INVESTIGATION OF A REALATIONSHIP BETWEEN SOAKED CBR AND DCP CBR VALUE FOR DIFFERENT TYPES OF SOILS

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

"I certify that this thesis does not incorporate without acknowledgement any material previously submitted for degree or diploma in any university to the best of my knowledge and believe it does not contain any material previously published, written or orally communicated by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation. If accepted, to be make available for photocopying and for interlibrary loans and for the title and summary to be made available to outside organization "

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ABSTRACT

When planning and design a highway. Assessment of subgrade shear strength is very important. General practice is to measure the subgrade strength in terms of California Bearing Ratio (CBR). However CBR is an empirical method to assess the strength of compacted layers and it is possible to obtain the CBR through either laboratory or field test. But there are several limitations to the current method such as compromising the location itself and danger to the personnel performing the evaluation in hostile environments. In addition, both laboratory and field CBR methods are time consuming methods. Standard laboratory testing process requires sampling and transport of soil to laboratory and takes at least four day period for the testing procedures. Due to these reasons Dynamic Cone Penetrometer (DCP) is used in the field to minimize the CBR testing frequency and assess CBR of soil to a reasonable accuracy.

The significant advantages of the DCP test that it is a low cost, robust, quick and simple to use. Very little damage is made to the pavement being tested (effectively nondestructive) and very useful information can be obtained. One of the major advantages of the test is that the pavement is tested in the condition at which it performs under actual compaction level. The simplicity of the test allows repeated testing to minimize errors and also to account for temporal effects but it should never be used as an absolute indicator of the insitu CBR of a material in a pavement. The results should be assessed in terms of the insitu condition of material, it must always be remembered that the DCP CBR is determined at the insitu moisture contents and density of the pavement layers at the time of testing.

It was found that effect of following factor are mainly affect to change both D.C.P , field CBR, Field moisture content, Field Density ,Plasticity Index and Instrumental and manmade errors. From this research it is reveal that when PI of soil is less than ten reliable linear relationship can be formulate between Lab CBR vs. DCP CBR.

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LIST OF ABBRIVIATIONS

Abbreviation	Description
ASTM	American Society for Testing and Material
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetration Test
DN	DCP Number
DS-CBR	Disturbed Soak CBR
DU-CBR	Disturbed Unsoaked CBR
E	Elastic Modulus
FD	Field Density
FMC	Field Moisture Content
GW	Well Graded Gravel
MC	Moisture Content
LHS	Left Hand Side
MDD	Maximum Dry Density
M.S	Mean Square
OMC	Optimum Moisture Content
PR	Penetration Rate
PI	Plasticity Index
R-Sq	Coefficient of Determination
RHS	Right Hand Side
`` SCBR	Soaked CBR
S-W	Well Graded Sand
SS	Sum of Squares
TRL	Transport Research Laboratory

UCBR	Unsoaked CBR
UK	United Kingdom
UU	Undisturbed Unsoaked

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, there has been increasing number of full scale and small scale strength and stiffness measuring devices available in many parts of the world for characterizing subgrade and granular layers. Dynamic Cone Penetration test is one of the commonly used tests by the Pavement Engineers to assess the subgrade strength of the soil. DCP Test is originally developed in Australia by A.J.Scala in 1956 and later, adopted by other countries.

1.2 CBR and DCP Testing for Pavement Design

In Srilanka DCP instrument is widely used to evaluate California Bearing Ratio (CBR) value of existing subgrade at field moisture content and in-situ density. This test result is adopted in both new pavement design and upgrading of existing pavement. It is simple to use and inexpensive. During last decade, various researchers have developed modification to the testing equipment and the testing procedure .There is various types of DCP equipment are available in the world. But they are operated on the same principle. A DCP consist of 8kg weight dropping through a height of 575 mm and a 30/60 degree cone having a base diameter of 20 mm as shown in figure 1.2. Penetration of the cone is measured using calibrated scale. It is possible to measures up to 800mm depth without an extension rod and up to1200mm depth with an extension rod. It needs three operators, holding the instrument, raising and dropping the weight and recording penetration.

To assess the structural properties of the sub grade, the DCP values are usually correlated with CBR value.

1.3 CBR Test

The California bearing ratio test is penetration test meant for the evaluation of subgrade strength of pavement. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement. The CBR Test was originally developed by O.J Potter for the California Highway Department during the year 1920. It is load – deformation test performed in the field or in laboratory. CBR test procedure is specified in ASTM D 1883-05.

1.3.1 Advantages & Disadvantages of CBR Test

CBR test is an empirical test widely applied in design of flexible pavements over the world. There are some inherent advantages and disadvantages of the test.

Advantages of CBR test are given below.

1 The CBR methods adapt more quickly to pavement design and result can be immediately used than any other method.

2 It is possible to test soil with simple and portable equipment.

3 It can run tests either in the field or laboratory for design, construction Quality control, or evaluation of existing construction.

4 The test is preliminary intended for subgrades but applicable for wide range of different materials.

5 This test will help to give characteristics of strength of material.

6 Many pavement design and analysis procedures are based on CBR value.

7 Soaked, un- soaked or preferred condition of material can be measured.

8 Density, moisture variation towards the material can be measured.

9 The test is correlated to service behavior and construction methods and has been successfully used for many years.

10 The test can be performed by personnel with relatively little experience and training.

Disadvantages of CBR test are given below.

1 The laboratory and insitu test will give different result. Because physical conditions such as compaction level, moisture content and homogeneity of soil is not identical. However, comparative tests indicate that reasonable correlation of results can be obtained from field compacted materials and Samples compacted under similar conditions in the laboratory.

2 CBR test is unable to conduct, Because of added strength to highly stabilized surfaces such as asphaltic concrete.

3 Assumption of a completely saturated subgrade condition sometimes results in a too conservative factor of safety.

4 Because of many of the procedures are of an arbitrary nature, Test must be run to the exact standards in order to, design tables to be valid.

5 Test is laborious, expensive and relatively slow to conduct.

1.4 **Application of DCP Testing**

DCP test can be adopted in various stages of road works such as design construction, maintenance and rehabilitation. The important aspect concerning this is to, understand the process, theoretical background and hence the limitations and assumptions incorporated in the analysis in order to develop confidence in using the procedure.

1.4.1 Preliminary Investigations

The DCP testing can be used to investigate road subgrades prior to construction. The data produced by DCP test, include in-situ strength and thickness of subgrade layers, relative compactions, and broad indication of material types. This is quick way of determining subgrade strengths for pavement design and identifying uniform sections and the design strengths for these sections. It should be noted that the data obtained are at insitu moisture and density and this needs to be taken into account.

1.4.2 Re-gravelling and Upgrading of Unsealed Road

DCP survey of any unsealed road prior to re-gravelling indicates the existing structure and usefulness in determining the required quantity of material which need to be imported as well as any further improvement of subgrade is necessary prior to the importation such as replacement of poor material, re-compaction, scarification and recompaction etc.

1.4.3 Pavement Design

A comprehensive method of designing for light but well balance pavement structures for specific design traffic categories are summarized in catalogues. Then design strength profile is integrated with the in-situ soil strength profile to optimally utilize the in-situ material strength. Figure 1.1 shows DCP layer strength analysis report of A-09 road at 233+000 km.

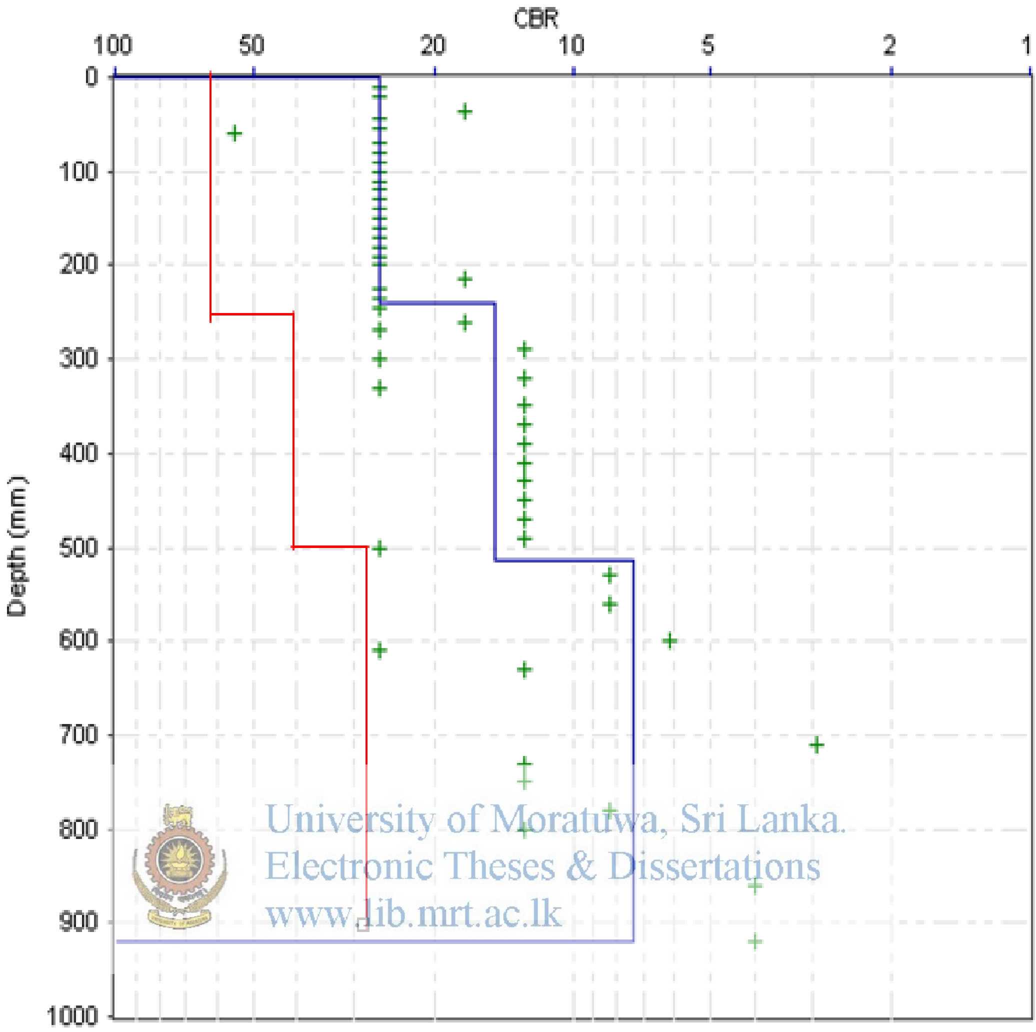

Figure 1.1 Layer Strength

Design Layer Strength

Existing Layer strength

1.4.4 Quality Control

The DCP test can be used for quality control work during construction. It can either be used for absolute comparison with the required datum, relative comparison within an area, or can be used to check the compaction quality. This is the best based on proof rolling, prior to compaction. This method involves the preparation of materials to the required moisture content and then DCP testing of the layer after each roller pass. A point will be identified at which no further densification occurs.

1.4.5 Pavement Rehabilitation

Significant work has been carried out using the DCP test for rehabilitation of Asphalt surfaced roads. Comparison with various rehabilitation methods including the asphalt institute method, Mechanistic methods and standard catalogue method have been carried out. DCP survey can provide sufficient information to design appropriate overlays. In other words DCP test will help to identify areas where overlays are insufficient and additional structural material is required.

1.4.6 Failure Investigation and Audits

The DCP test can be used to carry out investigation and technical audits. It can be used prior to any destructive testing to determine the layer thickness and condition with respect to the original design and specifications. This assists with the selection of areas for detailed investigation and allows optimization of the in-situ testing to minimize investigation cost.

1.4.7 Foundations

The DCP penetration rate has been correlated with the bearing capacity of soil for founding structures. (P Paige-Green and L Du Plessis, 2009) This provides a general indication and should not replace conventional testing. But can be useful addition to extend the results of to their test using cheap in-situ test method. One such model is:

$$\text{Bearing Capacity (KPa)} = 3426.8\,(DN)^{-1.0101}$$

1.4.8 Research

- Evaluation of the pavement performance
- Quality control

1.4.9 Advantages & Disadvantage of DCP Test

The Dynamic Cone Penetration Test provides a measure of a material's in-situ resistance to penetration. This mechanism is simple and easy to use even for the laymen. But this method of testing inherent some advantage as well as disadvantage. These can be explained as follows.

Advantage of DCP test is given below.

1 DCP is an inexpensive and easily transportable tool
2 Equipment is Portable, Durable and very easy to use
3 DCP test is Non – destructive test.
4 Test can be performed with little time.
5 Continuous record of soil strength is possible.
6 Possible to obtain the thickness of the road pavement layers.
7 Can be used for wide range of material types including granular materials.
8 Correlations are available between insitu CBR vs. unconfined compressive strength, subgrade modulus, Lime Stone Bearing Ratio and Resilient Modulus of the soil.
9 Lesser number of operators is needed to execute the test.

Disadvantages of DCP test is given below.

1 There is no specific method to measure soaked DCP value.
2 Penetration rate is not a fundamental soil property.
3 This is not suitable for gravel soils which may be bent during testing. Variability of the results can be expected to be significant in such soils.
4 This is dynamic test, which is somewhat difficult to analyze and interpret.

1.5 **Limitations of the Usage of the DCP**

However, the expected site conditions and limitations of the test are taken into account in this research. The main limitations that are likely to affect the results and interpretations of the results are given below.

1. Test on Very hard cemented layers.
2. Test on Heavily patched and repaired roads, particularly when overlaid.
3. Test on Highly variable pavement structures and on old dry asphalt.
4. Not recording of very weak layers when taking depth measurements (after every 5 blows.)
5. Poorly executed tests such as hammer not falling the full distance, non- vertical DCP and excessive movement of the depth measuring rod.

Many of these limitations are controllable if noted early enough on site.

1.6 Types of Dynamic Cone Penetrometers

Two types of dynamic cone penetrometers could be seen in the civil engineering field.

