STATIC COMPACTION CHARACTERISTICS OF SOILS

A dissertation submitted in

partial fulfilment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

In

CIVIL ENGINEERING

(With specialization in Geotechnical Engineering)

Under

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

SESSION: 2023-25

Submitted by

NIKUMANI KALITA

MTech 3rd Semester

Roll No: PG/C/23/10

ASTU Roll No: 230620062008

ASTU Registration No: 368104119

Under the guidance of

DR. (MRS) BINU SHARMA

Professor, Assam Engineering College

Department of Civil Engineering

Assam Engineering College

Jalukbari, Assam, 781013

DECLARATION

I hereby declare that the work presented in this report entitled "**STATIC COMPACTION CHARACTERISTICS OF SOILS**" in partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical engineering submitted to the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science and Technology University, is an authentic record of my own work carried out in the said college for six months under the supervision and guidance of Dr. Binu Sharma, Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati- 13, Assam.

I do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

Date:

Place:

Name: NIKUMANI KALITA

MTech 3th Semester

College Roll No: PG/C/23/10

ASTU Roll No: 230620062008

ASTU Registration No: 368104119

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati- 781013

CERTIFICATE

This is to certify that the work presented in this report entitled — "**STATIC COMPACTION CHARACTERISTICS OF SOILS**" is submitted by Nikumani Kalita, Roll No: PG/C/23/10, a student of MTech 3th semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfilment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Date:

Place:

DR. (MRS.) BINU SHARMA

B.E. (Gau), M.E. (U.O.R), Ph.D. (Gau)

Professor, Department of Civil Engineering,

Assam Engineering College

Jalukbari, Guwahati-781013

Certificate from the Head of the Department

This is to certify that the following student of MTech 3th semester of Civil Engineering Department (Geotechnical Engineering), Assam Engineering College, has submitted her project on— "**STATIC COMPACTION CHARACTERISTICS OF SOILS"** in partial fulfilment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Name: NIKUMANI KALITA

College Roll No: PG/C/23/10

ASTU Roll No: 230620062008

ASTU Registration No: 368104119

Date:

Place:

DR. JAYANTA PATHAK

Professor & Head of Department

Department of Civil Engineering

Assam Engineering College, Jalukbari

Guwahati- 781013

ACKNOWLEDGEMENT

I would like to extend my sincere appreciation to Dr. (Mrs.) Binu Sharma, Professor in the Department of Civil Engineering at Assam Engineering College, for her extensive support and encouragement throughout the project. Her guidance, constant supervision and provision of necessary information were invaluable to me. Working under her was an inspiring and great experience, and I am highly indebted to her.

This project would not have been possible without the help of; laboratory assistants and staffs, for their guidance in various ways. Without their guidance and support it would not have been possible for me to prepare and complete this study.

I am also grateful to Dr. Jayanta Pathak, Professor and Head of the Department of Civil Engineering at Assam Engineering College as well as the entire community of the Department of Civil Engineering at Assam Engineering College for providing us with the necessary infrastructure and comfort throughout the course, particularly during my project.

Date:

Place:

Name: NIKUMANI KALITA

M.Tech 3^{th} Semester

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati- 781013

ABSTRACT

This study aims to analyze soil compaction behavior through both static and dynamic compaction tests, focusing on the development of static compaction energy curves to quantify the energy required for efficient soil compaction under varying conditions. The research seeks to derive equivalent static compaction energy values and correlate these with Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) as determined by the standard Proctor Compaction Test. Using regression analysis, the study establishes relationships between soil parameters and compaction characteristics, enabling the prediction of MDD and OMC values through multiple regression techniques. The study also compares the effects of static and dynamic compaction on fine-grained soils, evaluating how gradual sustained pressure (static compaction) versus repeated impact forces (dynamic compaction) influence compaction behavior. The objectives include comparing static and dynamic compaction results, deriving static compaction energy curves, and predicting equivalent static energy, MDD, and OMC values based on different soil parameters.

CONTENTS Page No

CHAPTER 1

INTRODUCTION

1.1 General

Soil compaction is the process of increasing soil density by mechanically reducing the volume of air in pore spaces. Not only does it decrease the compressibility, but it also reduces the permeability of the soil mass by its loss in porosity, thus resulting in an increase in both strength and stiffness. From the engineering point of view, compaction is one of the primary tests in the field of soil mechanics.
It provides soil with unique physical properties best for a certain project. An evaluation of the compacted material can be quantitatively derived using dry unit weight and related moulding moisture content. Dry unit weight of the soil, to be improved via compaction mainly relies on its moisture content in conjunction with applied energy during compacting. It is that moisture content in various types of soil at which the maximum dry density for a particular amount of compaction energy can be obtained.

The primary use of dynamic or static efforts is for soil compaction. Among the dynamic compaction processes, the most widely used process is the determination of the compaction characteristics of soil in a laboratory. The standard Proctor test was developed by R. R. Proctor, and the OMC and MDD value for a specific soil is obtained using this method. The dynamic compaction is generally applied using a standard rammer with specified drops over a soil mass in a standard mould in the laboratory. However, rollers are applied in the field for compaction. Compactive effort is number of passes or coverage of a roller and weight in a given volume of soil. Hence, field compaction dependency is on type, moisture content, number of passes, type of the compactor, the speed, etc.

Analyzing how different compaction procedures affect soil compaction is crucial because compaction fundamentally alters soil structure. The primary goal of compaction is to enhance the strength and stiffness of the soil by decreasing its compressibility. It's possible that the compaction method employed—whether static or dynamic—can influence the soil's strength. Therefore, evaluating the effects of various compaction techniques on the soil's compaction curve and its mechanical strength is very important. This study aims to compare the strength of soil samples that have been compacted at the same moisture content to achieve the same bulk densities using both static and dynamic compaction methods. The soil samples were compacted using both techniques at dry of optimum, at optimum moisture content, and at wet of optimum moisture content.

1.2 Objective of the study

This study, therefore, strives to comprehensively analyze soil compaction behaviors, both static and dynamic compaction tests. The approach is aimed at developing static compaction energy curves to quantify energy required for efficient soil compaction under varying conditions. It tries to obtain the equivalent static compaction energy by evaluating the curves and equate this value to MDD and OMC, as calculated from the standard Proctor Compaction Test. The study uses regression analysis to establish relationships between soil parameters and compaction characteristics, which can be used to predict MDD and OMC values through multiple regression techniques. Its goal is to evaluate and compare how these different techniques affect the behavior of fine-grained soils. Specifically, it examines the impact of static compaction, which involves applying gradual and sustained pressure, versus dynamic compaction, which uses repeated impact forces.

The objective of this research is as follows

- To compare the static and dynamic compaction test results.
- To derive static compaction energy curves.
- To determine the equivalent static compaction energy in which MDD values at OMC can be obtained as determined from standard Proctor Compaction Test.
- To compare static and dynamic compaction energies.
- To predict Equivalent Static Energy from different parameters by regression
- To predict OMC and MDD values by multiple regression

CHAPTER 2

REVIEW OF LITERARTURE

2.1 Introduction:

Different research workers intended to predict the compaction properties of soil by standard Proctor approach, modified Proctor approach and static compaction approach at different time and also tried to give the comparison between the three methods. However, literature in static compaction is very scarce. Some of these works are discussed briefly in this chapter.

2.2 Review of literature:

Laboratory compaction by standard Proctor and modified Proctor methods are important tests to obtain the relationship between maximum dry density and optimum moisture content values. Kenneth and Steven (1968), Reddy and Jagadish (1993), Mesbah et al (1999) ,Kenai et al(2006), Hafez et al (2010) ,Yuce, E. and Kayabali, K. (2010), Dario et al (2011) , Sharma, B. and Talukdar, P. (2014) presented the static compaction method as an important laboratory technique.

Kenneth and Steven (1968) in their research conducted kneading and static compaction method in the laboratory. Then the results obtained from kneading compaction and static compaction methods were compared. Based on the comparison of the maximum dry density (MDD) and optimum moisture content (OMC) curves, it was found that the value of MDD obtained from static compaction method was higher as compared to that of the kneading method. The MDD value obtained from static compaction was 94 lb per cu ft, while obtained from kneading compaction was 84 lb per cu ft.

Reddy & Jagadish (1993) described a new static compaction test for soils to be used in production of compacted soil blocks. The static compaction tests described can be used to obtain a continuous relationship between compaction energy and OMC. They stated that static compaction is of two types which are constant peak stress- variable stroke compaction and variable peak stress- constant stroke compaction. In constant peak stress- variable stroke compaction method, the applied load is varied gradually at a definite rate until a specific peak stress is reached. The thickness of the compacted specimen depends on the moisture content. In these tests, compaction curves similar to Proctor curves were generated, but the energy input to the soil varied with moisture content and hence such a compaction curve cannot be interpreted with reference to a specific energy input.

Thus, **Reddy & Jagadish (1993)** devised a static compaction test based on the variable peak stress- constant stroke compaction process in which static force is gradually applied to a soil mass until a specific final thickness is achieved. The force at the end of compaction can vary depending on the moisture content of the soil. Even this test does not lend itself to a constant energy input compaction; however, they made an attempt to derive the energy input-OMC relationship indirectly. They obtained a relationship of compaction energy, dry density and OMC by static compaction of a soil into a small cube at different moisture contents while the energy input to the cube is monitored. This relationship provided specific information on the OMC to be used to achieve a given dry density when the compaction energy available in the compaction device is known.

The results of static compaction with those of Proctor compaction test were compared by superimposing the Proctor compaction curves on the static compaction curves. It was found that the static compaction curves show only the “rising” portion of the compaction curve while “drooping” portion beyond the OMC normally noticed in the Proctor curve is not present. The curves also show that for the same input energy and OMC value, the static compaction produces a much higher dry density. The Proctor compaction achieved a dry density of 17.46 kN/m^3 at an OMC of 16.3%, a static compaction using the same energy per unit volume achieved a dry density of 18.15 kN/m^3 at an OMC of 16.6%. This indicates that the static compaction process is more energy efficient than the Proctor method, perhaps because of the higher energy losses during the impact of the falling weight in the Proctor test. However, Reddy & Jagadish (1993) concluded that static compaction test described in their work is cumbersome and hence a simpler, faster test procedure is required to facilitate a rapid compaction analysis.

Mesbah et al. (1999) described a quasi-static compaction technique in their technical paper. The technique involves pressing the soil into the mould in two-way directions which are from the top and from the bottom. Based on the quasi-static compaction design, the soil specimen was compacted homogeneously. Mesbah et al (1999) in their technical paper compared the quasi-static and dynamic compaction methods to define which method present higher density. As a conclusion, the higher density value was obtained by the quasi-static technique as compared to the standard Proctor technique although the same amount of energy was applied in both the methods.

Kenai et al (2006) studied the effect of different compaction methods on the performance of stabilised soil. The compaction methods used were either static compaction by applying a static pressure using a universal compression testing machine, dynamic compaction by a drop weight method and static compaction coupled with vibration. All these methods were applied on unstabilised soil or cement stabilised soil.

Static compaction is obtained by applying a static pressure using a universal testing machine on stabilised soil put in a cylindrical mould of 100 mm diameter and 165 mm height at a strain rate of 1.27 mm/min until the desired compaction stress was obtained. In vibro static compaction, the specimens were first vibrated on a laboratory shaking table for one minute before being subjected to static compaction force. In dynamic compaction, a modified Proctor test was used in order to overcome the drawbacks of static compaction which could not lead to a perfect grain arrangement whatever static pressure was applied.

They tried to find the effect of compaction methods on soil properties. They found that the effect of static compaction on the dry density of soil is more pronounced when the water content is on the dry side of the curve. They also observed vibration seems to enhance the dry density only when the static compaction stress is low. Vibro-compaction did not enhance the performance of soil when lower water content is used but for higher water content than optimal values, vibro-compaction seems to be the best compaction method. They observed that the highest dry density was obtained with the dynamic method when water content is on the dry side of the curve. They concluded that mechanical stabilisation by dynamic compaction seems to enhance the mechanical properties and water resistance of the soil as compared to the static or vibrostatic compaction methods. Dynamic compaction with about 8% of cement content seems to give the best performance for the soil investigated.

Hafez et al (2010) introduced a new laboratory compaction method known as static packing pressure test which is designed as a static compaction technique. This method is suitable for Malaysian soil because Malaysia is close to cohesive soils area and static rolling machine is a common method of compaction in the field for finding the MDD. But in the laboratory MDD is determined by standard Proctor method which applies standard energy for all types of soil and the data not distinctive to a particular soil. Therefore, to close the gap between laboratory test & field method to measure the value of MDD, a new static compaction method has been developed.

In static packing pressure test, a constant compression force is applied to the soil by using a new static mould designed with certain amount of energy. The amount of energy is dependent on characteristic and conditions of each type of soil. Therefore, from static compaction test, each soil has certain amount of energy per unit volume compared to dynamic compaction which applies standard energy for all categories of soils. The static packing pressure machine uses a load cell which is connected to a data logger to measure force values. Hydraulic pump is used to produce the needed pressure on the soil packed in the mould. In static compaction process, the soil is compacted by gradual static force while the soil inside the mould is turned slowly into a rigid homogeneous body. So static packing pressure compaction has the advantage of compacting the soil in one homogeneous layer compared to the dynamic compaction where the soil is compacted into three layers.

This technical paper also drew the comparison between static and dynamic compaction test. It has been found that the results come out from static method is higher in OMC & MDD value compare to dynamic method. Therefore, the static compaction test can be used to measure the degree of compaction value in the laboratory to correlate with field data of static compaction technique. The static compaction is also described as a faster, easier and simpler method that can be carried out in the laboratory in short duration time compared to dynamic concept.

Yuce, E. and Kayabali, K. (2010) developed a miniature static compaction test to account for the energy loss and large quantity of material required for testing during standard Proctor test. The diameter and height of the compaction mould are kept as 5cm. They applied the same energy in static compaction method as it was in standard Proctor method (592.7 kJ/m^3). They used ten samples of predominantly fine material with different plasticity. Each of the ten samples was subjected to standard Proctor and modified Proctor tests utilizing an automated compactor as well as the static compaction test by employing a conventional uniaxial compression apparatus. The static compaction test was performed at a constant speed and load was recorded. When the total energy reached the work of standard Proctor method, the loading was terminated (i.e. 592.7 kJ/m^3). At the optimum moisture content of each of the three compaction methods, the soil samples were recompacted and the falling head permeameter and unconfined compression tests were conducted on the recompacted samples. On analysis of the results, they found that the maxima of static compaction curves fall mostly between those of standard Proctor & modified Proctor methods. Also, the undrained shear strengths & permeabilities of the recompacted soil at the optimum water contents using the static compaction method fall between those of standard Proctor and modified Proctor methods which were similarly recompacted at their optimum water contents.

Dario et al (2011) in their technical paper addressed the influence of the static and dynamic soil compaction procedures in the compaction curves and mechanical strength of two types of residual soils from the Zona da Mata Norte , in the of Minas Gerais, Brazil. The two residual soils are silty-sandy clay and clayey-silty sand. Their laboratory testing program was directed to compaction of specimens at standard Proctor compaction effort and at the optimum moisture content, and also to determine the unconfined compressive strength of the compacted specimens. They have also done micromorphological analysis of thin sections of the compacted specimens using optical microscopy as well as statistical analysis of the laboratory testing program data. They found that compared to the dynamic compaction, the static procedure produced specimens with higher UCS with clayey soil and lower UCS with granular soil. They also found that there was statistically significant influence of the compaction procedures on the optimum compaction parameters. They also concluded that incorporation of the micromorphological analysis to their study allowed them to identify differences in the structures produced by the static and dynamic compaction procedures.

Sharma, B. and Talukdar, P. (2014), in their studies reproduced the compaction characteristics through static compaction test in the laboratory and also derived the equivalent static pressure required to obtain the MDD and OMC as obtained from the standard Proctor test. For this purpose, a laboratory static compaction method was introduced which consists of placing of a known weight of soil with known moisture content into the standard Proctor mould of 1000 mL and then statically compacting it with a cylindrical plunger. Each soil sample was compacted in three separate soil layers. Each time after the static compaction of a particular soil thickness or layer, the compacted soil was completely removed from the mould and the empty mould was again filled with the next soil thickness or layer. Thus the process of static compaction was repeated thrice for a particular moisture content of each soil sample. On plotting the curve between static pressure and dry density, it was observed that at lower static pressure, a significant variation in dry density was obtained but this variation becomes negligible with the increase in static pressure and after a particular static pressure, the dry density becomes constant. Also in this study, it was attempted to find the effect of static compaction with the height of soil. However no significant variation in dry density corresponding to different static pressure was observed with the change in height of soil.

It was observed that static compaction test carried out gives a parabolic relationship between moisture content and dry density for the different static pressures. On superimposing the static compaction curves corresponding to different static pressures with standard Proctor compaction curve, it was observed that at higher static pressure, higher MDD is obtained then that obtained from the standard Proctor test. The equivalent static pressure required to obtain the MDD at OMC as determined from the standard Proctor test is found to be around 820 kN/m^2, the results have been found consistent for all the eight different soil samples tested in the three separate soil thickness. The study has further shown that maximum dry density and optimum moisture content (OMC) can also be determined by the static compaction test and the static pressure for this should be around 820 kN/m^2.

Going by the literature review it has been observed that comparisons can be made between the static compaction method, standard Proctor method and modified Proctor method. In this study, an attempt has been made in the same direction. Also an attempt is made to determine the equivalent static pressure from which the maximum dry unit weight as obtained from the standard Proctor test, modified Proctor test, reduced standard Proctor test and reduced modified Proctor test can be determined.

Sharma et al. (2016) in their study reproduce the compaction characteristics of fine-grained soil through static compaction test in the laboratory and also derived the equivalent static pressure required to obtain the MDD and OMC as obtained from the standard Proctor test. For this purpose, laboratory static compaction method was introduced which consist of placing a known weight of soil with known moisture content into the standard Proctor mould of 1000 cc capacity and then statically compacting it with a cylindrical plunger. Each soil sample was compacted in three separate soil layers. Each time after static compaction of a particular soil thickness or layer, the compacted soil was completely removed from the mould and the empty mould was again filled with the next thickness or layer. Thus the process of static compaction was repeated thrice for a particular moisture content of each soil sample. On plotting the curve between static pressure and dry unit weight, it was observed that at lower static pressure, a significant variation in dry unit weight was obtained but this variation becomes negligible with the increase in static pressure and after a particular static pressure, the dry unit weight becomes constant. Also in this study, it was attempted to find the effect of static compaction with the height of soil. However no significant variation in dry unit weight corresponding to different static pressure was observed with the change in height of soil.

It was observed that static compaction test gave a parabolic relationship between moisture content and dry unit weight for the different static pressures. On superimposing the static compaction curves corresponding to different static pressures with standard Proctor compaction curve, it was observed that at higher static pressure, higher MDD was obtained then that obtained from the standard Proctor test. The equivalent static pressure required to obtain the MDD at OMC as determined from the standard Proctor test is found to be around 820 kN/m^2. The findings have been found to be consistent for all the eight different soil samples tested in the three separate soil thickness. The study has further shown that MDD and OMC can also be determined by the static compaction test and the static pressure for this should be around 820 kN/m^2. The initial form of this same work was also described by Sharma and Talukdar (2014) in their technical paper.

Sharma and Deka (2016) attempted to obtain compaction characteristic using static compaction method, using the same mechanism as proposed by Sharma et al. (2016). An attempt has been made to determine the equivalent static pressures to the modified Proctor test (MP), the reduced modified Proctor test (RMP), the standard Proctor test (SP) and the reduced standard Proctor test (RSP), to obtain the maximum dry unit weight and the optimum water content corresponding to the four different compactive efforts. Altogether, seven fine-grained inorganic soil samples were tested to determine static compaction characteristics and their relevant physical properties. The MP, RMP, SP and the RSP tests were also performed to determine the dynamic compaction characteristics. The relationship between static pressure and dry unit weight, corresponding to different water contents, has been plotted in the form of curves which is found to be nonlinear. It is observed from the curves that the dry unit weight increases to its maximum value and then 14 remains constant with further increase in static pressure. For a particular static pressure and water content, the relationship between water content and dry unit weight is found to be parabolic in nature. One common characteristic in all the curves in all the soil samples was that, beyond a static pressure of around 1513 kN/m^2, there was no change in dry density. It has been observed that degree of saturation can reach a maximum value of 93–98% depending on the soil sample at around the optimum water contents. Superimposing the static compaction curves of a particular soil sample corresponding to different static pressures with the dynamic compaction curves of the SP, RMP, SP and RSP, it is observed that a static pressure in the range of 750– 875 kN/m^2 is required to obtain the maximum dry unit weight value at OMC for standard Proctor test and reduced standard Proctor test, and a static pressure in the range of 1375–1500 kN/m^2 is required to obtain the maximum dry unit weight value for reduced modified Proctor test curves in all the seven soil samples. Further, it is observed that the parabolic curve corresponding to the maximum static pressure of 1513 kN/m^2 lies below the modified Proctor test curve in all the seven soil samples.

B Sharma et al. (2018) tried to study the static compaction characteristics of coarsegrained and fine-grained soils and compared it with that of the dynamic compaction characteristics at different compactive effort. The modified Proctor test, reduced modified Proctor test, standard Proctor test and reduced standard Proctor test were used to determine dynamic compaction characteristics of soil to reinforce the understanding of compaction characteristic of both fine grained and coarse-grained soil. Static compaction test was done by the method devised by Sharma et al. (2016). Altogether 12 soil samples of IS classification CH, CI, SC, SM & SP are included in this test study for determining the static compaction characteristics of both coarse- and fine-grained soils so as to determine the transition in the static compaction characteristics of soils from fine gained soil to coarse grained soil. By analyzing the test results, it was concluded that the relation between moisture content and dry unit weight in static compaction for different static pressure is parabolic in nature for CI & CH class of soil. For SP class of soil, both the static and dynamic compaction curves show an undulatory pattern with maximum dry unit weight near dry and towards saturated condition. The dynamic compaction curve for both SC and SM class of soil is parabolic in nature. For SM class of soil, static compaction curve shows a wavy pattern with maximum dry unit weight at dry and near saturated condition whereas for SC class of soil only one-sided compaction part of the curve for the rising portion of the dry of optimum side was generated. In case of coarse-grained soils, an equivalent static pressure, at which maximum dry unit 15 weight at optimum moisture content can be obtained corresponding to different dynamic efforts, could not be determined as that of fine-grained soils.

Kayabali et al. (2020) in their work investigated the proper level of the compactive effort for the static compaction test and compared the compaction characteristics from standard Proctor and static compaction tests. They also compared the undrained shear strength and hydraulic conductivity obtained from both tests. Standard Proctor and static compaction tests were employed as compaction methods for ten soil samples of different gradational and plasticity characteristics. The theoretical energy delivered to compacted soil in this test was 592.7 kNm/m3 . In their work they found that when using the static compaction method, a soil's compaction curve could be created with 60% less energy. The entire soil mass is subject to displacement in the static compaction test, no energy is wasted, and nearly all the energy is utilized to densify the soil. According to the results of the compaction energy applied to all soil samples, the compaction energy level needed for the static compaction test is approximately 40% of the standard Proctor method, or 237 kJ/m^3.

Xu L et al. (2021) have described a procedure for creating and compacting specimens using a homemade double-faced static compaction mould, and compares it to the traditional dynamic Proctor test. The study measures compaction energy and matric suction for each sample, and concludes that:

1) similar to Proctor tests, a series of iso-energy curves are identified for the set of static compaction tests, with increased energy leading to a reduction in optimum moisture content and an increase in maximum dry density.

2) A new term, "optimum saturation degree," is introduced as the degree of saturation where maximum dry density is achieved for a given compaction energy and method.

3) For a specific earth type, the optimum saturation degree is constant and a unique compression curve linking degree of compaction to this saturation degree exists, regardless of method or energy.

