ADDIS ABABA SSCIENCE AND TECHNOLOGY UNIVERSIRTY

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COMPARISION OF CORRELATIONS DEVELOPED IN ETHIOPIA AND TRL, OVERSEAS ROAD NOTE 8 BETWEEN DCP AND CBR FOR LOCALLY USED SUBGRADE MATERIALS

By

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Meng project

Submitted to Addis Ababa Science and Technology University in partial fulfilment of the requirement for the degree of Master of Engineering in Road and Transport Engineering

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APPROVAL PAGE

This **Meng** project entitled with “comparison of Correlations developed in Ethiopia and TRL, overseas road note 8 between DCP and CBR for locally used subgrade materials” has been approved by the following examiners in partial fulfilment of the requirement for the degree of Master of Engineering **Meng** in **Road and Transport Engineering**

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ABSTRACT

California bearing ratio is the parameter used in determining strength of subgrade materials in pavement design. But it is time taking and expensive method; to solve this situation many researchers find better way of finding strength of the subgrade material representing CBR. From this prediction of CBR value from DCP has been found good alternative. Dynamic cone penetration test method is very quick, economical and easy way of subgrade and sub-base field test instrument. DCP is field testing method is used to evaluate the thickness and bearing capacity of sub-base and subgrade of pavement. Many correlations have been found to correlate CBR and DCP test methods to get better and accurate estimated value.

Now a day Ethiopian researchers have found correlation for local soils in Ethiopia (Ytagesu Desalegn 2012, Gebremariam G. feleke). The correlation developed by ytagesu shows better than TRL. Ytagesu has recommended that correlations developed in his study the test conducted at in-situ density and moisture content rather than soaked CBR. Hence, it may not be employed directly for design purpose unless the DCP be made when the soil is at its worst condition. Therefore, in order to use this correlation for design and/or analysis directly it is recommended that future research on the strength reduction factor should be conducted. In addition he recommended that his research has been done on specific one project; so it is better to check at several locations of the country.

This project was carried out to compare correlation between DCP with CBR values that best suit the type of soils in Ethiopia rather than TRL. Several laboratory tests from Adama-Awash Expressway road project have been selected from lab and field test data's from Beza consulting Engineers P.L.C (designer of the project). From the tests Atterberg limits, gradation, lab CBR and DCP data were selected. Based on this laboratory and field test results analyses were carried out using correlation developed by Ytagesu Desalegn (log (CBR) = 2.954 -1.496log (DCPI) with R^2=0.943), G/mariam G. feleke (log10SCBR=2.015-0.906log10DCPI (R^2=0.93)) for soaked fine grained soil and TRL (log (CBR) = 2.48 – 1.057log (DCPI)) and compare and check the applicability locally developed correlation. Percentage difference prediction CBR from lab CBR and scatter plot methods were used for comparision. From the analysis results and comparision, it is observed the prediction found by Ytagesu Desalegn's correlation shows good and near to lab test CBR values.

LIST OF ABBREVIATIONS

1. AASHTO, American Association of State Highway and Transportation Officials
2. BC, Blow count
3. CBR, California Bearing Ratio
4. DP, depth penetration
5. DCP, Dynamic Cone Penetration
6. DCPI, Dynamic Cone Penetration Index
7. DCPT, Dynamic Cone Penetration Test
8. OMC, Optimum Moisture Content
9. MDD, Maximum Dry Density
10. LL, Liquid Limit
11. PL, Plastic Limit
12. PI, Plasticity Index
13. TRL Transport Research Laboratory
14. Km, Kilometer
15. SN, serial number
16. CPT Cone Penetration Test
17. m, meter
18. mm, millimeter
19. cm, Centimeter
20. R^2, Coefficient of determination
21. N, Newton
22. KN, Kilo newton
23. MPa Mega Pascal
24. Kg Kilogram

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

In pavement design evaluation of strength of subgrade or foundation of road pavement is one primary target. California bearing ratio is the parameter used for measuring the quality or strength of this subgrade or other unbound material.

The California Bearing Ratio (CBR) test was developed by the California State Highways Department in the 1930's. It is in essence a simple penetration test developed to evaluate the strength of road sub grades or soil below the pavement and makes no attempt to determine any of the standard soil properties such as density. It is merely a value and it is integral to the process of road design. It is however, by far the most commonly used in Pavement Design.

Dynamic cone penetration test (DCP) is field test instrument designed to provide quick and economical measure of the in-situ bearing capacity of mostly/commonly of subgrade material.

DCP has been intended to alleviate many of the deficiencies of systems that are manually pushed into soil or paving materials. The device is relatively simple in design and operation, and operator variability is reduced and thus correlations with strength parameters are more accurate. The DCP consists of a steel rod with a steel cone attached to one end driven into the pavement structure or sub grade using a sliding hammer.

DCP testing is conducted in which the number of blows to achieve mostly 100mm of penetration was counted for this project. Alternatively, the depth of penetration may be measured after each blow when extremely soft materials are encountered. In either case, the output of the DCP test is a penetration rate, expressed in mm per blow.

In Ethiopia construction and design sector, mostly in road construction, the use of dynamic cone penetration is limited to few design offices. This is due to the absence of developed design charts which correlate DCP and CBR test results for Ethiopian soils. {1}

Thus, due to the relatively fast and easy use of DCP test the development of correlations between CBR and DCP test for locally available sub grade materials can reduce cost and time required for design and construction.

Besides, commonly used correlation used by Ethiopian road engineers are not developed based on the test made on local soil, it may either underestimate or overestimate the soil strength. In either case, it may have a negative impact on the economy of the country in general and on the construction industry in particular. However, currently some correlations are developed by

Ethiopian researchers namely ytagesu desalegn AAIT thesis 2012, Gebremariam G. Feleke Mekelle University. DCP and CBR Correlation developed by Ytagesu shows better than TRL, overseas road note 8, correlation which is commonly used in Ethiopia currently.

1.2 Statement of the Problem

California Bearing Ratio (CBR) test is most widely used for analysis and design of pavement layers. CBR is basic parameter in determining strength of subgrade and is crucial for pavement design. However, California Bearing Ratio test is expensive, relatively time taking. There is much interest in finding quick, cheap test methods to carry out the required design and analysis efficiently with short time.

Dynamic cone penetration (DCP), being light and portable offers an attractive means of determining in situ soil strength at a comparative speed and ease of operation and its higher repeatability from CBR, various correlations have been developed by different researchers from samples of their locality. Hence, adopting those developed correlations without adjustment for locally available sub grade soils leads misinterpretation of the local soil behavior.

Correlations developed between DCP and CBR for locally used sub grade materials to enable the pavement/material Engineer or road designers to use the empirical curves developed for CBR to determine the thickness of pavement and its component layers and to verify the adequacy of the existing pavement layer easily and promptly is desired.

There are number of correlations developed by Ytagesu Desalegn AAIT thesis 2012, Gebremariam G.Feleke Mekele University for local subgrade materials. The correlation developed by Ytagesu shows better estimation of CBR than TRL, overseas road note 8 which is commonly used by Ethiopian pavement designers currently. From this we can understand that having local correlation is better than using correlations developed in other location for precise prediction of CBR using DCP test.

Therefore, bearing in mind the above considerations it is necessary to compare and check the applicability of the correlations developed in the country with the common and currently used correlation which is TRL, overseas road note 8 before using for design purpose.

1.3 Objectives

The general objective of this project is to check and compare the accuracy of correlation developed in Ethiopia by ytagesu desalegn AAIT thesis 2012 and Gebrameraiam G. Feleke with TRL, overseas road note 8 between CBR and DCP of subgrade soil.

The specific objectives are:-

1. Compare the locally developed correlation with TRL, overseas road note 8 between DCP and CBR for locally used subgrade materials and suggest the best correlation.
2. Check if the correlation developed by Ytagesu Desalegn is applicable for saturated or partially saturated condition of DCP test with soaked CBR laboratory test.

1.4 Methodology

Literatures regarding Dynamic Cone penetration (DCP) and California bearing ratio (CBR) was studied. Published correlations that relate the CBR values with Dynamic cone penetration was reviewed.

Representative sample test results were collected from Beza consulting Engineers; from Adama-Awash Expressway. These sample test result were selected those; which are conducted their DCP test on saturated or partially saturated condition; so the result much with soaked CBR test results.

The collected DCP data for the analysis were substituted into correlations to find the estimated CBR values. The estimated CBR values from the correlations were compared with the CBR values obtained from the laboratory. Comparison of the results are reported and discussed in the study to assess the suitability and accuracy of the locally developed correlation for Ethiopia.

Finally Conclusions and recommendations have done.

Study area

The data for the study were collected from Adama-Awash expressway. Since Adama-Awash Express way road project was conducted at worst (saturated or partially saturated) condition during July-August, 2014 by Beza consulting Engineers P.L.C. The correlation developed by Ytagesu Desalegn works either dry DCP with un-soaked CBR test or at saturated/wet DCP test with four days soaked CBR value. In addition G/Mariam G. Feleke's correlation developed on soaked CBR is used for this project. Based on this consideration several laboratory tests and field tests on Adama-Awash road project were collected.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Dynamic Cone Penetration

When required to assess the strength of a pavement or to design improvement works, the pavement engineer needs to know as much as possible about the thicknesses of the existing pavement layers and their condition. In some cases the quickest and easiest way to do this is to inspect the design to which the pavement was originally built and perhaps also the as-built records made during construction. However, designs indicate only an intended construction and as-built records are often only indicative of the construction work carried out. Furthermore, both designs and as-built records give no information as to what has happened to the pavement since construction and the condition it is currently in. To give useful information, it is therefore necessary to investigate the current pavement condition using some form of destructive or nondestructive testing.

The usual method of destructive testing is to dig test pits at suitable intervals along the road. These are very useful as pavement thicknesses can be measured and sample can be easily taken for laboratory testing. However, test pits are expensive to dig and reinstate and are rarely dug at intervals of less than 2-3 kilometers.

The Dynamic Cone Penetrometer is an efficient way of testing pavement at more frequent intervals. Tests using the DCP generate data which can be analyzed to produce accurate information on in situ pavement layer thicknesses and strengths. Tests can be carried out very rapidly and test sites can be repaired extremely easily. The DCP can therefore give information of sufficient quality and quantity to allow the pavement strength to be estimated and improvement works designed. Results from DCP tests can also be used to locate test pits in the most suitable positions. [7]

The development of DCP was in response to the need for a simple and rapid device for the characterization of sub grade soils due to its economy and simplicity; better understanding of the DCPT results can reduce significantly the effort and cost involved in the evaluation of pavement and sub grade soils. The Dynamic Cone Penetrometer has been increasingly used in many parts of the world in soil or sub grade, granular material, and lightly stabilized soils through its correlation with California Bearing Ratio.

The basic design of the Dynamic Cone Penetration has been relatively unchanged since its inception in the 1950s. The mass of the falling weight has been altered several times. The cone tip has also undergone numerous revisions to its basic design.

Development of the hand-held DCP is credited to Scala of Australia in the mid- 1950's. Pavement design procedures in Australia then did not specifically require in-situ strength tests of the sub grade soils because of the time and complexity of available test methods. The device Scala developed included a 9.1-kg drop hammer falling a distance of 508 mm. A 15.9 mm diameter rod calibrated in 50.8 mm increments was used to determine the penetration. The configuration used a 30 degree included angle cone tip. Scala conducted tests correlating CBR with DCP data and proposed a pavement design procedure based on this correlation. Use of this DCP device was adopted by the Country Roads Board, Victoria, and gained widespread acceptance.

The next generation of DCP equipment was developed by Van Vuuren from South Africa. Basically it was similar to the DCP apparatus developed by Scala except the weight of the drop hammer was changed to 10 kg and the drop height was changed to 383.5 mm. The shaft diameter measured 16 mm while the apex angle remained at 30 degrees.

Van Vuuren concluded that DCP is suited for use with soils having CBR values of 1to 50. The present version of the DCP used in this road project was developed by Kleyn. Van Vuuren's basic design was utilized in Kleyn's work; however, the hammer weight was reduced to 8 kg and the height of the drop was increased to 576 mm. Kleyn studied two cone angle configurations of 30 degrees and 60 degrees. The cone angle utilized by the consultant in this project road was based on the 60 degree included angle. More recently, the automated dynamic cone Penetrometer has been suggested to automate the operation, data collection and analysis procedures. [10]

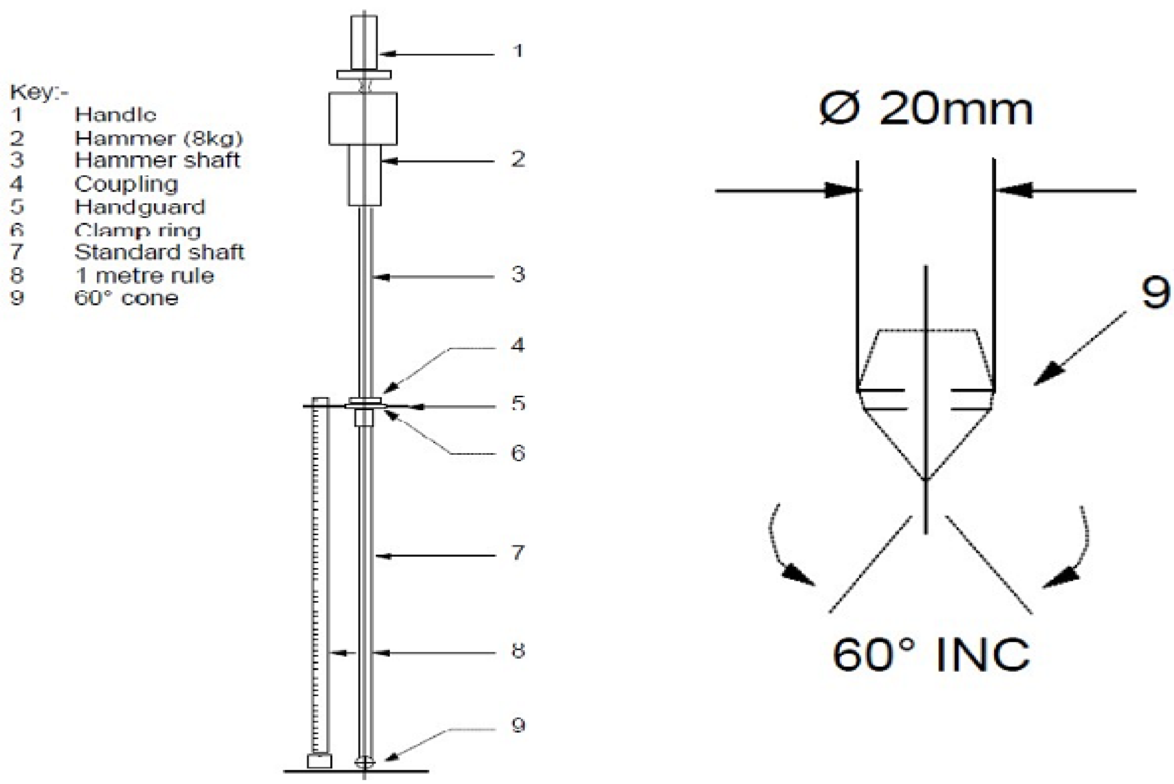


Figure2.1: Components of dynamic cone penetration test equipment

As shown in the figure above, the DCP consists of upper and lower shafts. The upper shaft has 8 kg drop hammer with a 575 mm drop height and is attached to the lower shaft through the anvil. The lower shaft contains an anvil and a cone attached at the end of the shaft. The cone is replaceable and has a 60 degree cone angle. As a reading device, an additional rod is used as an attachment to the lower shaft with marks at every 5.1 mm.

In order to run the DCPT three operators, two laborers and one supervisor are required. The supervisor controls the reading and recording of the results, whilst the two laborers alternate between holding the apparatus vertical and operating the hammer. The first step of the test is to put the cone tip on the testing surface. The lower shaft containing the cone moves independently from the reading rod sitting on the testing surface throughout the test. The initial reading is not usually equal to 0 due to the disturbed loose state of the ground surface and the self-weight of the testing equipment. The value of the initial reading is counted as initial penetration corresponding to blow 0.