1. Manual DCP machine
2. Automated DCP machine

Figure 1.2 shows manual DCP machine, Figure 1.3 shows the automated DCP machine.

Figure 1.2 shows manual DCP machine, Figure 1.3 shows the automated DCP machine.

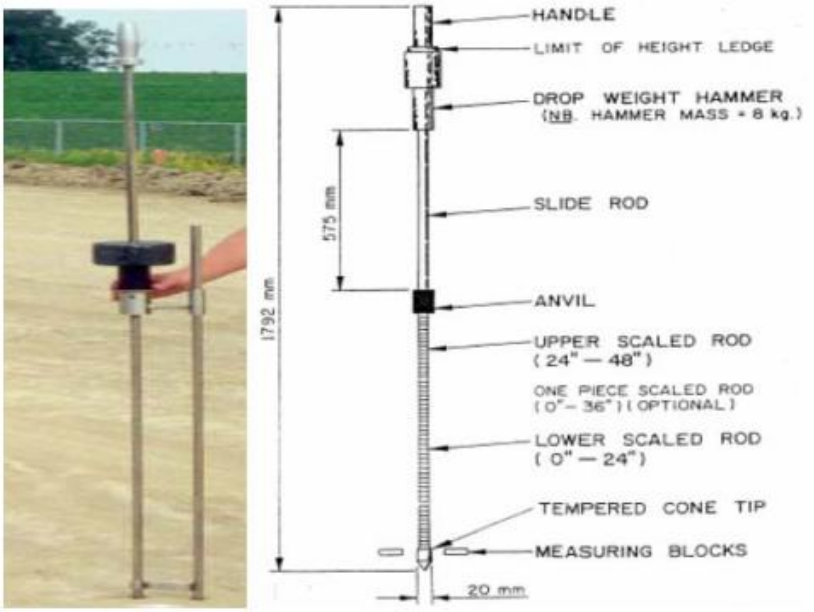

Figure 1.2 Manual DCP Equipment

(Source; Paige-Green and L.DuPlessis, 2009)

Figure 1.3 Automated DCP Equipment

(Source: P.Paige-Green and L.DuPlessis, 2009)

For good quality granular basses, reading every 5 to 10 blows are usually satisfactory, but for weaker sub-base layers and sub grades reading every 2 blows may be appropriate. There is no advantage in taking too many readings, but if readings are taken too infrequently, weak spots may be missed and it will be more difficult to identify layer boundary accurately. After completing the test the DCP is removed by tapping the hammer upwards against the handle. Care should be taken when doing this if it is done too vigorously the life of the instrument will be reduced. DCP can be driven through thin bituminous seals but thick hot mixed asphalt surfacing should be cored prior to testing the lower layers. Little difficult is normally experience with the preparation of most type of granular layer or lightly stabilized materials however it is more difficult to penetrate strongly stabilized layers, granular material with larger particles, and very dense, high quality crush stones. Penetration rates as low as .5mm/blow are acceptable but if there are measurable penetration after 20 consecutive blows it can be assumed the DCP will not penetrate the material. Under these circumstances hole can be drill through the layer using the electric or phenuematic drill. The lower payment layers then can be tested. In normal way, If only occasional difficulties are experience in penetrating in granular materials, it is worthwhile repeating any failed tests a short distance away from the original test point.

If during the test, the DCP leans away from the vertical. No attempt should be made to correct it because contact between the shaft and the sides of the hole can give rise to erroneous results. If the lean become too severe and the hammer slides down the hammer shaft, rather than dropping freely, the test should be abandon and test repeated approximately one meter away.

If the DCP is used extensively for hard materials, wear on the cone itself will be accelerated. The cone is replaceable part and it is recommended that it should be replaced when its diameter is reduced by 10 %. However, other causes of wear can also occur hence the cone should be inspected before every test. (Project Report PR/INT/277/04 TRL publication) Table 1.1 gives recommended test spacing and table 1.2 gives the test data entry format DCP test.

Table 1.1- Recommended Test Spacing

Objective	Minimum Test spacing
Routing testing for the rehabilitation of paved roads	500m or less
Area of distress in paved roads	100m or less
Upgrading of gravel roads to seal roads	500m or less
Design of spot improvements	50m or less

Table 1.2- DCP Test Data Form

<table>
<tr><td colspan="3">Chainage (Km):</td><td colspan="3">Layer Removed; None One Two</td></tr>
<tr><td colspan="3">Location;</td><td colspan="3" rowspan="2">Surface Type: Thin bituminous Seal/HMA/Unpaved/Concrete/Other</td></tr>
<tr><td colspan="3">Lane Number:</td></tr>
<tr><td colspan="3">Offset(m);</td><td colspan="3">Surface Condition:1 2 3 4 5 Unknown</td></tr>
<tr><td colspan="3">Direction:</td><td colspan="3">Strength Coefficient(if condition Unknown/)</td></tr>
<tr><td colspan="3">Cone angle 30^0/60 :</td><td colspan="3">Surface thickness(mm) if removed)</td></tr>
<tr><td colspan="3">Zero error;</td><td colspan="3" rowspan="2">Base Type(if removed):Bituminous/Cement treated / Coarse granular</td></tr>
<tr><td colspan="3">Test date;</td></tr>
<tr><td colspan="3" rowspan="2">Remarks;</td><td colspan="3">Base thickness (mm)9if removed)</td></tr>
<tr><td colspan="3">Strength Coefficient base(if removed)</td></tr>
<tr><td>No of blows</td><td>Depth(mm)</td><td>No of blows</td><td>Depth(mm)</td><td>No of blows</td><td>Depth(mm)</td></tr>
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</table>

1.7 UK-DCP Software

UK DCP 3.1 is software tools that can be used to analyzed and interpret data collected using a Dynamic Cone Penetrometer (DCP). This software is not intended to replace normal engineering judgment. The procedures used are intended for users who already have a thorough understanding of DCP analysis and are capable of deciding which method of analysis is most appropriate for individual situations.
This software was introduced by TRL publications and its open source software. Figure 1.4 represent UK DCP software interface.

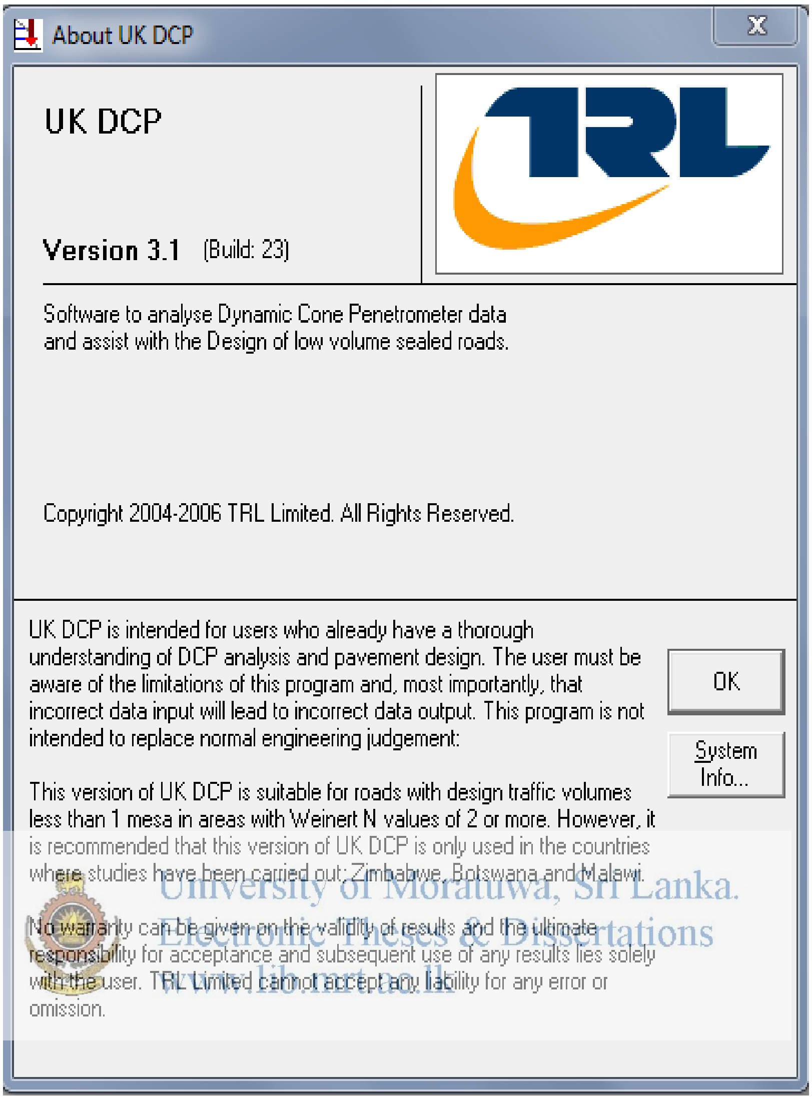

Figure 1.4:UK DCP Software

The facilities of the UK-DCP software are summarized below.

1. The software allows for maximum 999 DCP tests to be entre for any one project.
2. Data entry allows for the use of an extension rod which can penetrate up to depth of 1200mm or for harder layers to be drilled out using electrical drill.
3. Two method of analysis are provided.
   - A system procedure, which identifies changes in layer strength, up to maximum of 10 layers.
   - A user procedure- which allows the user to identify, layers of uniform strength.
4. During the analysis the software calculate the thickness and strength of each pavement layer identified. Determine the structural number.

5 After analysis the software graphically displays the results of the individual tests and allows the user to identify any tests to re analyzed.

6 Once the DCP analysis is finished the software allow to identify following.

- Base CBR
- Sub Base CBR
- Subgrade CBR
- Structural Number
- Base thickness
- Sub base thickness
- Pavement thickness
- TRL Publication

(Details are taken from software UK DCP Version 3.1 help page)

1.8 Problem Statement

Assessment of minimum in-situ CBR of an existing subgrade during the design life of the road pavement is the major problem face by the pavement designers. Because CBR at particular location is determined through lab test, But existing field conditions are not considered. This will give CBR value at optimum moisture content of the particular soil stratum. But that value may be much lower than the CBR (Design CBR) that can be experience during the design life of the pavement. In return designer will end up with design which may well above the real requirement for the location causing high cost to the country.

The other thing is when assessing the field CBR through DCP test. It is only possible to get the in-situ CBR at the testing location at particular moisture content.

But when moisture content change, it will directly affect the soil behavior. As a result of that, different CBR values will be appeared for the same location. This variation sometimes get irregular manner. In practice it is necessary to identify factors that directly affect this variation. Then subgrade and sub base assessment will be much easy and that will help to avoid from unnecessary laboratory test.

1.9 Objective

Objective of this study is to introduce relationship between design CBR and DCP values.

1.9.1 Research Scope

To accomplish objective of the research, detail soil investigation and DCP test were carry out at various location of the country. Large data set of DCP values and soil parameters were collected. After that, most probable soil parameters which assume to have much effect on bearing capacity of soil were identified and various combinations are formulated as mentioned below.

Finally by using the statistical software, reliability of these combinations has been assessed and then most satisfactory combination is adopted for road design.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

There have been various researches done to formulate relationship between in-situ CBR with DCP value. Numerous publications appeared in many local and international journals and other literature. However basic underline theories in most of these publications take similar nature. But, the most important thing is assessing design CBR of soil subgrade according to prevailing site condition.

2.2 Correlation between Soak CBR Value and DCP CBR Value

Correlation between Soak CBR value and CBR value Obtained with Dynamic Cone Penetrometer was done by Kaur, K. S. Gill, and B. S. Walia (2012) .As explain in ASTM-D6957-3(2003), the DCP tests were conducted at all six locations. Series of test performed in the field and laboratory. The following tests were conducted in this study.

- ❖ In situ density test (Sand replacement method)
- ❖ DCP test (Soaked condition)
- ❖ Sieve Analysis
- ❖ Atterberg's Limit.
- ❖ Laboratory CBR test (Soaked Condition at in situ density)

2.2.1 Sample Preparation for Soaked CBR Test

To find the soaked CBR value at in-situ density, specimens were prepared in the laboratory by varying the number of blows at different compaction levels. In this study, four compaction levels i.e. 10, 25, 35 and 55 blows were adopted for different percentage of water content. Then in situ densities were calculated for the different compaction levels and the graph is plotted between the in situ density and number of blows. Hence, the numbers of blows calculated from that graph, corresponding to the desired in-situ density were used to prepare the sample in the CBR moulds. Table 2.1 indicates dry densities at four compaction levels. Figure 2.1 shows a typical variation between the dry density and the number of blows. Graph was developed by using statistical software -R. Similar results were obtained for the other locations.

Table 2.1 Dry Density for Different No of Blows
(Source: http://www.euroasiapub.org/IJREAS/Feb2012/122.)

