ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Evaluation of Dynamic Cone Penetrometer (DCP) for Purpose of Soil Investigation for Low Volume and Inaccessible Road Design

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
In partial fulfillment of the requirements for the degree of
Master of Science in Civil and Environmental Engineering
(Road and Transport Engineering)

By
Nebiyu Giday Gebrehiwot
May, 2014

Advisor
Bikila Teklu (Phd)

ACKNOWLEGMENT

My deep appreciation and many thanks go to my advisor, Dr. Bikila Teklu, for his open handed support and guidance starting from proposal writing up to completion of this thesis work. Without his guidance and valuable comments, this study would not have come to outlook.

Special thanks go to my sponsor Saba Engineering Plc for letting me pursue my graduate study and my sincere appreciation goes to the General Manager and owner of the company, Ato Samson Bekure.

I am also grateful to all the Geotechnical Department staffs of Saba Engineering plc especially Ato Ayehutsega Awgechew for supporting and providing me all the necessary laboratory data that I need for my research work.

Last but not least, I would like to thank my wife W/ro Frtuna Tekie, for her strong support to bring my research work fruitfully. I am also grateful to all my families, relatives, colleagues and friends for their genuine and positive support.

LISTOF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Definitions
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
ALT-I	Alternative one
ALT-II	Alternative two
b/n	Between
BS	British Standard
CBR	California Bearing Ratio
CFC	Cumulative Frequency Curve
CL	Center Line
DC	Design Category
DCP	Dynamic Cone Penetrometer
DCPI	DCP penetration resistance (mm/blow)
DS	Design Standard
E	Easting
ERA	Ethiopia Roads Authority
FDRE	The Federal Democratic Republic of Ethiopia
G7	Improved Subgrade with minimum soaked CBR of 7%
G20	Improved Subgrade with minimum soaked CBR of 20%
GPS	Global Positioning System
GWC	Gravel Wearing Course
Km	Kilo meter
LHS	Left Hand Side
LL	Liquid Limit
LVR	Low Volume Road
m	meter
Max	max
MDD	Maximum Dry Density
Min	minimum
Mm	mili meter

Mod.	Modified Proctor
N	Northing
Na	Afar Series geological formation
Nn	Nazret Series geological formation
NMC	Natural Moisture Content
NMSA	National Meteorological Service Agency
NP	Non Plastic
OMC	Optimum Moisture Content
ORN	Overseas Road Note
PI	Penetration Index (for DCP)
PI	Plasticity Index
PL	Plasticity Limit
Plc	Private Limited Company
PNa	Alajae geological formation
q_{al}	Allowable bearing pressure for settlement limited to 25 mm
R/ship	Relation Ship
S	Subgrade Bearing Class
S3	Subgrade class, with soaked CBR, ranging from 3 to 6%
S7	Subgrade class, with soaked CBR, ranging from 7 to 14%
S15	Subgrade Class, with soaked CBR, greater than 15%
SATCC	South Africa Design Manual
SPT	Standard Penetartion Test
TP	Test pit
TRRL (TRL)	Transport Research Laboratory
UCS	Unconfined Compressive Strength
URRAP	Universal Rural Roads Access Program

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PICTURES

ABSTRACT

The Dynamic Cone Penetrometer (DCP) is the most versatile rapid, in-situ evaluation device currently available for pavement and foundation design and for various quality control programs.

Low volume and Inaccessible roads are those roads which have a design Annual Average Daily Traffic, (AADT design) less than 300 and have problem of access using motorized vehicle especially during rainy weather condition.

Design of this type of road in general and soil investigation in particular using conventional method (test pitting and sampling at an average interval of 500m) is very challenging, time taking and very expensive; as the method requires more number of manpower, test pits and soil samples for laboratory testing. Beside, transportation of the collected soil samples to the central laboratory is very challenging due to absence of nearby laboratory places. All these tasks will have a negative impact on the financial and service period of the design work. In contrast, design of low volume roads have budget and time constraints. To give solution for the above problems, searching for other alternative investigation methods is compulsory. Because of its portability, simplicity, cost effectiveness and other benefits, investigation using DCP instrument is one possible alternative method that comes to picture.

Therefore, in this thesis, investigation method using DCP method (Alternative-I) is evaluated against the conventional method (Alternative-II) for low volume and inaccessible road design projects considering major evaluation parameters such as cost, time and quality.

A case study section has been considered on Anokober – Aliyuamba – Awash arba junction Road Project, from km 36+000 up to km 46+500 with a total of 10.5km as this section represent the low volume and inaccessible road design project. Previously, investigation and pavement design using conventional method has been carried out [1]. For comparison purpose, investigation and data analysis was carried out at the study time at an interval of 500m, and the outcomes are compared with that of the conventional method.

Finally, based on the evaluation, as it was expected Alternative-I (using DCP) method is concluded as the better option for the soil investigation for Low volume and inaccessible road design projects.

1 INTRODUCTION

1.1 BACKGROUND

The Dynamic Cone Penetrometer (DCP) is a simple, cheap and effective apparatus for assessing the bearing capacity of in situ materials for different applications. Among its various application, DCP apparatus uses as in-situ evaluation device for pavement design, foundation design and quality control purpose. Although this is a simple, cheap and effective method for assessing the bearing capacity of in situ materials for various applications, a fundamental understanding of the in situ condition is very essential.

Low volume roads are those roads which have a design AADT (AADT design) less than 300 [6]. These roads provide important links from homes, villages and farms to markets and offer the public access to health, education and other essential services. These roads also provide important links between Wereda Centres and the Federal road network.

During design of low volume roads, the project fall in one of the following categories i.e a new road following the general alignment of an existing track or trail, upgrading of a lower class of the road to a higher class or completely new road where nothing currently exists [6]. Among the mentioned categories, the last one are very difficult to access them using motorized vehicle especially during rainy weather condition, thus for case of this study, these projects are categorized as inaccessible roads.

Various design manuals have been developed in Africa countries and almost all design manuals adopt similar design parameters from TRL, as they follow similar design techniques. Here, in Ethiopia, ERA pavement design manual 2002 is usually the main design manual to design the pavement structure of the project road. In this manual, conventional method (i.e test pitting and sampling at an average interval of 500m) is followed [3, 4]. However, alternative investigation approach such as DCP method (DCP testing at an interval of 500m) should be considered for some specific projects such as low volume and inaccessible road design for alleviating the time and cost constraints.

1.2 STATEMENT OF THE PROBLEM

The Government of the Federal Democratic Republic of Ethiopia (FDRE) continues its commitment to give the road sectors the highest priority and is preparing more projects for funding by donors and from the national budget.

To fulfil the intended program, the quality of the design and construction of these roads has a vital role. Currently, besides those upgrading and rehabilitation of the existing roads, design and construction of the inaccessible roads has a great value for effective road network in terms of national and international economic value of the country.

Currently, there are a lot of road projects designed in remote areas and these roads are characterized by very challenging weather or terrain or both conditions that results difficulty for accessing the road using motorized vehicles. This access problem will have negative impact on the overall design work in general and geotechnical investigation work in particular. Among the various geotechnical works, alignment soil investigation is the major one.

In such inaccessible road conditions, soil investigation using conventional method i.e test pitting and sampling at an average of 500m interval [3,4] became very challenging. Besides, availability of laboratory centers is unlikely, in such conditions, all collected soil samples will be transported to main laboratory center areas such as to Addis Ababa. All these tasks will have a negative impact on the financial and expected period of the design work.

In contrast, design of low volume roads have budget and time constraints [6]. To alleviate the above problems, searching for other alternative investigation methods is compulsory. Because of its portability, simplicity, cost effectiveness and other benefits, investigation using DCP instrument is one possible alternative method that comes to picture.

1.3 RESEARCH OBJECTIVE

The objectives of the study are;

- ☞ To evaluate the use of DCP apparatus for purpose of soil investigation for low volume and in accessible road design, and
- ☞ To compare the effectiveness of DCP based investigation approach with respect to the conventional design method.

1.4 SCOPE AND LIMITATIONS

The research focuses on soil investigation for low volume and inaccessible roads using DCP method, and comparison is made against the conventional methods of investigations, however, the study has the following limitations;

- ☞ Subgrade moisture condition is assumed uniform and is a direct function of the climate
- ☞ Evaluation criteria for the two alternative methods are only based on major parameter such as quality, cost and time. Weights given for each criterion are based on experience such as ERA and other rural road authority.

2 LITERATURE REVIEW

The following provides a brief overview of literature on various study of DCP and its investigation method for Low Volume and Inaccessible road;

2.1 THE DCP

The DCP, also known as the Scala Penetrometer, was developed in 1956 in South Africa as an in situ pavement evaluation technique for evaluating pavement layer strength [11]. Since then, this device has been extensively used in South Africa, the United Kingdom, the United States, Australia, and many other countries, because of its portability, simplicity, cost effectiveness, and the ability to provide rapid measurement of in situ strength of pavement layers and subgrades. The DCP has also been proven to be useful during pavement design and quality control program [11].

The DCP is a simple piece of equipment and easy to transport, maintain and operate.

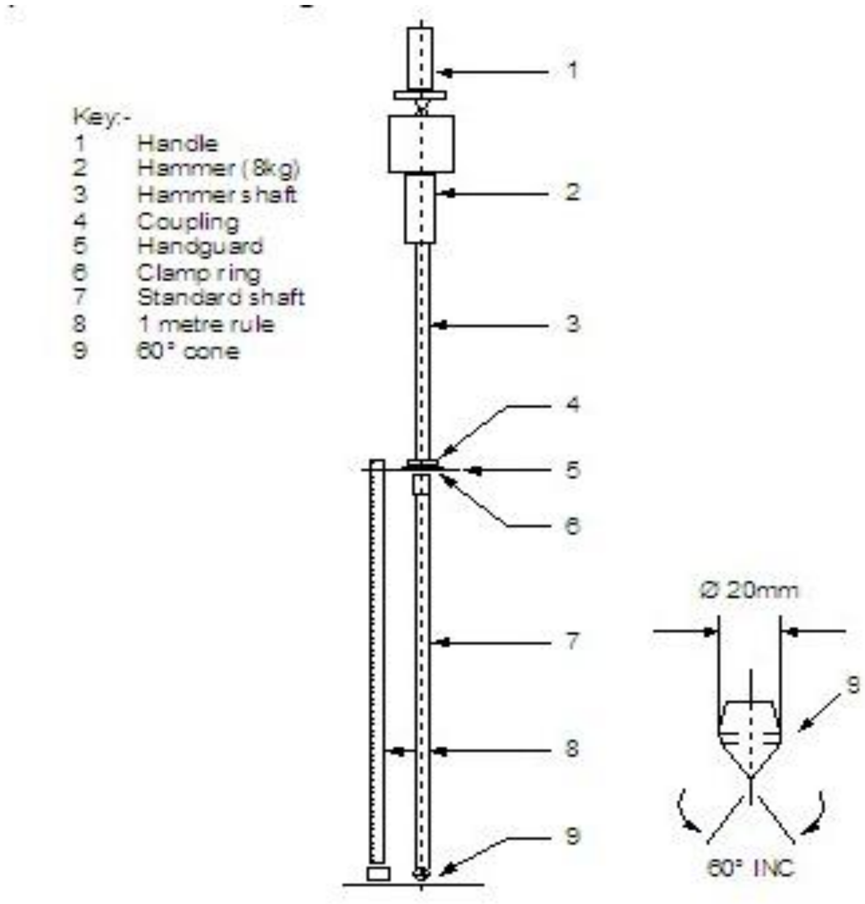


Figure 2.1 DCP instrument
(Source: TRL Manual, 1990)

The Dynamic Cone Penetrometer (DCP), shown in Figure 2.1, is an instrument designed for the rapid in situ measurement of the structural properties of existing road pavements with unbound granular materials [12]. The dynamic penetrometer consists of a steel rod with a cone at one end. A hole is made in the pavement bituminous surfacing course and the steel rod is driven in to base, subbase and subgrade layers using a sliding hammer.