Figure 2.2 shows the penetration result from the first drop of the hammer. Hammer blows are repeated and the penetration depth is measured for each hammer drop. This process is continued until a desired penetration depth is reached. DCPT results consist of number of blow counts versus penetration depth. Since the recorded blow counts are cumulative values, results of DCPT in general are given as incremental values defined as follows,

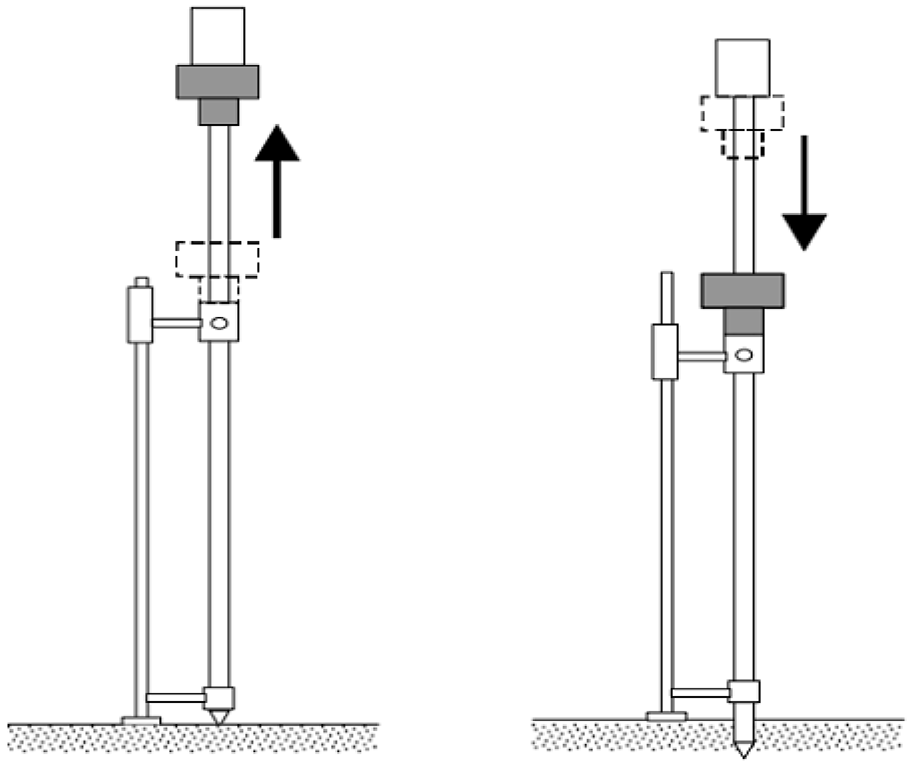
$$PI = \frac{\text{change in Dp}}{\text{change in BC}}$$

Where; PI=penetration index

DP=penetration depth

BC=blow count with corresponding to penetration depth

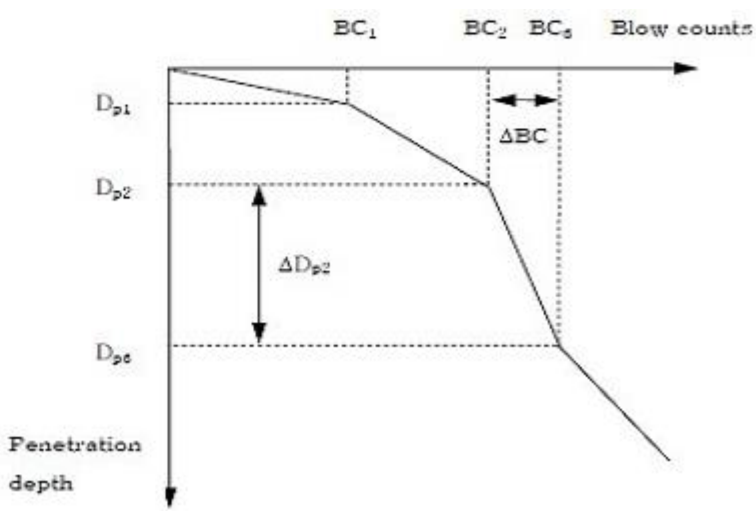
The DCP results, when plotted, describes the number of blows to reach a certain depth affording an instantaneous visual illustration of in-situ material strength (Fig 2.3). The slope of the curve at any point expressed in terms of mm/blow is called the dynamic cone penetration index (DCPI) which represents the resistance offered by the material; the lower the DCPI the stiffer the material, and vice versa.[9]



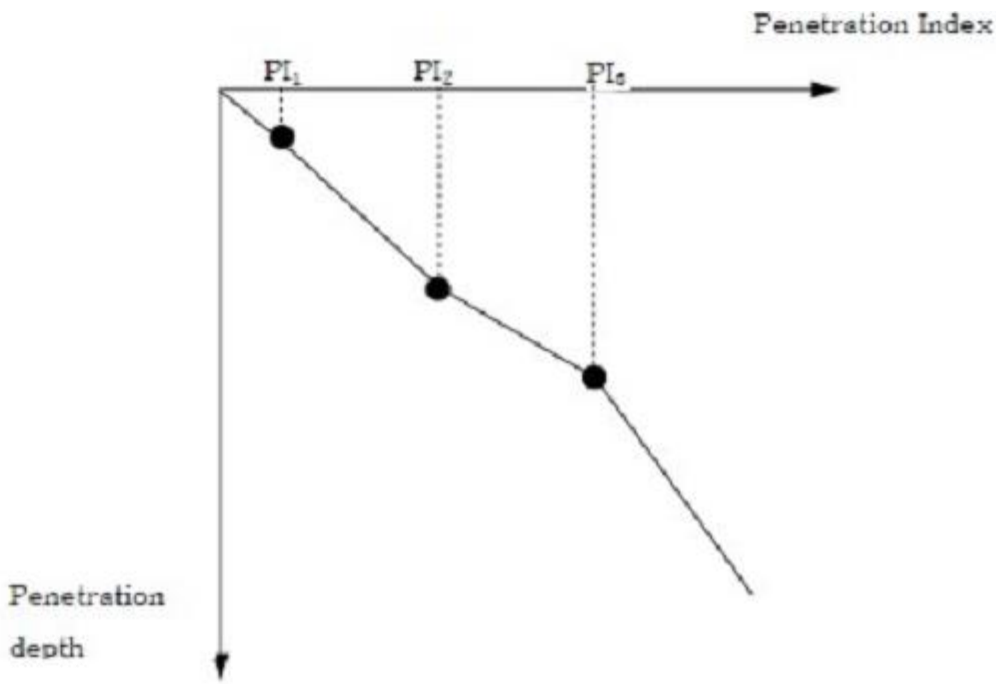
a. before hammer dropped

b. after hammer dropped

Figure 2.2 Dynamic cone penetration tests



a) blow count vs. penetration depth



b) PI vs. penetration depth

Figure2.3 typical DCP results

The DCP cannot penetrate some strong surface and base materials such as hot mix asphalt or cement treated bases. These layers must be removed before the test can begin and their strength assessed using different criteria. Thus, if the cone does not penetrate 25 millimeters after 10 blows with the 8kg hammer (20 blows with the 5.05 kg hammer), the test should be stopped. If this firm material is a stabilized soil or high-strength aggregate base layer, it should be cored or drilled with an auger to allow access of the DCP cone to underlying layers. The DCP test can then proceed through the access hole after the depth of the material layer has been recorded. The material layer is assigned a CBR value of 100+. However, if a core or auger drill is not available, the 8kg DCP hammer can normally be used to drive the lower rod and cone through the firm material. If the cone penetration was stopped by a large rock or other object, the DCP should be extracted and another attempt made within a few meter of the initial test. The DCP is generally not suitable for soils having significant amounts of aggregate greater than a 2-inch-sieve size.

Besides, if repeated DCP tests are conducted longitudinally, a longitudinal picture of the selected section can also be developed which allows delineation of the area into homogeneous sections. [7]

2.2 California Bearing Ratios (CBR)

California bearing ratio (CBR) is the force required to penetrate a piston or plunger of 1936mm^{2}cross section in to soil in a mold at a rate of 1.25mm/min to that required for similar penetration in to a standard sample of compacted crushed rock or lime.

The CBR is a comparative measure of the shearing resistance of a soil. The CBR is the Mega Pascal required forcing a piston in to the soil, a certain depth expressed as percentage of the load required to force the piston the same depth in to a standard sample of crushed rock, usually depths of 2.5mmor 5mm are used penetration loads for bearing value.

The California Bearing Ratio test was developed by the California State Highways Department in the 1930's. It is in essence a simple penetration test developed to evaluate the strength of road sub grades (soil below the pavement) and makes no attempt to determine any of the standard soil properties such as density. It is merely a value and it is integral to the process of road design. It is however by far the most commonly used in Pavement Design. The CBR test should be used with soil at the calculated equilibrium moisture content. Almost all design charts for the road foundations are based on the CBR value of the sub grade materials. It is also used as a means of classifying the suitability of a soil for use as sub grade or base course material in highway construction. During World War II, the US corps of engineers adopted the test for use in airfield construction [5].

The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. The test yields the bearing ratio number, but from previous statement, it is evident that this number is not a constant for a given soil but applies only for the tested state of the soil. The CBR number is obtained as the ratio of the unit load (KN/m^2) required affecting a certain depth of penetration of the penetration piston in to a compacted specimen of soil at some water content and density to the standard unit load required to obtain the same depth of penetration on a standard sample of crushed stone. It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. In equation form

$$\text{CBR}(\%) = \frac{test\ unit\ load}{standard\ load} * 100$$

The CBR values are usually calculated for penetration of 2.54 mm and 5.04 mm. Generally the CBR value at 2.54 mm will be greater that at 5.04 mm and in such a case/the former shall be taken as CBR for design purpose. If CBR for 5.04 mm exceeds that for 2.54 mm, the test should be repeated. If identical results follow, the CBR corresponding to 5.04 mm penetration should be taken for design. [5]

The CBR value for a given soil will depend upon its density, molding moisture content, and moisture content after soaking. The result of a CBR test also depends on the resistance to the penetration of the piston. Therefore, the CBR indirectly estimates the shear strength of the material being tested. [6]

Relative ratings of supporting strengths as a function of CBR values are given in Table below

Table 2.1: Relative CBR values for sub base and sub grade soils [4]

CBR	Material	Rating
>80	Sub base	Excellent
50-80	Sub base	Very good
30-50	Sub base	Good
20-30	Sub grade	Very good
10-20	Sub grade	Fair-good
5-10	Sub grade	Poor-Fair
<5	Sub grade	Very poor

Clay soils have a CBR value of less than or equal to 6, Silty and sandy soils have CBR value of 6 to 8. The best soils for road-building purposes are the sands and gravels whose CBR values normally exceed 10. [4]

2.2.1 Laboratory CBR Test

The test is carried out using the procedure outlined in AASHTO T193- 63, CBR tests are usually made on test specimens at the optimum moisture value for the soil as determined using the standard (or modified) compaction test.

Three molds of soil are often compacted in modified method with 10blows, 30blows and 65 blows each five layer and soaked for a period of 96 hours with a surcharge approximately equal to the pavement weight used in the field but in no case the surcharge weight is less than 45N. Swell readings are taken during this period at arbitrary selected times. At the end of the soaking period, the CBR penetration test is made to obtain a CBR value for the soil in saturated condition. Penetration tests for the CBR values, a surcharge of the same magnitude as for the swell test is placed on the soil sample. The test on soaked gives information concerning the expected soil expansion beneath the pavement when the soil becomes saturated.

Penetration testing is accomplished in a CBR machine using a strain rate of 1.27mm/min. reading of load vs. penetration are taken at each 0.5mm of penetration to include the value of 5.08 mm, and then at 2.54 mm increment thereafter until the total penetration is 12.7mm. Typical test results are illustrated in Figure 2.4. It sometimes happens that the plunger is still not perfectly bedded in the specimen and, because of this and other factors, a load-penetration curve with a shape similar to that of the curve for Test -2 in Figure 2.4 may be obtained instead of the more normal shaped curve illustrated by the curve for Test 1. When this happens, the curve must be corrected by drawing a tangent at the point of greatest slope and then transposing the axis of load so that zero penetration is taken as the point where the tangent cuts the axis of penetration.

The corrected load-penetration curve is the tangent from the new origin to the point of tangency. The typical CBR test results are shown in table 2.4 below.

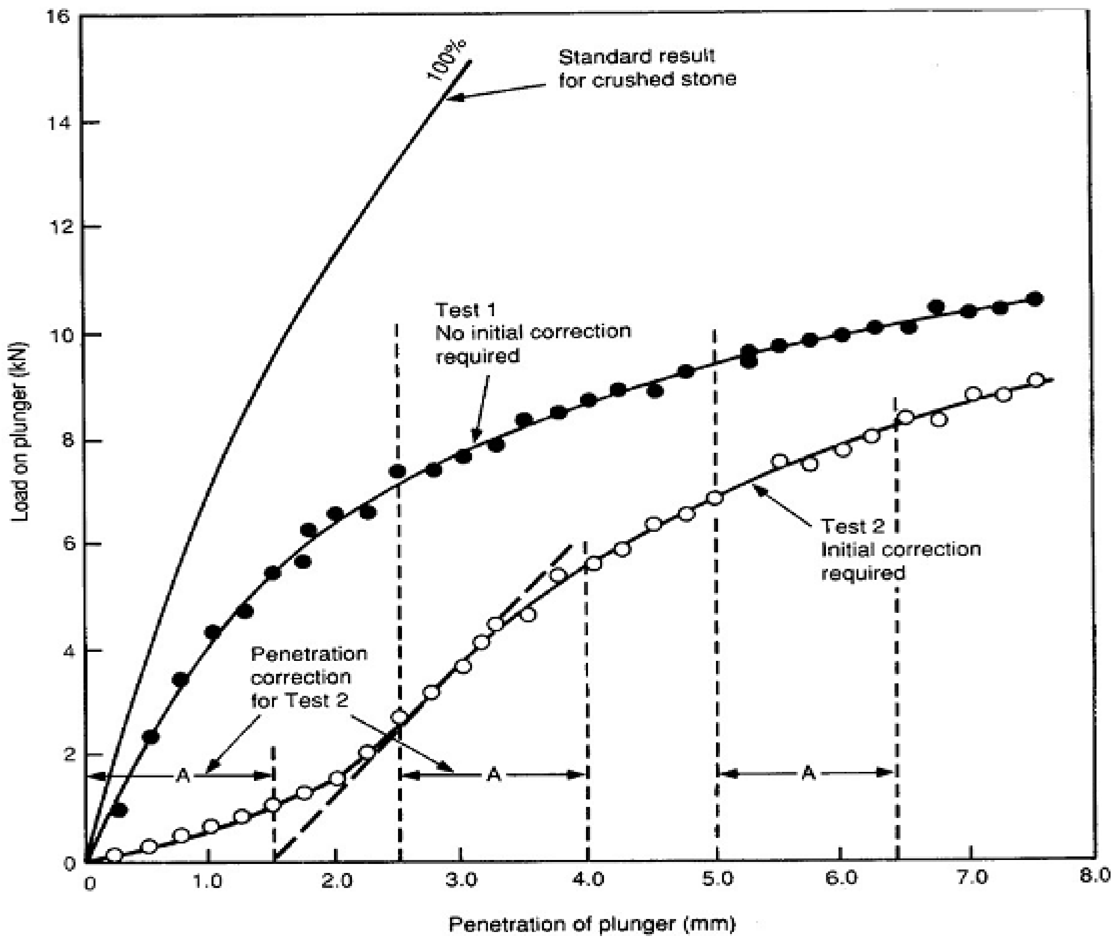


Fig 2.4 Typical CBR Test Result

The CBR values is then determined by reading from the curve the load that causes a penetration of 2.54 mm and 5.08 mm and dividing these values by the standard load 6.9 MPa and 10.3 MPa respectively required producing the same penetration in the standard crushed stone as

$$CBR(\%) = \frac{\text{measured force}}{\text{standard force}} * 100$$

The two values are then compared; generally the CBR value at 2.54 mm will be greater that at 5.08 mm and in such a case the former shall be taken as CBR for design purpose. If CBR for 5.08mm exceeds that for 2.54mm, the test should be repeated. If identical results follow, the CBR corresponding to 5.08 mm penetration should be taken for design.

2.2.2 Application of CBR Value

Pavement design charts are published in which one enters a chart with the CBR or Structural Number together with design traffic class and reads directly the thickness of sub base, base-course, and/or flexible pavement thickness based on expected wheel loads .Sometimes the CBR is converted to a sub grade modulus or also using charts before entering the paving design charts using the formula. [8]

California Bearing Ratio mainly used is to evaluate the stiffness modulus and shear strength of sub grade. Generally, the sub grade soil cannot bear the construction and commercial traffic without any distress, therefore; a layer of rigid or flexible pavement is required to be laid on top of the sub grade to carry the traffic load.

Thickness determination of the pavement layer is governed by the strength of sub grade, thus the information on the shear strength of sub grade are required before any pavement design is carried out. These parameters are necessary to determine the thickness of the overlying pavement in order to achieve optimum and economic design. The stiffness modulus and shear strength of sub grade are controlled by soil type, particularly plasticity, degree of remolding, density and effective stress. [1]

Due to the number of factors that make the measurement of shear strength of sub grade complicated, it is necessary to adopt a more simplified test method that can be used as an index test. This is where CBR test come into frame in measurement of sub grade strength. The CBR test is a simple strength test that compares the bearing capacity of a material with that of a well graded standard crushed stone base material. This means that the standard crushed stone material should have a CBR value of 100%. The resistance of the crushed stone under standardized conditions is well established. Therefore, the purpose of a CBR test is to determine the relative resistance of the sub grade material under the same conditions.

