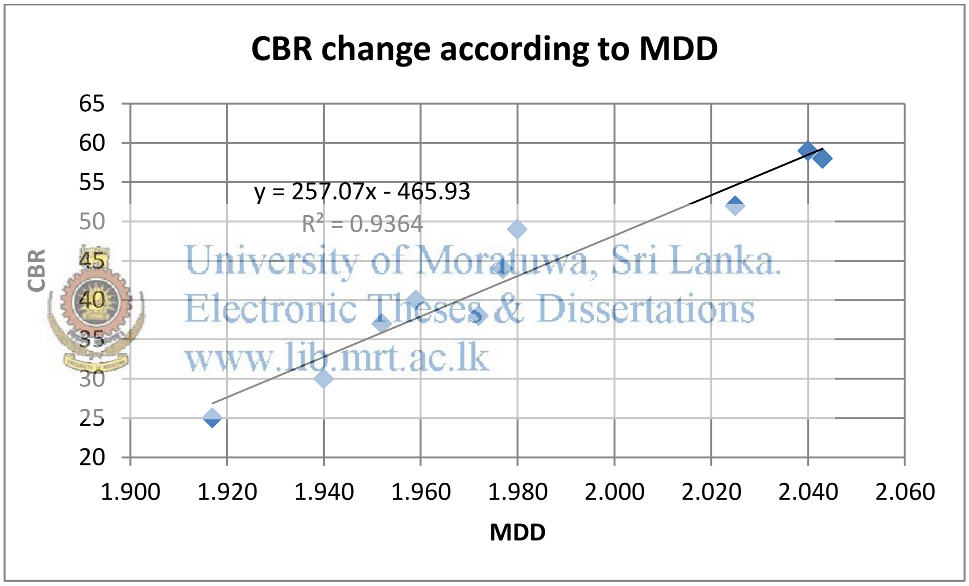


Figure 5.10: Relationship between CBR and MDD

5.2.5 Relationship between CBR vs. OMC

Change of CBR according to OMC variation was found.CBR values of the material decreased with the increase of OMC value.

Correlation coefficient (R^2) of the fitted model was 0.953 as depicted in Figure 5.11.Hence, the fitted model is significant.

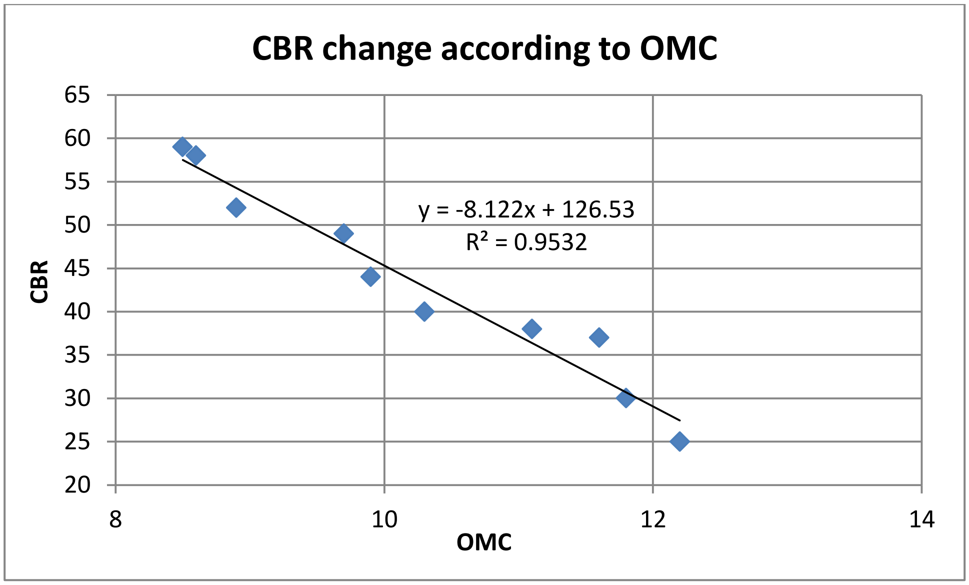


Figure 5.11: Relationship between CBR and OMC

5.2.6 Relationship between MDD vs. OMC

Change of MDD according to OMC variation was found.MDD values of the material decreased with the increase of OMC value.