Sieve No	No of Blows	Dry Density (Kg/m3)
1	10	14.20
2	25	16.65
3	35	17.72
4	55	19.40

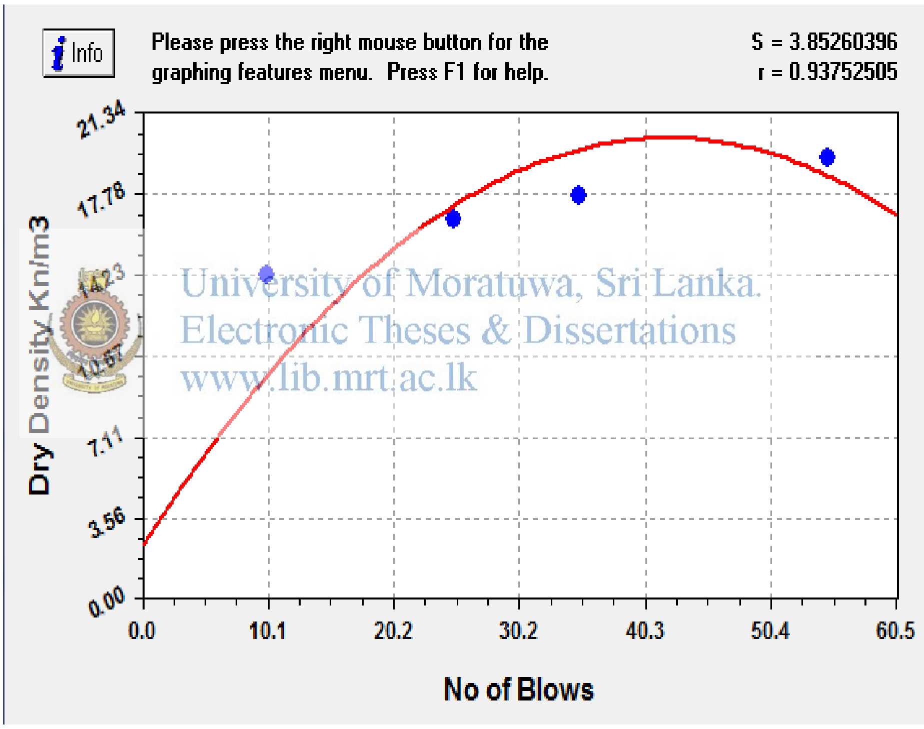

Figure 2.1 Dry Densities for different No of blows

2.2.2 Soak CBR Vs Soak DCP CBR correlation

The other tests wer performed in the laboratory according to IS Code (Indian Standard). The sieve analysis and the Atterberg's limits were carried out in the laboratory. Sand replacement tests were performed at each location in the field to find the in situ density. The DCP tests were done on all six locations for soaked condition at existing sub grade surface to calculate the CBR value at in situ densities. At every location three different points were selected and the average CBR values from these three locations were calculated based on Dynamic Cone Penetration Index(DCPI).

To conduct DCP test in soaked condition, the 3m x 3m area was flooded with water by constructing dykes around that area. The sites were kept flooded for 8 hrs before conducting DCP test, because the soil tested was silty sand. Measurement for soil resistance was done in terms of DCPI (mm/blow). For 500 mm penetration of cone, the numbers of blows were counted and then penetration per blow was calculated. To determine the C.B.R. value, following co-relation was used, which is suggested by ASTM 6951-3(2003).

CBR = 1.12 (DPI)/ 292 ---------------(1)

Where DPI is Dynamic Cone Penetration Index and it is equal to penetration per blow.

2.2.3 Results

Table 2.2 shows the results of various tests performed in laboratory and in the field

Table 2.2 Tests results
(Source: http://www.euroasiapub.org . 2001)

Chainage Km	In situ W.C (%)	O.M.C(%)	MDD (KN/ M^3)	In situ D.D(KN/ M^3)	% Compa:	Sand(%)	L L	P.I
0	8,69	9.8	19.10	17.9	93.71	65	19	NP
1	5.26	9.5	19.06	18.1	94.96	66	18	NP
2	3.62	9.8	19.02	16.4	85.4	60	19	NP
3	7.56	10.2	19.36	17.2	88.8	58	20	NP
4	2.0	9.9	19.25	14.2	73.76	52	18	NP
5	2.0	9.85	19.25	17.7	91.95	55	18	NP

It can be observed that soil at all six locations are almost uniform with sand content varying from 52% to 66%. Nature of soil is non-plastic. The liquid limit is raging from 18% to 20%. In situ moisture content lies in the range of 2.04% to 8.69% and in situ density at that locations are varying from 3.89% to 8.6%. It is observed from the table given below that DCPT based on CBR values for soaked condition is less than the CBR values obtained for soaked CBR tests. This is due to higher confinement pressure in the rigid mould using in the test procedure of soaked CBR tests. Table 2.3 shows soak CBR taken based on soak DCP test with conventional soaked CBR.

Table 2.3 Comparison of CBR values based on Soaked DCPT with conv. soaked CBR values

Location Nos	Soak CBR Value as Code (%)	Soak CBR Value as DCP(%)	% Difference
1	6.9	5.75	16.67
2	8.6	7.49	12.91
3	5.98	4.9	18.06
4	7.07	5.75	18.67
5	3.89	3.24	16.71
6	7.39	5.91	20.03

It has been observed from the above table, that the variation between CBR value based on Soaked DCP test and conventional CBR value is in the range of 12.91% to 20.03% the graph given below is showing the relationship between the soak CBR and the soak DCP test base CBR at different location. Figure 6 shows the graph generated based on the values in Table 2.2. Harsh Taneja and Ashima Singh (2012).

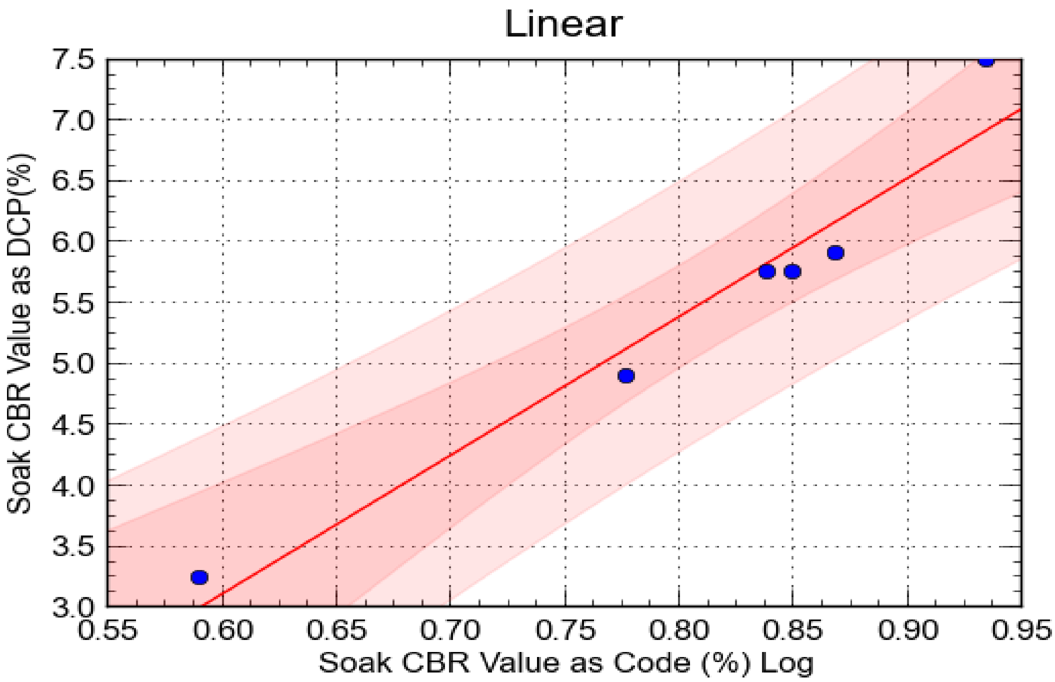

Figure 2.2 Soak CBR Value as Code (%) vs Soak CBR Value as DCP(%)

Overview

Name	Linear
Kind	Regression
Family	Linear Regressions
Equation	y = a + b*x
Indep. Vars	1
Standard Error	0.370211
Correlation Coeff. (r)	0.971391
Coeff. of Determination (r^2)	0.943601
DOF	4
AICC	-11.356979

Parameters

	Value	Std Err	Range (95% confidence)
a	-3.705551	1.136190	-6.860120 to -0.550983
b	11.377645	1.390792	7.516186 to 15.239103

2.2.4 Findings of The Studies

The following conclusions can be drawn on the basis of this study.

1. The soaked CBR values of uniform soils which has similar characteristics can be determined quickly and will have adequate accuracy using DCP test results.

2. For existing conditions, the in situ DCP can be conducted for determination of field CBR value for in situ density.

3. It may be helpful to control quality and achieving more uniform structural property in enhancing highway construction.

2.2.5 Review

- This analysis is quite different to the research scope. Because It tries to form a relationship between CBR (Lab) and Soak DCP CBR. But in practice it will be difficult to form soak condition at site.
- Similarity with our research to this literature is when PI value is getting low; relationship can be formed between Lab CBR and DCP CBR (Soak).

2.3. Prevailing Correlation between DCP and CBR.

2.3.1 Research Carried Out Internationally

To assess the structural properties of the pavement subgrade, the DCP values are usually correlated with the CBR value. Kelyn (1983) conducted DCP tests on 2,000 samples of pavement materials in standard moulds directly following CBR determination.

Based on his Results the following correlations were suggested. Figure 2.3 shows the relationship between penetration index and unconfined compression test.

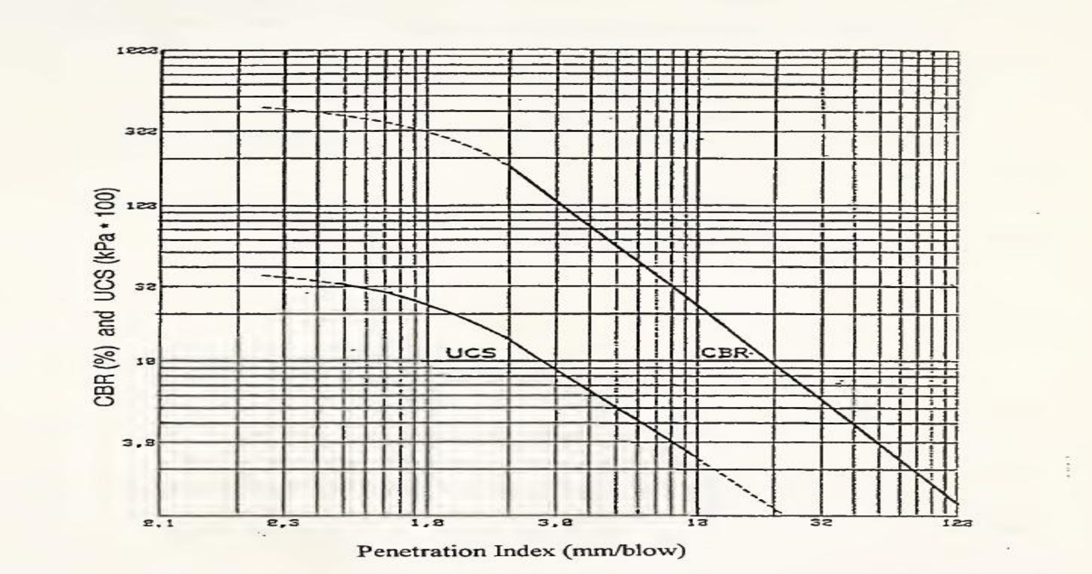

Figure 2.3 The Relationship between Penetration Index and Unconfined Compression Test (Source; Kleyn, 1983)

Log CBR =2.62 -1.27 log PR ---------- (2)

Base on the field study, Smith and Pratt (1983) suggested the following equation

Log CBR =2.56 -1.15 log PR ---------- (2)

Liveneh and Ishia (1987) conducted a correlation between the DCP -PR (Penetration Rate) and the in-situ CBR values using a wide range of undisturbed and compacted fine grained soil samples With and without saturation. Compacted granular soils were tested in flexible moulds with variable controlled lateral pressures. [5]

The equation 3 was obtained between CBR and DCP –PR·

Log CBR =2.2-0.7 1 (log PR) 1.5 ---------- (3)

Harrison also suggested equations 4 and 5 for different soils

Log CBR =2.56-1.16 log PR ---------- (4)

For clayey -like soil of PR <10 (mm/blow)

Log CBR =2.56-1.16 log PR ---------- (5)

For granular soil of PR <10 (mm/blow)

Minnesota Department of Transportation (Mn DOT) also adopted equation 6, They found that the effects of soil moisture content and dry density influence both CBR and DCP values in a similar way.

$$\text{Log CBR} = 2.456 - 1.12 (\log PR) \text{ or}$$

$$CBR = 292/PR^{1.12} \quad \text{----------} \ (6)$$

Where, PR is in mm/blow. A DCP value which is available in the literature is the correlation suggested by Army Corps of Engineers. Figure 2.4 shows correlation of DCP CBR vs. DCP Index.

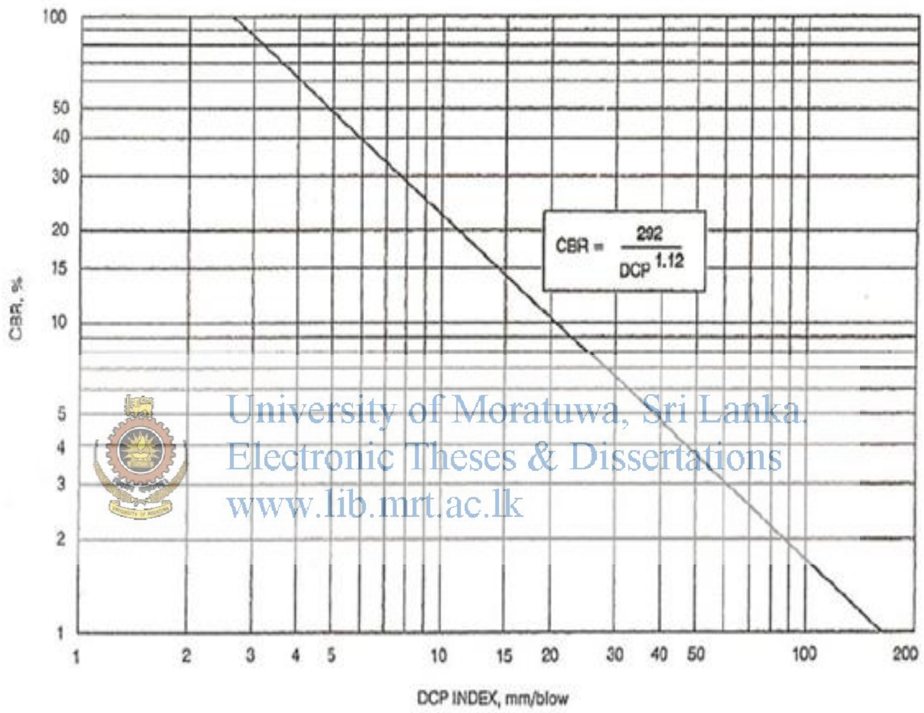

Figure 2.4 Correlation of DCP CBR vs. DCP Index (US Army and Air Force 1994)

The penetration Rate (DN (DCP no) in mm/blow) is converted to an equivalent CBR as a measure of stability and strength. Extensive researches has been carried out to investigate the correlations between DCP and CBR and to enhance the level of confidence of the DCP usage for CBR determination. The most widely accepted log-log models for converting DCP penetration rate to insitu CBR are list in Table 2.4.