4) Matric suction of specimens compacted with the homemade mold is slightly higher than that of the Proctor test at the same moisture content, and dry density has little correlation with variation in matric suction.

Lastly, the paper suggests a new method for earth compaction control, which aims to compact earth to a target density while meeting design requirements and maintaining optimum saturation degree.

Zhang et al. (2020) and Lee and Park (2021) have continued to investigate the static compaction characteristics of soils, particularly focusing on fine-grained soils such as silts and clays. Zhang et al. (2020) found that the interaction between compaction energy and moisture content in silty soils led to a more complex relationship compared to sand and clay. They also identified that the type of compaction equipment used (e.g., static vs. dynamic) plays a significant role in the results of laboratory compaction tests.

Lee and Park (2021) examined the role of soil plasticity and grain size distribution on compaction in cohesive soils. Their study revealed that clays with higher plasticity required more significant compaction effort and moisture control to achieve satisfactory results. They also proposed new compaction models that account for both the static pressure and moisture content, which could help improve compaction predictions in real-world scenarios.

Das and Sharma research seeks to enhance the uniaxial static compaction method, overcoming the disadvantages of the conventional Proctor dynamic compaction technique. The conventional Proctor test is sometimes very labor-intensive and does not provide optimal soil density or compactness in certain instances. The improved static compaction method proposed in this study has significant advantages, including less labor, higher soil density, and higher compactness. This new approach investigates a range of fine-grained soils with varying plasticity, focusing on the relationship between static compaction characteristics and various soil parameters. Notably, the study introduces the concept of Equivalent Static Compaction Energy (ESCE) and establishes its correlation with compaction parameters such as degree of saturation, void ratio, and plastic limit. The research demonstrates the creation of constant-energy curves for static compaction, which were compared with dynamic compaction curves from four different compaction attempts. The values of ESCE corresponding to standard Proctor, reduced standard Proctor, and reduced modified Proctor tests fall in the ranges of 180-340, 155-308, and 532-664 KJ/m^3, respectively. On the other hand, the study also reveals that upon reaching maximum compaction, any increase in energy of compaction does not increase the dry unit weight of the soil, thus showing a point of compaction energy beyond which more energy does not have a significant effect in changing the density of the soil. This research contributes to the understanding of static compaction methods and their applicability in geotechnical engineering by providing a more efficient, less labor-intensive method of gaining desirable soil compaction and improving soil behavior for construction purposes.

CHAPTER 3
TEST PROGRAM AND TEST RESULTS

3.1 Introduction:

The test program of different tests performed in the laboratory and their results have been discussed in this chapter.

3.2 Test Program:

The main objective of the test program is to determine the maximum dry unit weight and optimum moisture content of different types of soil in the laboratory by static compaction, standard Proctor test,reduced standard Proctor test and reduced modified Proctor test, to make a comparison of the compaction properties by all the methods and to determine an equivalent static pressure and equivalent static energy at which the maximum dry unit weight value at optimum moisture content for standard Proctor test, reduced standard Proctor test and reduced modified Proctor test can be obtained.

Thus after careful planning the entire test programme is divided into four phases as follows:

1) Collection of the soil samples.
2) Preparation of the disturbed sample for testing.
3) Determination of the physical properties of the soils.
4) Determination of the compaction properties of soils by static compaction, standard Proctor test, reduced standard Proctor test and reduced modified Proctor test.

3.2.1 Collection of the soil samples:

Four soil samples are collected from four different sites. For collecting the soil sample the top 30 to 60 cm thick layer of soil containing grass and vegetable roots was removed by excavation with a spade and the ground surface was leveled. About 1m x 1m square area was prepared for collecting the soil sample for determination of the physical properties and then about 120 kg of the soil sample was collected for determination of compaction properties from each site.

3.2.2 Preparation of the disturbed samples for testing:

Soil samples obtained from the field need to be prepared by standard methods before testing so that reproducible results can be obtained. The usual procedure consists of drying of the soil sample followed by pulverization and removal of stones before testing. In the IS method, the soil is allowed to dry in the room temperature.

3.2.3 Determination of the physical properties of the soils:

1) Determination of liquid limit was performed by cone penetration method according to IS 2720 (Part 5) 1985
2) Determination of plastic limit was carried out in the laboratory according to IS 2720 (Part 5) 1985.
3) Determination of specific gravity was performed according to IS 2720 (Part 3) 1980.
4) Determination of gradation of the soil samples by wet sieve analysis was performed according to IS 2720 (Part 4) 1985.

3.2.4 Determination of the compaction properties of soils:

By dynamic compaction method: For the determination of the compaction properties by dynamic method, standard Proctor test,reduced standard Proctor test and reduced modified Proctor test have been carried out in the laboratory.

All the four tests as mentioned above are discussed below briefly.

- Standard Proctor Compaction Test (as per IS: 2720-part vii, 1980): Soil was compacted into a mould in 3 equal layers, each layer receiving 25 numbers of blows of a rammer of weight 2.6 kg. The height of drop of rammer was 0.31 m.
- Reduced Standard Proctor Compaction Test: The procedure and equipment is essentially the same as that used for standard Proctor test. However, each layer received 15 numbers of blows of a rammer per each layer.
- Reduced Modified Proctor Compaction Test: The procedure and equipment is essentially the same as that used for modified Proctor test. However, each layer received 15 numbers of blows of a rammer per each layer.

By static compaction method: For the determination of the compaction properties by static compaction, the method devised by Sharma, B. and Talukdar, P. (2014) in their study has been used. Their laboratory method consists of placing a known weight of soil with known moisture content into the standard Proctor mould and then statically compacting it with a cylindrical plunger. Each soil sample was compacted in three separate soil layers or thicknesses at particular moisture content. They studied the effect of static compaction with the height of soil and found that there was no significant variation in dry density corresponding to different static pressures with the change in height of soil.

Therefore, in the present study the static compaction test is performed in only one soil thickness or layer having a height of 100 mm for a particular moisture content. For this purpose, air dried soil sample weighing 1.5 kg in total was prepared for each moisture content. In this way six sets were prepared with six different moisture contents for each soil sample. Each time for a particular moisture content, a known weight of soil was placed into the mould upto a particular height (100 mm) and was statically compacted. After static compaction, the soil was completely removed from the mould and the process was repeated for the next moisture content.

Thus, it is clear that for all the soil samples, irrespective of different moisture contents, the height of the soil sample was kept constant.

3.2.5 Static compaction test procedure: The test begins with the placing of a prepared soil sample upto a height 100 mm, with known moisture content in the standard Proctor mould of 1000 ml capacity along with the base plate.

Fig 3.1: Two metal plate and Mould used in Static Compaction

Two metal plates of diameter 98 mm and thickness 5 mm and 16 mm respectively were placed one above the other, on top of the soil sample in the mould. The entire assembly was placed under a cylindrical plunger of diameter 50 mm of the loading frame.

The test consists of statically compacting the soil in the standard Proctor mould by the cylindrical plunger. The height of presentation of the metal plate from the top surface of the mould was measured corresponding to different load levels. The different loads applied to the soil sample are obtained from the dial gauge readings attached to the proving ring with a constant of 6 kg/div.

For different applied loads, the amount by which the soil was compacted can be calculated by measuring the height of the soil mould which got reduced as the load went increasing. The load was applied till the penetration ceased or the measured height of the soil inside the mould became constant with further increase in load.

After measuring the heights corresponding to a number of load levels the compacted soil inside the mould was completely removed. Again, the mould was filled with soil with different moisture content and the entire aforementioned process was repeated.

Figure 3.2: Static compaction mould with two base plates

Figure 3.3: Filling the soil into the mould upto 100 mm height

Figure 3.4: Placing of bottom metal plate

Figure 3.5: Placing of top metal plate

Figure 3.6: The static compaction test apparatus along with the mould

The static pressure was calculated by dividing the different applied load values by the area to which it was applied. With the measured height of the soil inside the mould for different load values, the corresponding bulk unit weight of the soil was determined, as the weight of each layer was kept constant. Knowing the moisture content and bulk unit weight of a soil, the dry unit weight of the soil for a particular static pressure was determined. By this procedure, corresponding to a number of static pressures the dry unit weight of the soil was determined. In this manner all the soil samples were tested.

3.3 Test Results:

The experimental results obtained from the various tests performed are shown below in the form of tables and graphs.

3.3.1 Test results of the physical properties:

Table 3.1 gives the test results of the physical properties for the four soil samples. The classification of the soil samples as per IS soil classification system has also been presented in Table 3.1.

Table 3.1: Physical properties of soil samples

Sample No	Site Location	Colour	Odour	Specific Gravity (G)	Liquid Limit (W_L) (%)	Plastic Limit (W_P) (%)	Plasticity Index (PI)	IS Classification
1	**Lab Mixed Soil**	Brown	Nil	2.8	28	17.56	10.43	CI
2	**Pathsala 1**	Grey	Nil	2.78	34	22.06	12	CL
3	**Pathsala 2**	Grey	Nil	2.78	42	21.7	21	CI
4	**AEC view point**	Red	Nil	2.82	56	28.9	21.7	CH

The gradation curve of soil samples were obtained by wet sieve analysis and the results obtained for the all the seven soil samples are shown below from Figure 3.7 to 3.10.

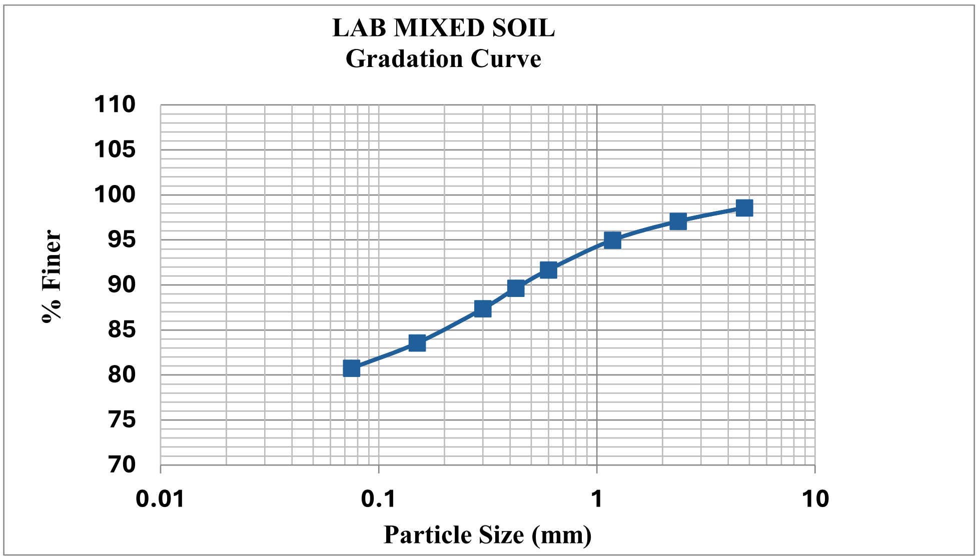

Figure: 3.7: Gradation curve of sample 1

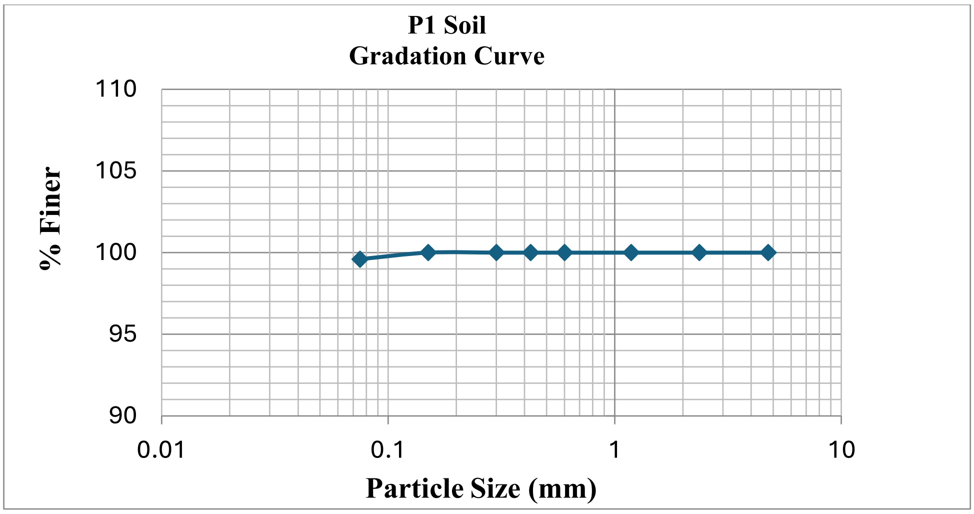

Figure: 3.8: Gradation curve of sample 2

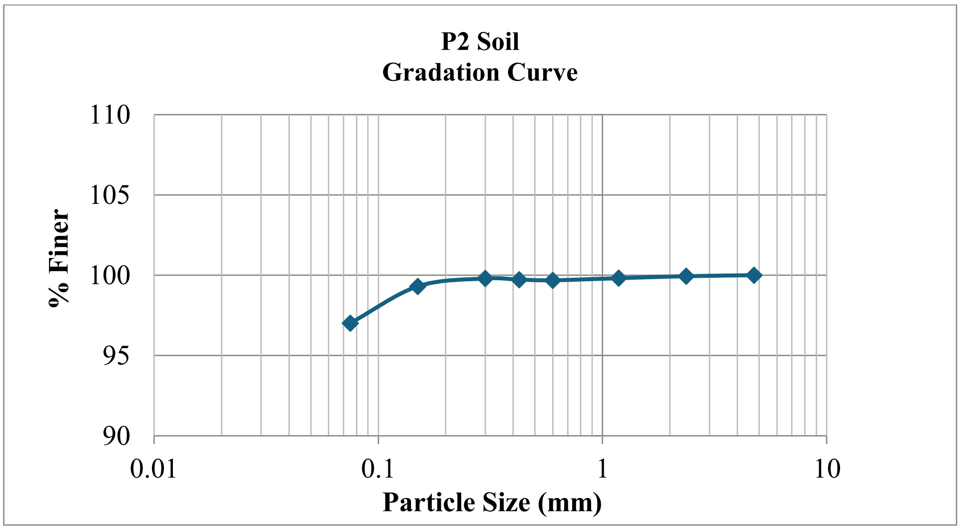

Figure: 3.9: Gradation curve of sample 3

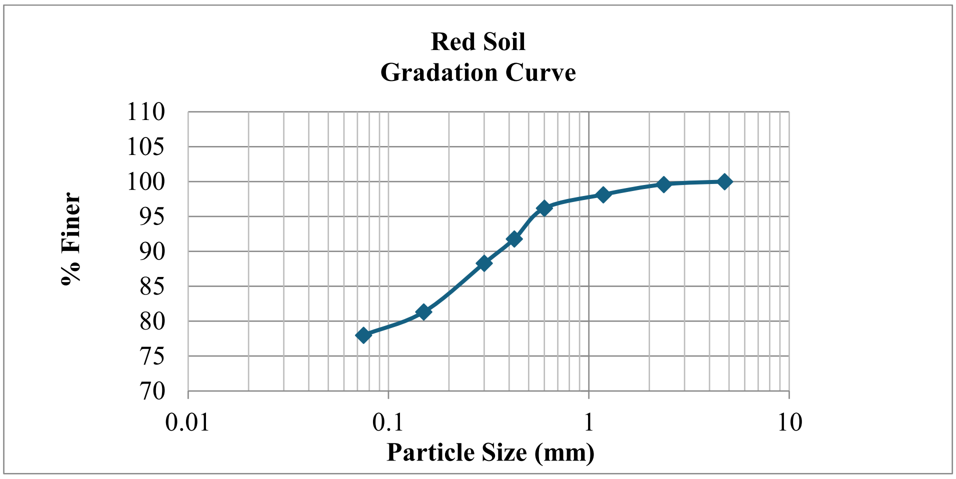

Figure: 3.10: Gradation curve of sample

3.3.2 Test results of compaction properties of soil:

The compaction test of the soil samples was performed by standard Proctor test, reduced standard Proctor test and reduced modified Proctor test. The experimental results of the above-mentioned compaction tests for seven soil samples have been presented in Table 3.2.

Table 3.2: OMC and MDU weight by Different Compaction test

Sample No	Site Location	Standard Proctor Test		Reduced Standard Proctor Test		Reduced Modified Proctor Test	
		M.D.U weight (kN/m^3)	OMC (%)	M.D.U weight (kN/m^3)	OMC (%)	M.D.U weight (kN/m^3)	OMC (%)
1	**Lab Mixed Soil**	16.76	14.6	16.47	14.8	17.57	14.3
2	**Pathsala 1**	16.2	20.4	15.9	20.55	17.06	20.1
3	**Pathsala 2**	16.1	19.79	15.86	19.8	16.93	19.6
4	**AEC view point**	15.33	25.22	15.09	25.3	15.88	25.08

The compaction curves for all the four soil samples for standard Proctor test, reduced standard Proctor test and reduced modified Proctor test are shown below from Figure 3.11 to Figure 3.14

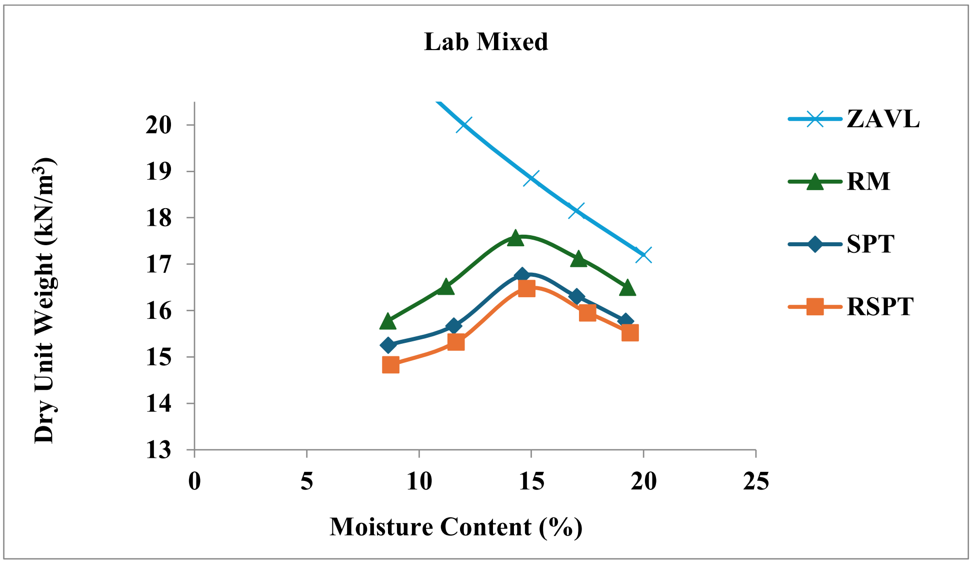

Figure 3.11: Compaction curves for Soil 1

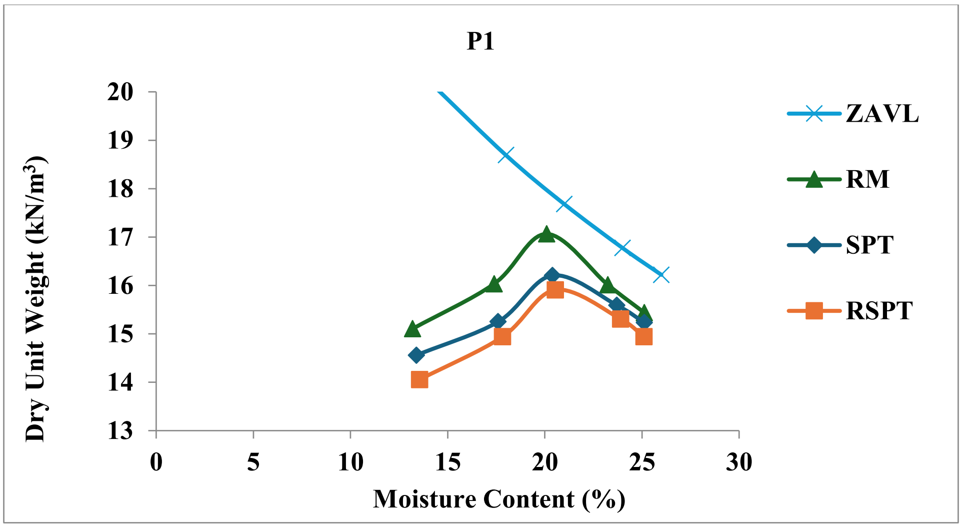

Figure 3.12: Compaction curves for soil 2

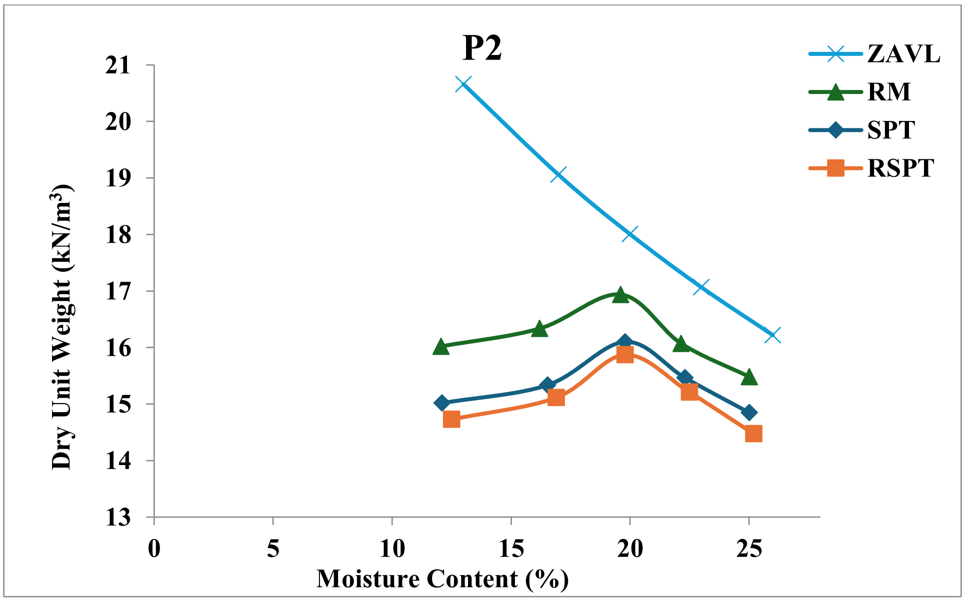

Figure 3.13: Compaction curves for sample 3

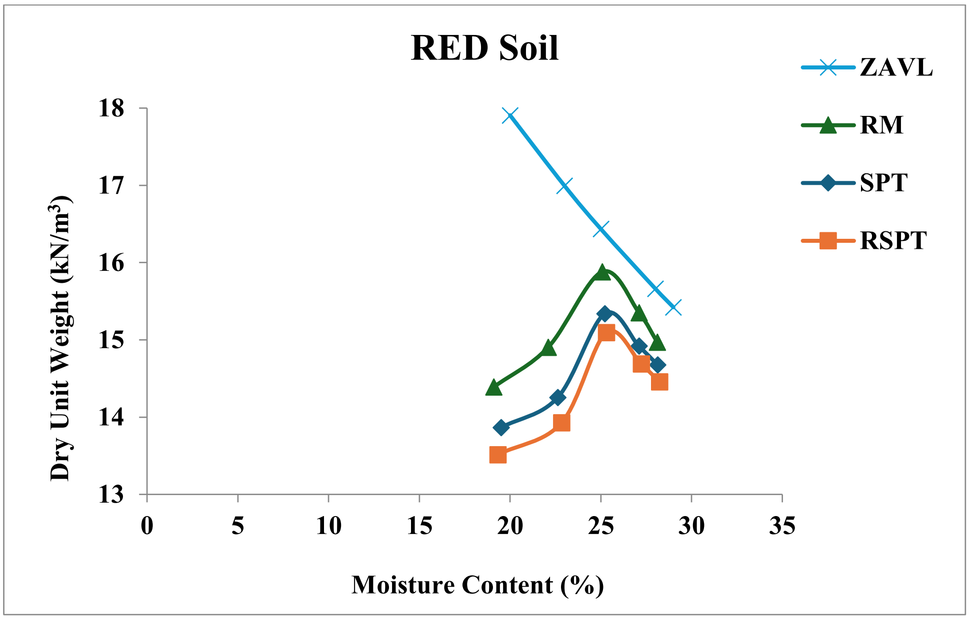

Figure 3.14: Compaction curves for sample 4

The experimental results of the static compaction test performed on the four soil samples have been presented with the help of graphs. In the static compaction test, for a particular moisture content, the soil was subjected to different static pressure and the dry unit weight was calculated. The relationship between static pressure and dry unit weight, for all the four soil samples, corresponding to different moisture contents have been plotted in the form of curves.