The DCP instrument characteristics are as follows [3, 12]:

- Mass weight: 8kg
- Fall height: 575mm

2.2 THE DCP TEST PROCEDURE

The amount of penetration of the cone is measured at intervals. Each layers resists penetration and the resistance of each layer can be related to the in-situ CBR value of that layer. The general DCP equipment and operation procedure are carried out in accordance with the British TRRL Road Note No. 8 [12].

Using the DCP instrument to collect penetration data is straightforward. After recording the "zero error", the reading on the vertical scale when the cone is resting on the flat level surface, the DCP is held vertically at the test point and the hammer is repeatedly raised and dropped on to the coupling. As the cone penetrates in to the pavement, the number of blows and the penetration depth are recorded onto a Test data sheet and then plotted on to a penetration graph.

The gradient of the graph indicates the strength of the material through which the cone is passing and a change in gradient indicates a boundary between layers of different strength material. Layer strength can be calculated from the gradients using known relationships, and layer thicknesses can be determined from where boundaries are indicated.

The DCP cannot penetrate strong or very coarse granular layers such as hot mix asphalt, water bound macadam or cement treated bases. These layers must be removed by coring or drilling and their strength is assessed using other means.

If during the test, the DCP leans away from the vertical no attempt should be made to correct it, although if the lean becomes too severe and the hammer slides down the hammer shaft, rather than dropping freely, the test should be abandoned and repeated close by.

It is possible to measure up to 800 mm depth of penetration. However, it is also possible to measure penetrations of up to 1200 mm depth when fitted with an extension rod. Using this device, we can measure the subgrade strength in terms of penetration in millimeters per hammer blow. The DCP came to be increasingly used in many parts of the world for the evaluation of subgrades, granular material, and lightly stabilized soils. A number of studies have been performed to correlate the results of the DCP test for the estimation of in-situ California Bearing Ratio (CBR).

Though, the DCP is a highly cost effective technique for acquiring large quantities of data on sub-surface material strength and thickness quickly and essentially in a non-destructive process, the strength information acquired is related directly to the in situ moisture and density conditions at the time of the investigation. Although the dry density of the in situ materials is relatively constant over time, the wet density of the materials beneath unsealed roads varies almost continuously with time and this is manifested in the in situ strength estimated from the DCP data. As the in situ strength is directly and inversely proportional to the density and the moisture content, respectively (i.e. the in situ strength increases with increasing density and decreases with increasing moisture content), it is essential, although difficult, that these relationships are considered during the pavement design process. The designer should preferably be on site during the DCP investigation.

Estimation of the moisture content at the time of testing can be difficult. Although it is recommended that samples are taken for gravimetric moisture determination, this is usually only practicable for the upper and possibly the second 150 mm layer without excavating large holes. Kleyn and Van Zyl [18] described the classification of the overall moisture regime at the time of DCP testing in terms of the expected moisture levels that will prevail during the service of the road. Excavation of holes into the wearing course and underlying layers and extraction of samples for laboratory moisture determination would be highly beneficial.

The in situ density obviously affects the DCP penetration rate considerably. This is a difficult parameter to estimate during the DCP survey, but on an existing unsealed road, it can be assumed that there has been some traffic compaction over time, probably to atleast that normally specified for a subgrade or even subbase under a sealed road. It is thus possible to relate the densities to the expected final pavement structure. If the road is to be widened, however, it is usually necessary to carry out testing adjacent to the road to assess the strength of the un-compacted in situ material. This, of course, can also be done to assess the effect of traffic compaction on the material density by comparing DCP penetration rates of obviously un-trafficked material adjacent to the existing road with trafficked material under the road.

2.3 DCP TESTING

The DCP needs three operators; one to hold the instrument, one to raise and drop the weight and a technician to record the results. The instrument is held vertical and the weight carefully raised to the handle. Care should be taken to ensure that the weight is touching the handle, but not lifting the instrument, before it is allowed to drop and that the operator lets it fall freely and does not lower it with his hands. If, during the test, the DCP tilts from the vertical, no attempt should be made to correct this, as contact between the shaft and the sides of the hole will give rise to erroneous results. If the angle of the instrument becomes worse, causing the weight to slide on the hammer shaft and not fall freely, the test should be abandoned [12].

It is recommended that a reading should be taken at increments of penetration of about 10 mm [12]. However, it is usually easier to take readings after a set number of blows. It is therefore necessary to change the number of blows between readings according to the strength of the layer being penetrated. For good quality granular road bases, readings every ten blows are normally satisfactory, but for weaker sub-base layers and subgrade readings, every one or two blows may be appropriate.

Little difficulty is normally experienced with the penetration of most types of granular or weakly stabilized materials. It is more difficult to penetrate strongly stabilized layers, granular materials with large particles and very dense, high-quality crushed stone. The TRL instrument has been designed for strong materials, and therefore the operator should persevere with the test. Penetration rates as low as 0.5 mm/blow are acceptable, but if there is no measurable penetration after 20 consecutive blows, it can be assumed that the DCP will not penetrate the material. Under these circumstances, a hole can be drilled through the layer using either an electric or pneumatic drill or by coring. The lower layers of the pavement can then be tested in the normal way.

The DCP has been used to evaluate the strengths and depth of thick soft materials using a 2 meter (and even 3 m) long lower shaft. This is not recommended for harder materials (CBR >15) where inertia effects, side friction on the rod and other energy losses may influence the results. Energy can be lost through compression of the DCP rod, elastic compression of the soil and various other unknown factors. It is not clear whether the standard DCP-CBR correlations can be directly applied to longer DCPs.

2.4 DCP SURVEY

Depth, Interval and number of DCP tests;

The DCP survey will be carried out to a depth of at least 450 mm but preferably to at least 600 mm, the so-called material depth of the pavement [16]. It is recommended that DCP testing is carried out at 200 m intervals with additional testing in any obviously problematic areas (e.g., wet, cracked). In relatively uniform areas, testing at up to 500 m intervals could be accepted. In general a minimum of about 10 tests per uniform section should be carried out.

Moisture Conditions;

The moisture conditions at the time of the DCP survey need to be carefully estimated. As the moisture content at the time of testing determines the in situ strength at that time, this needs to be carefully assessed and preferably supported by laboratory determinations of the moisture content.

Uniform Sections;

The road should then be divided into uniform sections based on the DCP results. Various techniques are available for this, but it has been found that the cumulative sum technique [17] is simple and appropriate. This involves determining the average DCP CBR for all of the results (for each 150 mm layer tested), subtracting the individual results from the average and then summing these. A plot of the results will show inflection points where each section changes.

Once the uniform sections have been identified, each of these will need a specific pavement design or treatment.

Specific Treatments;

To minimize costs, use of the in situ material in all of the layers should be considered. However, mechanical treatment of the in situ materials such as ripping and re-compaction may not always be sufficient for the proposed pavement design and some other form of treatment or stabilization may be necessary. This could range from removal and replacement, heavy compaction or mechanical or chemical stabilization.

Indications of the need for treatment will be obtained from the DCP results when particularly poor material properties in the upper layers are identified.

2.5 LOW VOLUME ROADS AND THEIR DESIGN PRINCIPLE

The approach to the design of low volume roads follows the general principles of any good road design practice. There are, however, some differences from the conventional road design practice. Thus, effective method of design should be found to provide the client with an optimized design based on the financial, technical and time constraints that will define the project [6] .

Investigation method using the conventional one (e.g ERA design manual) is conservative and builds in factors of safety that provide for their perceptions of risk and extremes of cautions, and then ultimately uses scarce or inappropriate resources and results in high financial costs for the clients and the country. Using this method, it is very common to see that more numbers of samples are collected and transported to central laboratory (most of the time to Addis Ababa) even if the road is low volume road design.

On the other hand, soil investigation for low volume road and inaccessible road (new road) using DCP method (i.e DCP testing supported by visual survey) is very cost and time effective irrespective of its level of technical acceptance. However, for design of low volume roads, certain level of risk with good engineering judgment is much preferable as the road will be upgraded to higher standard with the demand of the generated traffic [6].

The successful design of low volume roads relies on [6]:

- ☞ A full understanding by the design engineer of the local environment (natural and social);
- ☞ An ability to work within the demands of the local environment and to turn these to a design advantage;
- ☞ Recognition and management of risk;
- ☞ Innovative and flexible thinking through the application of appropriate engineering solutions rather than following traditional thinking related to road design;
- ☞ A client who is open and responsive to innovation;

The functional classification of roads in Ethiopia is based on five classes [6]:

- ☞ Trunk roads: roads linking Addis Ababa to centres of international importance and to international boundaries;
- ☞ Link roads: connecting centres of national and international importance such as principal towns and urban centres;
- ☞ Main access: connecting centres of provincial importance;
- ☞ Collectors: connecting locally important centres to each other or to a more important centre or to a higher class road; and
- ☞ Feeder roads: connecting minor centres such as a market to other parts of the network.

Low volume roads can be represented in all five of these functional classes [6].

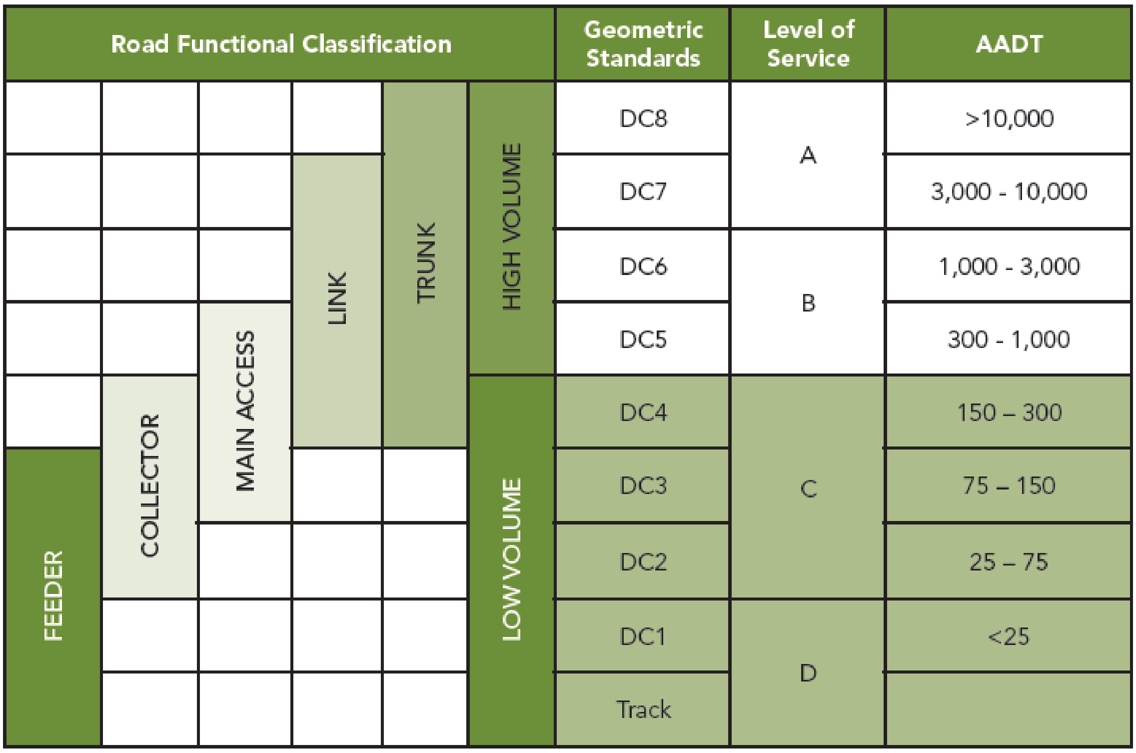
Roads in Ethiopia can be further divided into three categories depending on ownership and the authority responsible for them [6] . These are:

- ☞ Federal (the responsibility of the Ethiopian Roads Authority);
- ☞ Regional (the responsibility of the Regional or Rural Roads Authorities); and
- ☞ Other rural roads (the responsibility of local authorities at Wereda or Kebele level or communities).

ERA is responsible for major roads falling into the higher design classes, predominantly DC5 and above, but also has a substantial stock of roads below DC5. Regional and local authorities are responsible for roads in classes DC4 – DC1 [6].

