THE DYNAMIC CONE PENETROMETER AS A VALIDATION TOOL FOR COMPACTION OF CRUSHED ROCK BASE

By

Felix Bakobie, BSc Civil (Hons)

A Thesis Submitted to the Department of Civil Engineering,
Kwame Nkrumah University of Science and Technology, Kumasi
In Partial Fulfillment of the Requirement for the Award of the Degree of

Master of Science

Faculty of Civil and Geomatic Engineering
College of Engineering

May 2008

CERTIFICATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

Felix Bakobie	.... Signature	30/07/08 .... Date

Certified by:

Dr. S.I.K. Ampadu	.... Signature	30/07/2008 .... Date

Certified by:

Dr. S.I.K. Ampadu	.... Signature	30/07/2008 .... Date

ACKNOWLEDGEMENT

I am grateful to the Mr. Francis Dzeble, the Engineer Representive on the Rehabilitation of Awiankwanta-Yamorasa Road Project, being executed by M/s Cymain (Gh) Limited and his staff for the help and support given me during my field study.

My sincere gratitude also goes to my supervisor, Dr. S. I. K. Ampadu for the encouragement and guidance given me throughout my research and making it possible for a successful completion of this project work

I also wish to express my appreciation to the staff and management of M/s Cymain (Gh) Limited for their support and the use of their site for the study.

Finally, I wish to thank all staff of RTEP who in diverse ways helped to the success of this work.

Thank you all and the Good Lord bless you all in your endeavour.

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Standard Testing Methods
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
DPI	Dynamic Penetration Index
GHA	Ghana Highway Authority
LC	Level of Compaction
MDD	Maximum Dry Density
MoT	Ministry of Transportation
OMC	Optimum Moisture Content
TRL	Transport Research Laboratory

ABSTRACT

The traditional method of verifying the level of compaction achieved on construction sites using sand replacement method is very time consuming and sometimes difficult to perform. Furthermore, on sites open to traffic the safety of the inspectors while conducting sand cone testing on a construction site can be a concern. Therefore, the objective of this study is to ascertain the extent to which the DCP can be used as a tool to verify the level of compaction achieved in-situ on a crushed rock base.

Studies were conducted on an on-going road project to ascertain the extent to which the Dynamic Cone Penetrometer (DCP) can be applied in compaction verification on crushed rock. Compaction studies were conducted on three sections of the project site using a 17 ton vibratory roller. DCP test was conducted alongside sand replacement test to determine the level of compaction for one, two, four and eight roller passes. A linear relation was developed between the level of compaction and DPI values from the DCP test which is of form Log (LC) = $\alpha - \beta^*$ log (DPI), where LC is level of compaction by the sand replacement method and DPI is the penetration rate of the DCP. The values of α and β were found to 2.134 and 0.109 respectively.

A further study was also conducted in the laboratory to adjust the DPI values at various water content to constant water content. Three levels of compaction were calibrated and the result relation is linear and is of the form DPI= $\kappa + \lambda w$, κ is a constant that depends on the level of compaction and w is the water content of the material at time of testing.

CR-B10:	DPI = 3.874 + 0.855w	LC=93%
CR-B25:	DPI = 1.228 + 0.836w	LC=97%
CR-B55:	DPI = 1.316 + 0.470w	LC=101%

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

The performance of a pavement during its life does not only depend on the quality of pavement material, but also on the strength of the constructed pavement which principally on the level of compaction achieved. It is important that high levels of compaction are achieved during the construction of the sub-grade, sub-base, base and even wearing course, so that the pavement experiences minimum volumetric changes from post-construction traffic loads. It is therefore necessary that road engineers ensure that high levels of compaction are achieved during road construction to minimize maintenance costs and increase pavement life.

Quality assurance within road agencies particularly in Ghana is based on a much heavier ASTM Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (ASTM D 1557-91) commonly referred to as the Modified AASHTO laboratory compaction (AASHTO T180). The Ministry of Roads and Transport (MRT 2006) specification in Ghana for base and sub-base respectively requires the attainment of at least 98 % and 95% of the maximum dry density achieved in the laboratory by the Modified AASHTO.

The most frequent method of compaction verification in the field is the ASTM Test for Density of Soil in Place by the Sand Replacement Method (ASTM D1556-90), locally referred to as the sand replacement method. The difficulty encountered with the sand replacement method has been with the determination of the water content on site so that the dry density could be quickly determined. With the advancement in technology, instant moisture detectors such as the Speedy Moisture Tester (ASTM D 4944-89) and the use of the ASTM Standard Test for the Determination of Water Content of Soil by the Microwave Oven Method (ASTM D 4643-87) have been developed.

The strength of pavement layers have in many cases been measured by the use of Dynamic Cone Penetrometer apparatus; which correlates the California Bearing Ratio (CBR) of the pavement with the Dynamic Penetration Index (DPI) defined as the penetration per blow during the DCP test. Ampadu and Arthur 2006 indicated that the DCP may also be used to verify the level of compaction achieved in the field for lateritic material. This study was undertaken to determine the extent to which the DCP test may be used to verify the level of compaction achieved in the field on a pavement of crushed rock.

1.2 Research Objectives

The main objective of this study is to ascertain the extent to which the DCP can be used as a tool to verify the level of compaction achieved in-situ on a crushed rock base.

The specific objectives are to:

1. Determine the engineering characteristics of crushed rock used for base construction,
2. Determine the correlation between the level of compaction achieved on crushed rock base and DPI Index in-situ,
3. Make adjustments in the correlation for the dependence of DPI on moisture content variation.

1.3 Justification

1. The traditional method of verifying the level of compaction achieved on construction sites using sand replacement method is very time consuming and sometimes difficult to perform. Furthermore, on sites open to traffic the safety of the inspectors while conducting sand cone testing on a construction site can be a concern,
2. However, once a calibration has been obtained the use of DCP is a rapid method of verifying the levels of compaction achieved,
3. The DCP is a simple and relatively less expensive equipment,
4. The DCP have been found to be a valuable tool for identifying non-uniformity in the levels of compaction, (Ampadu and Arthur, 2006). Whereas the sand replacement method of compaction verification only gives an average value of the levels of compaction across the whole pavement thickness, the DCP test results can indicate non-uniformity in compaction across the pavement thickness,
5. Previous studies have obtained correlations for using the DCP as a tool for compaction verification on lateritic soils. However, it appears such verification has not been done for crushed rock base.

1.4 Scope of Investigations

The scope of this study covers both laboratory and field work.

The laboratory test consists of:

1. Test for characterization of test material (i.e. crushed rock). These tests consisted of the Atterberg Limits, grading, compaction and CBR Test,

2. Tests for calibration of DCP results against moisture content changes in calibration chamber (CBR Mould),

The field studies consisted of:

1. The selection and preparation of a section on the Awiankwanta-Yamorasa Road, near (Awiankwanta-Assin Praso Section) in the Ashanti Region where rehabilitation of the road was underway,
2. Performing a DCP and the sand replacement test after various number of passes of a 17 ton vibratory roller.

2 LITERATURE REVIEW

2.1 Granitic Rocks in Ghana

Granites and granite gneisses which are Post-Tarkwaian granitic rocks cover about one fifth of the total area of Ghana. The distribution of granitic rock in Ghana is Shown in *Figure 2.1.* They are found mainly in the northern, western, south-western and southern parts of the country and are believed to be post-Birimian and pre-Tarkwaian in age.

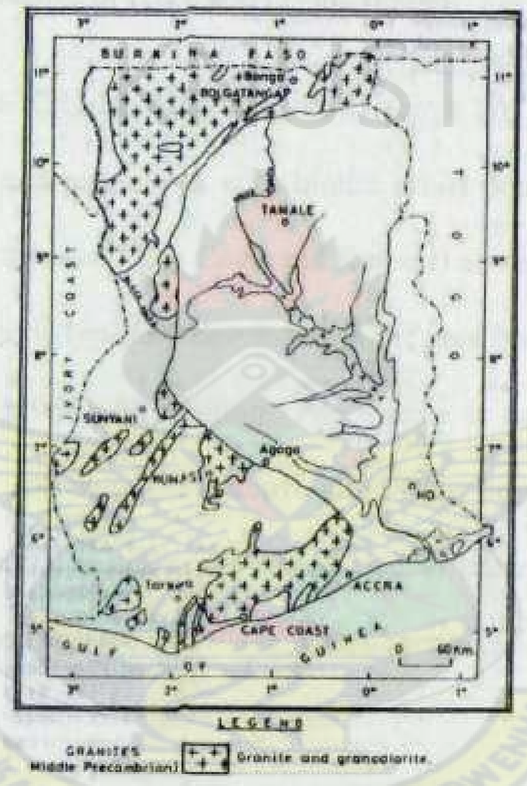


Figure 2.1 Map showing the Granite area of Ghana

These granites are a heterogenous association of rocks with wide range of chemical and mineralogical composition. These minerals include aplites, diorite, granodiorites adamellites, syenites, granites (sensu atricto), granite, gneisses and pegmatites.

The dominant ferro-magnesian mineral may be hornblende, alone or with biotite, or muscovite alone.

Texturally, the rocks vary from very fine-grained to coarse-grained. They may be massive, porphyroblastic, foliated or gneissic and can show preferred orientation in the field. Some have been severely altered whilst others are fresh and unaltered. They vary from beautiful black and white rocks to dark greenish, yellowish, light grey, reddish and many other combinations.

Granite in Ghana have been divided into three main groups comprising (1) the Cape Coast or (G1); (2) the Dixcove or (G2); and (3) the Bongo.

The Cape Coast granite (G1) is older than the Dixcove and is mainly a biotite and muscovite granodiorite and pegmatites with biotite schist pendants. It occurs in very large batholiths (such as those of Cape Coast and Kumasi) as well as in smaller masses. The Dixcove (G2) granite is typically developed in the area between Axim, Akoko and Takoradi and also has a wide distribution. The granite is normally a biotite and/or hornblends granodiorite. Although the Dixcove granite has been inferred to be younger than the Cape Coast granite, it has never been found to intrude it. However, granites similar to members of the Dixcove suits have been observed within biotite gnesis of the Cape Coast type in many areas throughout Ghana

In general, it has been observed that throughout Ghana, the Lower Birimian sediments are associated with the Cape Coast complex and the Upper Birimian volcanics with hornblende granoiorites of the Dixcove type.

The Dixcove granite is typically unfoliated while the Cape Coast granite is usually gneisses and often migmatitic. The Na/K ratio is higher in the Dixcove granites than in the Cape Coast granites. The fieldpars in the Dixcove granites are severely altered, while in the Cape Coast granites they can be fresh.

The Bongo granites are mainly reddish microcline granites found mainly in the upper region of Ghana in the Togo and Bongo areas. Their relationship with the coast and Dixcove granites is still unknown.

2.2 The Distribution of Quarries in Ghana

The distribution of quarries is shown in *Figure 2.2.* Table 2.1 shows the location of quarries and type of rock mined.

It can seen that quarries in Ghana have been sited in rocks made of gneiss and granite and a few in gabbro and tonolite.

Figure 2.2 Quarry Locations in Ghana

Table 2.1The Quarries in Ghana showing the type of Rock being mined.

REGION	QUARRY	LOCATION	ROCK TYPE
GREATER ACCRA	BBC	Shai Hills	Garnet Gneiss
	CP	Ablekuma	Gneiss
	Eastern	Shai Hills	Garnet Gneiss
	Sonitra	Gbawe	Gneiss
	Twin Rock	Shai Hills	Garnet Gneiss
VOLTA	Bilfinger	Akosombo Road	Gneiss
	Sonitra	Kpetoe	Gneiss
	Volta	Adaklu	Gneiss
EASTERN	GHA	Nsawam	Gneiss
	KASAP	Akuse	Garnet Gneiss
	Peabo 1	Nsawam	Gneiss
	Peabo 2	Off Adeiso Rd	Gneiss
CENTRAL	CP	Ejuegyei	Granite
	Eyiaba	Assin	Quartz Gabbro
	Twin rock	Assin	Quartz Gabbro
WESTERN	Eagle Star	Baminkor	Granite
	GDC	Essipon	Gabbro
	SICOL	Essipon	Gabbro
ASHANTI	Consar	Barekese	Tonolite
	GHA	Barekese	Tonolite
	Limex	Buokrom	Granodiorite
	Fosu Stone Quarry	Kwapia ,Ash	Granite
	KAS	Buoho	Tonolite
	Sonitra	Yawkwei	Granite
	Aarsleff Ghana J.V	Asonomanso	Granite
	Kumasi Stone	Buoho	Tonolite
BRONG AHAFO	KASAP	Buoko	Granite
	Nsemmere	Sunyani	Granite
	P.W (Gh)	Ntensere	Granite
	KAS Ltd	Buoko	Granite
	TAYSEC	Wenchi	Granite
NORTHERN	Mod. Gh. Builders	Sawla	Granite
UPPER EAST	Upper	Pwalugu	Granite
UPPER WEST	P & W	Wa	Granite

Source: Ghana Highway Authority (Quarries in Ghana Manual, 2005)

2.3 Soil Compaction

2.3.1 The Compaction Process

Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight.

The characteristics of a soil during compaction depends on several factors including the type of soil, the water content, the compactive effort and the method of effort application. The effect of compaction on a soil is usually captured by the dry density water content relationship.

Fundamentally, the compaction process causes the expulsion of air from the soil resulting in a denser material. The compaction process has significant differences for cohesive soil versus cohesionless soils. The major difference is cohesive soils are typically very moisture dependent and cohesionless soils are not (Winterkorn, 1975). According to Winterkorn and Fang, the compaction theories based on effective stresses explain the shape of the compaction curve better than the theories based on lubrication and viscous water (Winterkorn and Fang, 1975).

2.3.2 Factors affecting Compaction

The dry density of the soil is increased by compaction. The increase in the dry density depends upon the following factors:

Effect of Water Content

For Cohesive Soil as the water content is increased, the soil particles get lubricated. The soil mass becomes more workable and the particles have closer packing. The dry density of the soil increases till the optimum water content is reached, the density and the moisture content at this maximum values are the maximum dry density (MDD) and the optimum moisture content (OMC) respectively. At that stage, the air voids attain approximately a constant volume. With further increase in water content, the air voids do not decrease, but the total voids (air plus water) increase and the dry unit density decreases.

The relationship between dry density and moisture content is illustrated in *Figure 2.3* for a typical cohesive soil.

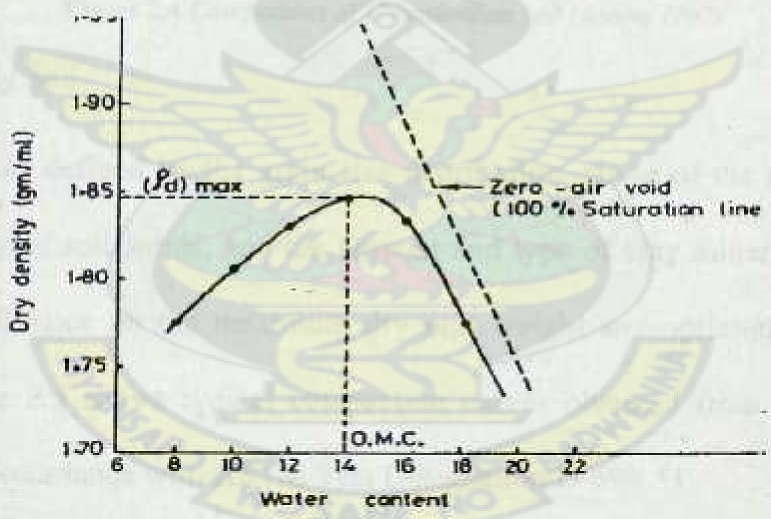


Figure 2.3 Compaction for cohesive soils (Arora, 1997)

Figure 2.4 illustrates the compaction of cohesionless soils. The figure show that the dry unit weight has a general tendency first to decrease as moisture content increases, and then to increase to a maximum value with further increase of moisture. The initial decrease of dry unit weight with increase of moisture content can be attributed to the capillary tension effect. At lower moisture contents, the capillary tension in the pore water inhibits the tendency of the soil particles to move around and be densely compacted.

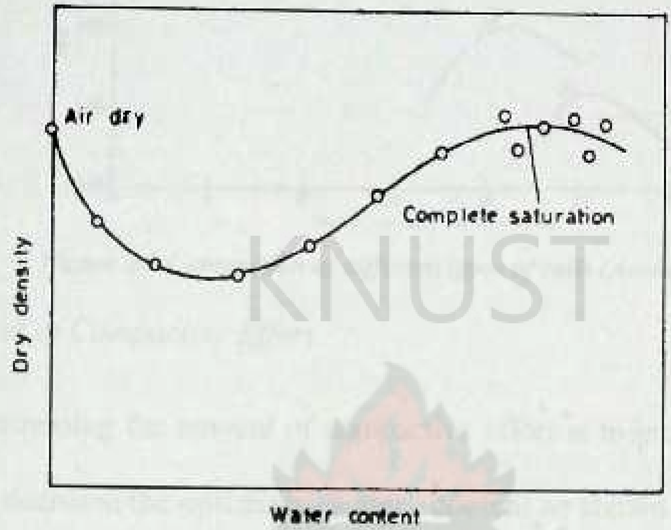


Figure 2.4 *Compaction of Cohesionless soil (Arora, 1997)*

Effect of Type of Soil

The soil type, as defined by the grain-size distribution, shape of the soil grains, specific gravity of soil solids, and the amount and type of clay minerals present has a great influence on the maximum dry unit weight and optimum moisture content. *Figure 2.5* shows typical compaction curves obtained from four soils, compacted in accordance with ASTM Test Designation D-698.

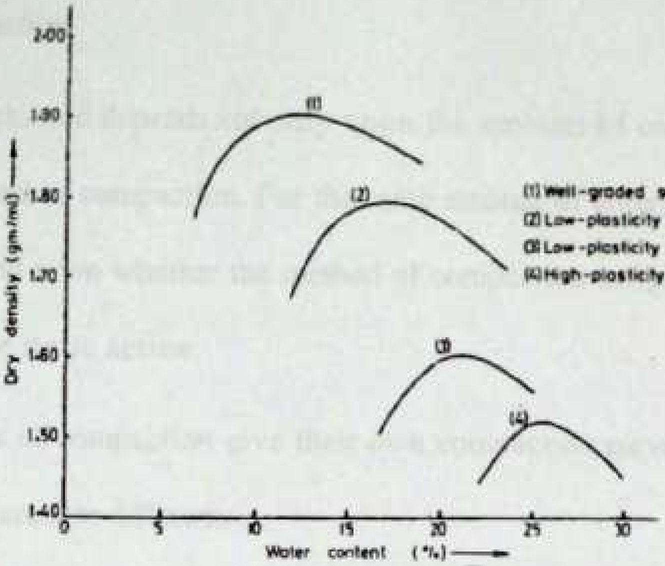


Figure 2.5 Compaction of different types of soils (Arora, 1997)

Effect of Amount of Compactive Effort

The effect of increasing the amount of compactive effort is to increase the maximum dry density and to decrease the optimum water content as shown in *Figure 2.6*.

The line of optimums which joins the peaks of the compaction curves of different compactive efforts follows the general trend of zero-air void line. This corresponds to air voids of about 5%.

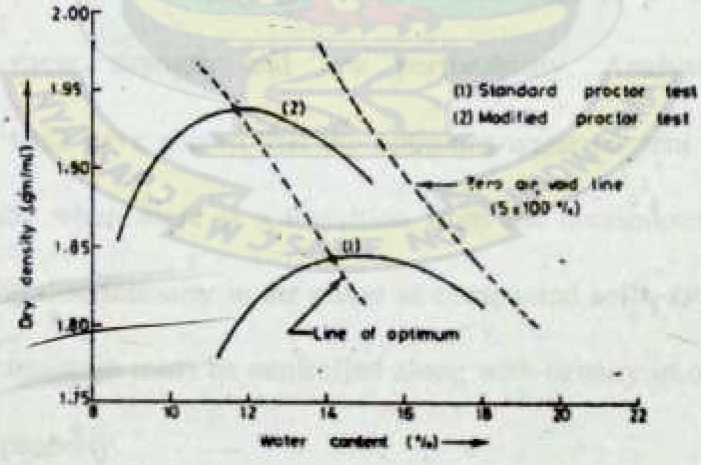


Figure 2.6 Effect of different compaction effort on soil (Arora, 1997)

Method of Compaction

The dry density achieved depends not only upon the amount of compactive effort but also on the method of compaction. For the same amount of compactive effort, the dry density will depend upon whether the method of compaction utilizes kneading action, dynamic action or static action.

Different methods of compaction give their own compaction curves. Consequently, the lines of optimums are also different.

2.3.3 The Effect of Compaction on Soil Structure

Soils compacted on the dry side of optimum have flocculated structure with few but larger voids as in *Figure 2.7(b)* while soils compacted on the wet side have dispersed structure regardless of method of compaction as show in *Figure 2.7(a)*.

Flocculated structured soils are induced by low shear strains and therefore have low compressibility and high permeability with high shear strength. Dispersed structure on the other hand is induced by large shear strain and it is flexible with high compressibility, shear strength and low permeability. Analysis of compaction characteristics of soils have shown that the optimum water content and maximum dry density are reached when there is a transition from the continuous air phase to the occluded state with discontinuity in air phase in compacted soils, (Pandian et al,1997). Thus compaction moisture must be controlled along with density in order to achieve the required material property.

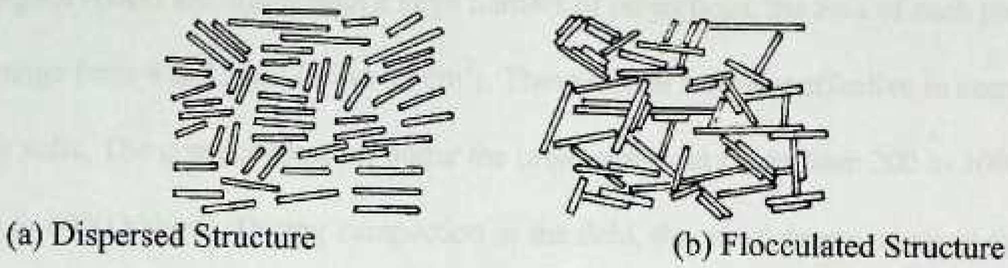


Figure 2.7 Illustration of Soil Structure (after Gopal and Rao, 2000)

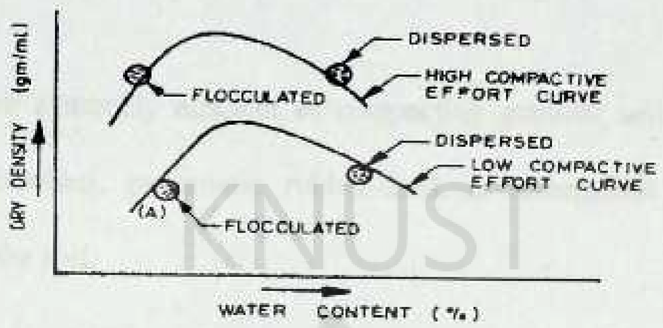


Figure 2.8 *Structure of a compacted soil (Arora, 1997)*

2.3.4 Field Compaction

Smooth-wheel rollers are suitable for proof rolling subgrades and for finishing operation of fills with sandy and clayey soils. These rollers provide 100% coverage under the wheels, with ground contact pressures as high as 45 to 55 lb/in.^{2} (310 to 380 kN/m^2). They are not suitable for producing high unit weights of compaction when used on thicker layers.

Pneumatic rubber-tired rollers are better in many respects than the smooth-wheel rollers. The former are heavily loaded with several rows of tires. These tyres are closely spaced four to six in a row. The contact pressure under the tyres can range from 85 to 100 lb/in.^{2} (585 to 690 kN/m^2), and they produce about 70 to 80% coverage. Pneumatic rollers can be used for sandy and clayey soil compaction. Compaction is achieved by a combination of pressure and kneading action.

Sheepsfoot rollers are drums with a large number of projections, the area of each projection may range from 4 to 13 in.^{2} (25 to 85 cm^2). These rollers are most effective in compacting clayey soils. The contact pressure under the projections can range from 200 to 1000 lb/in.^{2} (1380 to 6900 kN/m^2). During compaction in the field, the initial passes compact the lower portion of a lift. Compaction at the top and middle of a lift is done at a later stage.