The static compaction curves for all the four soil samples are shown below from Figure 3.15 to Figure 3.19 and the curves for other three samples are shown in appendix I.

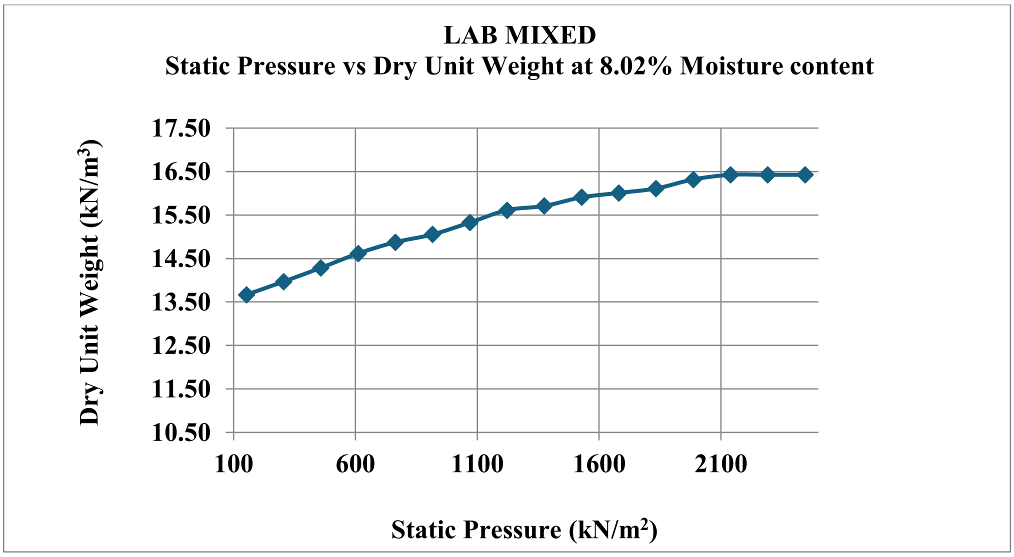

Figure 3.15: Static pressure vs Dry unit weight curve of Lab mixed soil at 8.02% water content

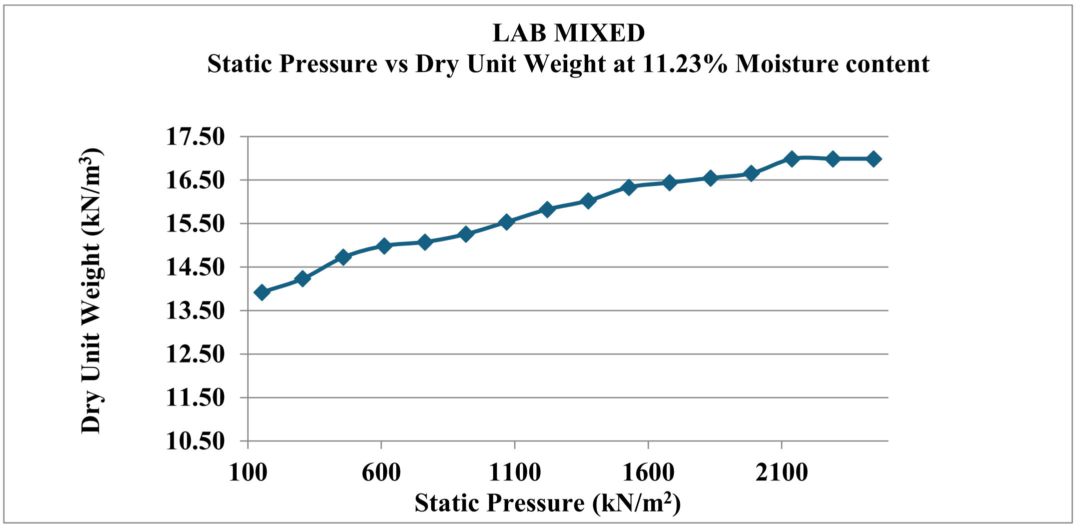

Figure 3.16: Static pressure vs Dry unit weight curve of Lab mixed soil at 11.23% water content

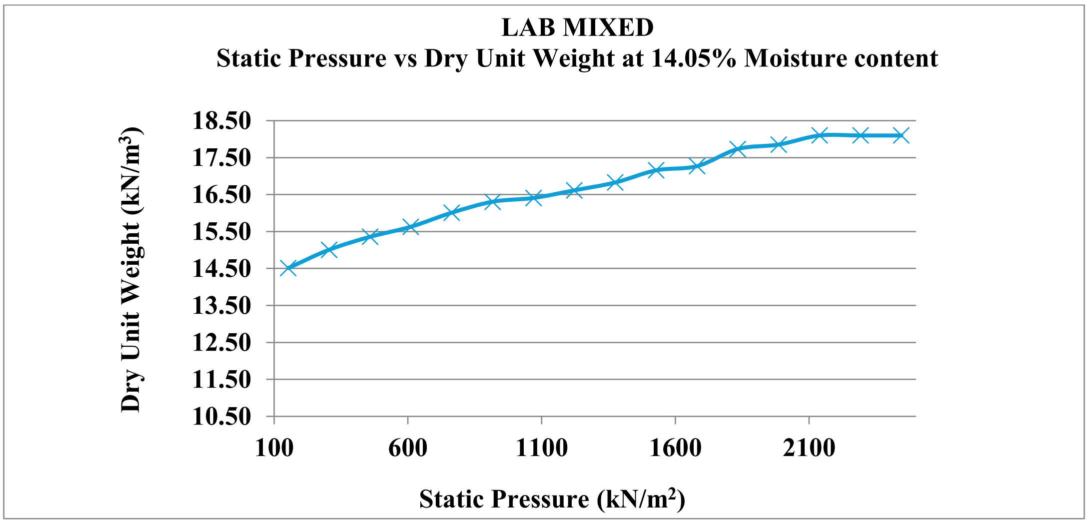

Figure 3.17: Static pressure vs Dry unit weight curve of Lab mixed soil at 14.05% water content

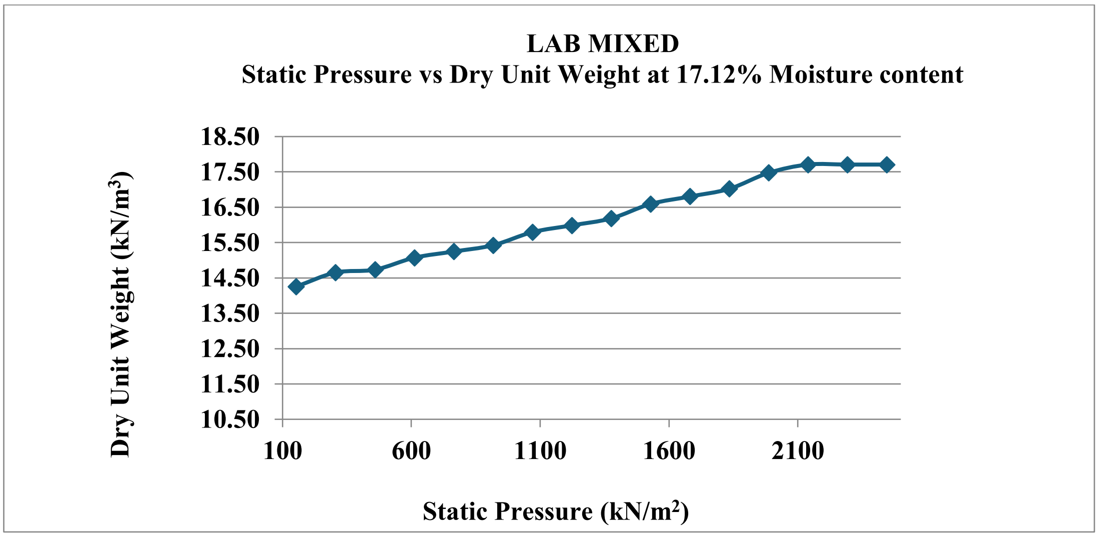

Figure 3.18: Static pressure vs Dry unit weight curve of Lab mixed soil at 17.12% water content

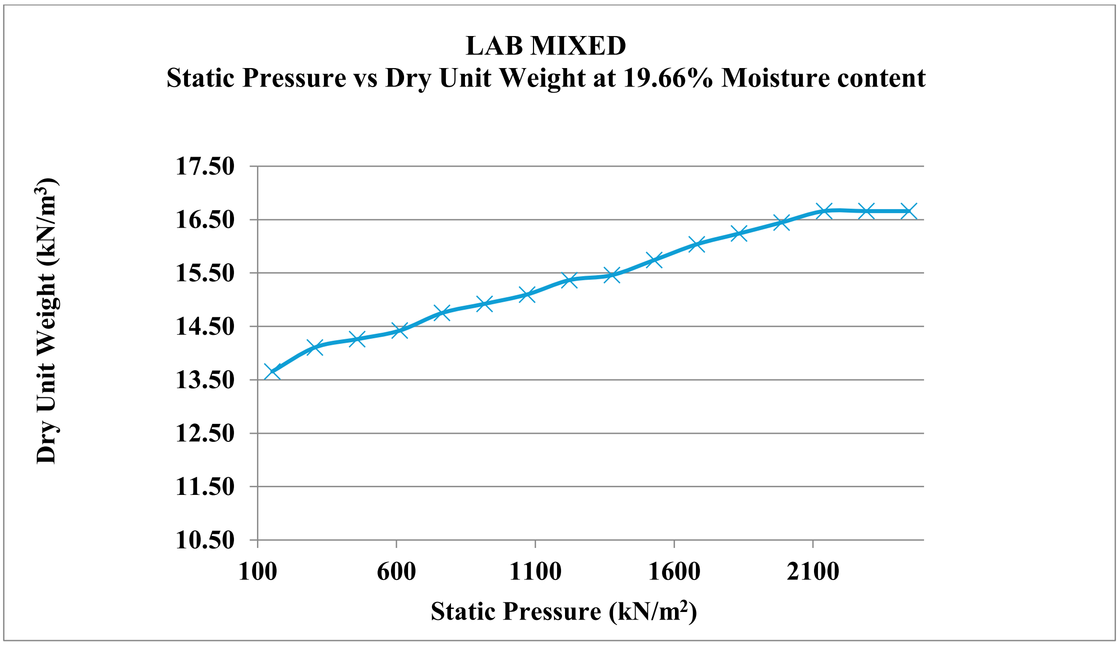

Figure 3.19: Static pressure vs Dry unit weight curve of Lab mixed soil at 19.66% water content

The results from the static compaction curves when plotted in the form of curves between static energy and dry unit weight show a similar pattern for all the four soil samples. The static compaction test was carried out for different moisture contents which were similar to the moisture contents in which standard Proctor test, reduced standard Proctor test and reduced modified Proctor test were performed.

For all the four soil samples, after a particular value of static pressure, the increase in dry unit weight becomes insignificant and it becomes constant irrespective of the increase in static pressure.

3.3.3 Static Energy Calculation:

The energy of soil compaction is the compaction effort applied to the soil per unit volume. Compaction energy is one of the important elements in the compaction process. In this process the energy needed to achieve a desired density by static compaction was analysed for the soils. An equivalent amount of energy input is levied to all kinds of soil through dynamic compaction method, while the energy input by static compaction is different for each type of soil. The static compaction test directly measures the amount of energy based on the characteristic of soil and also the amount of moisture content of soil.

The energy was calculated by multiplying the different applied load values with different displacements of soil during the compaction process (which was obtain by subtracting the measured height of the soil inside the mould for different load values from the initial height of the soil).Since the volume of the soil was changing during the compaction process so energy will be the energy per unit volume which is calculated by dividing energy by its corresponding volume.

- Energy = Load × Displacement
- Energy per unit volume = Energy/Volume

The energy requirement for different laboratory method is different. To select the most efficient method it requires knowledge of the input of compaction energy per unit volume. The analytical result of the compaction energy of four different soil sample have been presented with the help of graphs. The compaction energy is calculated from the load that is required for a static pressure and the displacement that occurred during the static compaction corresponding to each static pressure for a particular moisture content. The relationship between energy per unit volume and dry density for all the four soil samples corresponding to different moisture content have been plotted in the form of curves.

The static compaction curves in terms of energy for one soil samples are shown below from Figure 3.20 to Figure 3.24 and for other three samples are given in appendix I.

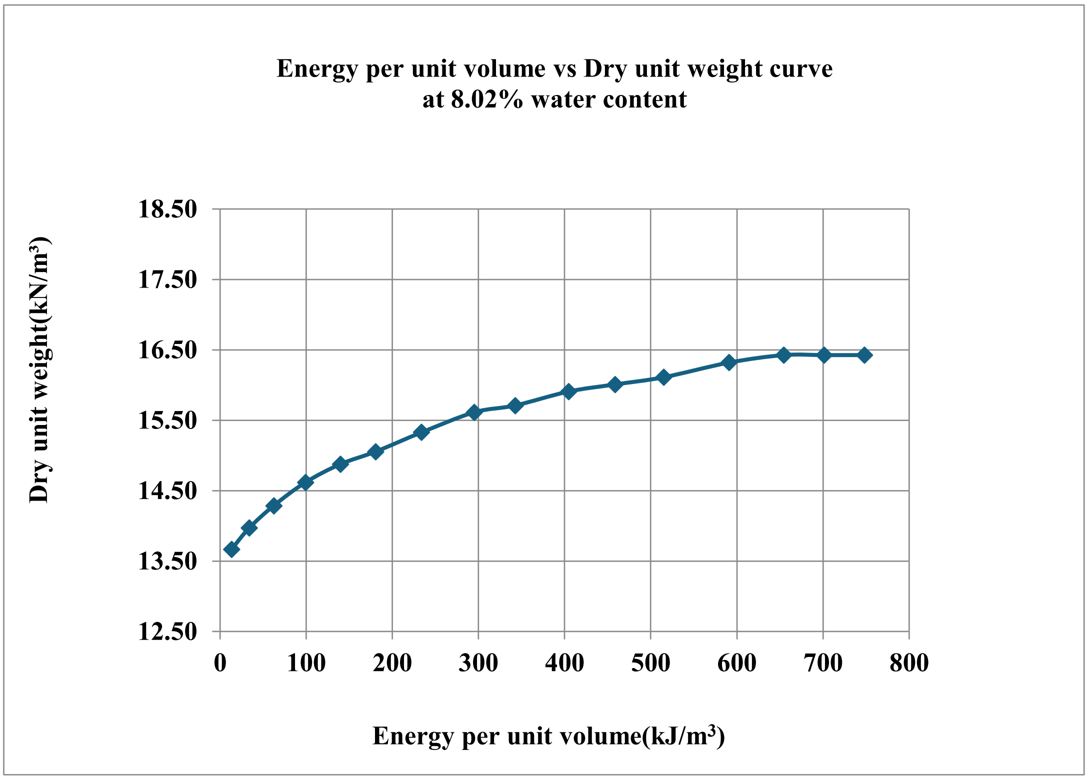

Figure 3.20: Static Energy per unit volume vs Dry unit weight curve of Lab mixed soil at 8.02% water content

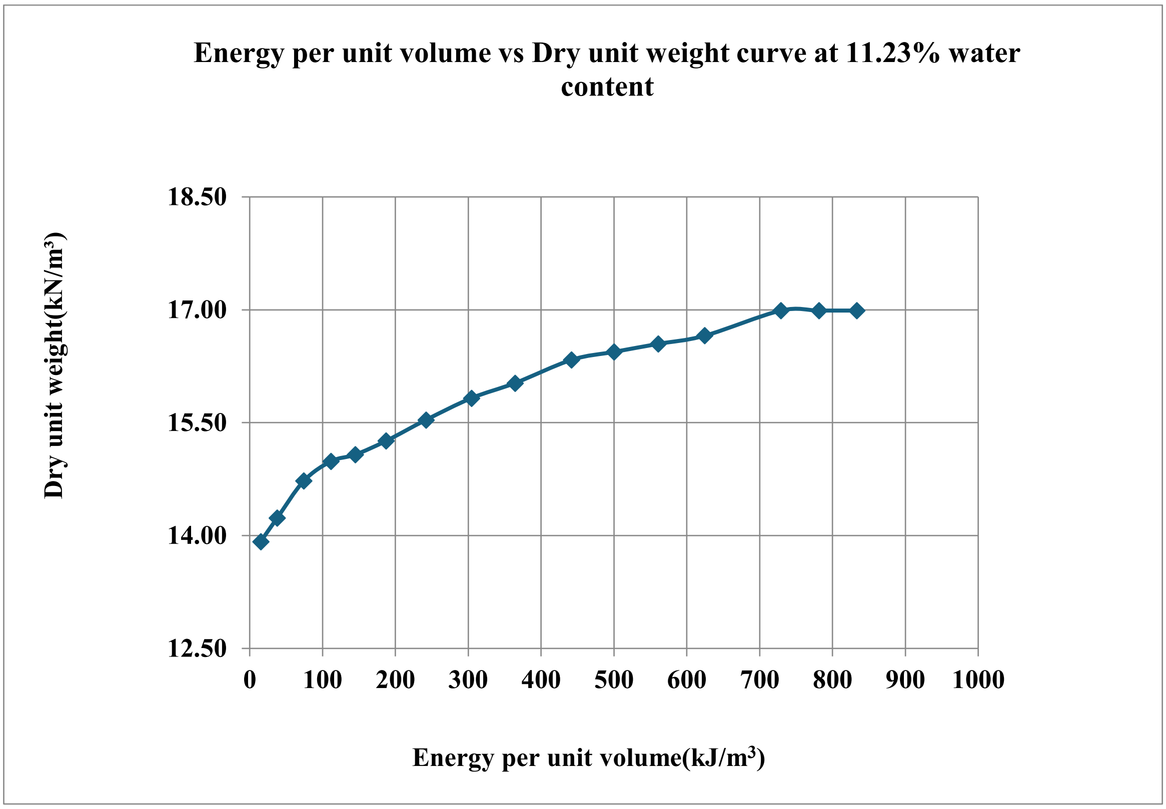

Figure 3.21: Static Energy per unit volume vs Dry unit weight curve of Lab mixed soil at 11.23% water content

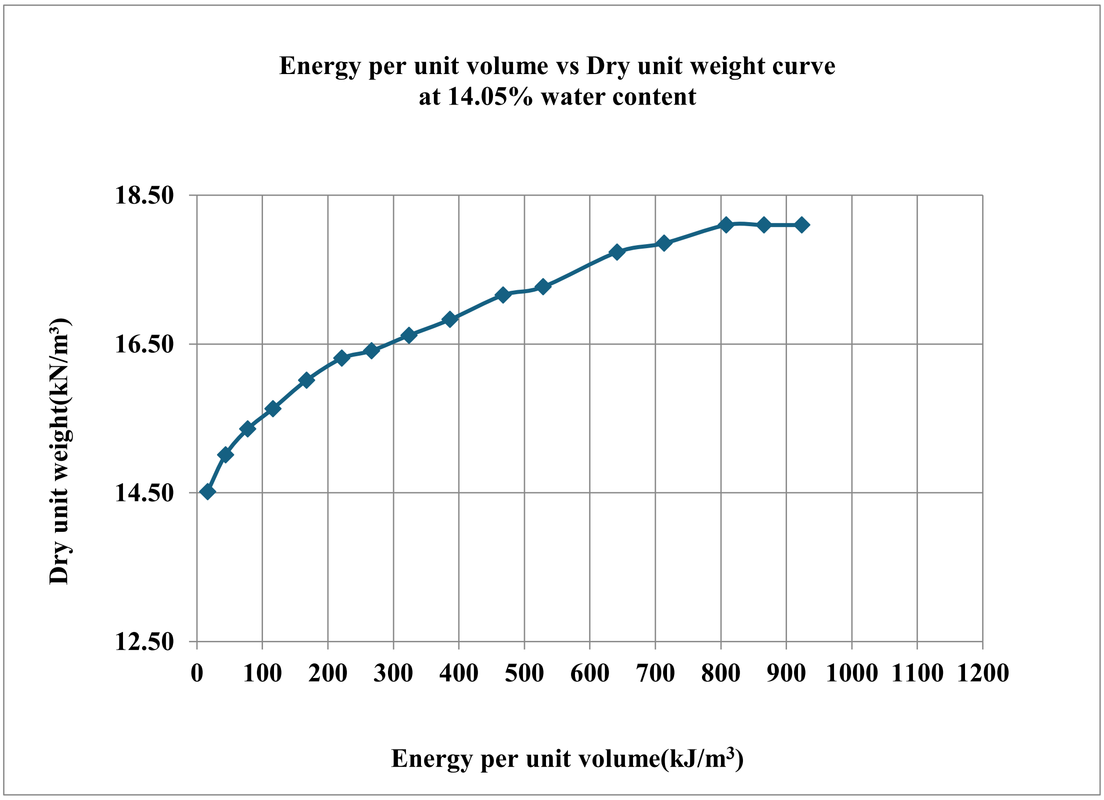

Figure 3.22: Static Energy per unit volume vs Dry unit weight curve of Lab mixed soil at 14.05% water content

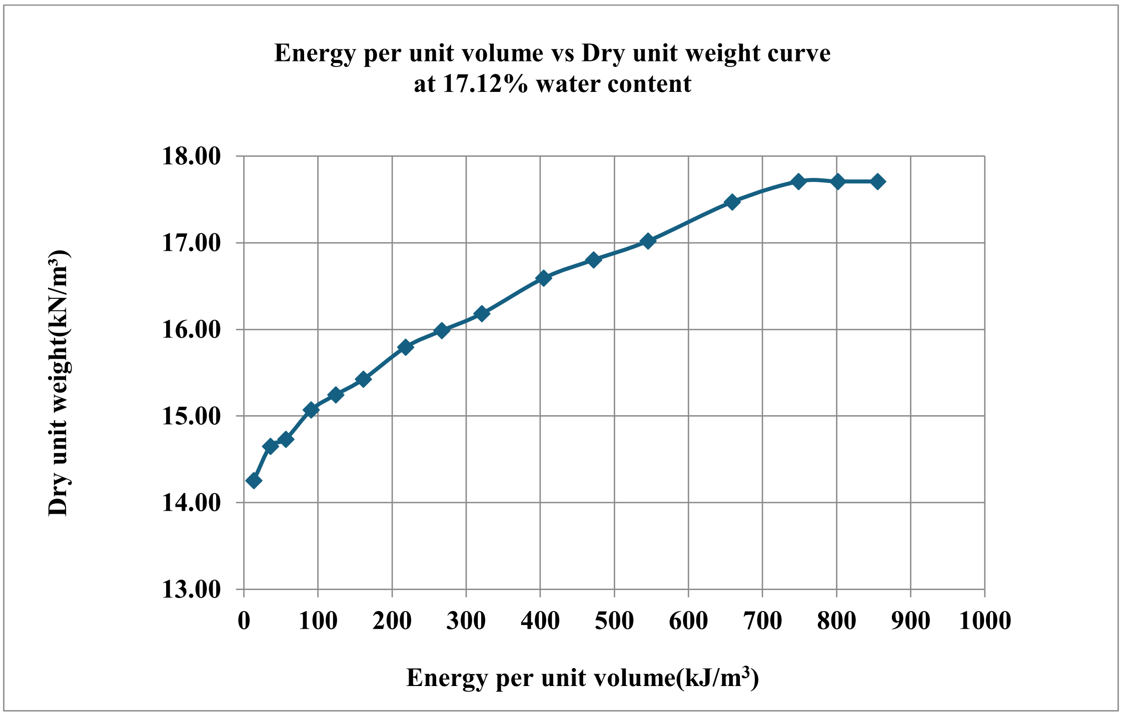

Figure 3.23: Static Energy per unit volume vs Dry unit weight curve of Lab mixed soil at 17.12% water content