Correlation coefficient (R^2) of the fitted model was 0.902 as shown in Figure 5.12. Thus, the fitted model is significant.

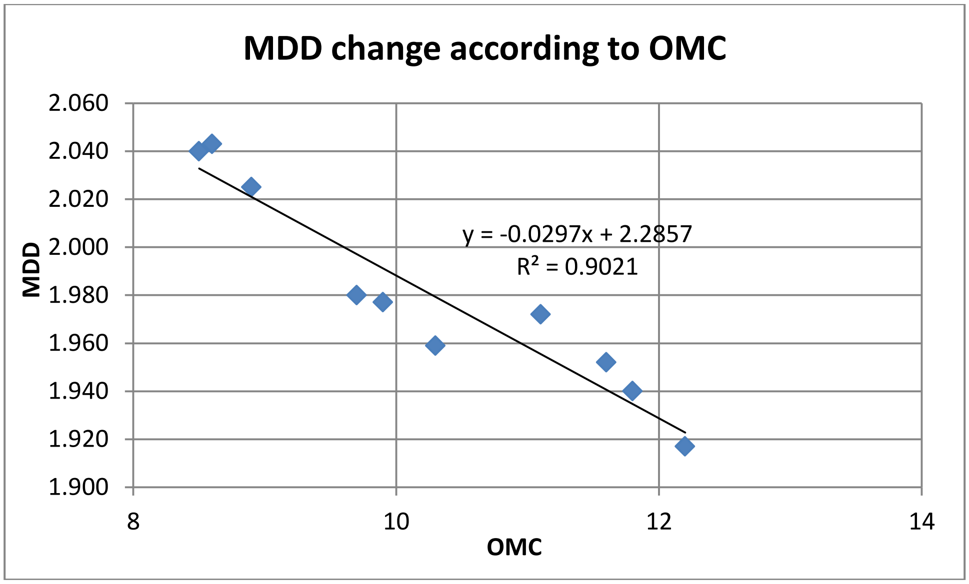


Figure 5.12: Relationship between MDD and OMC

5.3 Combined effect of fine fractions on CBR

Finally, stepwise regression was carried out for following situations:

a) CBR variation according to percentage of passing through 425µm and retain on 300µm, passing through 300µm and retain on 75µm, and passing through 75µm sieves.

Following model represents CBR value of the prepared material:

Y=77.295-1.308 x (425µm passing & 300µm retain)-0.258 x (300µm passing & 75µm retain)-0.945 x 75um passing ----------------------- Eq.5.1

Correlation coefficient(R Square) = 0.942

Correlation coefficient value is very high to this model, near to 0.95, and thus, the fitted modal is significant.

b) CBR variation according to percentage of passing through the 300µm and retain at 75µm sieves, and passing through 75µm sieve.

Following model represent the CBR value of the prepared material:

Y= 76.062 - 0.448 x(300µm passing and 75µm retain)- 1.051 x 75um passing

----------- Eq.5.2

Correlation coefficient (R Square)= 0.898

Correlation coefficient value is very high to this model, near to 0.90, and therefore fitted model is significant.

The Eq.5.2 was used to predict CBR values of 40 soil samples where LL, PI, MDD, and CBR values satisfied Subbase requirements (Appendix E). However, none of the predicted CBR values were close to actual CBR values. Therefore, it is confirmed that the models, Eq.5.1, and Eq.5.2, only represent the soil used for this experiment.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

By analysing the results, it can be concluded that fine fraction of a selected material affect the CBR value and MDD. When fine fraction increases, CBR and MDD values of the soil decrease. In addition, optimum moisture content increases as the fine fraction of the material increases.

The fitted models for CBR, MDD, and OMC expressed a significant relationship with the selected variables because the correlation coefficients for these models were higher than 0.80. A significant linear relationship exists between the CBR and MDD with the higher R^2 value. Since CBR and OMC change with the fine fraction of the soil, linear relationship could be expected between the CBR and OMC. According to Figure 5.11, a linear relationship was developed with a R^2 of 0.953 for CBR and OMC.