Figure 2.2 shows the definitive classification of roads in Ethiopia based on geometric standards with the appropriate level of service as defined below.

> ***Level A:*** *The highest level of service. Traffic is free flowing, with the volumes and types of traffic easily accommodated. Safety is a high priority. Design speed is very important and takes precedence over topographic constraints.*
>
> ***Level B****: Traffic may not flow smoothly in all situations. Safety is a high priority, but some safety controls may need to be enforced. Design speed is important, but topography may dictate some design changes and controls.*
>
> ***Level C****: The efficiency of traffic movement and flow is not a limiting factor. Traffic will be accommodated, but some design controls may need to be applied. Safety provisions are adapted to lower and variable speed scenarios. The topography will dictate alignment and the design speed.*
>
> ***Level D****: Service level is geared to provision of access rather than efficiency. Design standards for water-crossings may allow service interruption and some roads may even be closed to protect these assets. Other design standards for geometrics, surfacing and safety will reflect lower speed environments and access requirement.*



Road Functional Classification						Geometric Standards	Level of Service	AADT
				TRUNK	HIGH VOLUME	DC8	A	>10,000
			LINK			DC7		3,000 - 10,000
						DC6	B	1,000 - 3,000
		MAIN ACCESS				DC5		300 - 1,000
	COLLECTOR				LOW VOLUME	DC4	C	150 – 300
FEEDER						DC3		75 – 150
						DC2		25 – 75
						DC1	D	<25
						Track		

Figure 2.2 Road Classes in Ethiopia
(Source: LVR Manual, 2011)

The density of roads in most areas of Ethiopia is relatively low and many existing low volume roads are relatively long (>25km). Alternative routes are often long or non-existent and the consequences of disruption are high. It is prudent therefore to adopt design standards that provide an appropriate level of reliability and service commensurate with the functional characteristics of the road [6].

2.6 CURRENT APPLICATION AND PRACTICE OF DCP

The basic design of the DCP has been relatively unchanged since its inception in the 1956. The mass of the falling weight has been altered several times. The cone tip has also undergone numerous revisions to its basic design. More recently, the automated dynamic cone penetrometer has been suggested to automate the operation, data collection and analysis procedures [12].

In addition, many correlations that permit the estimations of various parameters as well as experience in the use of the DCP exist. A new standard test method, ASTM D6951, for use of the DCP in shallow pavement applications has been recently developed [2].

The following sections summarize the current applications and practices of the DCP test incorporated in the conventional design approach methods.

For Purpose of Pavement Investigation;

To rehabilitate a road it is often necessary to know as much as possible about the thickness of the existing pavement layers and their condition. This is vital when roads begin to fail prematurely indicating that there are inherent problems with the structure.

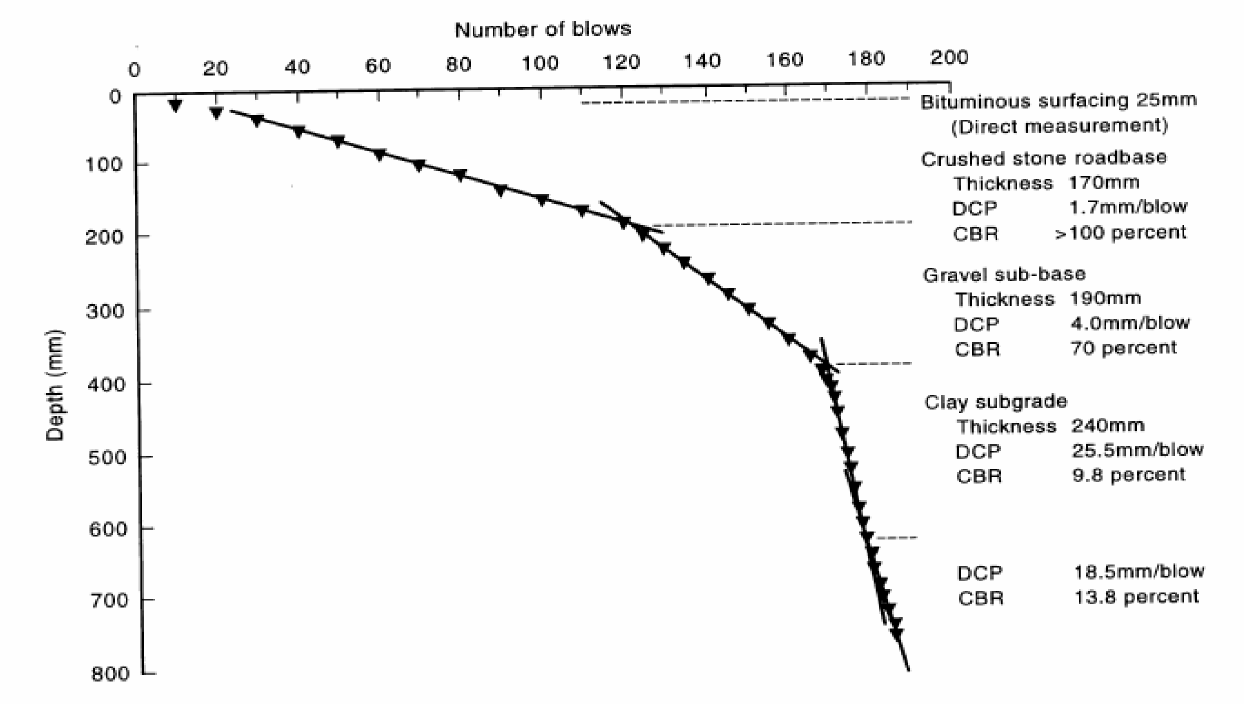
The quickest and easiest way to assess the thickness and condition of the pavement is to inspect the design to which the pavement was originally built and perhaps also the as-built records compiled during construction. However, designs indicate only an intended construction and as-built records are often only indicative of the construction work carried out and neither gives any information as to what has happened to the pavement since construction.

It is therefore necessary to investigate the current pavement condition using some form of destructive or non destructive testing. The usual method of destructive testing is to gig test pits at suitable intervals along the road. These are very useful as pavement thickness can be measured and material removed for testing in a laboratory. However, tests pits are expensive to dig and reinstate and are rarely dug at a spacing of less than 2-3 kilometres. Non destructive testing is cheaper, quicker and can be carried out at closer spacing. A type of non destructive testing which has proved to be successful in many countries is the Dynamic Cone Penetrometer (DCP).

Currently DCP is adopted by various road designers for purpose of existing pavement investigation. The rate of penetration of the DCP cone, when driven by a standard force, is inversely related to the strength of the material as measured by, for example California Bearing Ratio (CBR) test where the pavement layers can be identified and the thickness of the layers can be determined.

DCP can also be used effectively to determine the soil layer thickness from the changing slope of the depth versus the profile of the accumulated blows. It is confirmed that the layer thickness obtained from DCP tests correspond reasonably well to the thickness obtained from the test pits. It was concluded that the DCP test is a reliable alternative for project evaluation [10].

Figure 2.3 Typical DCP Test Result (Source: ERA Manual, 2002)



Picture 2.1 Application of DCP in Pavement Investigation (Gravel Road)

Picture 2.2 Application of DCP in Pavement Investigation (Asphalt Road)

For Purpose of Material Characterization;

The following relationship shows the application DCP for purpose of material characterization:

Extensive research has been performed to develop empirical relationships between DCP penetration resistance and CBR measurements. Based on the results of past studies, many of the relationships between DCP and CBR have the following form [9]:

Log (CBR) = a + b log (DCPI)

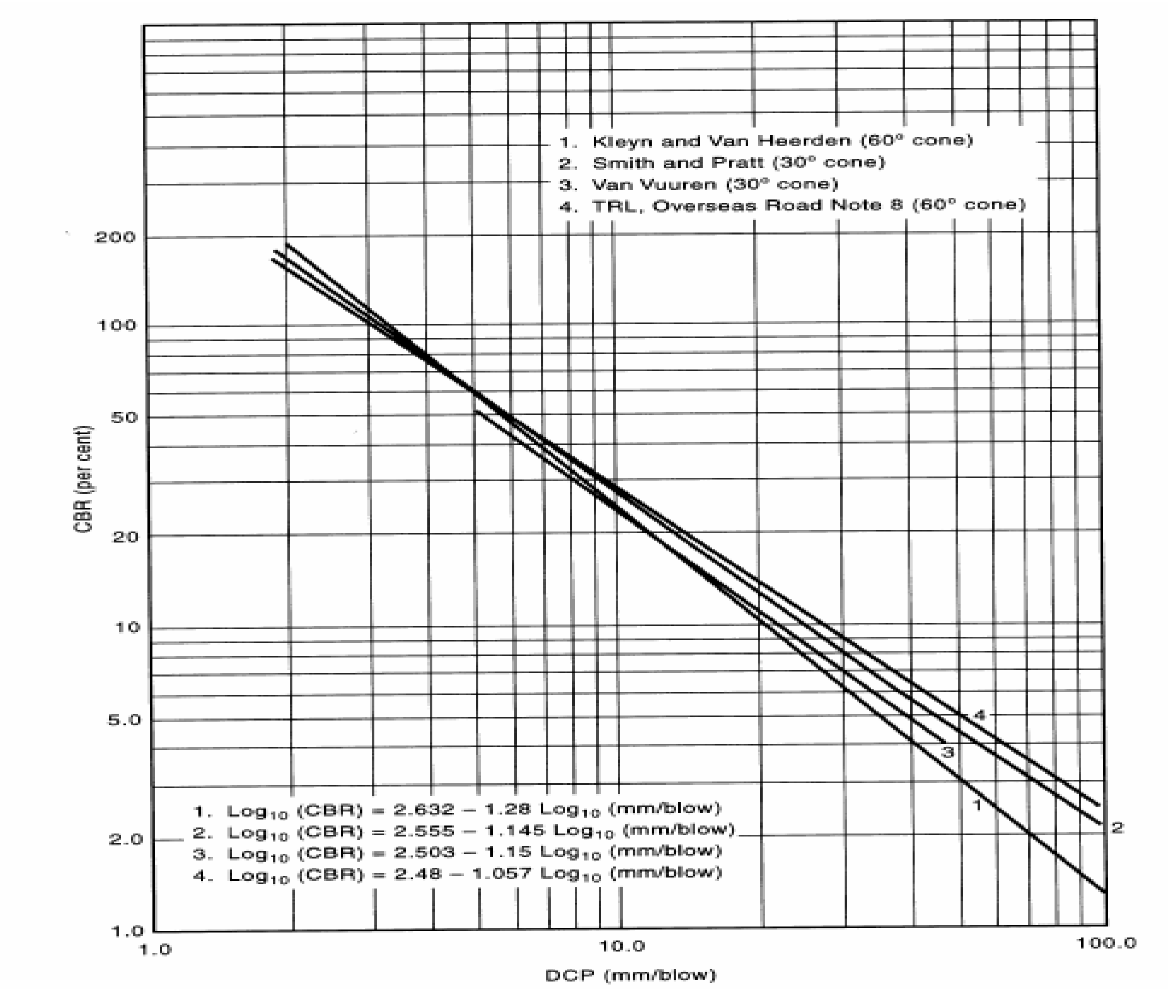
Where:
DCPI = DCP penetration resistance (mm/blow);
a = constant that ranges from 2.44 to 2.60; and
b = constant that ranges from -1.07 to -1.16

A summary of some of these correlations is presented in Figure 2.3 [3].

It is clear that all of the relationships have similar equations, with different coefficients. The correlation coefficients also vary significantly as the number of samples obviously affects the statistical significance of the correlation coefficients. It is also clear that the nature of the material affects the DCP penetration rate, but this can seldom be included in the analysis of full DCP profiles.

These relationships allow the use of the data in a basic manner where the strength of different layers could be read off manual plots and an indication of the thicknesses of various layers could be determined. Some indication could be obtained of the material type as well as the DCP structural number; although no predetermined depth of DCP testing was specified.