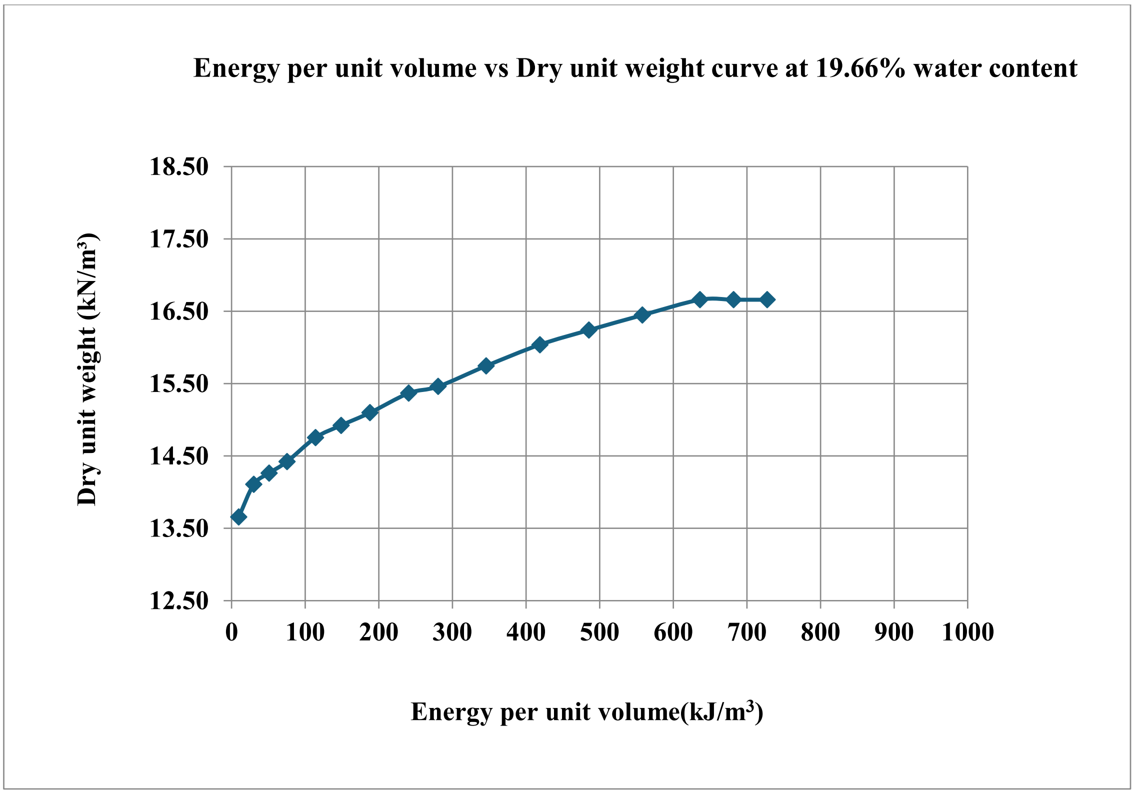

Figure 3.24: Static Energy per unit volume vs Dry unit weight curve of Lab mixed soil at 19.66% water content

CHAPTER 4
ANALYSIS OF TEST RESULTS

4.1: Introduction:

The moisture content – dry unit weight relationship for a soil sample is parabolic in nature and is unique for a particular soil. An attempt has been made to predict the compaction characteristics by the static compaction method and to derive the equivalent static pressures and energies at which maximum dry unit weight at optimum moisture content can be obtained by standard Proctor test, reduced standard Proctor test and reduced modified Proctor test respectively.

4.2: Analysis of compaction properties of soil tested:

The relationship between dry unit weight and static pressure and energies at different moisture contents for a soil sample has been obtained from the static compaction test and the relations are shown in chapter 3. The relationship between moisture content and dry unit weight for a particular soil at a particular static pressure and energies is found to be parabolic in nature. The relationship between moisture content and dry unit weight obtained by static compaction method corresponding to different static pressures energies are superimposed in the form of curves.

Next the static compaction curves of a particular soil sample corresponding to different static pressures and energies were superimposed with the standard Proctor test, reduced standard Proctor test and reduced modified Proctor test curves. It was attempted to ascertain the static pressure and energy value which gives the nearest value of maximum dry unit weight at OMC from standard Proctor test, reduced standard Proctor test and reduced modified Proctor test. The Parabolic curves for all the four soil samples are shown below from Figure 4.1 to Figure 4.8.

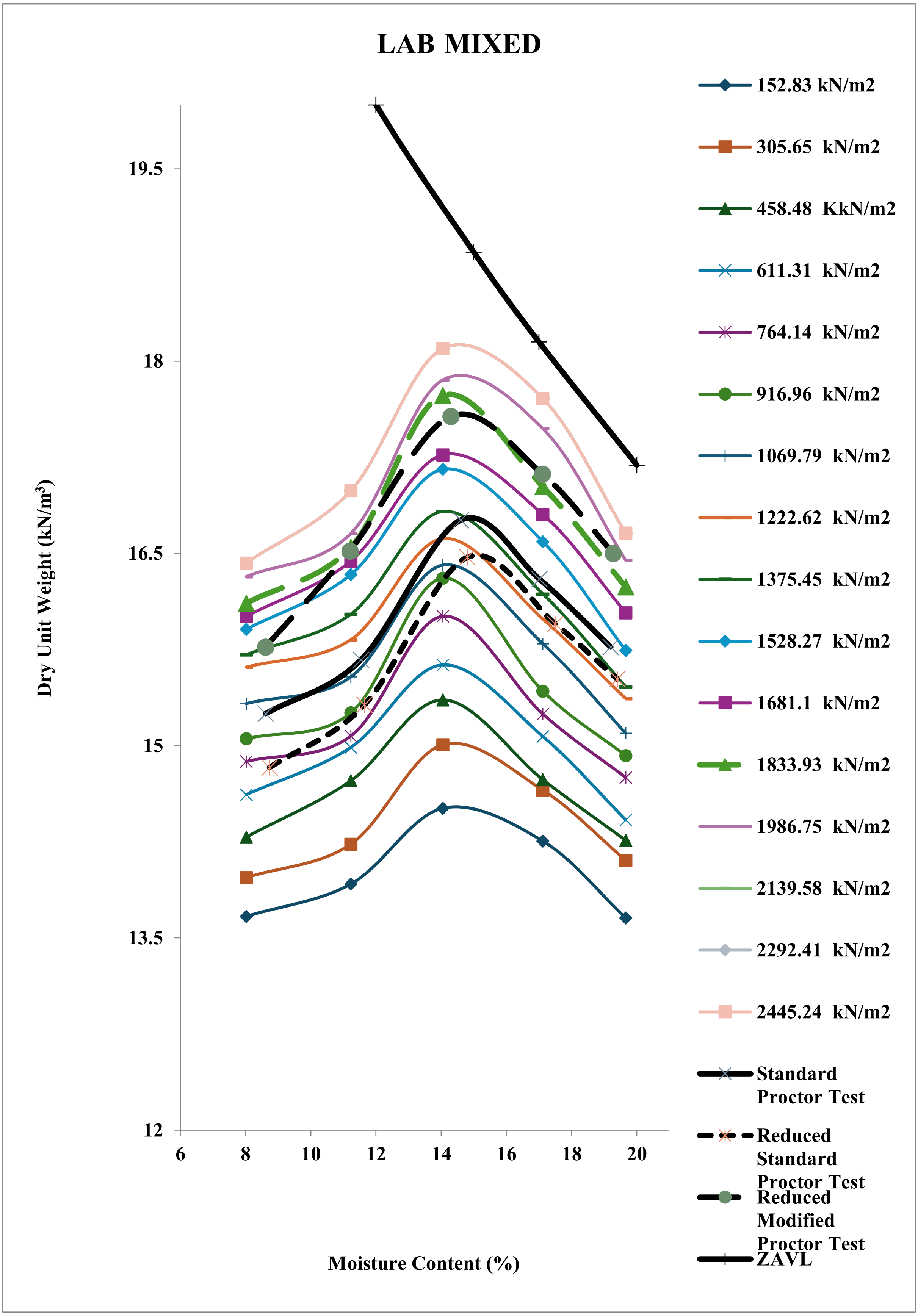

Figure 4.1: Moisture content vs Dry unit weight curves of sample 1 (According to Static Pressure)

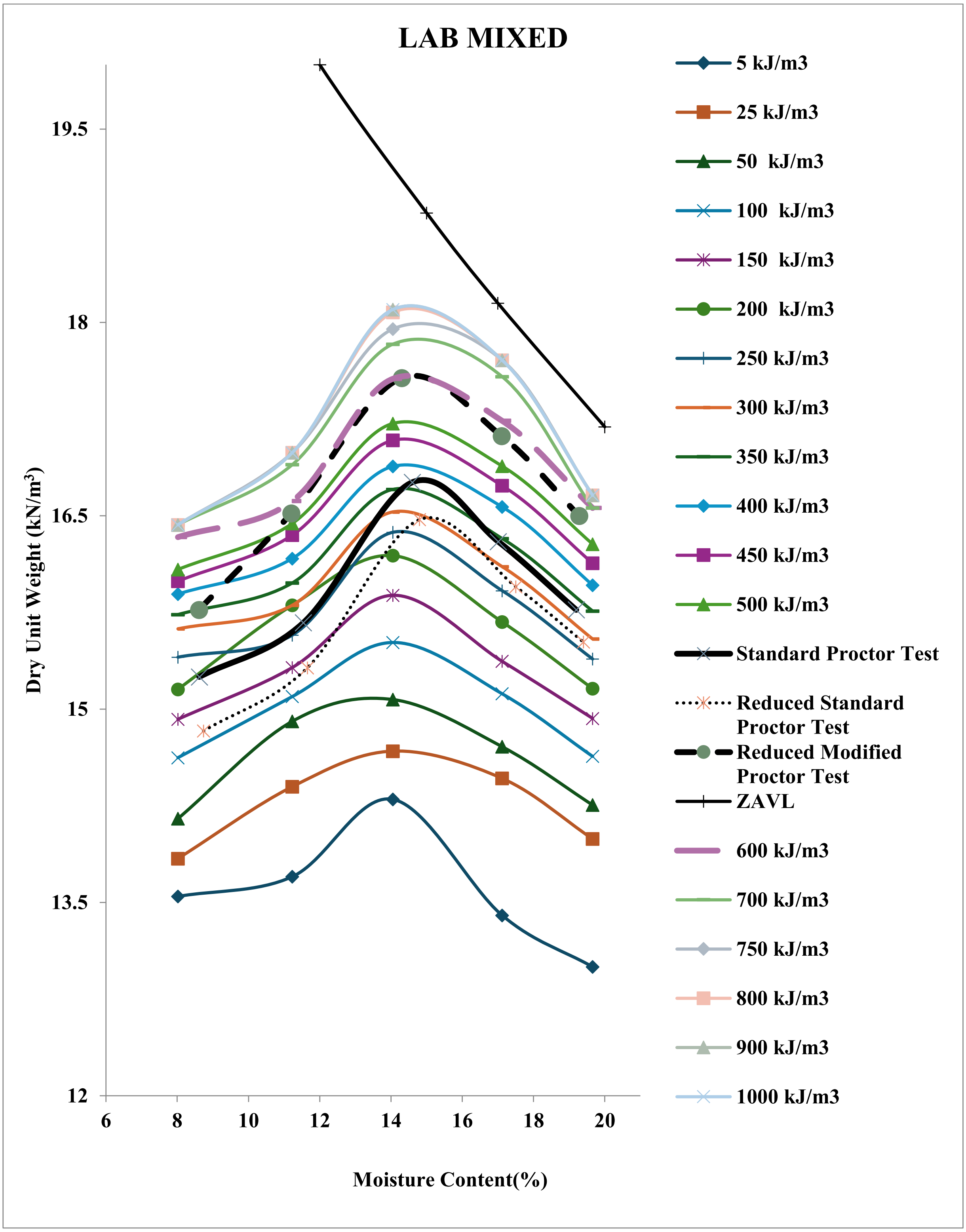

Figure 4.2: Moisture content vs Dry unit weight curves of sample 1 (According to Static Energy)

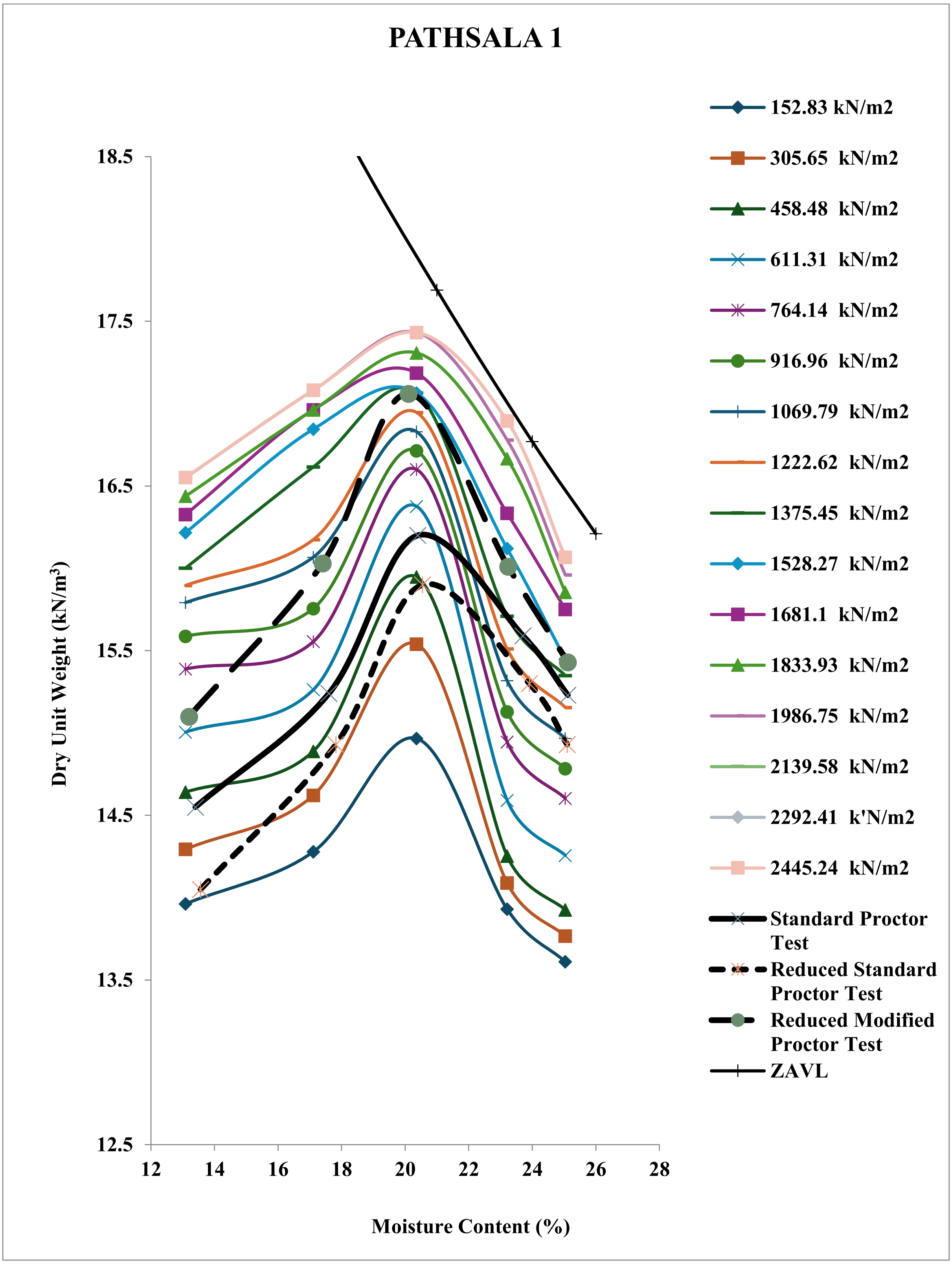

Figure 4.3: Moisture content vs Dry unit weight curves of sample 2 (According to Static Pressure)

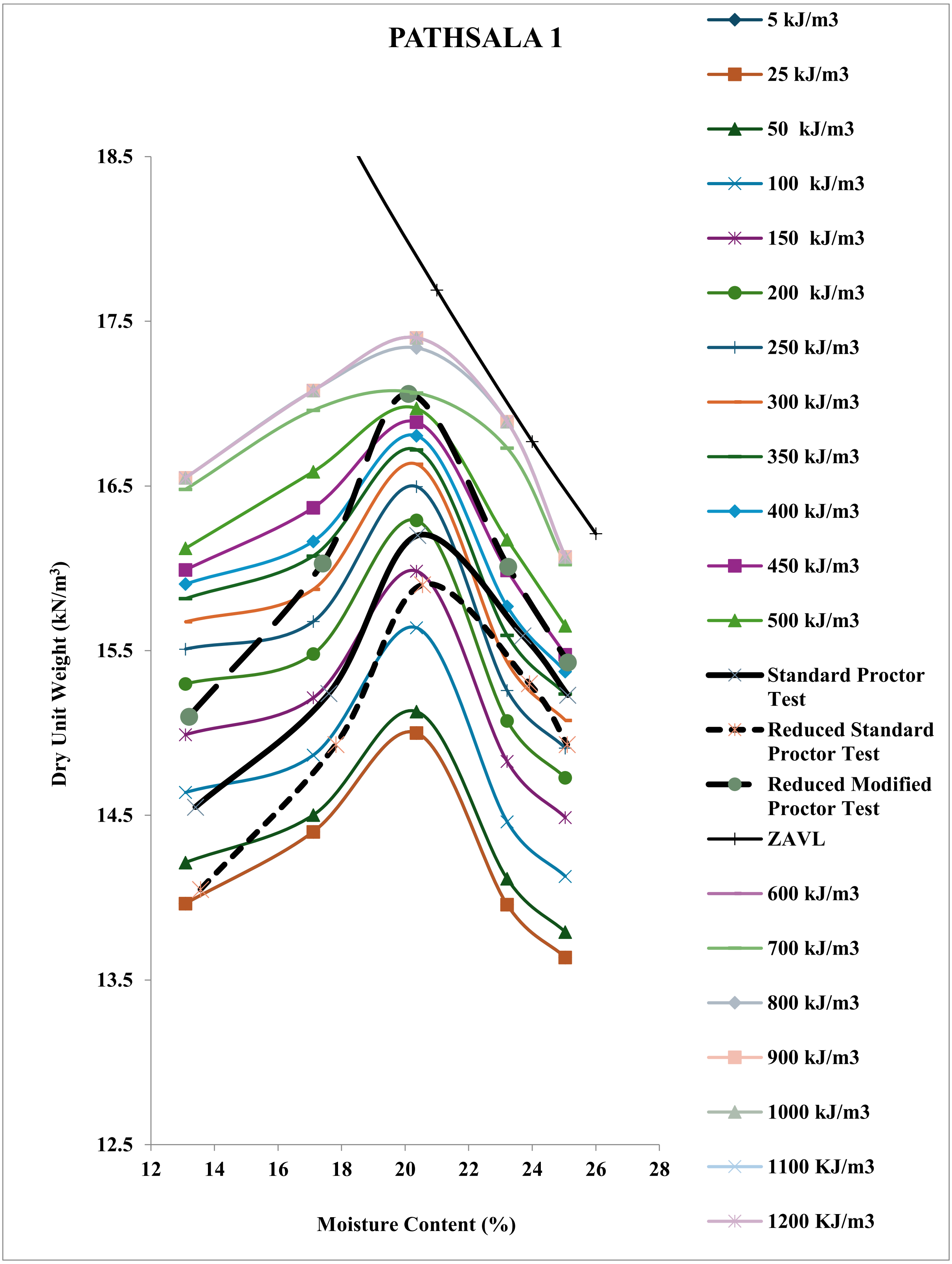

Figure 4.4: Moisture content vs Dry unit weight curves of sample 2 (According to Static Energy)

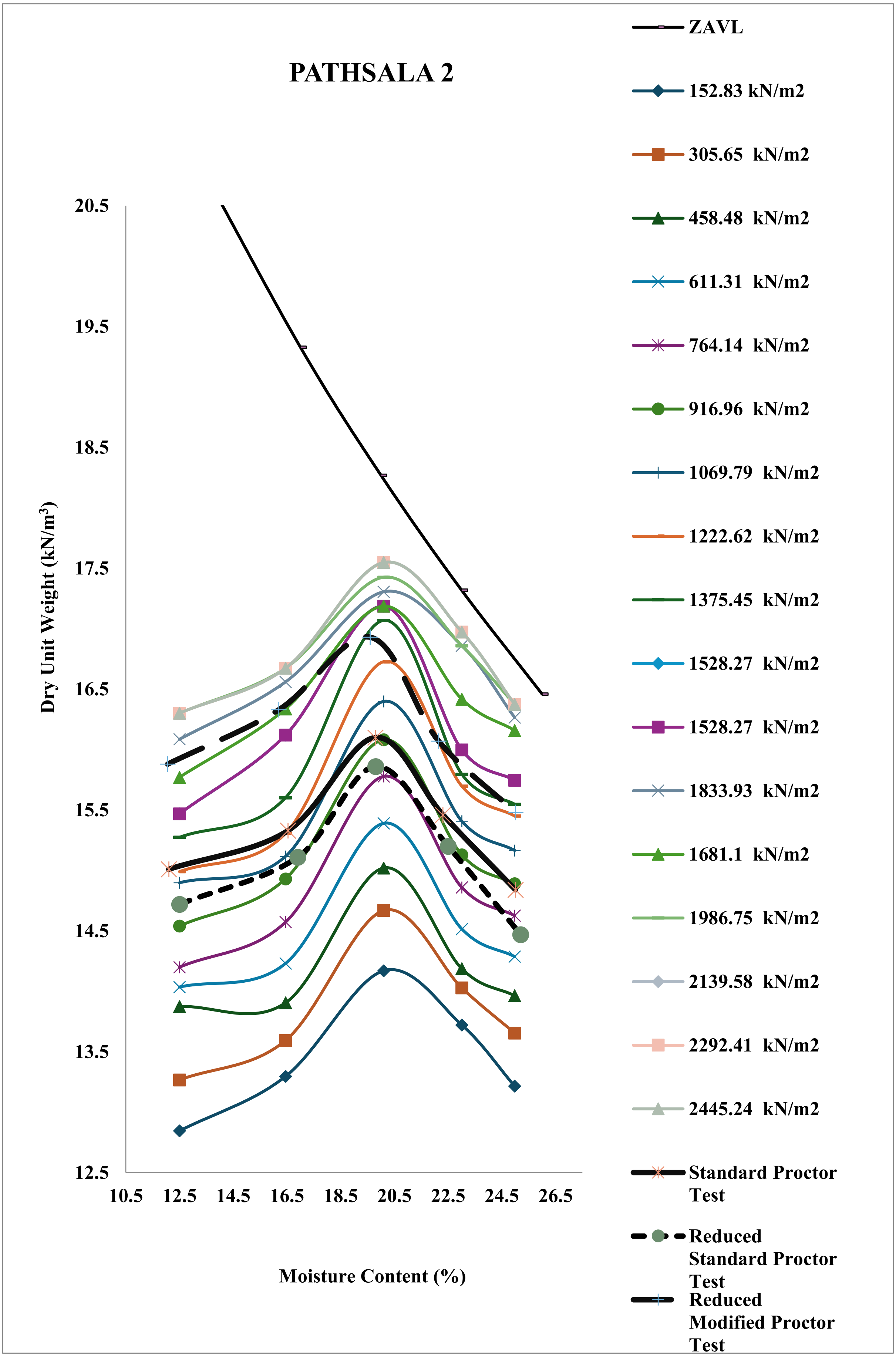

Figure 4.5: Moisture content vs Dry unit weight curves of sample 3 (According to Static Pressure)