Developed linear regression models to predict CBR showed high correlation coefficients with the independent variables of percentage passing of different sieve sizes (R^2 of 0.942 and 0.898 for equation 5.1 and equation 5.2 respectively). Statistical analysis revealed that material passing through 425µm and retained on 300 µm, and 75µm passing percentage are the significant parameters when predicting CBR of the selected soil in this study. These models help to estimate the CBR value by having the sieve analysis results and compare to the laboratory CBR value of the tested material. However, the regression equations developed are only applicable for the soil used in this study.

It is possible to recommend that grading band of No.200 sieve passing can be relaxed up to 35% if soil sample satisfy the specified CBR requirement (30), PI value is less than or equal to 10, and swell percentage is less than 2%.

Further studies are essential to revise the present grading band by extending this study for different type of soils.

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Appendix A: Data Analysis

CBR change according to 425 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing425um[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.962[a]	.926	.917	3.27554

a. Predictors: (Constant), Passing425um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1075.767	1	1075.767	100.266	.000[b]
	Residual	85.833	8	10.729		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), Passing425um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	76.584	3.491		21.937	.000
	Passing425um	-.780	.078	-.962	-10.013	.000

a. Dependent Variable: CBR

CBR change according to 300 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing300um[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.944[a]	.891	.877	3.97953

a. Predictors: (Constant), Passing300um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1034.907	1	1034.907	65.349	.000[b]
	Residual	126.693	8	15.837		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), Passing300um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	75.538	4.194		18.013	.000
	Passing300um	-.851	.105	-.944	-8.084	.000

a. Dependent Variable: CBR

CBR change according to 75 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing75um[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.943[a]	.889	.876	4.00607

a. Predictors: (Constant), Passing75um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1033.211	1	1033.211	64.380	.000[b]
	Residual	128.389	8	16.049		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), Passing75um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	76.012	4.281		17.755	.000
	Passing75um	-1.251	.156	-.943	-8.024	.000

a. Dependent Variable: CBR

MDD change according to 425 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing425um[b]	.	Enter

a. Dependent Variable: MDD

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.952[a]	.906	.894	.013936

a. Predictors: (Constant), Passing425um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.015	1	.015	76.742	.000[b]
	Residual	.002	8	.000		
	Total	.016	9			

a. Dependent Variable: MDD

b. Predictors: (Constant), Passing425um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.105	.015		141.701	.000
	Passing425um	-.003	.000	-.952	-8.760	.000

a. Dependent Variable: MDD

MDD change according to 300 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing300um[b]		Enter

a. Dependent Variable: MDD

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.942[a]	.888	.874	.015161

a. Predictors: (Constant), Passing300um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.015	1	.015	63.604	.000[b]
	Residual	.002	8	.000		
	Total	.016	9			

a. Dependent Variable: MDD

b. Predictors: (Constant), Passing300um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.102	.016		131.570	.000
	Passing300um	-.003	.000	-.942	-7.975	.000

a. Dependent Variable: MDD

MDD change according to 75 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing75um[b]	.	Enter

a. Dependent Variable: MDD

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.952	.946	.009919

a. Predictors: (Constant), Passing75um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.016	1	.016	159.267	.000[b]
	Residual	.001	8	.000		
	Total	.016	9			

a. Dependent Variable: MDD

b. Predictors: (Constant), Passing75um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.108	.011		198.887	.000
	Passing75um	-.005	.000	-.976	-12.620	.000

a. Dependent Variable: MDD

OMC change according to 425 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing425um[b]	.	Enter

a. Dependent Variable: OMC

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.964[a]	.930	.921	.38272

a. Predictors: (Constant), Passing425um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15.612	1	15.612	106.587	.000[b]
	Residual	1.172	8	.146		
	Total	16.784	9			

a. Dependent Variable: OMC

b. Predictors: (Constant), Passing425um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.238	.408		15.293	.000
	Passing425um	.094	.009	.964	10.324	.000

a. Dependent Variable: OMC

OMC change according to 300 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing300um[b]	.	Enter

a. Dependent Variable: OMC

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.951[a]	.904	.892	.44801

a. Predictors: (Constant), Passing300um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15.178	1	15.178	75.620	.000[b]
	Residual	1.606	8	.201		
	Total	16.784	9			

a. Dependent Variable: OMC

b. Predictors: (Constant), Passing300um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.344	.472		13.437	.000
	Passing300um	.103	.012	.951	8.696	.000

