DYNAMIC CONE PENETRATION TEST: AN ALTERNATIVE METHOD FOR QUALITY CONTROL OF SUBGRADE LAYER

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A thesis submitted to the Department of Civil Engineering of Daffodil International University (DIU) in partial fulfillment of the requirement for the degree of

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The thesis titled ***"Dynamic Cone Penetration Test: An Alternative Method for Quality Control of Subgrade Layer"*** Submitted by Anjon Tongcongya (Student ID: 173-47-598), and Md. Tanveer Hossain (Student ID: 173-47-609), Session: Fall 2017, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc.) in Civil Engineering on September 17, 2022.

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AUTHOR DECLARATION

This is hereby declared that this research work has been performed under the supervision and guidance of Mohammad Mominul Hoque, Assistant Professor in the Department of Civil Engineering at Daffodil International University, Dhaka, Bangladesh. Any part of this work has not been submitted elsewhere for the award of any degree of Diploma.

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DEDICATION

Dedicated

To

Our parents

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First of all, authors would like to express their deepest gratefulness and gratitude to Almighty Allah/God for his kindness and blessing for allowing us to complete this thesis work. Authors would like to express their appreciation to Mohammad Mominul Hoque, Assistant Professor, Department of Civil Engineering, Daffodil International University, for continuous assistance and guidance throughout the process of completing this research. Appreciation is also extended to all other teachers, who taught us at Daffodil International University.

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ABSTRACT

The durability of subgrade layer depends on the and compactness of the materials. However, the commonly used method for checking the density of subgrade layer is costly and time consuming. This study helps to eradicate these problems by introducing an alternative method to check the density at field. In this research the relationship between Dynamic cone penetrometer (DCP) and soil dry density was developed. The collected soil samples from LGED road development projects at 6 different locations were selected to develop the relationship. Grain size analysis, Liquid limit and Plastic limit, Specific gravity, Standard proctor test, sand cone test were performed on these samples. In laboratory the standard ASTM method was followed for compaction, a 4-inch diameter cylindrical mold and 2.5 kg hammer with drop height of 12 inch was used to prepare the test sample. The test samples were prepared at different density by varying the compaction rate and DCP penetration were measured. A number of DCP test were performed on compacted test samples to determine the penetration rate. Then the relationship were developed between DCP penetration and dry density. A linear relationship was developed between DCP penetration and dry density. The relationship developed from this study can be used to checked the density at field using DCP more efficiently comparing with sand cone method.

ABBREVIATION AND ACRONYMS

SRD	: Sand replacement density.
DCPT	: Dynamic cone penetration test.
DCP	: Dynamic cone penetration.
TRL-DCP	: Transportation Research Laboratory Dynamic Cone Penetration.
KG	: Kilogram.
mm	: Millimeter.
CBR	: California Bearing Ratio.
SPT	: Standard Penetration Test.
CPT	: Cone Penetration Test.
ASTM	: American Society for Testing and Materials.
TRRL	: Transportation Road Research Laboratory.
PI	: Penetration Index.
ABC	: Aggregate base course.
OMC	: Optimum Moisture Content.
UCS	: Unconfined Compressive Strength.
AASHTO	: American Association of State Highway and Transportation Officials.
LGED	: Local Government Engineering Department.
TS	: Test Sample.
$NaPO_3$	: Sodium Hexametaphosphate.
^oC	: Degree Celsius.
MDD	: Maximum Dry Density.
RMC	: Required Moisture Content.
M_b	: Mass of Sample used.
EMC:	: Existing Moisture Content.
Gs	: Specific Gravity.
FDD	: Field Dry Density.

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INTRODUCTION

1.1 GENERAL

Durability or strength of road layer are generally depending on material type, coarseness and shear strength, thus the compactness of the particular layer materials. Hence checking compactness as well as the density of any road layer material is an important issue. There are many effective and efficient methods for checking in situ density. Some of those are: - Water replacement method of field density test, Core cutter method, Rubber balloon method, nuclear moisture density meter etc. Sand replacement density (SRD) method or sand cone method for determining the density of subgrade layer is a common use method though out the world. In Bangladesh, SRD is one of the most common used methods.

But it is without a doubt can be said that those test procedure for checking density is guided by the other laboratory tests and is time consuming, which impacts the efficiency of the project implementation process. This paper talks about an alternative method to checking in situ compaction (Density) of road layer materials in a shorter time by using the Dynamic cone penetration test (DCPT) by establishing a correlation between dry density and penetration rates of DCPT. To establish the relation between dry density and penetration rates number of DCP tests were done on laboratory compacted soil and also on compacted road layer materials in the field.

1.2 STATEMENT OF THE PROBLEM

Generally, the quality of a subgrade is determined by comparing the dry density and water content of soils to the results of laboratory compaction tests (MDD). While the sand cone method was formerly a widely used technique for evaluating subgrades in practice, the nuclear gauge is now very popular. The nuclear gauge provides an extremely rapid and practical method for determining the in-situ soil density and water content. However, it is powered by nuclear energy and needs a specialized operator who has completed a specialized training program and is registered to operate. As a result, a more secure and convenient method of compaction control for road and general construction practices is sought. There has been little study undertaken till to date on the use of DCP in general and on its use in determining the densities of cohesive soils. This study is talking about a reliable process of finding dry density accurately by an alternative method.

1.3 OBJECTIVE

The primary objective of this study is to develop an alternative method for quality control of subgrade layer by establishing a reliable correlation between soil dry density and DCP penetration rate for different soils**.**

1.4 SCOPE OF WORK

In this research, soil was collected from different site location from Mirpur, Agargaon, Gazipur, Narayanganj, Jamalpur and Kishorganj. After the particle size analysis of soil sample, the test samples were compacted using the proctor method by AASHTO T 99 to get the maximum density and optimum moisture content. After that several samples were compacted at their optimum moisture content to get different density. DCP tests is then performed on the compacted soil. For reliability, similar DCP tests were performed in the field thus comparing with lab and field tests. A relationship between penetration rate of compacted soil and soil density were made.

1.5 ORGANIZATION OF THESIS

This thesis paper is organized into five different chapters to provide an understanding to the readers.

Chapter one presents a general overview of the paper following the scope of the study to be done and the objectives to gain regarding the study.

Chapter two contains the background for the study. It contains the literature review of the previous study on Dynamic cone penetration test and its result on the different methods to establishing relation on shear strength, soil bearing ratio, and unconfined compression capacity for the soil.

Chapter three gives the results of the laboratory test. It contains a summary of the tests conducted for the study, the graphical representation for the test result shows the compacted soil at various moisture content penetration rates which can be determined by DCP test at field.

Chapter four contains the discussion of the test results. How the compacted soil of various density gives different penetration rate for DCP test are shown and compared between lab and field test result are described.

Chapter five includes concluding remarks, limitations and recommendations for further research related to the scope of this study.

CHAPTER TWO

LITERATURE REVIEW AND APPLICATION

2.1 GENERAL

The present DCP machine was first developed in 1956. As its development and research continued through time many modifications were made. The current world uses the Transportation Research Laboratory Dynamic Cone Penetration (TRL-DCP) test apparatus. Which consists of an 8 kg rammer 22.6 inches guiding rod that produce 45 joules of potential energy. The use of DCP test is for rapid in situ measurement of structural properties.

However, there are many research paper on DCP which produces existing correlation such as follows:

- Relationship of DCPT and California bearing ratio.
- Relationship of DCPT, Dry unit weight.
- Relationship of DCPT and Relative density of sand.

the primary advantage of using DCPT is because of its tiny size and low weight. it can be confined within relatively small spaces. Another advantage of it is reduced cost-effectiveness and manpower. Which makes DCP an ideal choice for establishing faster and more effective results in the field.

2.2 HISTORY OF DYNAMIC CONE PENETRATION

For the rapid in situ measurement of the structural properties of existing road pavements with unbound granular materials, the Transportation Research Laboratory Dynamic Cone Penetration (TRL-DCP) test apparatus is designed. Continuous measurements can be made to a depth of 800 mm or 1200 mm when an extension rod is fitted. The driving principle behind the DCP is that the rate of penetration of the cone, when driven by a standard force, is inversely related to the strength of the material as measured by the California Bearing Ratio (CBR) test. This is a test in which the pavement layers each have their unique strength, the boundaries between the layers can be identified, and the thickness of the layers can be determined. The DCP requires three operators; one to hold the instrument, one to raise and lower the weight, and one to record the data. The instrument is held in a vertical position, the weight is lifted gently up to the handle, and then the weight is set to fall freely onto the anvil.

Before allowing the instrument to drop, care should be taken to ensure that the weight is in touch with the handle but is not lifting it. The operator does not use his hand to slow the weight's descent and instead allows it to fall freely. If during the test is being performed, the DCP leans away from the vertical, no attempt should be made to rectify this since doing so might cause the shaft to come into touch with the sidewalls of the hole, which would provide inaccurate results. If the angle of the instrument becomes worse, which causes the weight to slide on the hammer shaft instead of falling freely, then the test has to be scrapped and redone. It is advised that reading be obtained at intervals of penetration that are about 10 millimeters in size. On the other hand, taking readings after a predetermined number of blows is often simpler. Because of this, it is essential to adjust the number of blows that occurs in between readings in accordance with the thickness of the layer that is being measured.

Figure 2.1: Dynamic Cone Penetrometer

The Dynamic Cone Penetration test (DCPT) was developed in Australia by Scala (1956) (Scala, 1956) “the Transvaal Roads Department in South Africa (Luo, 1998) developed the current model. The mechanics of the DCPT shows features of both the CPT and SPT. The DCPT is performed by dropping a hammer from a certain fall height and measuring penetration depth per blow for a certain depth. Therefore, it is quite similar to the procedure of obtaining the blow count N using the soil sampler in the SPT. In the DCPT, however, a cone is used to obtain the penetration depth instead of using the split spoon soil sampler. In this respect, there is some resemblance with the CPT in the fact that both tests create a cavity during penetration and generate a cavity expansion resistance. In road construction, there is a need to assess the adequacy of a subgrade to behave satisfactorily beneath a pavement. Proper pavement performance requires a satisfactorily performing subgrade.

A recent joint transportation research program project by Luo (1998) was completed showing that the DCPT can be used to evaluate the mechanical properties of compacted subgrade soils".

DCP was developed in 1956 in South Africa as in situ evaluation of pavement layer strength (Scala, 1956) which is also known as the Scala penetrometer. Since then, this device has been extensively used in South Africa, the United Kingdom, the United States, Australia and many other countries, because of its portability, simplicity, cost-effectiveness, and the ability to provide a rapid measurement of in situ strength of pavement layers and subgrades. Later, DCP is standardized by ASTM (ASTM D 6951-03). The DCP has also been proven to be useful during pavement design and quality control programs. The DCP was not a widely accepted technique in the United States in the early 1980s (Ayers et. al., 1989). De Beer (1991), Burnham and Johnson (1993), Burnham (1997), Newcomb et al (1994) and Hasan (1996) have shown considerable interest in the use of the DCP for several reasons.

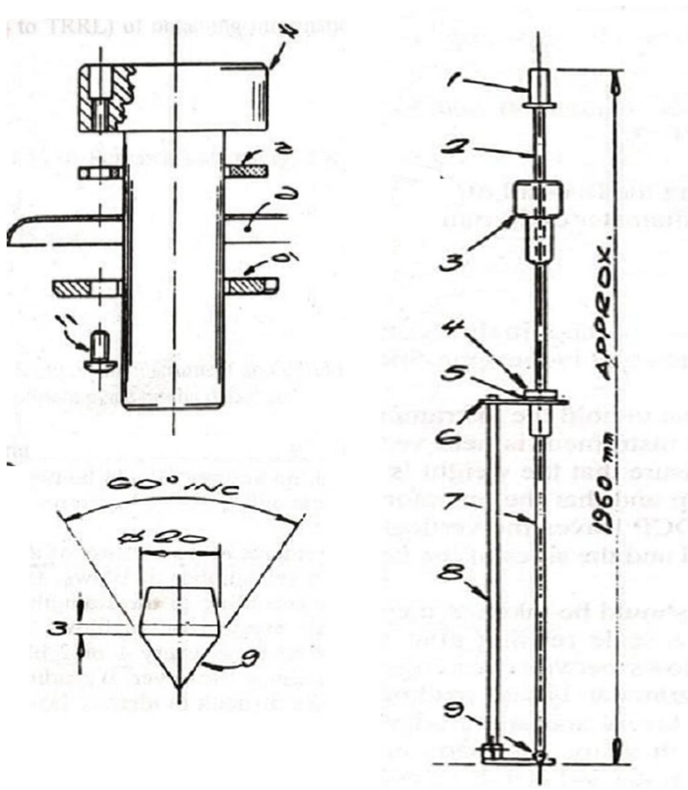
Firstly, the DCP is adaptable to many types of evaluations. Secondly, there are no other available rapid evaluation techniques and finally DCP test is economical.

DCP was developed in 1956 in South Africa as in situ evaluation of pavement layer strength (Scala, 1956) which is also known as the Scala penetrometer. Since then, this device has been extensively used in South Africa and the United Kingdom. The in-situ shear resistance was measured using a Dynamic Cone Penetrometer (DCP). On a log-log graph, the DCP measurement is shown against a CBR generated from lab tests; the connection between these two parameters is linear (Scala, 1956).

Despite putting in a lot of work to Figure out how to utilize the DCP curves as pavement quality indicate. Scala invented a Dynamic Cone Penetrometer (DCP) in 1956 in Australia, based on an earlier Swiss design, to assess the shear strength of a pavement. (Scala, 1956). "This included dumping a 9 kg (20 pounds) mass of 508 mm (20 inches) into the material being tested and striking a cone with a 30° tip into it. The device's promise was recognized, and development proceeded in South Africa" (Hopkins, 1960). With time, a variety of variations emerged, each with varied masses, fall distances, and even cone diameters, despite the fact that the energy imparted (mass x fall), remained essentially the same. The device was standardized in South Africa in the early 1970s with the following dimensions. (Figure 2.2): Mass 8 kg, fall distance 575 mm, Cone 60°. It should be mentioned that in South Africa, a mechanism with a

10-kilogram load dropping 460 mm is also employed. Although both setups have the same potential energy (mgh), the kinetic energy applied ($\frac{1}{2}mv^2$) varies dramatically.

The momentum (mv), which may be a more important metric, is the same in both arrangements. As a result, it is advised that just the setup illustrated in Figure 2.2 be utilized, as the rest of the course is based on discoveries made with this equipment.



1. Handel
2. Hammer Guide rod
3. Hammer (8Kg)
4. Anvil
5. Damping Washer
6. Handguard & Cursor
7. Drive rod
8. Vertical Scale
9. 60º Cone

Figure 2.2: Schematic of standard DCPT

2.3 DEVELOPMENT OF DCP

Although the initial DCP had a 30-degree cone, 60-degree cone has become more popular in the latest years due to its durability in high-strength materials, as reported in the current ASTM D 6951 method. Scala (Scala, 1956)"presented the dynamic cone penetrometer based on the previous designs in Switzerland. The drop height of the hammer was 508 mm, the hammer weight was 9 kg, and the cone angle was 30 degrees.

Scala's penetrometer was used with an extension to a depth of 1.8 m. In addition, Scala introduced the theoretical relationship between the applied energy and soil resistance and penetration rate, and developed the DCP-CBR correlation that was used for pavement design".

Gawith and Perrin (Gawith, 1962) reported the use of the same DCP in Australia with a DCP-CBR correlation curve.

“In the late 1960s, Dr. D. J. van Vuuren continued to develop the DCPT in Pretoria. He used a similar device, except for some differences in dimensions: a 10kg hammer was dropped from a height of 460mm, forcing a 30-degree cone connected to a 16mm diameter rod into the soil up to 1000mm” (van Vuuren, 1969). “The Transvaal Roads Department in South Africa began using the DCP to investigate road pavement in 1973” (Kleyn E. , 1975).

“Kleyn reported the relative results obtained using a 30° cone and a 60° cone. In 1982, Kleyn described another DCP design, which used a 60° cone tip, 8 kg hammer, and 575 mm free fall. He evaluated the effects of soil type, plasticity, moisture content, and density on the test results of DCPT” (Kleyn E. , 1975)

“Chua (1988) developed a model to connect the initial elastic modulus of soils to the penetration resistance of the DCP. Chua and Lytton (1988) mounted an accelerator on the top of the DCP and used this modified DCP to estimate the hysteretic and viscous damping ratios in situ. In their study, the DCP is modeled as a series of springs and masses, and the soil as a dashpot” (Chua, 1988). “Ayers et al (1989) conducted a series of DCP tests on granular materials in the laboratory, relating the shear strength of granular materials to DCP test data. When comparing compaction methods in narrow subsurface drainage trenches” (Ayers, 1989).

“Ford et al. (1993) utilized the DCP as a control method, indicating that the DCPT results generally correlated well with proctor compaction data, thus showing promise for evaluating compaction in narrow, granular-backfilled trenches” (Ford, 1993).

“Burnham and Johnson (1993) reported the application of the DCP in the projects of the Minnesota Department of Transportation. Little (1996) used the DCP to determine the in-situ strength and to verify the effective stiffness of lime-stabilized soils for back-calculation purposes” (Burnham T. a., 1993).

Presently, A TRRL (Transportation Road Research Laboratory, UK) model DCP is used widely in Bangladesh to evaluate the strength of road layer materials, layer thickness and comparative compaction condition. TRRL model DCP is consisting of 60^0 cones 20 mm in diameter. An 8 kg weight dropped from a constant height of 575mm.

From the above historical review of the development of the DCP, it is observed that the testing can be applied to the characterization of subgrade and base material properties. Table 1 summarizes. Some versions of the DCP.

Table 2.1: Few Versions of DCP *(Ampadu, 2005)*

Type	Cone Diameter (mm)	Mass of Hammer (Kg)	Height of Fall (mm)	Energy Per Blow per Cone Area (KN.m/m2)
Scala (1956)	20	9	508	143
Sowers & Hedges (1966)	38	6.8	508	30
Kleyn (1975)	20	8	575	144
Singh (1973)	35	10	500	51
Ampadu (2005)	20	10	460	144
TRRL, UK	20	8	575	144

2.4 COMPONENTS OF DCP

Because the design specifications of the parts have such a significant influence on the findings obtained from the testing, the different components of the DCP are of the utmost significance. Figure. 2.8 depicts the overall layout of the DCP instrument's diagrammatic representation. Stainless steel was used in the construction of the instrument so that it would be more durable and have a higher level of efficiency. The next paragraphs will provide an overview of the many components that make up DCP.

Cone for Probing: The probing cone is the component of the DCP instruments that are considered to be the most important. As soon as the test begins, the probing cone breaks through the surface of the sand. Therefore, the design of the probing cone must be perfect in accordance with the specifications. The height of the probing cone that we used is 1.95 centimeters, and the angle of the cone is 60 °. The diameter of the probing cone at the edge is 2.25 centimeters. The size of the cone has the potential to have a major impact on the outcomes.

Figure 2.3: Probing Cone

Anvil: Another essential component of DCP is the anvil. The hammer falls on the anvil each time data is intended to collect. A connection has been made between the anvil and the extension rod. Additionally, it is constructed out of stainless steel. In addition, the anvil contains the clamp that is accountable for maintaining the position of the scale.

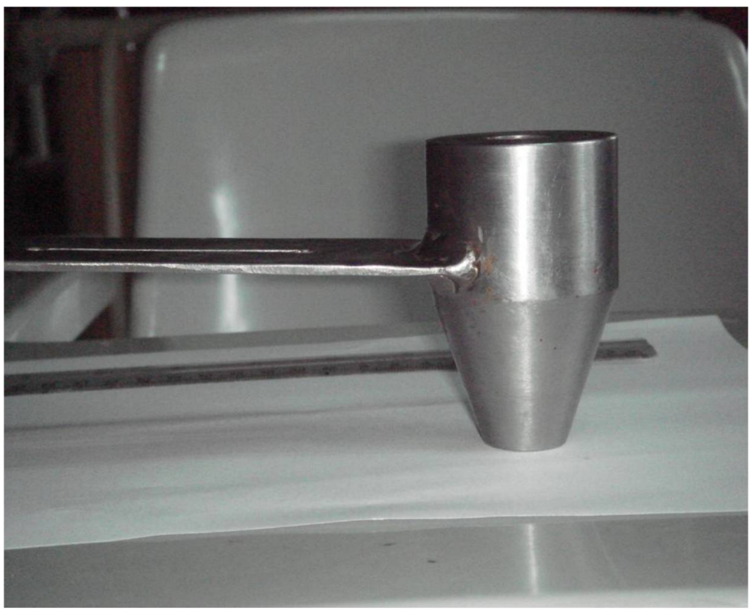


Figure 2.4: Anvil

Guide Rod: A guide rod is a rod that is used to direct the hammer so that it falls on the anvil. The diameter of the guiding rod is 1.6 centimeters, and it is manufactured of stainless steel. 81.4 centimeters is the length of the guide rod when it does not include the thread.

Figure 2.5: Guiding rod

Hammer: A hammer weighing 8 kg is used in the DCP. The hammer is pushed along the rod by the guide.