Vibratory rollers are extremely efficient in compacting granular soils. Vibrators can be attached to smooth-wheel, pneumatic rubber-tired, or sheepsfoot rollers to provide vibratory effects to the soil.

Handheld vibrating plates can be used for effective compaction of granular soils over a limited area. Vibrating plates are also gang-mounted on machines. These plates can be used in less restricted areas.

2.3.5 Factors Affecting Field Compaction

In addition to soil type and moisture content, other factors must be considered to achieve the desired unit weight of compaction in the field. These factors include the thickness of lift, the intensity of pressure applied by the compacting equipment, and the area over which the pressure is applied. These factors are important because the pressure applied at the surface decreases with depth, which results in a decrease in the degree of soil compaction. During compaction, the dry density of soil is also affected by the number of roller passes. *Figure 2.9* shows the growth curves for a lateritic soil. The dry density of a soil at a given moisture content increases to a certain point with the number of roller passes and thereafter remains approximately constant.

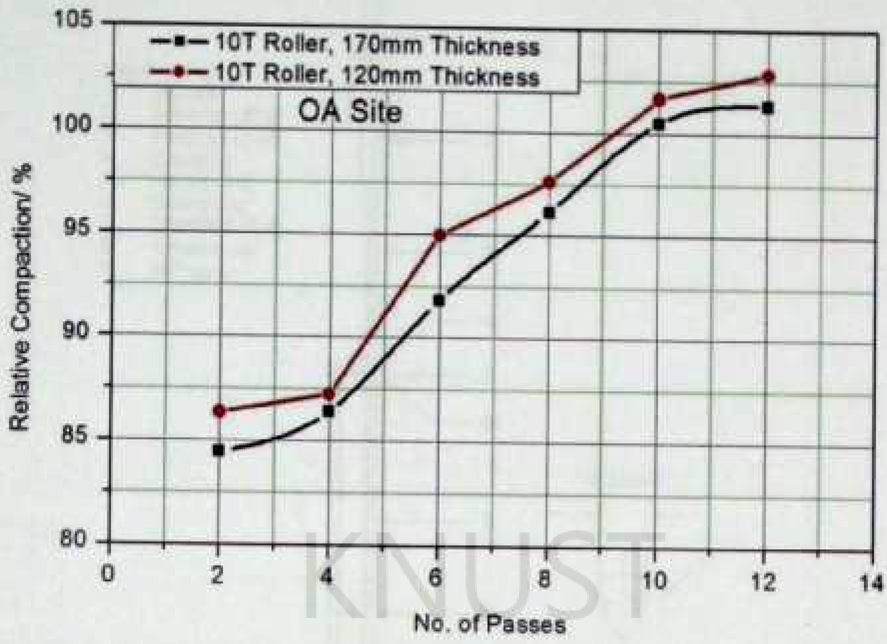


Figure 2.9 *Dry density growth curves with number of passes (Amissah, 2007)*

2.4 The Dynamic Cone Penetrometer

2.4.1 Development of the DCP

The early development of the Dynamic Cone Penetrometer (DCP) concept was reported in Australia (Scala, 1956). Van Vuuren, from South Africa developed a new DCP apparatus in 1969 (Van Vuuren, 1969) and showed that the DCP was only suitable for soils with CBR values ranging from 1 to 50. Kleyn modified Van Vuuren's DCP device and applied the modified DCP for pavement evaluation, (Kleyn, 1975). The present DCP device has the hammer weight of 8 kg, the drop height of 575 cm and cone angle of 60 degrees which conforms to TRL Model A 2465 as described in Overseaas Road Note 18. *Figure 2.10* show typical DCP equipment.

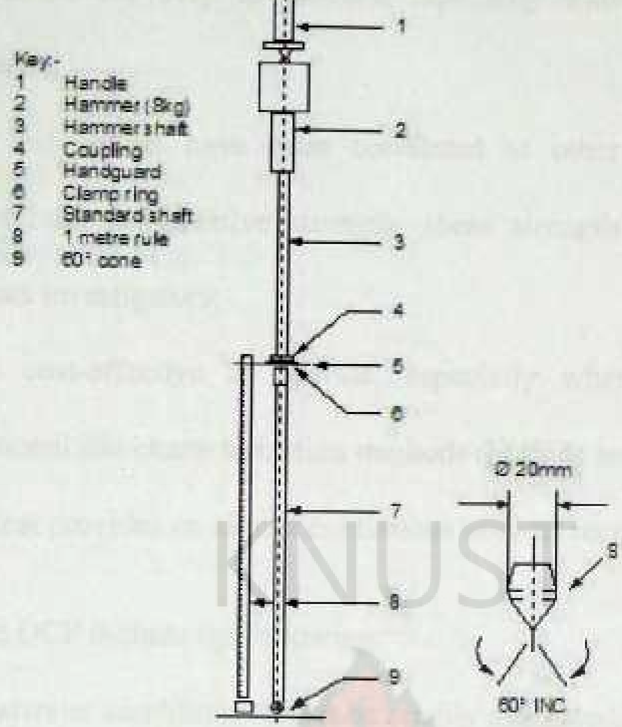


Figure 2.10 DCP instrument

2.4.2 Capabilities and Limitations of the DCP

The advantages of the DCP are:

(i) It is not expensive to acquire and can be manufactured in-house

(ii) It is portable and suitable when access and space becomes a constrain especially in confined areas such as inside buildings or at congested sites that would prevent the use of traditional boring equipments;

(iii) It is easy to learn how to operator in matter of minutes'

(iv) It is a simple device to operate, requiring 3 people for its efficient operation;

(v) The test is fast to conduct leading to gathering large amount of information over wider area;

Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering, KNUST.

(vi) Its results are easy to process, especially when used with appropriate software;

(vii) The test results have been correlated to other soil parameters (CBR, unconfined compressive strength, shear strength and SPT N-values) by various investigators;

(viii) It is cost-effective to operate, especially when compared with other traditional site characterization methods (borings and laboratory/field tests).

(ix) The test provides an almost continuous vertical record at a test spot.

Limitations of the DCP include the following:

(i) Groundwater conditions cannot be readily evaluated;

(ii) No samples of subsurface material are obtained for either visual inspection or further analysis;

(iii) The DCP is not suitable for gravel soils and hard formations such as highly weathering and fresh rock formations – the DCP rod can be bent during testing giving rise to significant variable results; and

(iv) The DCP being dynamic nature renders its values susceptible to variables other than those associated with variations in soil conditions.

2.4.3 DCP as a Compaction Verification Tool

The Dynamic Cone Penetrometer (DCP) instrument is used extensively for the rapid in-situ measurement of the structural properties of existing road pavements constructed with unbound materials without having to bore through them first. Extensive research by various researchers has established a correlation between the DCP penetration rate and the strength of the material as measured by the California Bearing Ratio (CBR). The general form of the correlation between the CBR and the penetration rate denoted by the parameter DPI is given by

$$\text{Log(CBR)} = \alpha - \beta(\text{LogDPI})^{n}$$

There have also been various studies that recommend the dynamic cone penetrometer for compaction control and verification. Recent recommendations include those of Chaigneau et al. (2000) and Gabr et al. (2001). Both recommendations, however, were laboratory investigation results and pointed to the need for field calibration.

Ampadu and Arthur (2006) and Amissah (2007) conducted compaction verification study on a model pavement along a road construction project using the dynamic cone penetrometer and the traditional sand replacement method for lateritic gravel. *Figures 2.11, 2.12 and 2.13* show results of the study respectively. The general form of the correlation between the level of compaction, LC and the penetration rate denoted by the parameter DPI is given by

$$\text{Log(LC)} = \kappa - \lambda\,(\text{Log (DPI)})$$

Table 2.2 presents summaries κ and λ Values for studies conducted by Ampadu and Arthur, 2006 and Amissah, 2007.

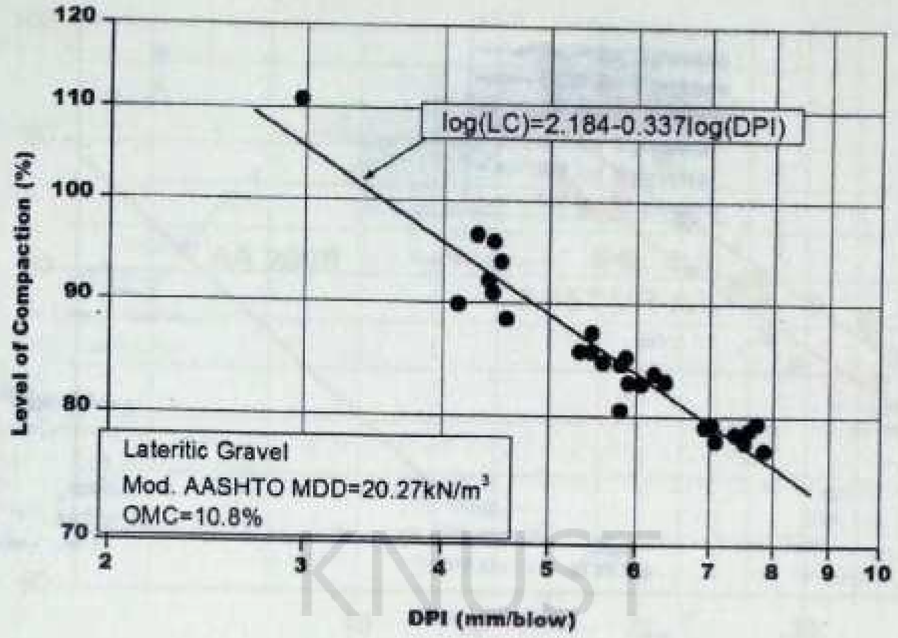


Figure 2.11 Correlation between sand replacement and DCP test results (**Ampadu and Arthur, 2006**)

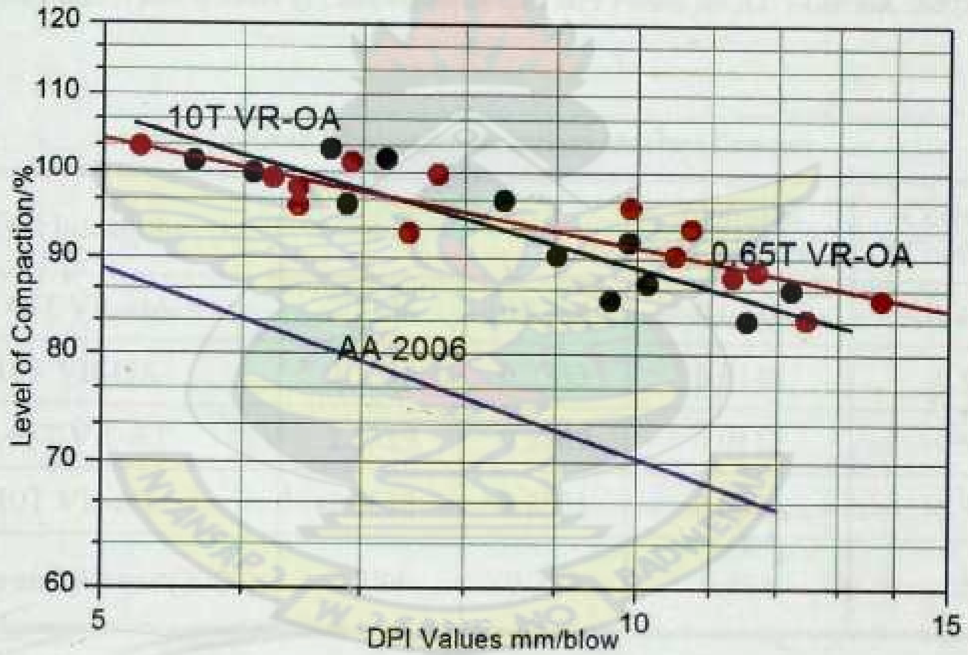


Figure 2.12 A plot of Level of Compaction against DPI Values for OA (Amissah, 2007)

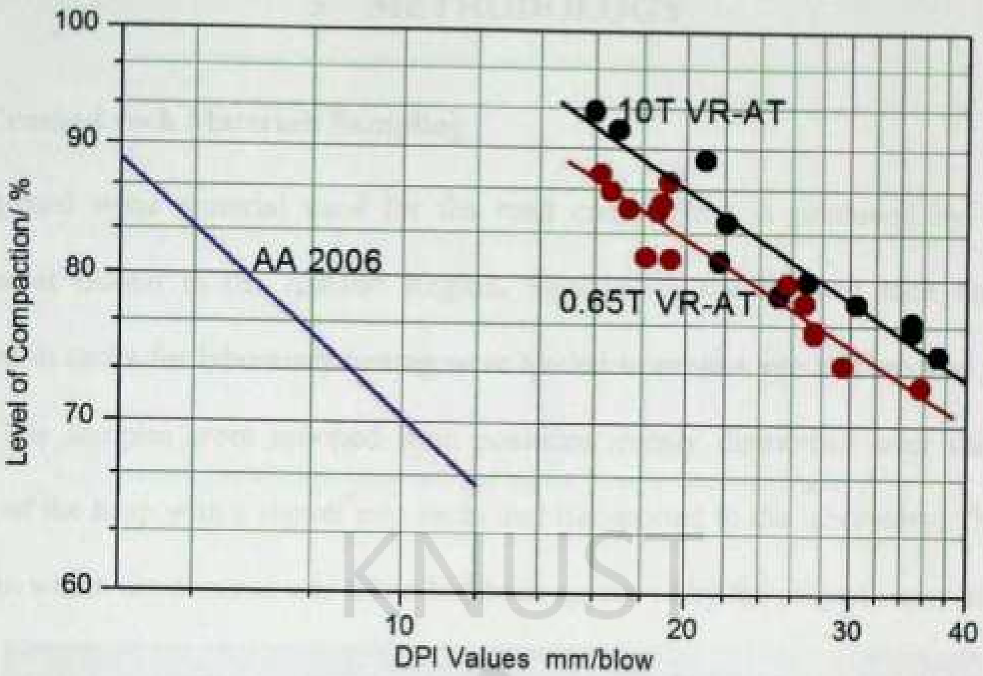


Figure 2.13 A plot of Level of Compaction against DPI Values for AT (Amissah, 2007)

Table 2.2 κ and λ Values for the various Moisture Contents

Test Location	κ	λ	Standard Deviation	Correlation Coefficient
0.65T VR-OA	2.1388	0.1794	0.0134	-0.8919
10T VR-OA	2.1835	0.2353	0.0146	-0.9045
0.65T VR-AT	2.2319	0.2407	0.0112	-0.9475
10T VR-AT	2.2638	0.2501	0.0096	-0.9446
Ampadu and Arthur (2006)	2.184	0.337	0.011	-0.955

3 METHODOLOGY

3.1 Crushed rock Materials Sampling

The crushed stone material used for the road construction is produced by Cymain Quarries at Buoho in the Ashanti Region. Samples of the crushed rock that were collected in sacks for laboratory testing were hauled to project site and stocked piled in heaps. The samples were scooped from positions evenly distributed over the whole surface of the heap with a shovel into sacks and transported to the laboratory. The stock pile from which the material was taken had been approved by the project supervisor.

Figure 3.1Stock pile from which samples were taken for laboratory characterization

3.2 Laboratory Testing for material Characterization

3.2.1 Sample Preparation

1) The material sample in the sack was air dried for about 2 to 3 days.

2) The samples were thoroughly mixed and quartered to obtain two portions; one portion was sieved through 20mm BS test sieve size.
3) The samples were then riffled through a box and one part of the riffled samples was used for the compaction test and the other parts used for the other laboratory tests.

3.2.2 Liquid limit

The Liquid Limit was determined using the Cone Penetrometer method in accordance with the BS 1377, Part 2, 1990. The procedures are summarized below:

Cone Penetration method

1. Part of the riffled material was sieved through 0.425mm test sieve and mixed thoroughly with distilled water to obtain a homogeneous paste.
2. About 300g of the soil paste was mixed further with water to produce material of sufficient consistency and used to fill the cup.
3. The tip of the cone was brought into position and released for 5 seconds and the penetration of the cone into the soil was recorded using a dial gauge. This was repeated by refilling the area of penetration and the average penetration was taken.
4. The moisture content of this sample was determined.
5. The experiment was repeated two more times using the same sample, to determine the cone penetrations for increased water contents such that the penetration was between 15mm to 25mm.

6. The moisture contents were plotted against the cone penetrations to determine the liquid limit as the moisture content corresponding to the cone penetration of 20mm.

3.2.3 Grading

The distribution of particles of various sizes in the crushed rock was determined by mechanical sieve analysis.

1. About 1459g of riffled sample was weighed and treated with hydrogen peroxide to remove organic matter.
2. It was then washed under water through sieve no. 200 and oven dried for 24 hours.
3. It was then sieved through a set of standard sieves specified by (BS 410:1976) and (ASTM E-11-70).

3.2.4 Compaction Test

Portion of the prepared samples were used for the Modified AASHTO compaction test. The test was performed in accordance with American Standard Testing Method (ASTM) Test Method for Laboratory Compaction Characteristics of Soils Using Modified Effort, ASTM D 1557-91.

Test Procedure:

1. Water was added to the soil and increased progressively in steps of 2% was thoroughly mixed.
2. The mould was filled with the sample which was manually compacted using 55 blows of the 4.5g hammer, each for 5 layers.

3. The weight of the compacted sample was determined together with the moisture content.
4. The dry densities were determined. The results are shown in *Appendix A.*

3.2.5 California Bearing Ratio Test (CBR)

California Bearing Ratio tests were conducted for soaked compacted samples. The CBR was carried out according to the test Standard BS 1377: part 2:1990, clause3

1. The OMC obtained during compaction was used to calculate the weight of Water needed to be added to the soil
2. The expected weight of the compacted material for CBR determination was also calculated by the use of the MDD, OMC, and mould factor from the relation: $\text{Expected Wt.} = \text{Mould Wt} + \frac{(100 \text{ x MDD} + \text{OMC})}{\text{Mould Factor}}$
3. The water was added to the sample and thoroughly mixed and put in polythene bag and tightened to prevent loss of moisture for an hour to allow for uniform mixture.
4. The mould was then filled with the sample in layers manually compacted using 55 blows, each for 5 layers. The test was repeated using 25 and 10 blows
5. The three compacted samples at 55, 25 and 10 blows were soaked in water for 4 days.
6. The conditioned sample was set up in the CBR apparatus, and the CBR determined using appropriate surcharge pressure of 2.5 kPa.

3.3 Laboratory DCP Testing

3.3.1 Sample preparation

1. The OMC obtained during compaction was used to calculate the weight of water required to be added to the soil.
2. The required water was added to the sample and thoroughly mixed
3. The mixed sample was put in polythene and tightened to prevent loss of moisture
4. The mould was then filled with the sample in 5 layers each layer received 55 blows
5. This was repeated for 25 and 10 blows. Nine samples were prepared for each level of compaction.

3.3.2 Moisture Conditioning

1. For each level of compaction, a set of four samples of the compacted soil were soaked in water for different time periods whist another same set were air dried. For the soaked conditioning, the samples were completely submerged in the water. The remaining four samples were allowed to dry in the laboratory for some length of time.

   The varying conditioning period was to ensure that the samples attained different moisture content before the test is performed.
2. The soaking and the air drying were done for same day (control), 1day, 2 days 3 days and 4 days in exactly the same as for the CBR.

3.3.3 DCP Test

1. DCP Test was performed on a set of three of the compacted soil samples at 55, 25 and 10 blows on the same day/control by the use of the DCP equipment in the CBR mould after which samples were taken at top, middle and bottom for moisture content determination. The test was repeated for 1 day, 2 days, 3 days and 4 days.
2. A graph of DCP penetration readings against cumulative blows was plotted to establish the DCP D-values (DPI).

The DCP equipment used in the study is shown in figure *Figure 3.2.*

Figure 3.2 The DCP equipment used in the study

Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering, KNUST.

3.4 Field Studies

3.4.1 Test Section Preparation

Three sections of the roadway, each 100m in length were selected for the study. The sub-base layer, on which the crushed stone were to be place had already been prepared, tested and approved by the supervisor. A paver was used to lay the crushed stone material to a loose lift thickness of 200 mm, corresponding to a compacted thickness of 150 mm. A ramp was created at the beginning and the end of test section to allow easy access of the roller on the bed. *Figure 3.3* shows a typical test bed.

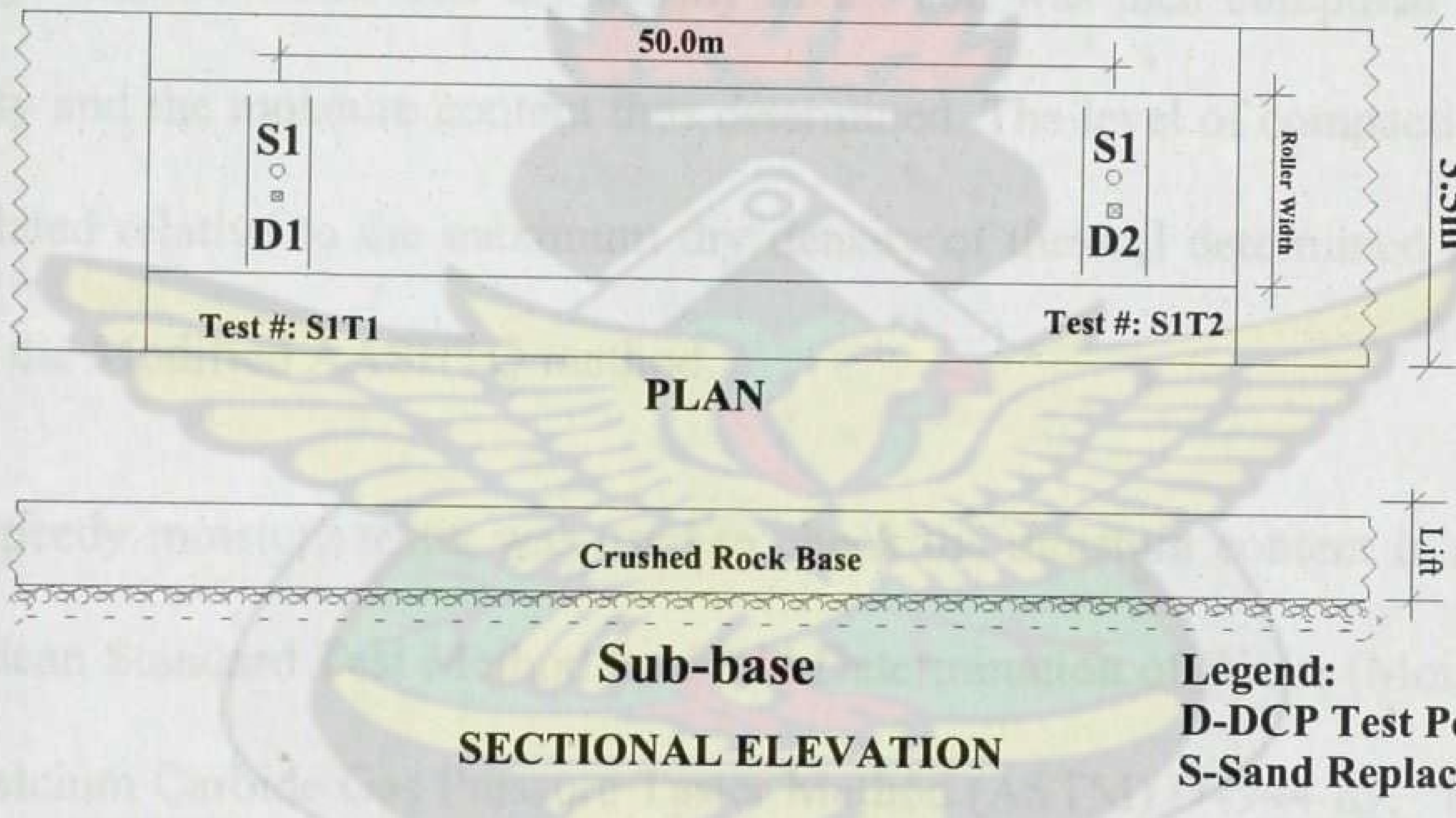


Figure 3.3 Layout and section of a typical Test Section used for study

3.4.2 Compaction Procedure

The compaction plant used in this study was a single drum vibratory roller of 17ton capacity. The compaction plant was mounted on the bed and driven slowly forward to the end of the bed and then reversed along the same track. This forward and backward movement along the same path constituted two roller passes.