a. Dependent Variable: OMC

OMC change according to 75 µm passing

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing75um[b]	.	Enter

a. Dependent Variable: OMC

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.932[a]	.868	.852	.52576

a. Predictors: (Constant), Passing75um

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.573	1	14.573	52.719	.000[b]
	Residual	2.211	8	.276		
	Total	16.784	9			

a. Dependent Variable: OMC

b. Predictors: (Constant), Passing75um

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.363	.562		11.326	.000
	Passing75um	.149	.020	.932	7.261	.000

a. Dependent Variable: OMC

CBR change according to MDD

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	MDD[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.968[a]	.936	.928	3.04001

a. Predictors: (Constant), MDD

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1087.667	1	1087.667	117.692	.000[b]
	Residual	73.933	8	9.242		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), MDD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-465.929	46.940		-9.926	.000
	MDD	257.071	23.696	.968	10.849	.000

a. Dependent Variable: CBR

CBR change according to OMC

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	OMC[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.953	.947	2.60783

a. Predictors: (Constant), OMC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1107.194	1	1107.194	162.804	.000[b]
	Residual	54.406	8	6.801		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), OMC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	126.532	6.583		19.221	.000
	OMC	-8.122	.637	-.976	-12.759	.000

a. Dependent Variable: CBR

MDD change according to OMC

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	OMC[b]	.	Enter

a. Dependent Variable: MDD

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.950[a]	.902	.890	.014191

a. Predictors: (Constant), OMC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.015	1	.015	73.731	.000[b]
	Residual	.002	8	.000		
	Total	.016	9			

a. Dependent Variable: MDD

b. Predictors: (Constant), OMC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.286	.036		63.808	.000
	OMC	-.030	.003	-.950	-8.587	.000

a. Dependent Variable: MDD

CBR change according to 425um passing & 300um retain, 300um passing & 75um retain, and 75um passing percentages

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing75, Pass425Ret300, Pass300Ret75[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.971[a]	.942	.913	3.34967

a. Predictors: (Constant), Passing75, Pass425Ret300, Pass300Ret75

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1094.278	3	364.759	32.509	.000[b]
	Residual	67.322	6	11.220		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), Passing75, Pass425Ret300, Pass300Ret75

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	77.295	3.627		21.313	.000
	Pass425Ret300	-1.308	.615	-.257	-2.127	.078
	Pass300Ret75	-.258	.476	-.102	-.542	.608
	Passing75	-.945	.250	-.713	-3.774	.009

CBR change according to 300um passing & 75um retain, and 75um passing percentages

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Passing75, Pass300Ret75[b]	.	Enter

a. Dependent Variable: CBR

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.948[a]	.898	.869	4.10693

a. Predictors: (Constant), Passing75, Pass300Ret75

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1043.532	2	521.766	30.934	.000[b]
	Residual	118.068	7	16.867		
	Total	1161.600	9			

a. Dependent Variable: CBR

b. Predictors: (Constant), Passing75, Pass300Ret75

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	76.062	4.389		17.329	.000
	Pass300Ret75	-.448	.573	-.177	-.782	.460
	Passing75	-1.051	.301	-.793	-3.494	.010