The higher the CBR value means that the sub grade is strong. Accordingly, the design of pavement thickness can be reduced in conjunction with the stronger sub grade. Thus, it will give a considerable cost saving in term of construction besides an optimum design. However, if the CBR value of sub grade indicates that the sub grade is weak i.e. low reading of CBR reading, the thickness of pavement shall be increased in order to spread the traffic load over a greater area of the weak sub grade. This is important to prevent the weak sub grade material to deform excessively and causing the road pavement fail. [3]

An alternative and easiest method to overcome this weak sub grade before the construction of pavement is by replacing the soil with adequately compacted soil in layers. Otherwise, the sub grade can be stabilized by lime, cement, or the use of a geotextile to produce a stable platform for construction equipment and traffic load in long term or realigning is the other option. It should also be noted that the change in pavement thickness needed to carry a given traffic load is not directly proportional to the change in CBR value of the sub grade soil. For example, a one-unit change in CBR from 5 to 4 requires a greater increase in pavement thickness than does a one-unit change in CBR from 10 to 9. [4] The CBR test is used exclusively in conjunction with pavement design methods and the method of sample preparation and testing must relate to the assumptions made in the design method as well as the assumed site conditions. For instance, the design may assume that soaked CBR values are always used, regardless of actual site conditions. [3]

2.3 CBR Correlation with DCP

Researchers have been conducted to develop empirical relationships between Dynamic cone penetration and California baring ratio measurements. Now a day local (in Ethiopia) studies are also coming with different correlation empirical relationships to get more accurate correlations of the two parameters. Based on the results of past studies, many of the relationships between DCP and CBR have the following form. [6]

$$\text{Log (CBR)} = a + b \log \text{(DCPI)}$$

Where DCPI=dynamic cone penetration index (mm/blow)

a and b=constants

Table 2.2: Relationships developed between CBR and DCP by different authors [1, 2, and 11]

Correlation equations	Material tested	reference
Log(CBR)=2.954-1.496log(DCPI), with (R^2=0.943)	Clay soil, un-soaked	Ytagesu (2012)
log10SCBR=2.015-0.906log10DCPI (R^2=0.93)	Fine grain soil soaked	Gebremariam G. Feleke Mekele University
log10SCBR=2.197-0.852log10DCPI with (R^2=0.836)	Coarse grain, soaked	
Log(CBR)=2.81-1.32log(DCPI)	All soils	Hirson (1989)
Log(CBR)=2.20-1.071log$(DCPI)^{1.5}$	All soils	Livneh (1987)
loge(CBR) = 6.15 – 1.248log(DN)	PI > 6 materials	Sampson
loge(CBR) = 5.93 – 1.1 loge(DN)	Plastic Materials	
loge(CBR) = 5.7 – 0.82 loge(DN)	PI < 6 materials	
loge(CBR) = 5.86 – 0.69 log(DN)	PI =0 materials	
log CBR = 2.465-1.12log(DCPI) or CBR = 292/ $DCPI^{1.12}$	All soils	U.S. army corps of engineers (1992)
Log(CBR) =2.555 –1.145 log	All soils	Smith and Pratt(30^o cone)
Log(CBR)=2.48-1.057log(DCPI)	For all soil type	TRL

Strengthen that regression analyses result with a coefficient of determination R2 = 0.705, or 70.5%, is substantial. The regression model is working very well. [12]

CHAPTER THREE

3. DATA COLLECTION

3.1 Source of Data

The data for the study were used secondary data and collected from Beza consulting Engineers P.L.C field and laboratory tests from the road project of Adama-Awash Expressway (60+000-72+5000Km) along the road.

The project is located in the eastern central part of the Ethiopia in Oromia and Afar Regional State along the road from Adama to Awash. The area is characterized by a seasonal rainfall from June to October. About 17 data on the soil properties and soaked California Bearing Ratio (CBR) conducted laboratory tests were selected. In addition; from laboratory sieve analysis, Atterberg limits, and proctor test results were also selected.

DCP field test row data were also collected from the design consultant. The DCP was used with falling hammer of 8Kg with 576mm falling height. In order to avoid the seasonal variations of the soil properties due to rainfall and other factors, both the laboratory and field tests are conducted on the saturated/partially saturated condition. DCP test has been tested on during July and August 2014 which is rainy season.

The California bearing ration laboratory test were conducted for the project according to AASHTO T 193 method, modified test and socked for 96 hours. Thus, 4.5kg rammer method had been adopted to compact the soil samples in the moulds. The value of lab CBR was obtained at 95% of maximum dry density (MDD).

3.1 Data Selection

The collection of test results were; by considering type of soil which should be clay soil sections and DCP test conditions (wet and moderate). This is because the correlation developed by

Ytagesu Desalegn 2012 works either for un-soaked CBR and dry condition DCP field test or Soaked CBR and saturated/partially saturated DCP test.

The Adama-awash Expressway is designed on new alignment; the tests were done on the natural sub grade soils. Seventeen field (DCP) test data and laboratory tests results were selected from different sections along the route (km 60+000-72+5000).

For each testing location, in addition to the DCP test data and soaked CBR value, particle size distribution (Sieve analysis), plastic limit, liquid limit, plasticity index, and test results were also collected.

Table 3.1 Laboratory and Field test results collected by Beza consulting Engineers P.L.C

SN.	Station (KM)	Particle size Distribution					Atterberg Limits (%)		CLASSIFICATION (AASHTO)	MDD (g/cm^3)	OMC (%)	LAB CBR at 95% MDD	DCPI
		19.0	4.75	2.0	0.425	0.075	LL	PI					
1	60+000 (CL)	100	99	98	94	90	39	12	Grayish clay with few silt soil (A-6)	1.55	22	14	19.3
2	60+500 (CL)	100	98	94	90	76	38	21	Gray clay soil (A-6)	1.45	26	13	21.7
3	61+000 (CL)	100	99	97	93	84	42	13	Light brown clay soil (A-7-6)	1.58	19	11	18.1
4	62+000 (CL)	100	98	96	92	87	40	13	Light grayish clay soil (A-6)	1.45	25	6	26.7
5	63+000 (CL)	100	89	86	83	73	43	14	light grey clay with little silt soil (A-7-6)	1.82	13	17	14.1
6	63+500 (CL)	100	100	100	92	57	41	11	Light grayish cay silt soil (A-7-6)	1.46	26	6	26.5
7	64+000 (CL)	100	97	94	91	87	46	11	Grayish clay soil (A-7-5)	1.39	29	6	32.9
8	64+500 (CL)	100	100	99	97	92	48	13	Grayish clay soil (A-7-5)	1.38	29	14	15.7
9	65+000 (CL)	100	99	89	80	70	45	11	Light grayish clay soil (A-7-5)	1.51	24	13	19.5
10	66+000 (CL)	100	98	96	92	85	51	18	Grayish clay silt soil (A-7-5)	1.43	27	6	26.0
11	66+500 (CL)	100	97	95	89	81	36	16	Light brown clay soil (A-6)	1.55	23	20	11.6
12	67+000 (CL)	100	96	93	88	78	57	35	Light yellowish clay soil (A-7-6)	1.34	23	19	14.3
13	67+500 (CL)	100	94	90	84	77	38	15	Light Yellowish clay with little silt soil (A-6)	1.47	23	13	16.4
14	69+500 (CL)	100	99	99	91	76	40	16	Grayish clay silt soil (A-6)	1.53	22	14	17.0
15	71+000 (CL)	100	97	94	92	87	35	14	Light brown clay silt soil (A-6)	1.36	25	10	19.3
16	71+500 (CL)	100	98	96	91	70	39	18	Light grayish clay with some silt soil (A-6)	1.50	21	21	12.9
17	72+500 (CL)	100	96	93	89	80	46	29	Gray clay soil (A-7-6)	1.24	22	6	26.6

CHAPTER FOUR

4. DATA ANALYSIS

4.1. General

Cumulative of DCP penetration depth and cumulative of blow counts were calculated to plot a scatter graph of summation of penetration depth vs. summation of blow counts. Blow counts were plotted on x-axis and penetration depth on Y-axis. Slopes were determined by making straight lines on the scatter graph. Average slopes were calculated to get DCPI value.

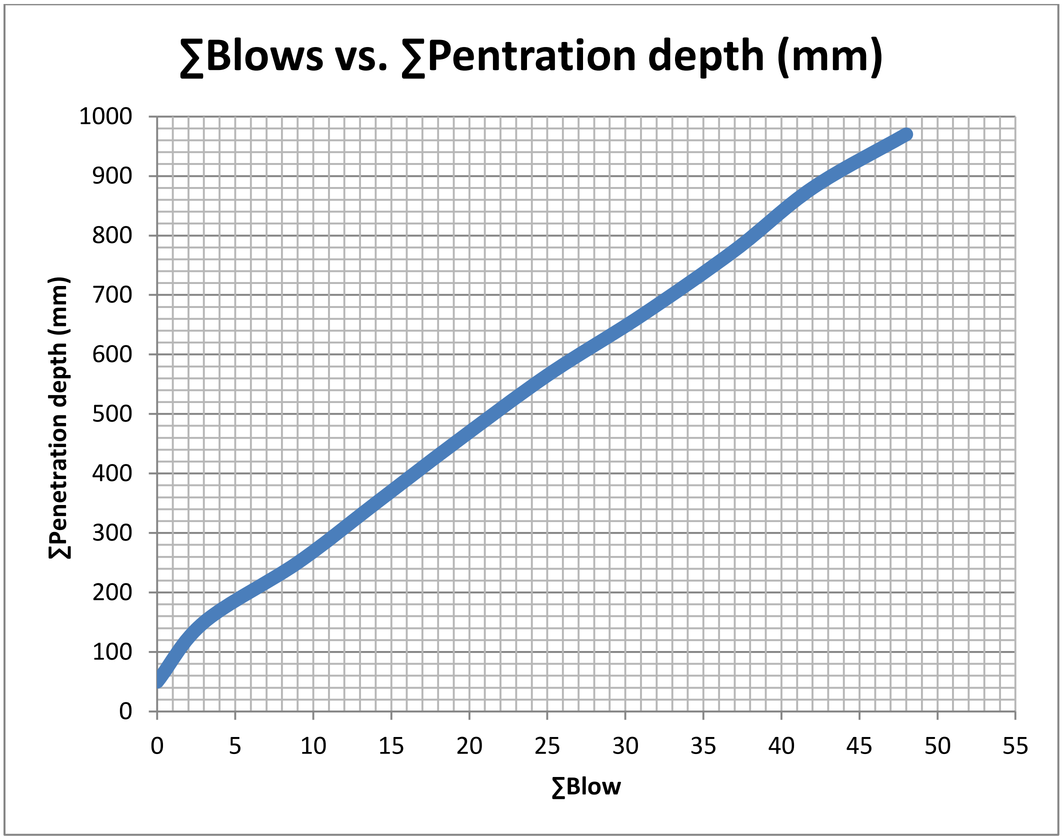
DCPI values were used to determine DCP-CBR from the different correlations used in this project namely Ytagesu Desalegn 2012, (Log CBR=2.954-1.496Log DCPI), G/mariam G. Feleke (log10SCBR=2.015-0.906log10DCPI), TRL, Overseas Road Note 8, Overseas (Log CBR=2.48 -1.057 Log DCPI). To show the actual work procedure one station (72+500Km CL) of DCPI calculation is presented below. The left are presented under annexes.

Table 4.1 calculation of summation of number of blows and summation of penetration depth,

Station 72+500 CL

Station 72+500			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	50
2	3	3	150
3	6	9	250
4	5	14	350
5	5	19	450
6	6	25	565
7	6	31	665
8	6	37	775
9	5	42	880
10	6	48	970

Figure 4.1 Summation of penetration depths vs. summation of blows



From the above scatter plot two straight have been drown and their slopes were calculated as table below. $\text{DCPI} = \frac{change\ in\ penetration}{change\ in\ number\ of\ blows}$

Table 4.2 DCPI calculation for station 72+500km

▲penetration	▲ blow	DCPI
50	0	36
140	2.5	17.29
970	48	
Average		26.6

Therefore the Dynamic cone penetration index (DCPI) for this station is=26.6.

Likewise all DCPI's are calculated same procedure and prediction of CBR was done for each DCPI and summarized in the table below.

Table 4.3 DCPI summary results

SN.	Station (KM)	LAB CBR at 95% MDD	DCPI
1	60+000 (CL)	14	19.3
2	60+500 (CL)	13	21.7
3	61+000 (CL)	11	18.1
4	62+000 (CL)	6	26.7
5	63+000 (CL)	17	14.1
6	63+500 (CL)	6	26.5
7	64+000 (CL)	6	32.9
8	64+500 (CL)	14	15.7
9	65+000 (CL)	13	19.5
10	66+000 (CL)	6	26.0
11	66+500 (CL)	20	11.6
12	67+000 (CL)	19	14.3
13	67+500 (CL)	13	16.4
14	69+500 (CL)	14	17.0
15	71+000 (CL)	10	19.3
16	71+500 (CL)	21	12.9
17	72+500 (CL)	6	26.6

4 .2 Comparisons of Values between the correlation with CBR

After determining the values of each correlation as shown in table 4.4; comparisons have been made between the local correlation (Ytagesu 2012 and G/Mariam G. Feleke) and the most commonly used correlation in our country (TRL, Overseas Road Note 8) CBR values in Table 4.5. From the comparison it is observed that the Ytagesu 2012 correlation yields a lower CBR value than TRL, Overseas Road Note 8 correlation and higher CBR value than correlation by G/Mariam G. Feleke. The laboratory and field test results used for the comparison of the correlations was fine grained soils (clay soil).

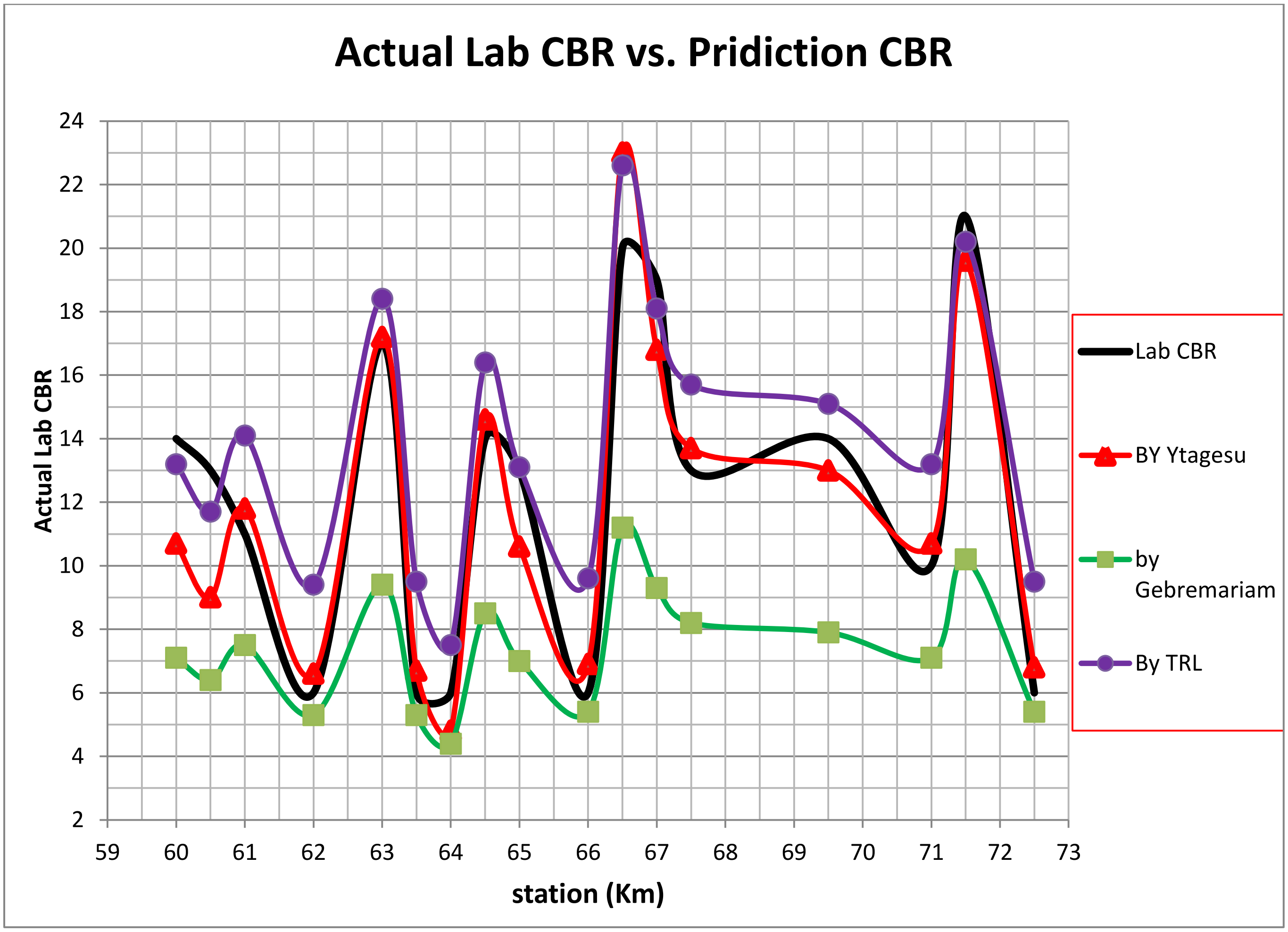
Table 4.4 Lab CBR and DCP-CBR using different correlations

SN.	Station (KM)	**LAB CBR at 95% MDD**	**DCPI**	Ytagesu Desalegn 2012	G/mariam G. Feleke	TRL, OVERSEAS ROAD NOTE 8 , OVERSEAS
				Log CBR=2.954-1.496Log DCPI	log10SCBR=2.015-0.906log10DCPI	Log CBR=2.48 - 1.057 Log DCPI
1	60+000 (CL)	14	19.3	10.7	7.1	13.2
2	60+500 (CL)	13	21.7	9.0	6.4	11.7
3	61+000 (CL)	11	18.1	11.8	7.5	14.1
4	62+000 (CL)	6	26.7	6.6	5.3	9.4
5	63+000 (CL)	17	14.1	17.2	9.4	18.4
6	63+500 (CL)	6	26.5	6.7	5.3	9.5
7	64+000 (CL)	6	32.9	4.8	4.4	7.5
8	64+500 (CL)	14	15.7	14.6	8.5	16.4
9	65+000 (CL)	13	19.5	10.6	7.0	13.1
10	66+000 (CL)	6	26.0	6.9	5.4	9.6
11	66+500 (CL)	20	11.6	23.0	11.2	22.6
12	67+000 (CL)	19	14.3	16.8	9.3	18.1
13	67+500 (CL)	13	16.4	13.7	8.2	15.7
14	69+500 (CL)	14	17.0	13.0	7.9	15.1
15	71+000 (CL)	10	19.3	10.7	7.1	13.2
16	71+500 (CL)	21	12.9	19.6	10.2	20.2
17	72+500 (CL)	6	26.6	6.8	5.4	9.5