Table 2.4 DCP rate -CBR Correlations

Cone angle (Deg)	Reference	Relationship
60	TRL	$Log_{10}(CBR) = 2.48 - 1.057 Log_{10}(DN)$
60	Sampson Plastic materials only PI > 6 PI < 6 PI = 6	$Log_{10}(CBR) = 5.8 - 0.95 Log_{10}(DN)$ $Log_{10}(CBR) = 2.48 - 1.1 Log_{10}(DN)$ $Log_{10}(CBR) = 6.15 - 1.248 Log_{10}(DN)$ $Log_{10}(CBR) = 5.70 - 0.82 Log_{10}(DN)$ $Log_{10}(CBR) = 5.86 - 0.69 Log_{10}(DN)$
	Livenh (1987,1991)	$Log\ CBR = 2.20 - 0.71 (log\ (DN)^{1.5}$
	Kleyn (1975)	$Log\ CBR = 2.62 - 1.27 log\ DN$
60	Harison Clayey Soils Sand S – W Gravel G – W Combined Data Soaked Samples Unsoaked Sample	$Log_{10}(CBR) = 2.81 - 1.32 Log_{10}(DN)$ $Log_{10}(CBR) = 2.56 - 1.16 Log_{10}(DN)$ $Log_{10}(CBR) = 3.03 - 1.51 Log_{10}(DN)$ $Log_{10}(CBR) = 2.55 - 0.96 Log_{10}(DN)$ $Log_{10}(CBR) = 2.81 - 1.32 Log_{10}(DN)$ $Log_{10}(CBR) = 2.76 - 1.28 Log_{10}(DN)$ $Log_{10}(CBR) = 2.83 - 1.33 Log_{10}(DN)$
30	Smith and Pratt	$Log_{10}(CBR) = 2.555 - 1.145 Log_{10}(DN)$

2.3.2 Research Carried Out Locally

DCP – CBR relationships for subgrade materials in Sri Lanka has been developed by Dr.A.G.H.J.Edirisinghe and Eng.K.A.K.Karunaprema. In that study conducted in 2001, following relationships have been developed.

- DCP – Undisturbed Unsoaked CBR (UU–CBR),
- DCP – Disturbed Unsoaked CBR (DU–CBR)

- ➢ DCP – Disturbed Soaked CBR (DS–CBR).

This particular research has been carried out on C Class Roads namely Katapitiya – Adiyathenne Road and Yatihalagala – Yahalathenna Road coming under Harispaththuwa AGA division in Kandy District. Nearly 30 sets of samples were collected from these road projects were subjected to UU–CBR, DU–CBR, DS–CBR, MC test, Particle Size Distribution test and Compaction test. CBR samples were prepared at Optimum Moisture Content corresponding to Proctor Compaction test. The soil types of the used samples were Clayey or Silty sand and very Clayey or Silty sand. The obtained data was analyzed and form following equations by using the simple regression.

Table 2.5 Equations derived from Karunaprema and Edirisinghe in 2001

Equation	Relationship Between	Equation No.
$\text{Log}_{10}\text{CBR} = 2.182 - 0.872\ \text{Log}_{10}\text{PR}$	PR and DU – CBR	(7)
$\text{Log}_{10}\text{CBR} = 1.145 - 0.336\ \text{Log}_{10}\text{PR}$	PR and UU – CBR	(8)
$\text{Log}_{10}\text{CBR} = 1.671 - 0.577\ \text{Log}_{10}\text{PR}$	PR and DS – CBR	(9)

Limits: 2 mm/blow $< PR <$ 75 mm/blow, 3 $< CBR <$ 26

In this research they have form relationship between

- ➢ CBR vs. MC
- ➢ CBR vs. DCP
- ➢ CBR vs. DD

About 23 sets of tests were carried out on the prepared soil samples by combining gravel, sand and fine particles to decided proportions. The DCP test was conducted by varying the MC and the DD which were obtained from the compaction test. To analyze the obtained results, regression methods were used. The results obtained from the research were given in table 2.6.

Table 2.6 Equations derived from Karunaprema and Edirisinghe in 2003

Equation	Relationship Between	Equation No.
$\text{Log}_{10}\,\text{UCBR} = 1.966 - 0.667\,\text{Log}_{10}\text{PR}$	UCBR vs. PR	(10)
$\text{UCBR} - \text{SCBR} = 25.6 - 11.5\,\text{Log}_{10}\text{PR}$	(UCBR – SCBR) vs. PR	(11)
$\text{UCBR} - \text{SCBR} = 67.1 - 1.5\,\text{MC} - 30.6\,\text{PR}^{1/\text{MC}}$	(UCBR – SCBR) vs. PR and MC	(12)
$\text{MC} = 0.5 + 6.9\,\text{Log}_{10}\text{PR}$	MC vs. PR	(13)
$\text{DD} = 1940.75 - 1783.3\,[1/(1+\text{MC})] - 0.06\,\text{PR}$	DD vs. PR and [1/(1+MC)]	(14)
$\text{DD}/\text{MDD} = 1.126 + 0.005\,\text{MC} - 0.156\,\text{PR}^{1/\text{MC}}$	(DD/MDD) vs. PR and MC	(15)

PR in mm/blow: MDD in kg/m^3

Finding from Research

- Therefore to form generalized equation between DCP and CBR. no of sample is to be increased based on various soil types.
- It is to be noted that above researches proposed few relationships between DCP and soil parameters to match with to Sri Lankan condition But Srilanka experience different climatic pattern and varying soil types.
- These relationships have been formulated by using lesser number of Samples.
- Sample were compacted manually to obtained pre-determined condition

Figure 2.5 shows Comparison of the relationships developed between for Log $_{10}$ UCBR versus Log $_{10}$ DCP PR for both Local and international study and Figure 2.6 shows Graph of MMD, Swelling Index vs. silt/clay.

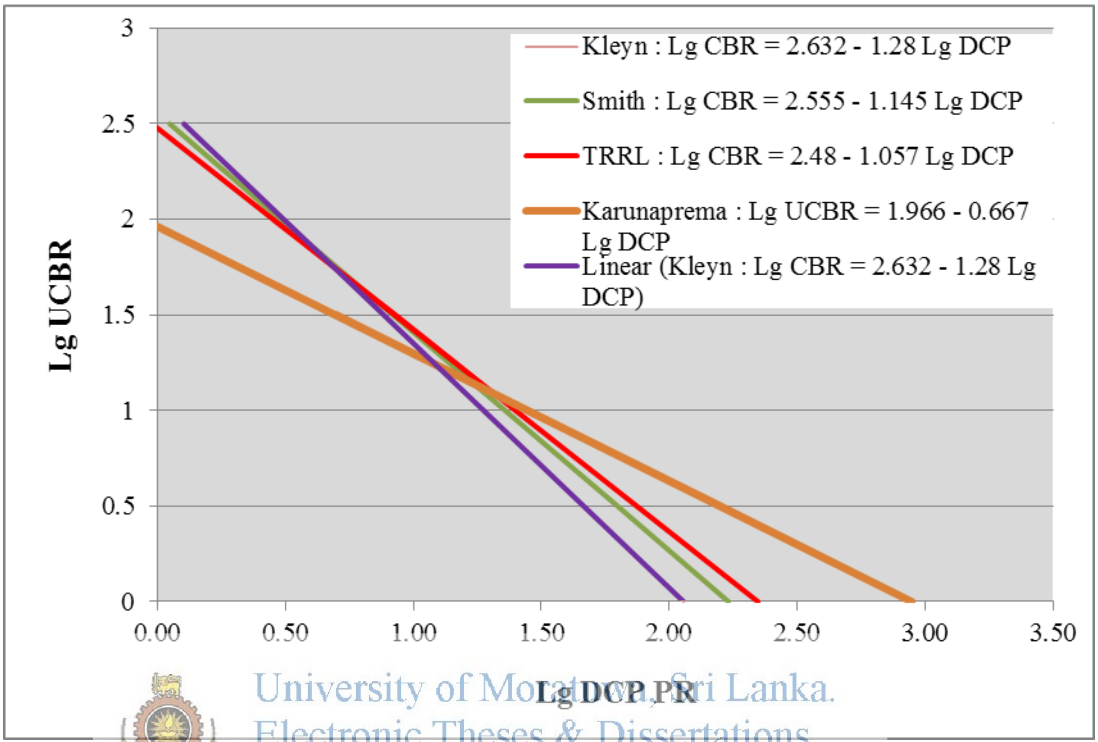

Figure 2.5 Comparison of the relationships developed both internationally and locally for Log $_{10}$ UCBR versus Log $_{10}$ DCP PR

Therefore, it can be concluded that the equation obtained in the present study (Dr.A.G.H.J.Edirisinghe and Eng.K.A.K.Karunaprema) was close to internationally developed equations by Kleyn (1975), Smith and Pratt (1983) and Van Vuuren (1969). But some deviation can be observed this may be due to involvement of limited no of samples.

However all these relationships is form based on unsoaked condition. But when clay fraction increased behavior of soil parameters such as MDD Swelling Index does not get linear relationship. Mukesh A. Patel1, Dr. H. S. Patel (2012).

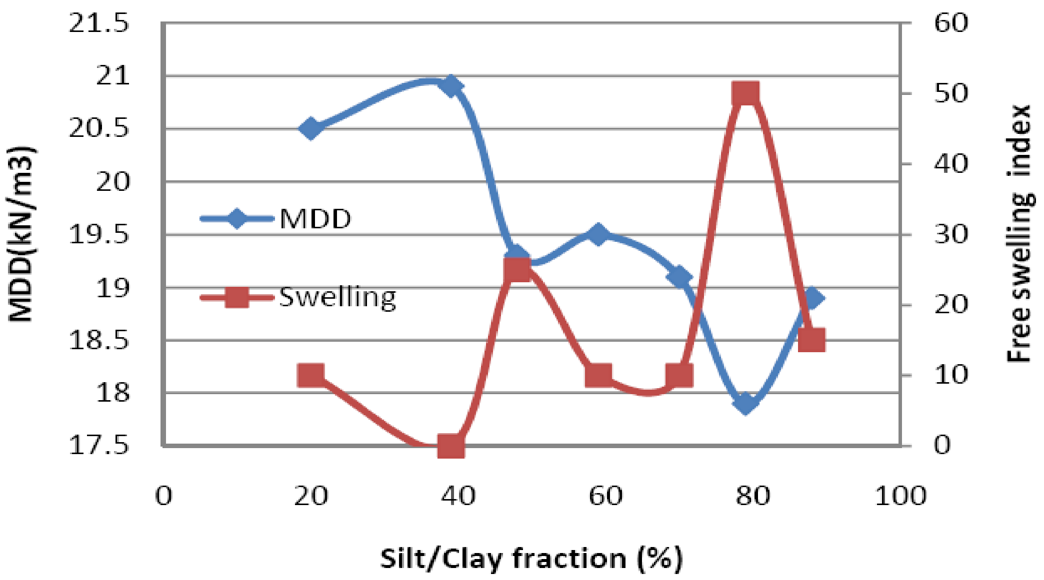

Figure 2.6 MDD, Swelling Index vs. silt/Clay

Therefore, it is understood that when relationship between soak CBR with DCP relationship to be viable, PI, clay content has to be taken into account. Please see Figure 2.6 & 2.7. Figure 2.7 shows Regression Results for Water content (%) vs. Silt fraction. Mukesh A. Patel1, Dr. H. S. Patel (2012)

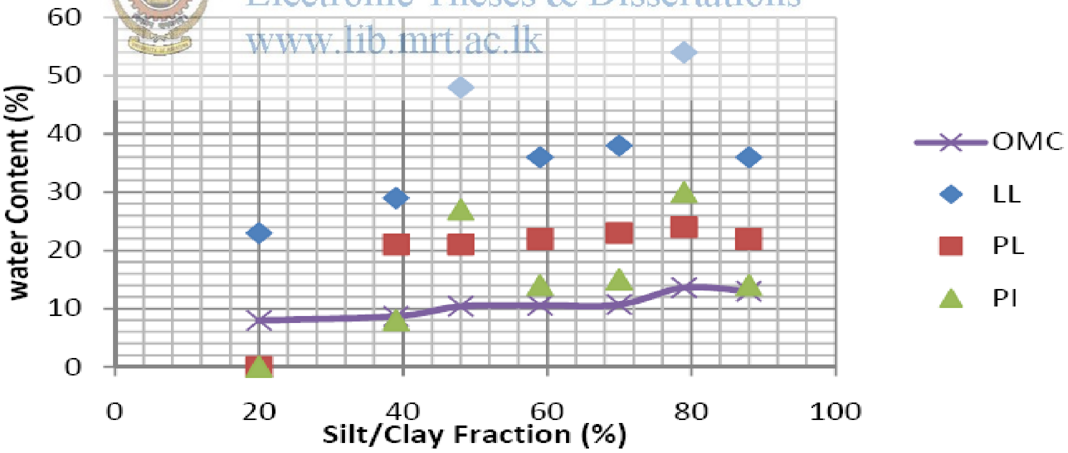

Figure 2.7 Water content (%) vs. Silt fraction

2.4 DCP Layer Strength Analysis Report

Table 2.7 shows site details of DCP layer Strength Analysis Report at Chainage of 233+000 km of A-09 road.