Figure 2.4 DCP–CBR Relationships (Source: ERA Manual, 2002)



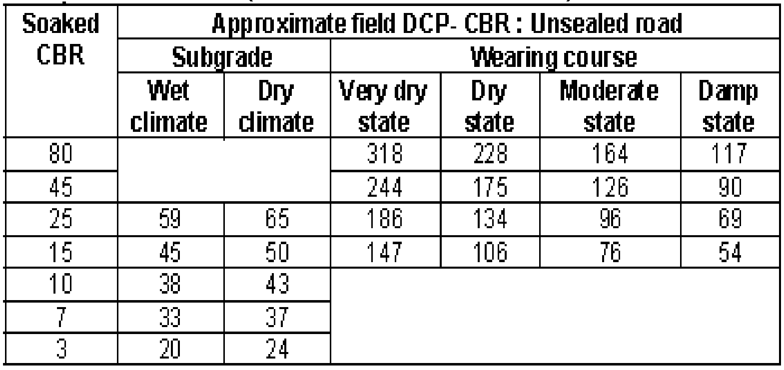
It should be noted that there are inherent inaccuracies in most CBR test results and these coupled with the material dependency of the DCP results make the DCP interpretation a very good indicator, but it should never be used as an absolute indicator of the in situ CBR strength of a material in a pavement. The results should be assessed in terms of the material properties, particularly grading and maximum particle size, plasticity, aggregate hardness, etc.

It must always be remembered that the DCP CBR is determined at the in situ moisture content (and density) of the pavement layers at the time of testing. Various attempts to relate this, through the CBR derived from the DCP, to the material strength used in South Africa have been made, with the following approximate correlations being proposed for materials in unsealed roads [14] as shown in table 2.1 and in sealed low volume roads [15] as seen in Table 2.2.

The use of this method requires a visual estimate of the field moisture content at the time of DCP testing but also has the limitation of assuming that the subgrade moisture content is uniform and is a direct function of the climate.

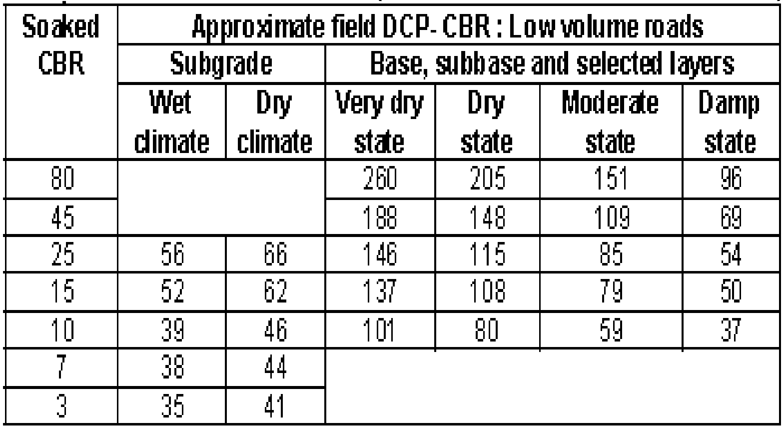
Use of the above table without actual moisture content determinations requires an estimate of the moisture content in terms of the optimum moisture content (OMC) for the materials. This can usually be obtained by experienced engineers based on squeezing a sample of the material in one hand and assessing the “cohesion”. At OMC (damp) the material can be squeezed into a “sausage” that remains intact. In the very dry state (less than about 25% of OMC), the material is dusty and loose and has absolutely no cohesion. In the dry state (about 50% of OMC), the material will have no cohesion [14,15].

Table 2.1 Relationship between DCP-CBR and soaked laboratory CBR for unsealed roads (Source: VAN ZYL, 1995)



Soaked CBR	Approximate field DCP- CBR : Unsealed road					
	Subgrade		Wearing course			
	Wet climate	Dry climate	Very dry state	Dry state	Moderate state	Damp state
80			318	228	164	117
45			244	175	126	90
25	59	65	186	134	96	69
15	45	50	147	106	76	54
10	38	43				
7	33	37				
3	20	24				

Table 2.2 Relationship between DCP-CBR and soaked laboratory CBR for sealed low volume roads (Source: PAIGE-GREEN, 1999)



Soaked CBR	Approximate field DCP- CBR : Low volume roads					
	Subgrade		Base, subbase and selected layers			
	Wet climate	Dry climate	Very dry state	Dry state	Moderate state	Damp state
80			260	205	151	96
45			188	148	109	69
25	56	66	146	115	85	54
15	52	62	137	108	79	50
10	39	46	101	80	59	37
7	38	44				
3	35	41				

Note; in Table 2.1 and 2.2, moisture contents are expressed as ratios of in-situ to Mod AASHTO optimum moisture content as follows; very dry = 0.5, moderate = 0.75 and damp = 1

The responsibility remains on the user of the DCP, however, to understand the situation, environment and implications of each test in relation to the in situ state of the material is very important. This includes aspects such as material composition, presence of large stones or hard layers, moisture content, density, etc. Significant engineering judgment and understanding as well as knowledge of the specific site are necessary to maximize the information that can be obtained from a DCP profile.

For Purpose of Foundation Investigations;

The Dynamic Cone Penetrometer (DCP) is cheap and quick to use, and it causes minimal disturbance to the ground. It can be applied between boreholes or test pits to obtain a continuous profile of soil layers, or to find the boundaries of boulders. DCP tests should be made close to each borehole or test pit, to provide a correlation between soil types and penetration specific to the locality of the site, and then at small intervals between boreholes and test pits. Table 2.4 shows a typical correlation between DCP and SPT values.

Table 2.3 Correlation between SPT value, N and density of granular soils
(Source: TRL, 1990)

N-Value	**Less than 10**	**10 - 30**	**30 - 50**	**More than 50**
Relative density	Loose	Medium dense	Dense	Very dense

Table 2.4 Correlation between DCP and SPT values
(Source: TRL, 1990)

DCP value, mm/blow	5	6	7	8	9	10	12	14	16	18	20
SPT value, blow/300mm	50	44	38	33	28	24	22	18	16	15	14

The bearing capacity for the soil layer could be calculated from the SPT N- values using Meyerhof's equation as follows [13]:

$$q_{all} = \frac{N}{F_2}\left(\frac{1+F_3}{B}\right)^2 K_d, \qquad B > F_4$$

Where q_{all} = Allowable bearing pressure for settlement limited to 25 mm.
K_d = $1+0.33D/B < 1.33$
F_2 = 0.08
F_3 = 0.3
F_4 = 1.2
B = Width of foundation
D = Depth of foundation

Picture 2.3 Application of DCP in
Foundation Investigation (Bridge Structure)

Picture 2.4 Application of DCP in
Foundation Investigation
(Electric Pole Transmission line)

Picture 2.5 Application of DCP in Foundation Investigation (Building Structure)

2.7 USE OF DCP COMPUTER PROGRAM, UK 3.1

DCP results are conveniently processed by computer and a program has been developed to assist with the interpretation and presentation of DCP Data. Among the different DCP Computers Programmes, UK DCP 3.1 is the well known one and it is developed by TRRL [12]. This software is designed for two categories of user: those who wish to analyze DCP data; and those who need to produce design for lengths of sealed roads used as spot improvements on low trafficked roads.

The design of these sections of sealed roads is based upon research carried out on roads with design traffic of less than 1 million equivalent standard axles in dry areas of Zimbabwe, Botswana and Malawi. The design function of UK DCP 3.1 should therefore not be used for roads at higher design traffic or in other climatic regions.

UK DCP 3.1 is not intended to replace normal engineering judgment. It is intended for users who already have a thorough understanding of DCP analysis and pavement design. The user must be aware of the limitations of this program as described here and, most importantly, must understand that poor data will lead to incorrect results.

The design function within UK DCP 3.1 compares the strength and thickness of the existing pavement with a pavement shown in a design catalogue and, using layers of the existing pavement as layers in the proposed pavement. If material in the existing pavement is to be used as a base or sub-base in the proposed new pavement, it is recommended that soaked CBR tests are carried out to accurately determine its strength.

Accordingly, all DCP data collected from site are processed using this software (UK 3.1) as presented in subsequent sections.

Data Inputs;

The input screens are designed so that data is input from the Test data sheet in a logical sequence. This includes the site details, upper layer details and penetration data. The software triggers suitable messages for valid data input to all mandatory fields. The software allows the user to record that one or two impenetrable surface layers were cored at the start of the test, and then to input the strength of these layers later in the process. If as-built or test pit information is available, it is possible to record the thickness of the surface, base and sub-base layers and then display them to assist layer identification.

Layer Analysis;

Penetration data entered for a test can be analysed and layers identiofied in two different ways: automatically and manually.

Automatic layer analysis identifies layer boundaries using the cumulative sum technique, a process which finds the points at which the graph deviates from the straight line. The only option for the user is to decide the point at which the pavement has been adequately divided into layers and it is not necessary for further boundaries to be identified where they may not actually exist.

Manual layer analysis allows the user to represent the penetration graph as a series of straight lines. UK DCP then generates a boundary wherever these straight lines intersect.
Both methods have advantages and disadvantages. Automatic analysis is quicker than manual analysis but the user has no control over where layer boundaries are located. It also can give inappropriate results on complex graphs, for example a strong layer overlaid by weaker layers or where a layer has been drilled. Manual analysis is slower but the user has more control over layer boundaries, drilled layers, strong lower layers and so on.

Automatic analysis is recommended for simple graph and manual analysis for complex graphs.

CBR Calculations;

The strength of each of the layers are calculated automatically by converting the penetration rate (mm per blow) to a California Bearing Ratio (CBR) value. A number of relationships between penetration rate and CBR value have been derived for 60^o and 30^o cones and are given in Table below;

Table 2.5 CBR-Penetration rate relationships
(Source: TRL, 1990)

Cone angel	Name of Relationship	Relationship
60^o cone	TRL	$Log_{10}(CBR) = 2.48 – 1.057Log_{10}(pen\ rate)$
	User-Defined	$Log_{10}(CBR) = [constant] – [coefficient]Log_{10}(pen\ rate)$ Constant and Coefficient can be defined by the user
30^o cone	Smith and Partt	$Log_{10}(CBR) = 2.555 – 1.145Log_{10}(pen\ rate)$
	User-Defined	$Log_{10}(CBR) = [constant] – [coefficient]Log_{10}(pen\ rate)$ Constant and Coefficient can be defined by the user

3 METHODOLOGY

3.1 GENERAL

In general, geotechnical investigations works are undertaken to determine the physical properties of the materials that built up the road, the sub grade on which the road is constructed and to study construction material availability in the vicinity of the project area.

Specifically, alignment soil investigation is carried out to determine and classify the natural soil formation so that it is possible to determine the structural pavement design for pavement composition.

Currently, conventional soil investigation method is adopted in different countries including our country, Ethiopia. Here, ERA pavement design manual is used as a guide line for investigation and design of roads [3,4,5,6]. However, as it was mentioned in section 1.2 of this report, still problems are arising when this method was applied in low volume and inaccessible road design. Therefore, looking for other alternative investigation method like DCP approach is mandatory.

Brief methodology of soil investigation and pavement design using DCP approach will be discussed below;

3.2 DATA TYPE

During preparation of this thesis, two types of data's have been collected as described below;

3.2.1 PRIMARY DATA

Primary data's are those data's directly collected from site such as in-situ (DCP) tests conducted on site and all other field findings. For sake of limited budget of the study works, only 10.5km case study section has been considered. In this case, both in-situ testing using DCP at an interval of 500m and additional test pits one from each homogenous section (total of three test pits) were excavated.

During the field stage, centreline ground investigations were investigated and the following field works were conducted for 10.5km case study section;

- ☞ Visual Soil Extension Survey
- ☞ Test pit investigation, one from each homogenous sections
- ☞ In-situ testing using DCP at an interval of 500m and
- ☞ Identification of problematic soil sections

The visual soil extension survey was conducted and the different soil types along the alignment have been mapped and classified according to color, texture and composition.

For confirmation of the visual survey, one from each homogenous section, three additional test pits were dug at km 37+000, km 41+000 and at km 45+000. DCP tests were conducted at an interval of 0.5km just to correlate with the test location of the conventional one (see Table 3.1).