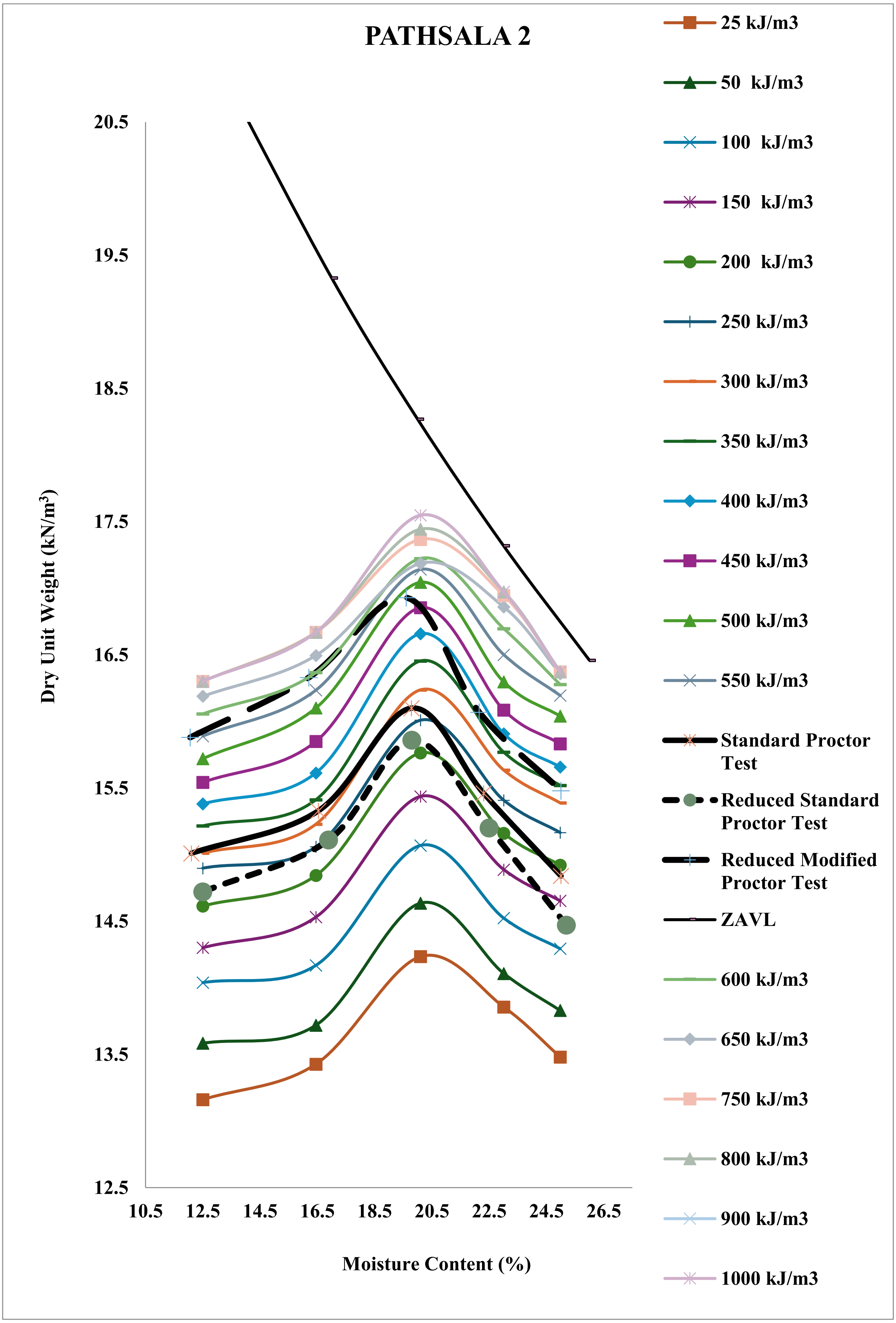

Figure 4.6: Moisture content vs Dry unit weight curves of sample 3 (According to Static Energy)

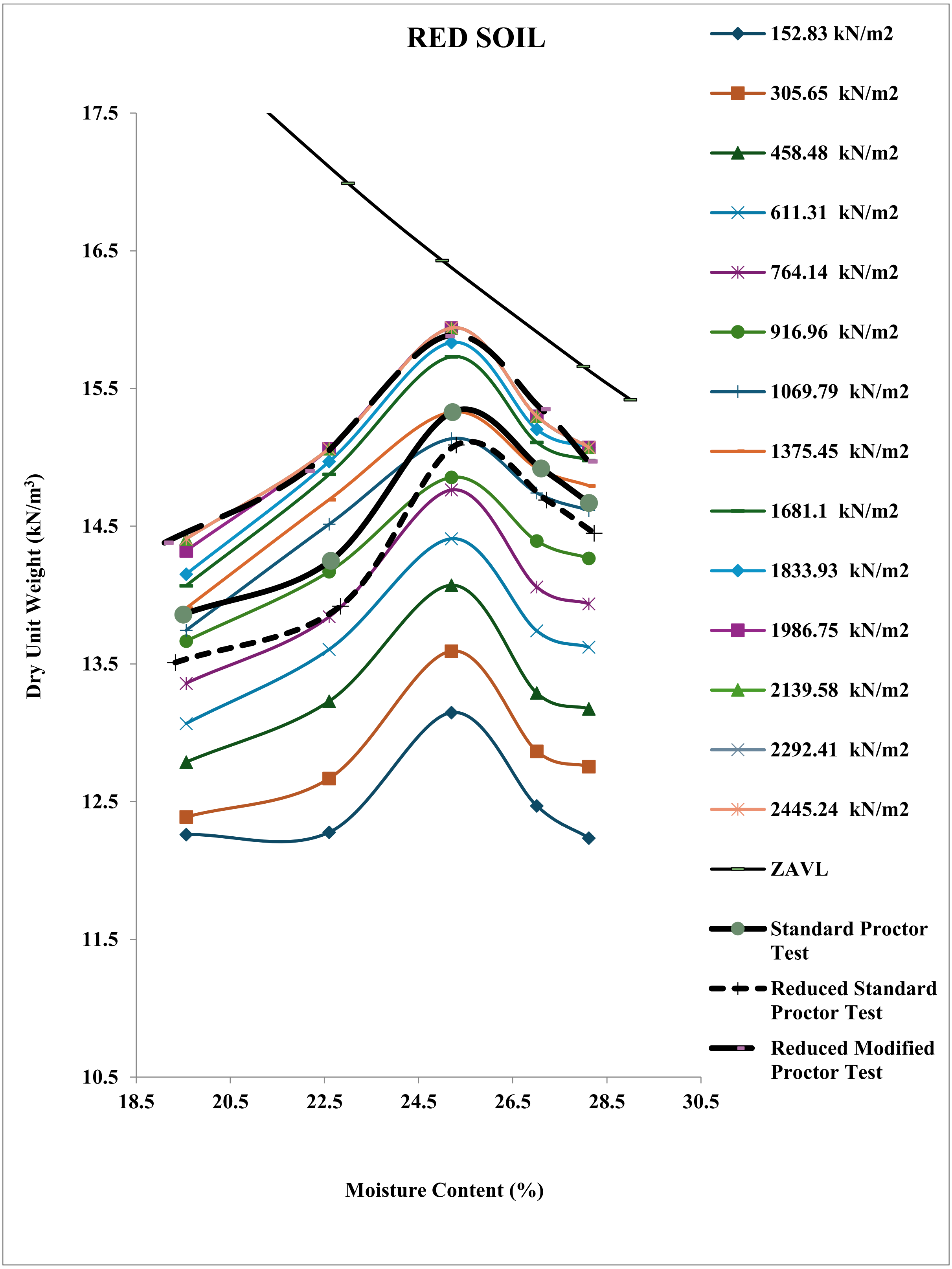

Figure 4.7: Moisture content vs Dry unit weight curves of sample 3 (According to Static Pressure)

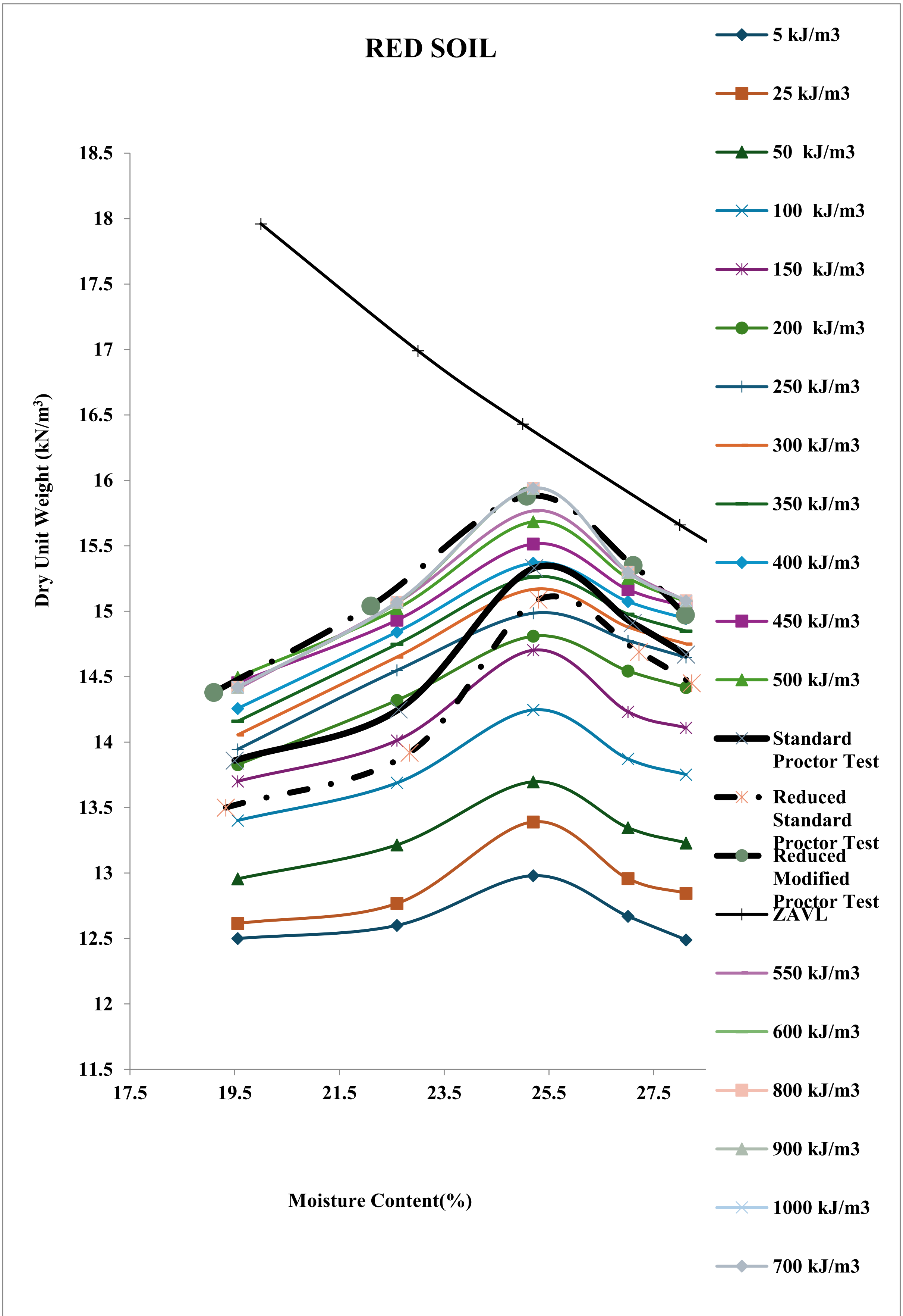

Figure 4.8: Moisture content vs Dry unit weight curves of sample 3 (According to Static Energy)

4.3 Determination of Equivalent Static Pressure and Static Energy

Equivalent Pressure and energy correspond to a dynamic compaction effort is defined as that static pressure and energy which should be applied to a statically compacting soil sample to obtain the same maximum dry unit weight value at optimum moisture content as that obtained by the dynamic compaction effort. To determine the equivalent pressure and energy, two maximum dry densities were considered in such a way that one is above the maximum dry density as obtained from standard Proctor's test and other is below it. These values of maximum dry densities corresponding to the two preesures and energies are then plotted in the form of curves. In this study an attempt has been made to predict the equivalent static compaction energy from different parameter.

The graphical representation of determining the equivalent static pressure and energy corresponding to standard Proctor test, reduced standard proctor test and modified proctor test competitive effort are shown below from figure 4.9 to figure 4.13 and the curves for other three samples are shown in appendix II.

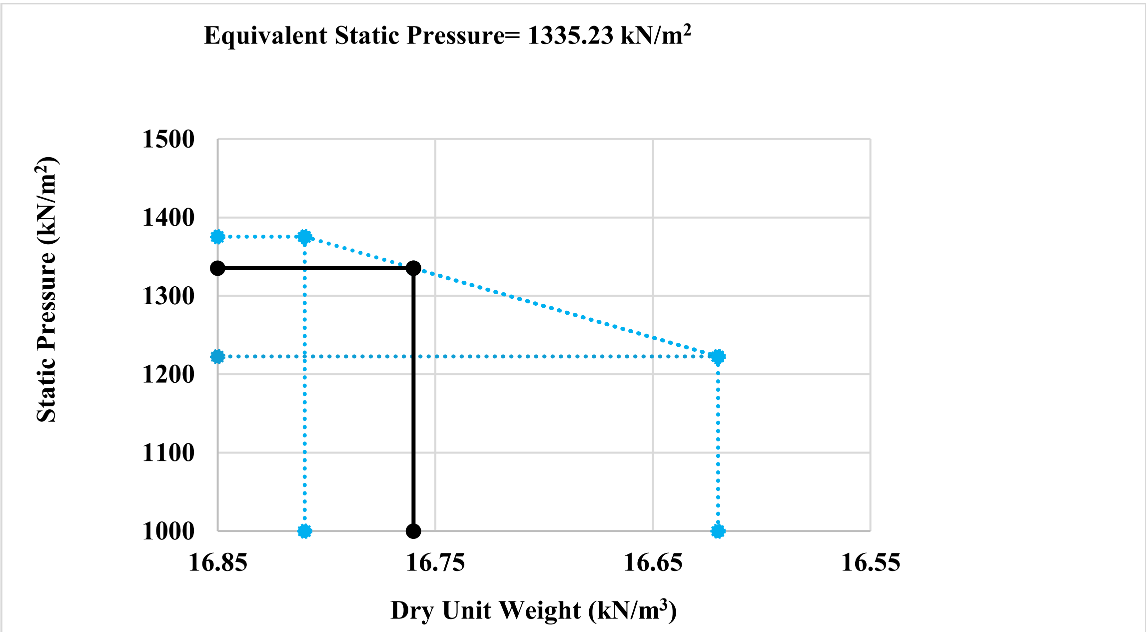

Fig4.9: Determination of Static Equivalent Pressure of Lab Mixed sample (According to Standard Proctor)

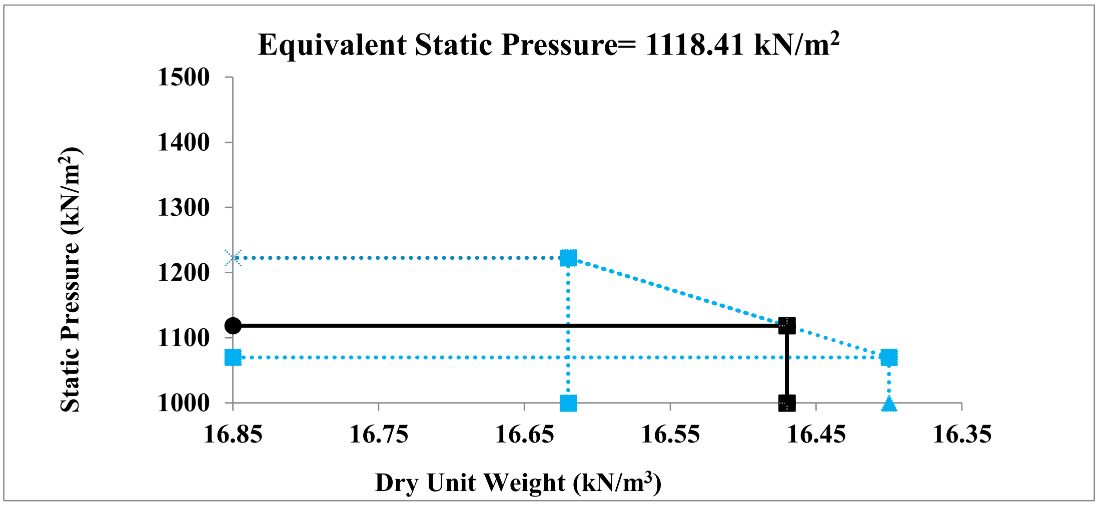

Fig4.10: Determination of Static Equivalent Pressure of Lab Mixed sample (According to Reduced Standard Proctor)

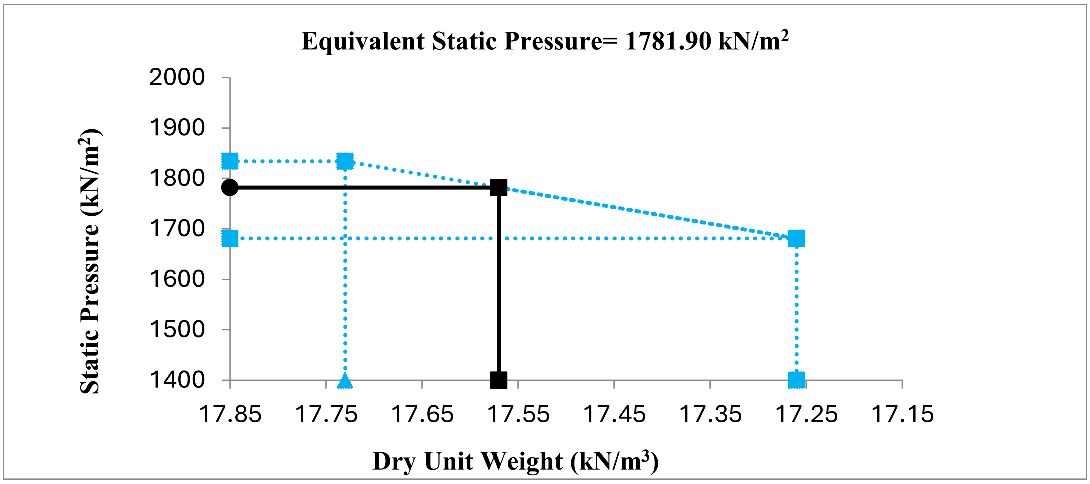

Fig4.11: Determination of Static Equivalent Pressure of Lab Mixed sample (According to Reduced Modified Proctor)

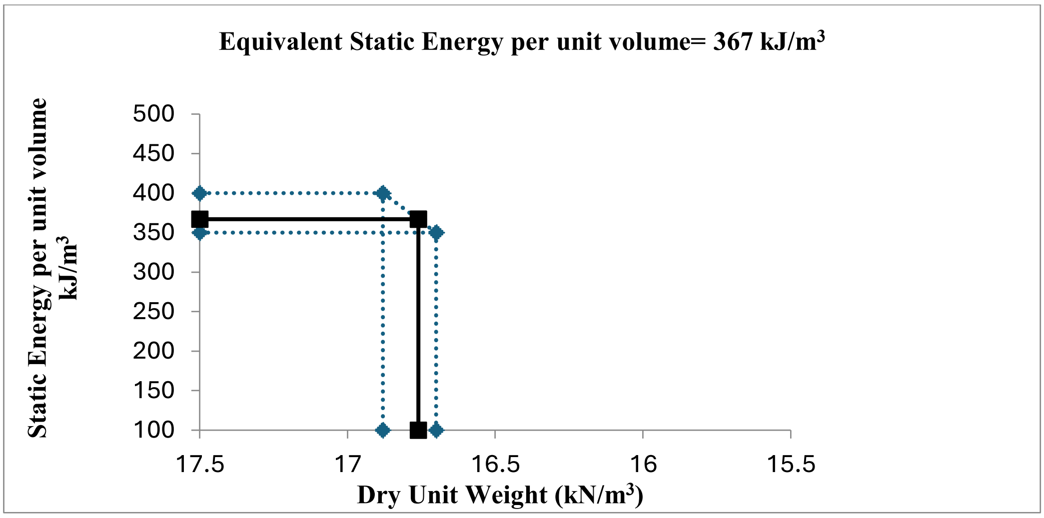

Fig4.11: Determination of Static Equivalent Energy of Lab Mixed sample (According to Standard Proctor Test)

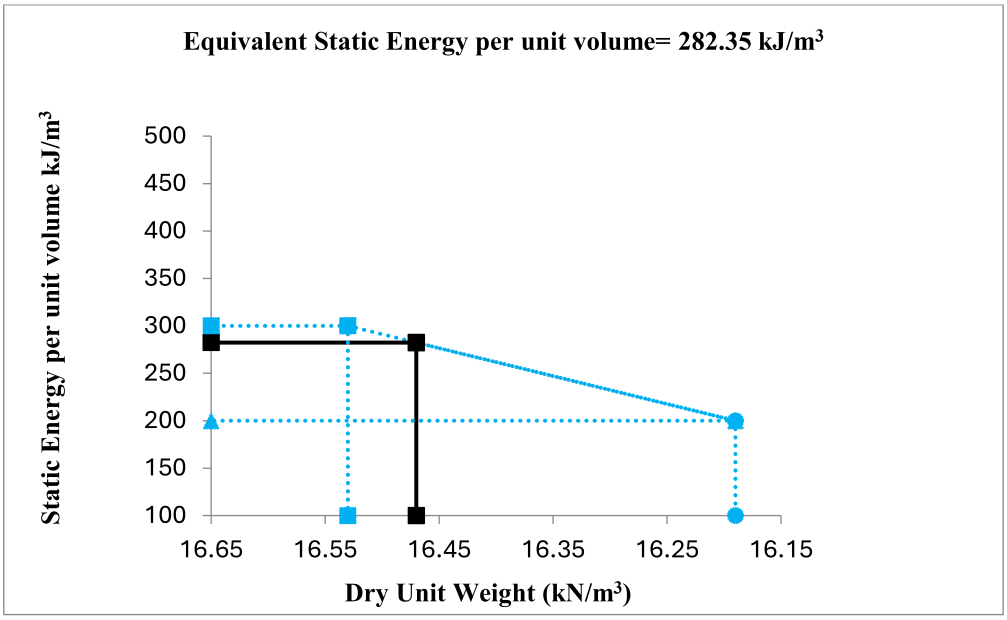

Fig4.13: Determination of Static Equivalent Energy of Lab Mixed sample (According to Reduced Standard Proctor)

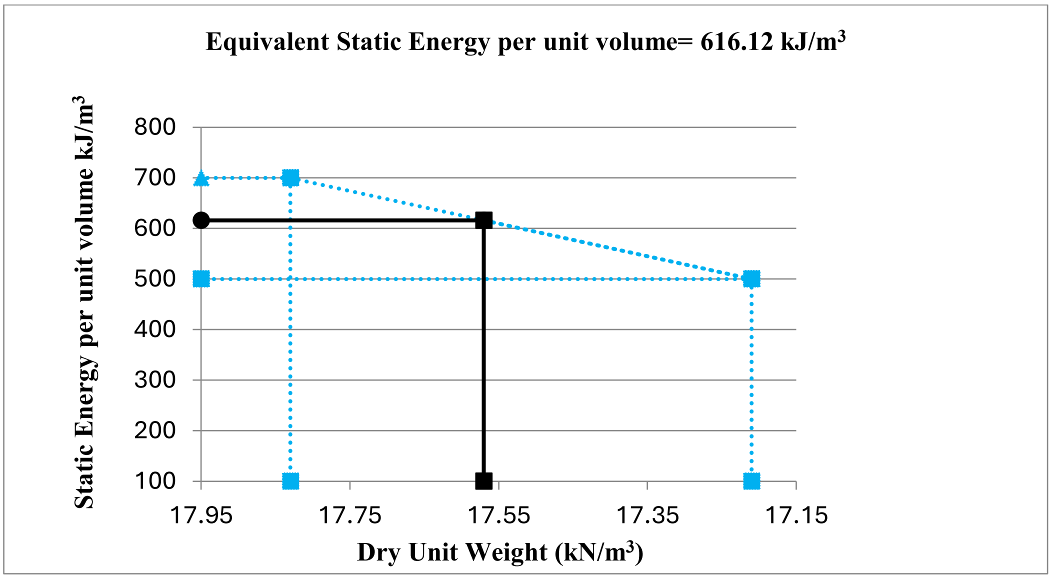

Fig4.14: Determination of Static Equivalent Energy of Lab Mixed sample (According to Reduced Modified Proctor)

The values of equivalent energy (according to standard proctor test, reduced standard proctor test, reduced modified proctor test) obtained from the curves are shown below in the table 4.3 to table 4.5

Table 4.3: Equivalent static energy required to obtain the maximum dry unit weight as obtained from standard Proctor test for different soil samples

Sample no.	Site Location	Equivalent Static Energy (kJ/m^3)
1	LAB MIXED	365.71
2	PATHSALA 1	185.48
3	PATHSALA 2	271.73
4	RED SOIL	378

Table 4.4: Equivalent static energy required to obtain the maximum dry unit weight as obtained from reduced standard Proctor test for different soil samples

Sample no.	Site Location	Equivalent Static Energy (kJ/m^3)
1	LAB MIXED	282.35
2	PATHSALA 1	138.57
3	PATHSALA 2	220.83
4	RED SOIL	280.55

Table 4.5: Equivalent static energy required to obtain the maximum dry unit weight as obtained from reduced modified Proctor test for different soil samples

Sample no.	Site Location	Equivalent Static Energy (kJ/m^3)
1	LAB MIXED	616.12
2	PATHSALA 1	556.25
3	PATHSALA 2	471.79
4	RED SOIL	616.66

Average Equivalent Static Energy of the four soil samples according to standard proctor test, reduced standard proctor test, reduced modified proctor test are found 300.23 kJ/m^3, 230.575 kJ/m^3 and 565.205 kJ/m^3

CHAPTER 5
Experimental Investigations Outcome

5.1 Prediction of Equivalent Static Energy by Linear Regression:

In linear regression, a sufficient amount of data is required to accurately estimate the relationship between the independent and dependent variables. The more data points available, the more reliable and precise the regression model will be, as it can better capture the underlying patterns and reduce the impact of outliers or noise in the data. Therefore, taking values from previous studies can be helpful in situations where acquiring new data is challenging or time-consuming. By leveraging existing datasets, we can still build a reliable regression model, provided that the data is relevant and representative of the current context.