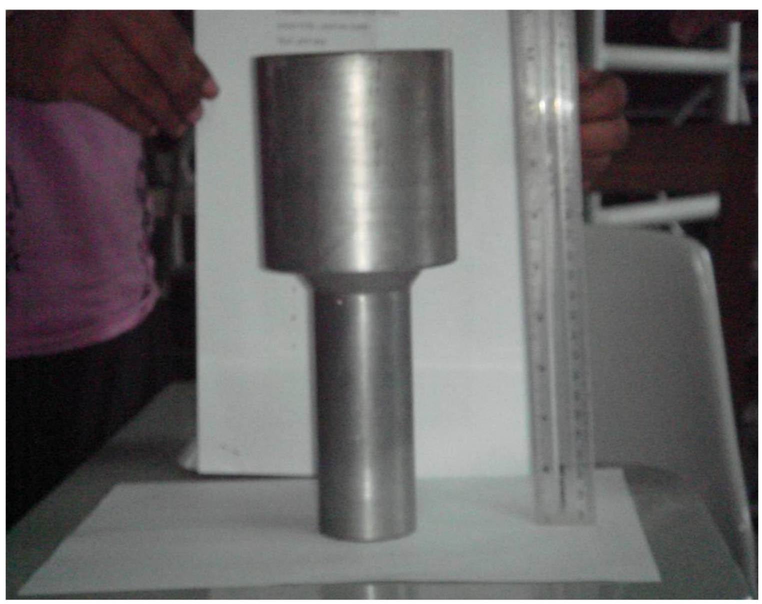


Figure 2.6: 8kg Hammer

Extending Rods: By connecting successively longer extending rods to one another, we may produce longer extending rods.

Figure 2.7: Extension rods

a longer rod that can reach greater depths. The extension rods have a length of 100 centimeters and a diameter of 1.6 centimeters.

Handle: A handle is often fastened to the very top of a guide rod. It is a guide for the operator to follow in order to get the hammer up to that level, in addition to assisting the operator in holding the instrument in position.

Figure 2.8: Handle to hold DCP during test.

Damping Washer: A damping washer is the sound of the impact and also increases the instrument's durability for a longer period of installation at the point where the hammer and the anvil meet. It softens time. It might be a piece of geotextile or any other material that dampens sound.

1 m Scale: Additionally, a one-meter stainless steel scale is used in order to get a reading of the rod that has been pierced in millimeters per blow.

2.5 APPLICATION OF DCP

2.5.1 CALIFORNIA BEARING RATIO (CBR)

The California Bearing Ratio (CBR) test is a test that is often used as a measure of the strength of a subgrade soil, as well as a subbase and base course material, in roadway and airport pavement systems. This test is quite straightforward. The ASTM D1883-99 standard includes a description of the test.

The CBR test's primary purpose is to experimentally calculate the needed thicknesses of flexible pavements, and it does this by measuring the pavement's resistance to compression. In most cases, the procedure is carried out on remolded (compacted) specimens; however, it may also be carried out on undisturbed soils or soils found in the wild. If the CBR is to be determined at 100 percent of the maximum dry unit weight and the optimal moisture content, remolded specimens may be compressed to their maximum unit weights at their optimum moisture contents. In addition, CBR tests may be carried out at the unit weights and moisture contents of the subject's choosing. To replicate very degraded soil conditions, test soil samples are submerged in water for ninety-six hours before being examined. CBR is defined as the ratio (expressed as a percentage) that is obtained by dividing the standard penetration stress of 1,000 psi by the penetration stress required to cause a piston with a diameter of 49 mm (1.95 inches) to penetrate 0.10 inches into the soil. This ratio is then expressed as a percentage. This standard penetration stress is nearly equivalent to what is necessary to induce the same piston to penetrate 0.10 inches into a pile of crushed rock. You might think of the crushed rock equivalent, or CBR, as a measure of how strong the soil is in comparison to the strength of crushed rock.

It is important to note that the conventional penetration stress for 0.10-inch penetration is 1,000 psi, which is found in the denominator of the equation. If the bearing ratio based on penetration stress required to penetrate 0.20 inches with corresponding standard penetration stress of 1,500 psi is greater than the one for a 0.10inch penetration, the test should be repeated. If the result is still the same after the second run, the ratio based on the 0.20 inch penetration should be reported as the CBR value.

According to the procedure described in ASTM D1883-99, if the CBR is desired at an optimum water content and some percentage of maximum dry unit weight, three specimens should be prepared and tested from soil to within 0.5 percent of the optimum water content while using a different compacted effort for each specimen such that the dry 2.36100 is achieved. This is necessary in order to achieve the desired results.

$$\boldsymbol{CBR = \frac{Pentration\ stress\ (psi) required\ to\ penetrate\ 0.10\ inch}{1000\ psi}\ x\ 100}$$

The unit weights of these specimens may be found to be both higher and lower than the value that is required. After that, the CBR values for the three samples should be plotted against the values that correspond to their dry unit weight, and the CBR value for the required dry unit weight should be computed using this plot.

The CBR test is very sensitive to the texture of the soil, the water content of the soil, and the density of the soil after it has been compacted. The outcome of a CBR test is also determined by the amount of resistance that is presented to the penetration of the piston. As a result, the CBR provides an estimate that is somewhat indirect of the shear strength of the material that is being evaluated (Rodriguez et al. 1988).

2.5.2 RELATIONSHIP BETWEEN DCPT AND CALIFORNIA BEARING RATIO (CBR)

The CBR and DCPT both use comparable testing procedures. As a consequence, the results of the tests may represent identical mechanical properties. In comparison to the preceding section's study on PI-CBR relationships, (PI = penetration index mm/blow). Numerous researches have shown a relationship between DCPT and CBR in Table 2.2

Table 2.2: Relation Between DCPT and CBR

Author	Correlation	Field or laboratory-based study	Material tested
Kleyn (Kleyn, 1975)	Log (CBR) = 2.62-1.27 log (PI)	Laboratory	Unknown
Harison (Harison, 1987)	Log (CBR) = 2.56-1.16 log (PI)	Laboratory	Cohesive
Harison (Harison, 1987)	Log (CBR) = 3.03-1.51 log (PI)	Laboratory	Granular
Livneh et al (Livneh M. I., 1995)	Log (CBR) = 2.46-1.12 log (PI)	Field and Laboratory	Granular and Cohesive
Ese et al. (Ese, 1994)	Log (CBR) = 2.44-1.07 log (PI)	Field and Laboratory	ABC*
Coonse (Coonse, 1999)	Log (CBR) = 0.53-1.14 log (PI)	Laboratory	Piedmont residual soil
Gabr (Gabr, 2000)	Log (CBR) = 1.40-0.55 log (PI)	Field and Laboratory	ABC*
TRRL,UK	Log (CBR)= 2.493-1.0177 log (PI)	Field and Laboratory	Cohesive

*Aggregate base course

2.5.3 RELATIONSHIP BETWEEN DCPT, DRY UNIT WEIGHT AND MOISTURE CONTENT

PI values, according to Harrison (Harison, 1987), are dependent on the amount of moisture in the sample and its dry weight, and specific relationships between the two have been found. Figure 2.3 depicts the normal trend of PI in terms of dry unit weight and moisture content.

Figure 2.3 (b) shows decreasing PI values as dry unit weight increases. This seems to be a plausible conclusion, given that denser soils are more resistant to penetration.

The compaction curve is shown in Figure.2.3 (c), which reveals a correlation between PI values and moisture contents. With increasing moisture level, the PI value falls up to the optimal moisture content (OMC) for given compaction energy, as illustrated in the Figure.

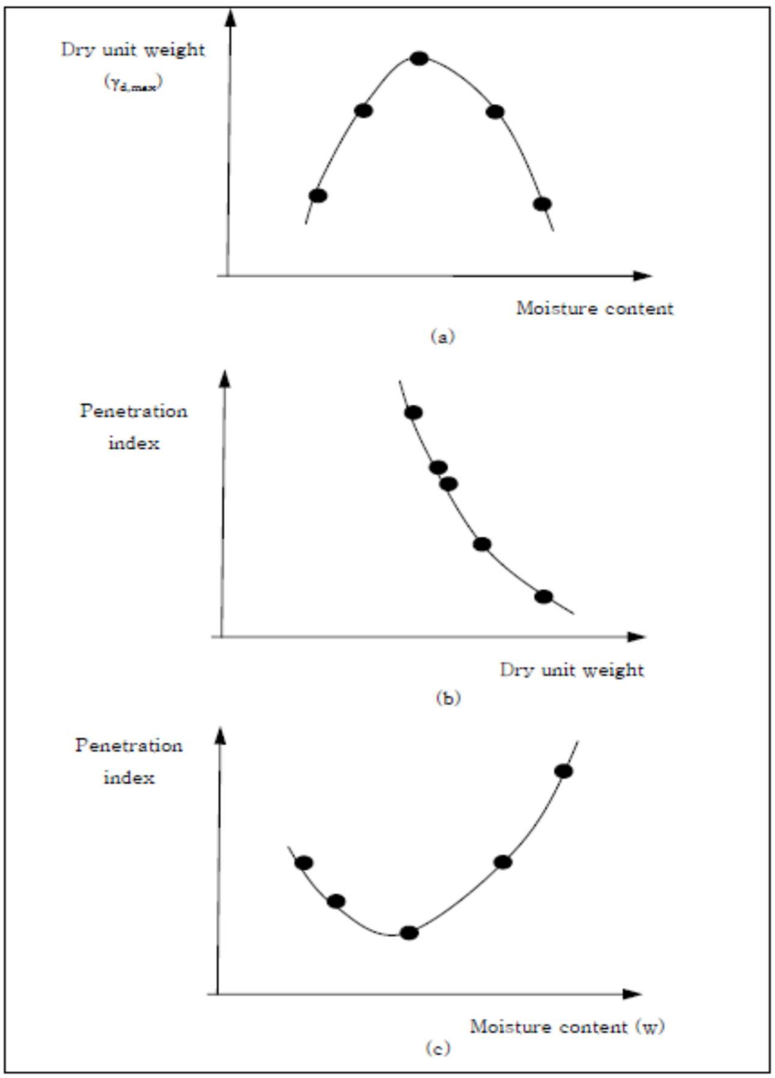


Figure 2.9: PI vs Compaction parameters from laboratory result *(Harison, 1987)*.

2.5.4 RELATIONSHIP BETWEEN DCPT AND SHEAR STRENGTH

Gawith (Gawith, 1962) performed a laboratory study to determine relationships between the PI and the shear strength (the angle of internal friction ϕ):

ϕ (deg) = 52.16/ (PI) 0.13

2.5.5 RELATIONSHIP BETWEEN DCPT AND UNCONFINED COMPRESSIVE STRENGTH (UCS):

A graphical relationship between DCPT test results CBR and UCS is in shown the figure.

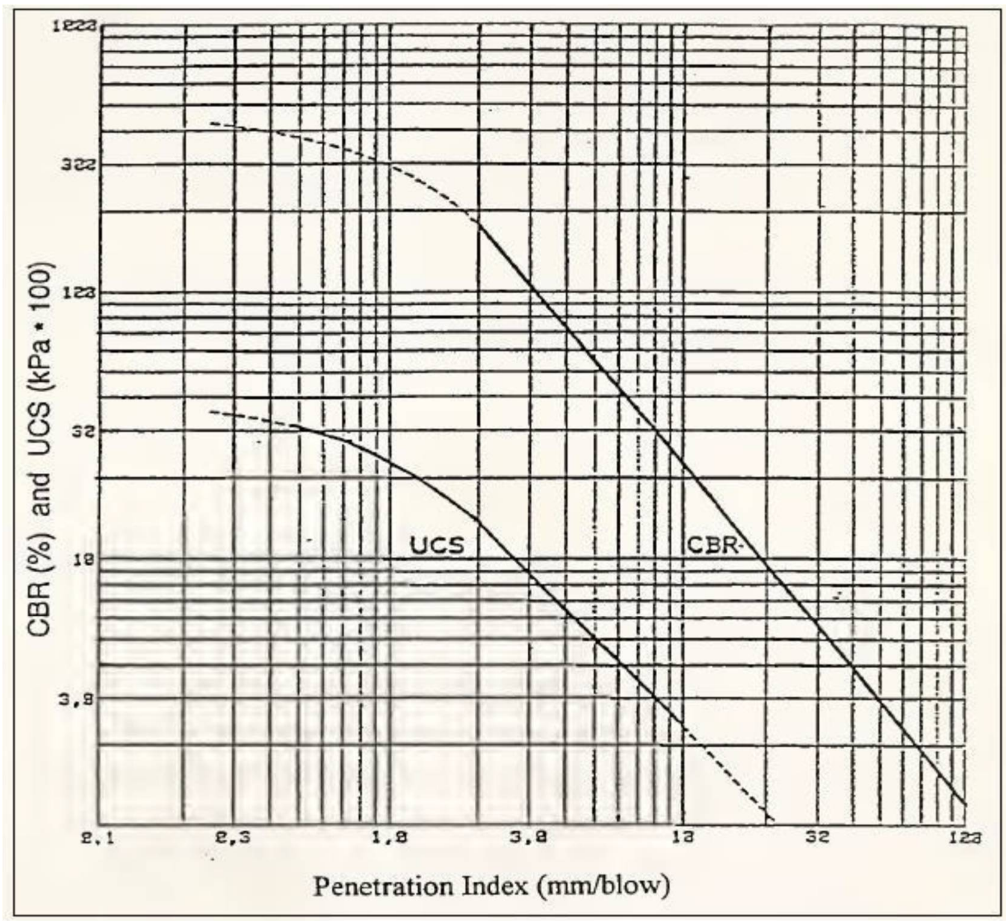


Figure 2.10: The relationship between PI and UCS Test. (Kleyn E. a., 1982)

2.5.6 APPLICATION OF DCP IN PERFORMANCE EVALUATION OF PAVEMENT LAYERS

"Performance evaluation of pavement layers is needed regularly to categorize the implementation of rehabilitation measures (e.g., Kleyn, et al., 1982). The Minnesota Department of Transportation, based on the analysis of Mn/Road DCP testing, has recommended the following limiting values for DCP index during a rehabilitation study" (Burnham T. , 1997).

a) Silty/Clayey material: DCP index less than 25 mm/blow (1.0 in/blow)

b) Select granular material: DCP index less than 7 mm/blow (0.28 in/blow)

c) Mn/Road Class 3 special graduation requirements: DCP index less than 5 mm/blow (0.2 in/blow)

The following values are dependent on the assumption that appropriate confinement exists near the testing surface. In the case that higher values exceed the above-mentioned limitation levels, additional testing methods are required. Note that the above values are independent of the moisture content. Moisture content might cause substantial variability in DCP test findings. Nevertheless, a limiting value was recognized. Gabr et al. (Gabr, 2000) "proposed a model by which the DCP data are utilized to evaluate the pavement distress state. They proposed a model to predict the distress level of pavement layers using penetration resistance of the subgrade and aggregate base course (ABC) layers based on coupled contribution of the subgrade and the ABC materials. They provided a step-by-step procedure, based on the correlation of the DCP index with CBR, by which the DCP data can be used to evaluate the pavement distress state for categorizing the need for rehabilitation measures. Although their pavement stress model was specific in this study regarding the type of the ABC material tested, the framework of the procedure can be used at other sites".

2.5.7 APPLICATION OF DCP TO OBTAIN LAYER THICKNESS

DCP may also be used to determine the thickness of a soil layer based on the changing slope of the depth vs the profile of accumulated blows. Livneh (Livneh M. , 1987) showed that the layer thickness obtained from DCP tests corresponds reasonably well to the thickness obtained from the test pits. It was concluded that the DCP test is a reliable alternative for project evaluation".

2.6 PURPOSE OF A DYNAMIC CONE PENETRATION TEST

The dynamic cone penetration test (DCPT) is a common way to test the quality of soil in the field. It is hard to get undisturbed soil samples, especially when sand is loose or underwater, which makes it easier to use this method to predict the engineering properties of soil around the world.

The dynamic cone penetration test is a way to measure how hard a material is to break through in real life. The test is done by repeatedly hitting a metal cone from 575 mm away with an 8 kg weight. This drives the cone into the ground.

After each blow, the cone's depth of penetration is measured and written down. This gives a continuous measure of the shearing resistance up to 5 feet below the surface of the ground. The test results can be connected to California Bearing Ratios, in-situ density, resilient modulus, and bearing capacity.

2.7 PREVIOUS LITERATURE REVIEW

Soil liquefaction occurs due to applied stress on sand fill beneath the structure and surrounding area. Due to the expensiveness of the mitigation measures to prevent soil liquefaction, compaction control of sand fill is generally done.

The sand cone method is commonly used in compaction control by determining field density, which is a common practice in Bangladesh. This test has to be performed tends to be expensive and cumbersome to do after completion of compaction in every single layer. The paper represented by Mohammad Shahadat Hossain on the relative density of sand using dynamic cone resistance aims to an alternative method that can be used to determine an easier and faster process of finding relative density.

From that experimental study, it is concluded that a generalized correlation between Relative Density and P_{index} was found which is applicable to clean sand off any particle size. Resistance of sand increases exponentially with relative density. The larger the particle size greater the resistance to penetration for a certain relative density of sand. Denser sand gives more resistance to a specific type of sand. The proposed method can be used as an indirect method to determine in situ relative density of sand deposit for up to 2 m depth. – (Hossain & Mohammad, 2009)

2.8 ADVANTAGES AND DISADVANTAGES OF THE DCP TEST

2.8.1 ADVANTAGES:

1. It is inexpensive.
2. This test does not need a borehole.
3. This test can be performed quickly so that it covers a large area making it economical.
4. It is a simple device, requiring two people for its operation, whereas the automated DCPT requires only one operator.
5. It is fast to conduct, leading to large amounts of data over the area.
6. It is portable and suitable when access and space become a constraint especially in confined areas such as inside buildings to be rehabilitated or at congested sites that would prevent the use of traditional boring equipment.
7. The test results can correlate to other soil parameters (CBR, shear strength, and SPT N-values).
8. It is cost-effective to operate, especially when compared with other traditional site characterization methods (borings and laboratory/field tests).

2.8.2 DISADVANTAGES:

1. No samples are obtained.
2. This test could not be performed on very loose cohesionless soil.
3. It is not possible to determine the mechanical properties of soil by this test.
4. It is not possible to measure soil friction that occurs significantly along the extension rod at a great depth.
5. It is not yet a standard testing method, although a proposed ASTM standard is being considered.
6. It is not suitable for gravel soils: the DCP rod may be bent during testing. Variability of the results can be expected significantly in such soils.
7. It is a dynamic test, which means it is somewhat difficult to analyze and interpret.
8. It does not permit groundwater conditions to be readily evaluated.

CHAPTER THREE

LABORATORY AND FIELD TESTS

3.1 GENERAL

This chapter talks about the experiments on the different types of sourced material. At first, the collected soil samples from the field were classified to observe the different density-penetration relations on different soil types.

After visual inspection of the test sample, Grain size analysis was performed to determine the percentages passing of soil components. Hydrometer tests are also performed for clayey and silty soil and a brief soil finer graph ware made to understand the complete particle passing.

To acquire the compacted density, water were mixed varying 2% into the soil and compacted following AASHTO T-99 for Standard proctor. DCP test performed on the compacted soil samples of different densities. From observing the test data, it is understandable that due to the variable of moisture content there was no correlation between penetration rate and soil dry densities.

After the first attempts of establishing a relation between dry density and penetration rate of soil test results were impermissible. A second attempt were taken to prepare the sample in optimum moisture content, compact the sample in different density and DCPT were performed on the test samples. The result shows a linear disproportional relation between density and penetration rate.

On the basis of this finding, several lab and field tests were performed on the test samples and test result remains the same for each trial.

3.2 COLLECTIONS OF SOIL FROM THE FIELD

For our thesis, the collected test samples were from the subgrade layer. The field work was done at an ongoing project under LGED Dhaka, Gazipur, Jamalpur, Narayanganj, Kishorganj districts. Several samples from each location were obtained using a manual auger or trial pit.

About 20 kg of soil samples were collected from the field to perform classification, and density test by proctor method or by CBR. Before performing compaction, CBR or DCP; classification is very important. About 150 gm specimens were dried for sieve analysis, aggregated samples were sent to the laboratory for further tests.

Table 3.1: Test samples Sequence according their location.

Location	Sample Name
Mirpur	Test sample_1
Gazipur	Test sample_2
Agargaon	Test sample_3
Narayanganj	Test sample_4
Jamalpur	Test sample_5
Kishorganj	Test sample_6

Figure 3.1: Different site location (From google map)

3.3 LABORATORY INVISTIGATION

List of Tests performed in the lab

- Grain size analysis
    - Sieve analysis
    - Hydrometer analysis
- Liquid limit and Plastic limit
- Soil classification and grouping
- Specific gravity
- Maximum dry density test
- Dynamic cone penetration

List of tests performed in the field

- Sand cone
- Dynamic cone penetration

3.3.1 GRAIN SIZE ANALYSIS

For the classification of the soil sample, it is required to perform grain size analysis. After the collection of the test sample from the field. To classify the soil sample, ASTM method of classification ware followed. It includes the complete classification process of the soil particle based on the particle percentage of the soil sample at visual inspection. For coarse particles, ASTM standard instructs us to perform sieve analysis. As for the fine particle, it is required to perform hydrometer analysis for determining the percentage of silt & clay.