Table 3.1 Summary for in-situ tests conducted on Subgrade layer

Sri. No	Description	No. of tests	Tested for	Use in pavement
1	Dynamic Cone Penetrometer, DCP	22*	In-situ strength	Sub-grade / Embankment

**Number of DCP test at an interval of 0.5km for a total of 10.5km road section*

Picture 3.1 Test Pit Investigation
(at Km 45+000, C/L)

Picture 3.2 DCP Testing Preparation
(at Sta. 46+000, C/L)

Picture 3.3 Conducting DCP on site
(at Sta. 41+000)

Picture 3.4 Conducting DCP on site
(at Sta. 42+500)

DCP results are conveniently processed by computer and a program has been developed to assist with the interpretation and presentation of DCP Data. Among the different DCP Computers Programmes, UK DCP 3.1 is the well known one and it is developed by TRRL (1990). This software is adopted to analyze the DCP raw data as presented in the subsequent sections.

3.2.2 SECONDARY DATA

Secondary data are those data collected from previous records that were collected or conducted at the site. In this case, secondary data's source of the case study will be the Soil and Material Report of the captioned project i.e Soil and Material Report for Ankober – Aliyu Amba – Dulecha – Awash Arba Junction road project [1].

During preparation of the thesis, the following secondary data are employed;

- General project description
- Geological setting of the area
- Climatic conditions of the area
- Data collected using conventional method
- Traffic data and analysis, and
- Terrain condition of the area

3.3 DATA PROCESSING

All the field data have been analyzed and all design parameters have been computed. Based on the analyzed results, considering the prevailing climatic condition, gravel pavement design has been proposed as the road belongs to DS6 design standard which is unpaved (gravel) road standard.

For comparison purpose, the investigation data collected using conventional method has been analyzed.

Finally, evaluation of the two methods with respect to technical, financial and time aspects has been done as summarized in the flow chart presented in figure 3.1.

3.4 THE STUDY AREA

A case study section has been considered in Ankober – Aliyu Amba – Dulecha – Awash Arba Junction road, which is located in the Amhara and Afar Regional States, in the Eastern Central part of Ethiopia. The proposed road starts at the town of Ankober and ends at Awash Arba Junction which is about 230 km from Addis on the Addis – Djibouti trunk road.

The project route alignment lies in two physiographic Regions. The topographic set up of the route corridor varies from a steep and mountainous and escarpment terrain (from Ankober to Dulecha town, first 36 Kms), to dominantly flat terrain in the Rift Valley to the end of project road at Awash Arba junction.

According to Meteorological Map of Ethiopia, 1979, Ankober and Aliyu Amba are classified as cool (Dega) region with mean annual rainfall in the range from 1000mm-1200mm, Dulecha area receives 600-700mm (moderately dry), and the low land, from Dulecha to the end of the project, is in the Ethiopian Main Rift which is warm (Kolla) with mean annual rainfall in the range from 400-500mm. The average moisture index in the warm (Kolla) area is 0.25 and it is uncomfortable most of the time.

Referring to the geological map of Ethiopia (second edition, 1996) and based on the site visit, the following formations are encountered along the project road. The formation along the first 37 Km consists of Afar Series (Na) and Alajae type, and Nazret Series (Nn) is the dominant formation along the rest of the project road. Alluvial and lacustrine deposits: sand, silt, clay and beach sand covers the section from Km 37 to Km 88.

Currently, the project road is designed with gravel, partially paved DS6 design standard following the conventional method of investigation [1]. In this project, the section from Km 35+500 up to 65+300, is an earth road passable only in dry seasons and such earth trail roads are normally considered as new road as per the pavement condition survey [1]. In this section, the total traffic volume in the first year in both directions of the year 2012 is considered. Accordingly, the number of commercial vehicles is estimated to be 89 [1].

Due to limited budget of the study works, only 10.5km case study section has been considered. Therefore, case study section was selected from Km 36+000 up to Km 46+500, with total length of 10.5km as this section represent low volume and inaccessible road project.

Accordingly, investigation using DCP method was carried out in the study section at an interval of 500m, and compared with that of the conventional method.

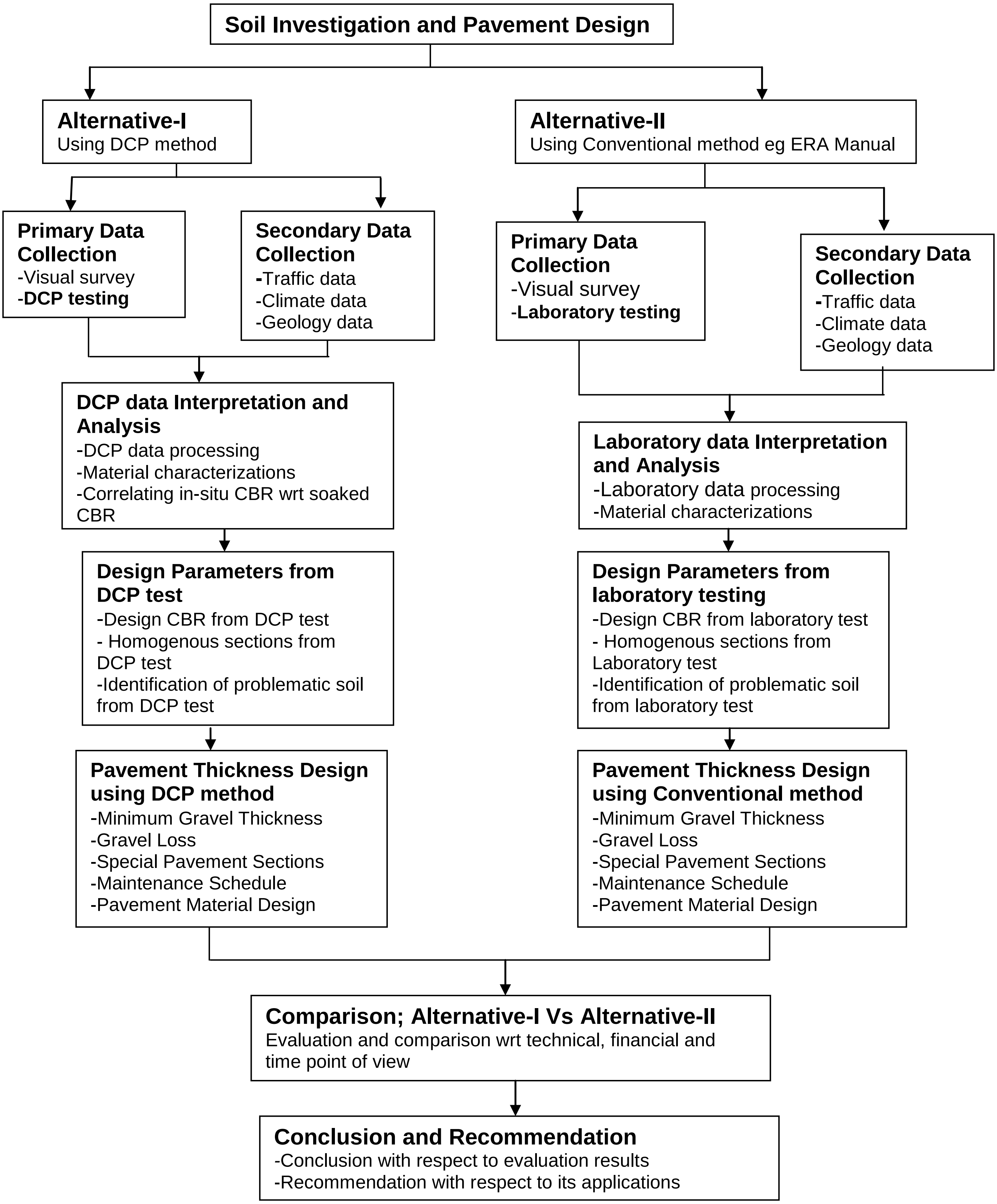


Figure 3.1 Evaluations for Alternative Soil Investigation Methods

4 DATA COLLECTION AND ANALYSIS USING DCP

4.1 DATA COLLECTION

During preparation of this thesis, the following data's have been collected as discussed below;

Condition Survey;

During the field work, the general road alignment in particular the study section (from km 36+000 to km 46+500) was assessed to identify the condition of the existing road if any, to identify the type of soil observed along the alignment using visual survey.

Based on the visual survey, it is found that section from Dulecha (km 35+500) to Awash River (km 65+300) that also include study case section i.e from km 36+000 to km 46+500, is an earth road passable only in dry seasons and such earth trail roads are normally considered as new road in the pavement condition survey evaluation. Regarding to the type of soil, the natural soil formation over significant portion of the road in the lowland (from km 36+000 to km 46+500) is covered by light brown, clayey SILT.

Detailed soil extension was conducted and the different soil types along the alignment have been mapped and classified according to colour, texture and composition as summarized in table below;

Table 4.1 Visual Soil Extension Survey

Sri. NO	STATION		LENGTH, km	VISUAL DESCRIPTION
	Start	End		
1	36+000	39+200	3.2	Light brown clayey SILT with few rounded gravels
2	39+200	42+750	3.55	Dark brown to dark grey silty CLAY with few gravels
3	42+750	46+500	3.75	Light brown sandy silty CLAY

Test Pit Investigation;

Following the soil extension survey, one from each homogenous section, a total of three test pit investigation were conducted at km 37+000, km 41+000 and km 45+000 and it is found that all test pit log confirmed that the subgarde materials are similar to the soil extension type mentioned as presented in Table 4.2;

Table 4.2 Test Pit Logging

Sri. No	Station	GPS Co-ordinate	Test Pit Logging	
			Depth, m	Material Description
1	37+000	E = 0605984 N = 1055359	0.00 – 1.00	Dark brown silty CLAY overlaid by 15cm loose brown clayey silt top soil (deposit)
2	41+000	E = 0609287 N = 1053687	0.00 – 1.10	Black to dark brown silty CLAY overlaid by thin layer (10cm) loose brown silty clay top soil
3	45+000	E = 0612332 N = 1051353	0.00 – 1.00	Reddish brown to brown sandy CLAY

DCP Testing;

For the visual survey, in-situ data using Dynamic Cone Penetrometer (DCP) were conducted at an interval of 500m at the following locations;

Table 4.3 Locations where DCP test conducted

Km	Penetration Index (PI)	Depth of Penetration, mm	Moisture Condition
36+000	5.73	793	Dry
36+500	6.09	876	Dry
37+000	6.13	795	Dry
37+500	6.74	830	Dry
38+000	4.21	825	Dry
38+500	5.77	880	Dry
39+000	5.74	720	Dry
39+500	12.04	797	Wet
40+000	8.58	858	Wet
40+500	6.69	876	Wet
41+000	8.86	755	Wet
41+500	5.22	887	Wet
42+000	6.64	877	Wet
42+500	7.08	895	Wet
43+000	4.79	791	Dry
43+500	5.3	830	Dry
44+000	6.27	704	Dry
44+500	5.98	795	Dry
45+000	5.72	884	Dry
45+500	5.09	927	Dry
46+000	4.48	881	Dry
46+500	6.06	860	Dry

Where;

Penetration Index (PI) = depth of penetration per number of blows (mm/blows)

4.2 DATA INTERPRETATION AND ANALYSIS

DCP Test Analysis;

The DCP data are analyzed and converted to CBR value using TRL empirical relations between CBR values and penetration resistance (strength) as follows [12] as this correlation is a well known relationship in east Africa region and has resulted acceptable results for soil type similar to the study section [12];

TRL equation:

$$\mathbf{Log_{10}\,(CBR) = 2.48 - 1.057Log_{10}\,(strength,\ mm/blow)}$$

The resulting data will enable to rapidly define the thickness of the subgrade structure layers forming and each layer’s materials bearing capacity (CBR) in accordance with the above equation.

The underlying principle of the DCP is that the rate of penetration of the cone, when driven by a standard force, is inversely related to the strength of the material as measured by, for example California Bearing Ratio (CBR) test as shown in Figure 4.1.

Summary for the analysis result of the DCP Data that includes penetration index (PI), in-situ (DCP) CBR and the equivalent soaked CBR are presented in Table 4.4.