Based on the analysis of equivalent compaction energies the conclusions that can be drawn are incorporated in this chapter. In this study it has been attempted to predict the equivalent compaction energies by linear regression.

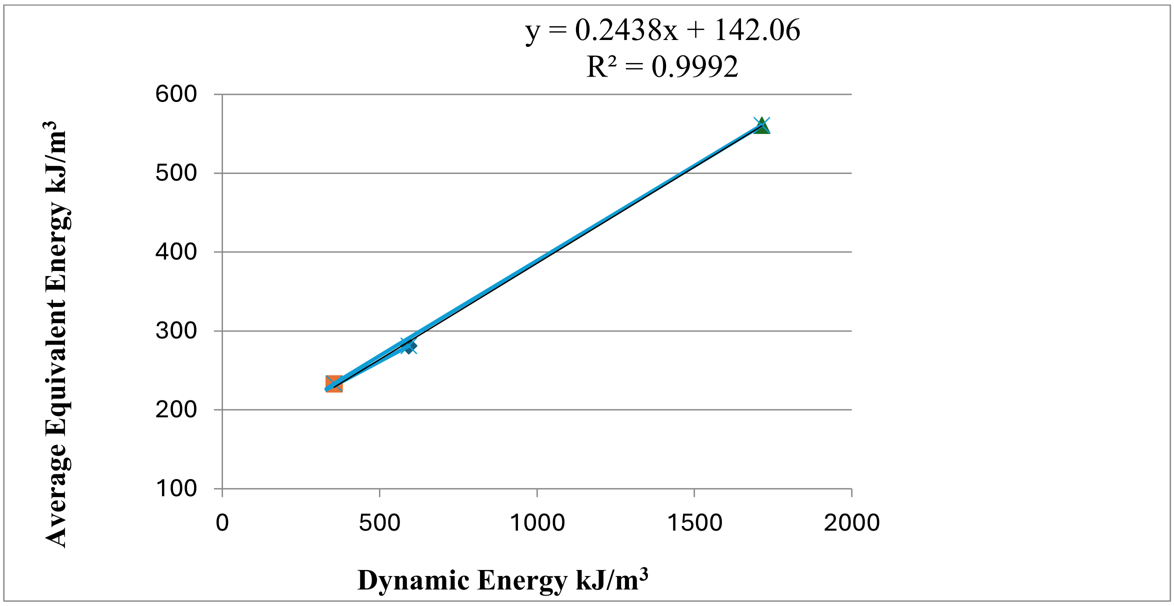

Figure 5.1: Average ESE vs Dynamic Energy

Dynamic Energy values are taken from the Laboratory Proctor Test, i.e.

- Standard Proctor Test = 592.5 kJ/m^3
- Reduced Standard Proctor Test = 355.5 kJ/m^3
- Reduced Modified Proctor Test = 1714.5 kJ/m^3

The Average Equivalent Static Energy taken from eleven soil samples according to SP, RSP, RM.

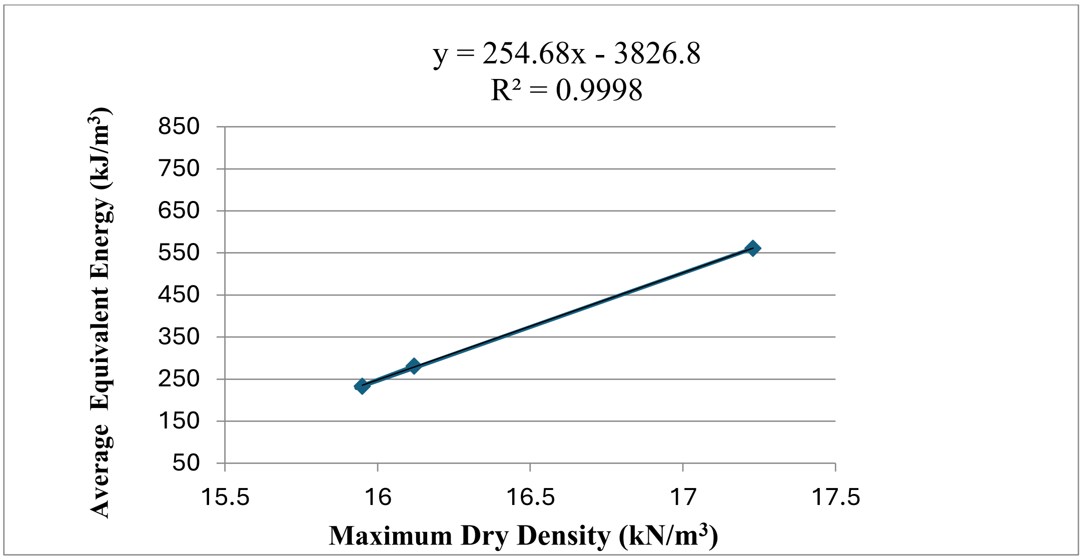

Figure 5.2: Average ESE vs MDD

MDD is taken from laboratory test (SP, RSP, RM) done in eleven soil samples.

Note: Seven soil samples data are taken from previous work.

5.2 Prediction of OMC and MDD

The study involves analyzing test result data and conducting a statistical analysis to propose general prediction equations for MDUW and OMC of statically compacted soil. These prediction equations correlate with other soil indices, such as peak saturation level (Sp), static compaction energy (Estatic), and plastic limit (Wp). The study conducted static compaction tests on various soil types at different moisture levels and applied static loads. Respective values of input compaction energy, dry unit weight, void ratio, and degree of saturation were measured. Furthermore, variations of dry unit weight with moisture content at different energy levels were also obtained. The relationship between degree of saturation and Static energy is shown below:

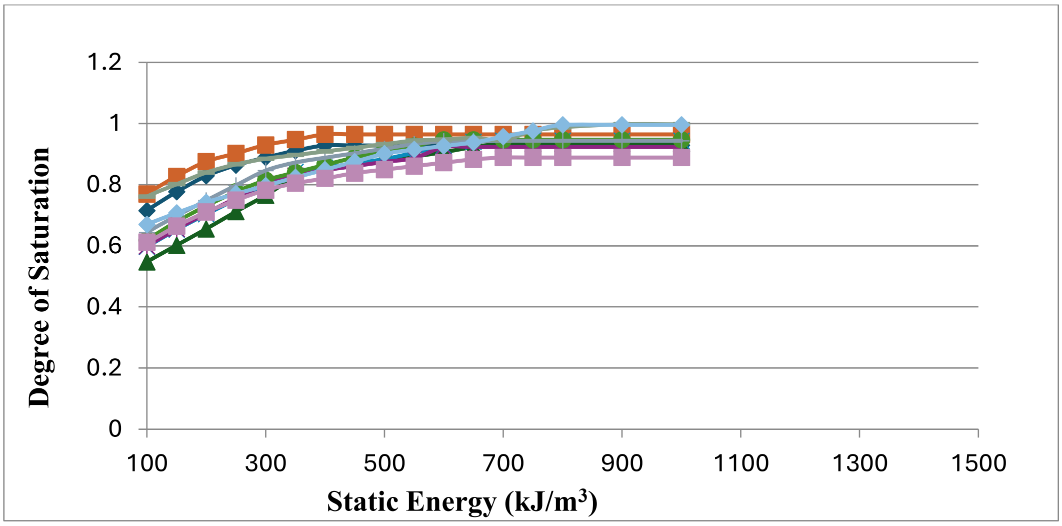

Fig 5.3: Static Energy vs Degree of Saturation at OMC of 10 soil samples

In Figure 5.1, we present the variation curves of Sp along with the corresponding Estatic values for all the tested soil samples. We observed that as the Estatic increases, Sp gradually rises until it reaches a range between 0.78 and 0.82, with the induced compaction energy ranging from 300 kJ/m^3 to 400 kJ/m^3. Therefore, to ensure consistency and reliability in the regression model, we omitted Sp values corresponding to compaction energies up to 400KJ/m3 and only used values higher than 0.8. It is worth noting that the manual filling of soil into the compaction mould might not have been entirely uniform, and this could have led to unevenly compacted soil samples.

Prediction of MDD with Static Energy, Void Ratio, DOS, & PL:

MDD = 18.94+0.002 Es+0.3 S-2.7 e-0.08 PL

Where MDD = predicted maximum dry density
Es = Static energy
S= degree of saturation
e = void ratio
PL = plastic limit of the soil sample

Prediction of OMC with Static Energy, DOS, Void Ratio, & PL:

OMC = -14.5-0.001 Es+21.2 S+23.4 e+0.08 PL

Where MDD = predicted maximum dry density
Es = Static energy
S= degree of saturation
e = void ratio
PL = plastic limit of the soil sample

Table 5.1: Regression analysis model fitness metrics for MDUW and OMC in relation to Estatic, Sp, Wp, and e for fine-grained soil

Dependent Variable	R	R square	Adjusted R Square	Standard Error of the Estimate
MDD	0.954	0.912	0.907	0.239
OMC	0.994	0.988	0.988	0.247

In regression analysis, R refers to the correlation coefficient between the observed values of the dependent variable and the predicted values from the regression model. It measures the strength and direction of the linear relationship between the observed and predicted values. Multiple R ranges from 0 to 1. A value closer to 1 indicates a stronger linear relationship, meaning the model explains a larger proportion of the variability in the dependent variable.

In multiple regression, R-square measures the proportion of the variance in the dependent variable that is explained by the independent variables in the model. R^2 values range from 0 to 1. If R^2 is 0.75, it means that 75% of the variation in the dependent variable can be explained by the independent variables in the model, while the remaining 25% is unexplained or due to other factors not included in the model.

In regression analysis, Adjusted R-squared adjusts the R-square value to account for the number of independent variables (predictors) in the model, helping to provide a more accurate measure of how well the model fits the data. Adjusted R-square can range from negative values (in cases of poor models) to 1. A value closer to 1 indicates a better fit, though negative values might occur if the model is extremely poor.

In regression analysis, the Standard Error (SE) refers to the standard deviation of the sampling distribution of a regression coefficient. It provides a measure of the precision or variability of an estimated coefficient (like the slope or intercept) in the model. A lower SE suggests a better fit of the model to the data, indicating that the predictions are close to the actual values. A higher SE suggests more variability in the residuals, meaning the model does not predict as accurately.

CONCLUSION

Based on the analysis of compaction energies the conclusions that can be drawn are incorporated in this chapter. In this study it has been attempted to reproduce the compaction energies through analytical analysis of static compaction test results and to derive the equivalent energy. Two correlations achieved through regression analysis enable the prediction of equivalent static energy without the need for static compaction. This suggests that by applying regression techniques to establish two correlations (likely based on empirical data or a mathematical model), one can predict the equivalent static energy of a system without performing static compaction. In some contexts, such as soil mechanics or material science, this step might typically be used to derive energy characteristics. However, with regression analysis, these energy predictions can be made directly from other available variables, potentially making the process more efficient and less resource-intensive.

REFERENCES

1. Bureau of Indian Standards (1980) Methods of test for soils: Determination of water content dry density relation using Light compaction, IS 2720-7, New Delhi, India.
2. Bureau of Indian Standards (1983) Methods of test for soils: Determination of water content dry density relation using Heavy compaction, IS 2720-8, New Delhi, India.
3. Bureau of Indian Standards (1980) Methods of test for soils: Determination of liquid limit and plastic limit, IS 2720-5, New Delhi, India.
4. Bureau of Indian Standards (1980) Methods of test for soils: Determination of specific gravity, IS 2720-3, New Delhi, India.
5. Bureau of Indian Standards (1980) Methods of test for soils: Grain size analysis. IS 2720-4, New Delhi, India.
6. Hafez. A.,DorisAsmani, M. And Nurbaya, S. (2010) Comparison between static and dynamic compaction methods, *Electronic Journal Geotechnical Engineering* (EJGE), Vol.15, pp.1641-1650.
7. Hogentogler, C.A. (1937) Engineering properties of soil, McGrew-Hill Book Company, Inc.. New York.
8. Kenneth and Steven (1968) Change in water content and density of compacted keolinite due to consolidation, Journal of Soil Mechanics and Foundation Div, Vol.95, pp. 1564-1567.
9. Oliver, M. And Mesbah, A. (1999) clayey soil behaviour under static compaction test. *Materials and Structures*, Vol. 32, pp. 687-694.
10. Proctor, R.R (1933) Fundamental principles of soil compaction, Engineering News Record, Vol. 111.
11. Reddy, B. V. V. And jagadish, K. S, (1993) The static compaction of soils, Geotechnical Journal, The Institution of Civil Engineers London, 43(2), pp.337-341.
12. Sharma, B. And Deka, A.(2016)Static compaction test and determination of equivalent static pressure, Proceedings of I.G.C., 2016,December 15-17, 2016,IIT Madras, Chennai, India, pp. 1-4

Appendix 1

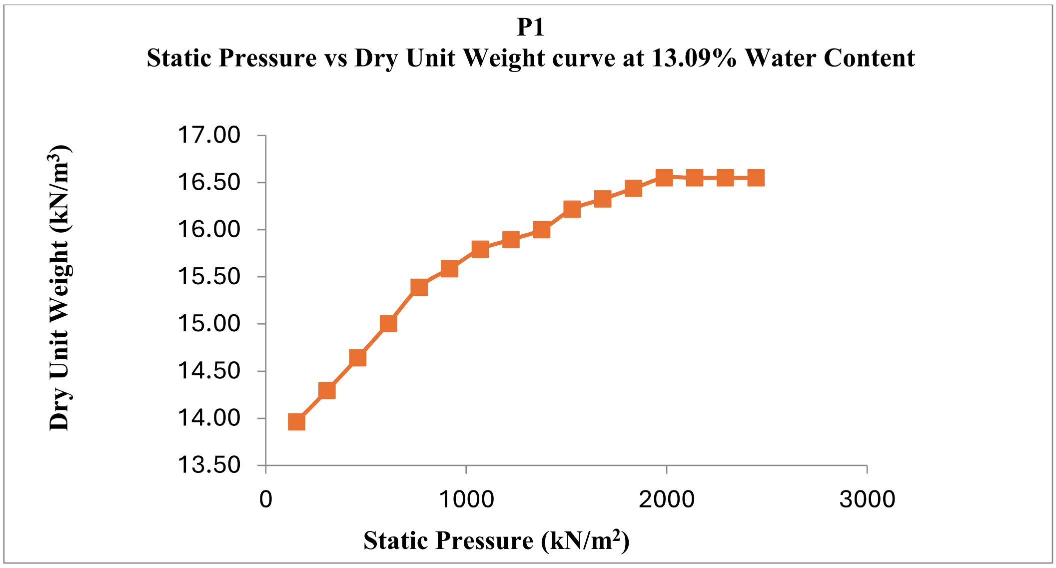

Figure 3.25: Static pressure vs Dry unit weight curve of Pathsala 1 soil at 13.09% water content

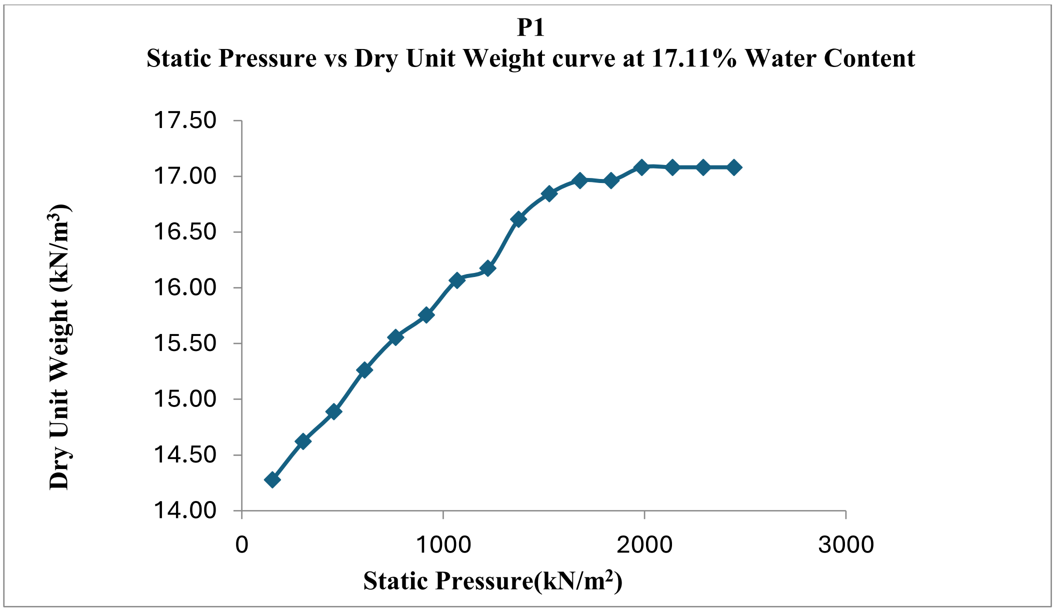

Figure 3.26: Static pressure vs Dry unit weight curve of Pathsala 1 soil at 17.11% water content

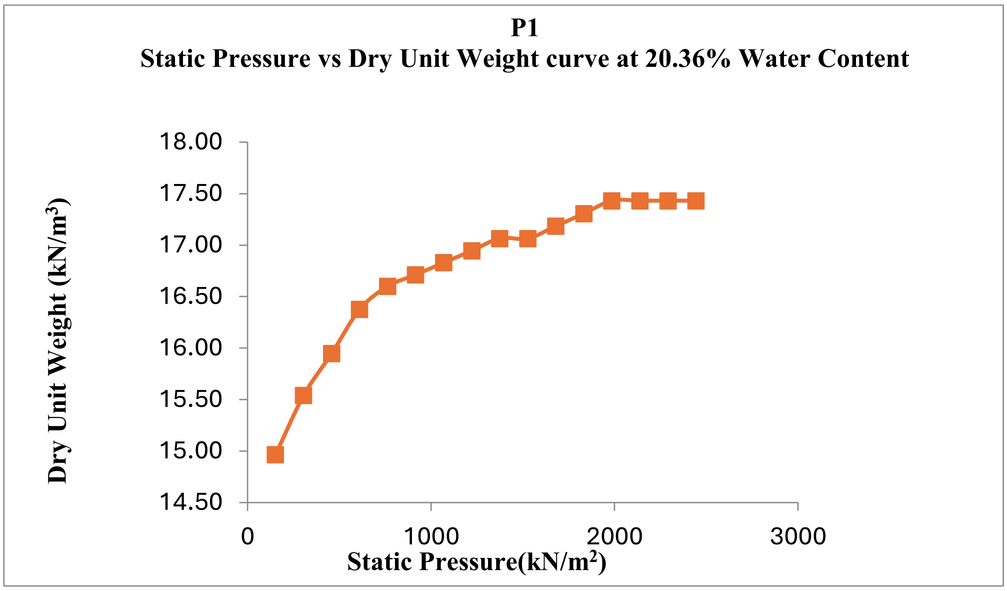

Figure 3.27: Static pressure vs Dry unit weight curve of Pathsala 1 soil at 20.36% water content

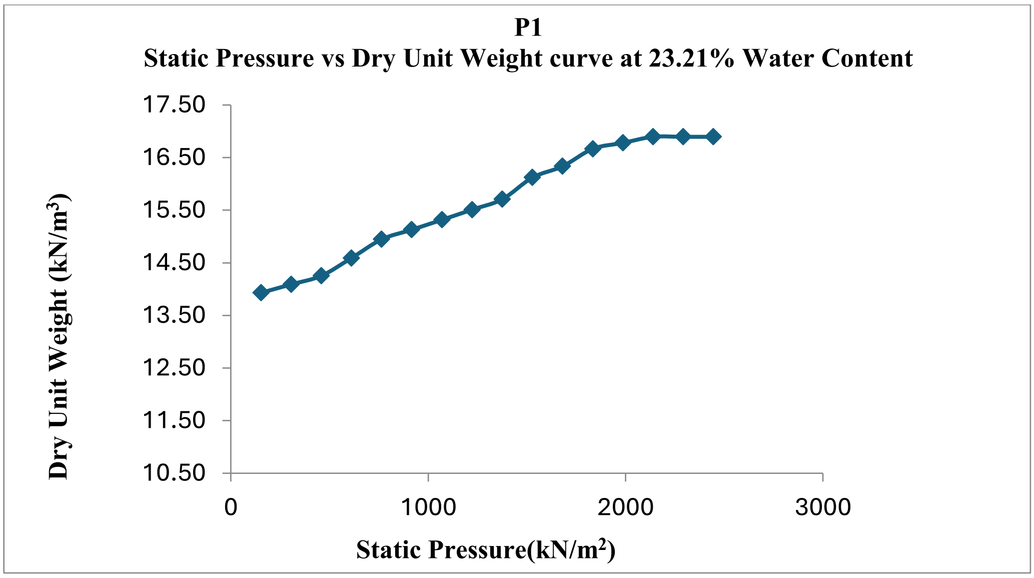

Figure 3.28: Static pressure vs Dry unit weight curve of Pathsala 1 soil at 23.21% water content