Table 4.5 comparisons of laboratory CBR and DCP-CBR using correlations

SN	Station (KM)	LAB CBR at 95% MDD	DCPI	Correlation by Ytagesu Desalegn 2012		Correlation by G/mariam G. Feleke		Correlation by TRL, OVERSEAS ROAD NOTE 8 , OVERSEAS	
				Log CBR=2.954 -1.496Log DCPI	% Difference From Lab CBR	log10SCBR=2.015 -0.906log10DCPI	% Difference From Lab CBR	Log CBR=2.48 -1.057 Log DCPI	% Difference From Lab CBR
1	60+000 (CL)	14	19.3	10.7	23	7.1	49	13.2	6
2	60+500 (CL)	13	21.7	9.0	31	6.4	51	11.7	10
3	61+000 (CL)	11	18.1	11.8	-7	7.5	32	14.1	-28
4	62+000 (CL)	6	26.7	6.6	-10	5.3	12	9.4	-56
5	63+000 (CL)	17	14.1	17.2	-1	9.4	45	18.4	-8
6	63+500 (CL)	6	26.5	6.7	-11	5.3	11	9.5	-58
7	64+000 (CL)	6	32.9	4.8	19	4.4	27	7.5	-25
8	64+500 (CL)	14	15.7	14.6	-4	8.5	39	16.4	-17
9	65+000 (CL)	13	19.5	10.6	15	7.0	44	13.1	-5
10	66+000 (CL)	6	26.0	6.9	-9	5.4	14	9.6	-53
11	66+500 (CL)	20	11.6	23.0	-15	11.2	44	22.6	-13
12	67+000 (CL)	19	14.3	16.8	12	9.3	51	18.1	4
13	67+500 (CL)	13	16.4	13.7	-5	8.2	37	15.7	-21
14	69+500 (CL)	14	17.0	13.0	7	7.9	43	15.1	-8
15	71+000 (CL)	10	19.3	10.7	-7	7.1	29	13.2	-32
16	71+500 (CL)	21	12.9	19.6	7	10.2	51	20.2	4
17	72+500 (CL)	6	26.6	6.8	-12.6	5.4	10.8	9.5	-58.8

Figure 4.2 graphical comparison of actual lab CBR vs. prediction CBR from the correlations.



From the scatter plot shown above prediction by Ytagesu shows near to the actual lab CBR relative to the other two predictions. Prediction by Gebremariam shows much less from the actual CBR as shown from the above graph. Predication by TRL shows better relative to Gebremariam's prediction, however it shows over prediction relative to Ytagesu's prediction.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of comparison showed that the actual CBR values determined by ytagesu results lower percentage difference relative to G/Mariam G. Feleke and TRL, Overseas Road Note 8 relation. The lower percentage difference indicated it is approaching to actual lab CBR value. The percentage differences of found by the correlation developed by G/Mariam G. Feleke shows; it under estimates the DCP-CBR from the lab CBR values. The percentage differences between DCP –CBR from lab DCP by TRL, overseas Road Note 8; shows it overs estimates relative to the other two correlations.

The comparison was also done using scatter plot, Predicted CBR by ytagesu Desalegn best fitted the actual lab CBR relative to predicted by Gebremariam G. feleke and TRL, Overseas Road Note 8.

Therefore; ytagesu’s correlation shows best for prediction over the other two for this specific site.

In addition to the above; from the result it is observed that the correlation also works on DCP-CBR under soaked CBR with DCP-CBR at saturated or partially saturated condition.

Correlations developed locally are better than those developed abroad; this is because due to difference in rain, soil or ground moisture in Ethiopia may not be same in different conditions (dry, partially saturated and saturated).

5.2 Recommendations

1. Further study or research should be done regarding these correlations developed locally for their accuracy of prediction.
2. The data for this independent project were used secondary data; for further study it is better to use primary data. So I recommend that own samples investigation may give better result. May be accurate field DCP tests will be collected by the researcher.
3. This study was done with limited number of data; I recommend to more accurate values it better to use a lot of data for analysis.
4. Correlation developed by ytagesu 2012 shows good result in dry and unsoaked conditions done by his own, and in this project also shows good correlation; so it is better if further investigation to be on dry and saturated condition to check its best applicability of the correlation.

6. REFERENCES

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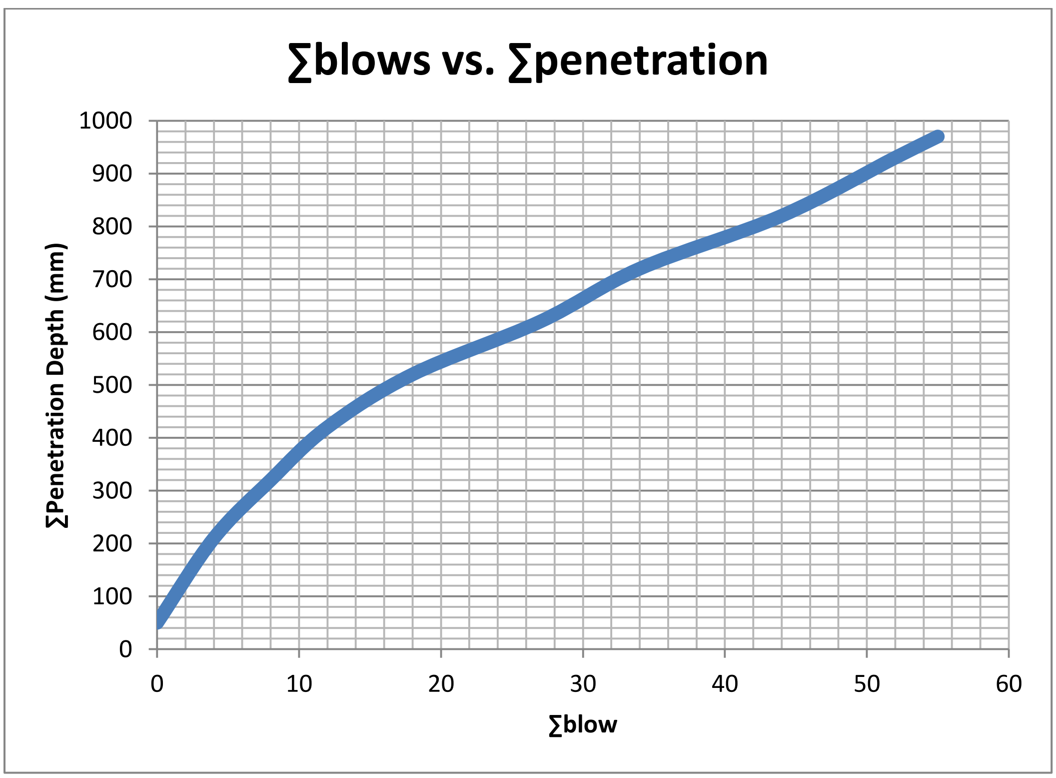
APPENDIXES

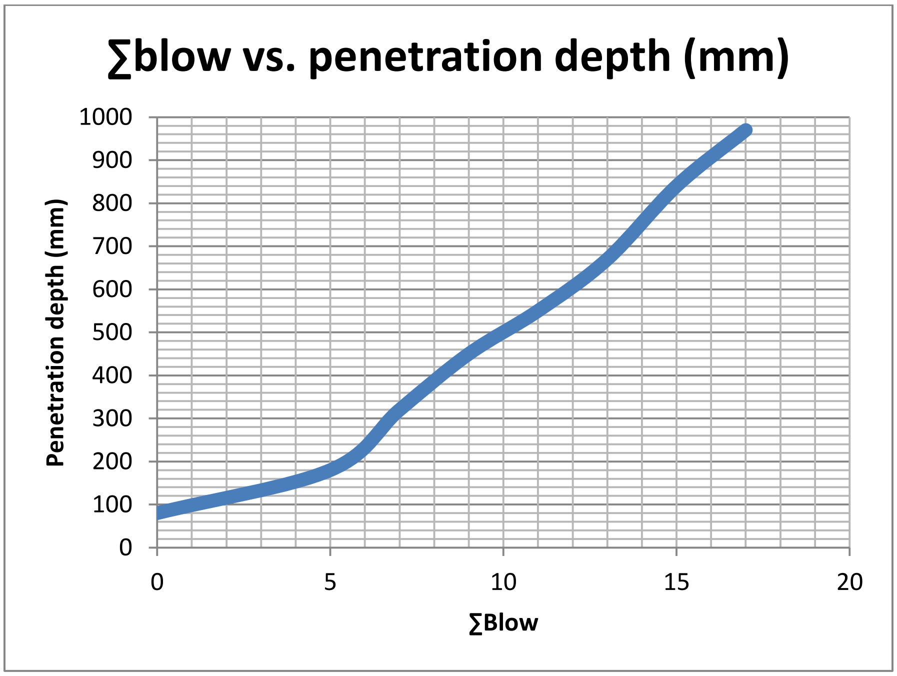
Plot of Summation of penetration depth vs. summation of Blow count

Station 62+000 CL

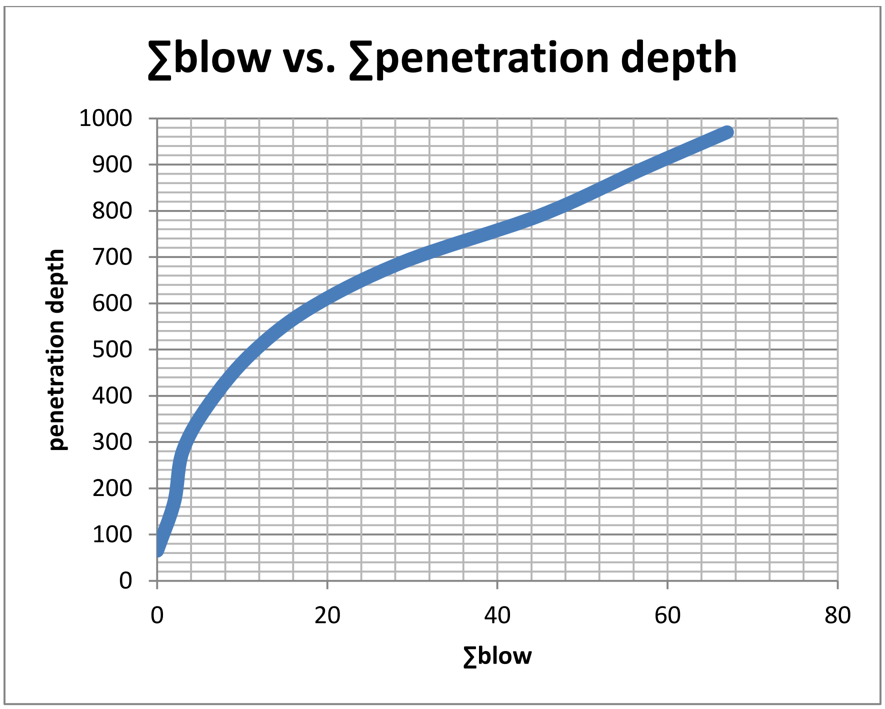
Station 60+000			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	50
2	4	4	210
3	4	8	320
4	4	12	420
5	6	18	520
6	9	27	620
7	7	34	720
8	10	44	820
9	8	52	930
10	3	55	970



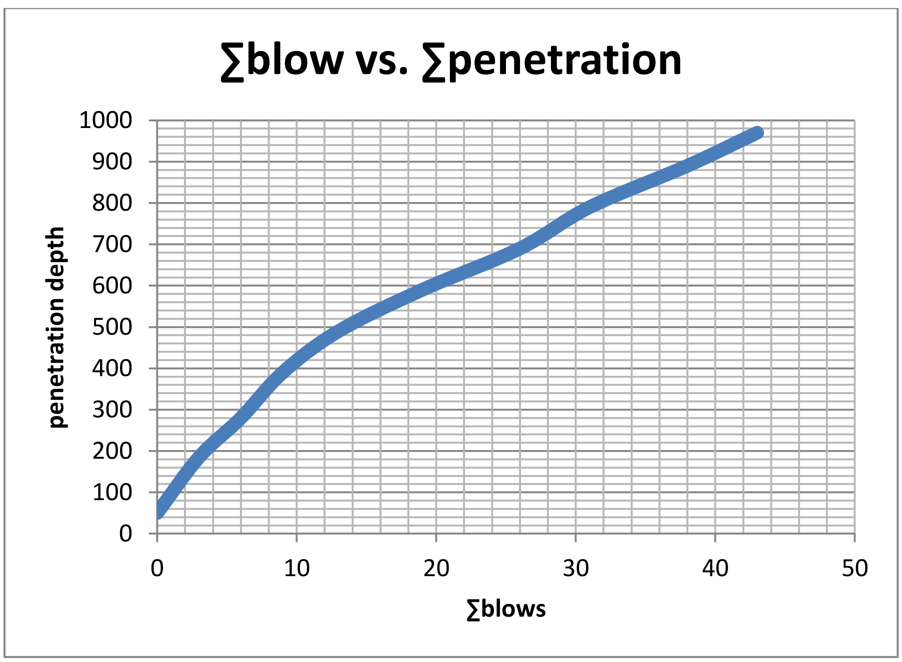
Station 60+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	80
2	5	5	180
3	2	7	320
4	2	9	450
5	2	11	550
6	2	13	670
7	2	15	840
8	2	17	970



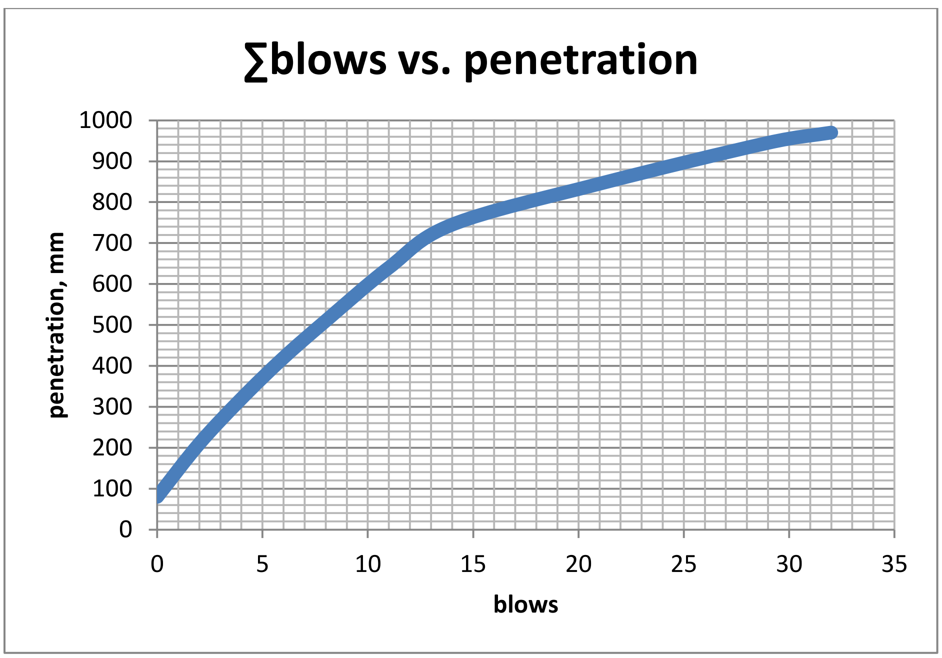
Station 61+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	65
2	2	2	170
3	1	3	280
4	3	6	380
5	5	11	490
6	7	18	590
7	11	29	690
8	16	45	790
9	12	57	890
10	10	67	970



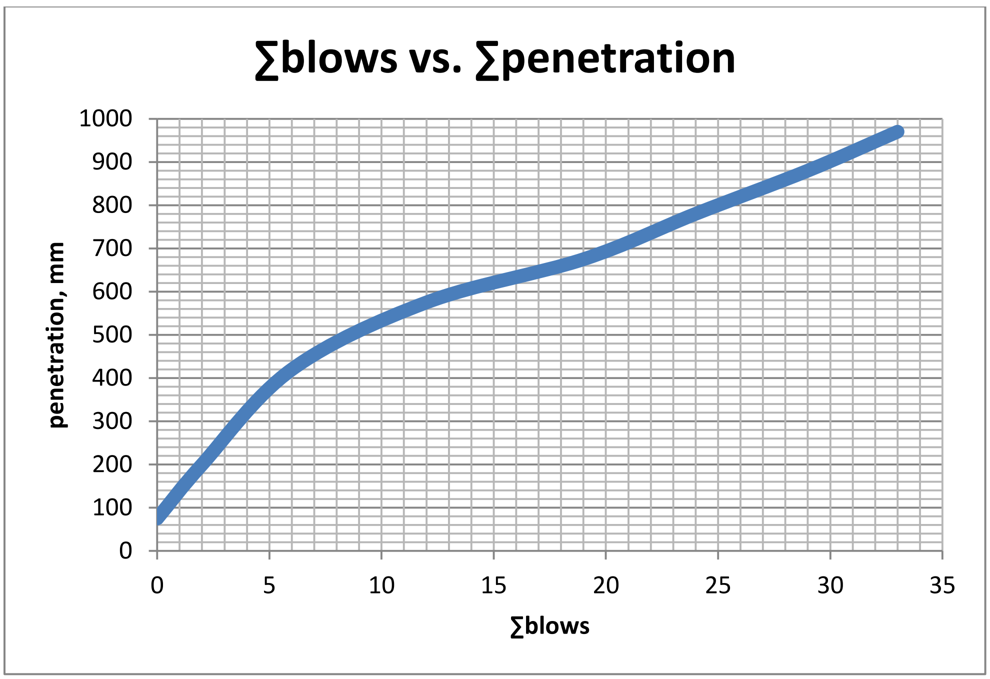
Station 62+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	50
2	3	3	185
3	3	6	280
4	3	9	390
5	4	13	490
6	6	19	590
7	7	26	690
8	5	31	790
9	7	38	890
10	5	43	970