Project Name A-09

Table 2.7 Site Detail **(**DCP Layer Strength Analysis Report**)**

Chainage	233 + 000
Direction	LHS
Location	Shoulder /4.3 m
Core Angle	60 Degrees
Error	40mm
Test Date	16/11/2010
Surface Type	Gravel
Thickness(mm)	300
Base Type	Gravel
Surface Moisture	1.8(200-350mm)
Test No	104

2.4.1 Layer Properties

Illustration of DCP Test carried out at 233.25Km of A-9 Road. Figure 2.8 represent CBR value as function of depth (CBR vs. Depth (mm). This will give a direct indication of the pavement structure. Figure 2.9 shows No of Blows vs. Depth (mm). By determining the slope of each line, penetration rate (DN) for that layer could be determined. This could then be converted directly to in situ CBR.

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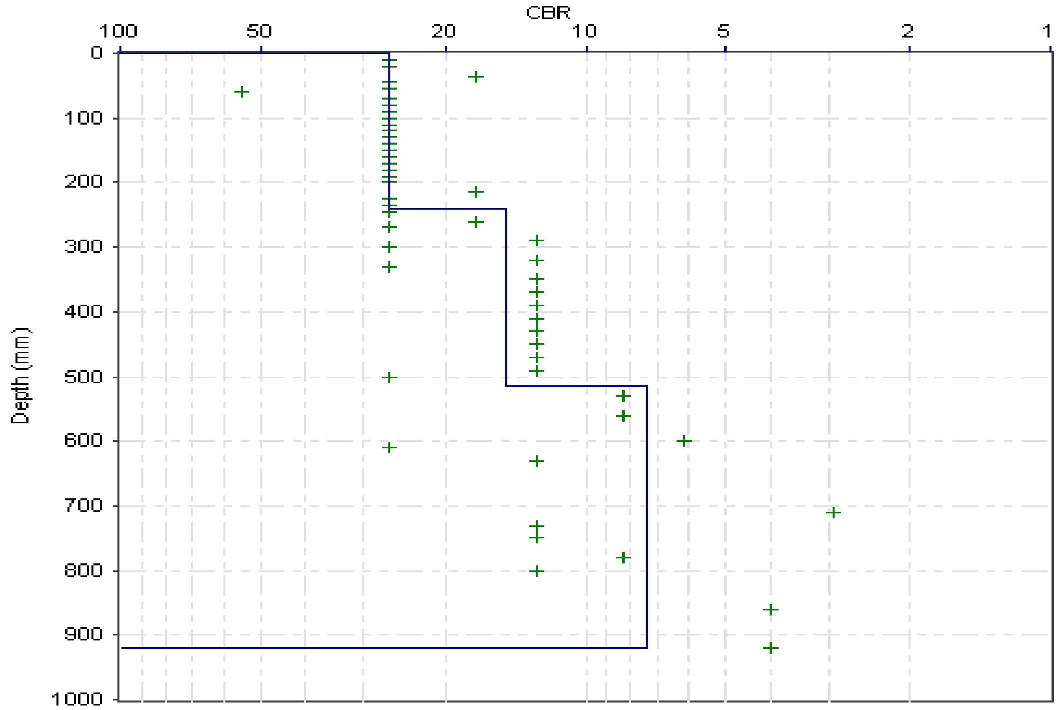

Figure No 2.8 CBR Chart (Project Name A-09)

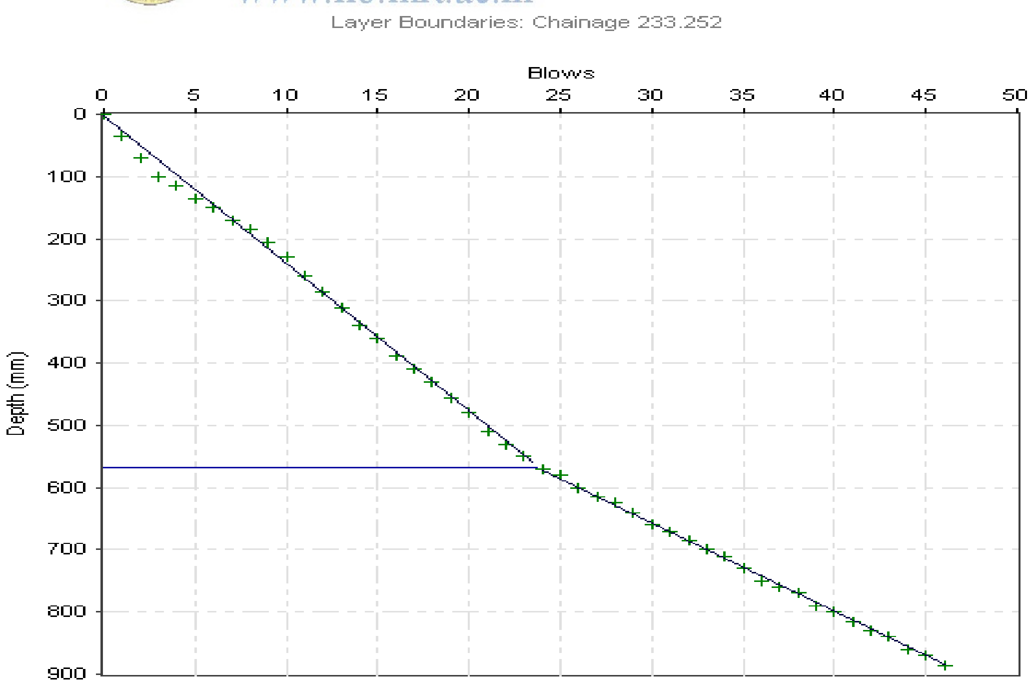

Figure 2.9 Layer Boundary Chart (Project Name A-09)

Table 2.8-CBR with Penetration Rate (Layer Properties) [A-9 Road Testing Data]

No	Penetration Rate (mm/Blow)	CBR (%)	Layer Thickness (mm)	Depth to layer Bottom (mm)
1	10.06	26	240	240
2	17.40	15	273	513
3	33.50	7	407	920

Considerable research have been carried out around the world on relating DCP penetration to strength and stiffness, both laboratory and field. Initial studies were focus on the CBR, but more recently they have been extended to unconfined compressive strength and elastic and resilient modulus. Although good correlations have been obtained, all studies have found that the results are material and moisture dependent. Equation should be used with care and only full understanding of the material properties of the soils on which the equation was developed and the soil being tested.

Although DCP interpretation is a very good indicator of in-situ strength and stiffness, inherent inaccuracies in most laboratory strength and stiffness test result, couple with material dependency of the DCP result, It imply that result should never be used as absolute indicator of the in-situ strength or stiffness of a material in a pavement or subgrade. Care must always be taken in the choice of equation used to determine the required strength or stiffness parameters. As the equations are sensitive to material properties and are typically only reliable over the range of data from which they were derived.

It should be remembered that DCP test, strength and stiffness are determine at in-situ moisture content and density of the pavement layers at the time of testing. That must be taken in to consideration, when relating these values back to those determined in a laboratory.

2.4.2 Most vulnerable site condition

However local condition play major role in any design. Therefore Researches done in foreign countries cannot be used without any Modification or Sometimes needs a fresh approach all together. However there are International research publications done specially to cover the condition Prevail in tropical countries like Srilanka In road note 8 TRRL publishers(The 1993 version Road Note 31) has develop a software (UK DCP 1.1.1) to calculate DCP to CBR value. This relationship between layer strength and CBR can be presented as mentioned in Table 2.4 in page 22.

CHAPTER 3

DESIGN PARAMETERS AND LABORATORY TEST

3 .1 Design Parameters

The main design parameter used here is the log equation, which used to transform DCP values to CBR value. However when formulating this equation, (Empherical formula) few assumptions were taken in to account.

3.2 Standard Specifications for the Test

There are three main tests that involved in this research. They are

- DCP Test — ASTM D6951 / D6951 M- 09
- CBR Test — ASTMD 1883
- Soil Investigation

  Under this there are few soil test that are very essential identify the soil characteristics Test. The test details and data are attached from page 53 to 63.

  - Plasticity Index — ASTM D4318 - 10
  - Moisture Content — ASTM D4643
  - Field density — ASTM D-6938
  - Dry Density of Soil — ASTM D7363-09

3.3 Estimation of Soil Properties

Soil is one of the most important engineering materials. Determination of soil condition is the most important and first phase of work for every type of civil engineering work. Basically, Soil properties were determined using following two methods. One is In-situ Testing. This method generally investigates much greater volume of soil more quickly than possible for laboratory test. Therefore this test have the potential to realize both cost saving and increase statistical reliability for foundation design. In addition to that, in-situ test provide more reliable correlation between soil properties and design parameters. Second one is Laboratory Testing, which is costly, comparatively slow and time consuming procedure. But it will help for detail analysis as required.

Observed soil properties are listed below.

- In-situ CBR
- D.C.P Test
- P.I Test
- O.M.C (Optimum Moisture Content)

- F.M.C (Field Moisture Content)
- F.D (Field Density)
- M.D.D (Maximum Dry Density)
- **P**article size distribution
- Atterberg Limits
- CBR
- Density
- Layer Strength
- Proctor
- Soil Classification

3.4 Establishment of Mathematical Model

After data's were tabulated and categorized based on plasticity index, MINITAB 16 statistical analysis' software have been used to find out the existence of any relationship between Soak CBR (Design CBR) vs. DCP & soil parameters.

3.5 Selection for Different Soil type

Soil mainly categorized based on plasticity Index, Fineness index.

Plasticity Index

- $0 < PI < 10$
- $10 < PI < 20$
- $PI > 20$

As mentioned in chapter 4 Data were collected and Please sea annex 1, 11 and 111

3.6 Soil Testing

A list of the laboratory test performed are mentioned in chapter 3.3

Mathematically analyzing this combination through software is much easier However following factors will effect to change DCP CBR.

- Field Moisture content
- Field Density
- Material Properties(Particle Size,Plasticity Inex and Moisture Sensitivity)
- Instrumental and other man made errors

3.7 DCP Testing

Figure 3.1 shows the selected soil stratum for the DCP test as well as four main factors that directly affect the result of the test.

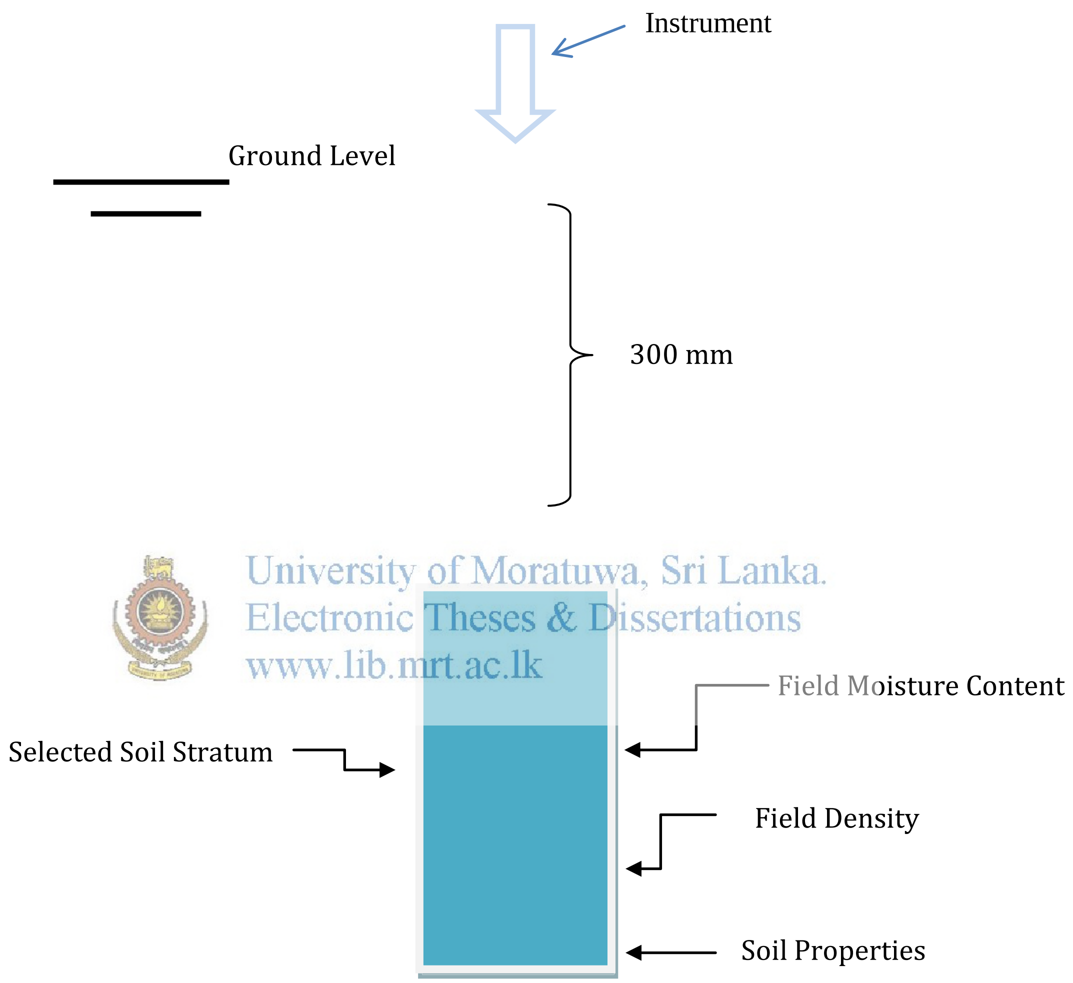

Figure 3.1 DCP Test

CHAPTER 4

METHODOLOGY

4.1 Introduction

Soil properties and other field condition such as moisture content, field density, PI, Lab CBR & DCP are collected from various pre-selected location of the country. Please see Annex 1, 11 and 111 for data. After examining these data it was revealed that there is a difficulty in building a common relationship for all soil types. Therefore Data were categorized based on the plasticity index of the soil as follows.

1) PI > 10
2) PI < 20

After that various combinations as explained in chapter 5.2 were formed and verify its confidence interval through Minitab 16 statistical software, based on above two categories. After that, best fitted combinations are identified and taken for analysis.