3.3.1.1 SIEVE ANALYSIS

After a General visual inspection of the soil sample, a basic understanding of the soil particulates was obtained. However, for a clear understanding need to perform a grain size analysis test. The test method covers the quantitative determination of the distribution of the soil particle according to their size.

ASTM D 6913 (ASTM, Standard Test Methods for Particle-Size Distribution (Gradation) of Soil Using Sieve Analysis., 2017) method covers the determination of the particle size distribution of fine and coarse aggregate by sieving. In this distribution, particle size larger than 75 microns or 0.075 mm (No. 200 sieve) is determined by sieving. The distribution of particles smaller than 0.075 mm is determined by the sedimentation process, using the hydrometer to secure the necessary data. ASTM D 7928 explains the full procedure. (ASTM, Standard Test

Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis, 2017)

Procedure:

- After visual inspection test samples are put in the oven at 110ºc to remove all the moisture for 16-24 Hr.
- Then test samples are washed in a No. 200 sieve.
- The sample was again put into the oven to remove water from the test sample.
- Selecting the Sieves by suitable sieve size:

Table 3.2: Sieve Size and opening

Sieve No.	Opening (mm)
# 4	4.74
# 8	2.36
# 16	2.00
# 30	0.600
# 50	0.300
# 100	0.150
# 200	0.075
Pan	--

- After drying, the soil samples are put through the selected sieve and hand shaken.
- Individual sieve provided the snug-filling pan and cover. In an inclined position, the sieve is stricken on the side with the rate of about 150 times per min, turn the sieve about one sixth of a revolution at intervals of about 25 strokes.
- Measuring the retained soil sample on each sieve.

Figure 3.2: Test sample Sieve analysis

Table 3.3: Sieve Analysis of Sandy Soil-TS_1 (Retained on 0.075 mm Sieve)

Sieve Size (mm)	% Passing
4.74	100
2.36	100
2.00	100
1.18	100
0.6	98
0.425	93
0.30	81
0.15	27
0.075	6

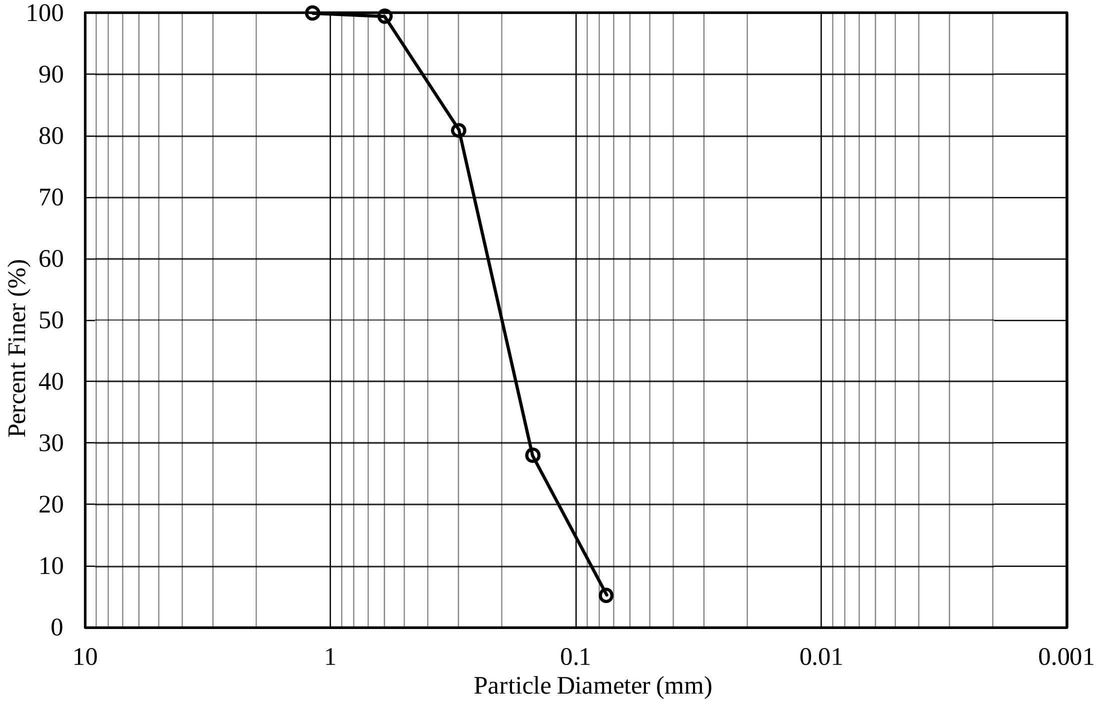


Figure 3.3: Graph of Sieve analysis (TS_1)

3.3.1.2 HYDROMETER TEST

A hydrometer test is performed to determine the grain size distribution of the finer portion of the soil sample. In sieve analysis, we distribute the partials that are retained on the No. 200 sieve. Passing soil partials are finer than 0.075 mm which cannot be determined by sieve.

Material finer than the 75-µm (No. 200) sieve can be separated from larger particles much more efficiently and completely by hydrometer analysis. For accurate determination of the test samples required the test method of ASTM D 6913 is not enough to determine the fine particle smaller than 75-µm. Therefore, hydrometer analysis using ASTM D 7928 method was performed. The total amount of finer material plus the obtained material from dry sieving is the result of grain size analysis.

There are two types of ASTM soil hydrometers. We used ASTM 152 hydrometer.

Hydrometer test uses sedimentation process. At fixed intervals, the density of soil solution is recorded as a result of the percentage value of clay and silt in the solution mixture obtain.

Figure 3.4: Grain Size Distribution Using Hydrometer Method**.**

Procedure:

- The weight of the test sample to approximately 50 gm.

  <u>Note</u>: If test sample mostly: Clay-silt 50 gm

  If test sample mostly: Sand 100 gm

- The test sample was placed in a 250 ml beaker and cover with 125 ml Sodium Hexametaphosphate ($NaPO_3$) solution and soaked the sample for 16 hr.
- At the end of the soaking period, disperse the sample further, using stirring apparatus.
- The solution ware pours into the special dispersion cup, washed down any residue from a beaker into the cup, and added distilled water so the cup is more than half full. Stirred it for 1 min.
- Immediately after dispersion, we transfer the soil-water slurry into the sedimentation cylinder and added water up to 1000 ml.
- Using a stirring device we mixed the solution for 1 min. at the end of 1 min, we started the take reading of the sedimentation in the intervals: 1 min, 2 min, 5 min, 15 min, 30 min, 1 hr., 2 hr., 4 hr., 8hr, 24 hr.

Figure 3.5: Hydrometer Test

Table 3.4: Hydrometer Reading

Elapsed Time (min)	Meter Reading (Div.)	Temperature (^{0}C)
1	49	23
2	43	23
4	40	23
8	38	23
15	36	23
30	34	23
60	32	23
120	30	23
240	28	23
480	27	23
720	26	23
1440	25	23
2880	24	23

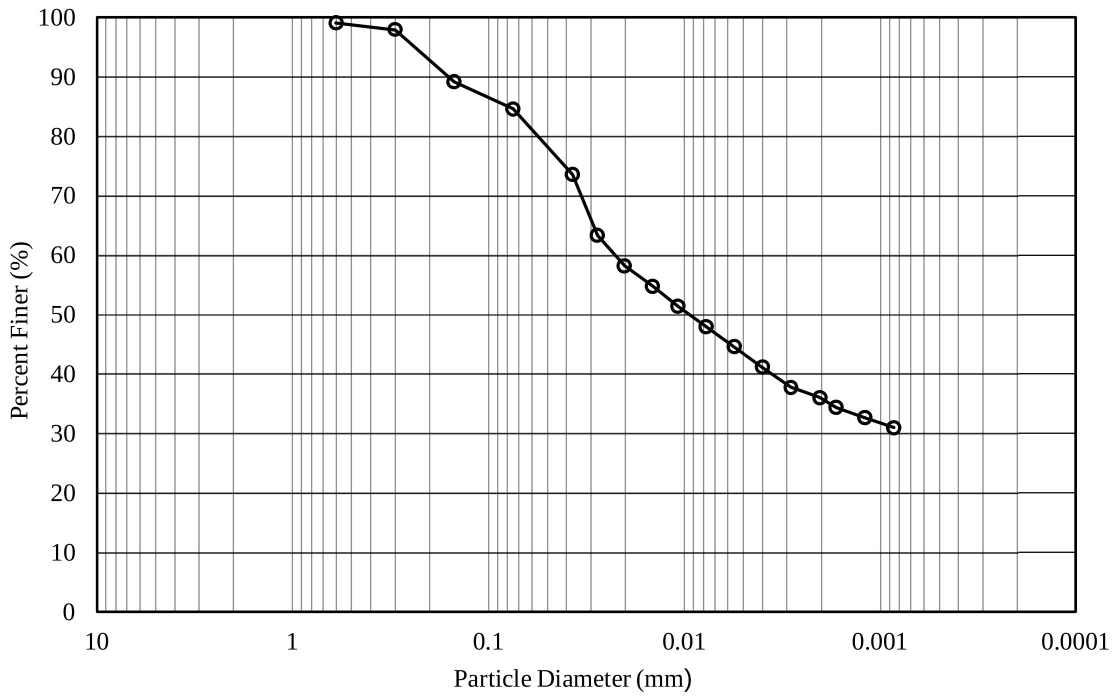


Figure 3.6: Hydrometer Sedimentation Graph (TS_2)

The method used for particle analysis is combined gradation using both methods of ASTM D 6913 and ASTM D 7928 for the total gradation process. The chart shows that the retained particle percentages from both sieve and hydrometer analysis form an s-curve that indicates the percentage of sand, silt and clay. Soil particle passing through 0.075 mm is considered, fine particle of soil sample and retained particle is coarse particle.

Table 3.5: Grain Size Analysis data of all samples

Sieve opening (mm)	% Finer	% Finer	% Finer	% Finer	% Finer	% Finer
	TS_1 (SP-SM)	TS_2 (CL)	TS_3 (CL-ML)	TS_4 (CL)	TS_5 (CL)	TS_6 (CL)
1.18	100	100	100	100	100	100
0.600	99	99	100	99	99	100
0.300	81	98	100	96	95	100
0.150	28	89	99	87	65	99
0.075	5	85	98	54	30	79
0.0383	-	74	64	29	20	43
0.0284	-	63	52	23	15	30
0.0209	-	58	44	18	12	24
0.0153	-	55	32	16	10	20
0.0113	-	51	24	12	8	18
0.0081	-	48	17	11	7	15
0.0058	-	45	15	10	6	14

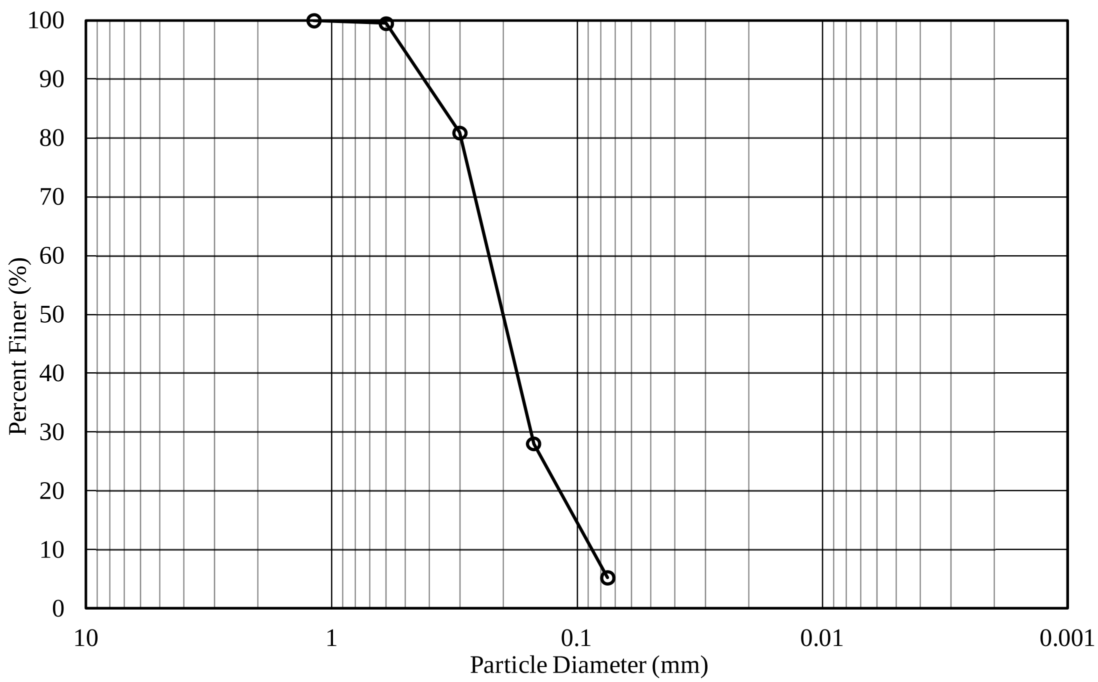


Figure 3.7: Grain Size Analysis of TS_1 (SP-SM)

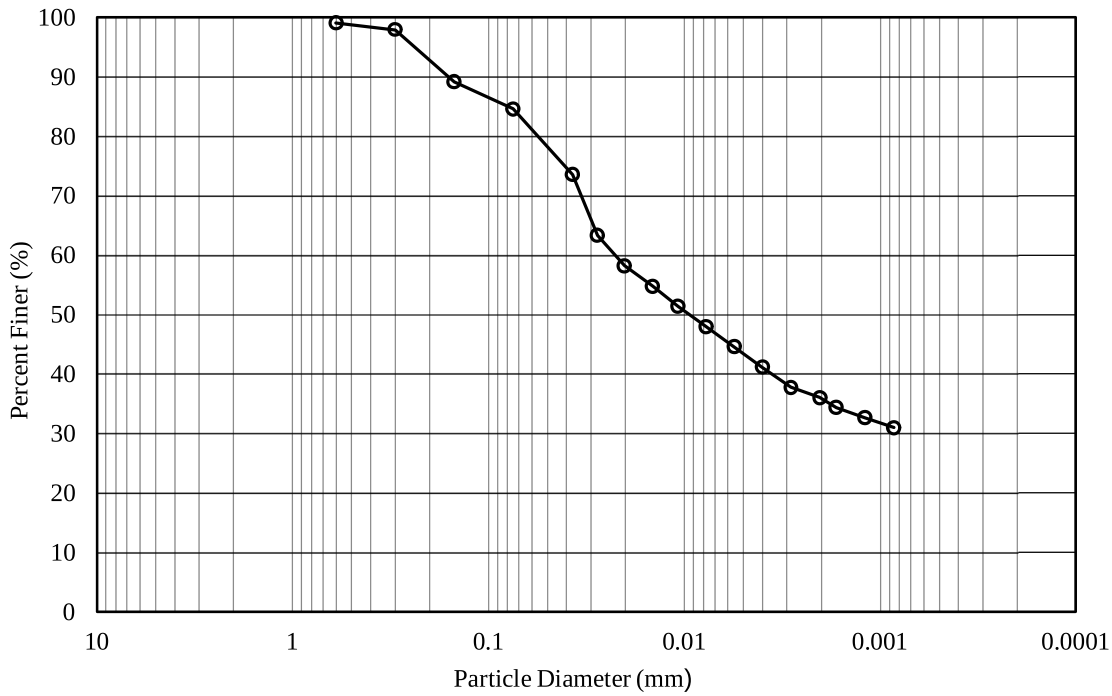


Figure 3.8: Grain Size Analysis TS_2 (CL)

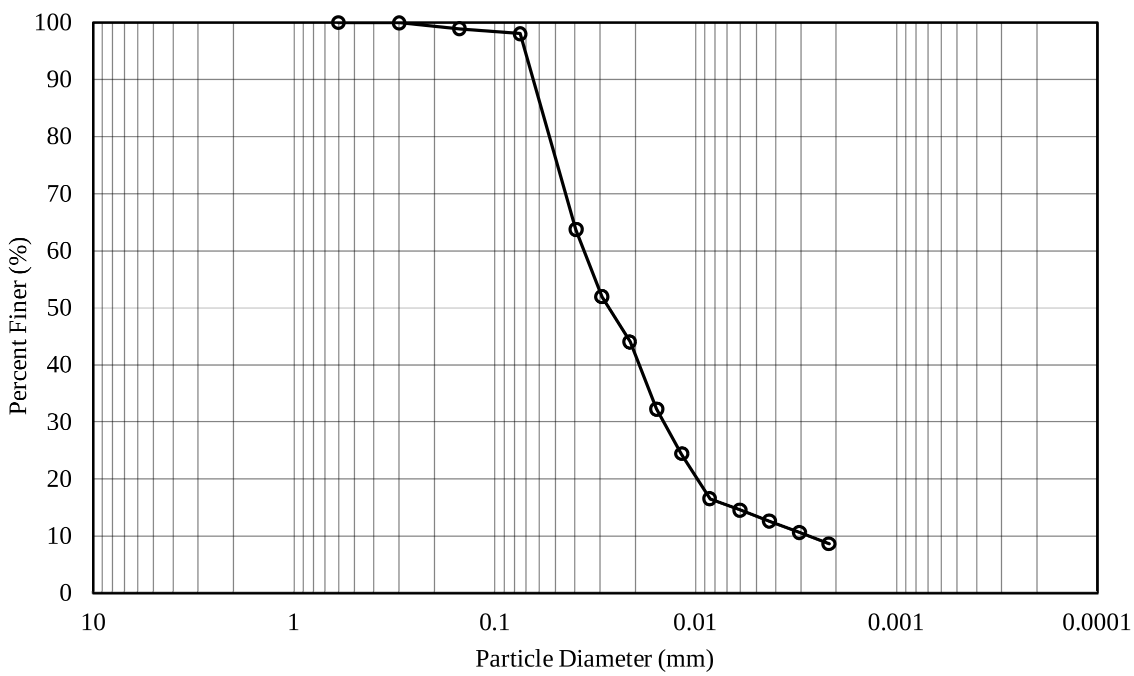


Figure 3.9: Grain Size Analysis of TS_3 (CL-ML)

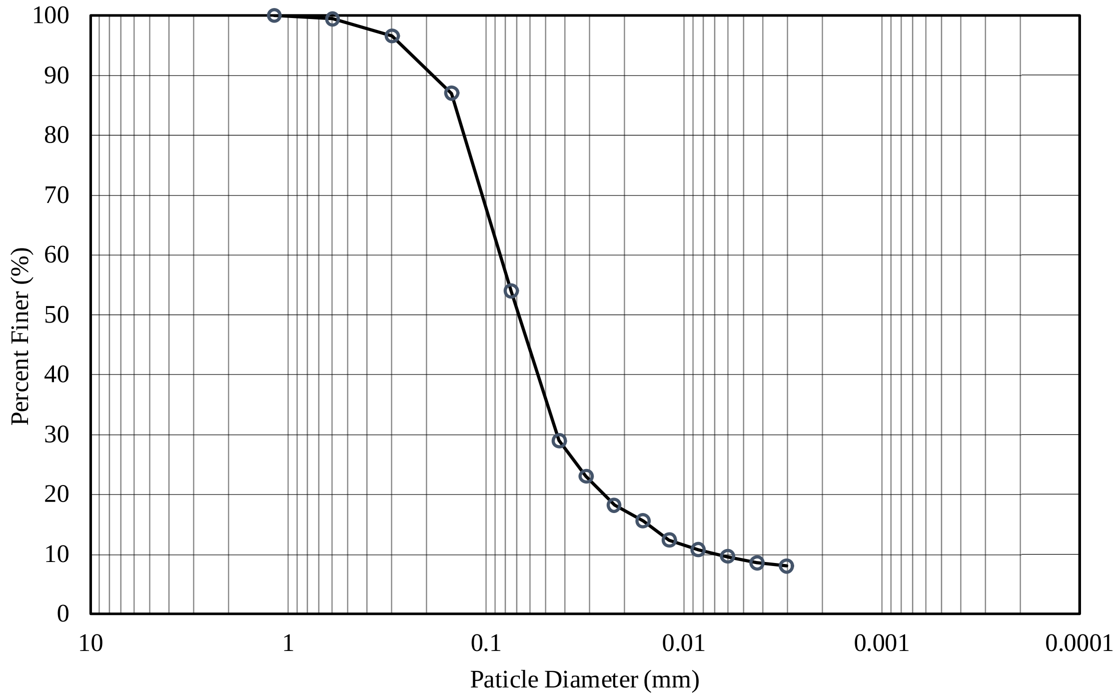


Figure 3.10: Grain Size Analysis of TS_4 (CL)