From the analysis, the in-situ CBR of the subgrade varies in wide range, ranging from 22% to 66% with an average value of 45.5% where as the penetration index (PI) varies from 4.2% to 12.04% with an average value of 6.33%.

Using correlation shown in Table 2.2, it is found that the corresponding equivalent soaked CBR varies from 2.2% to 25% with an average value of 9.82%. On the other hand, major part of the portion has got DCP penetration index that lies between 5 to 8mm /blows and after converting these values to an equivalent SPT values, they lies between 30 to 50 blows/300mm and these values shows that more than 90% of the in-situ subgrade condition has got dense relative density.

Table 4.4 Summary for DCP test outcomes

Section Km - Km	km	Penetration Index (PI)	DCP CBR	Moisture	Equivalent Soaked CBR
	Section-I				
36+000 - 39+200	36+000	5.73	48	Dry	10.5
	36+500	6.09	45	Dry	8.5
	37+000	6.13	44	Dry	7.0
	37+500	6.74	40	Dry	3.0
	38+000	4.21	66	Dry	25.0
	38+500	5.77	47	Dry	10.3
	39+000	5.74	48	Dry	10.5
	Section-II				
39+200 - 42+750	39+500	12.04	22	Wet	less than 3%
	40+000	8.58	31	Wet	less than 3%
	40+500	6.69	40	Wet	10.3
	41+000	8.86	30	Wet	less than 3%
	41+500	5.22	53	Wet	17.5
	42+000	6.64	41	Wet	11.0
	42+500	7.08	38	Wet	7.0
	Section-III				
42+720 – 46+500	43+000	4.79	58	Dry	14.0
	43+500	5.3	52	Dry	12.0
	44+000	6.27	43	Dry	6.0
	44+500	5.98	46	Dry	10.0
	45+000	5.72	48	Dry	10.5
	45+500	5.09	54	Dry	12.5
	46+000	4.48	62	Dry	15.0
	46+500	6.06	45	Dry	8.5

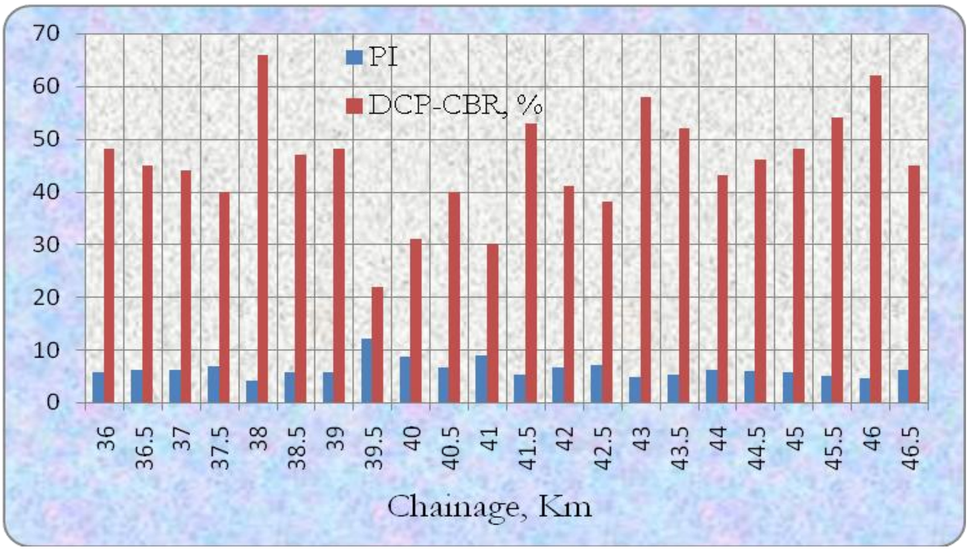


Figure 4.1 Penetration Index (PI) versus DCP CBR

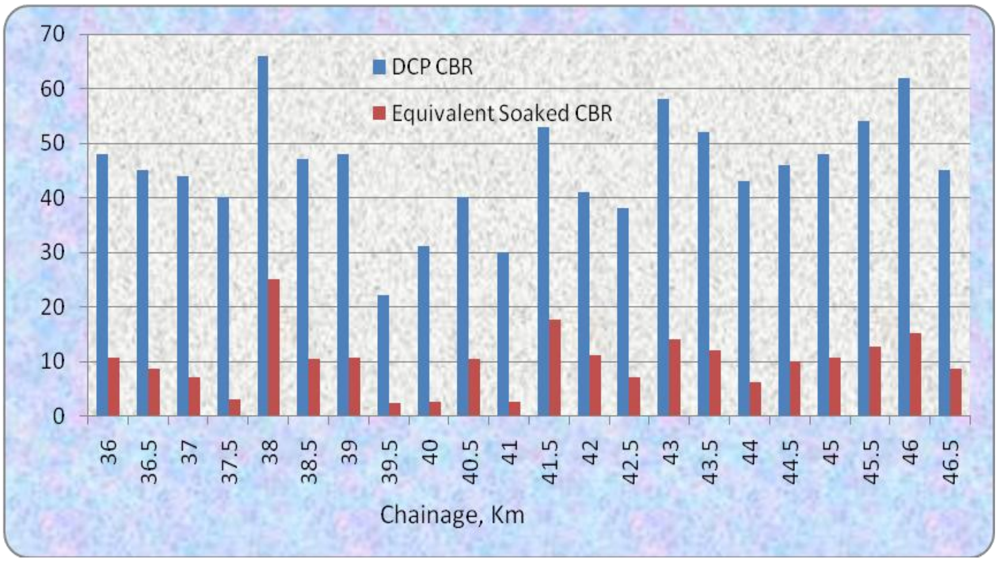


Figure 4.2 DCP-CBR and equivalent soaked CBR

Uniform Sections;

The following data sources have been combined to define these uniform (homogenous) sections:

- Results of the visual evaluations of sub-grade along the route
- Results of laboratory tests on sub-grade samples and
- Results of the in-situ tests on the sub-grade

Based on the above factors, three homogenous sections have been determined as listed below;

☞ **Section I, from Sta. 36+000 to Sta. 39+200**

The subgrade soil on this section is characterized by light brown clayey SILT with few rounded pebbles. From DCP test analysis, the in-situ CBR value varies from 40% to 66% with an average value of 48%. Similarly, the equivalent soaked (laboratory) CBR varies from 3% to 25% with 13% average value.

- ☞ **Section II, from Sta. 39+200 to Sta. 42+750**

  The subgrade soil on this section is characterized by dark brown to dark grey silty CLAY mixed with few gravels. From DCP test analysis, the in-situ CBR values also varies from 22% to 53% with an average value of 36% and the equivalent soaked (laboratory) CBR varies from 1% to 17.5% with 7% average value.

  Soil with soaked CBR less than 3% and swell greater than 2% are considered as problematic soil [3] and they are unsuitable to be used as road bed of the road structures.

  Both from visual and DCP test result, this section has got very low CBR (less than 3%) and higher swell (greater than 2%) thus considered as problematic soil section.

- ☞ **Section III, from Sta. 42+750 to Sta. 46+500**

  The subgrade soil on this section is characterized by light brown sandy silty CLAY with few types of gravel. From DCP test analysis, the in-situ CBR values also varies from 43% to 62% with an average value of 51% and the equivalent soaked (laboratory) CBR varies from 6% to 15% with 11.1% average value.

Design CBR;

For design purposes, the road is divided in to homogenous sections. The alignment soils have been subdivided into different sub-groups largely based on their CBR, AASHTO soil classification, their general behaviour, composition, range of laboratory test results, extent of occurrence, and etc... of the native subgrade considering designed geometry or finished road level of the alignment road.

The final pavement structure along the road length is based on the traffic loading and in-situ sub-grade quality. Various sub-grade quality parameters are therefore used to define significant sections of similar sub-grade strength, so that an approximate CBR (i.e design CBR) is defined for each sub-grade unit.

Most of the time, Cumulative Frequency CBR Curve has been plotted to determine the most suitable and safe design CBR values, which is commonly considered to be occurring 90% of the time, (i. e., the highest CBR value of the lowest 10% bracket). Outlier’s i.e extreme minimum and maximum CBR values are excluded in the computation of the design CBR.

The designs CBR for the Homogenous Sections are summarized in Table 4.5 below, and the design subgrade class is also assigned accordingly.

Table 4.5 Design CBR for Homogenous sections

Section	**Homogenous Sections**		
	36+000 – 39+200	**39+200 – 42+750**	**42+750 – 46+500**
No of Tests	7	7	8
Minimum CBR Value	3	Less than 3%	6
Maximum CBR Value	25	17.5	15
Average CBR Value	10.7	7	11.1
90%ile Design CBR Value	7.7	Less than 3%	8
Subgrade Bearing Class	S7	Problematic section	S7

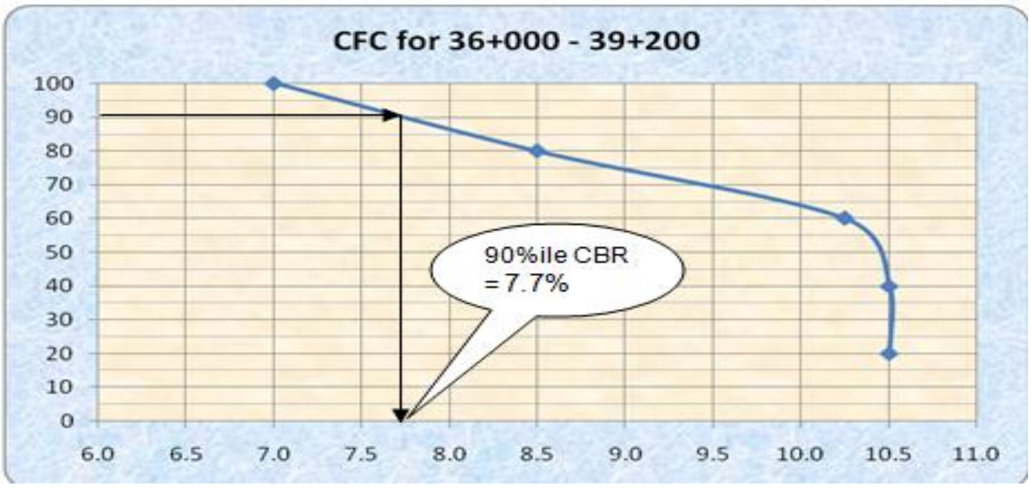


Figure 4.3 Cumulative Frequency Curve for Sta. 36+000 to Sta. 39+200

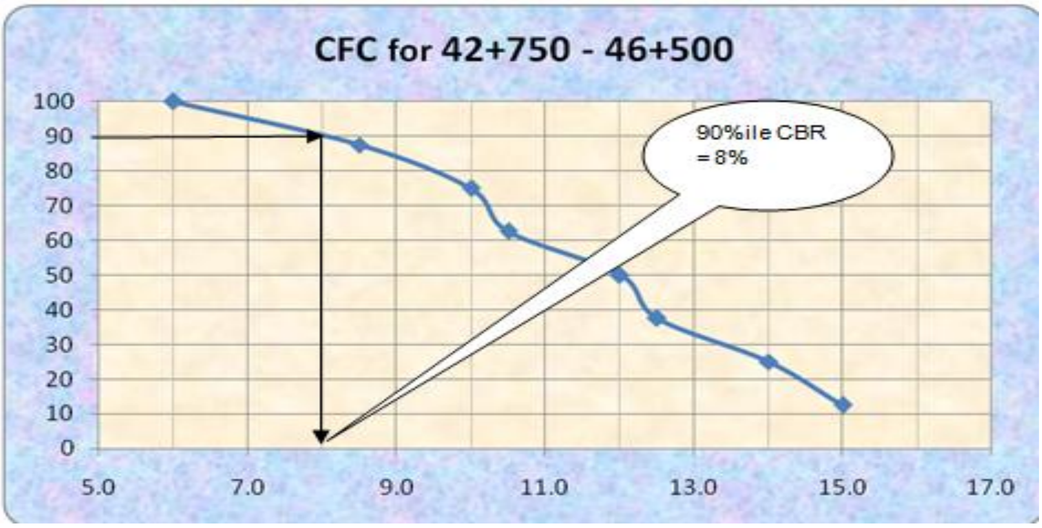


Figure 4.4 Cumulative Frequency Curve for Sta. 42+750 to Sta. 46+500

Table 4.6 Subgrade Class for Gravel Roads
(Source; ERA Manual, 2002)

Subgrade Bearing Class	Design CBR (%)		
	Wet or moderate climate (4 days soaked value)	Dry climatic zones	
		Tested at OMC	4 days soaked value
S3	3 - 6	3 - 6	2 - 6
S7	7 - 14	7 - 14	7 - 14
S15	Min 15	Min 15	Min 7

The results of all field and laboratory findings are duly employed together with the estimated traffic, climate and other specific features of the route alignment in arriving at a safe and economical pavement design.