3.4.3 Compaction Verification Using the Sand Replacement Method

The compaction achieved measured every two, four, eight and sixteen passes. The sand replacement method was used to determine the level of compaction achieved. In this method of measuring the in-situ density, a cylindrical hole approximately 150 mm in diameter and not exceeding 150 mm deep was carefully made using a template by excavating the compacted soil. The actual depth for the density measurement depended on the thickness of the bed, care being taken to ensure that the hole terminated in the compacted material. The moisture content of the excavated soil was determined using speedy moisture tester. The dry density of the soil was then computed from the in-situ density and the moisture content thus determined. The level of compaction achieved was calculated relative to the maximum dry density of the soil determined in the laboratory using the Modified AASHTO method.

The speedy moisture tester was used to check the moisture content in accordance with American Standard Test Method for Field Determination of Water (Moisture) of Soil by the Calcium Carbide Gas Pressure Tester Method (ASTM) D4944-89. In this method, a quantity of the material was taken from excavated material for sand replacement test in a container and weighed on a weighing balance. A measured quantity of calcium carbide was added and placed in the speedy moisture tester. The tester and its content were shaken for about three minutes and the moisture content was read from the dial gauge on the tester.

3.4.4 Compaction Verification Using the Dynamic Cone Penetrometer Testing

In the study, after selected number of passes, next to the sand replacement test locations, the DCP test was performed at the locations. Because the sand replacement method is a destructive test, the test locations were not reused.

The penetration achieved after every incremental blows was recorded for selected passes, two, four eight and sixteen.

4 DISCUSSION OF RESULTS

4.1 Project background

The Field Test was performed on two model section on the Rehabilitation of Awiankwanta-Yamorasa Road (Awiankwanta-Assin Praso Section) in the Ashanti Region. The project is being executed by a local contractor under the supervision of the Ghana Highway Authority. The base course is made up of 300mm thick crushed stone base, laid in two layers of 150mm. The studies were performed on the first layer of 150mm thick crushed stone base which was placed on the natural gravel sub-base.

4.2 Material Characteristics

4.2.1 Index Properties

The index properties of the crushed stone materials used in the study are summarized in Table 4.1. The material can be described as a crushed stone material belonging to A-1-a under the AASHTO Classification System.

Table 4.1 ***Characteristic of the test material***

Grading (%)			Atterberg		Compaction		
Gravel	Sand	Silt	LL (%)	PI (%)	OMC (%)	MDD (Mg/m3)	CBR at 95% MDD
48	48	4	29.2	NP	5.6	2.096	128

Figures 4.1 show the grading characteristics of the crushed stone materials superimposed on the MoT specification for crushed stone base (MoT, 2006). The grading curve for the material shows lower fines content than specification, but the deviation is so small that it can be neglected and accepted as meeting the grading criterion.

The results of the Atterberg limit test indicated the material was non-plastic (NP) and met the requirement of MoT specification: plasticity index (PI) ≤ 6.

The modified AASHTO laboratory compaction test results (compaction curve) are presented in *Figure 4.2*.

[See *Appendix A* for details of Atterbergs Limits test results, Grading Test, Compaction Characteristics and CBR Test Results].

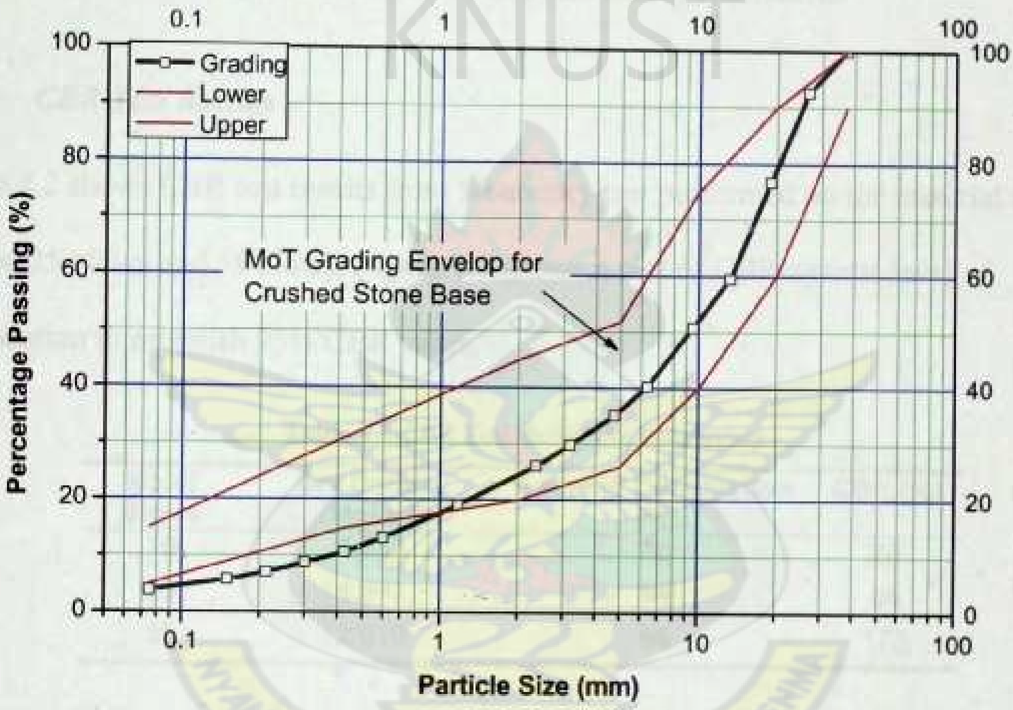


Figure 4.1 ***Grading of Characteristics of Test Material***

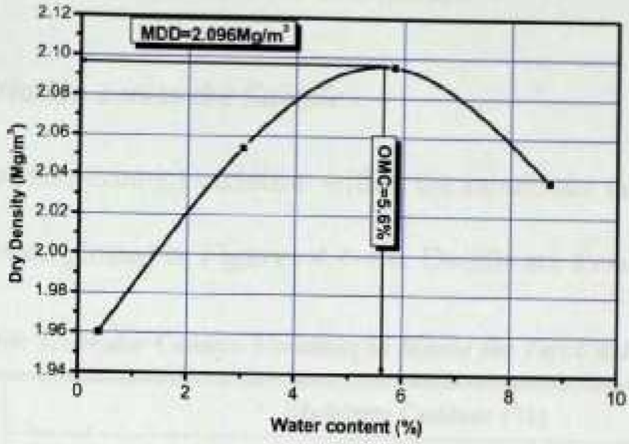


Figure 4.2 *Compaction Characteristics of Test Material*

4.2.2 CBR Test Results

Table 4.2 shows CBR test results from laboratory test performed on the material at 10 blows, 25 blows and 55 blows. *Figure 4.3* shows a plot of CBR against level of compaction to establish 95% CBR value.

Table 4.2 ***CBR Test Result the Laboratory***

No.of Blows	Dry Density (Mg/m3)	Level of Compaction (%)	CBR (%)
10	1.803	86	28
25	1.962	94	85
55	2.010	96	173

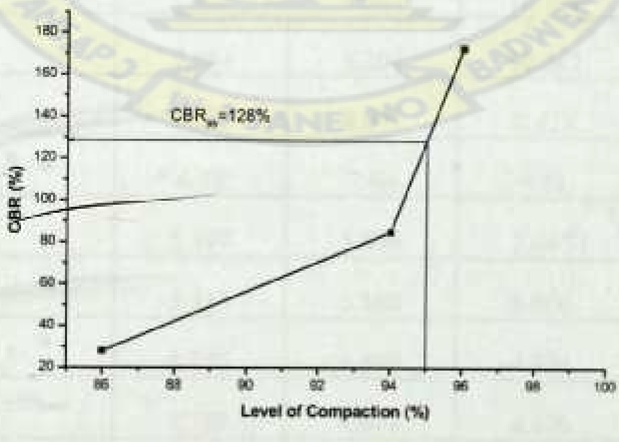


Figure 4.3 CBR Result for 95% Level of Compaction

4.3 Laboratory Calibration of the DCP in a Mould

4.3.1 Moisture Variation across the Sample

The results of the moisture content variation within the mould are tabulated in *Tables 4.3-4.5.* These have been plotted in *Figures 4.4-4.6.* Details are available at *Appendix B.*

Table 4.3 ***Water Content Variation in Mould for Test CR-B55***

Sample No.	Moisture Content (%)			
	Top	Middle	Bottom	Average
CR-B55-W4	6.584	6.871	8.467	7.307
CR-B55-W3	6.058	6.917	7.499	6.824
CR-B55-W2	6.743	6.766	7.884	7.131
CR-B55-W1	5.913	5.955	7.030	6.299
CR-B55-C0	5.991	5.001	5.591	5.528
CR-B55-D1	4.906	5.532	5.254	5.231
CR-B55-D3	4.204	5.033	4.869	4.702
CR-B55-D4	3.393	4.435	4.260	4.030
CR-B55-D5	3.038	3.502	2.946	3.162

Table 4.4 ***Water Content Variation in Mould for Test CR-B25***

Sample No.	Moisture Content (%)			
	Top	Middle	Bottom	Average
CR-B25-W4	7.825	7.901	10.590	8.772
CR-B25-W3	7.584	8.201	10.262	8.682
CR-B25-W2	7.523	8.091	9.429	8.347
CR-B25-W1	6.78	7.04	9.21	7.676
CR-B25-C0	5.397	5.696	5.685	5.593
CR-B25-D1	5.513	5.880	5.600	5.664
CR-B25-D3	4.757	4.699	4.821	4.759
CR-B25-D4	3.789	4.011	4.676	4.158
CR-B22-D5	2.477	2.780	2.819	2.692

Table 4.5 ***Water Content Variation in Mould for CR-B10***

Sample No.	Moisture Content (%)			
	Top	Middle	Bottom	Average
CR-B10-W4	8.773	8.915	12.604	10.097
CR-B10-W3	7.478	8.491	10.216	8.728
CR-B10-W2	8.29	9.32	8.22	8.611
CR-B10-W1	7.24	7.86	9.13	8.078
CR-B10-C0	5.191	6.118	5.958	5.756
CR-B10-D1	4.444	4.905	4.830	4.726
CR-B10-D3	3.734	4.516	5.482	4.577
CR-B10-D4	3.431	3.656	3.616	3.568
CR-B10-D5	2.299	2.810	2.794	2.634

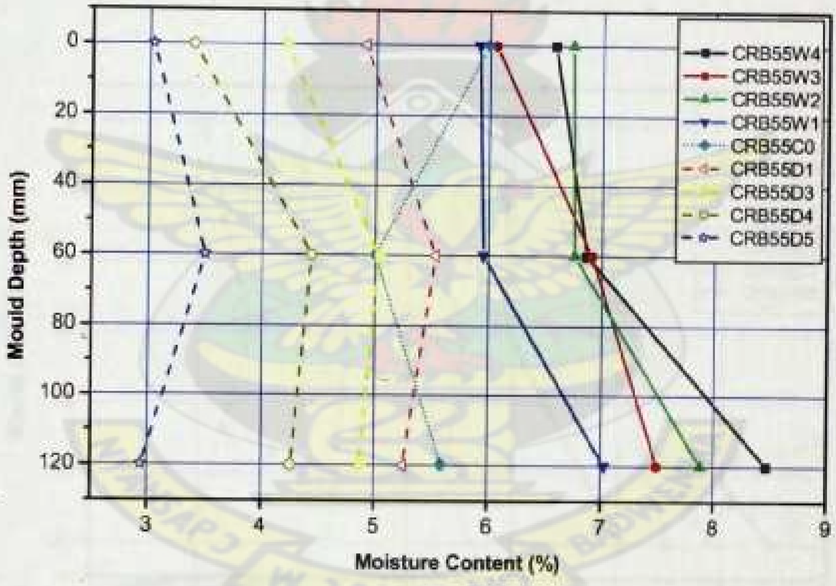


Figure 4.4 ***Moisture Variation with Depth for CR-B55***

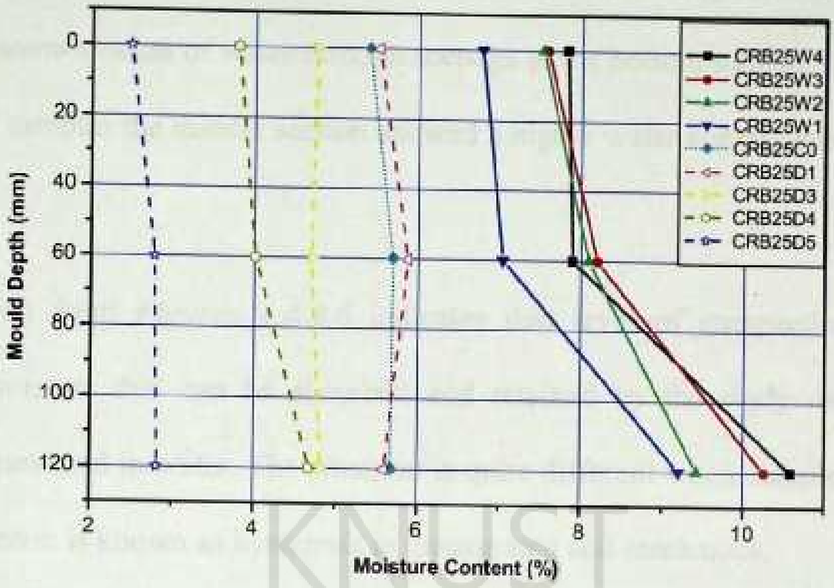


Figure 4.5 ***Moisture Variation with Depth for CR-B25***

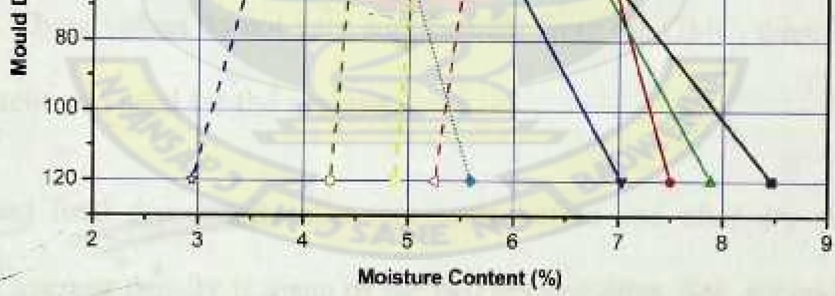


Figure 4.6 ***Moisture Variation with Depth for CR-B10***

The results show that for the wet samples the bottom showed higher water content than the top. The higher water content at the bottom is due the fact that the sample is porous

Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering, KNUST.

and drains well. Therefore, the period when the DCP test was being carried out the upper sections lost some amount of water through seepage to the bottom section.

For the dried samples the middle section showed a higher water content than the top and the bottom.

An observation from *Figures 4.4-4.6* indicates that level of compaction affect the amount of moisture that can be absorbed and retained by the study material when completely immersed in water. The situation is quite different when sample is air dried. This phenomenon is known as hysteresis in unsaturated soil mechanics.

4.3.2 DCP Test

The results obtained from the laboratory mould calibration test of the DCP are presented in *Tables 4.6-4.8*. The initial water and final water content represents the moisture content of the sample before and after conditioning respectively. The intended purpose was to prepare the sample at initial water content at the OMC of 5.6%. The average of the initial moisture content from the samples range from 5.20%-5.32% as shown in *Tables 4.6-4*. These values do not vary significantly from the OMC, therefore the initial moisture content was used for the analysis.

The initial and final dry density also represents before and after dry density of the samples. The average density is mean of the two dry densities. See *Appendices A and B for details.*

Tables 4.6-4.8 also presents the DPI values obtained for the DCP test carried out in the laboratory for 55, 25 and 10 blows respectively.

Table 4.6 ***Moisture Content and DPI variation with Conditioning for Test CR-B55***

Sample No.	Initial Water Content (%)	Final Water Content (%)	Initial Dry Density (Mg/m^3)	Final Dry Density (Mg/m^3)	Average Dry Density (Mg/m^3)	DPI (mm/blow)
CR-B55-W4	4.336	7.307	2.107	2.073	2.090	5.23
CR-B55-W3	4.976	6.824	2.130	2.115	2.123	4.64
CR-B55-W2	5.509	7.131	2.116	2.111	2.113	4.52
CR-B55-W1	5.858	6.299	2.133	2.137	2.135	4.32
CR-B55-C0	5.791	5.791	2.047	2.047	2.047	4.18
CR-B55-D1	5.858	5.231	2.134	2.137	2.135	3.83
CR-B55-D3	5.509	4.702	2.147	2.138	2.143	3.47
CR-B55-D4	4.976	4.030	2.149	2.128	2.139	3.23
CR-B55-D5	4.336	3.162	2.137	2.112	2.124	2.78
Average	**5.239**		**2.122**	**2.111**	**2.117**	

Table 4.7 ***Moisture Content and DPI variation with Conditioning for Test CR-B25***

Sample No.	Initial Water Content (%)	Final Water Content (%)	Initial Dry Density (Mg/m^3)	Final Dry Density (Mg/m^3)	Average Dry Density (Mg/m^3	DPI (mm/blow)
CR-B25-W4	4.82	8.77	2.031	2.011	2.021	8.920
CR-B25-W3	4.54	8.68	2.105	2.068	2.087	8.670
CR-B25-W2	5.71	8.35	2.054	2.039	2.047	7.670
CR-B25-W1	6.18	7.68	2.070	2.070	2.070	7.570
CR-B25-C0	5.59	5.59	1.979	1.979	1.979	7.500
CR-B25-D1	6.18	5.66	2.046	2.047	2.046	4.670
CR-B25-D3	5.51	4.76	2.050	2.039	2.045	4.570
CR-B25-D4	4.54	4.16	2.0765	2.0432	2.060	4.690
CR-B25-D5	4.82	2.69	2.0183	2.0107	2.015	4.270
Average	**5.321**		**2.048**	**2.034**	**2.041**	

Table 4.8 Moisture Content and DPI variation with Conditioning for Test CR-B10

Sample No.	Initial Water Content (%)	Final Water Content (%)	Initial Dry Density (Mg/m^3)	Final Dry Density (Mg/m^3)	Average Dry Density (Mg/m^3)	DPI (mm/blow)
CR-B10-W4	4.73	10.10	1.976	1.963	1.970	12.130
CR-B10-W3	4.86	8.73	1.958	1.971	1.965	11.630
CR-B10-W2	5.36	8.61	1.952	1.959	1.955	11.200
CR-B10-W1	5.59	8.08	1.970	1.972	1.971	11.140
CR-B10-C0	5.76	5.76	1.865	1.865	1.865	10.670
CR-B10-D1	5.59	4.73	1.986	1.994	1.990	9.000
CR-B10-D3	5.36	4.58	1.952	1.941	1.947	7.500
CR-B10-D4	4.86	3.57	1.9688	1.9557	1.962	6.710
CR-B10-D5	4.73	2.63	1.9462	1.9387	1.942	6.380
Average	**5.204**		**1.953**	**1.951**	**1.952**	

In the performance of the test it was observed especially for the higher density samples (i.e.55 blows) that upper section of the sample gave higher DPI values compared with the lower section indicating differences in strength. The cause of this could be because surcharges were not placed on the samples while performing the test as is done for CBR test.

4.3.3 Effect of Moisture Variation

The DPI value obtained in a test is not only affected by moisture content but also the density of the test sample. The purpose of this work as outline is to investigate the effect moisture variation on DPI value at constant density.

Contrary to this fact, *Tables 4.6-4.8* show a variation in the density of the test samples for each compaction level. It was therefore necessary to compare the variation in the test samples against the mean density to determine whether the two samples are significantly different.

A 95% Confidence Interval test on Test series CR-B55, CR-B25 and CR-B10 gave the following intervals 2.083-2.129, 2.005-2.050 and 1.922-1.979 respectively.

[See *Appendix D* for details of the statistical test results]

For Test series CR-B55 the data shows CR-B55-W4 and CR-B55-C0 falls outside the 95% Confidence Interval of the difference. Similarly for Test series CR-B25, CR-B25-W1 and CR-B25-C0 and Test series CR-B10, CR-B10-C0 and CR-B10-D1. These points are therefore neglected in the subsequent analysis.

Figure 4.7 shows the position indication of final dry density of the samples on the compaction curve, neglecting those outside the 95% confidence interval.

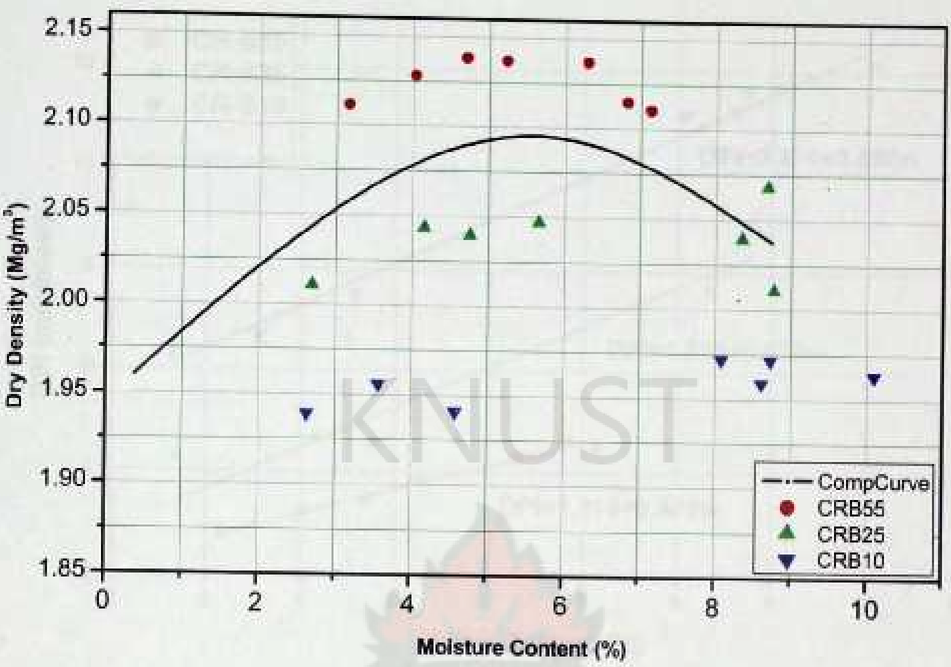


Figure 4.7 *Position indication of Dry Density on the Compaction Curve*

It can be seen that generally the DPI values increases with water content and decreases as the sample becomes denser. This is evidenced in *Figure 4.8* which shows a plot of DPI against the water content. The increase in DPI value with increase in the water content is due to decreasing shear strength with increase in water content.

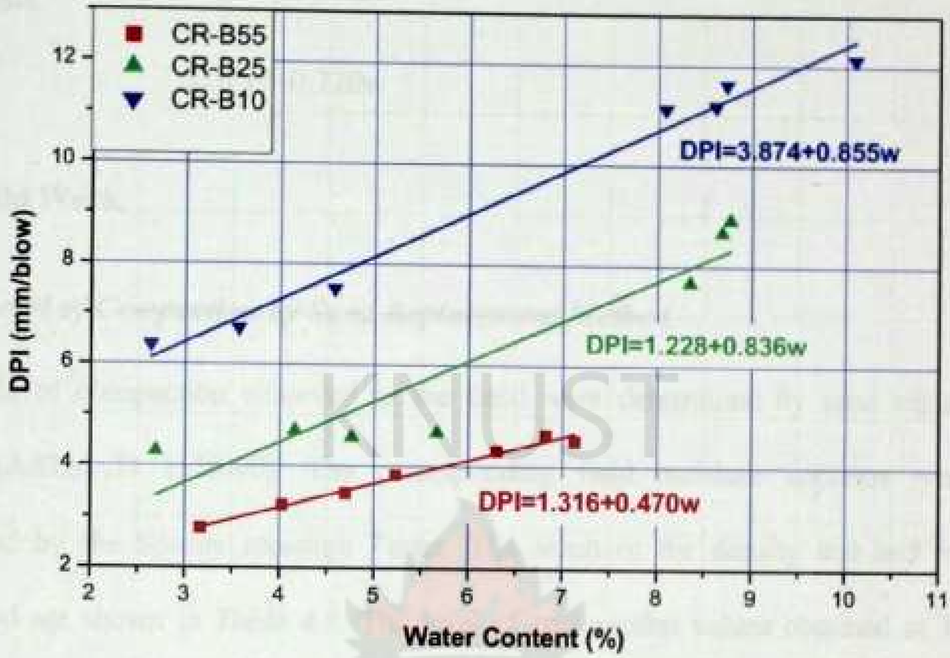


Figure 4.8 Correlation between DPI and water content for test CR-B10, CRB-25 & CRB-55

Figures 4.8 show plots of the correlation between DPI and water content for the various level of compaction. The regression equation is of the form

CR-B10:	DPI = 3.874 + 0.855w	LC=93%
CR-B25:	DPI = 1.228 + 0.836w	LC=97%
CR-B55:	DPI = 1.316 + 0.470w	LC=101%

In general, the correlation is of the form:

$$\text{DPI} = \kappa + \lambda \mathbf{w}$$

Where κ is a constant that is dependent on the level of compaction and λw is change in DPI due to water content. Since the range of λ is small, an average value is assumed for the analysis.

$$\Delta DPI = 0.720w$$

4.4 Field Work

4.4.1 Level of Compaction by Sand Replacement Method

The levels of compaction achieved in the field were determined by sand replacement method (ASTM D 1556-90). The corresponding field moisture contents were also determined by the Speedy moisture Tester. The result of the density test and moisture determined are shown in *Table 4.9.* The level of compaction values obtained at Test no. S2T2P1 and S3T2P1 are abnormal. The cause could not be verified; therefore those values will not be used in the subsequent analysis.