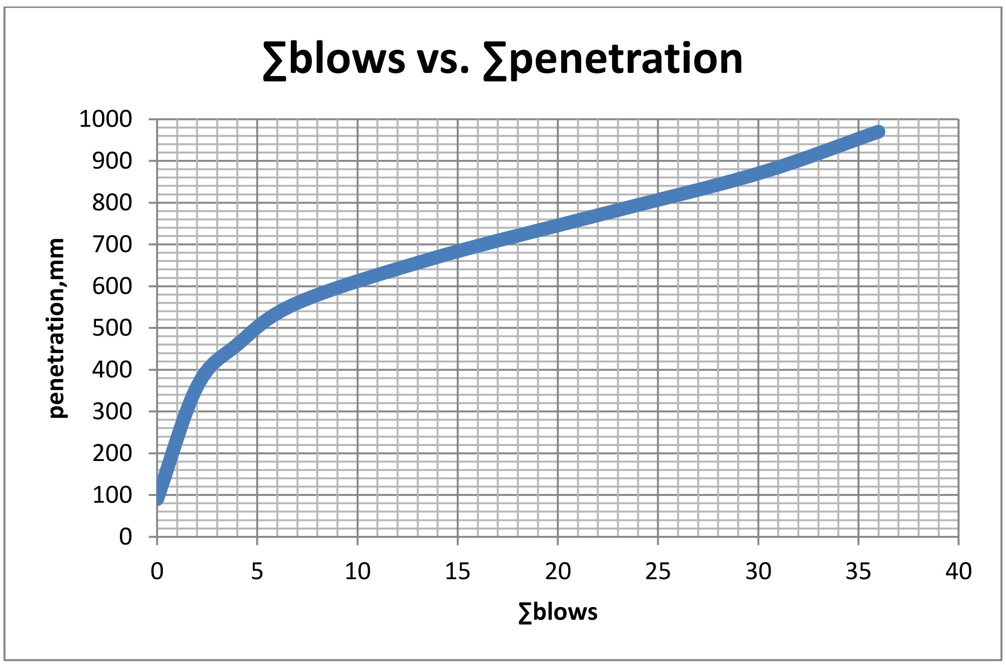
Station 63+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	80
2	2	2	210
3	2	4	320
4	2	6	420
5	2	8	510
6	3	11	640
7	3	14	745
8	7	21	845
9	8	29	945
10	3	32	970



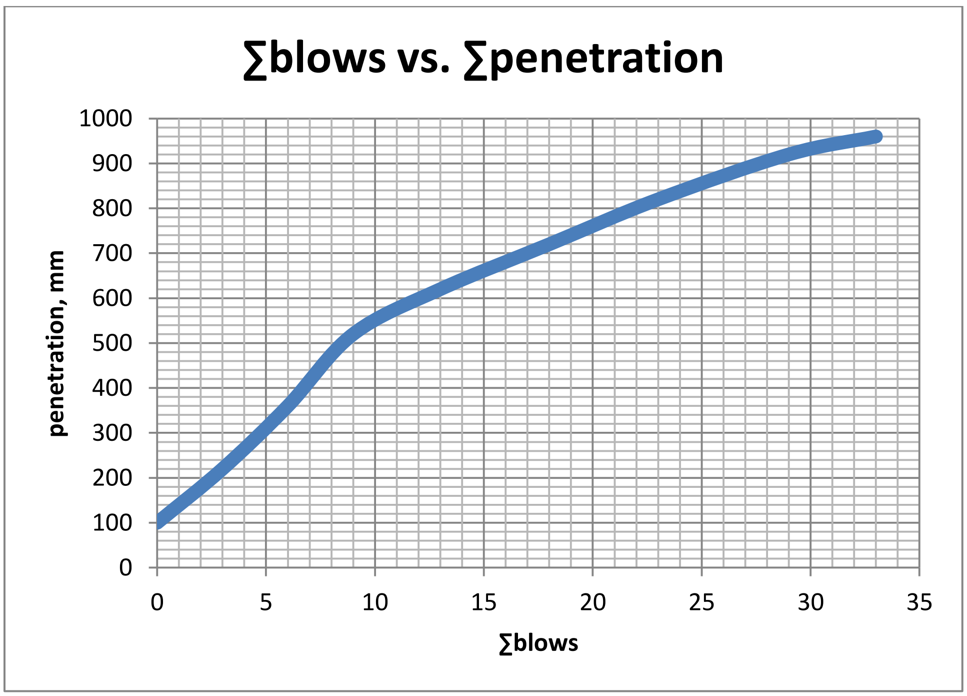
Station 63+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	75
2	2	2	200
3	4	6	420
4	6	12	575
5	7	19	675
6	5	24	780
7	5	29	880
8	4	33	970



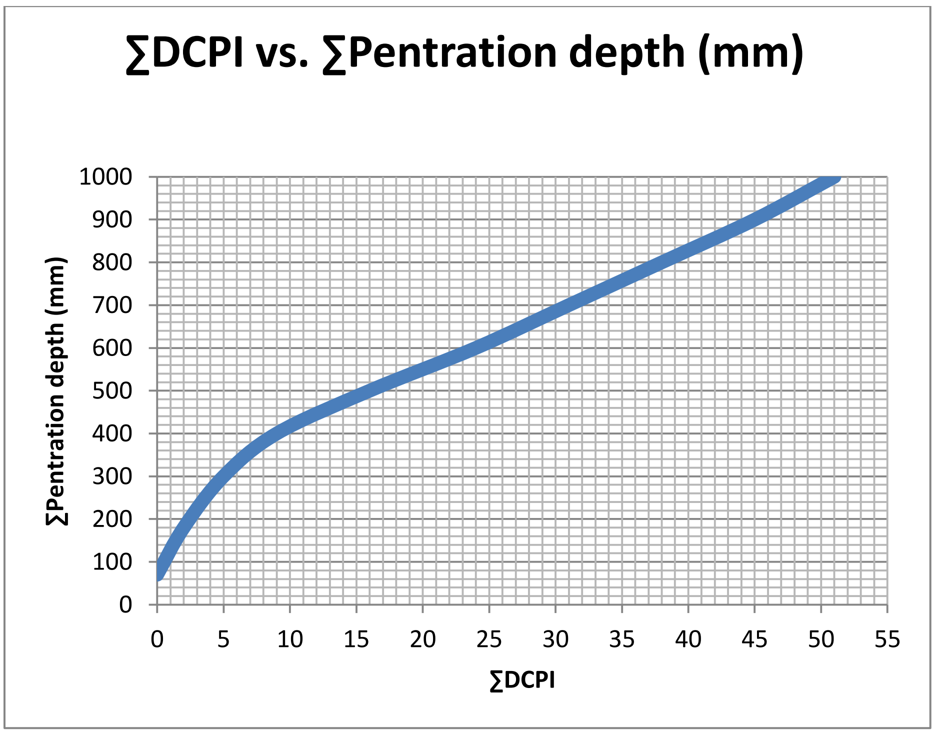
Station 64+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	90
2	2	2	360
3	2	4	460
4	3	7	560
5	7	14	670
6	8	22	770
7	8	30	870
8	6	36	970



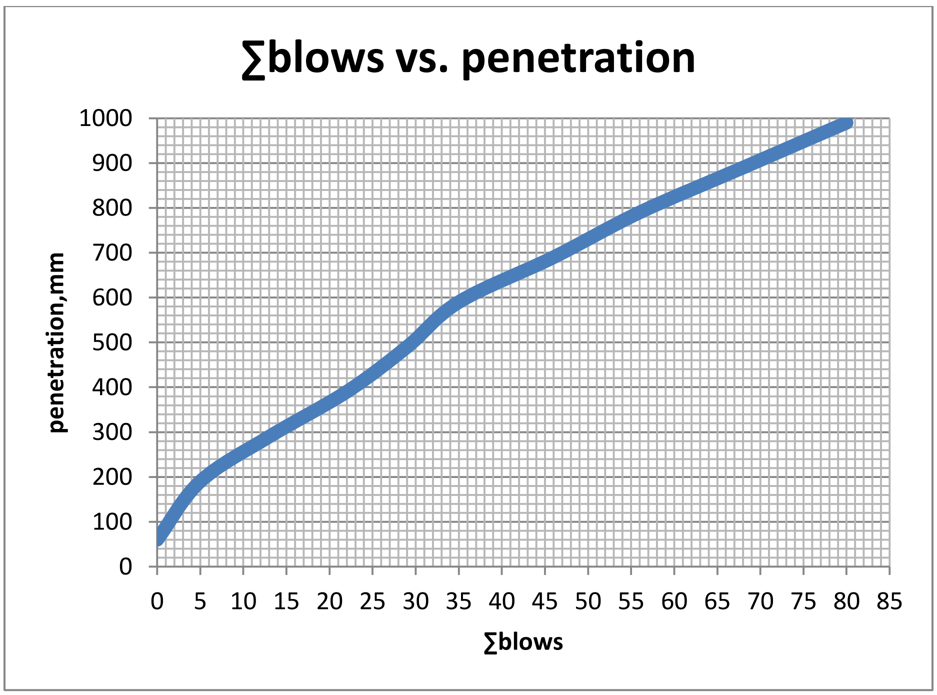
Station 65+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	100
2	3	3	220
3	3	6	360
4	3	9	520
5	4	13	620
6	5	18	720
7	5	23	820
8	6	29	920
9	4	33	960



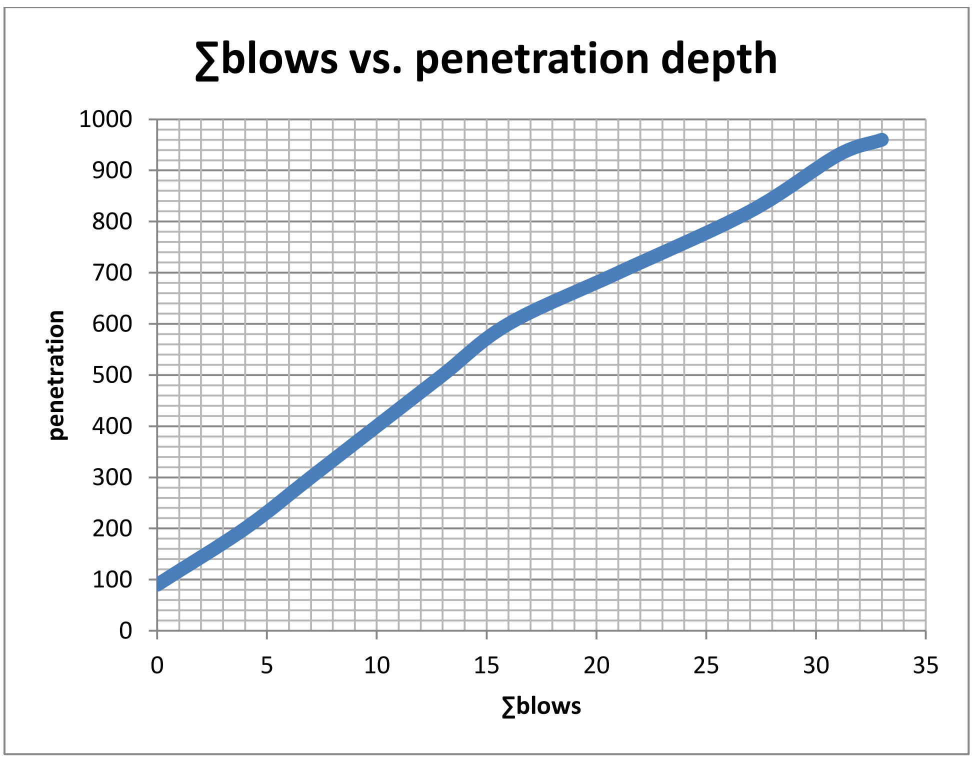
Station 66+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	70
2	2	2	180
3	3	5	300
4	4	9	400
5	7	16	500
6	8	24	600
7	7	31	700
8	7	38	800
9	7	45	900
10	6	51	1000



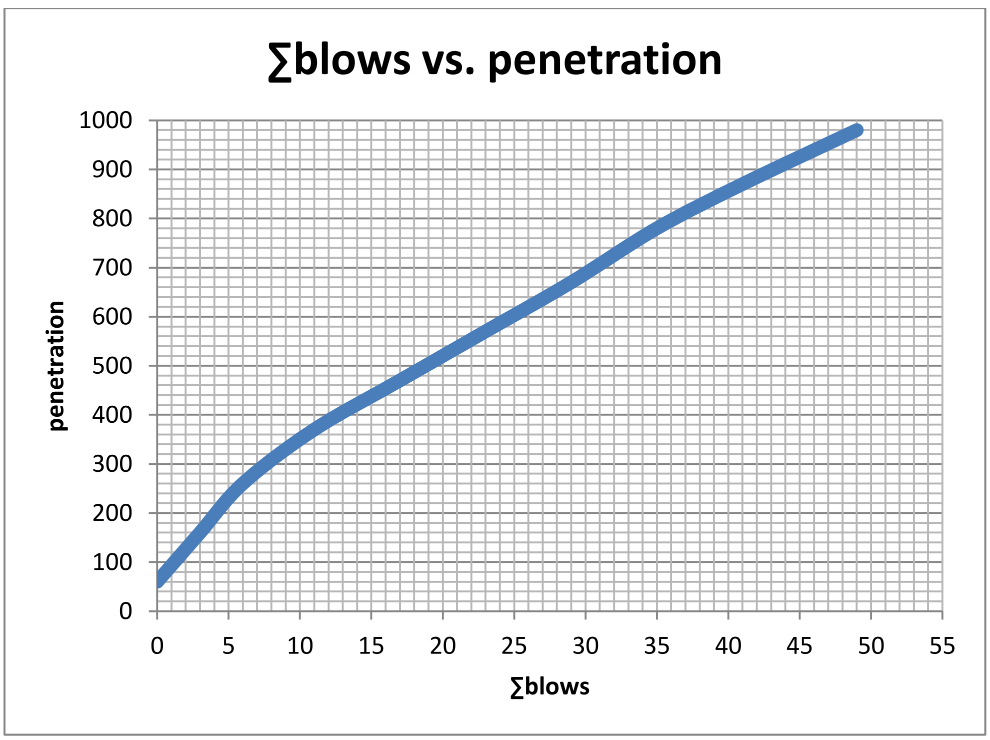
Station 66+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	60
2	5	5	190
3	8	13	290
4	9	22	390
5	7	29	490
6	6	35	590
7	11	46	690
8	10	56	790
9	12	68	890
10	12	80	990



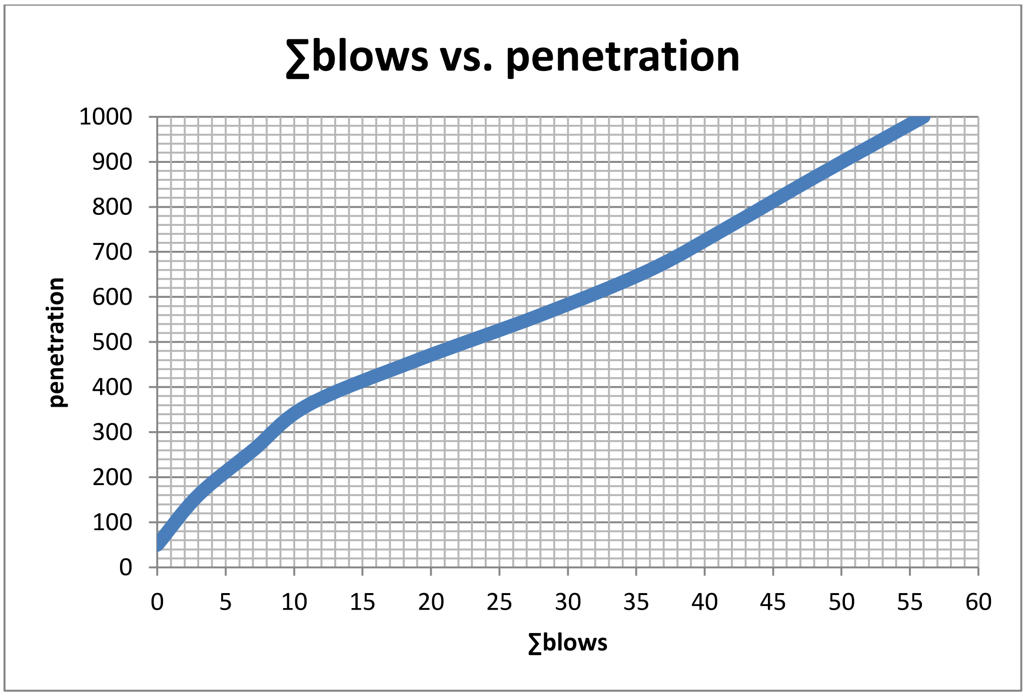
Station 67+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	90
2	4	4	200
3	3	7	300
4	3	10	400
5	3	13	500
6	3	16	600
7	5	21	700
8	6	27	820
9	4	31	930
10	2	33	960