Based on the design inputs i.e subgrade, traffic class, climate, geometry and others, the gravel pavement thickness of the project is computed as tabulated below [4];

Table 4.7 Recommended Pavement Structures using Alt-I (Using DCP Method)

Sri. No	Station		Length, km	Recommended Gravel Pavement Thickness, mm		
	Start	End		G7	G20	GWC
1	36+000	39+200	3.20	-	100	225
2	39+200	42+750	3.55	200	150	250
3	42+750	46+500	3.75	-	100	225

5 INVESTIGATION USING CONVENTIONAL METHOD

5.1 REVIEW OF AVAILABLE DESIGN MANUALS

Various pavement design methods have been developed in different parts of the world. Each method has been developed based on local experience and conditions with respect to climate, availability of materials, subgrade conditions, traffic volume and composition, economic trends and traffic growth trends, pavement performance records, etc.,

Due to the fact that most the design manuals developed in the African countries adopt many parameters from TRL, there is a visible similarity in the design techniques between these manuals [12]. Here, in Ethiopia, ERA Pavement Design Manual, 2002 is referred, however, to determine the most economical and safe structural layer of the project, additional reference will be made to the following manuals which are deemed to be suitable to prepare the pavement design:

- ☞ Transport Research laboratory (TRL), Overseas Road Note 31
- ☞ Tanzania Materials and Pavement Design Manual, 1999
- ☞ Kenyan Materials and Pavement Design Manual 1987 and
- ☞ South Africa Design Manual, SATCC, 2001

For the case study, the final version of the ERA Manual, 2002 is preferred as it considers more regarding to the actual physical, natural and climatic features of Ethiopia' in general and project case in particular, than the others manuals.

5.2 PREVOUS INVESTIGATION RESULTS

As it was explained before, soil investigation using conventional method (using ERA method) has been conducted for the whole project [1], and summery for the finding of the case study section (from Km 36+000 to Km 46+500) is extracted and summarized as follows;

Field Findings;

To examine engineering behaviour of the indigenous sub-grade soils, test pits were excavated along the centerline of the project road alignment at an average interval of 500m and their summary are tabulated in Table 5.1 below;

Table 5.1 Summary of Test Pit Log

Sri. No	STATION	DEPTH, m	MATERIAL DESCRIPTION
1	36+000	0.00 – 1.00	Dark brown silty CLAY with fine gravels
2	37+000	0.00 – 1.00	Dark brown silty CLAY
3	38+000	0.00 – 1.00	Light brown silty CLAY
4	39+000	0.00 – 1.00	Light brown silty CLAY
5	40+000	0.00 – 1.00	Black to dark grey silty CLAY
6	41+000	0.00 – 1.00	Black to dark grey silty CLAY
7	42+000	0.00 – 0.40	Dark brown to black silty CLAY
		0.40 – 1.00	Dark brown to grey silty sandy CLAY with few gravels
8	43+000	0.00 – 1.00	Light brown silty clayey GRAVEL
9	44+000	0.00 – 1.00	Dark brown silty CLAY
10	45+000	0.00 – 1.00	Reddish brown silty clayey GRAVEL
11	46+000	0.00 – 1.00	Reddish brown silty clayey rounded GRAVELS

Picture 5.1 Samples Transportation
(at the site)

Picture 5.2 Samples Transportation
(from site to the main road)

Laboratory Testing;

Laboratory testing was conducted on subgrade material samples collected during the field investigation. As it was mentioned, representative samples were collected from each test pits and they were subjected to the various tests (Table 5.2) and their results are summarized as shown in Table 5.3.

Table 5.2 Laboratory Tests for sub-grade materials (Source, ERA Manual, 2002)

Sri. No	Test Descriptions	Standard Test Designation
1	Liquid limit	AASHTO T89
2	Plastic Limit & Plasticity Index	AASHTO T90
3	Particle Size Distribution – Wet sieving	AASHTO T311
4	Compaction, Modified Proctor	AASHTO T180
5	CBR (3 point 4 days soaked)	AASHTO T193

Source; ERA Manual, 2002

Table 5.3 Laboratory Test Result Summary for subgrade materials

Station	Sieve Analysis			Atterberg limits		AASHTO Classification	CBR, %	Swell, %
	2.0 mm	0.425 mm	0.075 mm	LL, %	PI, %			
	Section-I							
36+000	84	77	69	57	21	A - 7 - 5(14)	4.7	2.51
36+500	84	77	69	58	23	A - 7 - 5(15)		
37+000	100	95	85	50	14	A - 7 - 5(12)	14.0	1.25
37+500	100	95	85	52	21	A - 7 - 5(14)		
38+000	92	83	66	37	10	A - 4(6)	20.0	0.92
38+500	92	83	67	42	15	A - 7 - 6(9)		
39+000	91	78	53	42	11	A - 7 - 5(5)	13.2	1.79
	Section-II							
39+500	91	79	54	45	15	A - 7 - 5(6)		
40+000	96	88	76	52	17	A - 7 - 5(13)	3.7	3.71
40+500	94	86	74	52	14	A - 7 - 5(12)		
41+000	98	93	86	62	24	A - 7 - 5(18)	2.9	5.86
41+500	98	93	86	60	22	A - 7 - 5(17)		
42+000	97	90	78	67	25	A - 7 - 5(18)	2.5	6.58
42+500	97	90	78	71	28	A - 7 - 5(20)		
	Section-III							
43+000	31	22	16	43	16	A - 2 - 7(0)	34.0	0.29
43+500	31	22	16	42	18	A - 2 - 7(0)		
44+000	95	82	60	48	16	A - 7 - 5(8)	10.0	2.17
44+500	95	83	61	50	18	A - 7 - 5(9)		
45+000	46	39	32	48	15	A - 2 - 7(1)	19.0	0.95
45+500	46	39	31	48	20	A - 2 - 7(1)		
46+000	58	46	36	45	17	A - 7 - 6(2)	19.0	0.70
46+500	58	46	35	48	21	A - 2 -7(2)		

Source; Soil and Material Report of the Project [1]

5.3 DISCUSSION OF FINDINGS

The tests conducted for AASHTO classifications were liquid limit, plastic limit and wet sieve analysis. These tests are indicators of the physical properties of subgrade soils. They are usually done at short intervals in the investigation of subgrade soils to reduce the number of CBR tests, and they are requirements to satisfy the suitability of natural subgrade.

Based on the AASHTO soil classification system (see Table 5.3), major part of the case study's subgrade soil (more than 63.6%) is classified as A-7-5 materials and the rests are classified as A-2-7, A-7-6 and A-4.

Wet sieve analysis and plasticity test results were employed to determine the grain size distribution of subgrade soils, since they are also one from the characteristics requirement of the material that uses for assessing their compliance with the requirement.

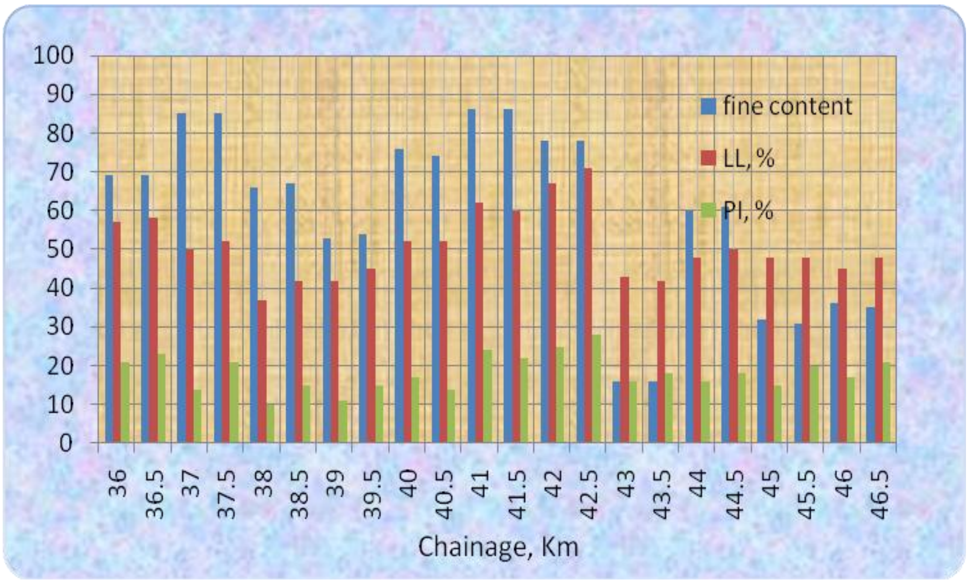


Figure 5.1 Plasticity Characteristics

Laboratory test conducted on these subgrade samples yield percentage passing 0.075mm sieve values ranges from 16% to 86%. Similarly, liquid and plastic limit varies in wide range, ranging from 37% to 71% and from 10% to 28% respectively (see Table 5.3).

In addition, three point CBR test were conducted using AASHTO – T180 method on sampled subgrade soils collected from test pits at 1km interval and modified Proctor was adopted for three point CBR tests [1].

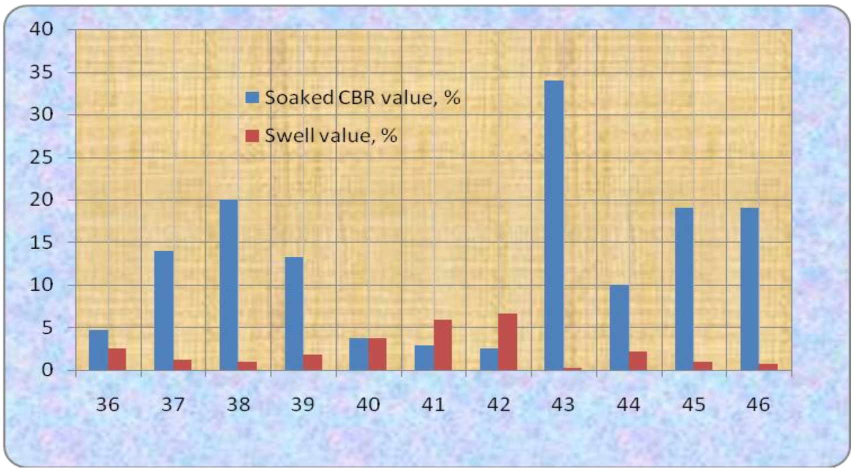


Figure 5.2 Soaked CBR and swell, %

Based on the test result, the strength of the alignment subgrade CBR varies in wide range ranging from 2.5% to 34% with an average value of 13%. On the other hand the swell potential also varies ranging from 0.29% to 6.58% with an average value of 2.43% (see Figure 5.2).