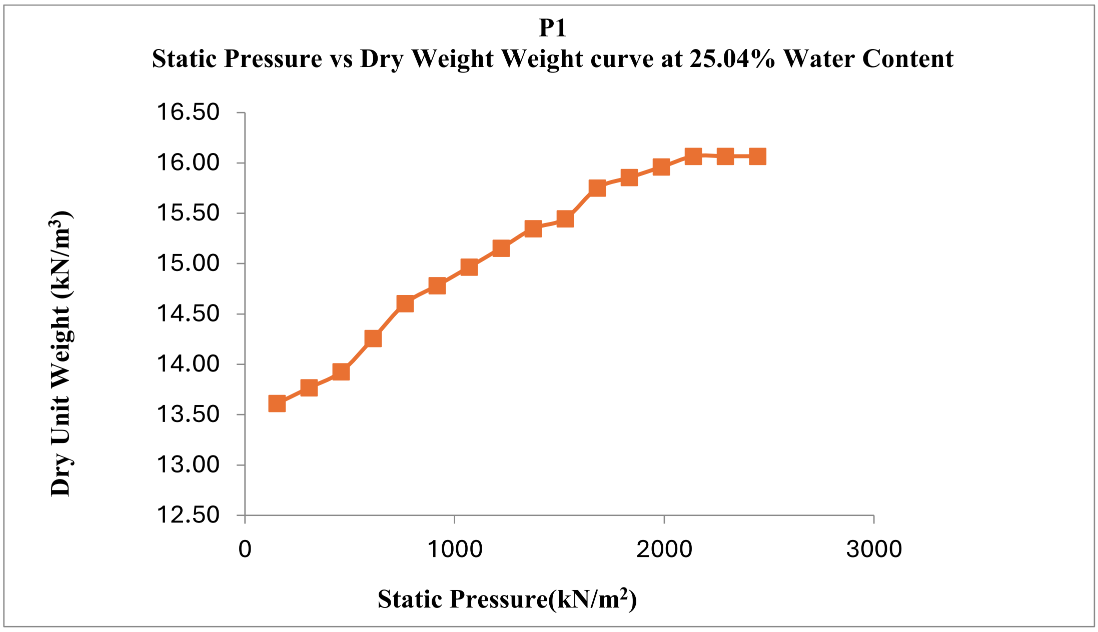

Figure 3.29: Static pressure vs Dry unit weight curve of Pathsala 1 soil at 25.04% water content

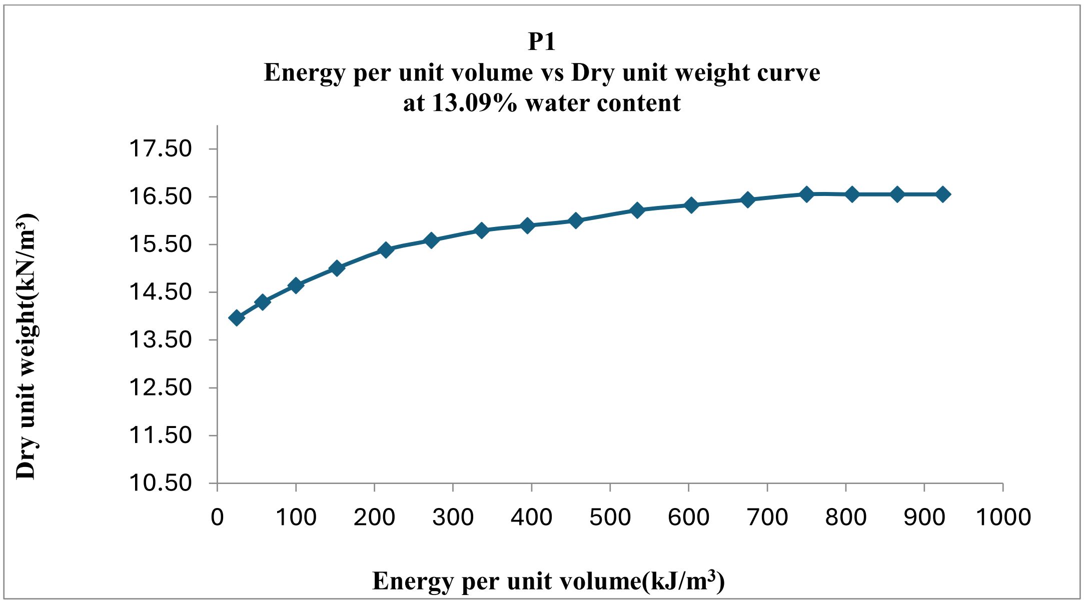

Figure 3.30: Static Energy per unit volume vs Dry unit weight curve of Pathsal 1 soil at 13.09% water content

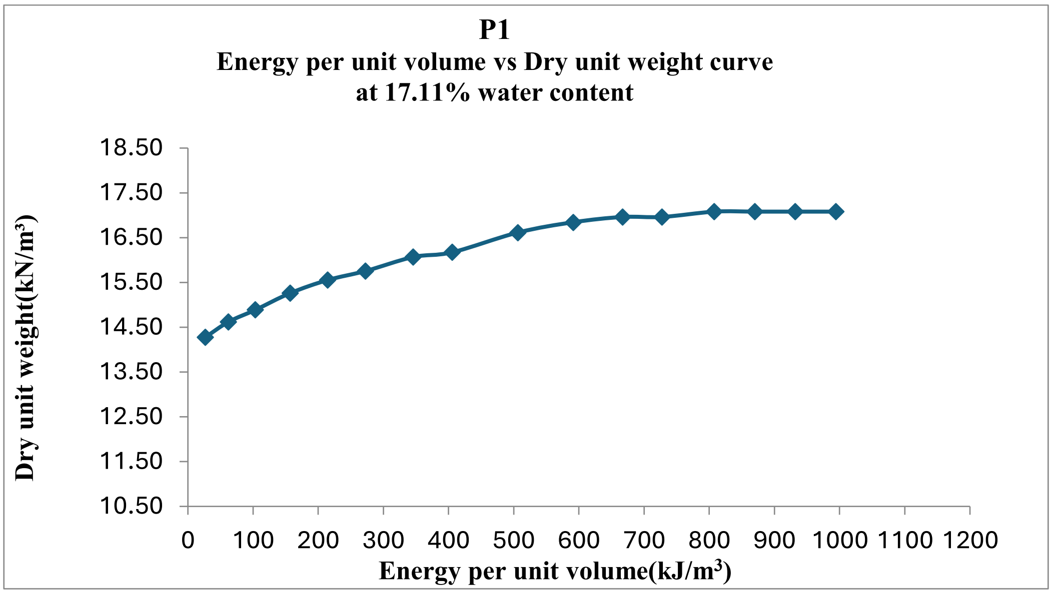

Figure 3.31: Static Energy per unit volume vs Dry unit weight curve of Pathsal 1 soil at 17.11% water content

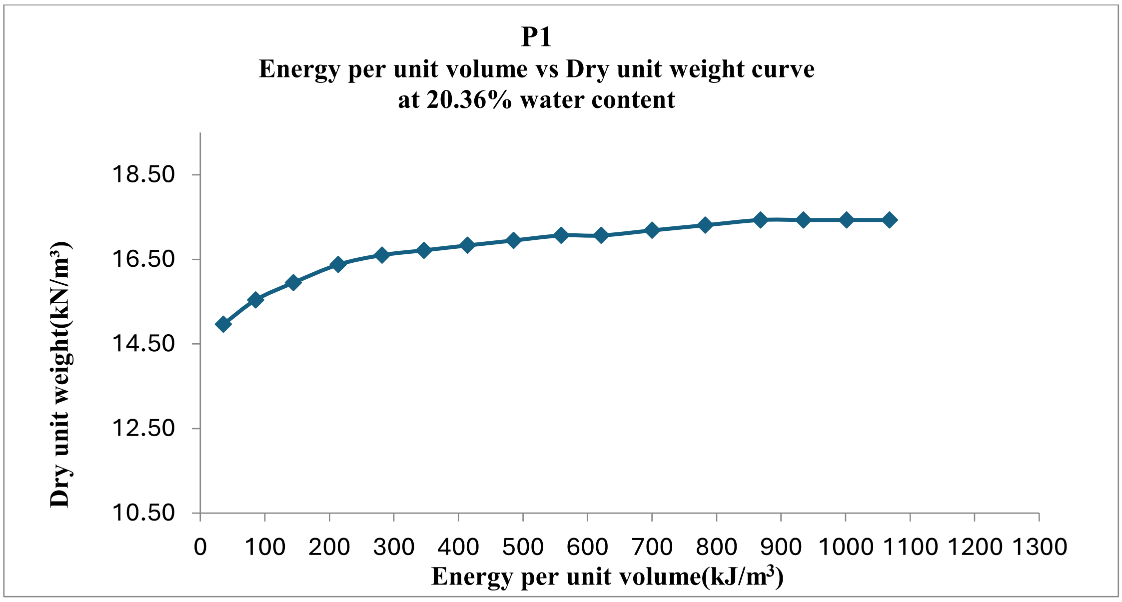

Figure 3.32: Static Energy per unit volume vs Dry unit weight curve of Pathsal 1 soil at 20.36% water content

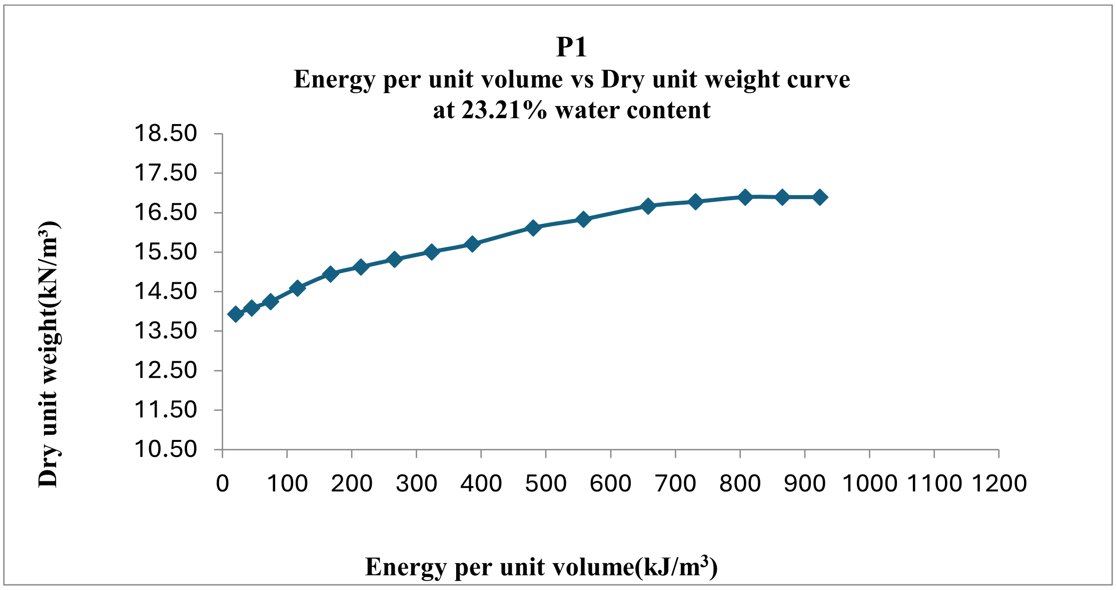

Figure 3.33: Static Energy per unit volume vs Dry unit weight curve of Pathsal 1 soil at 23.21% water content

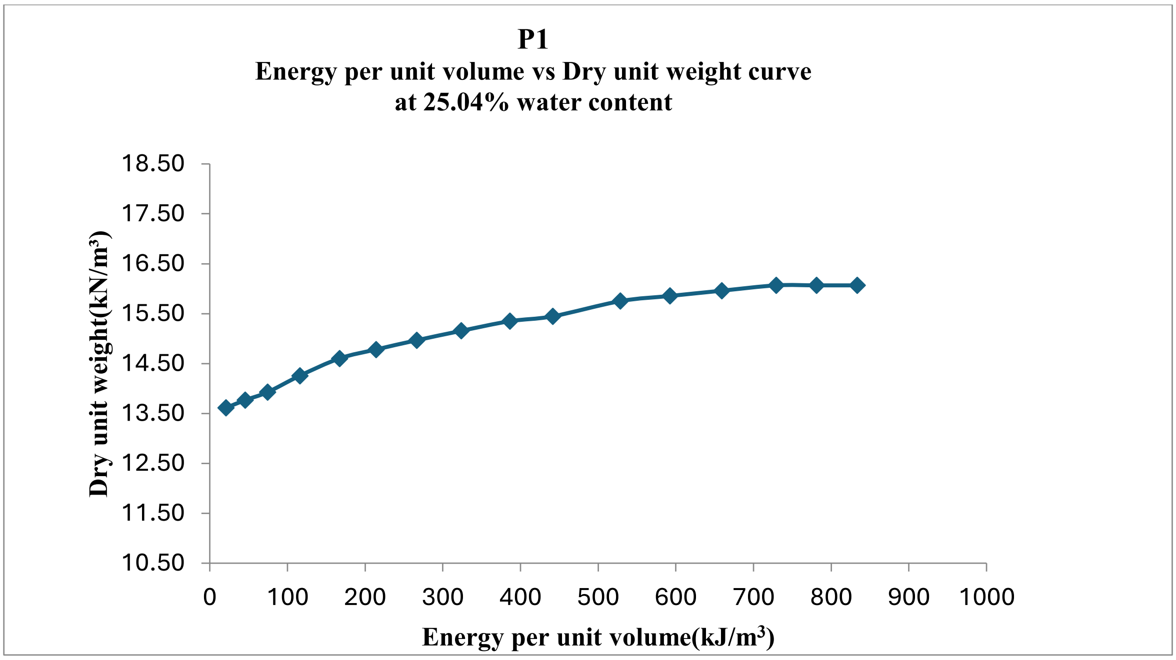

Figure 3.34: Static Energy per unit volume vs Dry unit weight curve of Pathsal 1 soil at 25.04% water content

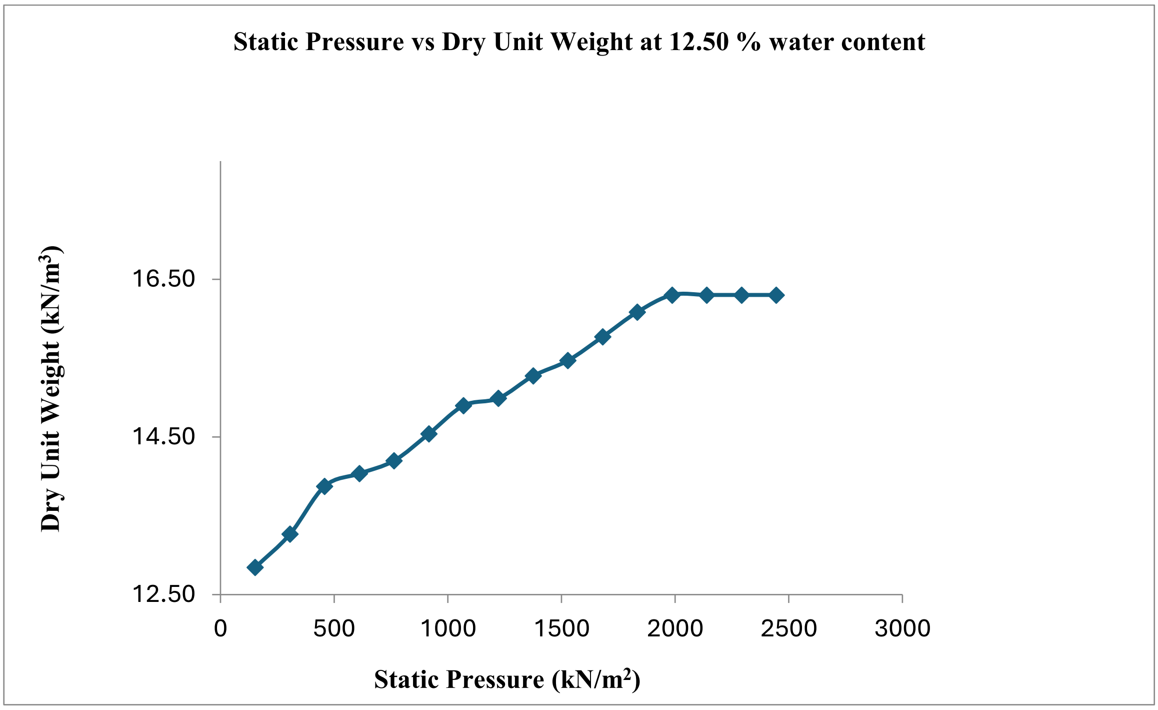

Figure 3.35: Static pressure vs Dry unit weight curve of Pathsala 2 soil at 12.50% water content

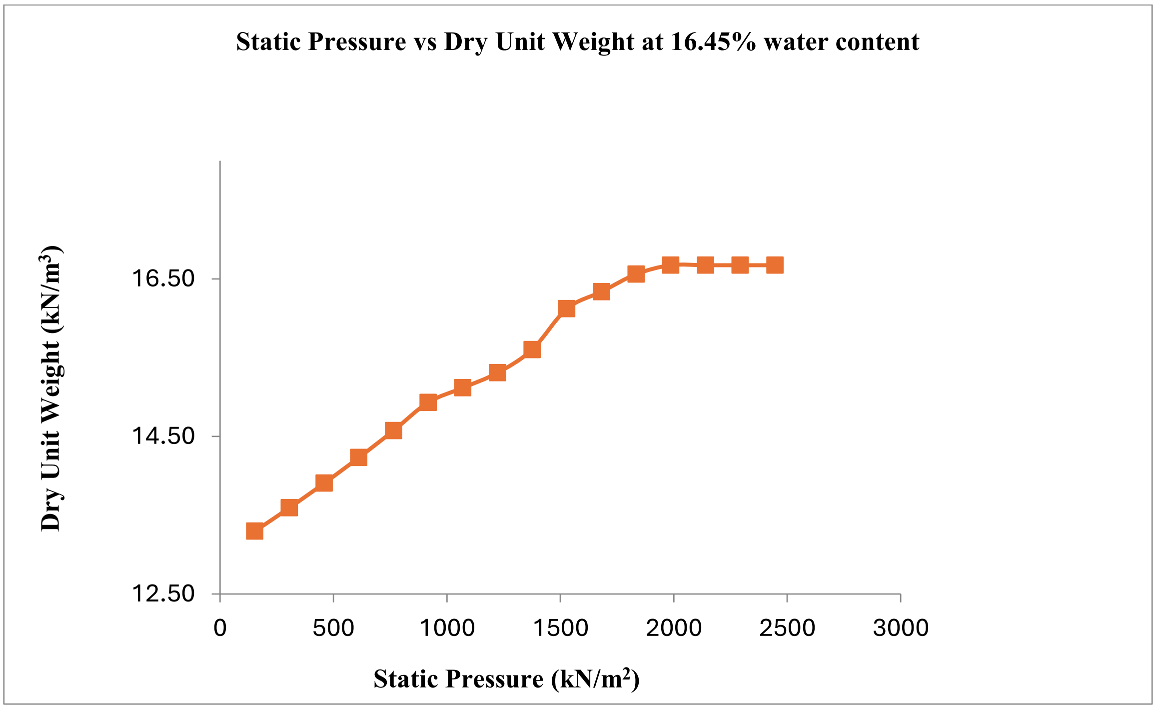

Figure 3.36: Static pressure vs Dry unit weight curve of Pathsala 2 soil at 16.45% water content

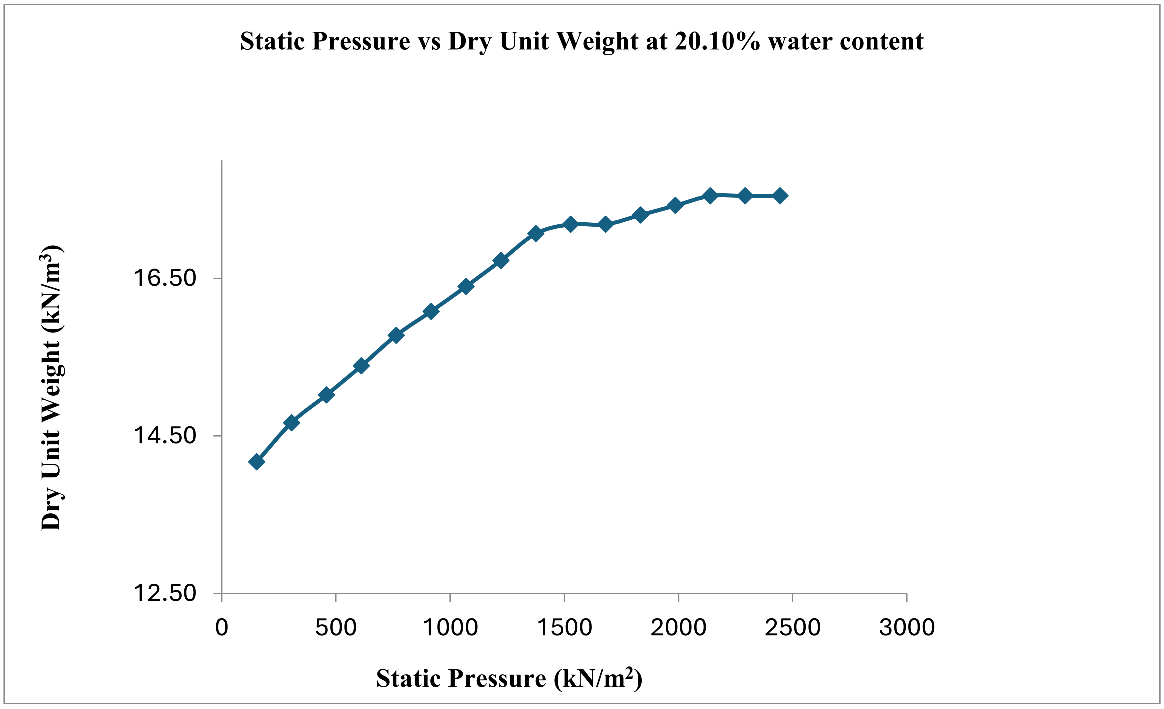

Figure 3.37: Static pressure vs Dry unit weight curve of Pathsala 2 soil at 20.10% water content

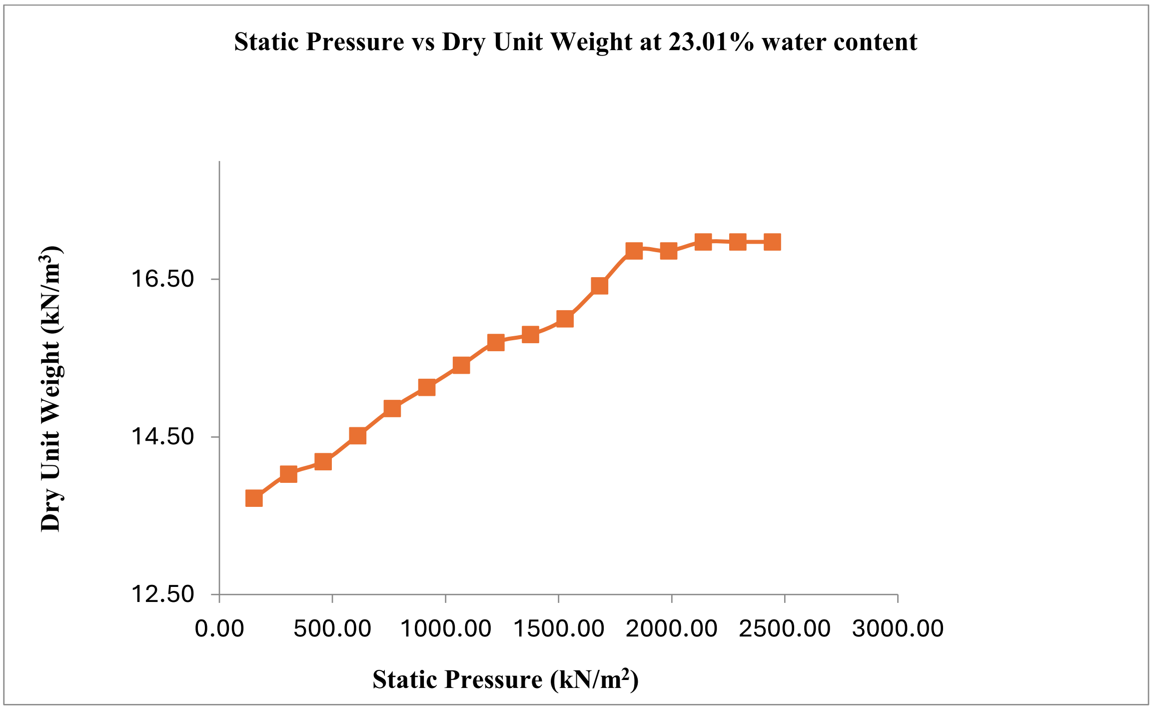

Figure 3.38: Static pressure vs Dry unit weight curve of Pathsala 2 soil at 23.01% water content