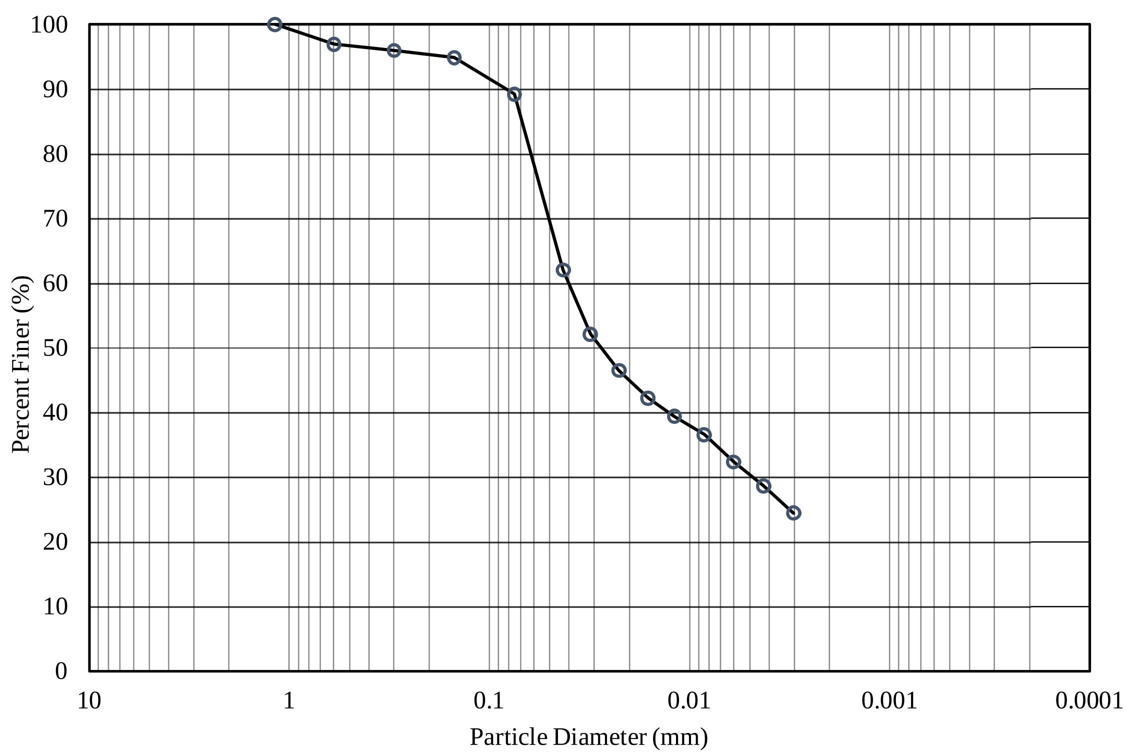


Figure 3.11: Grain Size Analysis of TS_4 (CL)

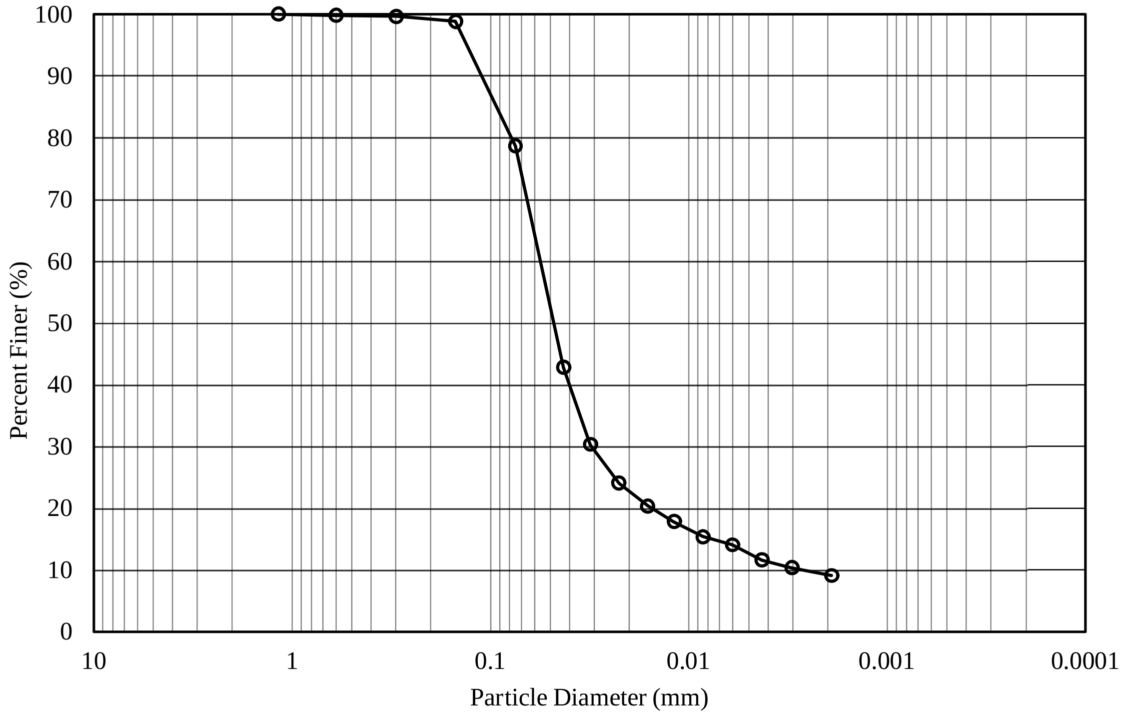


Figure 3.12: Grain Size analysis of TS_5 (CL)

3.3.2 LIQUID LIMITS AND PLASTIC LIMIT

Liquid limit and Plastic limit tests are mainly used for finding the range of water content in clayey soil. These tests are been performed on test samples following ASTM D 4318.

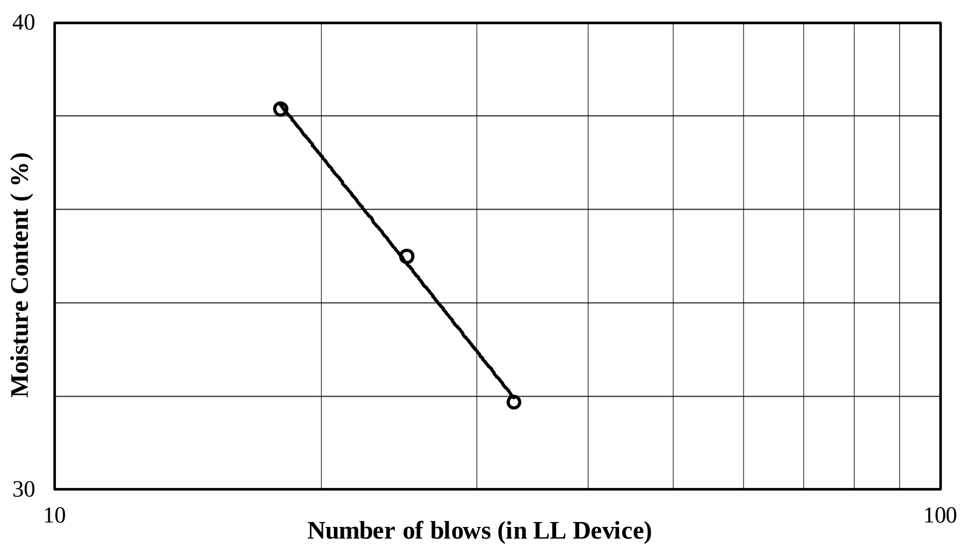


Figure 3.13: Liquid limit test for test sample_2

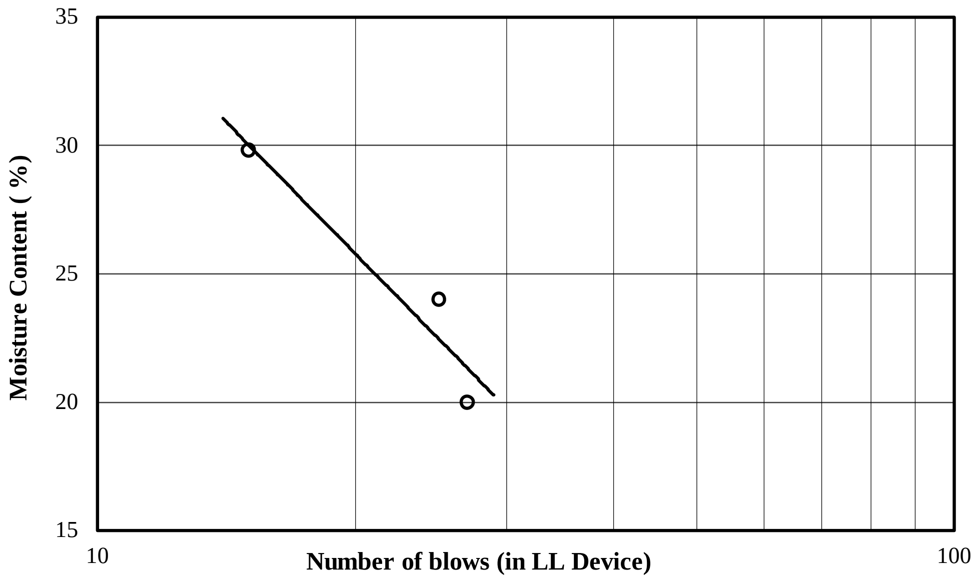


Figure 3.14: Liquid limit test for test sample_3

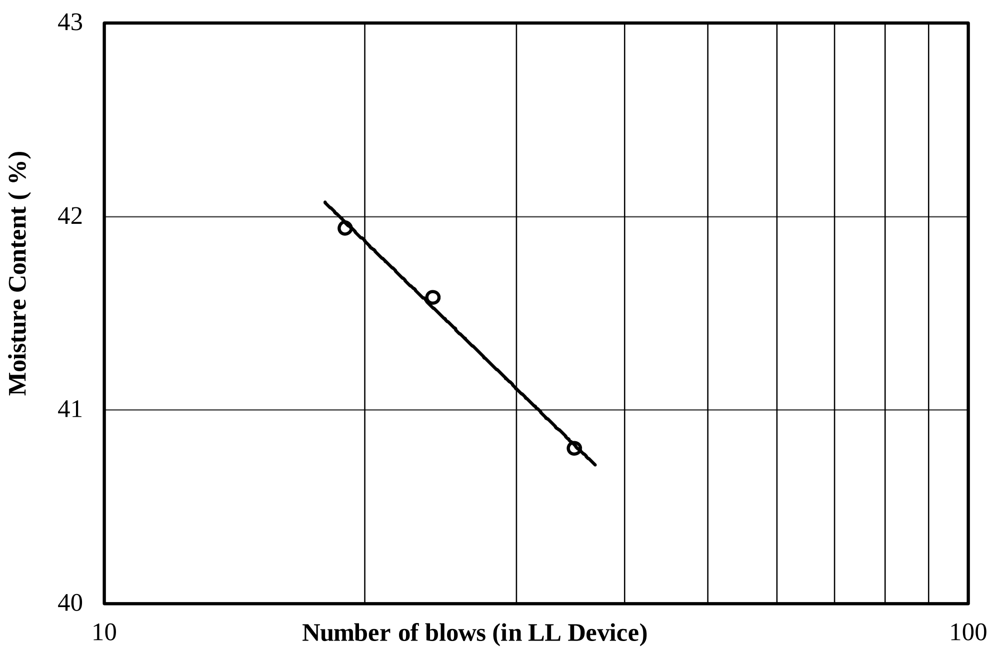


Figure 3.15: Liquid limit test for test sample_4

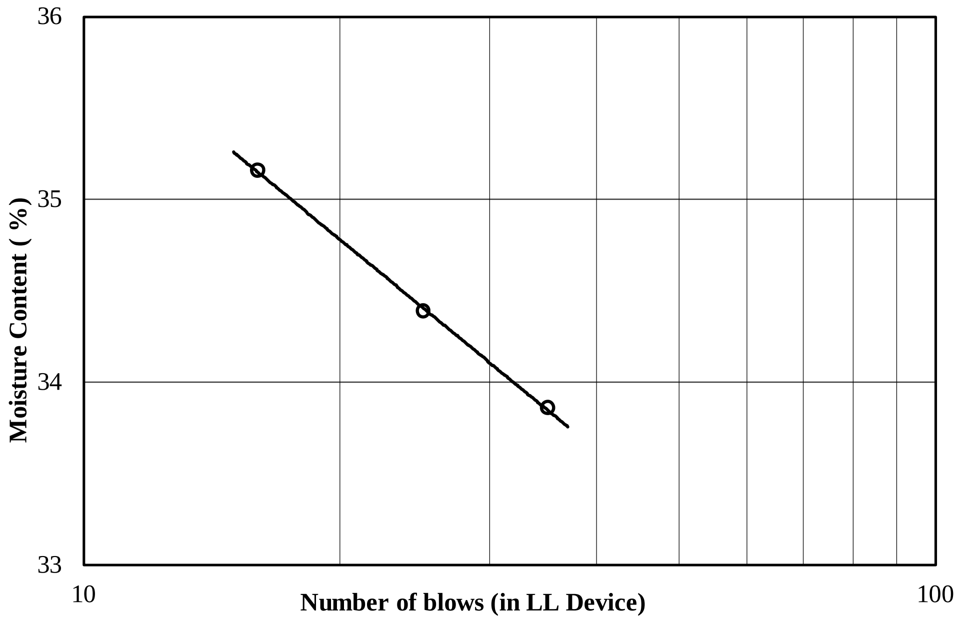


Figure 3.16: Liquid limit test for test sample_5

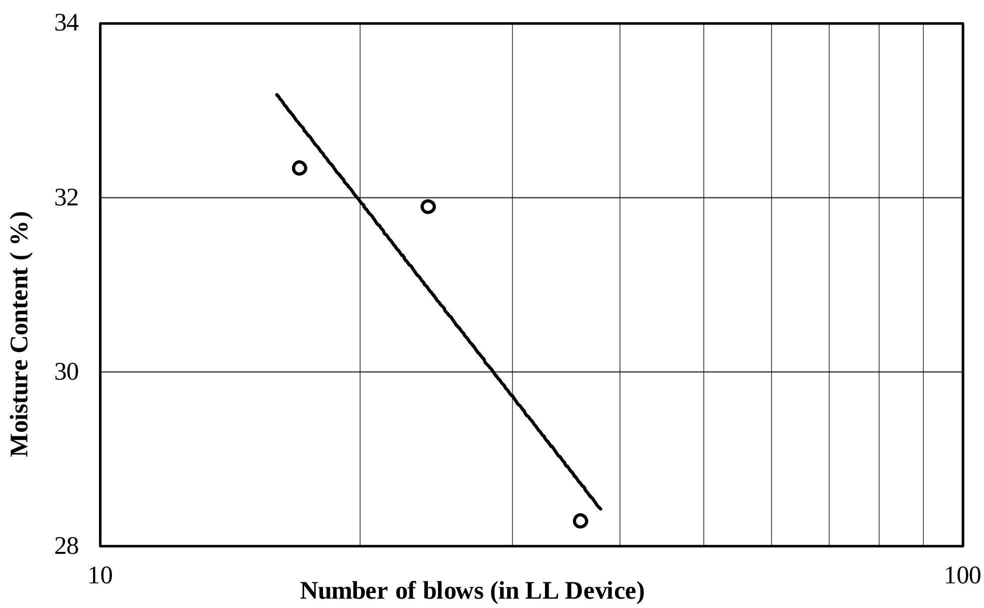


Figure 3.17: Liquid limit test for test sample_6

Table 3.6: Liquid limit and Plastic limit test

Test Sample	2	3	4	5	6
Plastic limit (%)	34	22	42	34	31
Liquid limit (%)	21	13	28	19	22
Plasticity Index (%)	13	9	14	15	9

3.3.3: SOIL CLASSIFICATION & GROUPING

For any soil investigation and test purpose, soil classification is a must to understand soil type. For this experiment and the types of tests that soil classification of test samples ware needed to perform. ASTM D 2487 for classification of soil samples is being followed.

In this method the percentage of different soil components is determined; (Sand, Silt and Clay).

For coarse grain soil (retained on No.200 sieve) sieve analysis is required.

For fine grained soil also can be said as silt & clay (passing No. 200 Sieve) Hydrometer analysis, Plastic limit and Liquid limit tests are required for classification. – ASTM D 2487 (ASTM, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), 2017)

Table 3.7: Classification of Test Sample by ASTM D 2487

Test Sample	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**Group Symbol**	**Classification form ASTM D 2487**
1	0	95	5	0	SP-SM	Poorly Graded Sand with silt
2	0	15	40	45	CL	Lean Clay with Sand
3	0	2	83	15	CL-ML	Silty Clay
4	0	46	46	8	CL	Sandy Lean Clay
5	0	11	59	30	CL	Lean Clay
6	0	21	66	13	CL	Lean clay with sand

3.3.4 SPECIFIC GRAVITY

The specific gravity of soil is used for the relationship phase of the soil. The specific gravity of the test sample is used to calculate the density of the soil solids. In this study, the specific gravity of the test samples is determined by the ASTM D 854.

Figure 3.18: Specific gravity test

Table 3.8: Specific Gravity test

Sample ID	#	TS_1 (SP-SM)	TS_2 (CL)	TS_3 (CL-ML)	TS_4 (CL)	TS_5 (CL)	TS_6 (CL)
Depth	M	Subgrade top					
Weight of Oven dry Soil	Gm	24.49	24.49	24.490	15.000	19.880	24.490
Weight of Pycnometer + Water	Gm	140.34	140.14	140.34	81.58	80.82	140.34
Wt. of Pycnometer. + Water + Soil	Gm	155.71	155.61	155.78	91.00	93.36	155.71
Observed Temperature, T_x	^0C	29	29	29	29	29	29
Specific Gravity of Water at T_x ^0C	G_T	0.9960	0.9960	0.9960	0.9960	0.9960	0.9960
Specific Gravity at T_x ^0C	G_s	2.68	2.71	2.68	2.68	2.70	2.70
Specific Gravity at 20 ^0C	G_s	2.68	2.71	2.68	2.68	2.70	2.70

Figure 3.19: Sample Preparation for Specific gravity test

3.3.5 STANDARD PROCTOR TEST

The test sample is being prepared for proctor test (MDD) to get different densities at different moisture content. After compaction of each specimen; DCP test ware made upon the molded sample and record the penetration rate and density. The Co-relation of Density Vs. Penetration rate on several samples was made.

But it is observed that the correlation could not be made. For our density determination, the standard proctor method was used. The representative test sample collected from the field was sun-dried for 16-24 Hr. and pass it through a 4.75 mm (# 4 No) sieve to separate coarser particles. Thoroughly mixed by quartering. For initial moisture, some samples were taken and put in the oven for 16-24 Hr. after noting down the initial weight of the soil sample. For Standard Proctor, we used a mound having an internal diameter of 102 mm and an internal height of 116 mm. Rammer: 2.49 kg in weight, with a fall of 12 inches

.

Figure 3.20: Separation of Coarse aggregate by Sieving

Procedure:

- A total of 5 samples were prepared each of 2.5 kg at different moisture.
- The amount of water is calculated by:

$$\textbf{Amount of water to be added} = \frac{\mathbf{RMC - EMC}}{\mathbf{100+EMC}} \times \mathbf{Mb}$$

RMC – Required moisture content,

EMC – existing moisture content,

Mb – mass of sample used

- Prepared samples adding 14%, 16%, 18%, 20% and 22% water content and left for soaking overnight (16 Hrs.) for plastic soil. If the soil is non-plastic holding time is 2 Hrs.
- Some test samples were taken and put in the oven for actual moisture.
- After holding time soils are homogenously mixed and it is compacted by 3 layers.

Figure 3.21: Sample Perpetration and Compaction of MDD

The collected samples from the different locations are compacted at different moisture content. With the proctor method of AASHTO T 99. The graphical representation shows the increase of density of soil components at the peak point of compaction for that type of soil with the fixed mound area and applied force.

Five different points of moisture are taken for a clear graphical explanation. As the result has shown in Figures 3.16 to 3.21 that after the peak point of the moisture content the density rate decreases due to the soil's inability to retain water.

Table 3.9: Maximum dry density (MDD) & Optimum Moisture Content (OMC) for different test sample

Test Sample	**Dry Density (kg/m^3)**	**OMC (%)**
1	1720	9
2	1622	22
3	1725	18
4	1505	25
5	1756	17
6	1652	18

3.3.6: ZERO AIR VOID COMPACTION

The soil particle consists of three-layered components first air, second water and third solids. To build a structure on a soil base the air voids have to be minimal for that the air voids are removed through compaction. But no matter how many attempts were taken to reduce the air void the soil component does not obtain zero air void. But theoretically speaking zero air void can be made through the calculation of the dry density and moisture content of the soil.