Identified Uniform Sections and Design CBR;

Based on field survey and laboratory test result, similar uniform sections are identified and their design CBR has been determined based on cumulative frequency curve and all results summarized as tabulated below;

Table 5.4 Design CBR for Homogenous sections

Section	**Homogenous Sections**		
	36+000 – 39+200	39+200 – 42+750	42+750 – 46+500
No of Tests	4	3	4
Minimum CBR Value	4.70%	2.50%	10%
Maximum CBR Value	20%	3.70%	34%
Average CBR Value	13%	3.03%	20.50%
90%ile Design CBR Value	8%	Less than 3%	13%
Subgrade Bearing Class	S7	Problematic section	S7

Similarly, the gravel pavement has been designed based on the design inputs as tabulated below;

Table 5.5 Recommended Pavement Structures using Alt-II (Using Conventional Method)

Sri. No	**Station**		**Length, km**	**Recommended Gravel Pavement Thickness, mm**		
	Start	**End**		**G7**	**G20**	**GWC**
1	36+000	39+200	3.20	-	100	225
2	39+200	42+750	3.55	200	150	250
3	42+750	46+500	3.75	-	100	225

6 COMPARISON OF DESIGN ALTERNATIVES

6.1 GENERAL

Various soil investigation and pavement design methods are adopted in different parts of the world. Each method has been developed based on local experience and conditions with respect to climate, availability of materials, sub-grade conditions, traffic type, volume and composition, pavement performance records, and etc...

On the other hand, geotechnical investigation particularly, alignment soil investigation for low volume and inaccessible roads needs special investigation methods as these roads require acceptable quality yet they are associated with budget and time constraints.

Therefore, on this section, alternative soil investigation using DCP method (Alternative-I) has been evaluated against the conventional investigation method (Alternative-II) which is adopted by different countries design manuals such as Ethiopia Roads Authority Manual here in case of Ethiopia.

6.2 EVALUATION PARAMETERS

Various evaluation parameters are available, however, quality, time and cost are found to be the basic parameters on the evaluation process and the others parameters are assumed to be similar for both type of investigation methods;

Therefore, the two type of investigation methods explained below has been evaluated as per the mentioned evaluation parameters in case of low volume and inaccessible road design;

- **Alternative I:** Using DCP methods i.e DCP test at an interval of 500m supplemented by visual condition survey and
- **Alternative II**: Using conventional investigation methods i.e test pit investigation, sampling and laboratory testing at an interval of 500m as adopted by ERA pavement design manual.

Technical Issue

Technically, the quality of the investigation approach for both methods has been evaluated based on the following inputs;

- Outcomes of the soil extension survey such as detailed visual description (logging), soil type delineation, etc ..
- Soil characterization such as plasticity, strength characteristics, in-situ characteristics, fine content, grain size analysis, soil classification, and etc .
- Identification of problematic soils
- Allocation of homogenous sections and
- Determination of Design CBR

Time Issue

Required time of the investigation approach for both methods has been evaluated based on the following inputs;

- Field work
- Laboratory testing
- Reporting

In both cases, to consider the practical field work challenge and other related factors, calculation was done for 50km length inaccessible road project, and then converted to 10.5km.

On the analysis, considering expirance of various field work done by different consultant, the following assumption of work rate (efficiency) has been taken;

- ☞ Soil extension survey, 25km per day
- ☞ Test pitting, 4km per day, 8 test pits per day i.e every 500m interval
- ☞ DCP testing, 10km per day, 20 DCP testing per day i.e every 500m interval
- ☞ Laboratory testing; it depends on size of the laboratory i.e number of manpower and equipments such as molds. However, for this specific purpose, expirance of the central laboratory of SABA Engineering Plc is taken as an example.
- ☞ Ten (10) number of homogenous sections are expected on fifty (50) Km length road.

Financial Issue

Direct cost of investigations (only labor, vehicle rent and equipment rent) for two methods are evaluated taking in to consideration the following factors;

- ☞ Field work and
- ☞ Laboratory testing

6.3 COMPARISON SUMMARY

The evaluation summary of the two approaches with respect to the above evauation parameters has been summarized as tabulated below;

Table 6.1 Required quality for Alternative-I and Alternative-II

Activities	Alternative-I (Using DCP Method)		Alternative-II (Using Conventional Method)	
	Percentage*	Remark	Percentage*	Remark
Soil extension survey	100%	excellent	100%	excellent
Soil characterization	65%	fair	95%	excellent
Problematic soil identification	65%	fair	100%	excellent
Homogenous section	100%	excellent	100%	excellent
Design CBR	100%	excellent	100%	excellent
Score value, %	430%	-	500%	-
Relative value, %	86%	-	100%	-

**Percentage assigned for the two method, is based on the expirance and judgment of senior Material and Pavement Engineers found in various consulting offices.*

Table 6.2 Required time for Alternative-I and Alternative-II

Activities	Length, km	Alternative-I (DCP Method)		Alternative-II (Conventional Method)	
		Number	Time, days	Number	Time, days
1. Field Work					
Visual soil extension survey	10.5	-	0.4	-	0.4
Test pitting, sampling and transportation every homogenous sections	10.5	3	0.4	22	2.75
DCP Testing, every 500m	10.5	22	1.1	-	-
2. Laboratory testing					
Grain size and atterberg limits, every homogenous section	10.5	3	0.63	22	3.2
Modified Proctor and three point CBR, every homogenous section	10.5	3	1.26	11	6.3
3. Reporting					
Field work analysis	10.5	-	1	-	2
Laboratory test result analysis	10.5	-	0.5	-	2
Report preparation	10.5	-	3	-	3
Score Value, days			8.29 days		19.65 days
Relative Value, %			100%		42%

Table 6.3 Required cost for Alternative-I and Alternative-II

Activities	Unit Cost (birr)	Alternative-I (DCP Methods)		Alternative-II (Conventional Method)	
		Required number	Amount, (birr)	Required number	Amount, (birr)
1. Field Work					
Vehicle rent	1200	1.5 days	1,800	2.7 days	3,300
Test pitting, sampling and transportation	250	3 pits	750	22 pits	5,500
DCP Equipment rent	450	1.1 days	495	-	-
DCP Testing	100	1.1 points	110	-	-
2. Laboratory Testing					
Grain size and atterber limits,	100	3 samples	300	22 samples	2,200
Modified Proctor and CBR	800	3 samples	2,400	11 samples	8,800
Score Value, %			5,855		19,800
Relative Value, %			100%		30%

The evaluation criteria selected are quliaty, time and cost. From prevous expirance on similar projects, various weights are given based on subjective judgment. On the selection process, quality has been given higher priority than time and cost. For this specfic case, double weight is given for quality issue. Based on this, evaluation summary of the two approaches has been summarized as tabulated below;

Table 6.4 Evaluation summary (Relative Value)

Activities	**Using**	**Using**
	DCP Method, %	**Conventional Method, %**
Technical Issue	86	100
Time Issue	100	42
Financial Issue	100	30
Score value, %	**93**	**68**
Rating	**1**	**2**

From the above table, it is possible to notice the following points;

- ✓ Alternative-II (Conventional Method) has got better advantage on describing the soil characterization of soil materials as there are more number of test pits and laboratory testing, therefore, using Alternative-II (e.g ERA manual method) is found preferable regarding to quality concern.
- ✓ It is obvious that the time for investigation using Alternative-I (DCP method) needs shortage time than that of using Alterative-II (Conventional Method) as number of trail test pits as well as number of sampled soils largely reduced, therefore, regarding to time issue, Alternative-I is found much better than that of Alternative-II.
- ✓ With similar justification as that of time issue, cost of investigation using Alternative-I (using DCP method) is much better than that of Alternative-II.
- ✓ After considering all the above parameters (quality, time and cost), Alternative I is found more effective than Alternative-II

Therefore, from the above comparison, it is concluded that for Low Volume and Inaccessible Road, Alignement Soil Investigation using Alternative-I (using DCP supllemented visual survey) is more effective than that of investigation method using Alternative-II (ERA Manual).

7 CONCLUSION AND RECOMMEDNATION

7.1 GENERAL

Road design for volume roads especially inaccessible roads should give freedom for rational, appropriate and affordable design approach such as ongoing project of URRAP which are constructed in rural areas throughout the country as most of the time; the clients have technical, social, environmental and time constraints. However, the sensitivity of the design should in general increase as the standard of the road increases.

As it was shown on the above sections, two alternative ways of investigation methods have been compared and evaluated.

7.2 CONCLUSION

Based on the evaluation and in consideration of the following reasons, Alternative-I (using DCP) method is recommended as the best option for the soil investigation for Low Volume and Inaccessible Road Design Projects.

- ☞ It is very economical and time effective
- ☞ It is very simple and this allows repeated testing to minimize errors
- ☞ It is rapid evaluation techniques
- ☞ The test is conducted in the condition at which it performs
- ☞ Possible to get large quantities of data as we required
- ☞ Easy to investigation subsurface condition (deep investigation especially for problematic soils)
- ☞ It is non destructive way and causes minimal disturbance
- ☞ Very useful to obtain continuous profile of soil layers and to find boundaries
- ☞ It is adaptability to many types of evaluation techniques and others

7.3 RECOMMENDATION

Following the selection of Alternative-I (using DCP method) for soil investigation of Low Volume Roads and Inaccessible Road Design, this effective method has been applicable to the following projects;

- ☞ Low volume projects where small number of vehicles are expected
- ☞ Inaccessible road projects where transportation of soil samples are very challenging
- ☞ Projects with financial constraints like URRAP projects
- ☞ Projects with time constraints
- ☞ Remote projects where laboratory testing is unavailable
- ☞ Projects with rainy weather condition and difficult for soil sampling

For successful application of DCP method, the following recommnedations are highly appreciable

- DCP test should be supported by good engineering judgment, site visual survey, on site test (hand test) and few labratory testing
- Considering additional parametres such as climate, temprature, pavemnt material properties, maintaenance scheme, qaulity control, etc...beside low volume and inaccessible roads, this invetigation method can be tried to other roads as well.
- Corroloation regarding local soil materials with DCP is highly adviced.
- Additional reasrches regarding application of this method are required.

References

1. Soil and Material Report for Ankober-Aliyuamba-Awash Junction road project, 2008
2. American Society of Testing Materials (2003), Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications, ASTM D 6951-03, ASTM International, West Conshohocken, PA
3. Ethiopia Roads Authority ERA (2002), Site Investigation Manual.
4. Ethiopia Roads Authority ERA (2002), Pavement Design Manual.
5. Ethiopia Roads Authority ERA (2002), Standard Technical Specification
6. Ethiopia Roads Authority ERA (2011), Design Manual for Low Volume Roads
7. Geological Survey of Ethiopia (1996), Geological Map of Ethiopia (Scale 1:2,000,000) Second Edition.
8. Harison, J. R. (1987), Correlation between California Bearing Ratio and Dynamic Cone Penetrometer Strength Measurement of Soils, Proc. Instn. Of Civ. Engrs., London, Part 2, pp. 83-87.
9. Kleyn, E. G. (1975), The Use of the Dynamic Cone Penetrometer (DCP), Rep. No. 2/74. Transval Roads Department, South Africa.
10. Livneh, M. (1987), “Validation of Correlations between a Number of Penetration Tests and In Situ California Bearing Ratio Tests, Transp. Res. Rec. 1219. Transportation Research Board, Washington, D.C., pp. 56-67.
11. Scala, A. J. (1956). Simple Methods of Flexible Pavement Design Using Cone Penetrometers,. New Zealand Engineering, Vol. 11, No. 2.
12. TRL Overseas Road Note 9, A design manual for small bridge, 1990
13. Bowles Joseph E, Foundation Analysis and Design, McGraw-Hill, Singapore, second edition, 1997.
14. VAN ZYL, GD, Visser, AT and Du Plessis, JA. 1995. Guidelines for structural design of low volume rural roads in southern Africa. Proc 6th Int Conf on Low Volume Roads, Minneapolis, Minnesota, June 1995, Vol 2, pp 108-117.
15. PAIGE-GREEN, P, Lea, J and Barnado, C. 1999. The relationship between in situ DCP strength and soaked CBR. Pretoria: CSIR Transportek. (Technical Report TR 99/003).
16. Committee of Land Transport Officials (COLTO), Structural design of flexible pavements for interurban and rural roads. Draft TRH 4, Department of Transport, Pretoria, 1996.
17. Ministry of Works, Transport and Communications. Pavement testing, analysis and interpretation of test data. Guideline No 2, International Cooperation Roads Department / NPRA Oslo, Norway, 2000.
18. E.G.Kleyn and G.G.Van Zyl, Application of the Dynamic Cone Penetrometer (DCP) to light pavement design, Pretoria: Transvaal Provincial Administration, Laboratory Report L4/87, 1987.