[Details of sand replacement test are available in *Appendix E].*

Table 4.9 ***Level of Compaction achieved as measured in the field***

Test No.		No. Passes			
		P1	**P2**	**P4**	**P8**
S1T1	Relative Density (%)	92.78	97.92	105.21	112.98
	Moisture Content (%)	4.40	3.40	4.20	4.00
S1T2	Relative Density (%)	89.87	100.83	107.61	115.68
	Moisture Content (%)	5.00	3.80	3.00	3.90
S2T1	Relative Density (%)	90.50	97.60	103.97	110.26
	Moisture Content (%)	4.00	3.50	3.60	4.20
S2T2	Relative Density (%)	100.24	99.54	100.90	107.37
	Moisture Content (%)	4.00	5.00	5.00	5.30
S3T1	Relative Density (%)	96.58	99.81	101.90	108.01
	Moisture Content (%)	6.40	4.00	3.80	7.30
S3T2	Relative Density (%)	102.12	101.00	104.98	109.48
	Moisture Content (%)	4.40	4.00	3.40	3.50

[Test No: SiTjPn Where S=Site, i=number of test, T=Test, j=number of test, P=passes and n=number of passes]

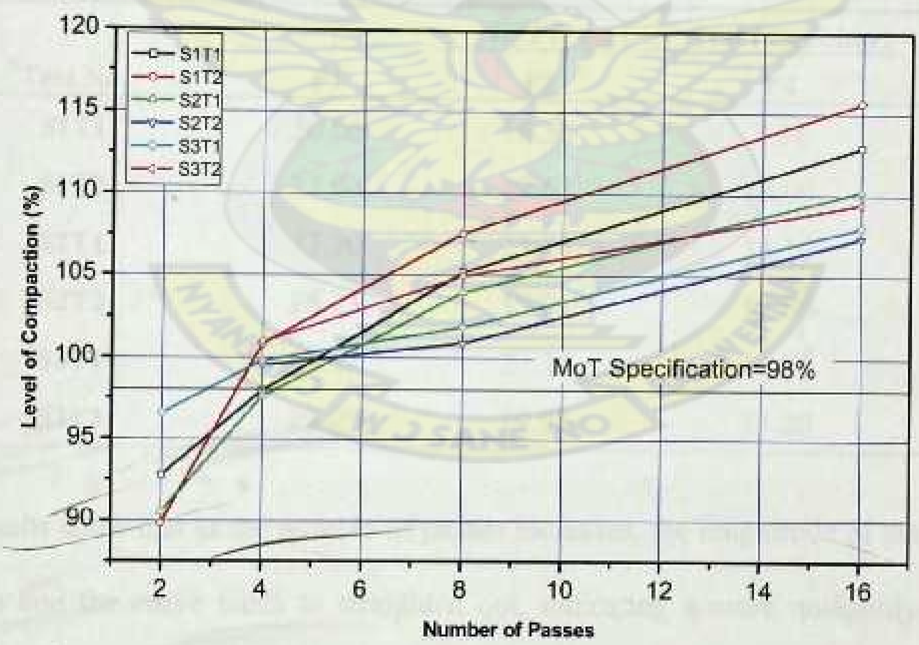


Figure 4.9 *Level of Compaction achieved in the field*

These levels of compaction achieved by sand replacement method are plotted against the number of passes in *Figure 4.9.* The results indicate that in the entire test conducted as the number of roller passes increases the level of compaction also increases. It is clear from the plot that at four passes the layer had exceeded the MoT specification of 98% of modified AASHTO compaction.

4.4.2 DCP Results

The DCP test results from the field are tabulated in *Table 4.10.* The cumulative number of blows of the DCP was plotted against the penetration depth for each test performed as shown in *Appendix F.* The DPI values which denote the slopes of the graph are the penetration rates which are measures of resistance of the soil mass across the depth of layers at any level of compaction.

Table 4.10 Field DCP Penetration Rate

Test No.	DPI from DCP Test (mm/blow)			
	P1	P2	P4	P8
S1T1	30.06	16.54	7.31	6.42
S1T2	22.93	19.63	10.00	9.10
S2T1	27.70	23.74	14.10	7.45
S2T2	26.25	19.01	12.86	12.37
S3T1	51.57	27.34	14.81	9.80
S3T2	29.25	19.98	13.20	10.28

The results show that as the number of passes increases, the magnitude of the DPI values reduces and the curve tends to straighten out, indicating a more uniformly compacted material with higher resistance to penetration. The results also suggest that for lower number of roller passes, approximately two layers of material can be identified. There is a top layer of lower resistance to penetration (i.e., lower density) and a bottom layer of higher resistance to penetration (i.e., higher density).

To correlate the DCP test results with the corresponding sand replacement results, it was necessary to determine the mean DPI for the two layers (Ampadu and Arthur, 2006). For this purpose, first for each Penetration-Cumulative Number of Blows curve, the DPIs [i.e., $(DPI)_i$] and corresponding thicknesses (i.e., H_i) for the top and bottom portions of the plot were determined as shown in *Figure 4.10*. The weighted mean DPI, for each of the specified number of passes is then calculated as shown below:

$$Mean(DPI) = \frac{(DPI)_i H_i + (DPI)_j H_j}{H_i + H_j}$$

The mean DPIs for the corresponding number of passes are shown in *Table 4.10*. See *Appendix E* for details of field data and plots of penetration verses cumulative number of blows.

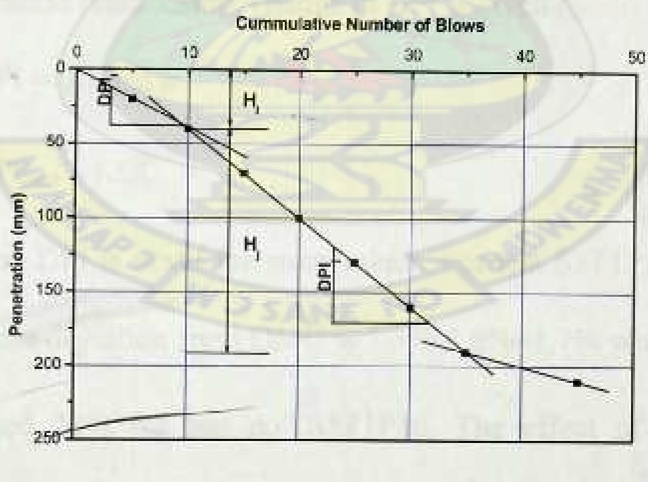


Figure 4.10 ***Illustration of Determination of Mean DPI (Ampadu and Arthur 2006)***

4.4.3 Level of Compaction Verification by DCP Test

Ampadu and Arthur (2006) suggested that a relation of the form:

$$\text{Log (LC)} = \alpha - \beta^* \log \text{(DPI)}$$

could be established between the level of compaction (LC) and DPI values after field compaction studies on a model test site. Their studies established that for laterite gravel of LL of 45 and PI of 19, values of 2.184 and 0.337 were obtained for α and β respectively. In the above study by Ampadu and Arthur 2006, the tests were performed at same water content for the different compaction plant but for this study the field water content water varied at each test location.

In this study it would therefore be necessary to correct the field DCP results since the tests were not performed under constant water content.

4.4.4 Effect water content on DCP Values

The field water content ranges from 3.4 % - 7.3% or 5.6±2.2 as shown in the *Table 4.1.* From DPI-water content relationship, change in DPI is given by

$$\Delta DPI = 0.720\Delta w$$

$$\Delta DPI_{max} = 1.58$$

The effect of this on DPI is small for most values. For test S3T1P16 the highest water content the maximum deviation from OMC is 7.3%-5.6%=1.7% which gives a ΔDPI of but does not exceed 24% for test no. S3T1P16. The effect of water content was considered insignificant on the DPI values and therefore was not considered in the subsequent analysis.

Table 4.11 Summary of Water Content, Level of Compaction and DPI Values from the field.

PASS	SECTION 1						SECTION 2						SECTION 3					
	S1T1			S1T2			S2T1			S2T1			S3T1			S3T2		
	WC	LC	DPI	WC	LC	DPI	WC	LC	DPI	WC	LC	DPI	WC	LC	DPI	WC	LC	DPI
P2	4.400	92.781	30.060	5.000	89.872	22.930	4.000	90.495	27.700	4.000	100.238	26.250	6.400	96.579	51.570	4.400	102.121	29.250
P4	3.400	97.919	16.540	3.800	100.831	19.630	3.500	97.597	23.740	5.000	99.537	19.010	4.000	99.814	27.340	4.000	101.002	19.980
P8	4.200	97.919	7.310	3.000	107.607	10.000	3.600	103.965	14.100	5.000	100.896	12.860	3.800	101.903	14.810	3.400	104.982	13.200
P16	4.000	105.208	6.420	3.900	115.675	9.100	4.200	110.258	7.450	5.300	107.370	12.370	7.300	108.006	9.800	3.500	109.479	10.280

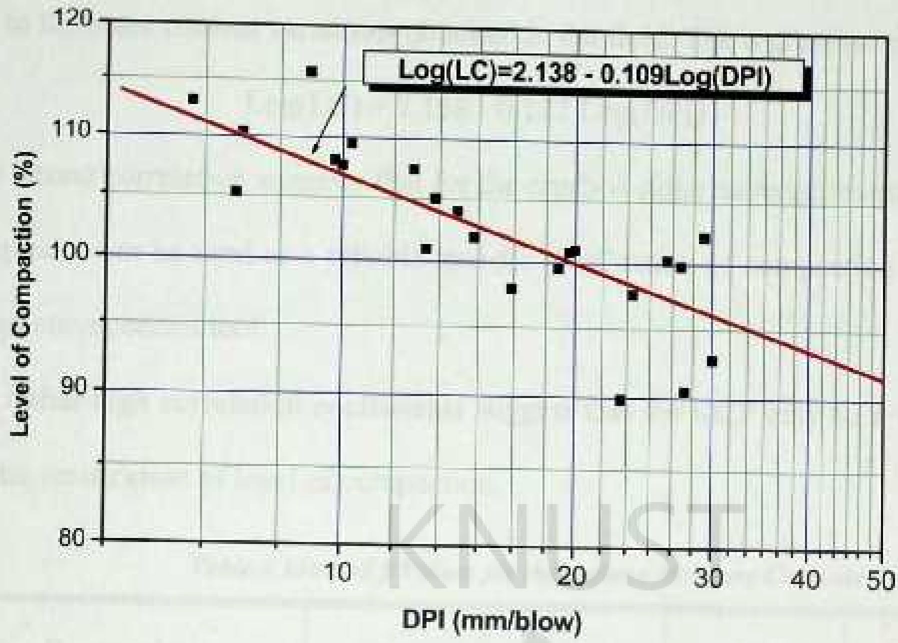


Figure 4.11 ***Correlation between Sand Replacement and DCP Test Results***

Table 4.12 α and β Values for the various Moisture Contents

Test	α	β	Standard Deviation	Correlation Coefficient
S1T1	2.13232	0.11353	0.01264	-0.96083
S1T2	2.25807	0.21247	0.02140	-0.92684
S2T1	2.16639	0.13641	0.01343	-0.95465
S2T2	2.14873	0.11878	0.01773	-0.6992
S3T1	2.08868	0.06195	0.00734	-0.95599
S3T2	2.15718	0.11849	0.00409	-0.9863
Average	**2.15856**	**0.12694**	**0.01277**	**-0.91396**

A linear regression analysis of the weighted mean DPIs and the corresponding LC values as shown in the log-log plot of *Figure 4.11* gives a high value of the coefficient of regression of -0.914 with a standard deviation of 0.0126 suggesting a high degree of correlation between the level of compaction as determined by the sand replacement method and the corresponding DCP penetration rates. The scatter in the results may be due to moisture content variations obtained in the field. The regression equation is

$$\text{Log(LC)} = 2.158 - 0.127\ \text{Log(DPI)}$$

This strong correlation suggests that for the crushed stone material investigated, the DCP equipment can be used as a reliable tool for verification of compaction and indeed as a compaction control tool.

The rather high correlation coefficients suggest that the DCP may be a valid instrument for the verification of level of compaction.

Table 4.13α and β Values for the various Moisture Contents

Researcher	α	B	LL	PI	CBR AT 95% MDD
Current study	2.158	0.127	29.2	NP	128
Amissah, 2007 (0.65T VR-OA)	2.1388	0.1794	51	19	-
Amissah, 2007 (10T VR-OA)	2.1835	0.2353	51	19	-
(Amissah, 2007 0.65T VR-AT	2.2319	0.2407	60	28	-
Amissah, 2007 (10T VR-AT)	2.2638	0.2501	60	28	-
Ampadu and Arthur (2006)	2.184	0.337	45	19	82

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Studies were conducted on an on-going road project in the Ashanti Region to ascertain the extent to which the Dynamic Cone Penetrometer (DCP) can be appied in compaction verification on crushed rock. The level of compaction achieved was verified using the sand replacement test and the dynamic cone penetrometer tests.

The results show for a given material, at controlled water content, a correlation equation of the form

$$\text{Log (LC)} = \alpha - \beta \log \text{(DPI)}$$

exists between the level of compaction as determined by the sand replacement method and the average rate of penetration (DPI) determined by the DCP apparatus, as suggested by Ampadu and Arthur, and that the α and β values may be dependent on the material characteristics and the moisture content at the time of the test.

A further study was also conducted in the laboratory to adjust the DPI values at various water content to constant water content Three levels of compaction were calibrated and the resultant relation is linear and is of the form DPI= $\kappa + \lambda w$, κ is a constant that is dependent on level of compaction and *w* is the water content of the material at time of testing:

CR-B10:	DPI = 3.874 + 0.855w	LC=93%
CR-B25:	DPI = 1.228 + 0.836w	LC=97%
CR-B55:	DPI = 1.316 + 0.470w	LC=101%

5.2 Recommendations

Based on the findings in the study

1. More DCP tests be carried out in different types of rock formation used in road base construction to validate correlation and the MoT should consider DCP specification for compaction.
2. The laboratory DCP test in the mould should be conduct with a surcharged on and compare with one without.
3. Further determine effect of material density and moisture on content on DCP readings.

References

AASHTO T180, Method D. Test standard for dry density- moisture content

Amissah, G. "A Comparative Study between Performance based Specification and Method based Specification for Compaction", Master Thesis, KNUST, July 2007

Ampadu S. I.K., Geotechnical Engineering Course Notes for CEH552, 2007.

Ampadu S. I. K., Arthur. T. D., The dynamic Cone Penetrometer in Compaction Verification on a Model Road Pavement." Geotechnical Testing Journal, Vol. 29 No. 1 January 2006

ASTM C120-88 and C127-88 test standard for specific gravity of gravel.

BS 1377 (1990) Methods of test of soil for civil engineering purposes. British Standards institution, London.

Ghana Highway standard method of test for soils March 1996.

Kleyn, E.G. "The Use of the Dynamic Cone Penetrometer," Report L2/L4, Transvaal Roads Department, Pretoria, South Africa, 1975.

Lambe, T. William, "The Engineering Behavior of Compacted Clay," Journal of the Soil Mechanics and Foundations Division, ASCE, 84 (SM2), 1655-1 to 1655-35, 1958.

Livneh, M. "The Use of Dynamic Cone Penetrometer in Determining the Strength of Existing Pavements and Subgrades," Proceedings of Southeast Asian Geotechnical Conference, Bangkok, Thailand, 1987.

Proctor, R. R, "Fundamental Principles of Soil Compaction," Engineering News-Record, Vol. 111 Nos. 9,10,12, and 13 1933, 1933.

Scala, A.J. "Simple Methods of Flexible Pavement Design Using Cone Penetrometer," New Zealand Engineering, Vol.11, No.2, February 15, 1956.

Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications, ASTM D6951-03, 2003.

Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications, ASTM D6951-03 International, 2003.

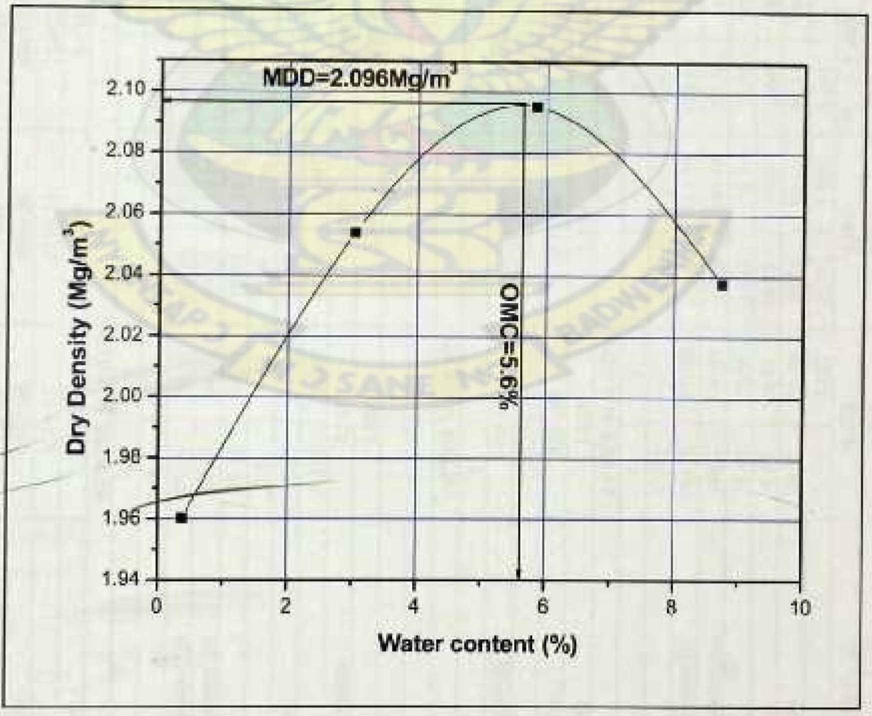
Winterkorn, Hans, F. and Fang, Hsai-Yang, Foundation Engineering Handbook, Van Nostrand Reinhold Company, New York, New York, 1975.

APPENDIX A:

Material Characterization: Laboratory Compaction Test Results, Grading, Atterbergs Limits and CBR Test Results.

EPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MODIFIED AASTHO COMPACTION TEST RESULTS

Mass of cylinder + wet sample (gm)	11720		12048		12273		12268	
Mass of cylinder	7371		7371		7371		7371	
Mass of wet sample	4349		4677		4902		4897	
Bulk density	1.968		2.116		2.218		2.216	
	1		2		3		4	
Container no.	D1	A40	DK	K4	B4	A	E3	E2
Mass of container + wet soil (gm)	68.36	68.69	72.12	64.34	71.21	72.42	75.26	68.72
Mass of container + dry soil (gm)	68.18	68.47	70.45	62.88	68.05	69.34	70.37	64.49
Mass container	15.98	14.75	14.19	15.65	15.58	14.87	15.79	14.76
Mass of wet soil (gm)	52.38	53.94	57.93	48.69	55.63	57.55	59.47	53.96
Mass of dry soil	52.20	53.72	56.26	47.23	52.47	54.47	54.58	49.73
Mass of water	0.18	0.22	1.67	1.46	3.16	3.08	4.89	4.23
Water content	0.3448	0.4095	2.9684	3.0913	6.0225	5.6545	8.9593	8.5059
Average water content	**0.3800**		**3.0298**		**5.8385**		**8.7326**	
Dry density	**1.9600**		**2.0538**		**2.0954**		**2.0376**	
Height of mould (cm)	**11.53**							
Diameter of mould (cm)	**15.62**							
Volume of mould (cm³)	**2210.32**							



Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
CBR TEST RESULTS

Date **14Th May 2008**

SOAKED CBR TEST RESULTS

BEFORE SOAKING

Mounld No	AA11	F4	A4
No. of blows per layer	10	25	55
Wet Sample + Mould (g)	11376.00	12100	12071
Mass of Mould	7214.00	7604	7393
Mass of Wet Sample	4162.00	4496.00	4678.00
Volume of Mould	2210.32	2210.32	2210.32
Bulk Density (g/cc)	**1.883**	**2.034**	**2.116**

BEFORE SOAKING

Test	1	2	1	2	1	2
Container No.	A15	K1	C1	F1	A20	
Wet Sample + Container (g)	91.16	98.13	83.30	83.18	98.08	88.03
Dry Sample + Container (g)	87.65	94.81	80.51	80.18	95.23	84.99
Mass Container	15.32	16.33	16.05	15.62	14.52	14.22
Mass of Water	3.51	3.32	2.79	3.00	2.85	3.04
Mass of Dry Sample	72.33	78.48	64.46	64.56	80.71	70.77
Water Content	4.853	4.230	4.328	4.647	3.531	4.296
Average Water Content	**4.542**		**4.488**		**3.913**	
Dry Density	**1.801**		**1.947**		**2.037**	

AFTER SOAKING

	1	2	1	2	1	2
Wet Sample + Mould (g)	11465.00		12239.00		12166.00	
Mass of Mould	7214.00		7604.00		7393.00	
Mass of Wet Sample	4251.00		4635.00		4773.00	
Bulk Density (g/cc)	**1.920**		**2.100**		**2.160**	

AFTER SOAKING

	1	2	1	2	1	2
Container No.	ACM	F1	A34	E3	A20	A23
Wet Sample + Container (g)	104.72	107.83	111.95	114.72	110.53	122.77
Dry Sample + Container (g)	100.2	100.98	107.2	106.81	104.89	114.28
Mass Container	15.45	15.59	14.12	15.7	14.52	15.28
Mass of Water	4.52	6.85	4.75	7.91	5.64	8.49
Mass of Dry Sample	84.75	85.39	93.08	91.11	90.37	99.00
Water Content	5.333	8.022	5.103	8.682	6.241	8.576
Average Water Content	**6.678**		**6.892**		**7.408**	
Dry Density	**1.803**		**1.962**		**2.010**	