The formula of Calculation for Zero air void line is:

Gs = Specific Gravity

w = Moisture Content (%)

Dry Density at "Zero Air-Void" in Kg/m^3 = $\frac{Gs\times 1000}{1+\frac{w\times Gs}{100}}$

Table 3.10: "Zero Void line" Compaction Calculation

TS_1	Specific Gravity (Gs)	2.68			
	Moisture content (%)	7	9	11	13
	Dry-Density (Kg/m^3)	2257	2159	2070	1988
TS_2	Specific Gravity (Gs)	2.71			
	Moisture content (%)	20.2	21.8	22.9	24.9
	Dry-Density (Kg/m^3)	1752	1705	1672	1619
TS_3	Specific Gravity (Gs)	2.7			
	Moisture content (%)	16.1	18.2	18.8	21.2
	Dry-Density (Kg/m^3)	1881	1811	1790	1716
TS_4	Specific Gravity (Gs)	2.68			
	Moisture content (%)	20	23	25	27
	Dry-Density (Kg/m^3)	1753	1661	1609	1549
TS_5	Specific Gravity (Gs)	2.70			
	Moisture content (%)	13	15	17	19
	Dry-Density (Kg/m^3)	2004	1922	1851	1792
TS_6	Specific Gravity (Gs)	2.682			
	Moisture content (%)	19	22	24	26
	Dry-Density (Kg/m^3)	1770	1687	1632	1580

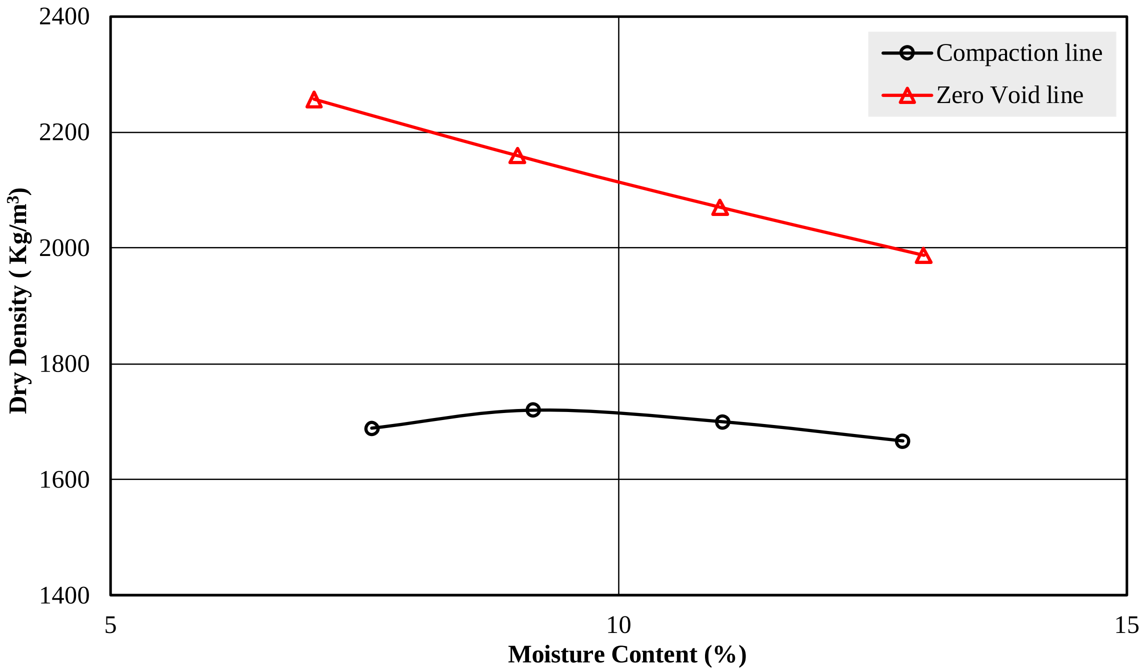


Figure 3.22: Compaction line and Zero Void line (TS_1)

Here, the figure represents test sample 1 (TS_1) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 9 and the maximum density is 1720 kg/m^3.

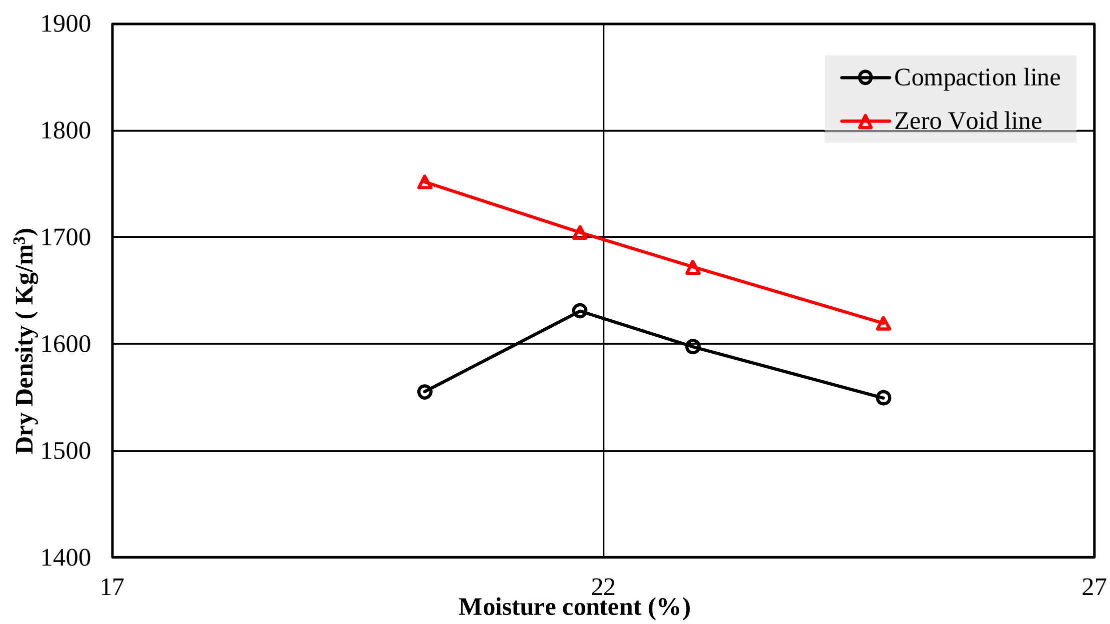


Figure 3.23: Compaction line vs Zero void line (TS_2)

Here, the figure represents the test sample 2 (TS_2) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 2 and the maximum density is 1622 kg/m^3.

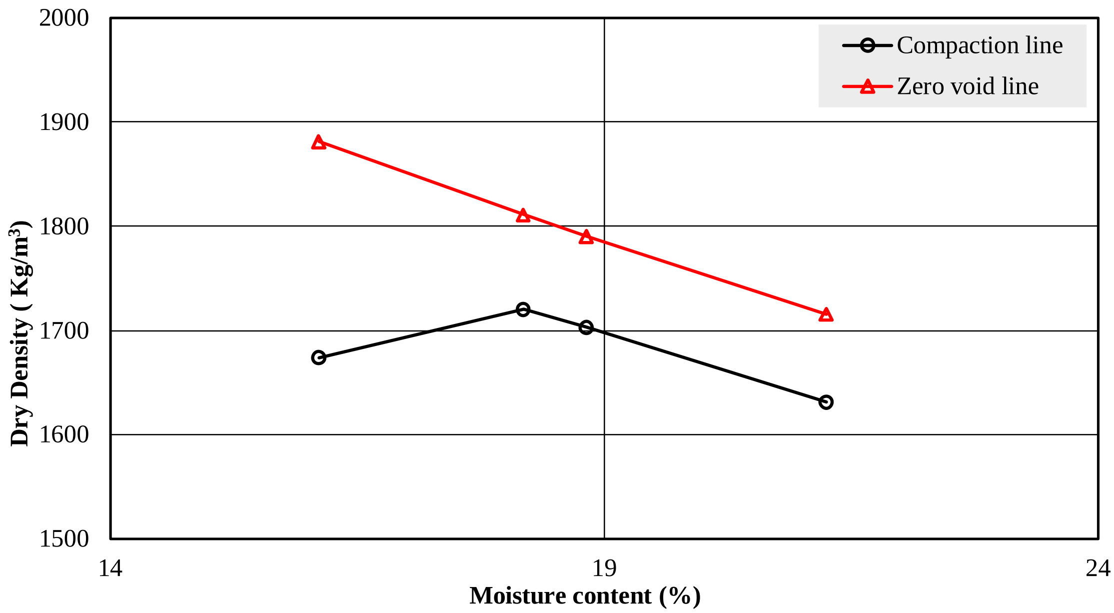


Figure 3.24: Compaction line vs Zero void line (TS_3)

Here, the figure represents the test sample 3 (TS_3) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 18 and the maximum density is 1725 kg/m^3.

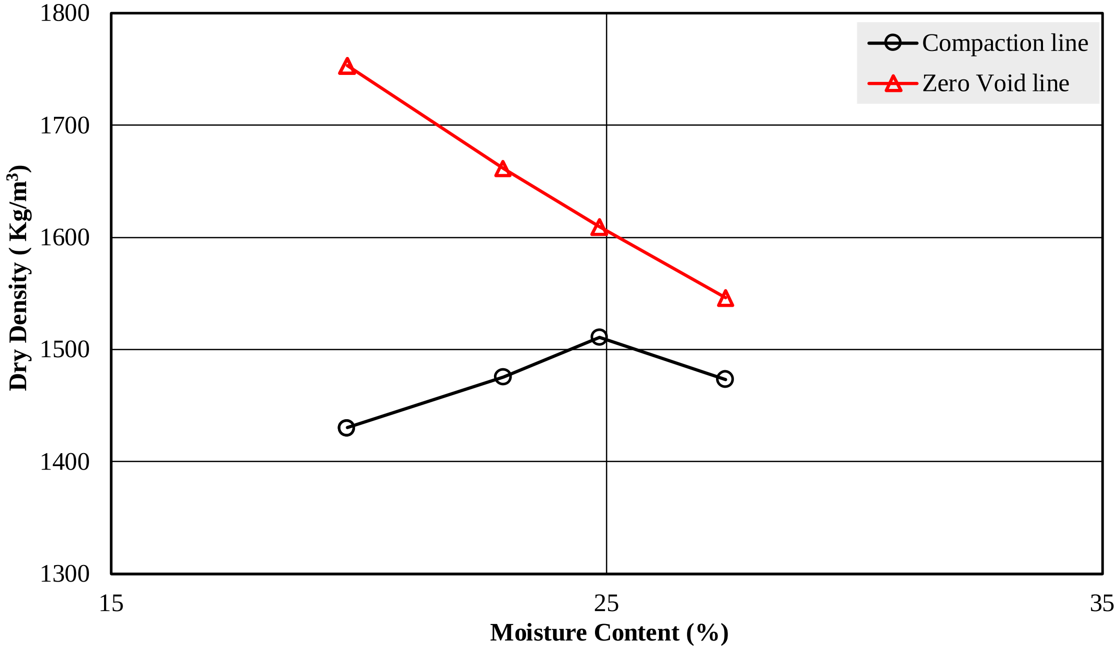


Figure 3.25:Compaction line and zero void line (TS_4)

Here, the figure represents the test sample 4 (TS_4) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 18 and the maximum density is 1725 kg/m^3.

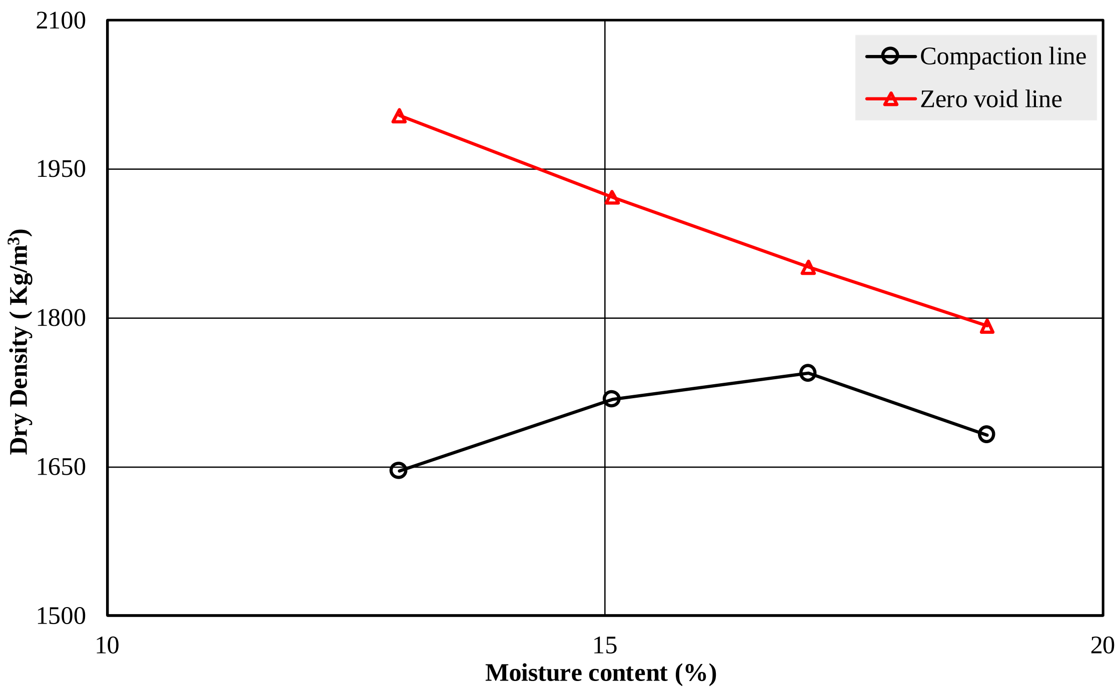


Figure 3.26: Compaction line and Zero Void line (TS_5)

Here, the figure represents test sample 5 (TS_5) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 17 and the maximum density is 1756 kg/m^3.

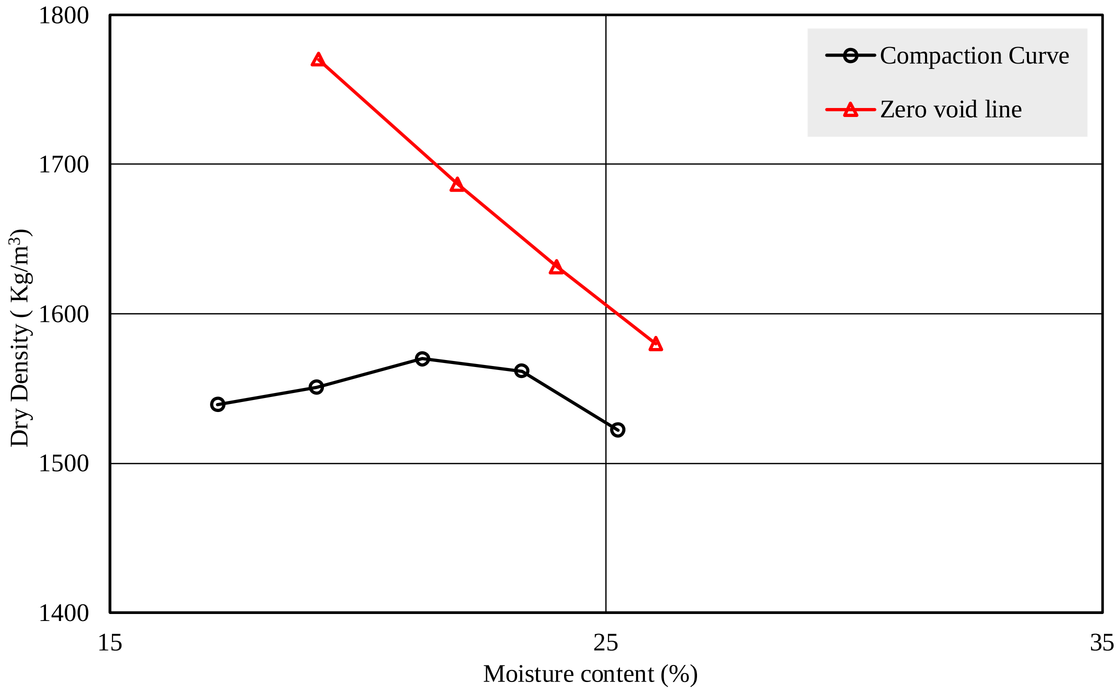


Figure 3.27: Compaction line and Zero Void line (TS_6)

Here, the figure represents the test sample 6 (TS_6) compaction line and zero void line. We can understand from it that the MDD test was correct. The compaction line also shows that the OMC of the test sample is 18 and the maximum density is 1752 kg/m^3.

3.3.7 SAND CONE TEST

The sand cone test also known as Field Dry Density (FDD) is the determination of the in-place density of soil. There are many tests method used to find the soil density the test method differs in the method. In this study ASTM D 1556 was used for FDD test. This test method in conjunction with ASTM D 1557 (Laboratory compaction characteristics of the soil) can be used to determine the degree of relative compaction and the % of water content achieved at the site. However, there are some limitations to this method of FDD test. This test method is not suitable for soils that would deform or compress during the excavation of the test pit". – (Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method, 2007)

Procedure:

- Fill up the sand jar with the calibrated sand and note down the density of calibrated sand.
- Prepare the surface of the location to be used for the test.
- Set the base plate on the surface of the test location and secure it with pegs. Dig the test hole inside the opening of the base plate.
- Without disturbing the bound of the dug hole carefully remove the soil.
- Put the jar on the top of the base plate and release the valve.
- After the sand fills up the hole, measure the weight in the jar.
- After all the calculation is made, scoop up the sand inside the dug hole carefully without mixing the other material in it.

Figure 3.28: Field Density by sand cone method

Table 3.11: Filed Dry density test result

Samples	TS_1			TS_2			TS_3		
Number of tests	1	2	3	1	2	3	1	2	3
Moisture content	8.7	8.9	8.4	21.6	20.0	21.8	17.2	17.9	17.9
Optimum Moisture content	9	9	9	22	22	22	18	18	18
Dry Density	1478	1686	1737	1367	1528	1661	1467	1587	1749
Maximum Dry density	1720	1720	1720	1632	1632	1632	1725	1725	1725
Degree of compaction	86	98	101	84	94	102	85	92	101

Samples	TS_4			TS_5			TS_6		
Number of tests	1	2	3	1	2	3	1	2	3
Moisture content	17.7	18.0	17.8	21.4	21.8	23.1	25.7	25.9	24.4
Optimum Moisture content	17	17	17	22	22	22	24	25	25
Dry Density	1372	1586	1686	1390	1544	1621	1478	1530	1741
Maximum Dry density	1756	1756	1756	1581	1581	1581	1505	1505	1505
Degree of compaction	78	90	96	88	98	103	98	102	116

3.3.8 DYNAMIC CONE PENETRATION TEST

This test method determines the measurement of the penetration rate of undisturbed soil samples with an 8 kg hammer. By this method estimate of the soil density by the penetration rate can be made. the DCP components are critical since their design specification has a major influence on the test outcomes. The instrument is constructed entirely of stainless steel for increased efficiency and durability.

The DCP tip drives into the soil by lifting the sliding hammer to the handle and then releasing it. The total penetration for a given number of blows is measured and recorded in mm/blow, which describes stiffness and estimates an in situ CBR strength from an appropriate correlation chart, or other material characteristics. ASTM D 6951 method and apparatus are used for this test procedure. - **ASTM D 6951** (ASTM, 2018)

Procedure:

- Pre-inspection of the apparatus is needed to inspect any type of excess wear and tear.
- DCP hammer is held vertically and raises the hammer till makes light contact with the handle.
- The hammed is allowed to free-fall and impact the anvil coupler assembly.
- The number of blows and corresponding penetration is recorded.
- Repeat steps 2 and 3 until the required depth of testing was achieved.
- After the testing was done, the gadget was extracted using a specially fitted jack.