Station 67+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	60
2	3	3	160
3	3	6	260
4	5	11	370
5	6	17	470
6	6	23	570
7	6	29	670
8	6	35	780
9	6	41	870
10	8	49	980

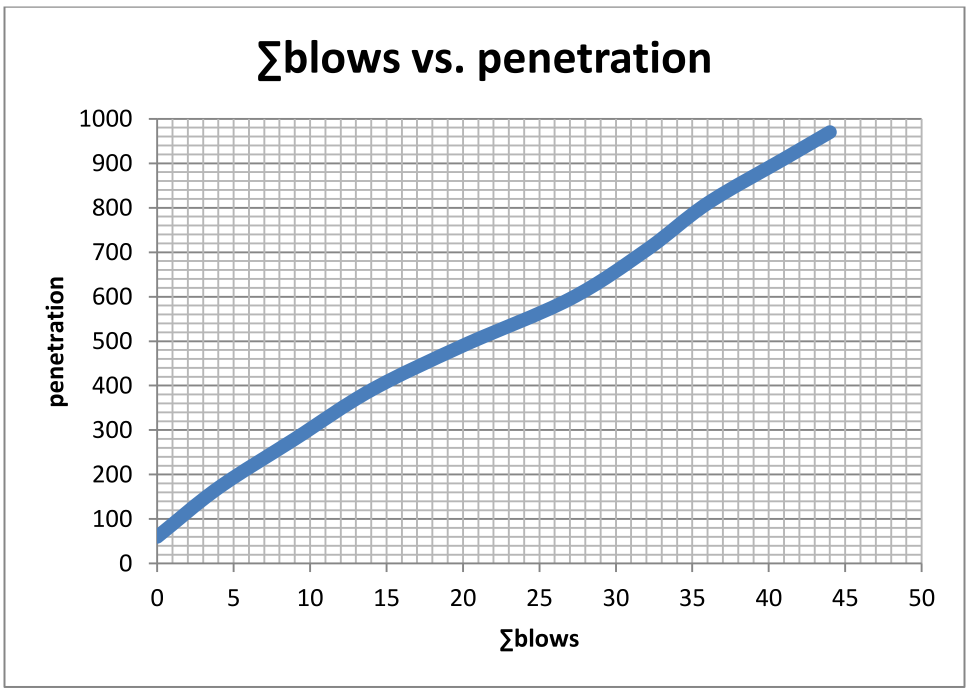


Station 69+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	50
2	3	3	160
3	4	7	260
4	4	11	360
5	8	19	460
6	9	28	560
7	8	36	660
8	6	42	760
9	6	48	865
10	8	56	1000



Station 71+000 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	50
2	3	3	210
3	3	6	310
4	5	11	410
5	5	16	510
6	6	22	630
7	4	26	740
8	5	31	850
9	6	37	980

Station 71+500 CL			
No.	No. of blows	∑blows	∑Penetration(mm)
1	0	0	60
2	4	4	170
3	5	9	280
4	5	14	390
5	6	20	490
6	7	27	595
7	5	32	705
8	4	36	810
9	5	41	910
10	3	44	970



LABORATORY CBR:

For the sake of time and space saving laboratory test appendixes are selected four stations only.

Station 60+000 CL

CALIFORNIA BEARING RATIO (AASHTO T 193)

density determination

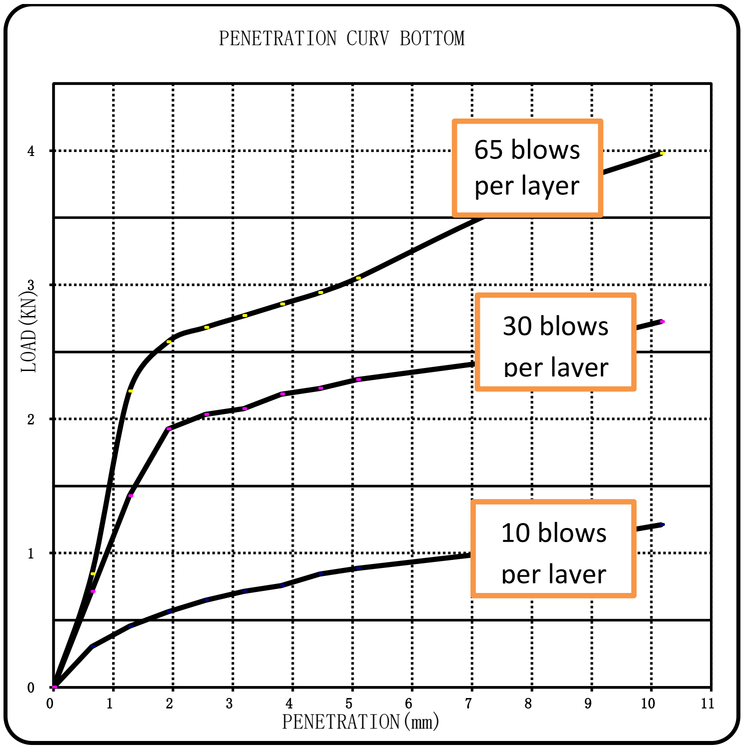
SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	16		24		8	
WEIGHT OF SOIL + MOLD, g	9679	10022	10021	10154	10478	10569
WEIGHT OF MOLD, g	6216		6168		6421	
WEIGHT OF SOIL , g	3463	3806	3853	3986	4057	4148
VOLUME OF MOLD, g	2124		2124		2124	
WET DENSITY OF SOIL, g/cm^3	1.630	1.792	1.814	1.877	1.910	1.953
DRY DENSITY OF SOIL, g/cm^3	1.323	1.314	1.486	1.441	1.561	1.560

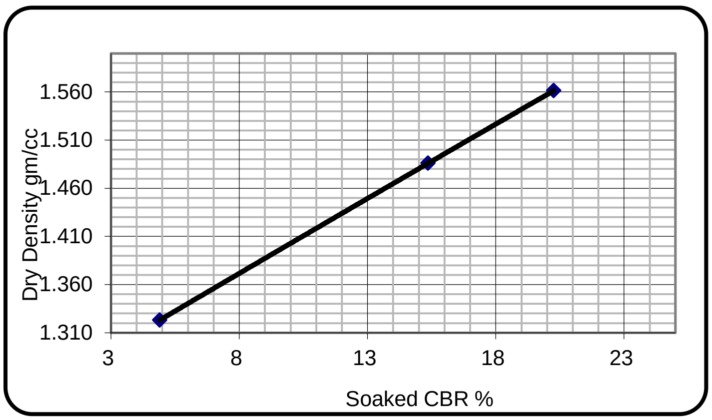
moisture determination

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
CONTAINER NUMBER	N9	OZ	N9	BH	M11	ZZ
WET SOIL + CONTAINER, g	239	246	239	247	282	249
DRY SOIL + CONTAINER, g	203	190	203	198	240	207
WEIGHT OF CONTAINER, g	48	36	40	36	52	40
WEIGHT OF WATER , g	36	56	36	49	42	42
WEIGHT OF DRY SOIL, g	155	154	163	162	188	167
MOISTURE CONTENT	23.2	36.4	22.1	30.2	22.3	25.1

penetration bottom test

PENETRATION DATE		14/02/'2007			RING FACTOR		0.02163		
PENETRATION (mm)	10 Blows			30 Blows			65 Blows		
	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)
0.00	0	0.00		0	0.00		0	0.00	
0.64	14	0.30		33	0.71		39	0.84	
1.27	21	0.45		66	1.43		102	2.21	
1.91	26	0.56		89	1.93		119	2.57	
2.54	30	0.65	**4.9**	94	2.03	**15.4**	124	2.68	**20.3**
3.18	33	0.71		96	2.08		128	2.77	
3.81	35	0.76		101	2.18		132	2.86	
4.45	39	0.84		103	2.23		136	2.94	
5.08	41	0.89	**4.4**	106	2.29	**11.5**	141	3.05	**15.3**
7.62	47	1.02		113	2.44		166	3.59	
10.16	56	1.21		126	2.73		184	3.98	


PENETRATION CURV BOTTOM
65 blows per layer
30 blows per layer
10 blows per layer
LOAD (KN)
PENETRATION (mm)
0
1
2
3
4
5
6
7
8
9
10
11


Dry Density gm/cc
1.560
1.510
1.460
1.410
1.360
1.310
3
8
13
18
23
Soaked CBR %

Station 63+000 CL

CALIFORNIA BEARING RATIO (AASHTO T 193)

DENSITY DETERMINATION

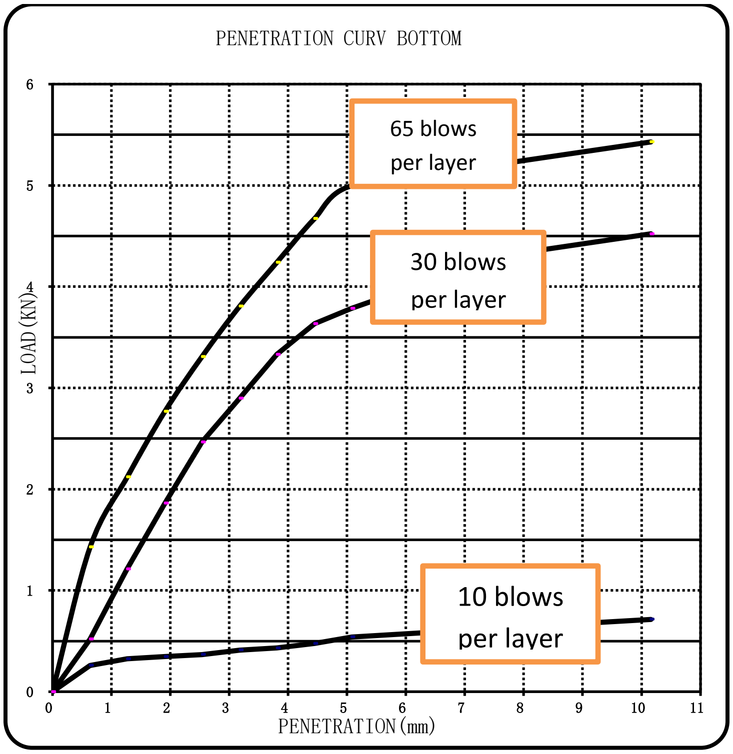
SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	44		7		21	
WEIGHT OF SOIL + MOLD, g	10204	10514	10653	10991	10600	10728
WEIGHT OF MOLD, g	6465		6550		6203	
WEIGHT OF SOIL , g	3739	4049	4103	4441	4397	4525
VOLUME OF MOLD, g	2124		2124		2124	
WET DENSITY OF SOIL, g/cm^3	1.760	1.906	1.932	2.091	2.070	2.130
DRY DENSITY OF SOIL, g/cm^3	1.524	1.484	1.711	1.667	1.793	1.717

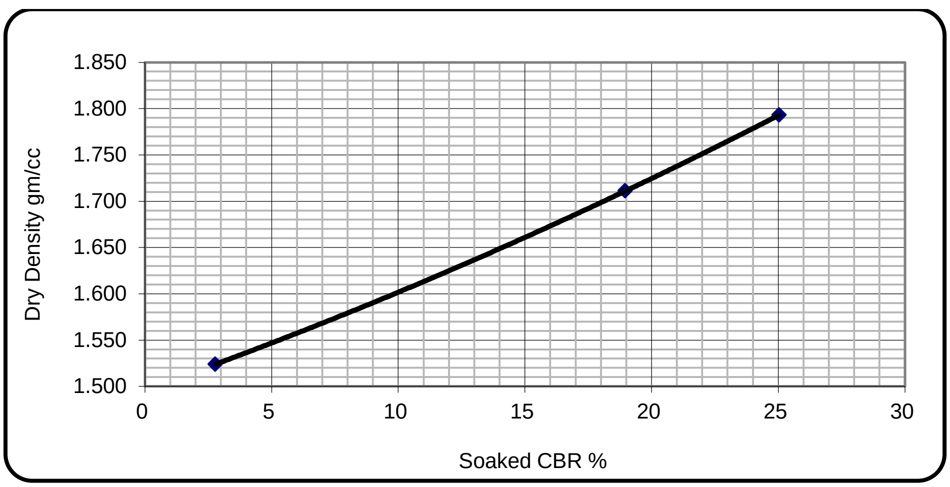
MOISTURE DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
CONTAINER NUMBER	AS	N4	40	TZ	AV	BC
WET SOIL + CONTAINER, g	163	229	178	206	267	240
DRY SOIL + CONTAINER, g	145	188	162	175	235	200
WEIGHT OF CONTAINER, g	29	44	38	53	28	34
WEIGHT OF WATER , g	18	41	16	31	32	40
WEIGHT OF DRY SOIL, g	116	144	124	122	207	166
MOISTURE CONTENT	15.5	28.5	12.9	25.4	15.5	24.1

PENETRATION BOTTOM TEST

PENETRATION DATE			03/02/'2007		RING FACTOR		0.02163		
PENETRATION (mm)	10 Blows			30 Blows			65 Blows		
	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)
0.00	0	0.00		0	0.00		0	0.00	
0.64	12	0.26		24	0.52		66	1.43	
1.27	15	0.32		56	1.21		98	2.12	
1.91	16	0.35		86	1.86		128	2.77	
2.54	17	0.37	**2.8**	114	2.47	**18.6**	153	3.31	**25.0**
3.18	19	0.41		134	2.90		176	3.81	
3.81	20	0.43		154	3.33		196	4.24	
4.45	22	0.48		168	3.63		216	4.67	
5.08	25	0.54	**2.7**	175	3.79	**19.0**	231	5.00	**25.0**
7.62	29	0.63		199	4.30		241	5.21	
10.16	33	0.71		209	4.52		251	5.43	


PENETRATION CURV BOTTOM
65 blows per layer
30 blows per layer
10 blows per layer
LOAD(KN)
PENETRATION(mm)
0
1
2
3
4
5
6
7
8
9
10
11


Dry Density gm/cc
1.850
1.800
1.750
1.700
1.650
1.600
1.550
1.500
0
5
10
15
20
25
30
Soaked CBR %

Station 65+000CL

CALIFORNIA BEARING RATIO AASHTO T 193

DENSITY DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	39		23		59	
WEIGHT OF SOIL + MOLD, g	9772	10254	9655	9980	10121	10250
WEIGHT OF MOLD, g	6420		6039		6167	
WEIGHT OF SOIL , g	3352	3834	3616	3941	3954	4083
VOLUME OF MOLD, g	2124		2124		2124	
WET DENSITY OF SOIL, g/cm^3	1.578	1.805	1.702	1.855	1.862	1.922
DRY DENSITY OF SOIL, g/cm^3	1.282	1.277	1.381	1.378	1.508	1.482

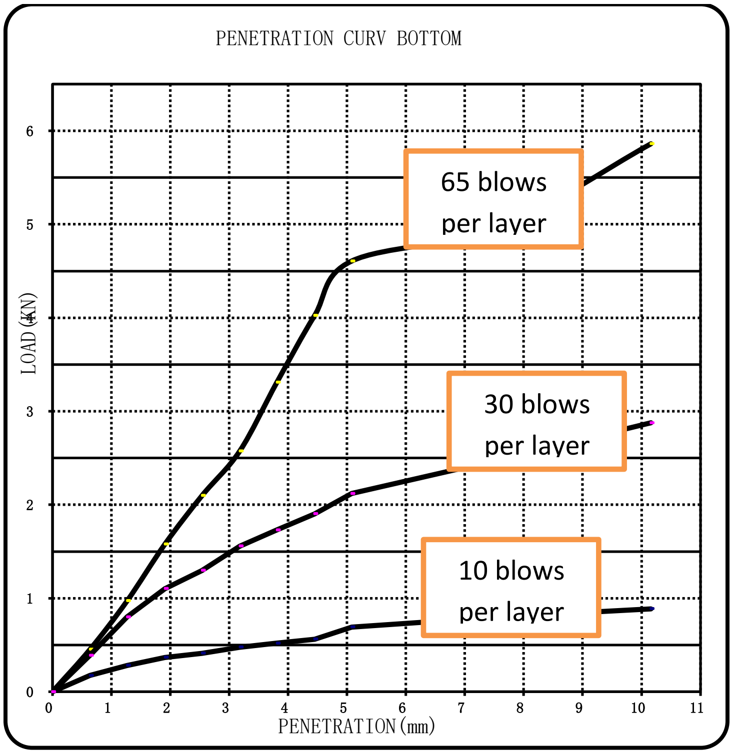
MOISTURE DETERMINATION

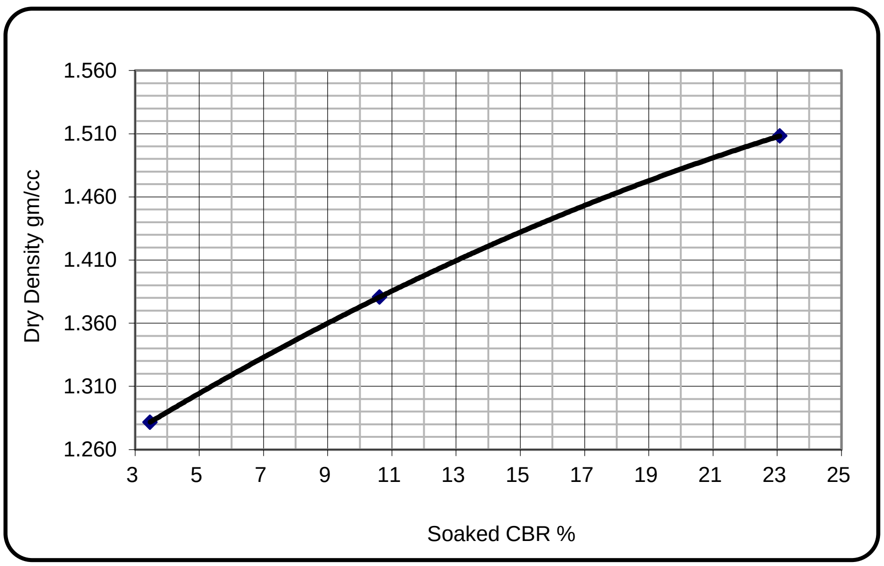
SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
CONTAINER NUMBER	ZF	BD	N7	AS	M1	GR
WET SOIL + CONTAINER, g	203	202	168	227	268	222
DRY SOIL + CONTAINER, g	172	152	144	176	227	181
WEIGHT OF CONTAINER, g	38	31	41	29	52	43
WEIGHT OF WATER , g	31	50	24	51	41	41
WEIGHT OF DRY SOIL, g	134	121	103	147	175	138
MOISTURE CONTENT	23.1	41.3	23.3	34.7	23.4	29.7