4.1.1 New approach to Determination of CBR of the Subgrade

Equivalent Subgrade Layer Strength New Approach to pavement Design Using Lime Established Subgrades By George Vorobieff, Greg Murphy, (2003)

Many Australian engineers have used the Japan Road Association's approach to establishing the weighted subgrade strength from stratified layers of subgrade strength. Recently, the method was presented in the use of the method is for subgrade materials within 1 meter of the underside of the sub base which shows vertical stratification. The determination of the design CBR is adjusted based on a multi-layered subgrade system.

$$CBR = \left\{ \frac{\sum_i hi\, CBRi^{.33}}{\sum_i hi} \right\}^3 \leq 20$$

CBR_i is the CBR value in the layer thickness h_i $\sum_i hi$ is taken up to depth of 1 m.

Above equation is subjected to following condition when applying for calculations.

1 Layer of thickness less than 200mm must be combined within an adjacent layer. After that CBR value must be adopted for the combined layer.
2 It is assumed that higher CBR materials will be used in the upper layer .The formula is not applicable where weaker layer are located in the upper part of the subgrade.

3 Filter layer must not be included in the calculation.

4 The maximum CBR from the use of this formula is 20%.

This equation has been adopted to calculate Insitu CBR[7]

4.2 Selection of Roads

To form reliable relationship, it is necessarily have considerable no of data. At the same time, Srilanka experience different climatic pattern such as Dry zone, Wet zone, and Intermediate zone. In addition to that, there are several soil types en-count within the country. Therefore it will be very difficult task to form relationships which satisfy entire country. However in this research Data have been collected from especially northern part of the country from consulting organizations which attach to the RDA. Data have been collected from following roads.

- A 9 Kandy - Jaffna
- A - 32
- B 68
- B 71 Roads In Jaffna
- B 74

Figure 4.1 shows Selected Roads For Analysis. Please sea annex 1 and 11 for data.

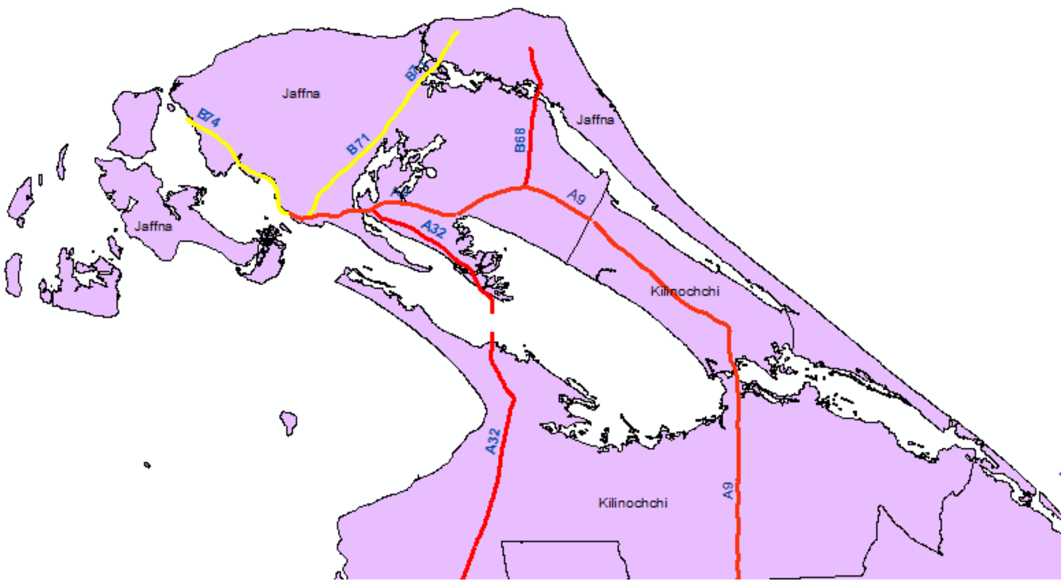

Figure 4.1 Selected Roads

4.2 Road Investigation for Pavement Design

All transportation systems are built either on, in, or with soil and products from the ground. Soil is arguably the most critical component of the transportation system, since most construction is dependent upon soil properties and characteristics. The characterization and evaluation of soil is critical to the performance of pavement structures. Therefore detail soil investigation is carried out depending on the DCP value as well as physical observation of soil properties. However, regardless the above mentioned two criteria, at least three tests per km were carried out in order to measure in situ soil densities and water content. Sometimes nuclear gauge was used for test location whereby DCP test ware conducted. For laboratory test program, soil sample are obtained from testing site. However, depending on the existence of different soil type this testing frequency was not uniform. Generally for each km, DCP test has been carried out at the interval of 100m and detail soil investigation carried out at as mentioned above.
The laboratory testing programme is carried out to observe the CBR value of the soil specially where DCP test has taken place. This study aims at characterizing the sub grade soil at sites to form relationship between soil parameters and DCP value.

CHAPTER 5

ANALYSIS AND DISCUSSION THE RESULT

5.1 Observations on Previous Analysis

In practical situation, field density and moisture content play major roll. However by evaluating the previous analysis it is understood that no researches have pay much attention to field conditions. Therefore direct conversion of in-situ DCP (CBR) values to design CBR will not give reliable result for all site conditions.

5.2 Probable Combinations

In order to find out interrelationship between soil properties, following probable combinations were formed and checked if there any viable relationship between soil properties .Viability of these relationships are checked by using statistical software.

1 LAB CBR Vs. OMC, MDD, PI

2 DCP CBR vs. FMC, FD, PI

3 DCP CBR vs. FMC

4 DCP CBR vs., FD

5 DCP CBR vs. PI

6 LAB CBR vs. DCP CBR MC (%), FD

1) When PI < 10

2) When PI > 10

5.3 Analyzing Using Minitab Software

Minitab and SPSS 17 software have been used to find out if there any relationship exists between above combinations.

5.3.1 LAB CBR Vs. OMC, MDD, PI

Regression Analysis: LAB CBR versus OMC, PI (%), MDD

The regression equation is

LAB CBR = 16.4 - 1.97 OMC - 0.781 PI (%) + 13.4 MDD

Predictor	Coef	SE Coef	T	P
Constant	16.40	30.38	0.54	0.592
OMC	-1.9748	0.8431	-2.34	0.024
PI (%)	-0.7810	0.2815	-2.77	0.008
MDD	13.39	11.83	1.13	0.265

S = 6.71238 R-Sq = 76.0% R-Sq(adj) = 74.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	5693.9	1898.0	42.12	0.000
Residual Error	40	1802.2	45.1		
Total	43	7496.2			

Observations

- R^2 (R-sq.) is less than 85% that means not relationship is not representative.
- However above equation indicate that there is some relationship.
- P value of OMC, ,MDD > Significance level (α %) Null hypothesis is true
- P value of PI (%) < Significance level (α %) Alternative hypothesis is true

Findings

- LAB CBR does not entirely depend on OMC, MDD, and PI.
- That implies there should have some other parameters which affect the lab CBR.

5.3.2 DCP (CBR) vs MC (%), FD, PI,MC (%)

Regression Analysis: DCP(FCBR) versus MC (%), FD, PI (%)

```
The regression equation is
DCP(FCBR) = 17.3 - 1.94 MC (%) + 15.1 FD - 0.906 PI (%)
```

Predictor	Coef	SE Coef	T	P
Constant	17.26	24.71	0.70	0.489
MC (%)	-1.9417	0.6922	-2.81	0.008
FD	15.08	10.64	1.42	0.164
PI (%)	-0.9061	0.3283	-2.76	0.009

```
S = 9.16904   R-Sq = 65.2%   R-Sq(adj) = 62.6%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	6292.1	2097.4	24.95	0.000
Residual Error	40	3362.9	84.1		
Total	43	9655.0			

Observations

- Result shows that when MC is increase DCP CBR will be reduced.
- R2(R-sq.) is less than 65% that means not relationship is not representative.
- However equation indicates that there is some inter relationship between parameters.

Findings

- Moisture content alone does not control the DCP CBR. There should have some other parameters.

5.3.3 DCP (FCBR) VS MC

Regression Analysis: DCP(FCBR) versus MC (%)

```
The regression equation is
DCP(FCBR) = 47.3 - 3.66 MC (%)


Predictor      Coef  SE Coef      T      P
Constant     47.297    3.690  12.82  0.000
MC (%)      -3.6623   0.5160  -7.10  0.000


S = 10.2235   R-Sq = 54.5%   R-Sq(adj) = 53.5%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  5265.2  5265.2  50.37  0.000
Residual Error  42  4389.8   104.5
Total           43  9655.0
```


Observations

- Result shows that when MC is increase DCP CBR will be reduced.
- R2(R-Sq.) is less than 54% that means not relationship is not representative.
- However equation indicates that there is some relationship between parameters.

Findings

- Moisture content alone does not control the DCP CBR. There should have some other parameters.

5.3.4 DCP (FCBR) VS

Regression Analysis: DCP(FCBR) versus FD

```
The regression equation is
DCP(FCBR) = - 82.0 + 52.8 FD
```

Predictor	Coef	SE Coef	T	P
Constant	-82.04	19.38	-4.23	0.000
FD	52.799	9.656	5.47	0.000

S = 11.5883   R-Sq = 41.6%   R-Sq(adj) = 40.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	4014.8	4014.8	29.90	0.000
Residual Error	42	5640.2	134.3		
Total	43	9655.0			

Observations

- Result shows that when FD is decrease DCP CBR will reduce.
- R-sq. is less than 85% that means relationship is not representative.
- However R-sq. has some value. It implies that above relationship cannot be discarded.

Findings

- Field Density alone does not control the DCP CBR. There should have some other parameters.

5.3.5 DCP (FCBR) VS PI (%)

Regression Analysis: DCP(FCBR) versus PI (%)

```
The regression equation is
DCP(FCBR) = 46.4 - 1.84 PI (%)


Predictor      Coef   SE Coef      T      P
Constant     46.401     3.923  11.83  0.000
PI (%)      -1.8388    0.2867  -6.41  0.000


S = 10.7769   R-Sq = 49.5%   R-Sq(adj) = 48.3%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  4777.1  4777.1  41.13  0.000
Residual Error  42  4877.9   116.1
Total           43  9655.0
```

Observations

- Result shows that when PI is increase. DCP CBR will reduce.

- R-sq. is less than 85% that means relationship is not representative.

- However R-sq. has some value. It implies that above relationship cannot be discarded.

Findings

- PI alone does not control the DCP CBR. There should have some other parameters.

5.3.6 DCP (FCBR) VS DCP CBR, MC (%), FD

When pi >10

Regression Analysis: LAB CBR versus DCP(FCBR), MC (%), FD

```
The regression equation is
LAB CBR = - 47.2 + 0.338 DCP(FCBR) + 0.491 MC (%) + 23.6 FD


Predictor      Coef  SE Coef      T      P
Constant     -47.25    15.38  -3.07  0.005
DCP(FCBR)   0.33787  0.09995   3.38  0.002
MC (%)       0.4914   0.3995   1.23  0.231
FD           23.630    7.108   3.32  0.003