Figure 3.29: Field DCP Test

Table 3.12: Lab Density-DCP Penetration test

Test Sample	#	TS_1 (SP-SM)					TS_2 (CL)					TS_3 (CL-ML)				
Number of Test	#	1	2	3	4	5	1	2	3			1	2	3	4	
Density	Kg/m^3	1584	1694	1733	1767	1780	1323	1466	1683			1608	1677	1619	1597	
Penetration Rate	mm/blow	53.0	31.1	25	21.7	15.6	70.0	40.0	30.0			40.0	32.0	39.0	41.0	
Test Sample	#	TS_4 (CL)					TS_5 (CL)					TS_6 (CL)				
Number of Test	#	1	2	3			1	2	3			1	2	3		
Density	Kg/m^3	1456	1641	1743			1339	1443	1583			1394	1551	1642		
Penetration Rate	mm/blow	25.7	20.8	18.2			78.9	62.1	44.2			51.0	34.8	23.5		

Table 3.13: Field Density-DCP Penetration Test

Test Sample	#	TS_1 (SP-SM)				TS_2 (CL)				TS_3 (CL-ML)			
Number of Test	#	1	2	3		1	2	3		1	2	3	
Density	Kg/m^3	1478	1686	1737		1367	1528	1661		1467	1587	1749	
Penetration Rate	mm/blow	71.0	31.1	23.1		59.2	45.8	26.5		55.6	41.3	25.2	
Test Sample	#	TS_4 (CL)				TS_5 (CL)				TS_6 (CL)			
Number of Test	#	1	2	3		1	2	3		1	2	3	
Density	Kg/m^3	1372	1586	1686		1621	1544	1390		1530	1741	1478	
Penetration Rate	mm/blow	27.7	22.5	19.7		35.3	51.7	70.5		36.0	16.0	42.8	

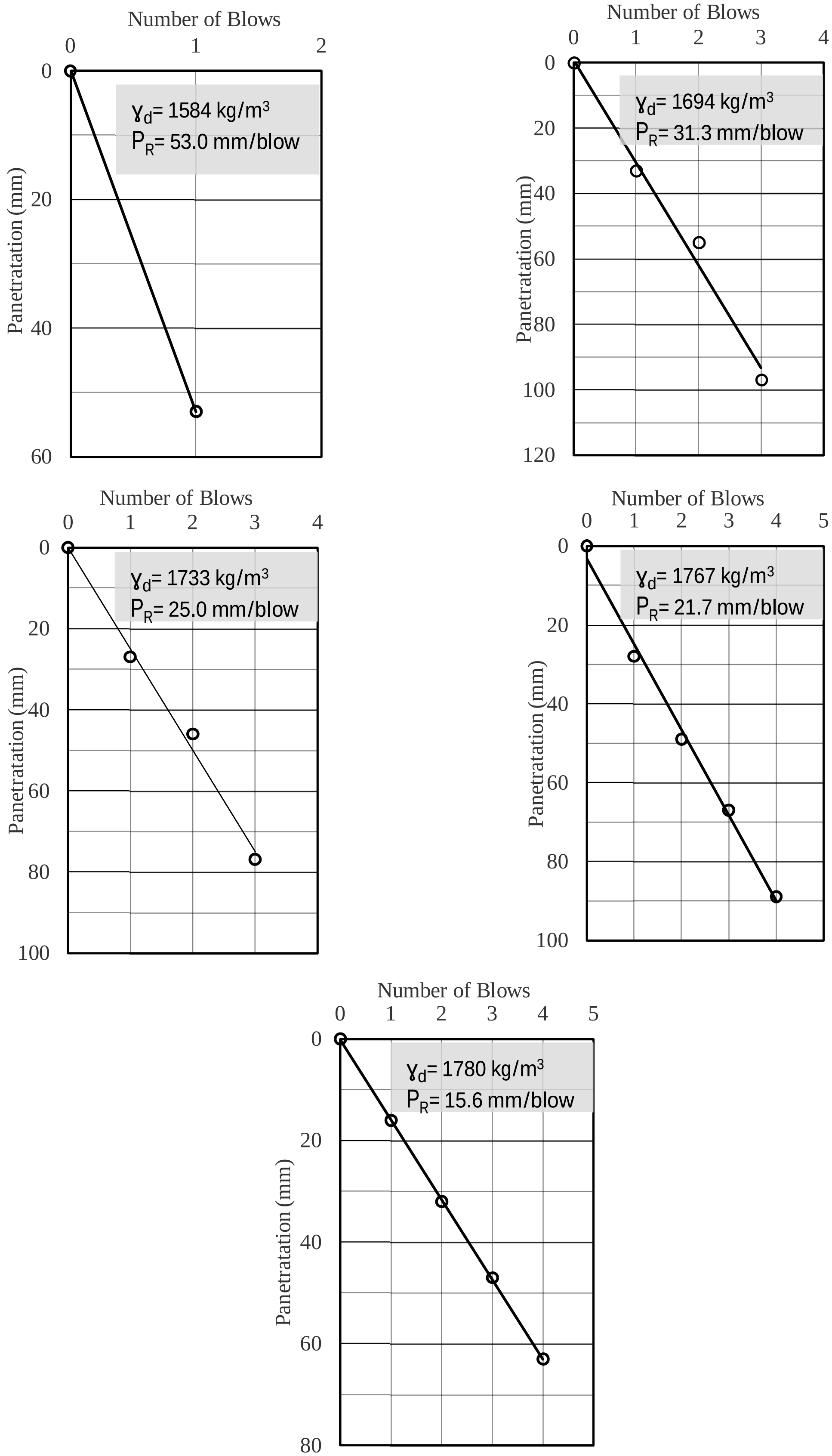


Figure 3.30: Lab DCP Test at TS_1 (SP-SM)

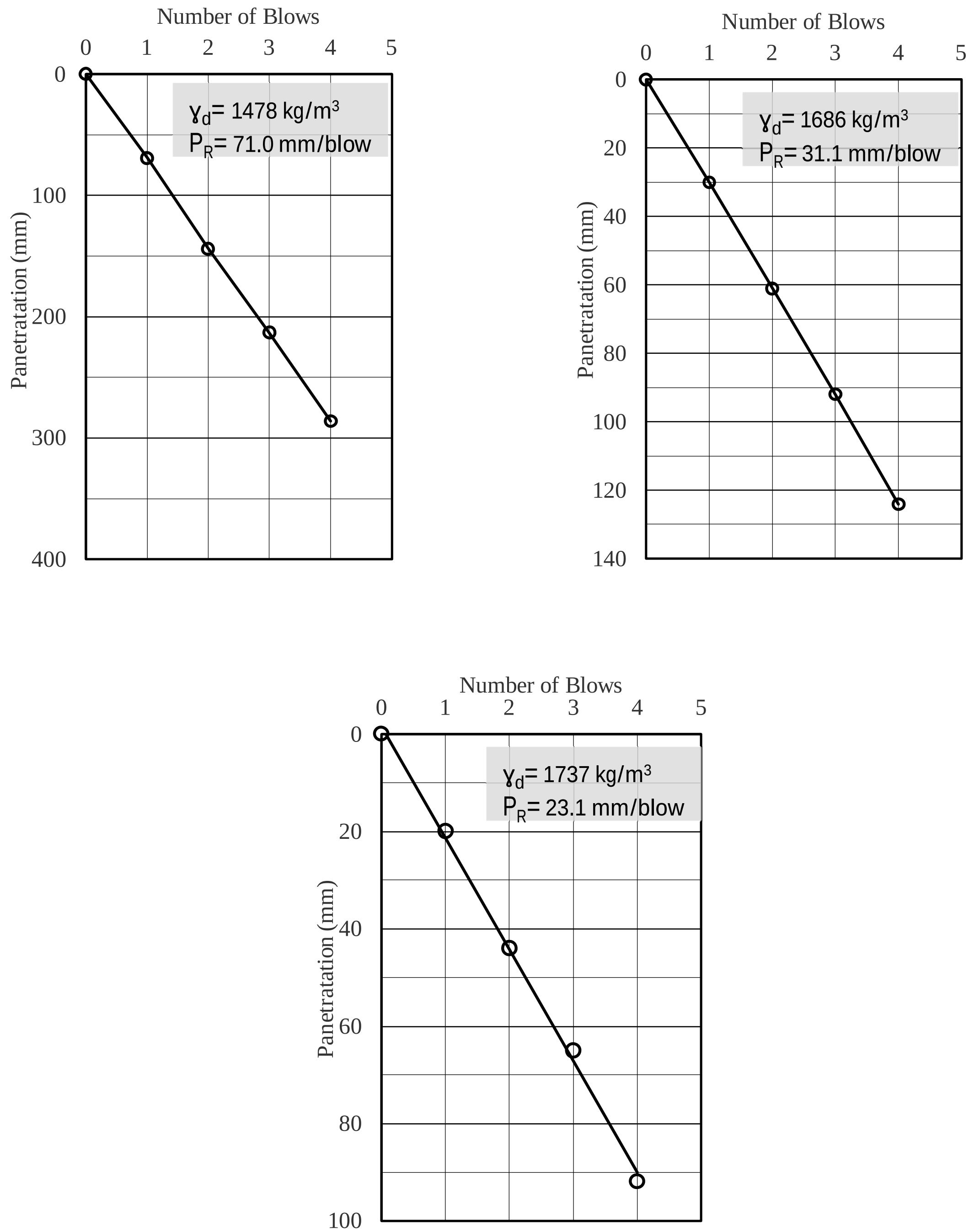
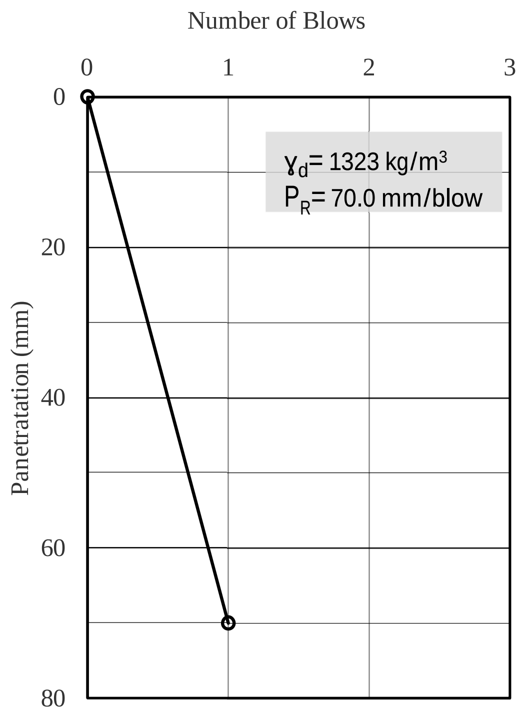
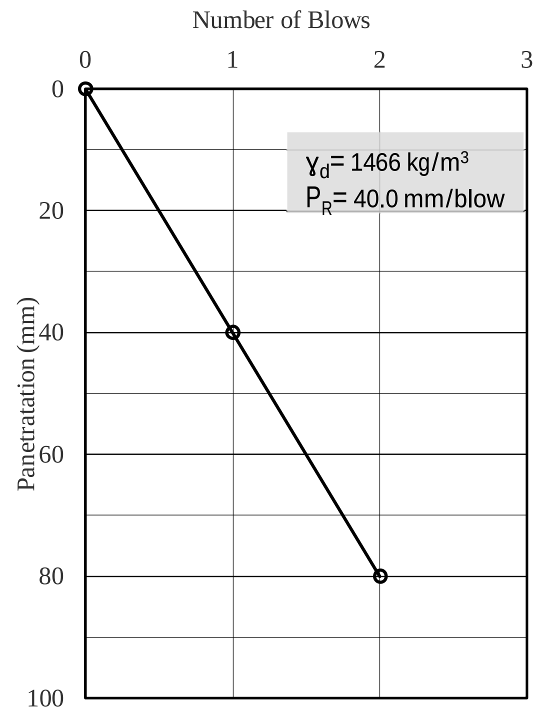


Figure 3.31: Field DCP Test at TS_1 (SP-SM)





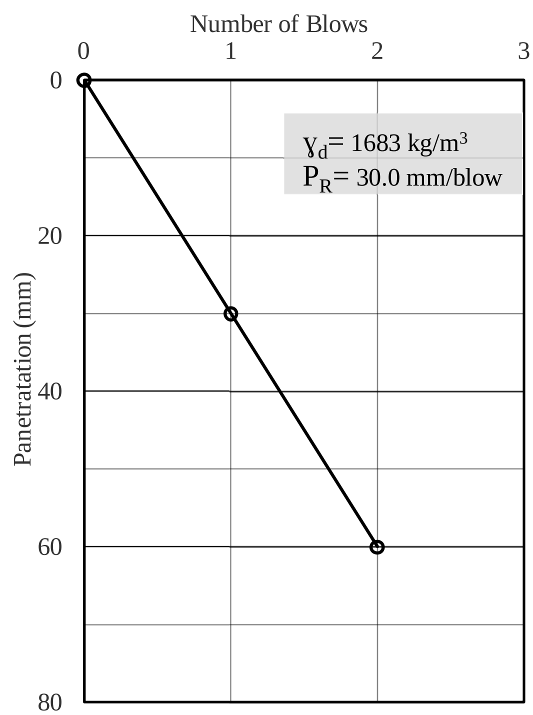


Figure 3.32: Lab DCP Test of TS_2 (CL)

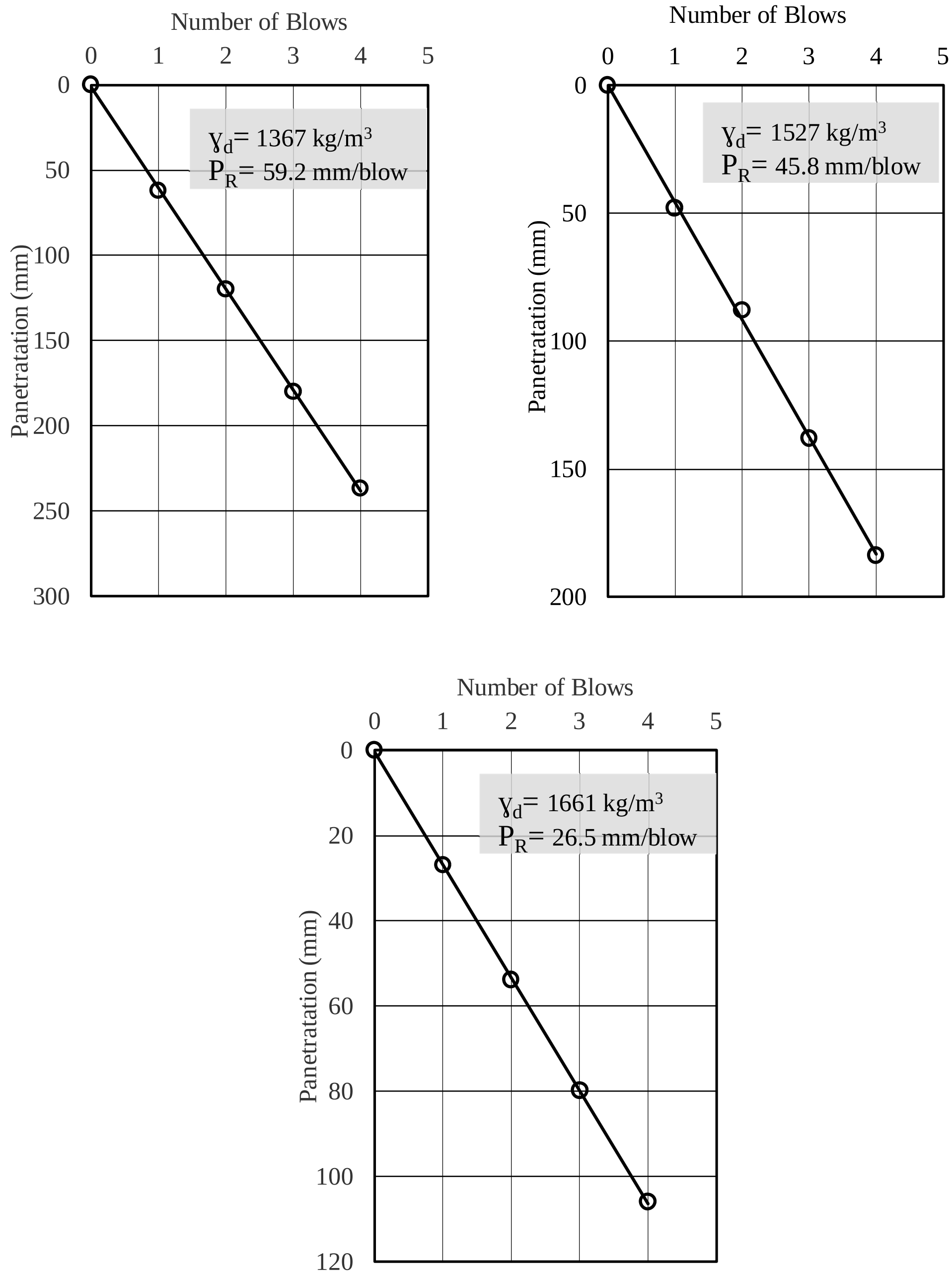


Figure 3.33: Field DCP Test of TS_2 (CL)

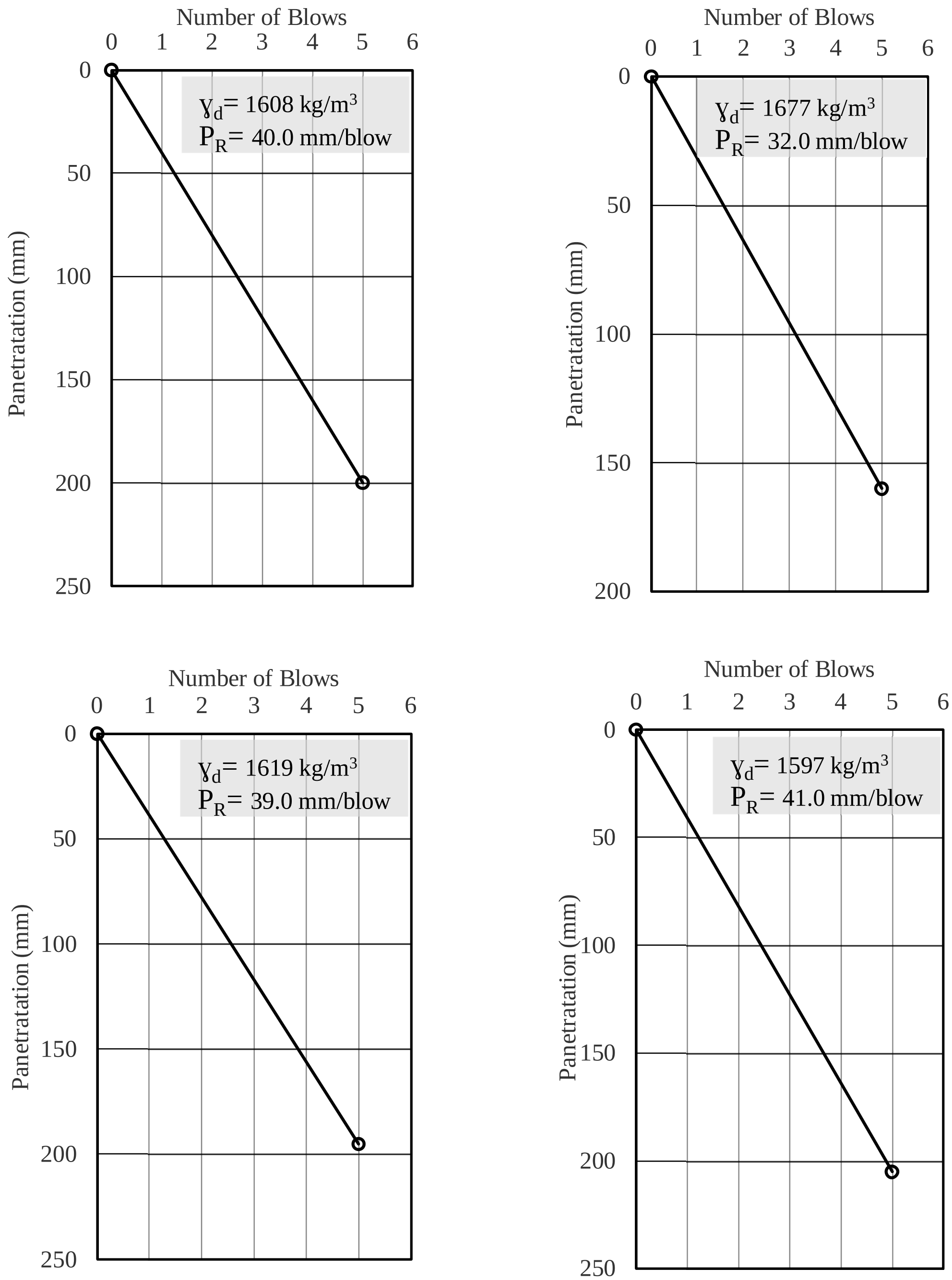


Figure 3.34: Lab DCP Test on TS_3 (CL-ML)

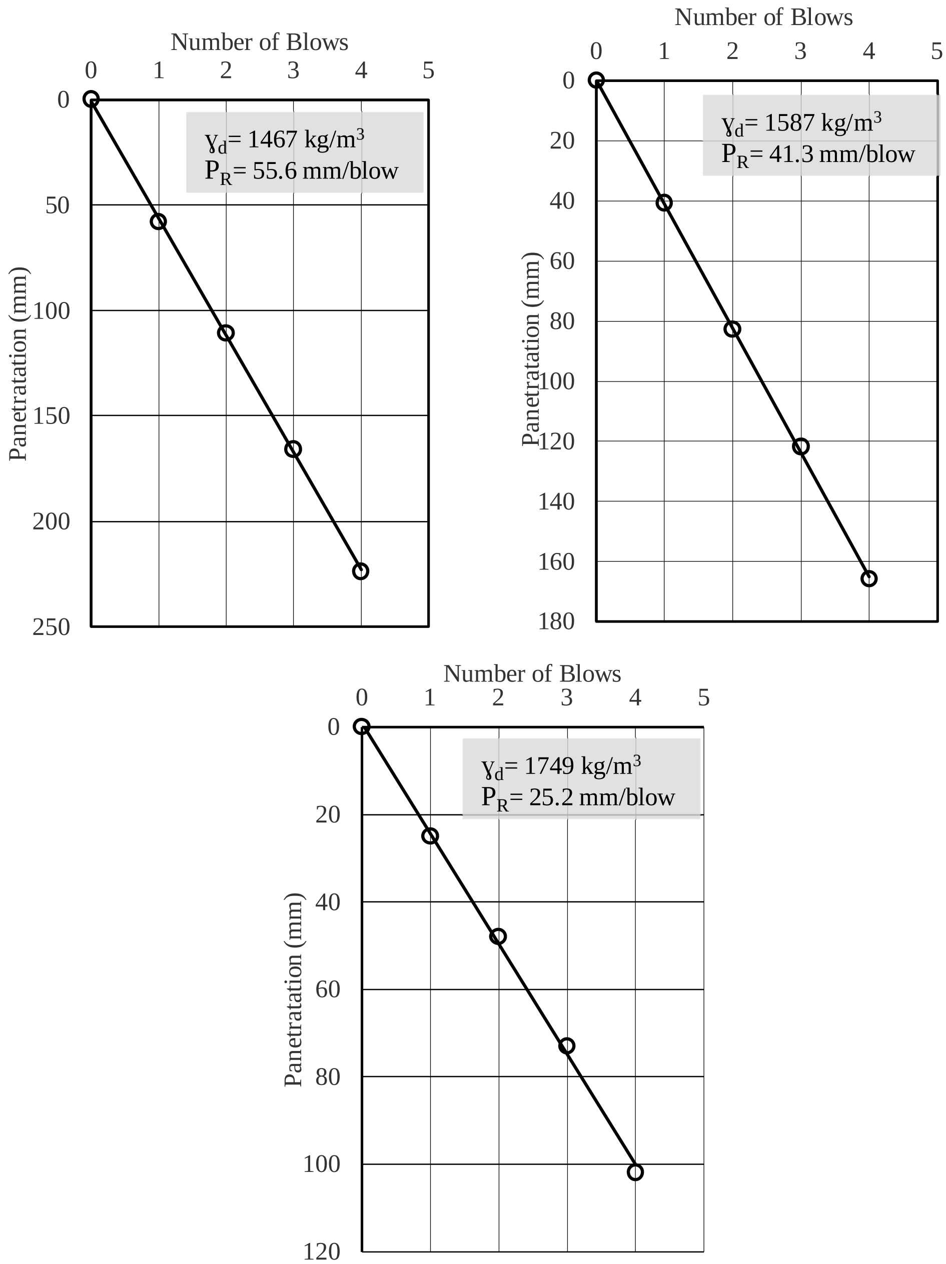


Figure 3.35: Field DCP Test on TS_3 (CL-ML)