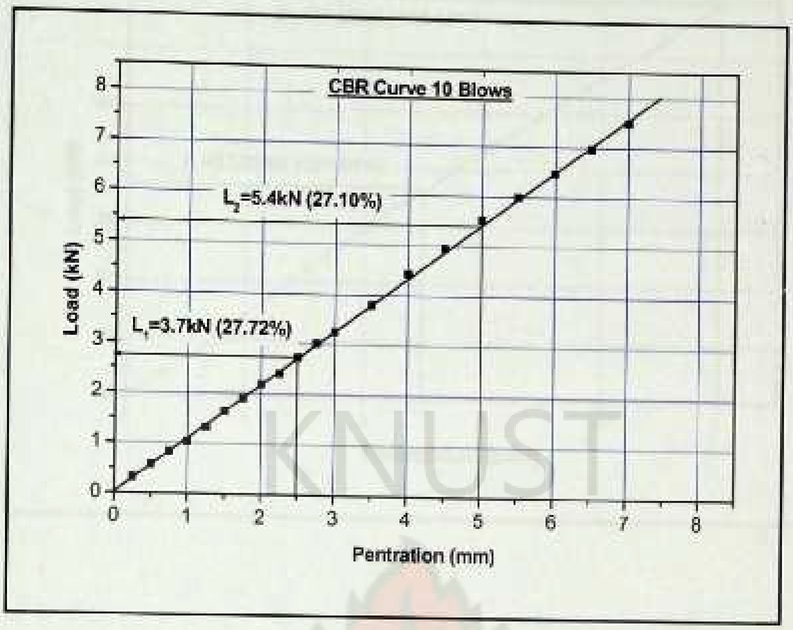
Proving Ring Constant: **0.026 kN/div**

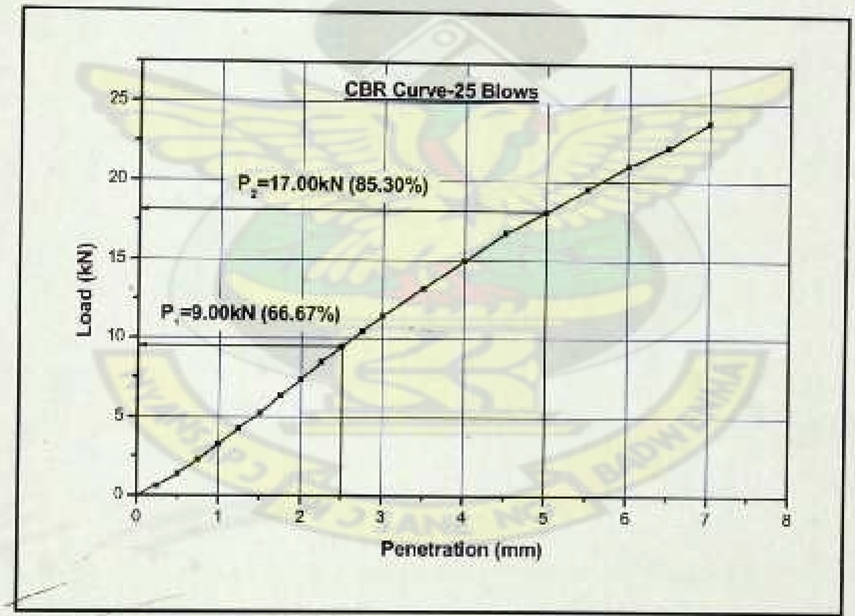
Penetration (mm)	10 Blows/Layer			25 Blows/Layer			10 Blows/ Layer		
	Load			Load			Load		
	(div)	(kN)	CBR	(div)	(kN)	CBR	(div)	(kN)	CBR
0.25	12	0.026	**0.312**	23	0.026	**0.598**	64	0.026	**1.664**
0.50	22	0.026	**0.572**	52	0.026	**1.352**	120	0.026	**3.12**
0.75	32	0.026	**0.832**	87	0.026	**2.262**	190	0.026	**4.94**
1.00	40	0.026	**1.040**	126	0.026	**3.276**	270	0.026	**7.02**
1.25	51	0.026	**1.326**	164	0.026	**4.264**	345	0.026	**8.97**
1.50	63	0.026	**1.638**	202	0.026	**5.252**	420	0.026	**10.92**
1.75	73	0.026	**1.898**	243	0.026	**6.318**	490	0.026	**12.74**
2.00	84	0.026	**2.184**	283	0.026	**7.358**	565	0.026	**14.69**
2.25	92	0.026	**2.392**	326	0.026	**8.476**	635	0.026	**16.51**
2.50	105	0.026	**2.730**	363	0.026	**9.438**	694	0.026	**18.044**
2.75	116	0.026	**3.016**	402	0.026	**10.452**	763	0.026	**19.838**
3.00	125	0.026	**3.250**	439	0.026	**11.414**	829	0.026	**21.554**
3.50	146	0.026	**3.796**	508	0.026	**13.208**	955	0.026	**24.83**
4.00	170	0.026	**4.420**	575	0.026	**14.95**	1080	0.026	**28.08**
4.50	190	0.026	**4.940**	644	0.026	**16.744**	1202	0.026	**31.252**
5.00	212	0.026	**5.512**	695	0.026	**18.07**	1333	0.026	**34.658**
5.50	230	0.026	**5.980**	752	0.026	**19.552**			
6.00	249	0.026	**6.474**	810	0.026	**21.06**			
6.50	268	0.026	**6.968**	855	0.026	**22.23**			
7.00	288	0.026	**7.488**	916	0.026	**23.816**			
7.50									
8.00									

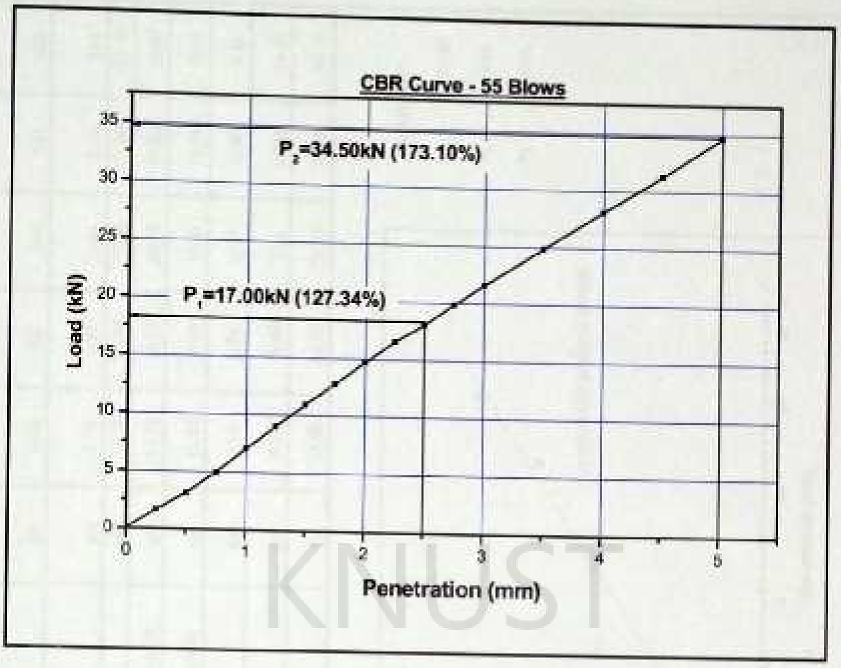
SWELL DATA

	Date	Time	Reading	Date	Time	Reading	Date	Time	Reading

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
CBR TEST RESULTS







CBR Curve - 55 Blows
P_2=34.50kN (173.10%)
P_1=17.00kN (127.34%)
Load (kN)
Penetration (mm)
0
5
10
15
20
25
30
35
1
2
3
4

DEPARTMENT OF CIVIL ENGINEERING

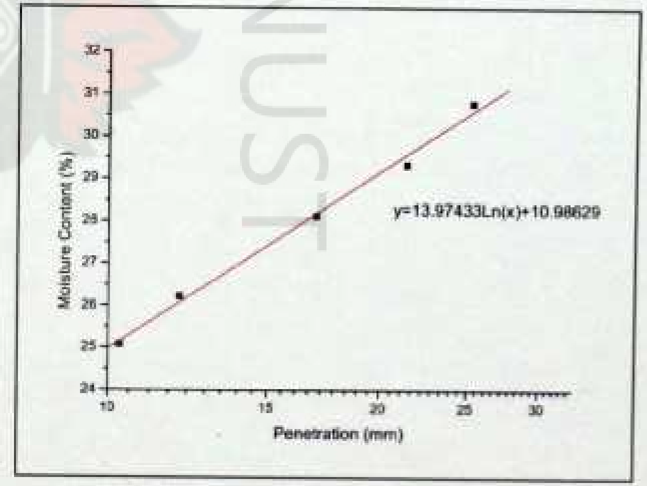
GEOTECHNICAL LABORATORY

GRADING AND ATTERBERG LIMIT TEST

DESCRIPTION:		Total Dry Weight (g)			1459.0
GRADING TEST		Weight Retained	Percentage Reained	Percentage	Corrected Percentage
Sieve size					
BS designation	Metric	(g)	(%)	(%)	(%)
	(mm)				
3 in	75.00				
2 ½ in	63.00				
2 in	53.00			100.00	100.00
1 ½ in	37.10	108.1	7.41	92.59	92.59
1 in	26.50	231.59	15.87	76.72	76.72
¾ in	19.00	251.36	17.23	59.49	59.49
½ in	13.20	125.98	8.63	50.85	50.85
⅜ in	9.50	153.39	10.51	40.34	40.34
¼	6.35	74.67	5.12	35.22	35.22
3/16	4.75	78.16	5.36	29.86	29.86
1/8	3.18	54.73	3.75	26.11	26.11
No. 7	2.36	53.28	26.64	73.36	19.16
No. 14	1.18	45.22	22.61	50.75	13.25
No. 25	0.600	19.15	9.58	41.18	10.75
No. 36	0.425	14.56	7.28	33.90	8.85
No. 52	0.300	13.37	6.69	27.21	7.11
NO. 72	0.212	10.31	5.16	22.06	5.76
No. 100	0.150	14.44	7.22	14.84	3.87
No. 200	0.075				

ATTERBERG LIMIT TEST

Liquid limit						
Container No	gm	A34	K6	A40	A34	A34
Mass of Container	gm	3.73	3.65	3.61	3.71	3.61
Penetration	mm	10.30	12.00	17.00	21.40	25.30
Mass of Container &Wet Sample	gm	15.30	20.93	20.78	23.02	22.47
Mass of Container & Dry Sample	gm	12.98	17.34	17.01	18.64	18.03
Mass of Water	gm	2.32	3.59	3.77	4.38	4.44
Mass of Dry Sample	gm	9.25	13.69	13.4	14.93	14.42
Water content	%	25.08	26.22	28.13	29.34	30.79



SUMMARY

LL	52.85
PL	N/A
PI	N/A

APPENDIX B:

Laboratory Compaction for DCP Calibration
(Moistures Density Results)

DEPARTMENT OF CIVIL ENGINEERING

GEOTECHNICAL LABORATORY

MOULD CALIBRATION RESULTS

ZERO CONTROL

Date: 14Th May 2008

Conditioning	**0/Control**									**0/Control**								
Test No.	**CR-B55-C0**			**CR-B25-C0**			**CR-B10-C0**			**CR-B55-CO**			**CR-B25-C0**			**CR-B10-C0**		
Mould No	A4			AA11			F4			A4			AA11			F4		
Number of Blows	55			25			10			55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12262			11833			11881			12262			11833			11881		
Final Mass of Cylinder + Wet Sample (gm)	12262			11833			11881			12262			11833			11881		
Mass of Cylinder	7476			7214			7521			7476			7214			7521		
Initial Mass of Wet Sample	4786			4619			4360			4786			4619			4360		
Final Mass of Wet Sample	4786			4619			4360			4786			4619			4360		
Initial Bulk Density	**2.165**			**2.090**			**1.973**			**2.165**			**2.090**			**1.973**		
Final Bulk Density	**2.165**			**2.090**			**1.973**			**2.165**			**2.090**			**1.973**		
	1			2			3			1			2			3		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	A40	A20	A38	A10	A11	HD	A5	ACM	F1	A40	A20	A38	A10	A11	HD	A5	ACM	F1
Mass of Container + Wet Soil (gm)	97.18	86.58	80.59	82.21	84.68	84.84	89.57	90.06	76.81	97.18	86.58	80.59	82.21	84.68	84.84	89.57	90.06	76.81
Mass of Container + Dry Soil (gm)	92.52	83.14	77.08	78.74	80.93	81.04	85.88	85.76	73.37	92.52	83.14	77.08	78.74	80.93	81.04	85.88	85.76	73.37
Mass Container	14.74	14.36	14.3	14.45	15.09	14.2	14.8	15.47	15.63	14.74	14.36	14.3	14.45	15.09	14.2	14.8	15.47	15.63
Mass of Wet Soil (gm)	82.44	72.22	66.29	67.76	69.59	70.64	74.77	74.59	61.18	82.44	72.22	66.29	67.76	69.59	70.64	74.77	74.59	61.18
Mass of Dry Soil	77.78	68.78	62.78	64.29	65.84	66.84	71.08	70.29	57.74	77.78	68.78	62.78	64.29	65.84	66.84	71.08	70.29	57.74
Mass of Water	4.66	3.44	3.51	3.47	3.75	3.8	3.69	4.3	3.44	4.66	3.44	3.51	3.47	3.75	3.8	3.69	4.3	3.44
Water Content	5.99	5.00	5.59	5.40	5.70	5.69	5.19	6.12	5.96	5.99	5.00	5.59	5.40	5.70	5.69	5.19	6.12	5.96
Average Water Content	**5.791**			**5.593**			**5.756**			**5.791**			**5.593**			**5.756**		
Dry Density	**2.047**			**1.979**			**1.865**			**2.047**			**1.979**			**1.865**		
Height of Mould (cm)	**11.53**																	
Diameter of Mould (cm)	**15.62**																	
Volume of Mould (cm³)	**2210.32**																	

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

ONE DAY CONTROL

Date **14Th May 2008**

Conditioning	**One Day Soaking**									**One Day Drying**								
Test No.	**CR-B55-W1**			**CR-B25-W1**			**CR-B10-WI**			**CR-B55-D1**			**CR-B25-D1**			**CR-B10-D1**		
Mould No	AA11			F4			A4			D3			10			C2		
Number of Blows	55			25			10			55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12207			12394			12074			12203			11976			11825		
Final Mass of Cylinder + Wet Sample (gm)	12238			12462			12188			12182			11956			11805		
Mass of Cylinder	7217			7535			7477			7211			7175			7189		
Initial Mass of Wet Sample	4990			4859			4597			4992			4801			4636		
Final Mass of Wet Sample	5021			4927			4711			4971			4781			4616		
Initial Bulk Density	**2.258**			**2.198**			**2.080**			**2.258**			**2.172**			**2.097**		
Final Bulk Density	**2.272**			**2.229**			**2.131**			**2.249**			**2.163**			**2.088**		
Initial Moisture Content	1			2			3			1			2			3		
Container No.	ACM	A20		E3	A22		F1	A5		A20	ACM		A22	E3		A5	F1	
Mass of Container + Wet Soil (gm)	95.91	94.15		94.03	96.7		80.44	85.83		94.15	95.91		96.7	94.03		85.83	80.44	
Mass of Container + Dry Soil (gm)	92.07	89.15		89.18	92.24		76.87	82.22		89.15	92.07		92.24	89.18		82.22	76.87	
Mass Container (gm)	15.48	14.55		15.79	14.82		15.67	14.8		14.55	15.48		14.82	15.79		14.8	15.67	
Mass of Wet Soil	80.43	79.6		78.24	81.88		64.77	71.03		79.6	80.43		81.88	78.24		71.03	64.77	
Mass of Dry Soil	76.59	74.6		73.39	77.42		61.2	67.42		24.60	76.59		77.42	73.39		67.42	61.2	
Mass of Water	3.84	5.00		4.85	4.46		3.57	3.61		5.00	3.84		4.46	4.85		3.61	3.57	
Water Content	5.01	6.70		6.61	5.76		5.83	5.35		6.70	5.01		5.76	6.61		5.35	5.83	
Average Water Content	**5.86**			**6.18**			**5.59**			**5.86**			**6.18**			**5.59**		
Dry Density	**2.133**			**2.0703**			**1.9696**			**2.134**			**2.0456**			**1.9863**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	A22	A20	C1	B4	E1	B3	E3	A4	K1	A9	A23	A21	K4	A15	A33	A12	A10	A34
Mass of Container + Wet Soil (gm)	97.36	86.39	75.7	87.03	78.48	76.95	99.21	79.29	90.05	98.38	89.83	89.26	87.81	86.09	81.06	85.98	85.87	95.93
Mass of Container + Dry Soil (gm)	92.75	82.35	71.78	82.43	74.36	71.66	93.57	74.55	83.88	94.45	85.93	85.51	84.04	82.16	77.51	82.93	82.53	92.16
Mass Container (gm)	14.78	14.51	16.02	14.6	15.81	14.22	15.72	14.24	16.31	14.34	15.43	14.14	15.65	15.32	14.12	14.3	14.44	14.1
Mass of Wet Soil	82.58	71.88	59.68	72.43	62.67	62.73	83.49	65.05	73.74	84.04	74.4	75.12	72.16	70.77	66.94	71.68	71.43	81.83
Mass of Dry Soil	77.97	67.84	55.76	67.83	58.55	57.44	77.85	60.31	67.57	80.11	70.5	71.37	68.39	66.84	63.39	68.63	68.09	78.06
Mass of Water	4.61	4.04	3.92	4.6	4.12	5.29	5.64	4.74	6.17	3.93	3.90	3.75	3.77	3.93	3.55	3.05	3.34	3.77
Water Content	5.91	5.96	7.03	6.78	7.04	9.21	7.24	7.86	9.13	4.91	5.53	5.25	5.51	5.88	5.60	4.44	4.91	4.83
Average Water Content	**6.299**			**7.676**			**8.078**			**5.231**			**5.664**			**4.726**		
Dry Density	**2.137**			**2.070**			**1.972**			**2.137**			**2.047**			**1.994**		
Height of Mould (cm)	**11.53**																	
Diameter of Mould (cm)	**15.62**																	
Volume of Mould (cm³)	**2210.32**																	

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

TWO DAYS CONTROL

Date 15th May 2008

Conditioning	**Two Days Soaking**								
Test No.	**CR-B55-W2**			**CR-B25-W2**			**CR-B10-W2**		
Mould No	A33			A7			B2		
Number of Blows	55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12324			12168			12039		
Final Mass of Cylinder + Wet Sample (gm)	12388			12252			12196		
Mass of Cylinder	7390			7368			7494		
Initial Mass of Wet Sample	4934			4800			4545		
Final Mass of Wet Sample	4998			4884			4702		
Initial Bulk Density	**2.232**			**2.172**			**2.056**		
Final Bulk Density	**2.261**			**2.210**			**2.127**		
Initial Moisture Content	1			2			3		
Container No.	A23	A38		E1	A21		C1	K1	
Mass of Container + Wet Soil (gm)	89.38	91.09		87.7	96.95		94.12	100.97	
Mass of Container + Dry Soil (gm)	85.48	87.12		83.77	92.54		90.24	96.56	
Mass Container (gm)	15.41	14.31		15.83	14.15		16.07	16.32	
Mass of Wet Soil	73.97	76.78		71.87	82.8		78.05	84.65	
Mass of Dry Soil	70.07	72.81		67.94	78.39		74.17	80.24	
Mass of Water	3.9	3.97		3.93	4.41		3.88	4.41	
Water Content	5.57	5.45		5.78	5.63		5.23	5.50	
Average Water Content	**5.51**			**5.71**			**5.36**		
Dry Density	**2.116**			**2.054**			**1.952**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	A5	E3	K4	A34	B4	B3	ACM	A23	A9
Mass of Container + Wet Soil (gm)	92.84	88.79	82.69	87.71	91.97	90.71	96.02	101.04	112.1
Mass of Container + Dry Soil (gm)	87.91	84.16	77.79	82.56	86.33	84.12	89.85	93.74	104.67
Mass Container (gm)	14.8	15.73	15.64	14.1	16.62	14.23	15.45	15.38	14.32
Mass of Wet Soil	78.04	73.06	67.05	73.61	75.35	76.48	80.57	85.66	97.78
Mass of Dry Soil	73.11	68.43	62.15	68.46	69.71	69.89	74.4	78.36	90.35
Mass of Water	4.93	4.63	4.90	5.15	5.64	6.59	6.17	7.30	7.43
Water Content	6.74	6.77	7.88	7.52	8.09	9.43	8.29	9.32	8.22
Average Water Content	**7.131**			**8.347**			**8.611**		
Dry Density	**2.111**			**2.039**			**1.959**		
Height of Mould (cm)	**11.53**								
Diameter of Mould (cm)	**15.62**								
Volume of Mould (cm³)	**2210.32**								

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

THREE DAYS CONTROL

Date 16[Th] May 2008

Conditioning	Three Days Soaking									Three Days Drying								
Test No.	CR-B55-W3			CR-B25-W3			CR-B10-W3			CR-B55-D3			CR-B25-D3			CR-B10-D3		
Mould No	F1			D1			F6			G8			B3			F8		
Number of Blows	55			25			10			55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12506			11682			11871			11855			11463			12208		
Final Mass of Cylinder + Wet Sample (gm)	12557			11785			12070			11796			11396			12147		
Mass of Cylinder	7563			6817			7332			6847			6674			7661		
Initial Mass of Wet Sample	4943			4865			4539			5008			4789			4547		
Final Mass of Wet Sample	4994			4968			4738			4949			4722			4486		
Initial Bulk Density	**2.236**			**2.201**			**2.054**			**2.266**			**2.167**			**2.057**		
Final Bulk Density	**2.259**			**2.248**			**2.144**			**2.239**			**2.136**			**2.030**		
Initial Moisture Content	1			2			3			1			2			3		
Container No.	A41	A31		E4	A15		E2	B3		A38	A23		A21	E1		K1	C1	
Mass of Container + Wet Soil (gm)	89.96	93.63		94.06	89.81		95.47	93.4		91.09	89.38		96.95	87.7		100.97	94.12	
Mass of Container + Dry Soil (gm)	86.28	89.97		90.55	86.63		91.9	89.57		87.12	85.48		92.54	83.77		96.56	90.24	
Mass Container (gm)	14.22	14.43		14.5	15.32		14.77	14.24		14.31	15.41		14.15	15.83		16.32	16.07	
Mass of Wet Soil	75.74	79.2		79.56	74.49		80.7	79.16		76.78	73.97		82.8	71.87		84.65	78.05	
Mass of Dry Soil	72.06	75.54		76.05	71.31		77.13	75.33		72.81	70.07		78.39	67.94		80.24	74.17	
Mass of Water	3.68	3.66		3.51	3.18		3.57	3.83		3.97	3.9		4.41	3.93		4.41	3.88	
Water Content	5.11	4.85		4.62	4.46		4.63	5.08		5.45	5.57		5.63	5.78		5.50	5.23	
Average Water Content	**4.98**			**4.54**			**4.86**			**5.51**			**5.71**			**5.36**		
Dry Density	**2.130**			**2.105**			**1.958**			**2.147**			**2.050**			**1.952**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	A15	K4	E3	C1	B4	F1	A23	A5	B3	A41	ACM	A20	A83	A9	K1	A31	M3	DK
Mass of Container + Wet Soil (gm)	90.78	86.90	91.69	84.56	84.79	82.87	95.55	92.73	93.43	93.05	76.40	76.55	87.65	76.05	86.77	94.12	93.29	88.47
Mass of Container + Dry Soil (gm)	86.47	82.29	86.39	79.73	79.47	76.61	89.97	86.63	86.09	89.87	73.48	73.67	84.33	73.28	83.53	91.25	89.88	84.60
Mass Container (gm)	15.32	15.64	15.71	16.04	14.60	15.61	15.35	14.79	14.24	14.22	15.46	14.52	14.54	14.33	16.32	14.39	14.37	14.00
Mass of Wet Soil	75.46	71.26	75.98	68.52	70.19	67.26	80.20	77.94	79.19	78.83	60.94	62.03	73.11	61.72	70.45	79.73	78.92	74.47
Mass of Dry Soil	71.15	66.65	70.68	63.69	64.87	61.00	74.62	71.84	71.85	75.65	58.02	59.15	69.79	58.95	67.21	76.86	75.51	70.60
Mass of Water	4.31	4.61	5.30	4.83	5.32	6.26	5.58	6.10	7.34	3.18	2.92	2.88	3.32	2.77	3.24	2.87	3.41	3.87
Water Content	6.06	6.92	7.50	7.58	8.20	10.26	7.48	8.49	10.22	4.20	5.03	4.87	4.76	4.70	4.82	3.73	4.52	5.48
Average Water Content	**6.824**			**8.682**			**8.728**			**4.702**			**4.759**			**4.577**		
Dry Density	**2.115**			**2.068**			**1.971**			**2.138**			**2.039**			**1.941**		
Height of Mould (cm)	**11.53**																	
Diameter of Mould (cm)	**15.62**																	
Volume of Mould (cm³)	**2210.32**																	