S = 4.40530   R-Sq = 55.3%   R-Sq(adj) = 49.7%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       3   575.67  191.89  9.89  0.000
Residual Error  24   465.76   19.41
Total           27  1041.43
```

Figure 5.1 shows CBR vs. DCP when PI value is greater than ten. Figure 5.2 shows model information of Figure 5.1.

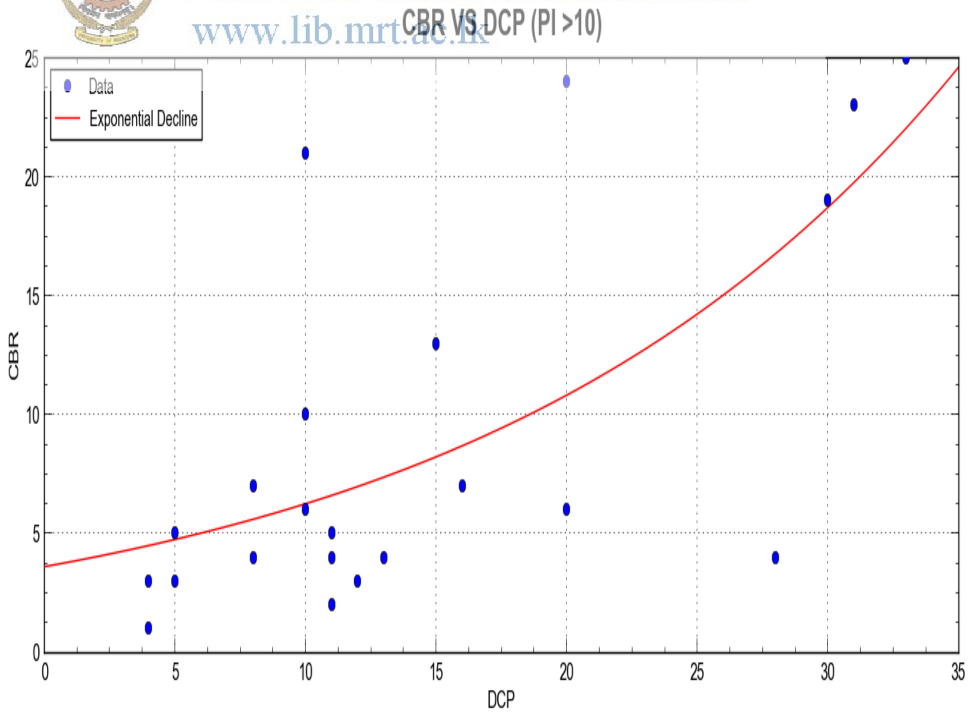

Figure 5.1 CBR VS DCP When PI > 10

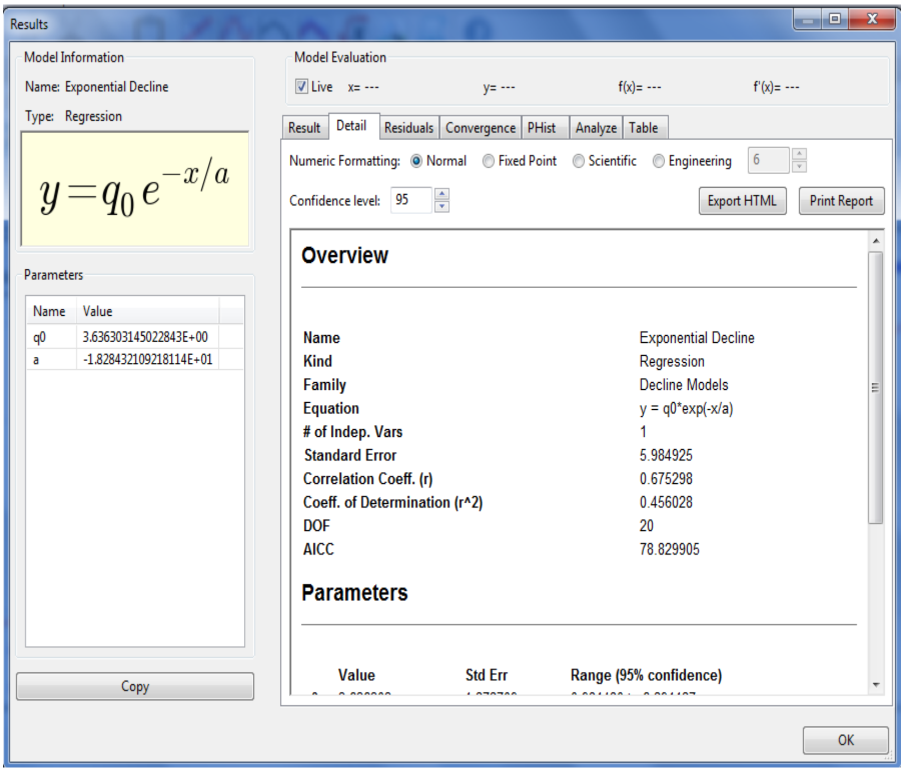

Figure 5.2 Model Information

Observation

- R^2(R-sq.) is 45% that means it is not possible to build even nonlinear relationship.
- Hypothesis Tests.
- Significant Level =0.05

H_0: Null Hypotheses H_1: Alternative Hypothesis

- Reject H_0 at α % significance level, if p-value$\leq$ α.
- Reject H_1 at α % significance level, if p-value$\geq$ α.
- Here DCP (CBR) p-value =0.002 $\leq$0.05 Null Hypothesis is rejected.
- In other words alternative Hypothesis is true.
- FD p-value = 0.02 $\leq$0.05 Null Hypothesis is rejected
- In other words alternative Hypothesis is true
- MC p-value =0.231$\geq$0.05 Alternative Hypothesis is rejected
- In other words alternative Hypothesis is true
- If Null Hypothesis is true original claim is true –There is a relationship

- If alternative Hypothesis is true original claim is not true- FD & DCP (CBR)
  But, R^2. (R-sq.) has some value that means correlation is there.

Findings

- When PI > 10. Soil properties will play major roll and difficult to build linear relationship among their properties.
- When PI is high liquid limit will be increased then soil properties such as clay content, particle size distribution will contribute lot to CBR value of that particular soil type.
- Field Density (FD) is very significant independent variable.

5.3.7 DCP (FCBR) VS DCP CBR, MC (%), FD

When pi <10

Step 1

Regression Analysis: LABCBR versus MC (%), DCPCBR, FD

```
The regression equation is
LABCBR = 7.5 - 1.79 MC (%) + 0.741 DCPCBR + 0.20 FD


Predictor      Coef   SE Coef      T      P
Constant       7.46     14.28   0.52  0.611
MC (%)       -1.795     1.202  -1.49  0.161
DCPCBR      0.74057   0.09803   7.55  0.000
FD            0.203     5.244   0.04  0.970


S = 2.78292   R-Sq = 92.6%   R-Sq(adj) = 90.7%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       3  1158.06  386.02  49.84  0.000
Residual Error  12    92.94    7.74
Total           15  1251.00
```


Observations

H_0: Null Hypotheses H_1: Alternative Hypothesis

- Reject H_1 at α % significance level, if p-value $\geq \alpha$.
- Null hypothesis is true but Coefficient of FD is not significant
- Therefore in second trial FD is omitted from the calculation.
- FD is not significant independent variable.

5.3.8 DCP (FCBR) VS DCP CBR, MC (%),

Step 2

```
The regression equation is
LABCBR = 7.93 - 1.81 MC (%) + 0.741 DCPCBR


Predictor       Coef   SE Coef      T      P    VIF
Constant       7.933     6.954   1.14  0.275
MC (%)        -1.813     1.066  -1.70  0.113  1.903
DCPCBR       0.74117   0.09297   7.97  0.000  1.903


S = 2.67391   R-Sq = 92.6%   R-Sq(adj) = 91.4%

PRESS = 181.604   R-Sq(pred) = 85.48%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       2  1158.05  579.03  80.98  0.000
Residual Error  13    92.95    7.15
Total           15  1251.00


There are no replicates.
Minitab cannot do the lack of fit test based on pure error