a. Dependent Variable: CBR

Appendix B: Tests Summary

Summary

SAMPLE NO	Type of Material :	Particle Size Analysis (% Passing)								Liquid limit	Plastic limit	Plasticity Index	Proctor Compaction		CBR 98%@ MDD & OMC (%)
		Sieve size (mm)											MDD	MDD & OMC (%)	
		50.0	37.5	20.0	5.0		0.425	0.300	0.075				(Mg/m$^{3)}$	(%)	
1	Subbase material	100	100	98.9	70.5	41.3		17.4	12.5	32	25	7	2.040	8.5	59.0
		100	100	98.9	70.5	41.3	22.8	17.4	12.5						
2	Subbase material: 2 units+ 05% of 0.425mm sieve passing soil from type 2 soil	100	100	91.9	65.7	41.4		22.6	14.1				2.043	8.6	58.0
		100	100	91.9	65.7	41.4	24.6	22.6	14.1						
3	Subbase material: 2 units+ 15% of 0.425mm sieve passing soil from type 2 soil	100	100	90.8	56.4	32.0		25.0	17.2				2.025	8.9	52.0
		100	100	90.8	56.4	32.0	27.5	25.0	17.2						
4	Subbase material: 2 units+ 25% of 0.425mm sieve passing soil from type 2 soil	100	100	90.1	65.7	43.0		33.0	25.9	37	29	8	1.980	9.7	49.0
		100	100	90.1	65.7	43.0	35.2	33.0	25.9						
5	Subbase material: 2 units+ 30% of 0.425mm sieve passing soil from type 2 soil	100	100	90.8	69.3	51.9		41.8	29.8				1.977	9.9	44.0
		100	100	90.8	69.3	51.9	45.0	41.8	29.8						
6	Subbase material: 2 units+ 40% of 0.425mm sieve passing soil from type 2 soil	100	100	95.5	67.1	58.6		42.6	30.1				1.959	10.3	40.0
		100	100	95.5	67.1	58.6	49.7	42.6	30.1						
7	Subbase material: 2 units+ 50% of 0.425mm sieve passing soil from type 2 soil	100	100	91.1	79.6	62.5		49.0	31.2	38	29	9	1.972	11.1	38.0
		100	100	91.1	79.6	62.5	54.5	49.0	31.2						
8	Subbase material: 2 units+ 60% of 0.425mm sieve passing soil from type 2 soil	100	100	93	76.3	60.7		49.4	32.4				1.952	11.6	37.0
		100	100	93	76.3	60.7	54.3	49.4	32.4						
9	Subbase material: 2 units+ 75% of 0.425mm sieve passing soil from type 2 soil	100	100	94.4	74.3	58.1		46.8	31.9				1.940	11.8	30.0
		100	100	94.4	74.3	58.1	55.1	46.8	31.9						
10	Subbase material: 2 units+ 90% of 0.425mm sieve passing soil from type 2 soil	100	100	93.9	77.6	64.5		52.5	37.2				1.917	12.2	25.0
		100	100	93.9	77.6	64.5	59.3	52.5	37.2						

SAMPLE NO	Type of Material :		4 day soak Swell % for mould with 10 blows	4 day soak Swell % for mould with 30 blows	4 day soak Swell % for mould with 65 blows
1	**Subbase material**	**Stock pile**	0.21	0.11	0.11
2	**Subbase material: 2 units + 05% of 0.425mm sieve passing soil from type 2 soil**	**5% Add**	0.16	0.14	0.10
3	**Subbase material: 2 units + 15% of 0.425mm sieve passing soil from type 2 soil**	**15% Add**	0.16	0.14	0.10
4	**Subbase material: 2 units + 25% of 0.425mm sieve passing soil from type 2 soil**	**25% Add**	0.20	0.10	0.09
5	**Subbase material: 2 units + 30% of 0.425mm sieve passing soil from type 2 soil**	**30% Add**	0.18	0.14	0.10
6	**Subbase material: 2 units + 40% of 0.425mm sieve passing soil from type 2 soil**	**40% Add**	0.19	0.14	0.10
7	**Subbase material: 2 units + 50% of 0.425mm sieve passing soil from type 2 soil**	**50% Add**	0.22	0.15	0.11
8	**Subbase material: 2 units + 60% of 0.425mm sieve passing soil from type 2 soil**	**60% Add**	0.20	0.15	0.10
9	**Subbase material: 2 units + 75% of 0.425mm sieve passing soil from type 2 soil**	**75% Add**	0.23	0.18	0.12
10	**Subbase material: 2 units + 90% of 0.425mm sieve passing soil from type 2 soil**	**90% Add**	0.25	0.19	0.13

Appendix C: Soil Classification in Samples

USCS Soil Classification for soil samples

Sample No.	Gravel %	Sand %	Fines %			A-line PI=0.73(LL-20)		Group Symbol		Group Name
1	29.5	58.0	12.5	Gravel<Sand	Fines>12%	8.76 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
2	34.3	51.6	14.1	Gravel<Sand	Fines>12%	8.76 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
3	43.6	39.2	17.2	Gravel>Sand	Fines>12%	8.76 >7	Below A-line	GM	Sand≥ 15%	Silty gravel with sand
4	34.3	39.8	25.9	Gravel<Sand	Fines>12%	12.41 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
5	30.7	39.5	29.8	Gravel<Sand	Fines>12%	12.41 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
6	32.9	37.0	30.1	Gravel<Sand	Fines>12%	12.41 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
7	20.4	48.4	31.2	Gravel<Sand	Fines>12%	13.14 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
8	23.7	43.9	32.4	Gravel<Sand	Fines>12%	13.14 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
9	25.7	42.4	31.9	Gravel<Sand	Fines>12%	13.14 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel
10	22.4	40.4	37.2	Gravel<Sand	Fines>12%	13.14 >7	Below A-line	SM	Gravel≥ 15%	Silty sand with gravel