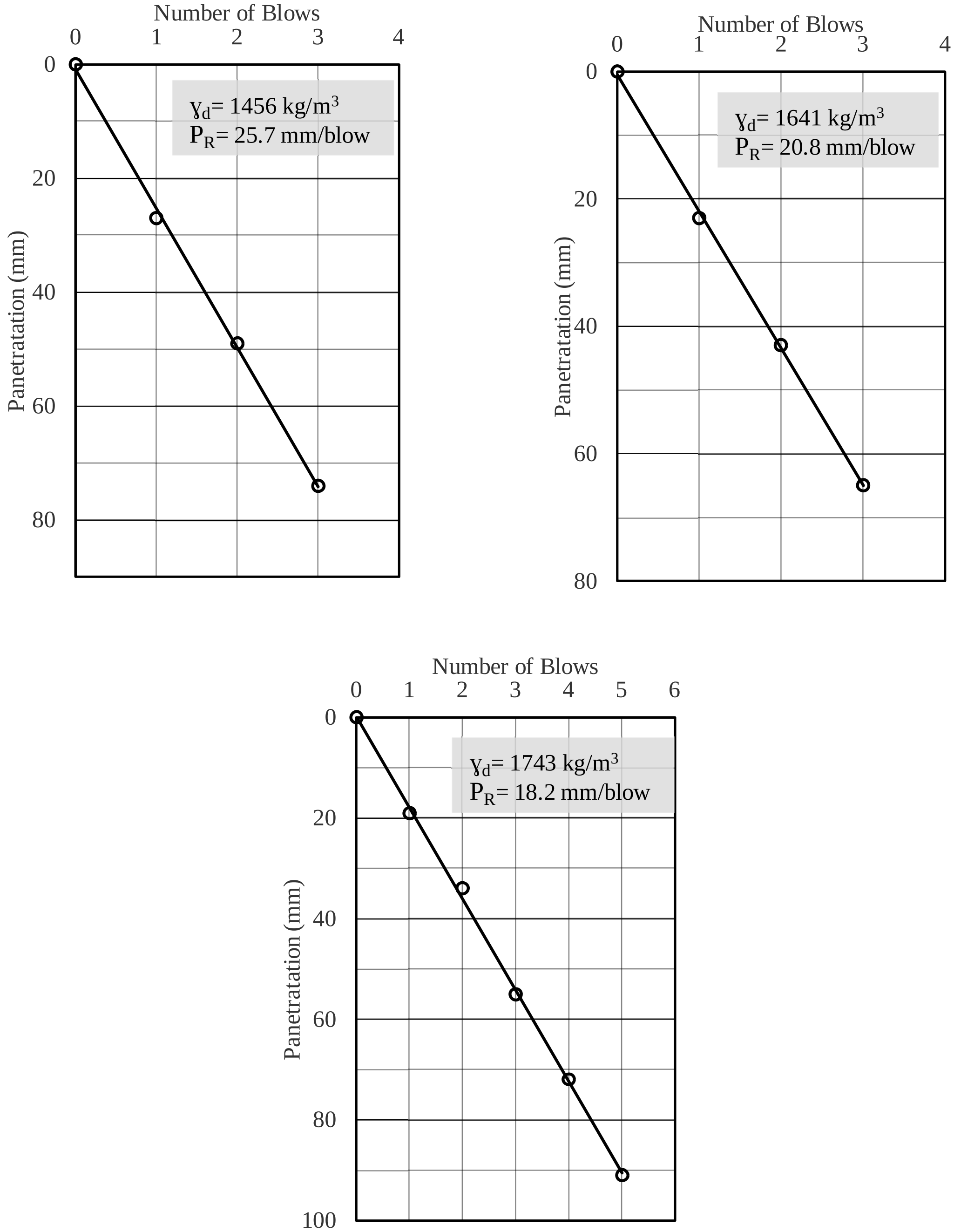


Figure 3.36: Lab DCP Test on TS_4 (CL)

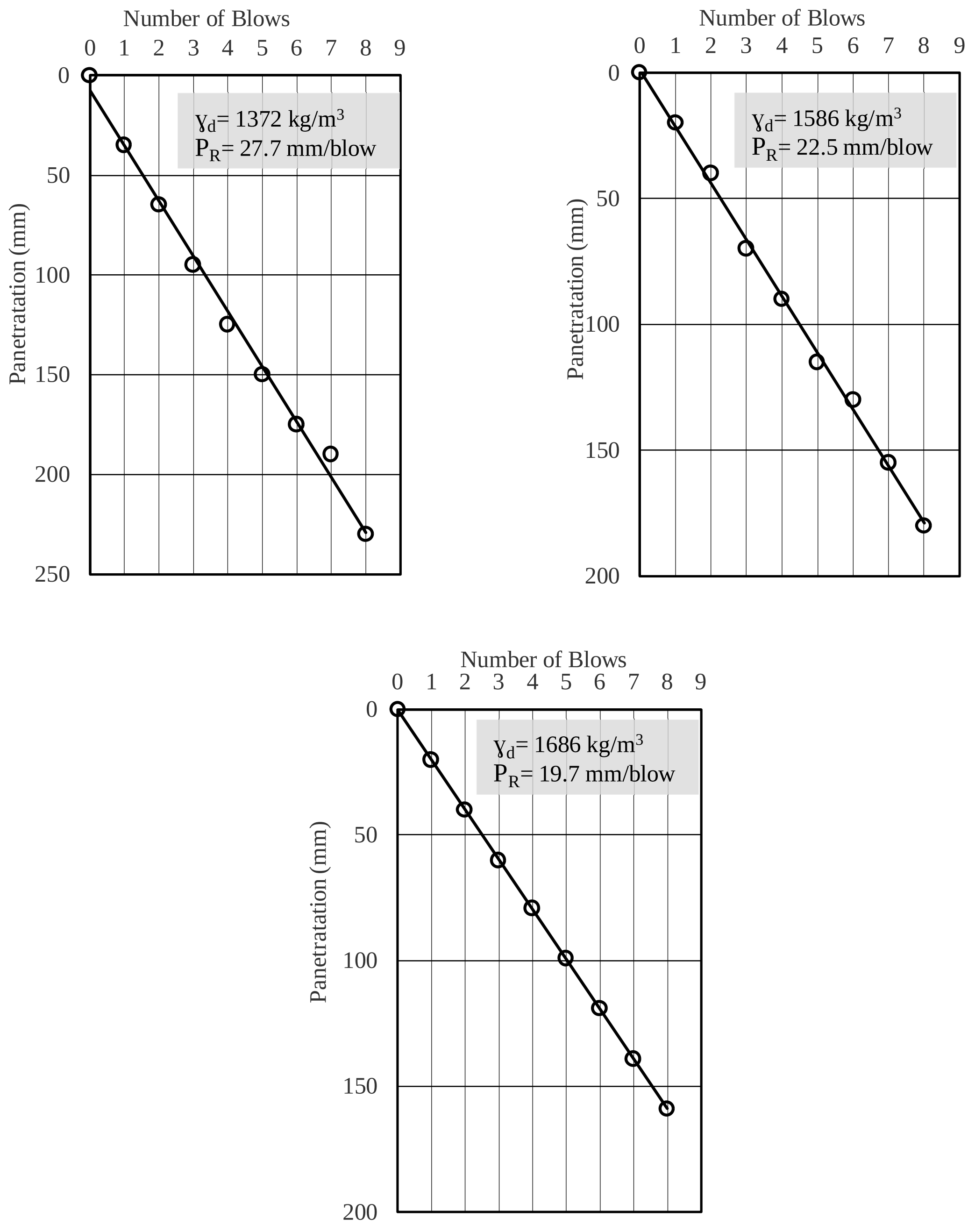


Figure 3.37: Field DCP Test on TS_4 (CL)

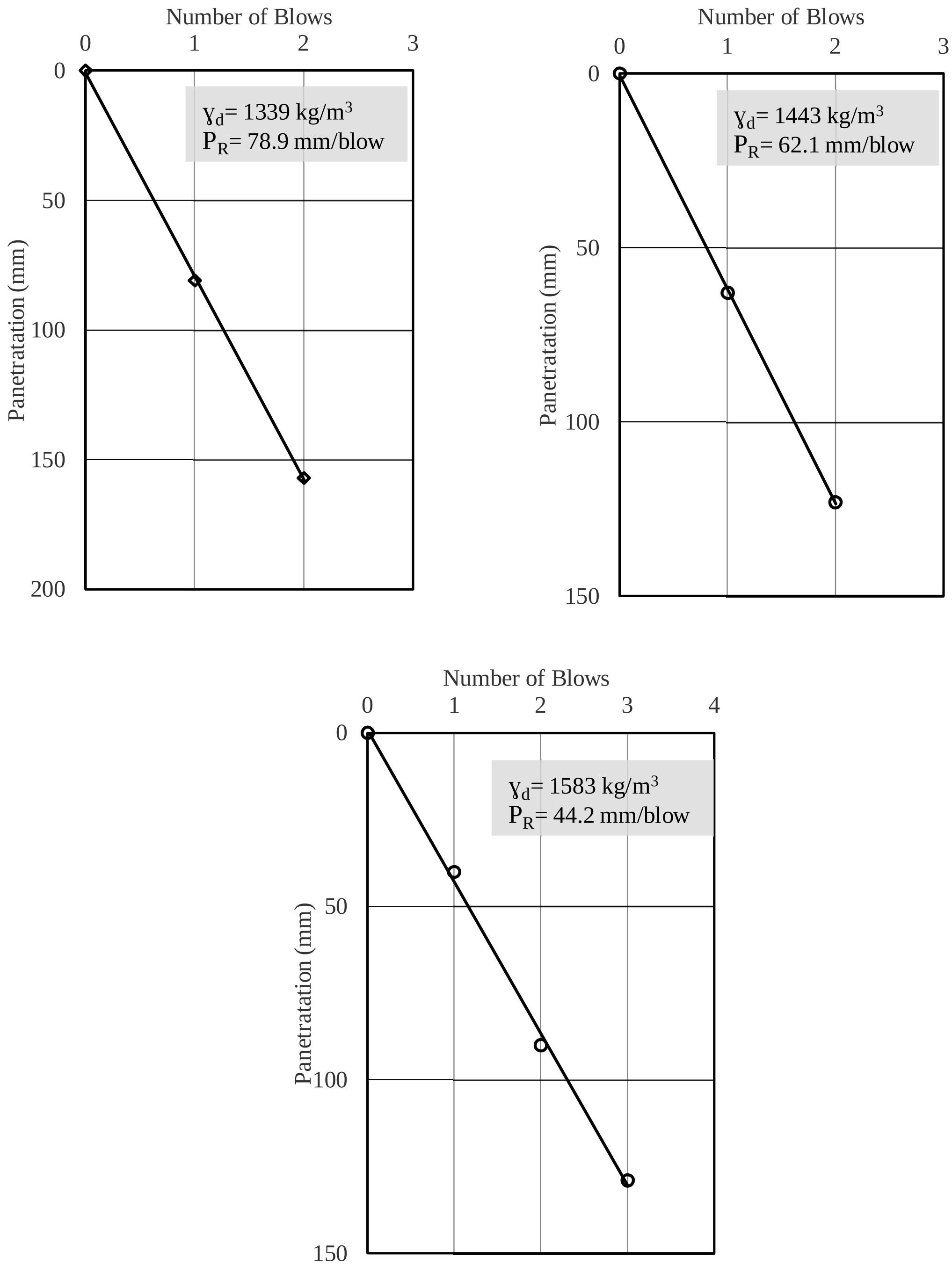


Figure 3.38: Lab DCP Test on TS_5 (CL)

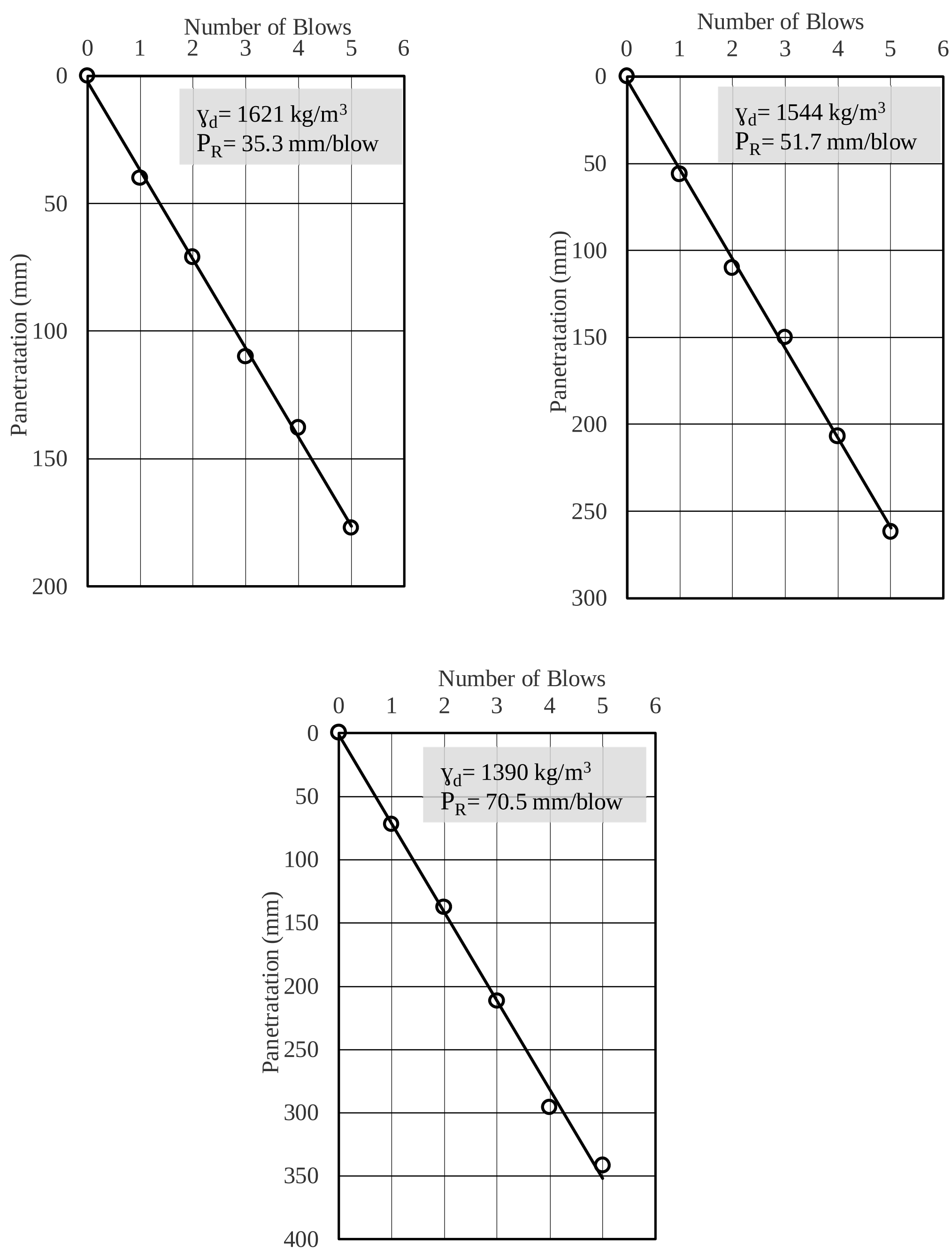


Figure 3.39: Field DCP Test on TS_5 (CL)

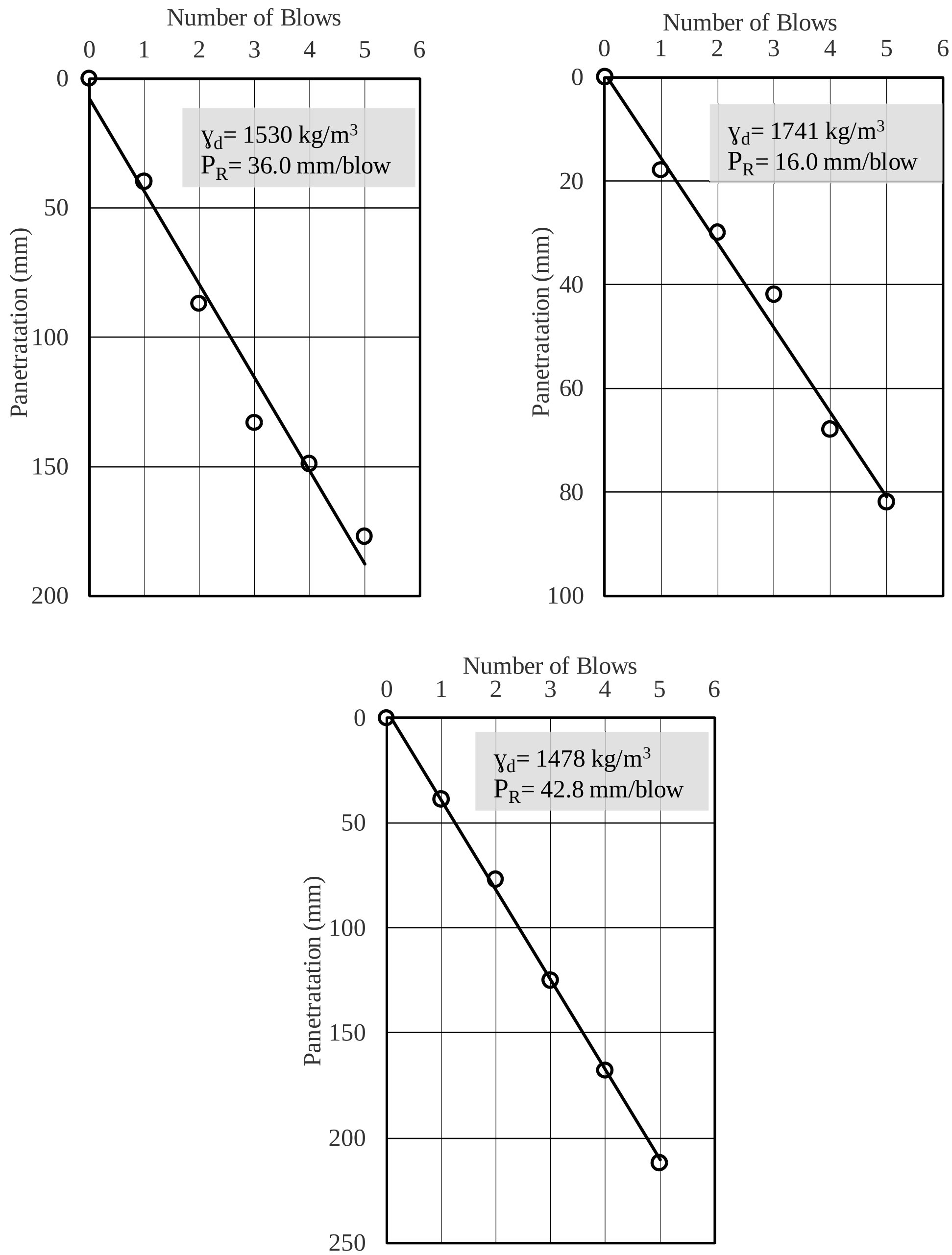


Figure 3.40: Field DCP Test on TS_6 (CL)