Durbin-Watson statistic = 2.33272
```


Observations 2

- Hypothesis Tests
- Significant Level = 0.05
- Null Hypothesis H_1: Alternative Hypothesis

All P values $\geq$ α.

- Reject H_1 at α % significance level, if p-value $\geq$ α.
- In other words Null Hypothesis is true
- If Null Hypothesis is true original claim is true

Findings

- When PI > 10. Soil properties will play major roll and difficult to build linear relationship among their properties.
- When PI is high liquid limit will be increased then soil properties such as clay content, particle size distribution will contribute lot to CBR value of that particular soil type.
- FD is not significantly independent variable.

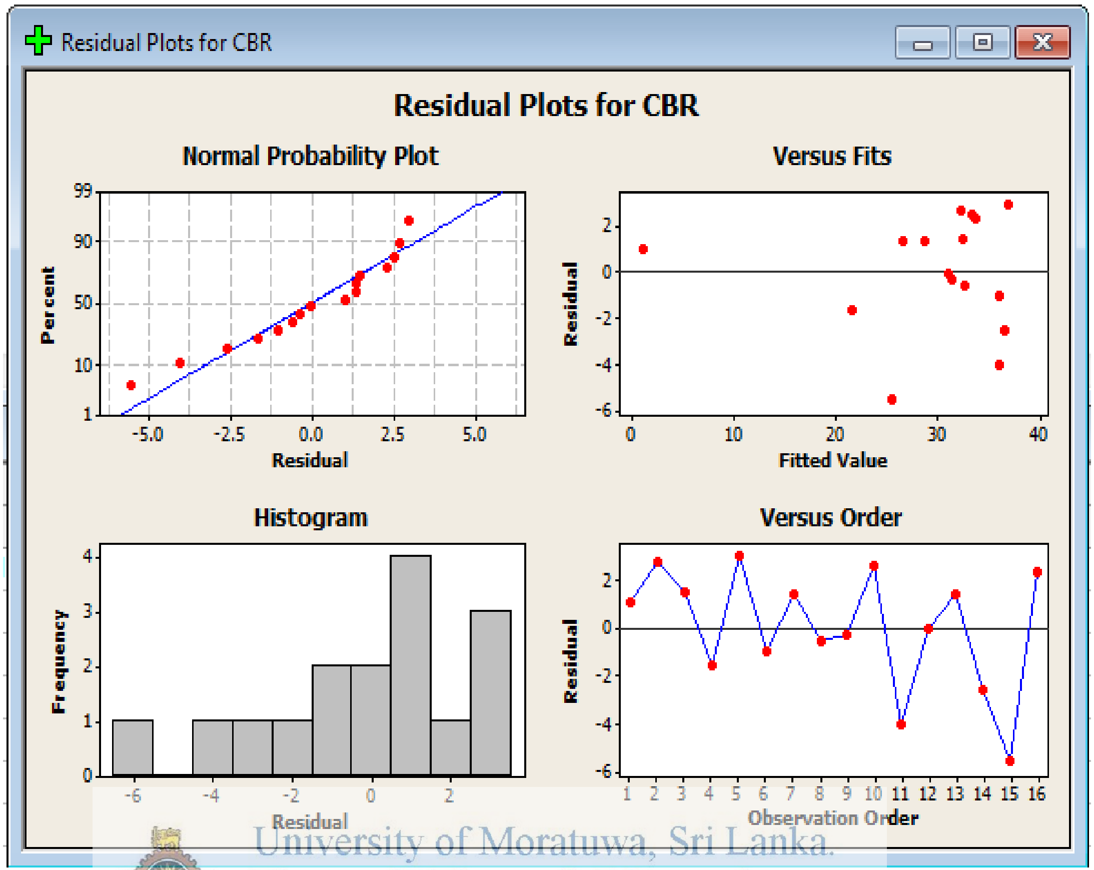

Figure 5.3 Residual Plot Lab CBR MC (%), DCP (CBR), FD

- R2(R-sq.) is greater than 93% that means relationship is representative.
- LABCBR=7.93+.741DCPCBR-1.81MC (%)
- When PI <10 DCP CBR will represent the LAB CBR value to some acceptable limit

Figure 19 shows Lab CBR vs. DCP CBR when Plasticity Index is less than 10. Figure 20 shows model information of Figure 19.

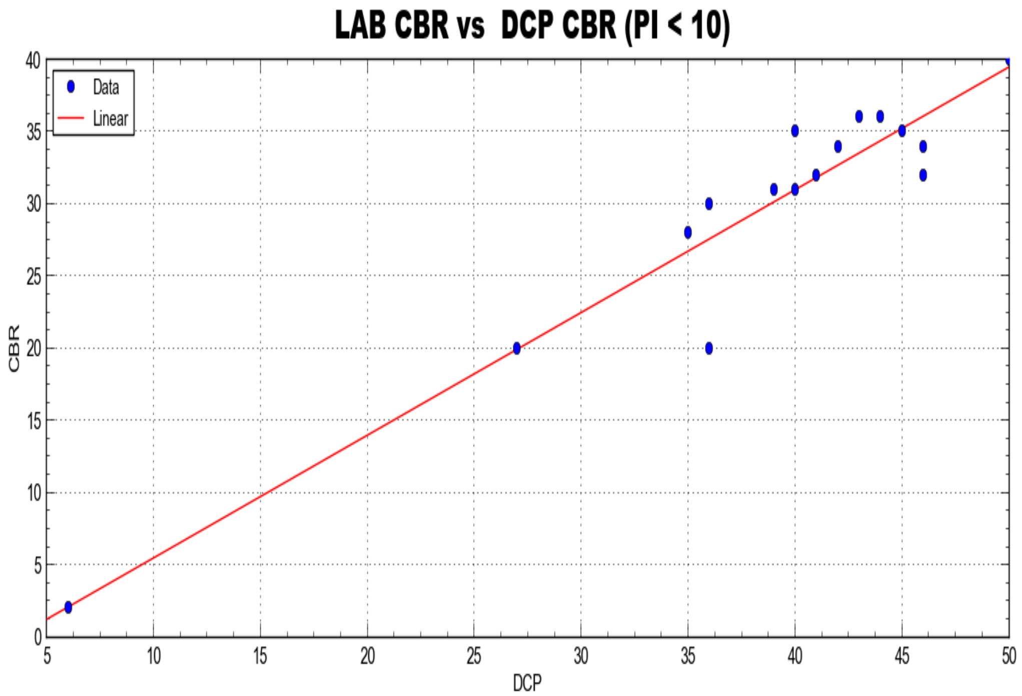

Figure 5.4 LAB CBR vs DCP CBR (PI < 10)

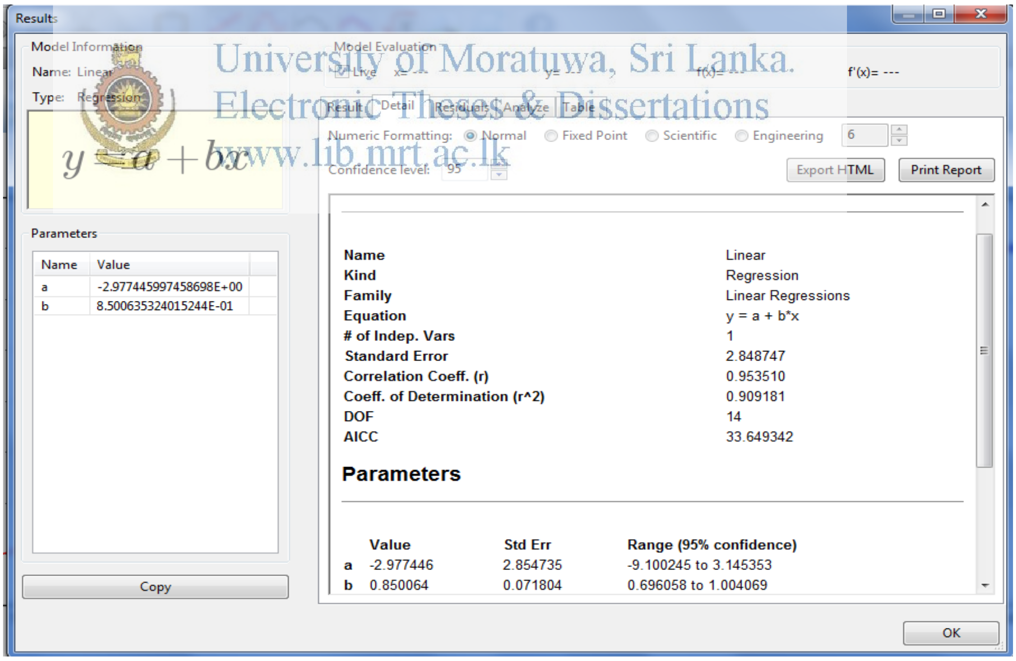

Figure 5.5 Model Information

- R2 (R-sq.) is greater than 90% that means linear relationship is exist and representative. But relationship level is comparatively lower than the LAB CBR vs. MC and DCP CBR that means moisture will play some role Evan PI is less than 10.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

DCP can be useful to predict the in-situ CBR at the time of testing. But it is difficult to formulate very representative relationship between CBR & DCP values to satisfying all site conditions. However when PI is less than 10 it is possible to build some reliable relationship. But when PI is greater than 10, reliable relationship does not exist. Therefore, it is understood that PI play major roll. Developed relationship between Lab_{CBR}, DCP_{CBR} & moisture content (MC) is as follows.

$$LAB_{CBR} = 7.93 + .741 DCP_{CBR} - 1.81 MC\ (\%).$$

For soil with PI less than 10, DCP_{CBR} and MC is sufficient to calculate Lab_{CBR} by using above linear relationship. However, When PI value is greater than 10. It is difficult to formulate linear relationship.

6.2 Recommendations

It is not possible to build common relationship between Design CBR (lab CBR) vs. DCP CBR for all soil types. However, depending on the PI value of the soil. This relationship can be formulated in such a way that when PI is getting more than ten, Relationships is not representative. Therefore following steps must be taken to analyse the situation.

1 Detail soil investigation has to be done for highway design.

2 Evan for the analysis large data sets is needed.

3 Different combinations must be adopted.

4 Equation should be used with care and thorough understanding of the material properties of soil, on which the equation was developed and the soil is being tested.

When PI is less than ten, Relationships is representative. So measuring moisture content (MC) and DCP_{CBR}, $Design_{CBR}$ can be calculated. This will avoid unnecessary testing.

It was found from these findings. That it is not possible to develop a common relationship that satisfy entire region.

REFERENCES

[1] Kleyn, E.G. (1975). *The Use of Dynamic Cone Penetrometer (DCP)*: 2/74, Transvaal Roads Department, Pretoria.

[2] Karunaprema, K.A.K., & Edirisinghe, A.G.H.J., (2001). *Dynamic Cone Penetrometer and its use in Highway Engineering.* Transactions: Institution of Engineers Sri Lanka, pp. 56-65.

[3] Smith, R.B., & Pratt, D.N., (1983). *A Field Study of in Situ California Bearing Ratio and Dynamic Cone Penetrometer Testing for Road Subgrade Investigations*. Australian Road Research, Vol.13, No.4, pp. 285-294.

[4] Liveneh, M., & Ishia, I., (1987).Pavement and Material Evaluation by a Dynamic Cone Penetrometer. *Sixth international Conference on the Structural Design of Asphalt Pavement,* Vol.1, Ann Arbor, Michigan, pp. 665-674.

[5] O'Flaherty, C.A., (1967). *Highway Engineering Vol .2* .London: Edward Arnold

[6] Road Development Authorities. Official Web Site Retrieved March, 2012, www.rda.gov.lk

[7] Taneja, & Ashima Singh. (February 2012). International Journal of Research in Engineering & Applied Sciences. Retrieved, March 30, 2012, from http://www.euroasiapub.org.

[8] Parampreet Kaur, K. S., Gill, B. S., Walia, (2012).Correlation between soaked CBR value and CBR value obtained with Dynamic Cone Penetrometer (DCP) test. *International Journal in Research engineering & Applied Sciences*. Retrieved March 30, 2012, from http://www.euroasiapub.org

[9] Karunaprema, K.A.K., & Edirisinghe, A.G.H.J., (2003). *A Laboratory Investigation on the Relationship between Dynamic Cone Penetrometer value and Soaked California Bearing Ratio*. Transactions: Institution of Engineers Sri Lanka, pp. 120-122.

[10] Mukesh, A. P., & Dr. Patel, H.S., (2012). *Correlation between Physical Properties and California Bearing Ratio Test on Soils of Gujarat Region in*

Both in Soak and Unsoak Condition. Retrieved April 30, 2013, from 1map_technical@yahoo.co.in, 2dr.hspatel@yahoo.com

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LIST OF ANNEXES

ANNEX 1

Following Soil properties were calculated and categorizes based on PI values .These values are listed below in two tables as When PI > 10 and PI <10

1.1 Soil Properties When PI >10

Chainage	LL (%)	PL (%)	PI (%)	MDD	OMC	CBR	FD	MC (%)	DCP
230+250	26	15	11	2.04	10	4	1.976	8.6	11
231+500	30	14	16	1.88	13.5	2	1.88	10.2	11
235+500	32	18	14	1.96	11	4	1.953	11.4	8
236+250	34	17	17	1.85	13	4	1.791	10.2	13
237+500	39	18	21	1.88	12.5	7	1.817	8.3	8
238+300	32	17	15	1.9	12	5	1.876	10.3	5
239+500	37	18	19	1.73	17.4	3	1.551	14.9	4
240+250	31	16	15	1.86	13.4	1	1.709	9.9	4
243+500	42	22	20	2	12.1	3	1.915	8.6	5
248+250	24	11	13	2.03	9.8	7	2.067	3.8	16
250+250	35	18	17	1.85	13	6	1.913	10.2	20
251+500	24	12	12	2.05	9.5	6	1.832	9.3	10
254+250	24	11	13	1.99	10	5	1.944	8	11
261+500	39	19	20	2.23	7.5	21	2.184	2.8	10
262+500	32	16	16	2.15	9.3	10	2.135	7.2	10
3+500	31	17	14	2.135	8.5	24	1.954	5.7	20
264+000	32	16	16	2.15	9.7	13	2.104	8.8	15
265+000	30	15	15	2.207	7.8	23	2.15	6.4	31

265+500	29	14	15	2.17	7.5	25	2.04	6	33
267+000	24	13	11	2.15	6.6	19	2.004	8.3	30
218+250	28	15	13	1.98	11.3	3	1.896	7.3	12
219+540	36	17	19	1.92	12.7	4	1.719	2.7	28
221+500	55	27	28	1.97	12.8	7	1.884	10.8	13
222+290	33	15	18	1.86	14.3	4	1.89	6.7	8

When PI value is getting more than 10 CBR DCP relationship is irregular that means there is no linear relationship between these two values. The most probable

1.2 Soil Properties When PI < 10 (A-9 Road)

Chainage	LL (%)	PL (%)	PI (%)	MDD	OMC	CBR	FD	MC (%)	DCP
252+250	38	28	10	2	10	2	1.781	6.3	6
257+000	16	13	3	2.278	6.9	35	2.067	2.9	40
258+500	20	12	8	2.29	6.2	34	2.153	3.6	42
260+000	20	12	8	2.285	6.1	20	2.245	3.5	27
266+500	19	13	6	2.21	5.3	40	2.132	4.4	50
267+390	16	13	3	2.29	6.5	35	2.25	2.9	45
268+000	20	12	8	2.21	7	30	2.18	3.3	36
268+900	19	12	7	2.61	7	32	2.59	3.2	41
268+500	18	13	5	2.05	6.2	31	2.01	3	39
269+000	17	14	3	2.13	6	36	2.1	3.5	43
269+000	16	11	5	2.16	6.2	32	2.14	3.3	46
269+400	21	13	8	2.05	7.2	31	2.035	3.6	40
270+150	20	11	9	2.15	8	28	2.1	4	35
270+950	17	12	5	2.17	6.1	34	2.15	3	46
271+400	25	15	10	2.01	11	20	1.98	5	36
272+000	16	13	3	2.31	6.1	36	2.28	3.8	44

ANNEX 2

2.1 DCP Summary of LHS Widening Section of A-9 Road

Chainage	Side	Layer	Thickness / [mm]	CBR	Design CBR
122+260	RHS	1	185	9.5	8
		2	277	6.2	
		3	162	4.5	
		4	135	9.3	
		5	176	17.7	
		6	155	31.0	
122+760	LHS	1	185	12.7	8
		2	245	5.8	
		3	150	8.3	
		4	100	18.2	
		5	401	12.0	
123+010	RHS	1	160	9.4	7
		2	830	6.5	
		3	80	12.7	
123+100	LHS	1	75	24.6	6
		2	95	13.4	
		3	160	7.7	
		4	750	6.2	
123+260	RHS	1	350	10.8	8
		2	130	15.9	
		3	255	7.8	
123+280	LHS	4	35	22.5	6
		5	159	6.2	
		6	50	26.5	
		7	185	10.9	
123+280	LHS	1	145	10.4	6
		2	165	7.5	
		3	175	20.9	
		4	75	13.6	
		5	159	7.8	
		6	220	4.4	
		7	150	10.1	
123+540	LHS	1	95	28.0	1
		2	95	36.9	
		3	210	14.7	
		4	260	9.6	

Chainage	Side	Layer	Thickness / [mm]	CBR	Design CBR
123+540	LHS	5	159	21.4	13
		6	100	34.9	
		7	170	19.9	
123+580	LHS	1	140	24.5	10
		2	195	17.3	
		3	55	34.2	
		4	420	9.5	
		5	159	42.7	
		6	40	12.7	
123+770	LHS	1	310	8.9	13
		2	60	31.2	
		3	270	11.2	
		4	230	20.4	
		5	159	16.2	
123+790	LHS	1	40	33.5	5
		2	120	8.3	
		3	610	4.3	
		4	160	9.4	
		5	159	11.1	
124+030	RHS	1	50	10.1	6
		2	260	23.3	
		3	125	12.2	
		4	195	2.4	
		5	159	21.4	
		1	45	11.2	
		2	120	19.5	
124+100	LHS	3	110	9.1	4
		4	795	3.3	
124+270	RHS	1	250	11.1	9
		2	280	3.4	
		3	230	25.3	
		4	130	11.7	
		5	159	23.2	
124+290	LHS	1	120	33.5	8
		2	170	24.8	
		3	85	11.9	
		4	435	8.0	
		5	90	26.5	
		6	130	44.0	
124+570	RHS	1	180	5.4	8
		2	360	3.3	
		3	270	6.4	
		4	115	27.7	

Chainage	Side	Layer	Thickness / [mm]	CBR	Design CBR
124+595	LHS	1	100	18.2	16
		2	135	11.2	
		3	175	19.2	
		4	210	14.7	
		5	340	19.9	
		6	17	100.4	
124+720	RHS	1	45	11.2	6
		2	140	5.2	
		3	425	3.3	
		4	215	5.7	
		5	220	15.2	
124+790	RHS	1	105	14.7	8
		2	430	6.3	
		3	245	4.9	
		4	85	24.8	
		5	105	30.5	
		6	125	20.9	
125+010	RHS	1	70	10.8	5
		2	400	4.8	
		3	190	6.5	
		4	300	5.7	
		5	115	11.0	
125+070	LHS	1	245	15.8	6
		2	120	8.3	
		3	455	5.3	
		4	90	11.2	
		5	140	26.5	
125+240	LHS	1	80	16.1	11
		2	90	17.3	
		3	90	8.3	
		4	403	4.8	
		5	197	8.9	
		6	220	14.0	
125+260	RHS	1	295	9.3	6
		2	325	10.9	
		3	355	4.0	
		4	115	8.7	
125+530	RHS	1	100	46.4	7
		2	195	21.5	
		3	80	16.1	
		4	195	3.7	
		5	90	11.2	
		6	440	4.4	

Chainage	Side	Layer	Thickness / [mm]	CBR	Design CBR
125+570	LHS	1	390	34.4	9
		2	70	10.8	
		3	250	2.8	
		4	165	7.5	
		5	175	14.7	
125+710	RHS	1	80	55.1	21
		2	250	40.1	
		3	190	16.3	
		4	340	10.4	
		5	195	17.3	
-	-	1	140	30.5	
		2	120	45.4	
		3	200	30.7	
		4	120	12.7	
125+790	LHS	5	215	32.4	17
		6	135	21.3	
		7	135	15.2	
126+020	RHS	1	80	12.7	11
		2	80	33.5	
		3	90	20.3	
		4	200	14.1	
		5	320	9.4	
		6	305	9.9	
		1	200	27.9	
		2	250	17.6	
126+047	LHS	3	230	13.3	10
		4	160	6.1	
		5	120	15.0	
		6	125	7.9	
126+260	RHS	1	115	13.3	8
		2	105	19.9	
		3	90	8.3	
		4	230	5.3	
		5	340	11.9	
		6	200	7.4	
126+290	LHS	1	100	15.4	7
		2	475	6.7	
		3	165	5.9	
		4	185	13.8	
		5	135	19.3	
126+540	RHS	1	160	21.3	10
		2	295	8.4	

Chainage	Side	Layer	Thickness / [mm]	CBR	Design CBR
126+595	LHS	1	330	27.3	9
		2	150	17.3	
		3	580	9	
126+780	RHS	1	150	8.3	2
		2	485	0.9	
		3	265	6.5	
		4	150	13.6	
126+795	LHS	1	105	17.3	7
		2	120	12.7	
		3	165	27.3	
		4	90	23.4	
		5	480	4.0	
		6	110	6.7	

ANNEX 3

3.1 Soil Test Report Summaries in Existing Road Pavement

Chainage km	Index Properties			Proctor Compaction		CBR (%) (4 Days Soak)		Field Density Test		Soil Layer
	LL (%)	PL (%)	PI (%)	MDD (Mg/m^3)	OMC (%)	At Field Dry Density	At 95% MDD	Field Dry Density (Mg/m^3)	Field MC (%)	
123+075	35	23	12	2.130	8.4	27	-	2.009	5.7	SUB
124+090	38	24	14	2.118	8.0	14	-	1.917	5.4	SUB BASE
124+090	32	21	11	2.160	6.6	-	22	-	-	SUB GRADE
125+100	27	17	10	2.152	7.9	23	-	2.008	5.3	SUB BASE
125+100	24	15	9	2.185	6.7	-	7	-	-	SUB G:

ANNEX 4

Summary of Test carried out

1. In-situ CBR
2. D.C.P Test
3. P.I Test
4. O.M.C (Optimum Moisture Content)
5. F.D (Field Density)
6. M.D.D (Maximum Dry Density)
7. **P**article size distribution
8. Atterberg Limits
9. CBR test
10. Dry Density
11. Layer Strength
12. MC
13. Proctor Test
14. Soil Classification