PENETRATION BOTTOM TEST

PENETRATION DATE	03/'02/2007	RING FACTOR	0.02163

PENETRATION (mm)	10 Blows			30 Blows			65 Blows		
	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)	Dial reading	Load (KN)	C.B.R (%)
0.00	0	0.00		0	0.00		0	0.00	
0.64	8	0.17		18	0.39		21	0.45	
1.27	13	0.28		37	0.80		45	0.97	
1.91	17	0.37		51	1.10		73	1.58	
2.54	19	0.41	**3.1**	60	1.30	**9.8**	97	2.10	**15.8**
3.18	22	0.48		72	1.56		119	2.57	
3.81	24	0.52		80	1.73		153	3.31	
4.45	26	0.56		88	1.90		186	4.02	
5.08	32	0.69	**3.5**	98	2.12	**10.6**	213	4.61	**23.1**
7.62	37	0.80		115	2.49		230	4.97	
10.16	41	0.89		133	2.88		271	5.86	


PENETRATION CURV BOTTOM
65 blows per layer
30 blows per layer
10 blows per layer
LOAD (KN)
PENETRATION (mm)
0
1
2
3
5
6
0
1
2
3
4
5
6
7
8
9
10
11


Dry Density gm/cc
Soaked CBR %
1.560
1.510
1.460
1.410
1.360
1.310
1.260
3
5
7
9
11
13
15
17
19
21
23
25

Station 67+500CL

CALIFORNIA BEARING RATIO AASHTO T 193

DENSITY DETERMINATION

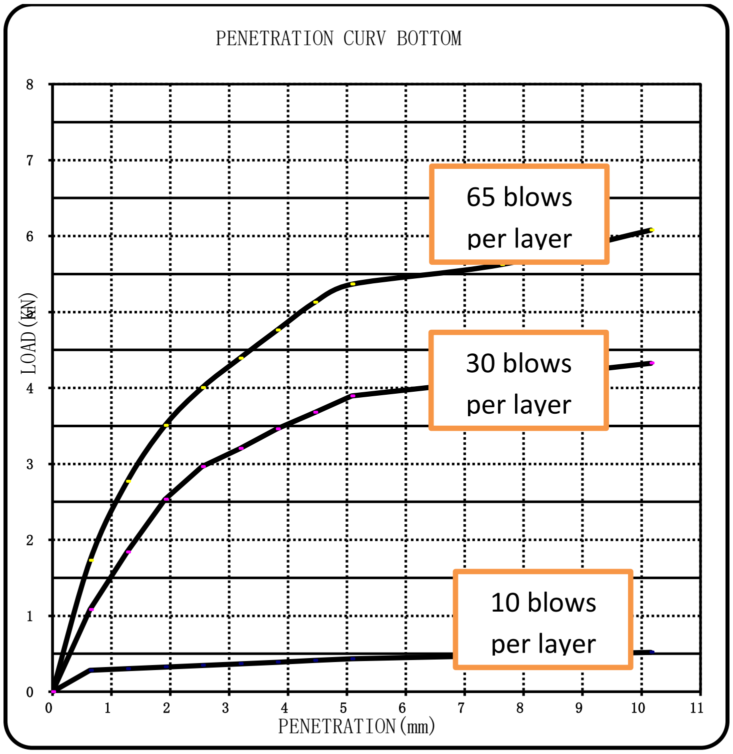
SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
MOLD NUMBER	23		29		24	
WEIGHT OF SOIL + MOLD, g	9532	9769	10150	10240	10120	10152
WEIGHT OF MOLD, g	6042		6315		6159	
WEIGHT OF SOIL , g	3490	3727	3835	3925	3961	3993
VOLUME OF MOLD, g	2124		2124		2124	
WET DENSITY OF SOIL, g/cm^3	1.643	1.755	1.806	1.848	1.865	1.880
DRY DENSITY OF SOIL, g/cm^3	1.337	1.257	1.462	1.437	1.513	1.417

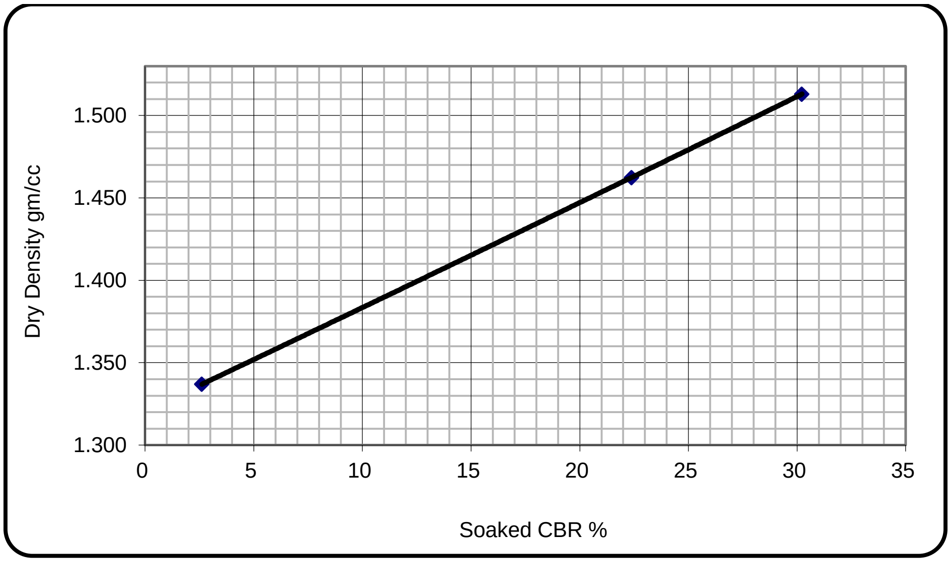
MOISTURE DETERMINATION

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	Before	After	Before	After	Before	After
CONTAINER NUMBER	0	39	BH	ZZ	M11	2
WET SOIL + CONTAINER, g	199	181	257	166	308	177
DRY SOIL + CONTAINER, g	169	141	215	138	258	146
WEIGHT OF CONTAINER, g	38	40	36	40	43	51
WEIGHT OF WATER , g	30	40	42	28	50	31
WEIGHT OF DRY SOIL, g	131	101	179	98	215	95
MOISTURE CONTENT	22.9	39.6	23.5	28.6	23.3	32.6

PENETRATION BOTTOM TEST

PENETRATION DATE			08/02/'2007			RING FACTOR	0.02163		
PENETRATION (mm)	10 Blows			30 Blows			65 Blows		
	Dial reading	Load (KN)	CBR(%)	Dial reading	Load (KN)	CBR(%)	Dial reading	Load (KN)	CBR(%)
0.00	0	0.00		0	0.00		0	0.00	
0.64	13	0.28		50	1.08		80	1.73	
1.27	14	0.30		85	1.84		128	2.77	
1.91	15	0.32		117	2.53		162	3.50	
2.54	16	0.35	**2.6**	137	2.96	**22.4**	185	4.00	**30.2**
3.18	17	0.37		148	3.20		203	4.39	
3.81	18	0.39		160	3.46		220	4.76	
4.45	19	0.41		170	3.68		237	5.13	
5.08	20	0.43	**2.2**	180	3.89	**19.5**	248	5.36	**26.9**
7.62	22	0.48		190	4.11		260	5.62	
10.16	24	0.52		200	4.33		281	6.08	


PENETRATION CURV BOTTOM
LOAD (kN)
PENETRATION (mm)
65 blows per layer
30 blows per layer
10 blows per layer
0
1
2
3
4
5
6
7
8
9
10
11


Dry Density gm/cc
1.500
1.450
1.400
1.350
1.300
0
5
10
15
20
25
30
35
Soaked CBR %

PROCTOR (MDD and OMC determination)

Station 60+000 CL

MOISTURE - DENSITY RELATION OF SOIL (AASHTO T 180)

No.blows 25 Wt of hammer, kg 4.5

No.layers 5 V of mold,cm^3 : 944

A	Mold	No.	1	2	3	4	5	
B	Wt. of Mold + Wet Soil	grams	5682	5764	5790	5865	5880	
C	Wt. of Mold	grams	4100	4100	4100	4100	4100	
D	Wt. Wet Soil	grams	1582	1664	1690	1765	1780	
E	Volume of Mold	cu.cm.	944	944	944	944	944	
F	Wet Density	gr/cu.cm.	1.676	1.763	1.790	1.870	1.886	
								N.M.C
G	Container	No.	N3	B	AE	AI	AC	T
H	Wt. Cont + Wet soil	grams	293	263	281	282	206	350
I	Wt. Cont + Dry soil	grams	261	231	243	240	175	319
J	Weight of Container	grams	40	53	38	42	39	32
K	Weight of water	grams	32.0	32.0	38.0	42.0	31.0	31.0
L	Weight of Dry Soil	grams	221.0	178.0	205.0	198.0	136.0	287.0

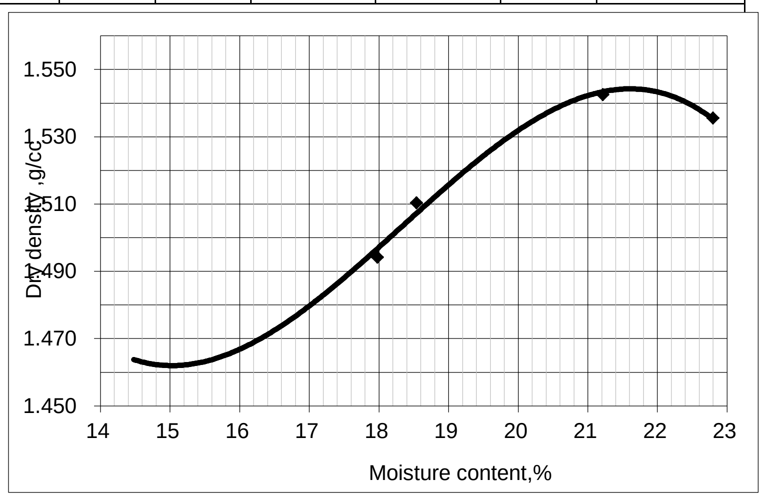
M	Moisture Content	%	14.48	17.98	18.54	21.21	22.79	10.8
N	Dry Density	gr/cu.cm.	1.464	1.494	1.510	1.543	1.536	

Maximum Dry Density (MDD):

MDD = 1.543 gm/cc

Optimum Moisture Content (OMC) :

OMC = 21.8 %



Station 63+000CL

MOISTURE - DENSITY RELATION OF SOIL (AASHTO T 180)

No. of blows :	25	Wt of hammer, kg :	4.5
No. of layers :	5	Vol of mold,cm^3 :	944

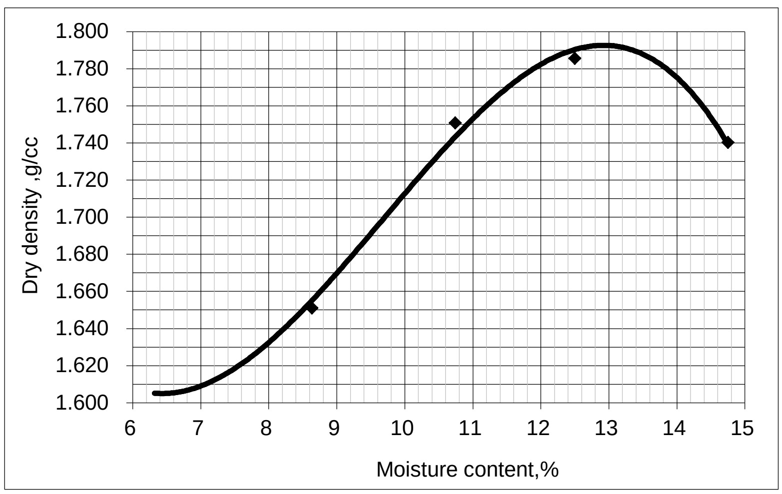
A	Mold	No.	1	2	3	4	5	
B	Wt. of Mold + Wet Soil	grams	5055	5136	5273	5339	5328	
C	Wt. of Mold	grams	3443	3443	3443	3443	3443	
D	Wt. Wet Soil	grams	1612	1693	1830	1896	1885	
E	Volume of Mold	cu.cm.	944	944	944	944	944	
F	Wet Density	gr/cu.cm.	1.708	1.793	1.939	2.008	1.997	
								NMC
G	Container	No.	PC	14	AR	N	AF	M11
H	Wt. Cont + Wet soil	grams	219	367	340	301	314	309
I	Wt. Cont + Dry soil	grams	208	343	311	272	278	303
J	Weight of Container	grams	34	65	41	40	34	43
K	Weight of water	grams	11.0	24.0	29.0	29.0	36.0	6.0
L	Weight of Dry Soil	grams	174.0	278.0	270.0	232.0	244.0	260.0
M	Moisture Content	%	6.32	8.63	10.74	12.50	14.75	2.3
N	Dry Density	gr/cu.cm.	1.606	1.651	1.751	1.785	1.740	

Maximum Dry Density (MDD):

MDD = 1.791 gm/cc

Optimum Moisture Content (OMC) :

OMC = 13.0 %



Station 65+000CL

MOISTURE - DENSITY RELATION OF SOIL AASHTO T 180

No. blows : 25   Wt of hammer,kg : 4.5

No. layers: 5   Volume of mold,cm^3 : 944

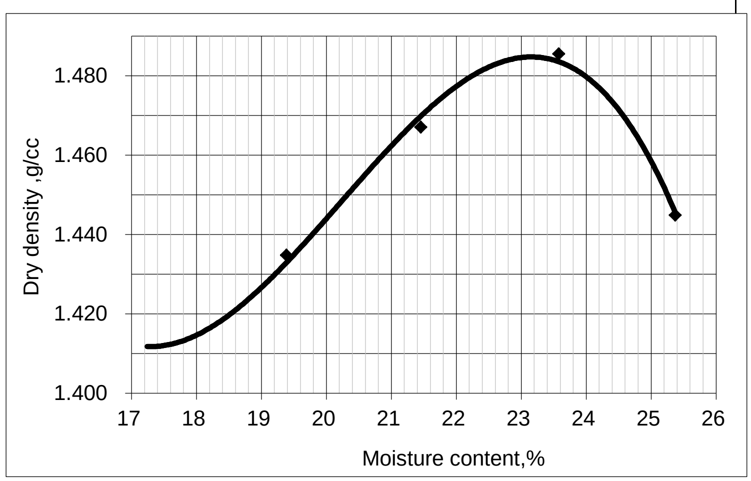
A	Mold	No.	1	2	3	4	5	
B	Wt. of Mold + Wet Soil	grams	5012	5067	5132	5183	5160	
C	Wt. of Mold	grams	3450	3450	3450	3450	3450	
D	Wt. Wet Soil	grams	1562	1617	1682	1733	1710	
E	Volume of Mold	cu.cm.	944	944	944	944	944	
F	Wet Density	gr/cu.cm.	1.655	1.713	1.782	1.836	1.811	
								NMC
G	Container	No.	N4	AH	AP	AR	AJ	K
H	Wt. Cont + Wet soil	grams	317	391	374	324	398	307
I	Wt. Cont + Dry soil	grams	277	334	315	270	330	280
J	Weight of Container	grams	45	40	40	41	62	35
K	Weight of water	grams	40.0	57.0	59.0	54.0	68.0	27.0
L	Weight of Dry Soil	grams	232.0	294.0	275.0	229.0	268.0	245.0
M	Moisture Content	%	17.24	19.39	21.45	23.58	25.37	11.0
N	Dry Density	gr/cu.cm.	1.411	1.435	1.467	1.486	1.445	

Maximum Dry Density (MDD):

MDD = 1.485 gm/cc

Optimum Moisture Content (OMC) :