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

FOUR DAY CONTROL

Date 17Th May 2008

Conditioning	Four Days Soaking								
Test No.	CR-B55-W3			CR-B25-W3			CR-B10-W3		
Mould No	E1			D5			G4		
Number of Blows	55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12040			11902			11721		
Final Mass of Cylinder + Wet Sample (gm)	12097			12031			11924		
Mass of Cylinder	7180			7197			7147		
Initial Mass of Wet Sample	4860			4705			4574		
Final Mass of Wet Sample	4917			4834			4777		
Initial Bulk Density	**2.199**			**2.129**			**2.069**		
Final Bulk Density	**2.225**			**2.187**			**2.161**		
Initial Moisture Content	1			2			3		
Container No.	A3	A10		B4	A34		K4	A9	
Mass of Container + Wet Soil (gm)	106.34	90.98		87.85	90.46		105.31	94.10	
Mass of Container + Dry Soil (gm)	102.82	87.55		84.96	86.46		101.05	90.69	
Mass Container (gm)	14.38	14.44		14.6	14.11		15.64	14.30	
Mass of Wet Soil	91.96	76.54		73.25	76.35		89.67	79.8	
Mass of Dry Soil	88.44	73.11		70.36	72.35		85.41	76.39	
Mass of Water	3.52	3.43		2.89	4		4.26	3.41	
Water Content	3.98	4.69		4.11	5.53		4.99	4.46	
Average Water Content	**4.34**			**4.82**			**4.73**		
Dry Density	**2.107**			**2.031**			**1.976**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	A83	A23	A9	F1	ACM	A5	A34	A20	K1
Mass of Container + Wet Soil (gm)	98.37	100.58	101.17	101.58	97.11	116.93	103.99	117.51	131.02
Mass of Container + Dry Soil (gm)	93.19	95.1	94.39	95.34	91.13	107.15	96.74	109.08	118.18
Mass Container (gm)	14.51	15.34	14.31	15.6	15.44	14.8	14.1	14.52	16.31
Mass of Wet Soil	83.86	85.24	86.86	85.98	81.67	102.13	89.89	102.99	114.71
Mass of Dry Soil	78.68	79.76	80.08	79.74	75.69	92.35	82.64	94.56	101.87
Mass of Water	5.18	5.48	6.78	6.24	5.98	9.78	7.25	8.43	12.84
Water Content	6.58	6.87	8.47	7.83	7.90	10.59	8.77	8.91	12.60
Average Water Content	**7.31**			**8.77**			**10.10**		
Dry Density	**2.073**			**2.011**			**1.963**		
Height of Mould (cm)	**11.53**								
Diameter of Mould (cm)	**15.62**								
Volume of Mould (cm³)	**2210.32**								

Conditioning	Four Days Drying								
Test No.	CR-B55-D3			CR-B25-D3			CR-B10-D3		
Mould No	N2			F2			F13		
Number of Blows	55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12284			12205			12021		
Final Mass of Cylinder + Wet Sample (gm)	12191			12111			11935		
Mass of Cylinder	7297			7407			7458		
Initial Mass of Wet Sample	4987			4798			4563		
Final Mass of Wet Sample	4894			4704			4477		
Initial Bulk Density	**2.256**			**2.171**			**2.064**		
Final Bulk Density	**2.214**			**2.128**			**2.025**		
Initial Moisture Content	1			2			3		
Container No.	A31	A41		A15	E4		B3	E2	
Mass of Container + Wet Soil (gm)	93.63	89.96		89.81	94.06		93.4	95.47	
Mass of Container + Dry Soil (gm)	89.97	86.28		85.63	90.55		89.57	91.9	
Mass Container (gm)	14.43	14.22		15.32	14.5		14.24	14.77	
Mass of Wet Soil	79.2	75.74		74.49	79.56		79.16	80.7	
Mass of Dry Soil	75.54	72.06		71.31	76.05		75.33	77.13	
Mass of Water	3.66	3.68		3.18	3.51		3.83	3.57	
Water Content	4.85	5.11		4.46	4.62		5.08	4.63	
Average Water Content	**4.98**			**4.54**			**4.86**		
Dry Density	**2.149**			**2.077**			**1.969**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	C1	A41	E3	A10	B4	A15	K4	B3	A12
Mass of Container + Wet Soil (gm)	88.56	85.32	81.29	89.22	83.57	86.29	98.23	93.32	94.22
Mass of Container + Dry Soil (gm)	86.18	82.3	78.61	86.49	80.91	83.12	95.49	90.53	91.43
Mass Container (gm)	16.04	14.21	15.7	14.43	14.6	15.32	15.63	14.22	14.27
Mass of Wet Soil	72.52	71.11	65.59	74.79	68.97	70.97	82.6	79.1	79.95
Mass of Dry Soil	70.14	68.09	62.91	72.06	66.31	67.8	79.86	76.31	77.16
Mass of Water	2.38	3.02	2.68	2.73	2.66	3.17	2.74	2.79	2.79
Water Content	3.39	4.44	4.26	3.79	4.01	4.68	3.43	3.66	3.62
Average Water Content	**4.03**			**4.16**			**3.57**		
Dry Density	**2.128**			**2.043**			**1.956**		

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

FIVE DAYS CONTROL — **Date 18[Th] May 2008**

Conditioning	**Drying**								
Test No.	**CR-B55-D5**			**CR-B25-D5**			**CR-B10-D5**		
Mould No	E4			F3			F5		
Number of Blows	55			25			10		
Initial Mass of Cylinder + Wet Sample (gm)	12461			12055			11785		
Final Mass of Cylinder + Wet Sample (gm)	12347			11943			11678		
Mass of Cylinder	7532			7379			7280		
Initial Mass of Wet Sample	4929			4676			4505		
Final Mass of Wet Sample	4815			4564			4398		
Initial Bulk Density	**2.230**			**2.116**			**2.038**		
Final Bulk Density	**2.178**			**2.065**			**1.990**		
Initial Moisture Content	1			2			3		
Container No.	A10	A3		A34	B4		A9	K4	
Mass of Container + Wet Soil (gm)	90.98	106.34		90.46	87.85		94.10	105.31	
Mass of Container + Dry Soil (gm)	87.55	102.82		86.46	84.96		90.69	101.05	
Mass Container (gm)	14.44	14.38		14.11	14.6		14.30	15.64	
Mass of Wet Soil	76.54	91.96		76.35	73.25		79.80	89.67	
Mass of Dry Soil	73.11	88.44		72.35	70.36		76.39	85.41	
Mass of Water	3.43	3.52		4.00	2.89		3.41	4.26	
Water Content	4.69	3.98		5.53	4.11		4.46	4.99	
Average Water Content	**4.34**			**4.8181**			**4.7258**		
Dry Density	**2.137**			**2.0183**			**1.9462**		
Final Moisture Content	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Container No.	B4	ACM	A34	C1	A12	A20	A23	F1	E3
Mass of Container + Wet Soil (gm)	98.70	99.08	92.03	94.23	93.44	101.33	99.86	87.29	95.16
Mass of Container + Dry Soil (gm)	96.22	96.25	89.80	92.34	91.30	98.95	97.96	85.33	93.00
Mass Container (gm)	14.59	15.44	14.11	16.03	14.42	14.51	15.31	15.59	15.69
Mass of Wet Soil	84.11	83.64	77.92	78.20	79.02	86.82	84.55	71.70	79.47
Mass of Dry Soil	81.63	80.81	75.69	76.31	76.88	84.44	82.65	69.74	77.31
Mass of Water	2.48	2.83	2.23	1.89	2.14	2.38	1.90	1.96	2.16
Water Content	3.04	3.50	2.95	2.48	2.78	2.82	2.30	2.81	2.79
Average Water Content	**3.162**			**2.692**			**2.634**		
Dry Density	**2.112**			**2.011**			**1.939**		
Height of Mould (cm)	11.53								
Diameter of Mould (cm)	15.62								
Volume of Mould (cm³)	**2210.32**								

APPENDIX C:
Laboratory DCP Test Results.

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

Control: Zero Control

Date: 14Th May 2008

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	Depth of Penetration (mm)											
	Test Number											
	Same Day											
	CR-B55-C0		CR-B25-C0		CR-B10-C0							
Initial Readings	265	**0**	256	**0**	280	**0**						
1	278	**13**	287	**31**	304	**24**						
2	285	**20**	301	**45**	322	**42**						
3	293	**28**	310	**54**	332	**52**						
4	300	**35**	316	**60**	345	**65**						
5	305	**40**	325	**69**	355	**75**						
6	310	**45**	332	**76**	369	**89**						
7	315	**50**	340	**84**	378	**98**						
8	320	**55**	346	**90**	386	**106**						
9	327	**62**	356	**100**	394	**114**						
10	331	**66**	359	**103**								
11	334	**69**	366	**110**								
12	340	**75**	369	**113**								
13	345	**80**										
14	348	**83**										
15	350	**85**										
16	356	**91**										
17	361	**96**										
18	365	**100**										
19	371	**106**										
20	375	**110**										
21	378	**113**										

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

Control: One Day | **Date: 14th May 2008**

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	Depth of Penetration (mm)											
	Mould Compaction Level											
	One Day Soaking						One Day Drying					
	CR-B55-W1		CR-B25-W1		CR-B10-W1		CR-B55-D1		CR-B25-D1		CR-B10-D1	
Initial Readings	265	0	265	0	275	0	265	0	265	0	272	0
1	275	10	287	22	297	22	275	10	280	15	295	23
2	282	17	301	36	323	48	285	20	288	23	310	38
3	288	23	310	45	328	53	290	25	295	30	315	43
4	291	26	316	51	341	66	295	30	300	35	325	53
5	297	32	325	60	351	76	296	31	305	40	334	62
6	302	37	332	67	362	87	300	35	310	45	342	70
7	305	40	340	75	373	98	305	40	315	50	350	78
8	310	45	346	81			310	45	320	55	365	93
9	313	48	356	91			312	47	325	60	370	98
10	317	52	359	94			316	51	328	63	375	103
11	321	56	366	101			321	56	332	67	386	114
12	322	57	374	109			325	60	335	70		
13	325	60	376	111			329	64	340	75		
14	328	63					332	67	345	80		
15	331	66					335	70	350	85		
16	335	70					336	71	350	85		
17	336	71					339	74	360	95		
18	341	76					341	76	365	100		
19	343	78					345	80	370	105		
20	346	81					349	84	374	109		
21	349	84					352	87	378	113		
22	354	89					355	90				
23	357	92					357	92				
24	360	95					359	94				
25	364	99					360	95				
26	367	102					363	98				
27	370	105					366	101				
28	373	108					370	105				
29	376	111					372	107				
30	379	114					375	110				
31							379	114				
32							380	115				

DEPARTMENT OF CIVIL ENGINEERING

GEOTECHNICAL LABORATORY

MOULD CALIBRATION RESULTS

Control: **Two Day Control** **Date : 15Th May 2008**

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	Depth of Penetration (mm) — Mould Compaction Level — Two Days Soaking					
	CR-B55-W2		CR-B25-W2		CR-B10-W2	
Initial Readings	265	0	265	0	280	0
1	278	13	287	22	304	24
2	285	20	301	36	322	42
3	293	28	310	45	332	52
4	300	35	316	51	345	65
5	305	40	325	60	355	75
6	310	45	332	67	369	89
7	315	50	340	75	378	98
8	320	55	346	81	386	106
9	327	62	356	91	394	114
10	331	66	359	94		
11	334	69	366	101		
12	340	75	374	109		
13	345	80	376	111		
14	348	83	380	115		
15	350	85				
16	356	91				
17	361	96				
18	365	100				
19	371	106				
20	375	110				
21	378	113				

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

Control: Three Days Control

Date : 16Th May 2008

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	Depth of Penetration (mm)											
	Mould Compaction Level											
	Three Days Soaking						Three Days Drying					
	CR-B55-W3		CR-B25-W3		CR-B10-W3		CR-B55-D3		CR-B25-D3		CR-B10-D3	
Initial Readings	265	0	265	0	277	0	262	0	264	0	267	0
1	280	15	285	20	302	25	272	10	278	14	283	16
2	285	20	294	29	320	43	276	14	285	21	297	30
3	293	28	304	39	332	55	282	20	295	31	309	42
4	298	33	312	47	341	64	285	23	298	34	318	51
5	305	40	320	55	351	74	289	27	302	38	325	58
6	312	47	328	63	362	85	294	32	308	44	333	66
7	318	53	335	70	374	97	297	35	312	48	344	77
8	322	57	344	79	386	109	299	37	316	52	350	83
9	323	58	351	86			302	40	320	56	357	90
10	325	60	360	95			306	44	322	58	364	97
11	330	65	369	104			310	48	326	62	371	104
12	334	69	375	110			315	53	330	66	378	111
13	340	75					317	55	332	68		
14	343	78					320	58	336	72		
15	347	82					322	60	340	76		
16	350	85					325	63	344	80		
17	354	89					327	65	347	83		
18	360	95					330	68	350	86		
19	364	99					332	70	353	89		
20	370	105					335	73	357	93		
21	373	108					338	76	360	96		
22	379	114					340	78	363	99		
23							340	78	366	102		
24							341	79	369	105		
25							344	82	375	111		
26							347	85				
27							348	86				
28							350	88				
29							353	91				
30							355	93				

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

Control: Four Days **Date : 17^TH May 2008**

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	Depth of Penetration (mm)											
	Test Number											
	Four Days Soaking						Four Days Drying					
	55 Blows		25 Blows		10 Blows		55 Blows		25 Blows		10 Blows	
Initial Readings	261	0	265	0	275	0	260	0	263	0	269	0
1	277	16	279	14	305	30	272	12	275	12	286	17
2	286	25	289	24	320	45	278	18	284	21	298	29
3	293	32	297	32	338	63	284	24	289	26	308	39
4	299	38	307	42	345	70	292	32	294	31	316	47
5	304	43	317	52	358	83	293	33	302	39	320	51
6	310	49	326	61	370	95	299	39	306	43	326	57
7	315	54	338	73	379	104	301	41	311	48	332	63
8	320	59	341	76	388		305	45	314	51	336	67
9	326	65	346	81			308	48	317	54	341	72
10	332	71	350	85			310	50	325	62	346	77
11	336	75	362	97			315	55	327	64	350	81
12	340	79	373	108			317	57	322	59	354	85
13	346	85					320	60	335	72	359	90
14	352	91					322	62	338	75	363	94
15	357	96					325	65	342	79	367	98
16	362	101					328	68	345	82	370	101
17	369	108					331	71	349	86	374	105
18	373	112					334	74	353	90		
19	375	114					338	78	356	93		
20							341	81	360	97		
21							343	83	363	100		
22							345	85	366	103		
23							347	87	369	106		
24							351	91	372	109		
25							355	95	374	111		
26							357	97	376	113		
27							360	100				
28							365	105				
29							367	107				
30							372	112				

DEPARTMENT OF CIVIL ENGINEERING
GEOTECHNICAL LABORATORY
MOULD CALIBRATION RESULTS

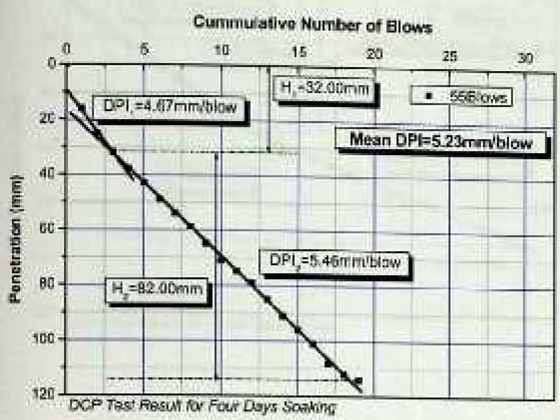
DYNAMIC CONE PENETROMETER TEST

Control: Five Days — **Date : 18Th May 2008**

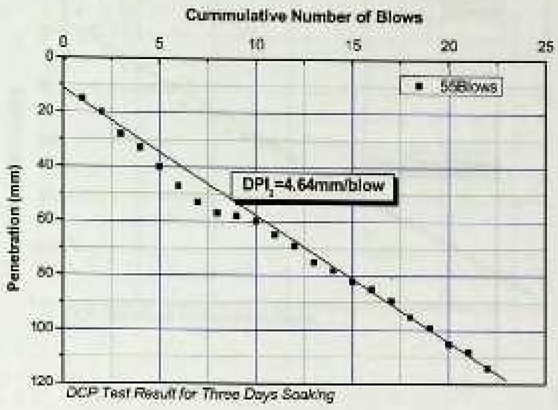
Cumm. No. of Blows	Depth of Penetration (mm)											
	Mould Compaction Level											
							Five Days Drying					
							CR-B55-D5		CR-B25-D5		CR-B10-D5	
Initial Readings							260	0	270	0	265	0
1							275	15	283	13	285	20
2							283	23	290	20	303	38
3							289	29	298	28	310	45
4							293	33	302	32	315	50
5							296	36	308	38	323	58
6							300	40	312	42	328	63
7							303	43	315	45	334	69
8							310	50	320	50	340	75
9							311	51	323	53	345	80
10							314	54	328	58	352	87
11							317	57	332	62	358	93
12							320	60	338	68	364	99
13							321	61	340	70	369	104
14							324	64	346	76	374	109
15							327	67	350	80		
16							330	70	350	80		
17							333	73	353	83		
18							337	77	360	90		
19							340	80	365	95		
20							344	84	368	98		
21							346	86	372	102		
22							348	88	378	108		
23							350	90				
24							352	92				
25							355	95				
26							357	97				
27							360	100				
28							362	102				
29							364	104				
30							367	107				
31							369	109				

Laboratory DCP Test Results

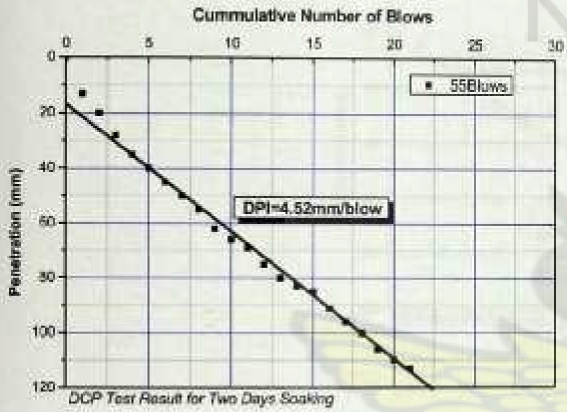
1. DPI Results for 55 Blows:



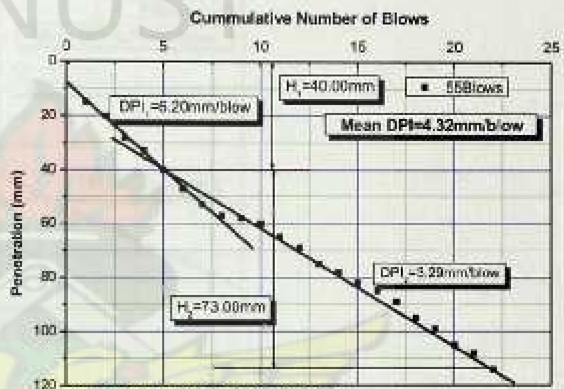
DCP Test Result for Four Days Soaking



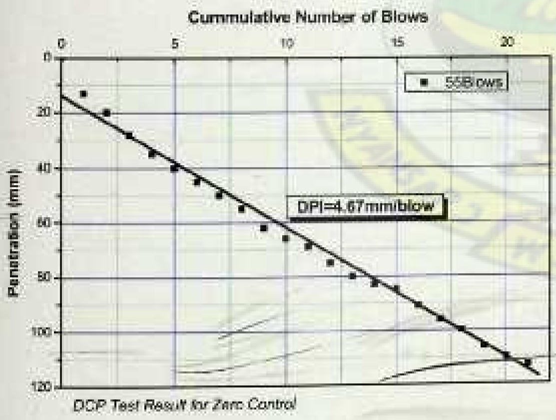
DCP Test Result for Three Days Soaking



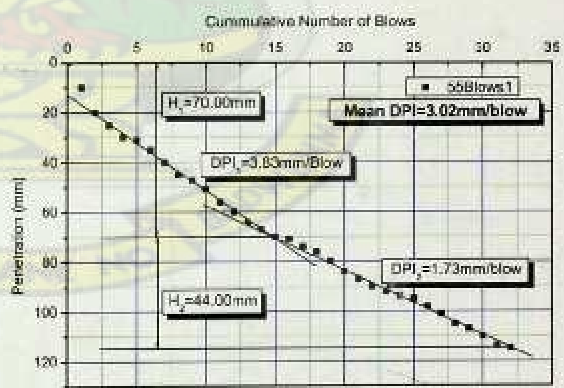
DCP Test Result for Two Days Soaking



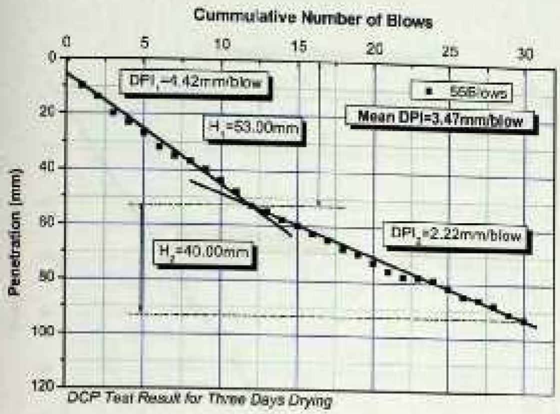
DCP Test Result for Three Days Soaking



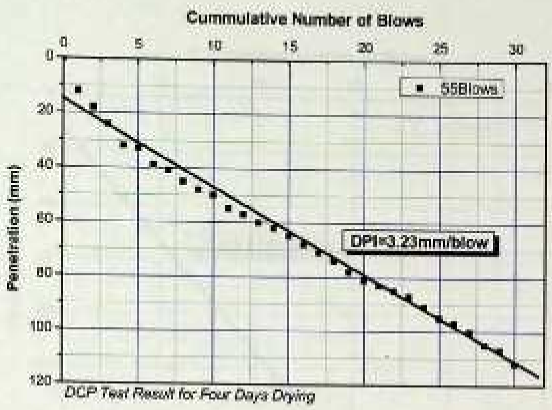
DCP Test Result for Zero Control



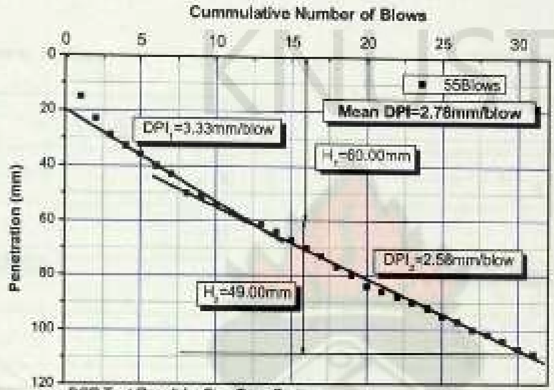
DCP Test Result for One Day Drying



DCP Test Result for Three Days Drying

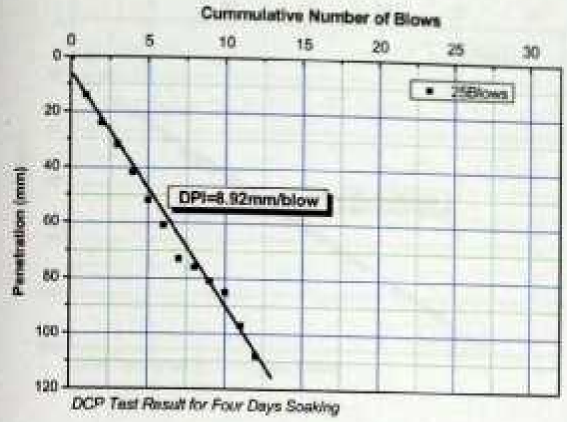


DCP Test Result for Four Days Drying

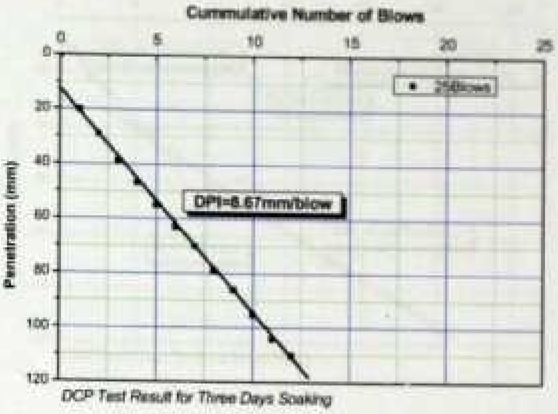


DCP Test Result for Five Days Drying

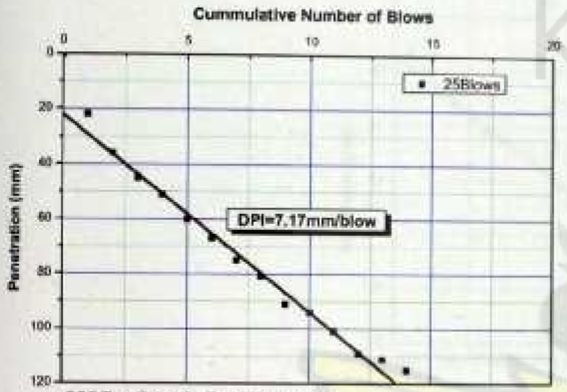
2. DPI Results for 25 Blows:



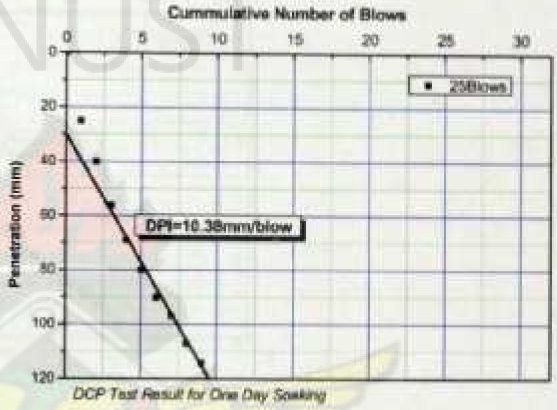
DCP Test Result for Four Days Soaking



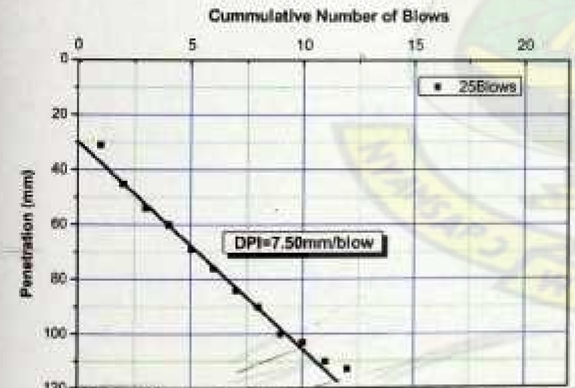
DCP Test Result for Three Days Soaking



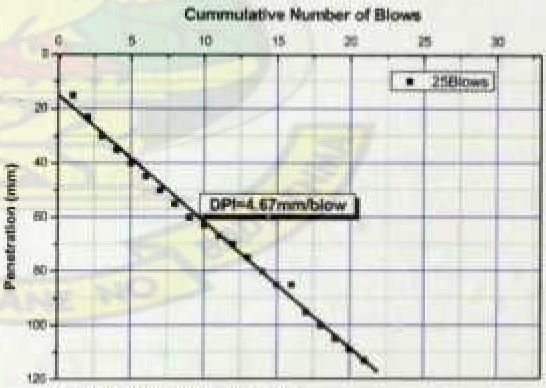
DCP Test Result for Two Days Soaking



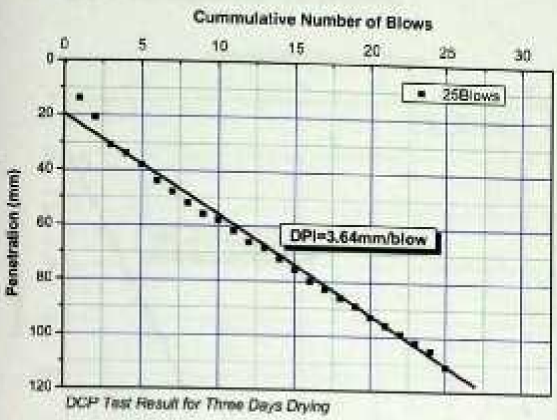
DCP Test Result for One Day Soaking



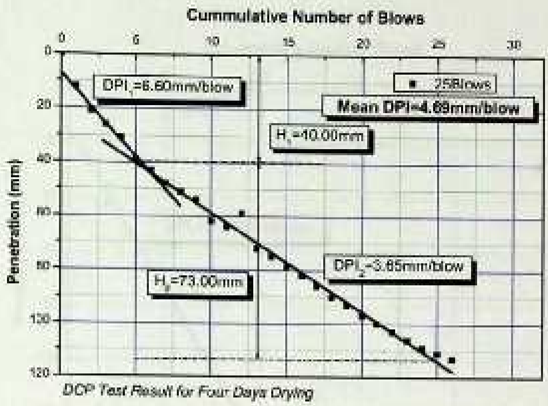
DCP Test Result for Zero Control



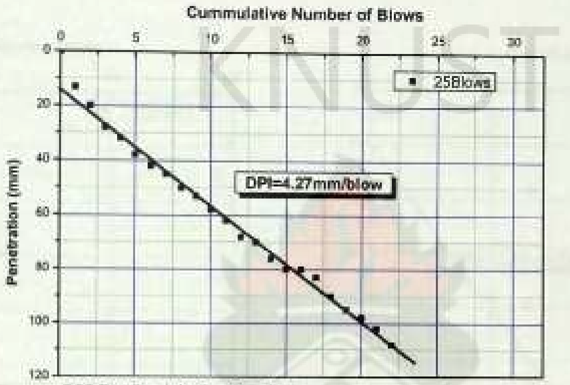
DCP Test Result for One Day Drying



DCP Test Result for Three Days Drying

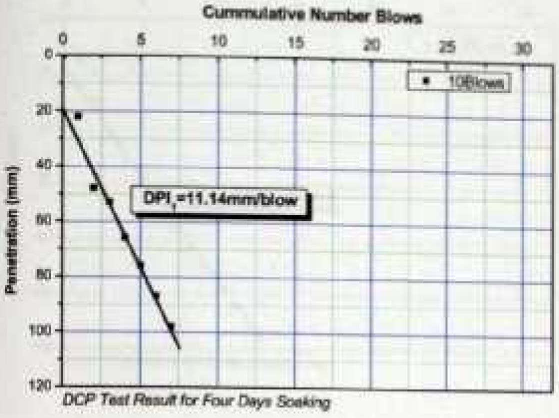


DCP Test Result for Four Days Drying

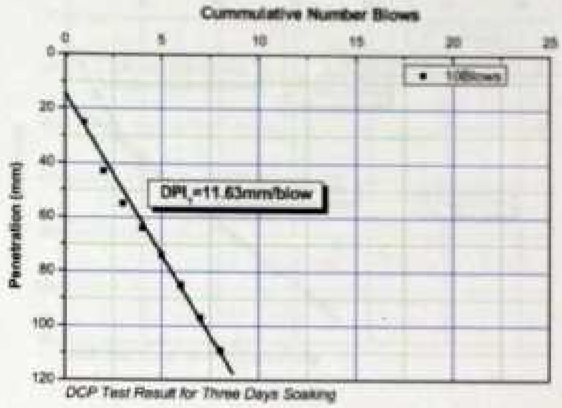


DCP Test Result for Five Days Drying

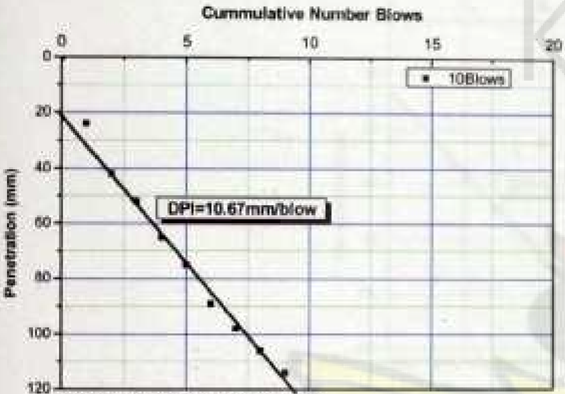
3. DPI Results for 10 Blows:



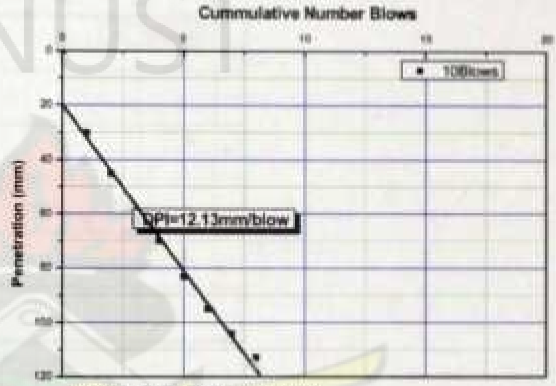
DCP Test Result for Four Days Soaking



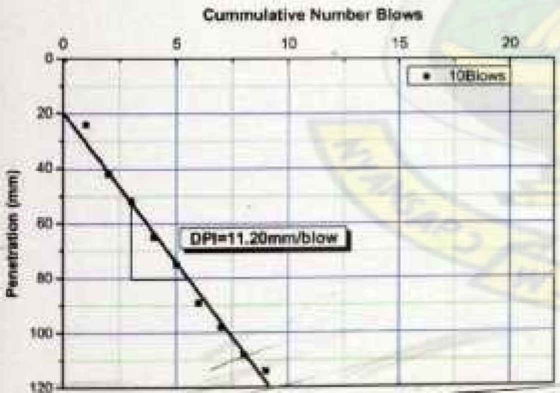
DCP Test Result for Three Days Soaking



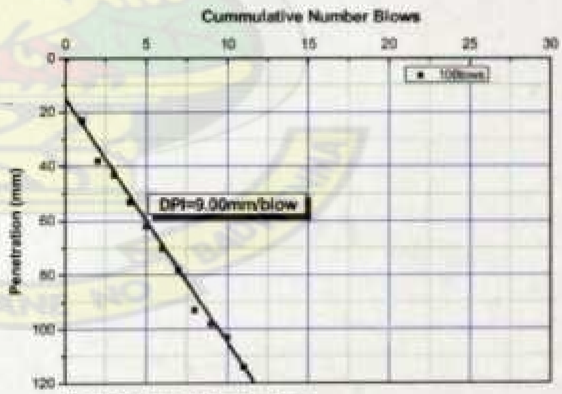
DCP Test Result for Two Days Soaking



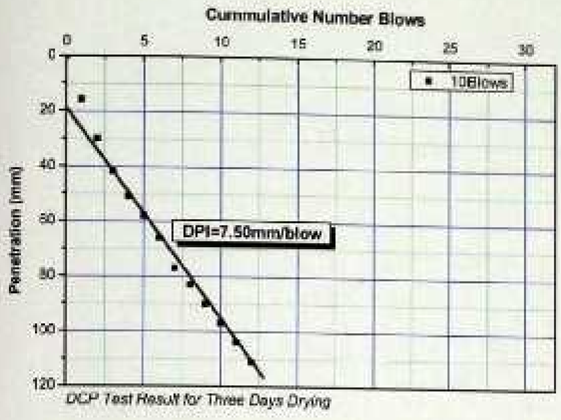
DCP Test Result for One Day Control



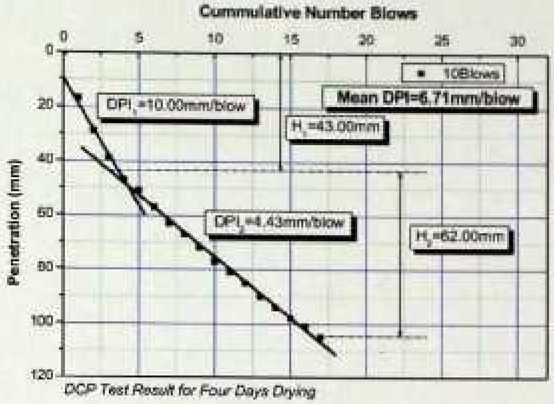
DCP Test Result for Zero Control



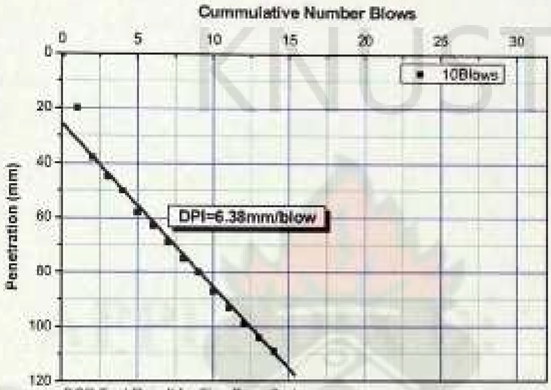
DCP Test Result for One Day Drying



DCP Test Result for Three Days Drying



DCP Test Result for Four Days Drying



DCP Test Result for Five Days Drying

Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering

APPENDIX D:
Statistical Tests Result

T-Test for CR-B55

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
CR-B55	9	2.1115	0.03035	0.01012

One-Sample Test

	Test Value = 2.117					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CR-B55	-0.545	8	0.601	-0.00551	-0.0288	0.0178

Null Hypothesis: Mean=2.117
Alternative Hypothesis: Mean <> 2.117
CR-B55: At the 0.05 level, the population mean is NOT significantly different with the test mean (2.117)

T-Test for CR-B25

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
CR-B25	9	2.0342	0.02935	0.00978

One-Sample Test

	Test Value = 2.041					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CR-B25	-0.697	8	0.506	-0.00682	-0.0294	0.0157

Null Hypothesis: Mean=2.041
Alternative Hypothesis: Mean <> 2.041
CR-B25: At the 0.05 level, the population mean is NOT significantly different with the test mean (2.041)

T-Test for CR-B10

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
CBR10	9	1.9511	0.03634	0.01211

One-Sample Test

	Test Value = 1.952					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
CBR10	-0.076	8	0.941	-0.00093	-0.0289	0.0270

Null Hypothesis: Mean=1.952
Alternative Hypothesis: Mean <> 1.952
CR-B25: At the 0.05 level, the population mean is NOT significantly different with the test mean (1.952)

APPENDIX E:
Field Density Results

Project:	**Rehabilitation of Awiankwanta-Yamorasa Road**
Section:	**Awiankwanta-Assin Praso**
Date :	**8Th April 2008**
Lab MDD:	2.096 Mg/m^3
Lab OMC	5.60 %
Wt of Sand in Cone:	2970 g
Bulk Density of Sand:	1.40 Mg/m^3
Thickness of Material:	150 mm
Roller Weight (Vibratory)	17 Tons
Test No.	**S1T1**

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	12080	10050	14000	18700
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	6700	8400	6500	4400
Wt of sand in hole+cone	gm	11300	9600	11500	13600
Wt of sand in hole (W_2)	gm	8330	6630	8530	10630
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**2.0303**	**2.1222**	**2.2978**	**2.4628**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	4.40	3.4	4.20	4.00
Dry density (Ds)	**Mg/m^3**	**1.9447**	**2.0524**	**2.2052**	**2.3681**
RELATIVE COMPACTION	**%**	**92.78**	**97.92**	**105.21**	**112.98**

Test No. S1T2

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	18550	16500	15150	11300
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	1900	4500	5900	8750
Wt of sand in hole+cone	gm	16100	13500	12100	9250
Wt of sand in hole (W_2)	gm	13130	10530	9130	6280
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**1.9779**	**2.1937**	**2.3231**	**2.5191**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	5.00	3.8	3.00	3.90
Dry density (Ds)	**Mg/m^3**	**1.8837**	**2.1134**	**2.2554**	**2.4246**
RELATIVE COMPACTION	**%**	**89.87**	**100.83**	**107.61**	**115.68**

Project:	**Rehabilitation of Awiankwanta-Yamorasa Road**
Section:	**Awiankwanta-Assin Praso**
Date :	**17[Th] April 2008**
Lab MDD:	2.096 Mg/m^3
Lab OMC	5.60 %
Wt of Sand in Cone:	2970 g
Bulk Density of Sand:	1.40 Mg/m^3
Thickness of Material:	150 mm
Roller Weight (Vibratory)	17 Tons
Test No.	**S2T1**

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	12160	12900	14400	14500
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	6400	6500	6100	6600
Wt of sand in hole+cone	gm	11600	11500	11900	11400
Wt of sand in hole (W_2)	gm	8630	8530	8930	8430
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**1.9727**	**2.1172**	**2.2576**	**2.4081**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	4.00	3.5	3.60	4.20
Dry density (Ds)	**Mg/m^3**	**1.8968**	**2.0456**	**2.1791**	**2.3110**
RELATIVE COMPACTION	**%**	**90.50**	**97.60**	**103.97**	**110.26**

Test No. S2T2

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	11050	11000	13450	14100
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	7950	8000	6550	6700
Wt of sand in hole+cone	gm	10050	10000	11450	11300
Wt of sand in hole (W_2)	gm	7080	7030	8480	8330
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**2.1850**	**2.1906**	**2.2205**	**2.3697**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	4.00	5.00	5.00	5.30
Dry density (Ds)	**Mg/m^3**	**2.1010**	**2.0863**	**2.1148**	**2.2505**
RELATIVE COMPACTION	**%**	**100.24**	**99.54**	**100.90**	**107.37**

Project:	**Rehabilitation of Awiankwanta-Yamorasa Road**	
Section:	**Awiankwanta-Assin Praso**	
Date :	**22Th April 2008**	
Lab MDD:	2.096	Mg/m^3
Lab OMC	5.60	%
Wt of Sand in Cone:	2970	g
Bulk Density of Sand:	1.40	Mg/m^3
Thickness of Material:	150	mm
Roller Weight (Vibratory)	17	Tons
Test No.	**S3T1**	

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	16200	14500	14300	14800
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	4500	5700	6000	6500
Wt of sand in hole+cone	gm	13500	12300	12000	11500
Wt of sand in hole (W_2)	gm	10530	9330	9030	8530
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**2.1538**	**2.1758**	**2.2171**	**2.4291**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	6.40	4.00	3.80	7.30
Dry density (Ds)	**Mg/m^3**	**2.0243**	**2.0921**	**2.1359**	**2.2638**
RELATIVE COMPACTION	**%**	**96.58**	**99.81**	**101.90**	**108.01**

Test No. **S3T2**

FIELD DENSITY TEST

No. of Pass		2	4	8	16
Wt. of wet soil from hole (W_1)	gm	20000	13100	12400	12350
Wt of sand before pouring	gm	18000	18000	18000	18000
Wt of sand remaining after pouring	gm	2500	6700	7400	7750
Wt of sand in hole+cone	gm	15500	11300	10600	10250
Wt of sand in hole (W_2)	gm	12530	8330	7630	7280
Wet density (W_1*S/W_2) (Mg/m^2)	**Dw**	**2.2346**	**2.2017**	**2.2752**	**2.3750**
MOISTURE CONTENT DETERMINATION					
Moisture content (m)	%	4.40	4.00	3.40	3.50
Dry density (Ds)	**Mg/m^3**	**2.1405**	**2.1170**	**2.2004**	**2.2947**
RELATIVE COMPACTION	**%**	**102.12**	**101.00**	**104.98**	**109.48**

APPENDIX F:
Field DCP Results

Project: Rehabilitation of Awiankwanta-Yamorasa Road
Road Name: Awiankwanta-Assin Praso
Chainage: 5+125
Date : 08/04/2008
Roller Weight: 17 Tons
Thickness of Material: 150mm

Test No: S1T1

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	No. of Passes							
	2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	**215**	**0**	**220**	**0**	**210**	**0**	**204**	**0**
1	270	**55**	244	**24**	215	**5**	214	**10**
2	295	**80**	255	**35**	225	**15**	220	**16**
3	317	**102**	272	**52**	236	**26**	228	**24**
4	329	**114**	290	**70**	245	**35**	236	**32**
5	340	**125**	309	**89**	255	**45**	240	**36**
6	350	**135**	328	**108**	262	**52**	247	**43**
7	355	**140**	342	**122**	267	**57**	255	**51**
8	359	**144**	350	**130**	275	**65**	260	**56**
9	362	**147**	354	**134**	285	**75**	264	**60**
10	367	**152**	360	**140**	290	**80**	271	**67**
11	372	**157**	364	**144**	300	**90**	277	**73**
12	375	**160**	365	**145**	305	**95**	283	**79**
13	378	**163**	368	**148**	310	**100**	290	**86**
14	380	**165**	372	**152**	318	**108**	295	**91**
15	385	**170**	375	**155**	325	**115**	300	**96**
16	388	**173**	378	**158**	332	**122**	304	**100**
17	390	**175**	379	**159**	337	**127**	309	**105**
18	393	**178**	382	**162**	340	**130**	312	**108**
19	396	**181**	385	**165**	345	**135**	317	**113**
20	398	**183**	386	**166**	354	**144**	323	**119**
21	400	**185**	390	**170**	360	**150**	328	**124**
22	405	**190**	391	**171**	365	**155**	332	**128**
23	409	**194**	393	**173**	372	**162**	336	**132**
24			395	**175**	380	**170**	340	**136**
25			397	**177**	385	**175**	345	**141**
26			398	**178**			349	**145**
27			400	**180**			353	**149**
28							357	**153**
29							363	**159**
30							368	**164**
31							372	**168**
32							377	**173**
33							382	**178**
34							384	**180**
35							386	**182**
36							389	**185**
37							391	**187**
38							393	**189**
39							395	**191**
40							397	**193**
41							399	**195**

Project: Rehabilitation of Awiankwanta-Yamorasa Road
Road Name: Awiankwanta-Assin Praso
Chainage: 5+175
Date : 08/04/2008
Roller Weight: 17 Tons
Thickness of Material: 150mm

Test No: S1T2

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	No. of Passes							
	2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	**220**	**0**	**210**	**0**	200	**0**	**200**	**0**
1	255	**35**	238	**28**	215	**15**	218	**18**
2	280	**60**	255	**45**	225	**25**	226	**26**
3	302	**82**	270	**60**	230	**30**	234	**34**
4	321	**101**	292	**82**	240	**40**	243	**43**
5	336	**116**	309	**99**	260	**60**	252	**52**
6	346	**126**	330	**120**	265	**65**	260	**60**
7	365	**145**	346	**136**	270	**70**	269	**69**
8	375	**155**	360	**150**	280	**80**	280	**80**
9	390	**170**	372	**162**	290	**90**	290	**90**
10	400	**180**	383	**173**	300	**100**	298	**98**
11	405	**185**	392	**182**	310	**110**	308	**108**
12	410	**190**	399	**189**	320	**120**	316	**116**
13	411	**191**	402	**192**	330	**130**	325	**125**
14	414	**194**	408	**198**	340	**140**	333	**133**
15	416	**196**	414	**204**	357	**157**	340	**140**
16	418	**198**	419	**209**	365	**165**	345	**145**
17	419	**199**	422	**212**	372	**172**	350	**150**
18	420	**200**	426	**216**	380	**180**	355	**155**
19			430	**220**	389	**189**	362	**162**
20			432	**222**			367	**167**
21							372	**172**
22							376	**176**
23							379	**179**
24							383	**183**
25							386	**186**

Project: Rehabilitation of Awiankwanta-Yamorasa Road
Road Name: Awiankwanta-Assin Praso
Chainage: 5+525
Date : 17/04/2008
Roller Weight: 17 Tons
Thickness of Material: 150mm

Test No: S2T1

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	No. of Passes: 2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	**218**	**0**	**200**	**0**	**210**	**0**	**203**	**0**
1	268	**50**	235	**35**	235	**25**	216	**13**
2	290	**72**	260	**60**	245	**35**	224	**21**
3	310	**92**	282	**82**	255	**45**	234	**31**
4	327	**109**	298	**98**	265	**55**	242	**39**
5	339	**121**	311	**111**	280	**70**	251	**48**
6	351	**133**	331	**131**	295	**85**	255	**52**
7	363	**145**	349	**149**	310	**100**	260	**57**
8	375	**157**	364	**164**	323	**113**	266	**63**
9	384	**166**	375	**175**	337	**127**	272	**69**
10	390	**172**	385	**185**	348	**138**	279	**76**
11	397	**179**	394	**194**	360	**150**	286	**83**
12	402	**184**	400	**200**	370	**160**	294	**91**
13	406	**188**	409	**209**	378	**168**	300	**97**
14	409	**191**	413	**213**	383	**173**	309	**106**
15	413	**195**	420	**220**	387	**177**	315	**112**
16	415	**197**	422	**222**	390	**180**	322	**119**
17	420	**202**	429	**229**			327	**124**
18	423	**205**					332	**129**
19	428	**210**					335	**132**
20	431	**213**					342	**139**
21							347	**144**
22							351	**148**
23							355	**152**
24							358	**155**
25							362	**159**
26							364	**161**
27							368	**165**
28							372	**169**
29							375	**172**
30							380	**177**
31							384	**181**
32							388	**185**
33							390	**187**