AASHTO Classification of soil samples

Sample No.	No. 200 sieve passing	LL Value of sample	PI Value of sample	No. 200 sieve Passing	LL	PI	Group Classification	Usual types of significant constituent materials	General Rating	Group Index GI
1	12.5	32	7	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
2	14.1	32	7	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
3	17.2	32	7	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
4	25.9	37	8	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
5	29.8	37	8	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
6	30.1	37	8	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
7	31.2	38	9	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
8	32.4	38	9	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
9	31.9	38	9	≤35 Granular material	≤40	≤10	A-2-4	Silty or clayey gravel and sand	Excellent to good	0
10	37.2	38	9	>35 Silt-clay material	≤40	≤10	A-4	Silty Soil	Fair to poor	0

Appendix D: Sample Questionnaire Form and Summary of Survey

Note: Refer Questionnaire Page 1

Note: Refer Questionnaire Page 2

Note: Refer Questionnaire Summary

Appendix E: Prediction of CBR Using the Model

CBR = 76.062 - 0.448 x(300µm passing and 75µm retain) - 1.051 x 75 µm passing

	Test No	300µm passing	75µm passing	300µm passing & 75 µm retain %	CBR value	Predicted CBR value by Equation
1	RDC/A15/Soil/037	26.8	13.3	13.5	32	56.0
2	RDC/A15/Soil/038	33.2	17.9	15.3	35	50.4
3	RDC/A15/Soil/062	24.6	8.3	16.3	37	60.0
4	735/S	25.0	21.0	4.0	34	52.2
5	733/S	14.0	8.0	6.0	31	65.0
6	719/S	31.0	30.0	1.0	33	44.1
7	729/S	13.0	8.0	5.0	30	65.4
8	725/S	22.0	15.0	7.0	30	57.2
9	716/S	24.0	19.0	5.0	36	53.9
10	709/S	21.0	17.0	4.0	30	56.4
11	702/S	22.0	15.0	7.0	30	57.2
12	692/S	35.0	28.0	7.0	40	43.5
13	687/S	17.0	12.0	5.0	31	61.2
14	786/S	18.0	12.0	6.0	35	60.8
15	687/S	5.0	4.0	1.0	35	71.4
16	747/S	24.0	19.0	5.0	32	53.9
17	702/S	22.0	15.0	7.0	30	57.2
18	692/S	35.0	28.0	7.0	40	43.5
19	687/S	17.0	12.0	5.0	31	61.2
20	683/S	29.0	22.0	7.0	32	49.8
21	656/S	10.0	7.0	3.0	30	67.4
22	675/S	16.0	14.0	2.0	32	60.5
23	676/S	18.0	18.0	0.0	31	57.1
24	672/S	24.0	4.0	20.0	32	62.9
25	671/S	24.0	4.0	20.0	40	62.9
26	653/S	3.0	1.0	2.0	31	74.1
27	640/S	10.0	7.0	3.0	46	67.4
28	645/S	20.0	14.0	6.0	36	58.7
29	642/S	22.0	15.0	7.0	30	57.2
30	639/S	17.0	14.0	3.0	32	60.0
31	635/S	14.0	9.0	5.0	36	64.4
32	637/S	14.0	2.0	12.0	31	68.6
33	630/S	18.0	13.0	5.0	36	60.2
34	621/S	20.0	15.0	5.0	43	58.1
35	628/S	13.0	10.0	3.0	32	64.2
36	615/S	22.0	12.0	10.0	30	59.0
37	605/S	17.0	11.0	6.0	31	61.8
38	597/S	19.0	13.0	6.0	40	59.7
39	581/S	18.0	13.0	5.0	36	60.2
40	569/S	10.0	8.0	2.0	38	66.8