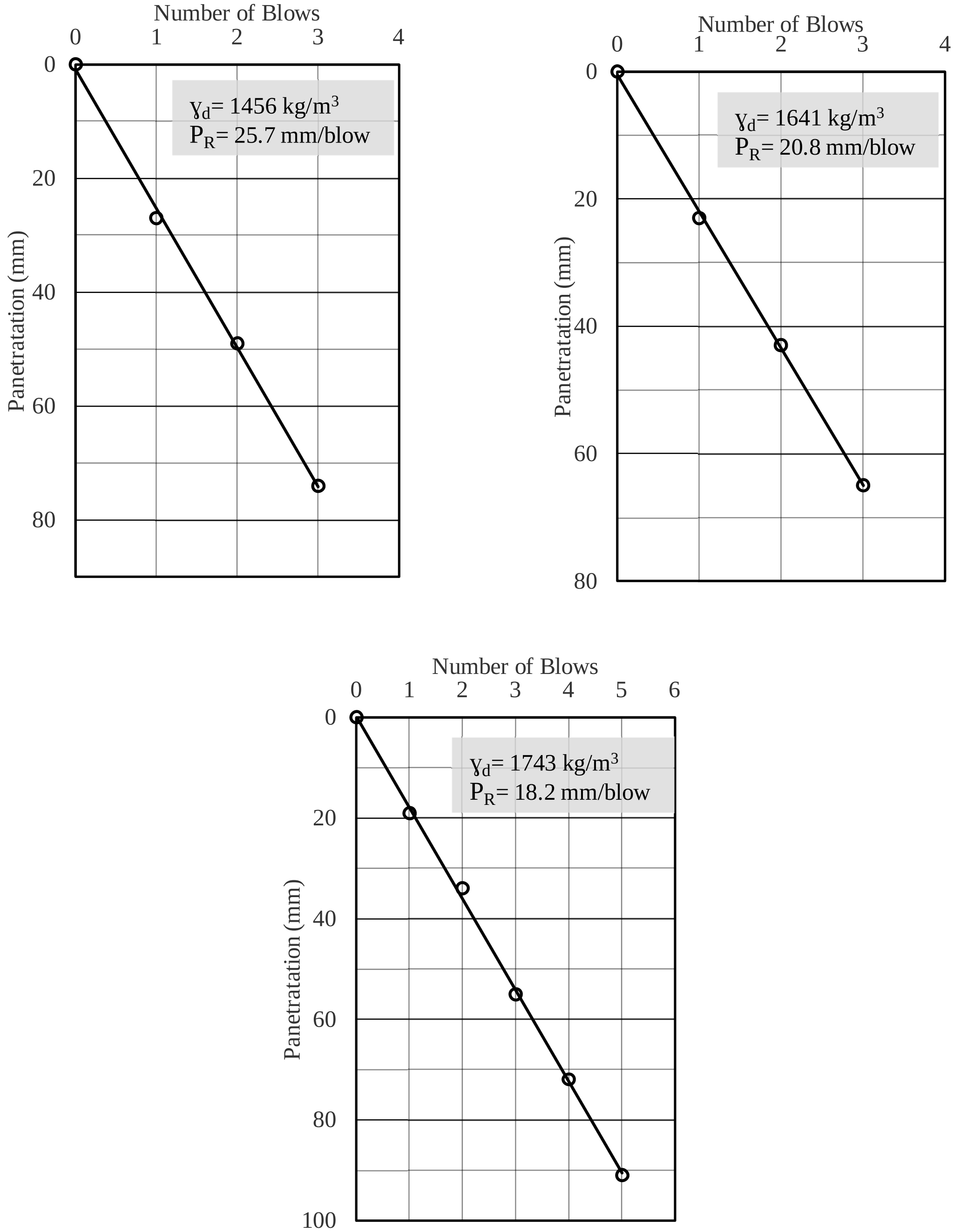


Figure 3.41: Lab DCP Test on TS_4 (CL)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GENERAL

In this research, Dynamic cone penetration (DCP) test were conducted on various soil samples collected from different locations of the site at Optimum moisture content (OMC) with different soil densities. The test data obtained from both field and lab tests were plotted on a graph for comparison. The significance of the results on penetration resistance and soil density are also discussed.

4.2 RELATION BETWEEN DRY DENSITY AND PENETRATION RATE

The penetration rate of test samples on various moisture cannot form a relationship. It is observed that due to the difference in the moisture of the test sample this happens. Therefore, the DCP penetration test ware taken at OMC and then performed DCP test on it. It is observed that the penetration rate on the soil sample increases when the density of the soil sample is low, also if the density is high then the penetration rate tends to decrease.

Table 4.1: Field Penetration vs Lab penetration

TS_1 (SP-SM)				**TS_2 (CL)**			
Lab		**Field**		**Lab**		**Field**	
Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate
Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow
1584	53.0	1478	71.0	1323	70.0	1367	59.2
1694	31.3	1686	31.1	1466	40.0	1527	45.8
1733	25.0	1737	23.1	1683	30.0	1661	26.5
1767	21.7						
1780	15.6						
TS_3 (CL-ML)				**TS_4 (CL)**			
Lab		**Field**		**Lab**		**Field**	
Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate
Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow
1597	41.0	1467	55.6	1394	51.0	1478	42.8
1608	40.0	1587	41.3	1551	34.8	1530	36.0
1619	39.0	1749	25.2	1642	23.5	1741	16.0
1677	32.0						
TS_5 (CL)				**TS_6 (CL)**			
Lab		**Field**		**Lab**		**Field**	
Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate	Density	Penetration Rate
Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow	Kg/m^3	mm/blow
1456	25.7	1372	27.7	1339	78.9	1390	70.5
1641	20.8	1586	22.5	1443	62.1	1544	51.7
1743	18.2	1686	19.7	1583	44.2	1621	35.3

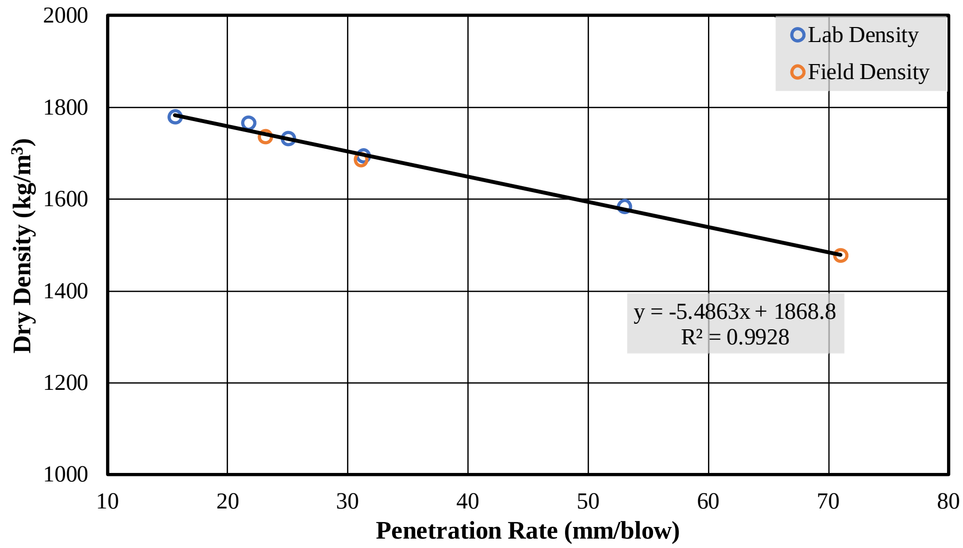


Figure 4.1: Field Penetration vs Lab penetration Comparison (Test Sample_1)

Here, we observe the data of test sample 1 from table 4.1 plotted in figure 4.1. the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

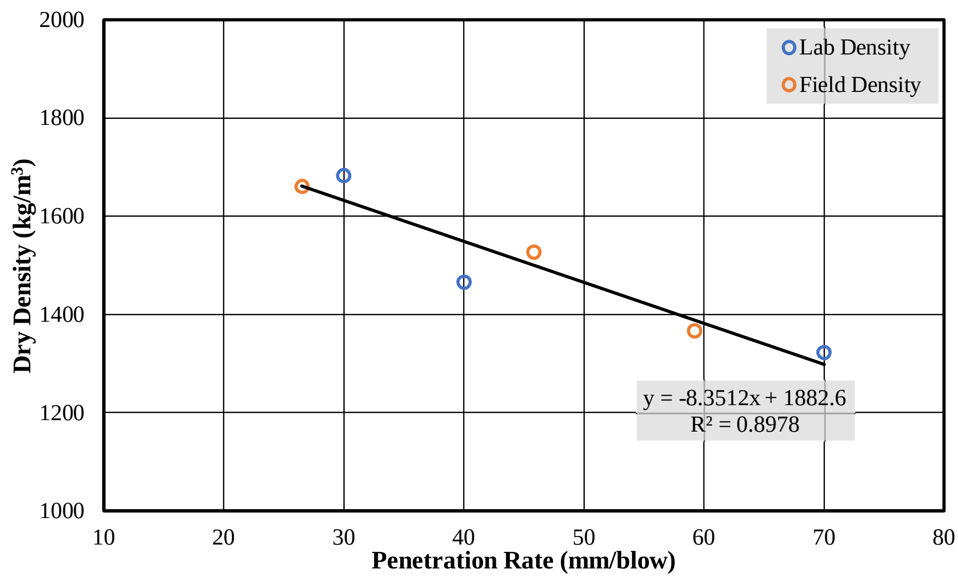


Figure 4.2**:** Field Penetration vs Lab penetration Comparison (Test Sample_2)

Here, we observe the data of test sample 2 from Table 4.1 plotted in figure 4.2. the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

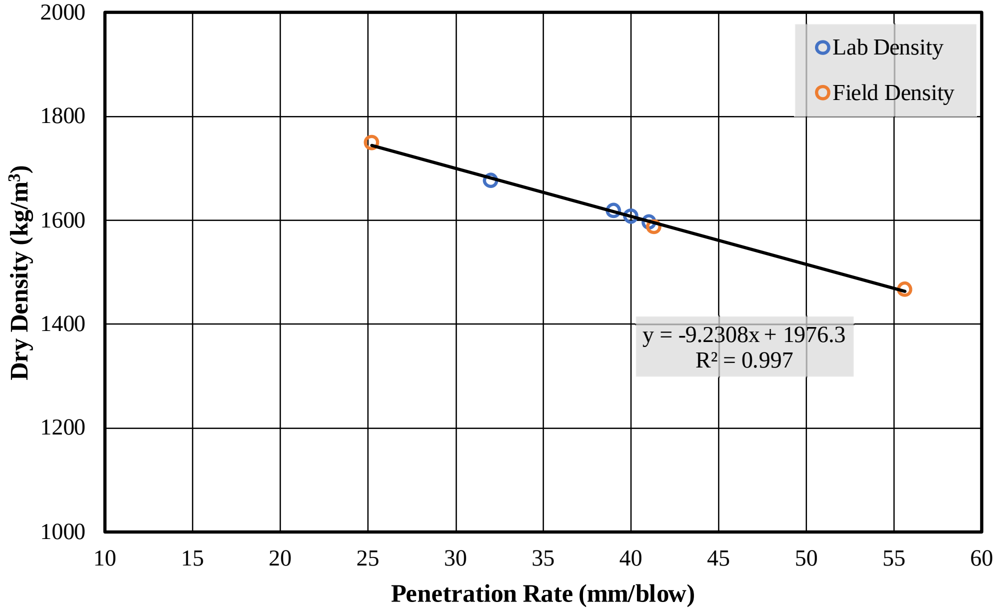


Figure 4.3: Field Penetration vs Lab penetration Comparison (Test Sample_3)

Here, we observe the data of test sample 3 from table 4.1 plotted in figure 4.3 the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

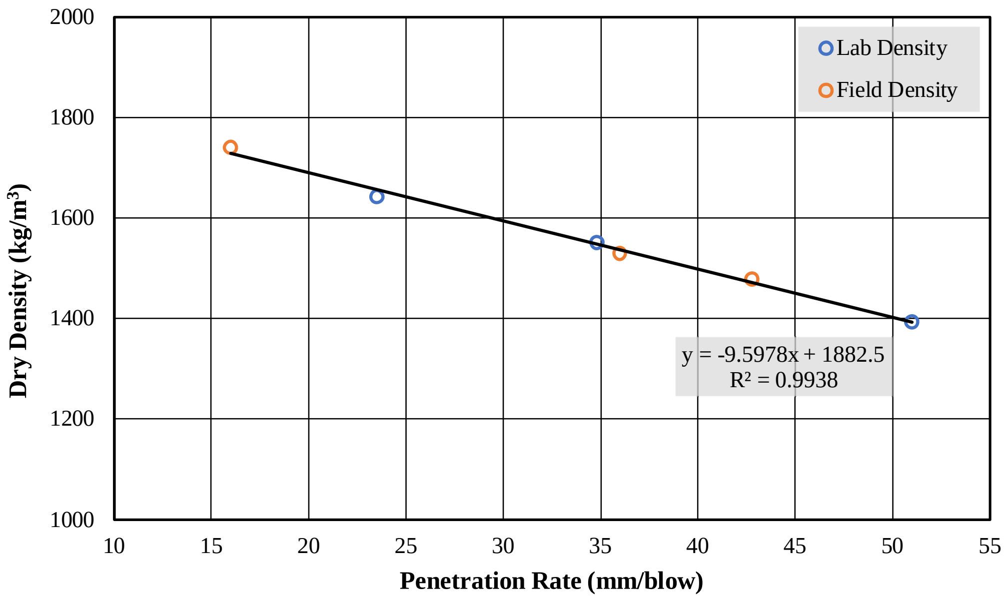


Figure 4.4: Field Penetration vs Lab penetration Comparison (Test Sample_4)

Here, we observe the data of test sample 4 from table 4.1 plotted in figure 4.4. the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

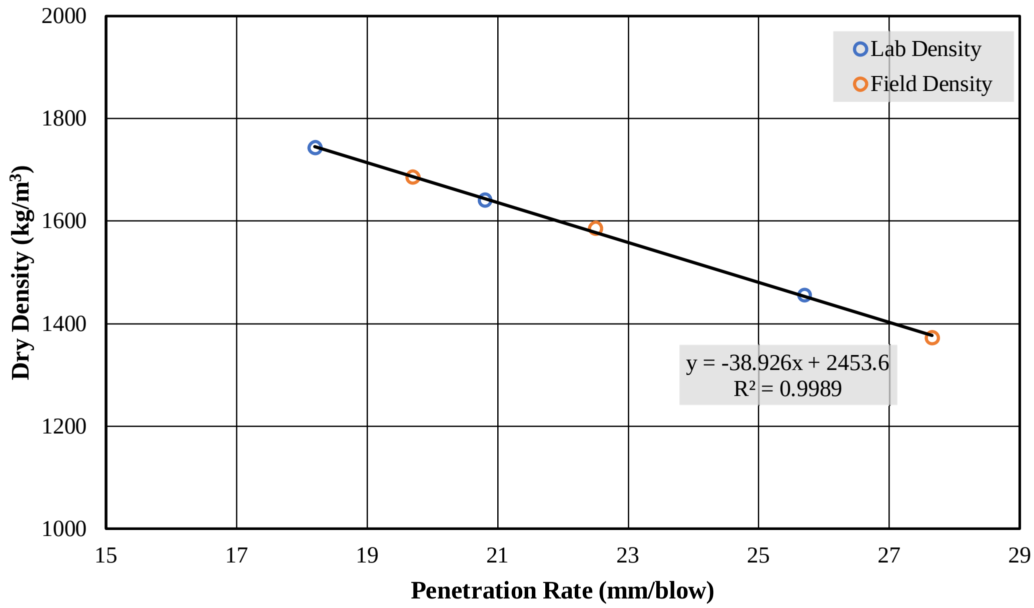


Figure 4.5: Field Penetration vs Lab penetration Comparison (Test Sample_5)

Here, we observe the data of test sample 5 from table 4.1 plotted in figure 4.5. the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

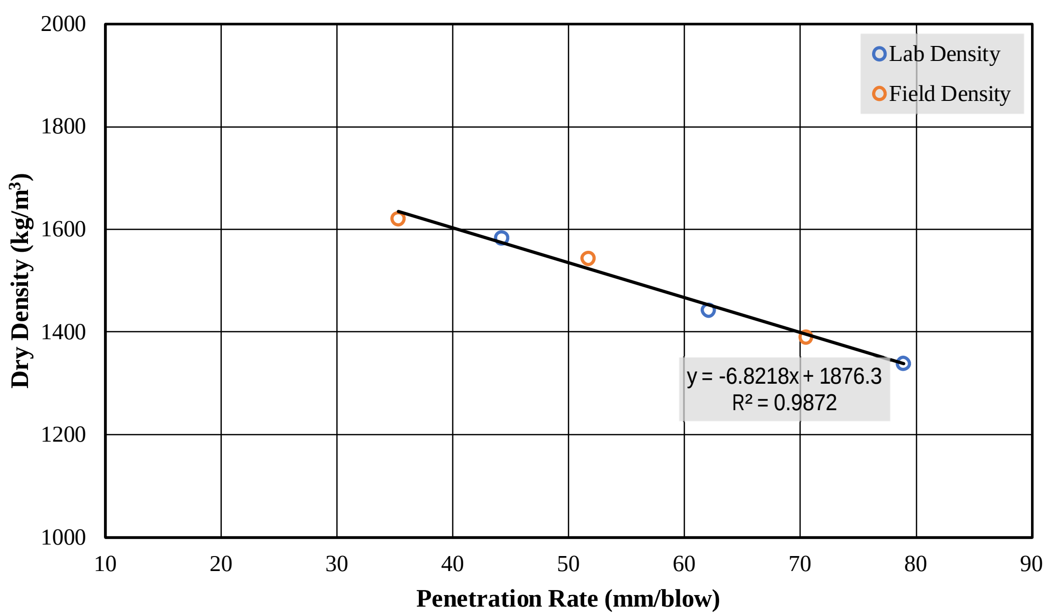


Figure 4.6: Field Penetration vs Lab penetration Comparison (Test Sample_6)

Here, we observe the data of test sample 6 from table 4.1 plotted in figure 4.6. the graphical representation shows that the lab test results and filed compacted test results are approximately similar compared to each other.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 GENERAL

This research talks about a method that uses DCP a simple, inexpensive, portable device that can be used easily with a minimum workforce in the field to determine soil density using the correlation obtained from this study. This chapter summarizes the conclusion of this research study and recommendations for future studies.

5.2 CONCLUSION

This study aims to solve one of the common problems in road construction. Though there are several methods and tests used for determining soil density. This study introduces DCP to make the testing procedure much more efficient and affordable. By creating a correlation between DCP and soil density. The collected sample from 6 different locations of the LGED road development project was selected for this study. The test samples were prepared at different densities by using the ASTM method and performed several DCP tests on them. Similar tests were done in the field. The test result obtained from those shows that DCP penetration rate and soil dry density produce a disproportionate liner equation. Although the result shows the linear equation for all test samples, the penetration rates are not the same.

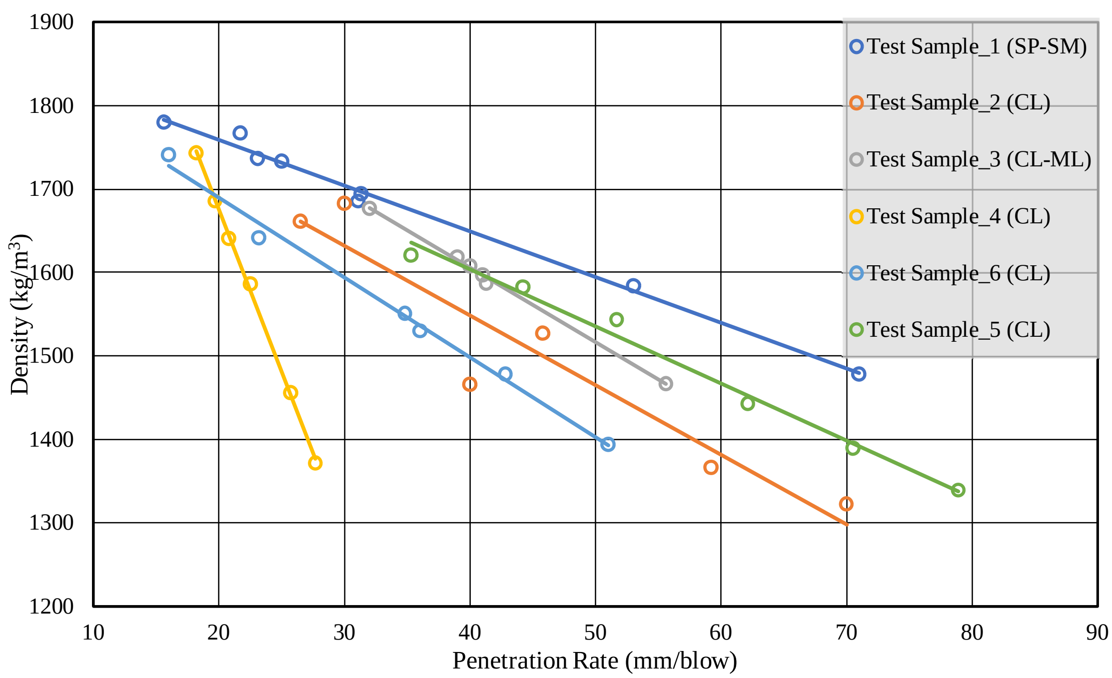


Figure 5.1: Soil Density vs Penetration rate correlation.

By performing grain size analysis on the test sample, it is found that each test samples have different particle percentages. Different percentage of finer particle penetration rate is different for each test sample.

5.3 RECOMMENDATION

This study is mainly correlating with the soil dry density and rate of penetration using Dynamic Cone Penetration (DCP). The durability or strength of the road layer depends on the compactness of its materials, by implementing this method the effectiveness increases significantly. However, in the future, there may exist more studies in the context of this study. The following recommendation may be: -

- More field study is required for the implementation of this correlation.
- Different soil samples with different characteristics may also be tested.

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