Project:	**Rehabilitation of Awiankwanta-Yamorasa Road**
Road Name:	**Awiankwanta-Assin Praso**
Chainage:	**5+575**
Date :	**17/04/2008**
Roller Weight:	**17 Tons**
Thickness of Material:	**150mm**

Test No: S2T2

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	No. of Passes							
	2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	**240**	**0**	**210**	**0**	**220**	**0**	**210**	**0**
1	280	**40**	235	**25**	245	**25**	229	**19**
2	300	**60**	258	**48**	260	**40**	245	**35**
3	325	**85**	292	**82**	260	**40**	260	**50**
4	350	**110**	305	**95**	275	**55**	273	**63**
5	375	**135**	318	**108**	288	**68**	283	**73**
6	385	**145**	330	**120**	300	**80**	294	**84**
7	388	**148**	340	**130**	315	**95**	302	**92**
8	390	**150**	350	**140**	325	**105**	313	**103**
9	395	**155**	364	**154**	338	**118**	325	**115**
10	398	**158**	380	**170**	349	**129**	335	**125**
11	399	**159**	385	**175**	360	**140**	345	**135**
12	404	**164**	389	**179**	370	**150**	352	**142**
13			394	**184**	378	**158**	360	**150**
14			395	**185**	385	**165**	369	**159**
15			396	**186**	388	**168**	374	**164**
16			398	**188**	392	**172**	380	**170**
17					395	**175**	385	**175**
18					396	**176**	390	**180**
19					397	**177**	393	**183**
20					400	**180**	396	**186**
21					402	**182**		

Project: Rehabilitation of Awiankwanta-Yamorasa Road
Road Name: Awiankwanta-Assin Praso
Chainage: 5+925
Date : 22/04/2008
Roller Weight: 17 Tons
Thickness of Material: 150mm

Test No: S3T1

DYNAMIC CONE PENETROMETER TEST

Cumm. No. of Blows	No. of Passes: 2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	**220**	**0**	**207**	**0**	**220**	**0**	**200**	**0**
1	290	**70**	254	**47**	245	**25**	216	**16**
2	330	**110**	280	**73**	263	**43**	224	**24**
3	355	**135**	300	**93**	279	**59**	257	**57**
4	375	**155**	319	**112**	290	**70**	265	**65**
5	397	**177**	335	**128**	301	**81**	275	**75**
6	410	**190**	348	**141**	312	**92**	285	**85**
7	420	**200**	362	**155**	324	**104**	294	**94**
8	421	**201**	373	**166**	337	**117**	304	**104**
9			385	**178**	350	**130**	316	**116**
10			392	**185**	359	**139**	320	**120**
11			396	**189**	369	**149**	327	**127**
12			398	**191**	379	**159**	338	**138**
13			400	**193**	384	**164**	348	**148**
14			401	**194**	389	**169**	357	**157**
15					392	**172**	367	**167**
16					393	**173**	375	**175**
17					395	**175**	380	**180**
18					398	**178**	384	**184**

Project: Rehabilitation of Awiankwanta-Yamorasa Road
Road Name: Awiankwanta-Assin Praso
Chainage: 5+975
Date : 22/04/2008
Roller Weight: 17 Tons
Thickness of Material: 150mm

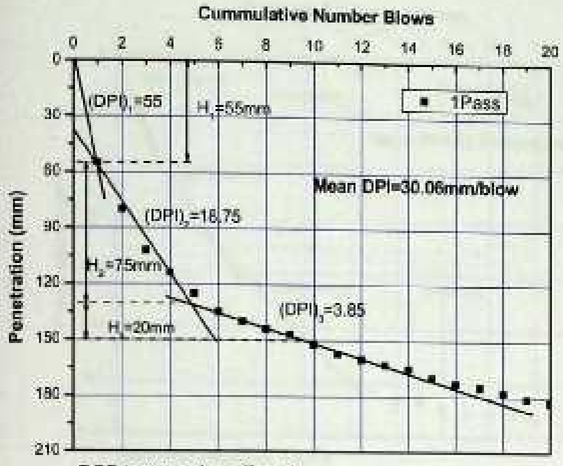
Test No: S3T2

DYNAMIC CONE PENETROMETER TEST

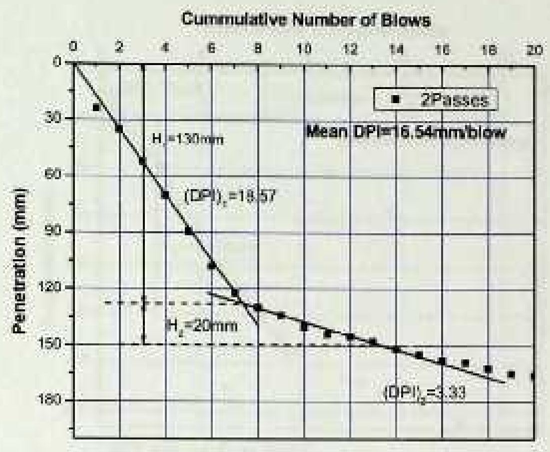
Cumm. No. of Blows	No. of Passes							
	2		4		8		16	
	Depth of Penetration (mm)							
Initial Readings	230	**0**	215	**0**	220	**0**	210	**0**
1	272	**42**	244	**29**	238	**18**	228	**18**
2	304	**74**	273	**58**	260	**40**	240	**30**
3	318	**88**	294	**79**	275	**55**	250	**40**
4	342	**112**	312	**97**	288	**68**	260	**50**
5	368	**138**	325	**110**	295	**75**	268	**58**
6	389	**159**	335	**120**	306	**86**	276	**66**
7	408	**178**	347	**132**	315	**95**	286	**76**
8	420	**190**	363	**148**	325	**105**	297	**87**
9	427	**197**	375	**160**	335	**115**	308	**98**
10	432	**202**	390	**175**	345	**125**	317	**107**
11	436	**206**	400	**185**	355	**135**	328	**118**
12	440	**210**	409	**194**	365	**145**	336	**126**
13			415	**200**	375	**155**	342	**132**
14			416	**201**	385	**165**	354	**144**
15			420	**205**	395	**175**	364	**154**
16			422	**207**	400	**180**	372	**162**
17					405	**185**	380	**170**
18					413	**193**	385	**175**
19					415	**195**	390	**180**
20							395	**185**

FIELD DCP TEST RESULT

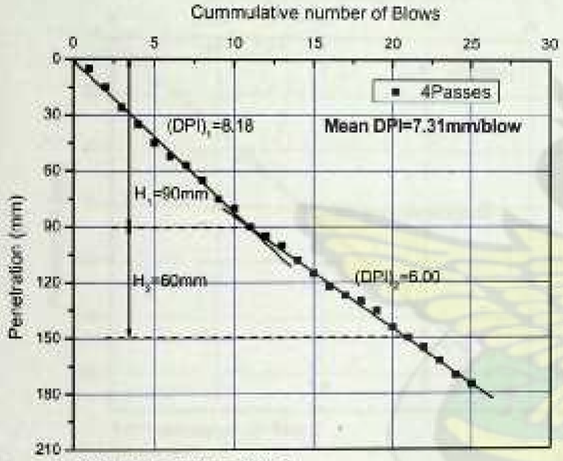
1. Test No. S1T1



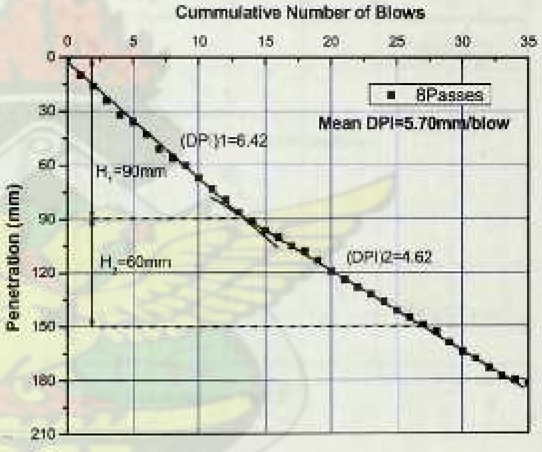
DCP test result on Test 1



DCP test result on Test 1

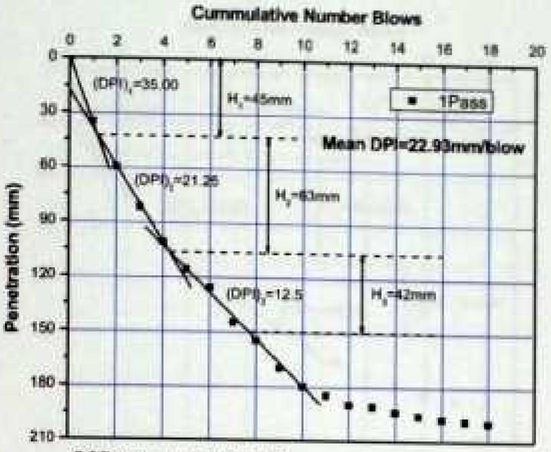


DCP test result on Test 1

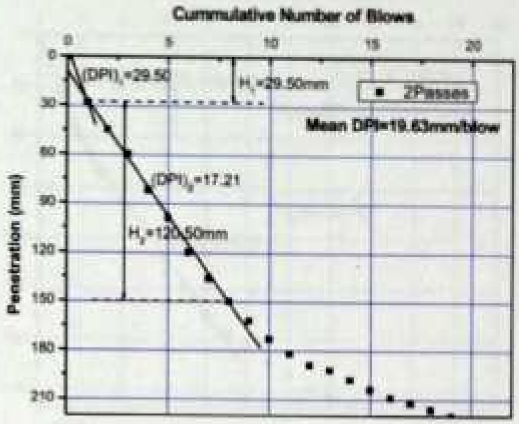


Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering

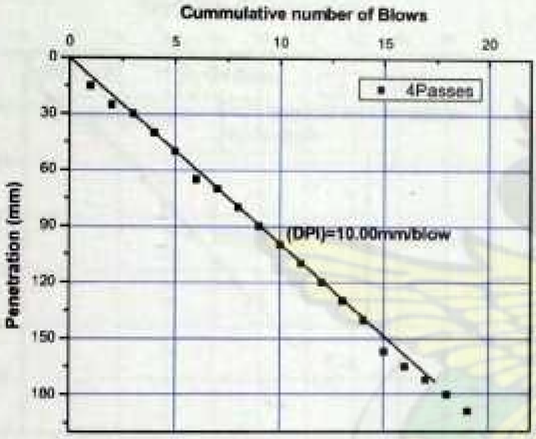
2. Test No. S1T2



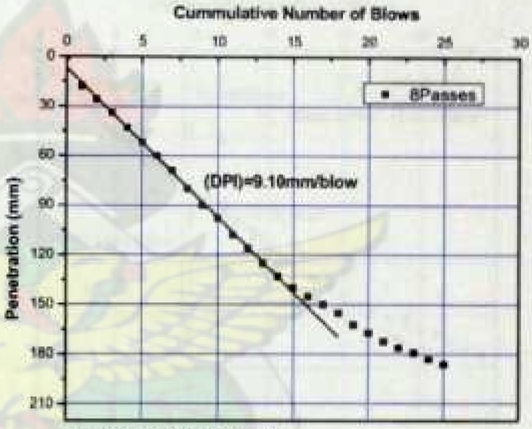
DCP test result on Test 2



DCP test result on Test 2

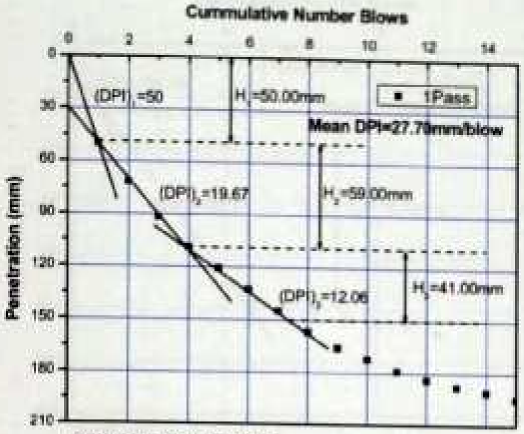


DCP test result on Test 2

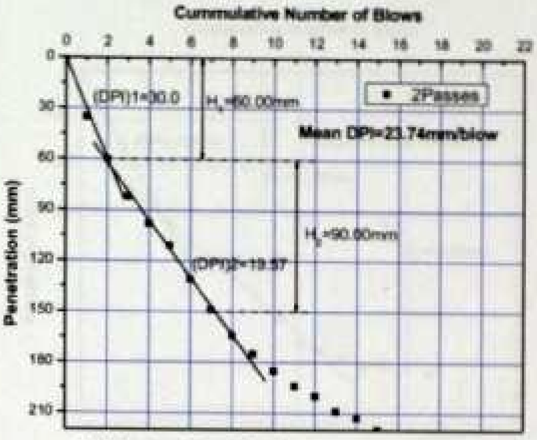


DCP test result on Test 2

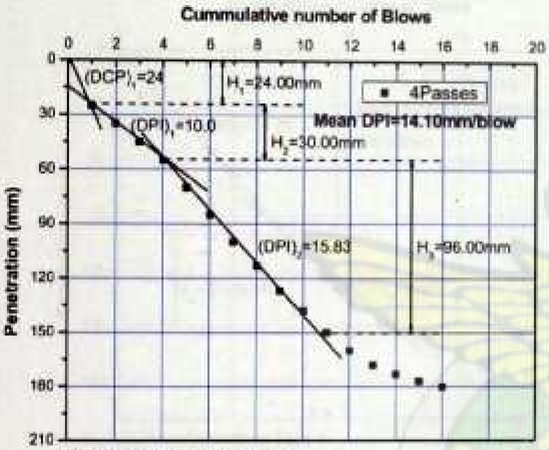
3. Test No. S2T1



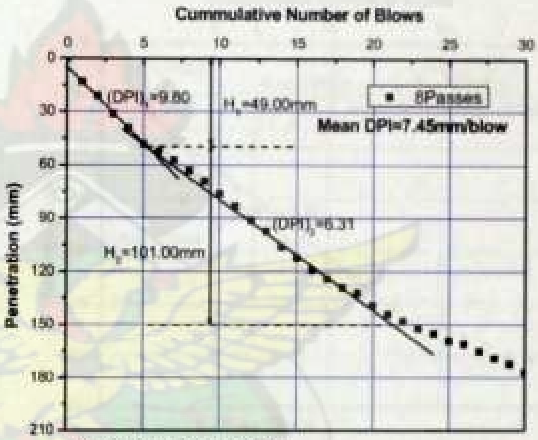
DCP test result on Test 3



DCP test result on Test 3

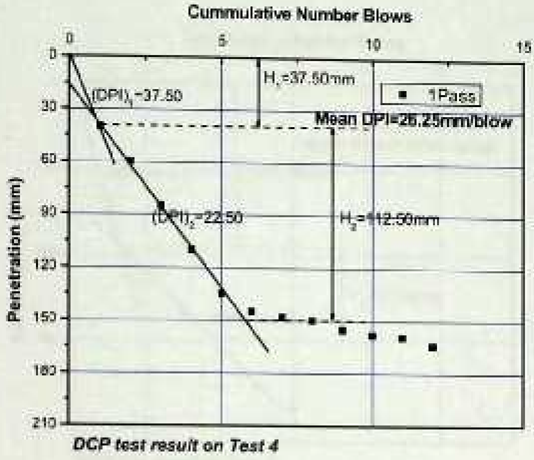


DCP test result on Test 3

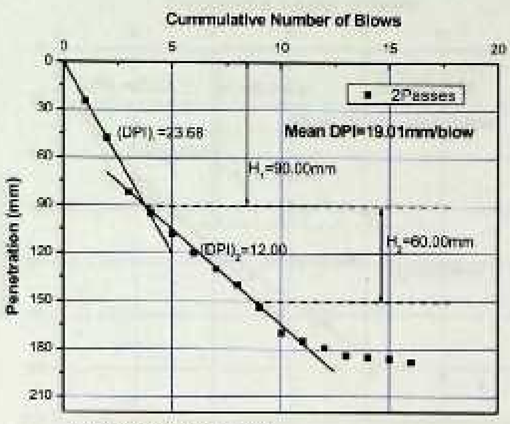


DCP test result on Test 3

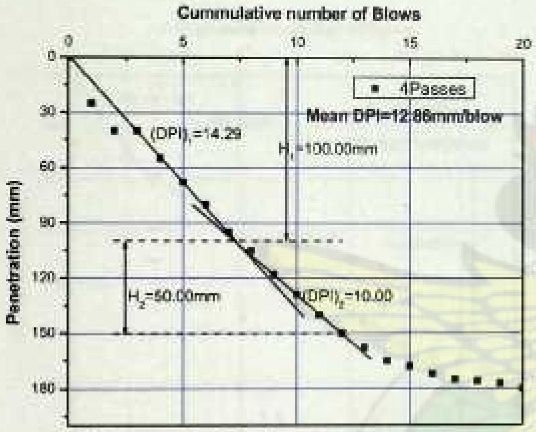
4. Test No. S2T2



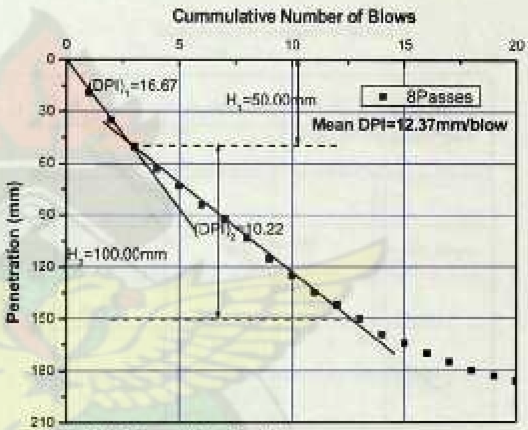
DCP test result on Test 4



DCP test result on Test 4



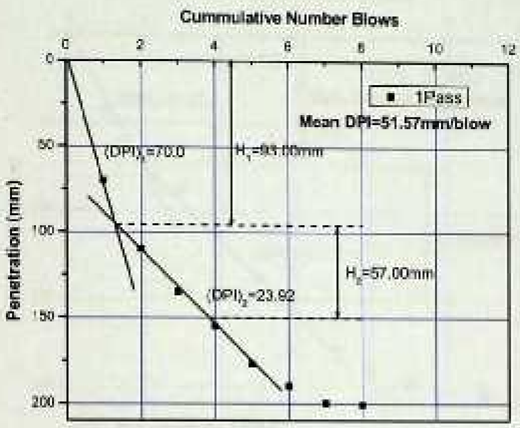
DCP test result on Test 4



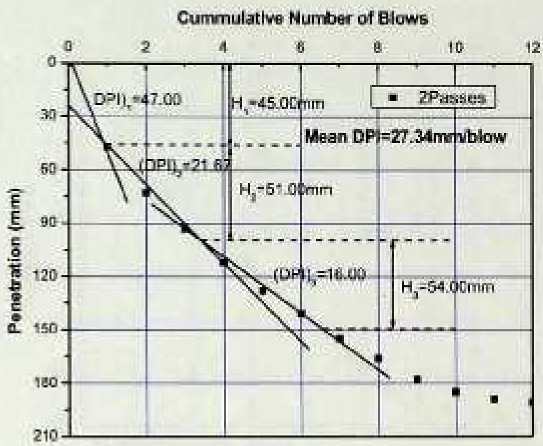
DCP test result on Test 4

Felix Bakobie, PG94342-06
MSc. Road & Transport Engineering

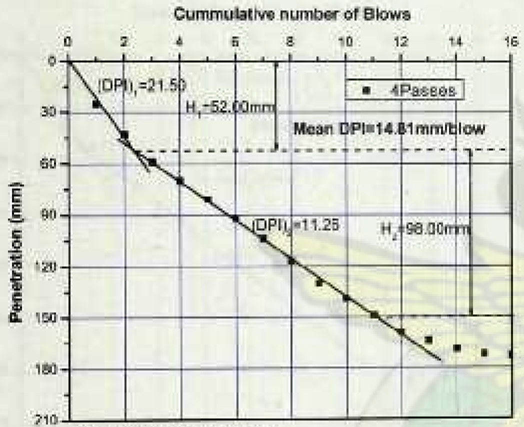
5. Test No. S3T1



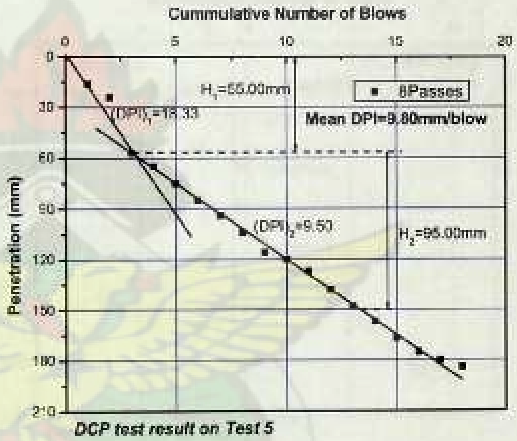
DCP test result on Test 5



DCP test result on Test 5

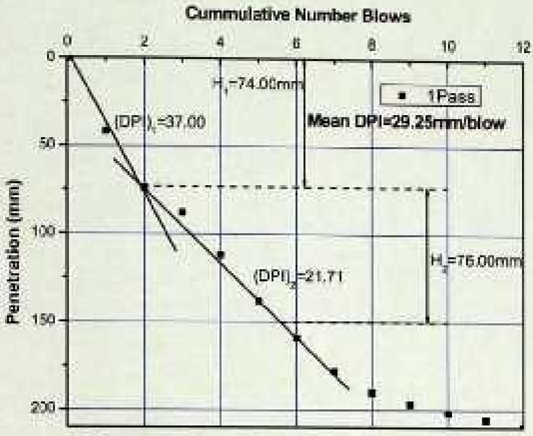


DCP test result on Test 5

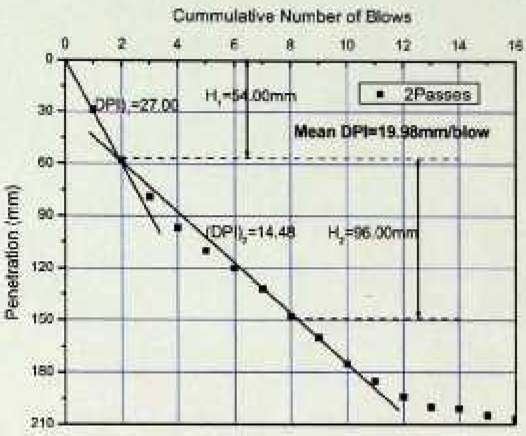


DCP test result on Test 5

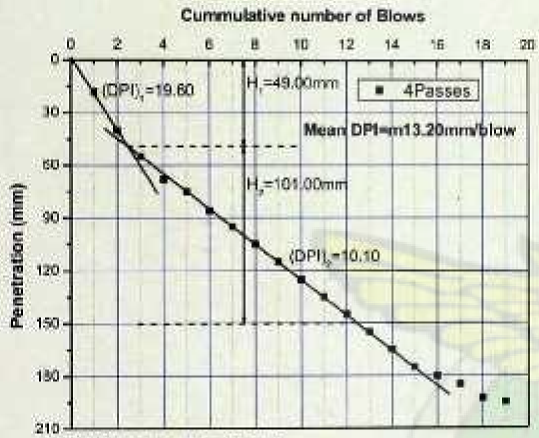
Test No. S3T2



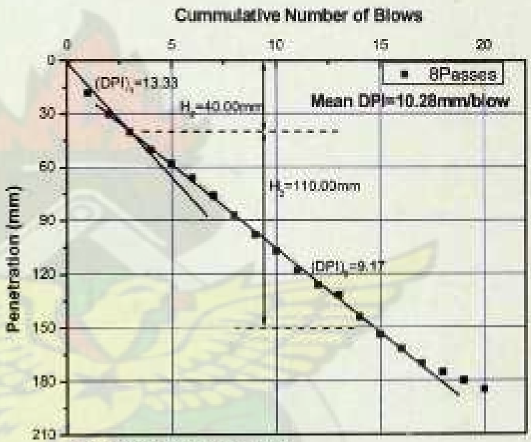
DCP test result on Test 6



DCP test result on Test 6



DCP test result on Test 6



DCP test result on Test 6