OMC = 23.2 %



Station 67+500CL

MOISTURE - DENSITY RELATION OF SOIL AASHTO T 180

No.blows	25	Wt of hammer,kg :	4.5
No.layers	5	Volume of mold,cm^3 :	944

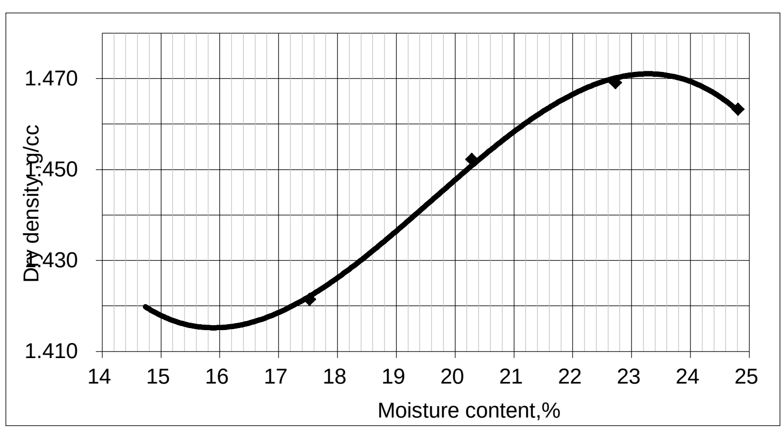
A	Mold	No.	1	2	3	4	5	
B	Wt. of Mold + Wet Soil	grams	5633	5672	5744	5797	5819	
C	Wt. of Mold	grams	4095	4095	4095	4095	4095	
D	Wt. Wet Soil	grams	1538	1577	1649	1702	1724	
E	Volume of Mold	cu.cm.	944	944	944	944	944	
F	Wet Density	gr/cu.cm.	1.629	1.671	1.747	1.803	1.826	
								NMC
G	Container	No.	68	55	KO	2	41	AR
H	Wt. Cont + Wet soil	grams	380	360	460	348	372	331
I	Wt. Cont + Dry soil	grams	338	316	389	293	306	305
J	Weight of Container	grams	53	65	39	51	40	41
K	Weight of water	grams	42.0	44.0	71.0	55.0	66.0	26.0
L	Weight of Dry Soil	grams	285.0	251.0	350.0	242.0	266.0	264.0
M	Moisture Content	%	14.74	17.53	20.29	22.73	24.81	9.8
N	Dry Density	gr/cu.cm.	1.420	1.421	1.452	1.469	1.463	

Maximum Dry Density (MDD):

MDD = 1.471 gm/cc

Optimum Moisture Content (OMC) :

OMC = 23.4 %



GRADATION OR PARTICLE SIZE DISTRIBUTION

Station 60+000CL

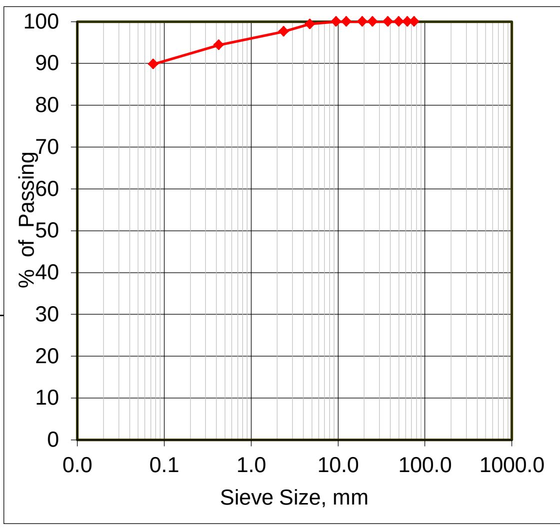
PARTICLE SIZE DISTRIBUTION (AASHTO T-27)

Sample preparation : Oven-dried sample

Method of sieving:

Wet sieving ☑

Dry sieving



sieve size, mm.	weight retained	% retained	% passing
75.0			100
63.0			100.0
50.0			100.0
37.5			100.0
25.0			100.0
19.0			100.0
12.5			100.0
9.5			100.0
4.75	3	0.6	99.4
2.36	9	1.8	97.6
0.425	16	3.2	94.4
0.075	23	4.6	89.8
Pan	449	89.8	
Dry weight before washing	500		

Station 63+000 CL

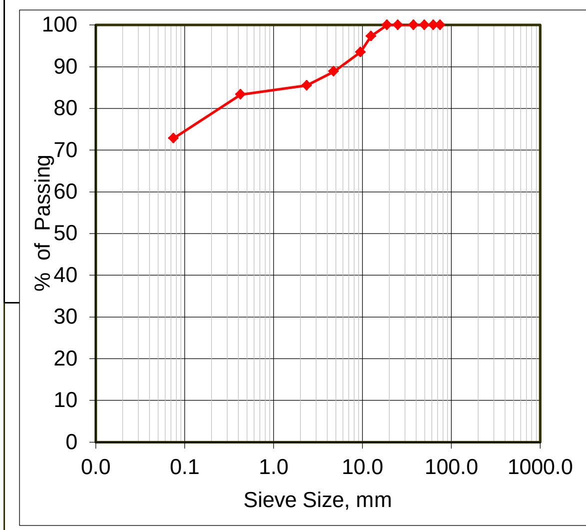
PARTICLE SIZE DISTRIBUTION (AASHTO T-27)

Sample preparation : Oven-dried sample

Method of sieving:

Wet sieving ☑

Dry sieving



sieve size, mm.	weight retained	% retained	% passing
75.0			100
63.0			100.0
50.0			100.0
37.5			100.0
25.0			100.0
19.0			100.0
12.5	16	2.7	97.3
9.5	23	3.8	93.5
4.75	28	4.7	88.8
2.36	20	3.3	85.5
0.425	13	2.2	83.3
0.075	63	10.5	72.8
Pan	437	72.8	
Dry weight before washing	600		

Station 65+000CL

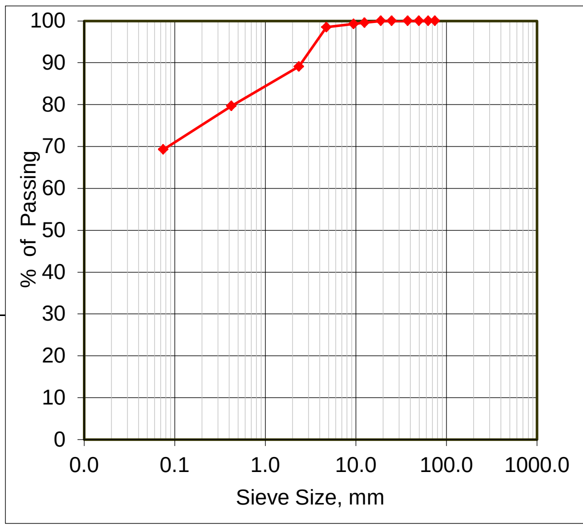
PARTICLE SIZE DISTRIBUTION AASHTO T-27

Sample preparation : Oven-dried sample

Method of sieving:

Wet sieving ☑

Dry sieving ☐



sieve size, mm.	weight retained	% retained	% passing
75.0			100
63.0			100.0
50.0			100.0
37.5			100.0
25.0			100.0
19.0			100.0
12.5	3	0.4	99.6
9.5	2	0.3	99.3
4.75	5	0.7	98.5
2.36	63	9.4	89.1
0.425	63	9.4	79.7
0.075	70	10.4	69.3
Pan	464	69.3	
Dry weight before washing	670		

Station 67+500CL

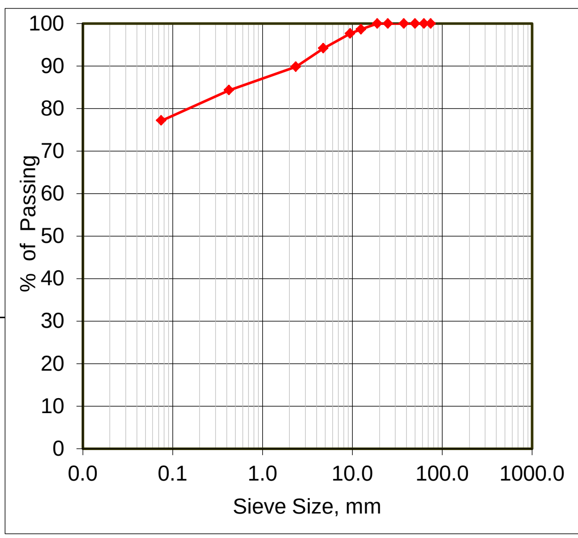
PARTICLE SIZE DISTRIBUTION AASHTO T-27

Sample preparation : Oven-dried sample

Method of sieving:

Wet sieving ☑

Dry sieving ☐



sieve size, mm.	weight retained	% retained	% passing
75.0			100
63.0			100.0
50.0			100.0
37.5			100.0
25.0			100.0
19.0			100.0
12.5	8	1.3	98.7
9.5	6	1.0	97.7
4.75	21	3.5	94.2
2.36	26	4.3	89.8
0.425	33	5.5	84.3
0.075	43	7.2	77.2
Pan	463	77.2	
Dry weight before washing	600		

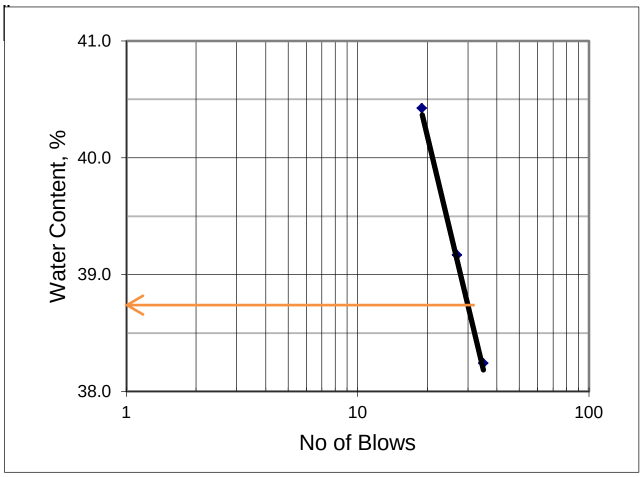
ATTERBBERG LIMIT

Station 60+000 CL

ATTERBERG LIMIT, AASHTO T-89 & T- 90

LIQUID LIMIT

Container No.	E10	NB	A2	
Wt of wet soil + container, gm	30.22	30.13	30.19	
Wt of dry soil + container, gm	26.40	25.81	25.93	
Wt of container	16.95	14.78	14.79	
Wt of water	3.82	4.32	4.26	
Wt of dry soil, gm	9.45	11.03	11.14	
Water content, %	40.4	39.2	38.2	
No. of blows	19	27	35	



Sample preparation

As received	☐
Washed on 0.425mm sieve	☐
Air dried at ……30°C	☑
Oven dried at …………oC	☐
Proportion retained on 0.425mm sieve	

Liquid Limit	**39**	%
Plastic Limit	**27**	%
Plasticity Index	**12**	%

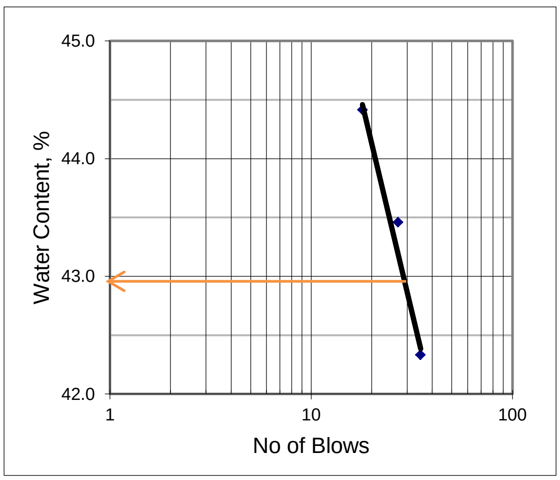
PLASTIC LIMIT

Container No.	OY	160		**Average**
Wt of wet soil + container, gm	27.06	28.34		
Wt of dry soil + container, gm	24.24	25.43		
Wt of container	13.92	14.82		
Wt of water	2.82	2.91		
Wt of dry soil, gm	10.32	10.61		
Water content, %	27.3	27.4		**27.4**

Station 63+000 CL

ATTERBERG LIMIT, (AASHTO T-89 & T- 90)

LIQUID LIMIT			
Container No.	116	76	173
Wt of wet soil + container, gm	31.27	32.63	32.45
Wt of dry soil + container, gm	26.26	28.08	27.26
Wt of container	14.98	17.61	15.00
Wt of water	5.01	4.55	5.19
Wt of dry soil, gm	11.28	10.47	12.26
Water content, %	44.4	43.5	42.3
No. of blows	18	27	35



Sample preparation

As received	☐
Washed on 0.425mm sieve	☐
Air dried at ……30°C	☑
Oven dried at …………oC	☐
Proportion retained on 0.425mm sieve	

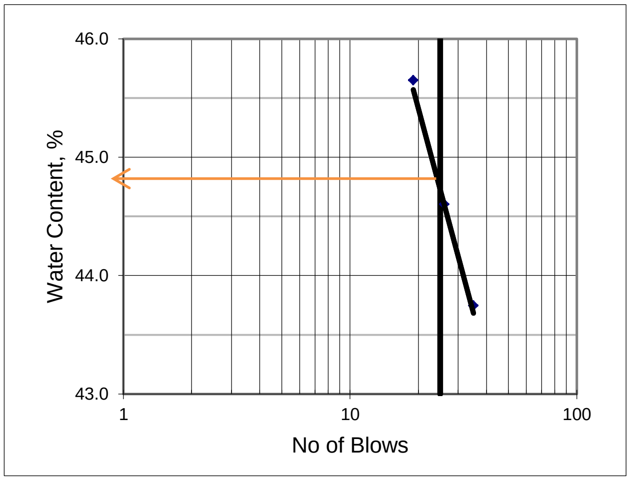
Liquid Limit	**43**	%
Plastic Limit	**29**	%
Plasticity Index	**14**	%

PLASTIC LIMIT				
Container No.	111	160		**Average**
Wt of wet soil + container, gm	20.79	20.94		
Wt of dry soil + container, gm	20.06	19.57		
Wt of container	17.60	14.83		
Wt of water	0.73	1.37		
Wt of dry soil, gm	2.46	4.74		
Water content, %	29.7	28.9		**29.3**

Station 65+000CL

ATTERBERG LIMIT, AASHTO T-89 & T- 90

LIQUID LIMIT				
Container No.	142	129	HH	
Wt of wet soil + container, gm	34.66	32.39	34.26	
Wt of dry soil + container, gm	28.52	27.02	29.19	
Wt of container	15.07	14.98	17.60	
Wt of water	6.14	5.37	5.07	
Wt of dry soil, gm	13.45	12.04	11.59	
Water content, %	45.7	44.6	43.7	
No. of blows	19	26	35	



Sample preparation		
As received	☐	
Washed on 0.425mm sieve	☐	
Air dried at ……30°C	☑	
Oven dried at …………oC	☐	
Proportion retained on 0.425mm sieve		
Liquid Limit	**45**	%
Plastic Limit	**34**	%
Plasticity Index	**11**	%

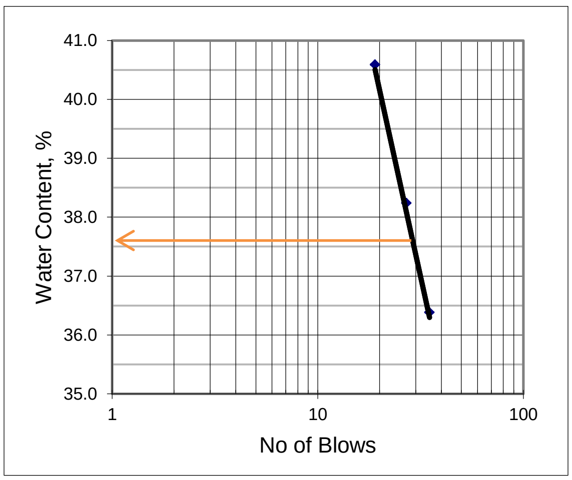
PLASTIC LIMIT				
Container No.	48	216		**Average**
Wt of wet soil + container, gm	25.18	30.21		
Wt of dry soil + container, gm	22.41	26.37		
Wt of container	14.24	14.90		
Wt of water	2.77	3.84		
Wt of dry soil, gm	8.17	11.47		
Water content, %	33.9	33.5		**33.7**

Station 67+500CL

ATTERBERG LIMIT, AASHTO T-89 & T- 90

LIQUID LIMIT

Container No.	124	DD	128	
Wt of wet soil + container, gm	31.38	33.47	34.26	
Wt of dry soil + container, gm	26.40	28.30	28.85	
Wt of container	14.13	14.78	13.98	
Wt of water	4.98	5.17	5.41	
Wt of dry soil, gm	12.27	13.52	14.87	
Water content, %	40.6	38.2	36.4	
No. of blows	19	27	35	



Sample preparation

As received ☐
Washed on 0.425mm sieve ☐
Air dried at ……30^{o}C ☑
Oven dried at ………..oC ☐
Proportion retained on 0.425mm sieve

Liquid Limit	**38**	%
Plastic Limit	**23**	%
Plasticity Index	**15**	%

PLASTIC LIMIT

Container No.	18	76		**Average**
Wt of wet soil + container, gm	29.27	34.55		
Wt of dry soil + container, gm	26.66	31.33		
Wt of container	15.19	17.30		
Wt of water	2.61	3.22		
Wt of dry soil, gm	11.47	14.03		
Water content, %	22.8	23.0		**22.9**