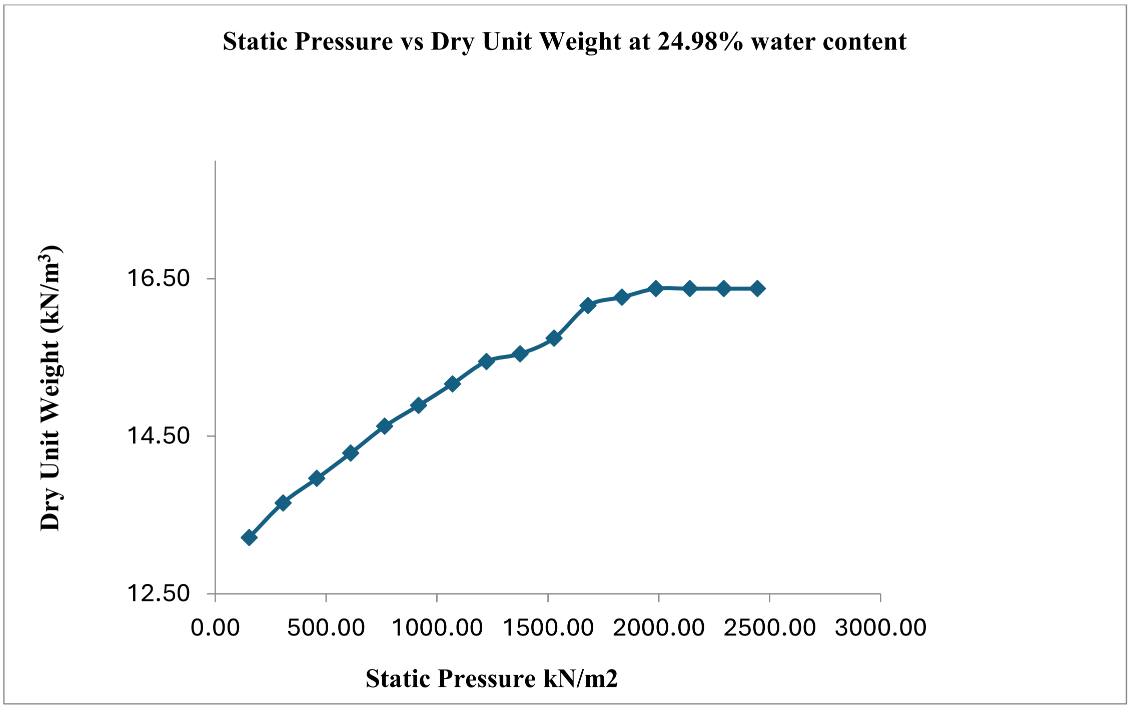

Figure 3.39: Static pressure vs Dry unit weight curve of Pathsala 2 soil at 24.98% water content

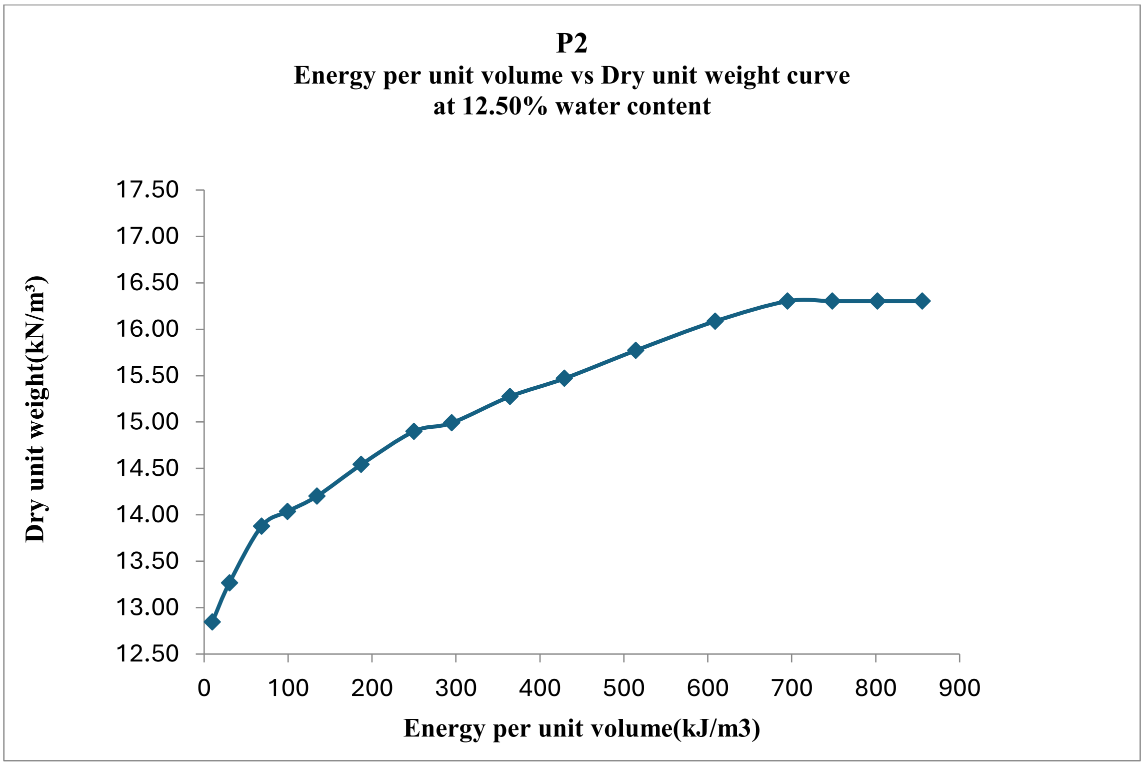

Figure 3.39: Static Energy per unit volume vs Dry unit weight curve of Pathsal 2 soil at 12.50% water content

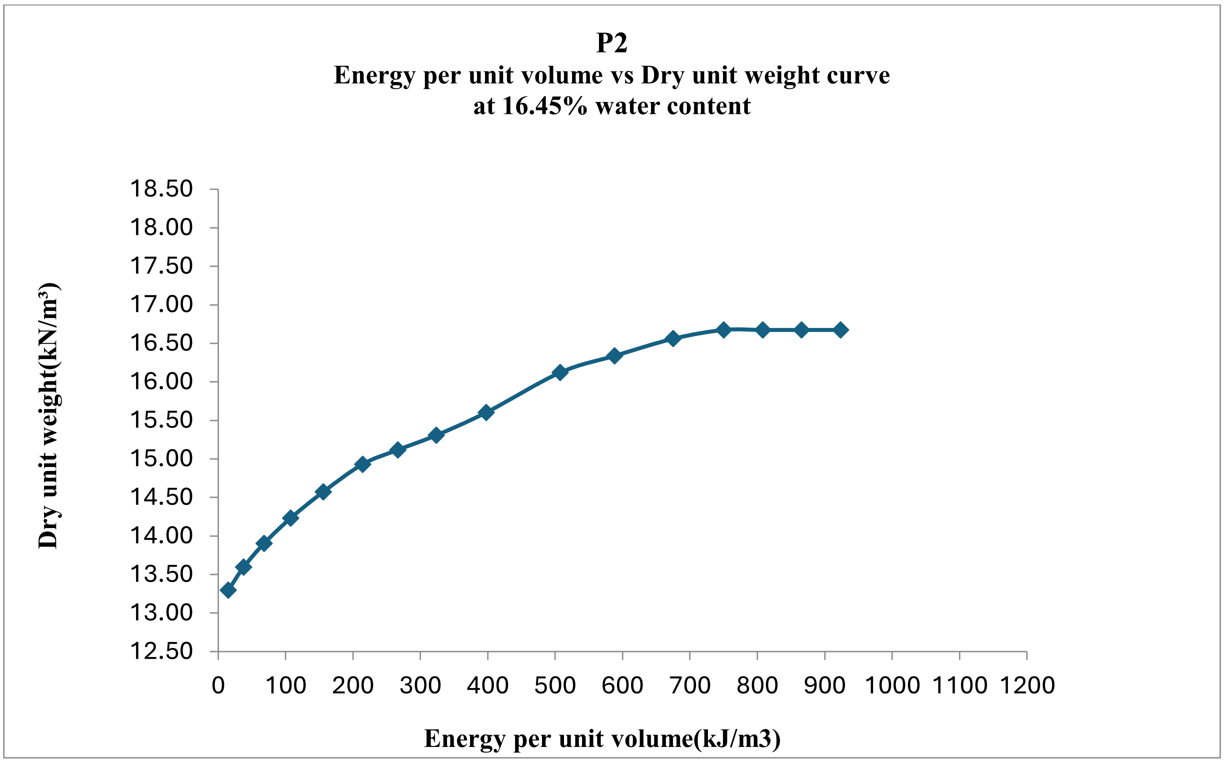

Figure 3.40: Static Energy per unit volume vs Dry unit weight curve of Pathsal 2 soil at 16.45% water content

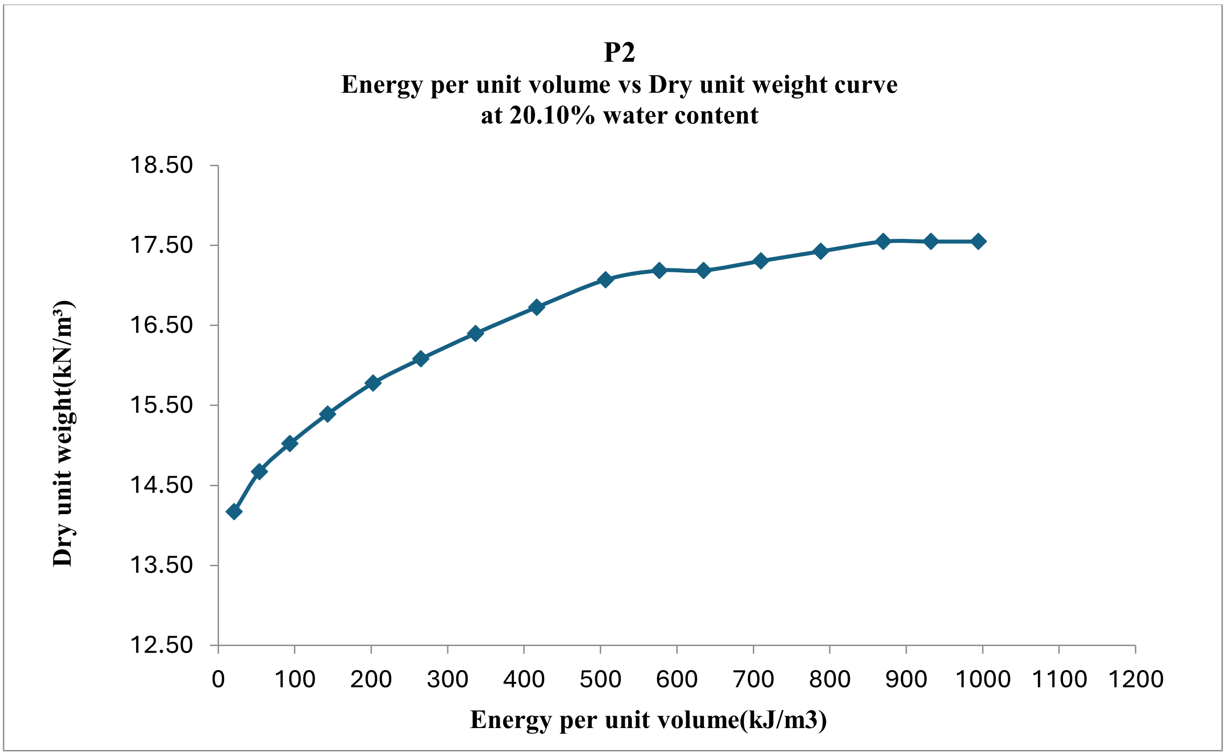

Figure 3.41: Static Energy per unit volume vs Dry unit weight curve of Pathsal 2 soil at 20.10% water content

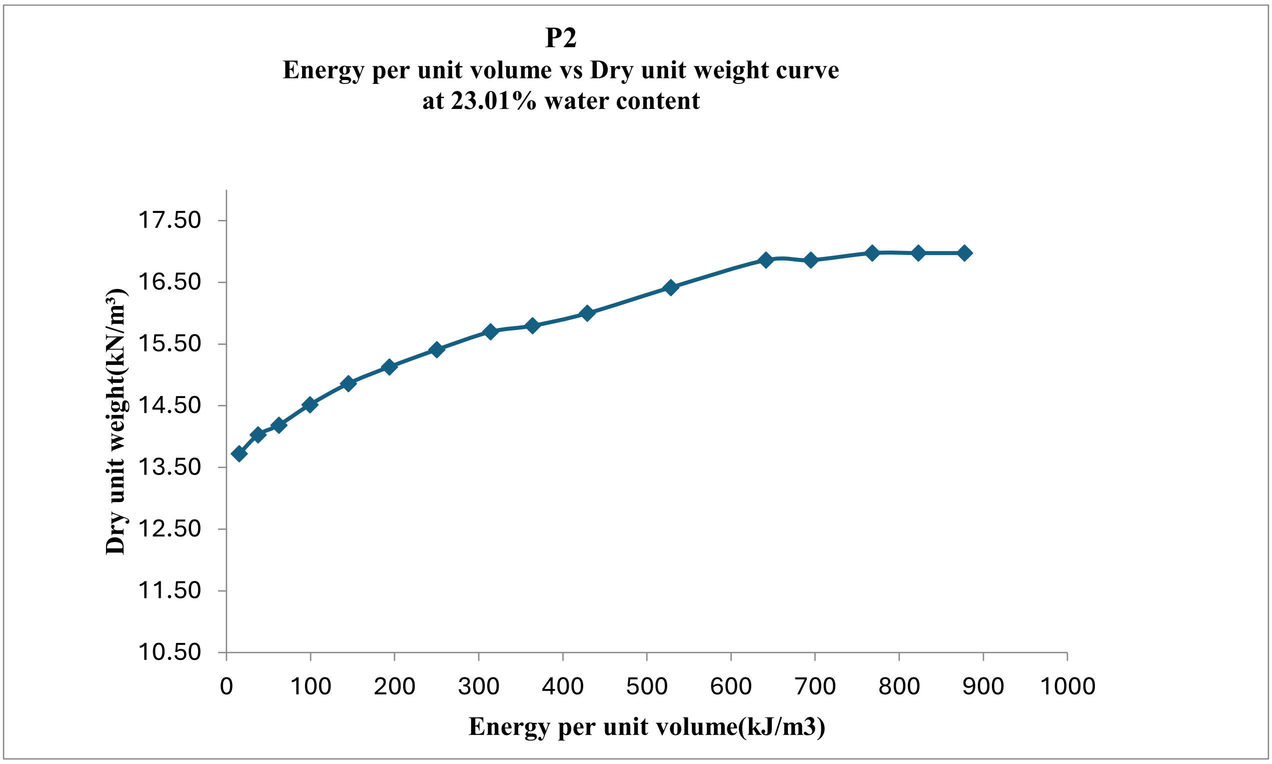

Figure 3.42: Static Energy per unit volume vs Dry unit weight curve of Pathsal 2 soil at 23.01% water content

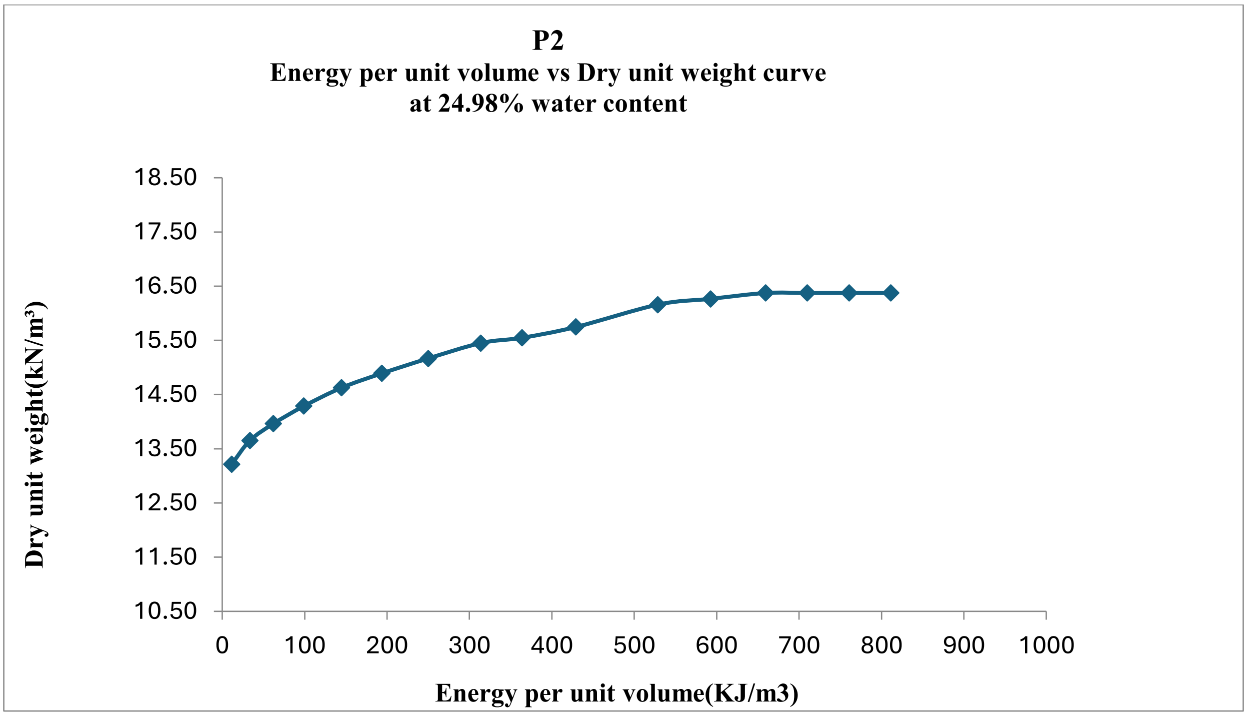

Figure 3.43: Static Energy per unit volume vs Dry unit weight curve of Pathsal 2 soil at 24.98% water content

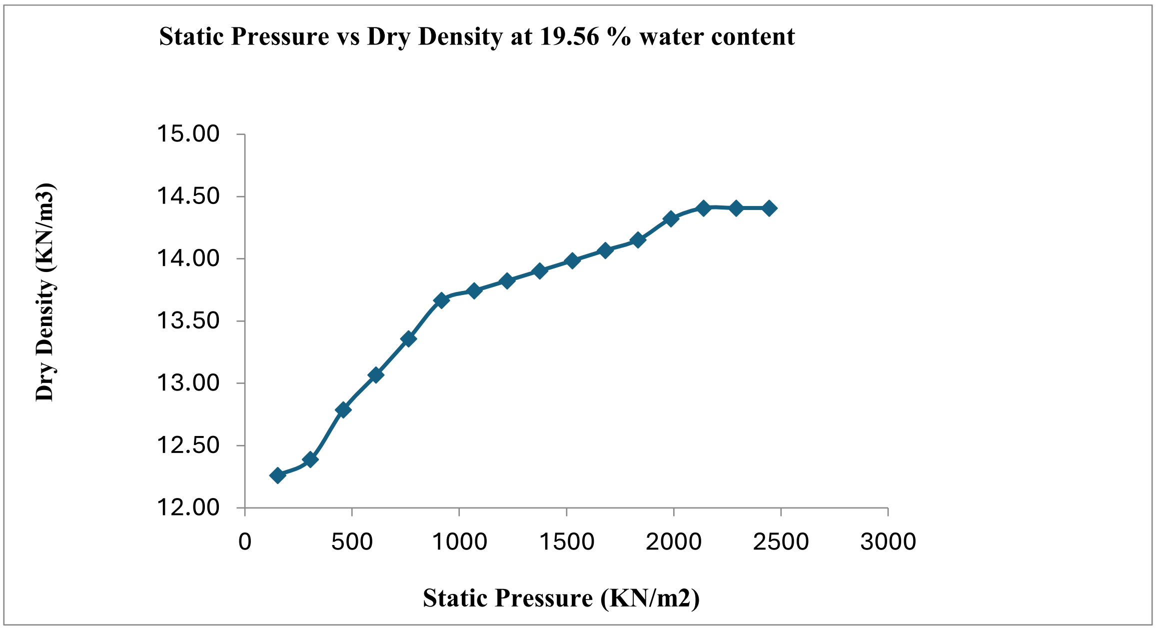

Figure 3.44: Static pressure vs Dry unit weight curve of Red soil at 19.56% water content

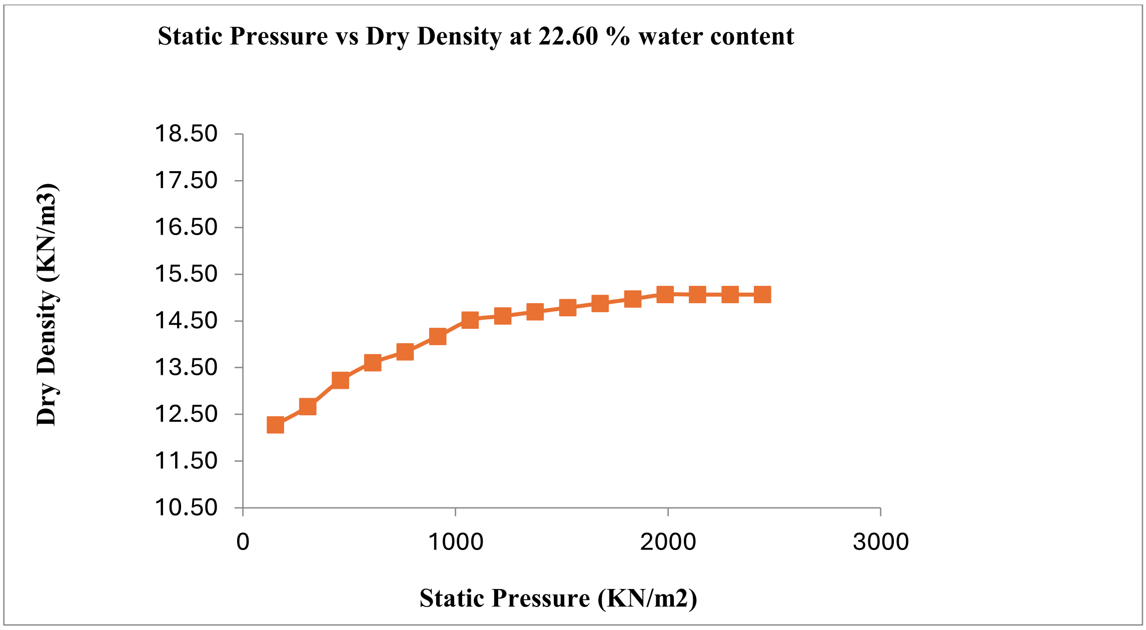

Figure 3.45: Static pressure vs Dry unit weight curve of Red soil at 22.60% water content

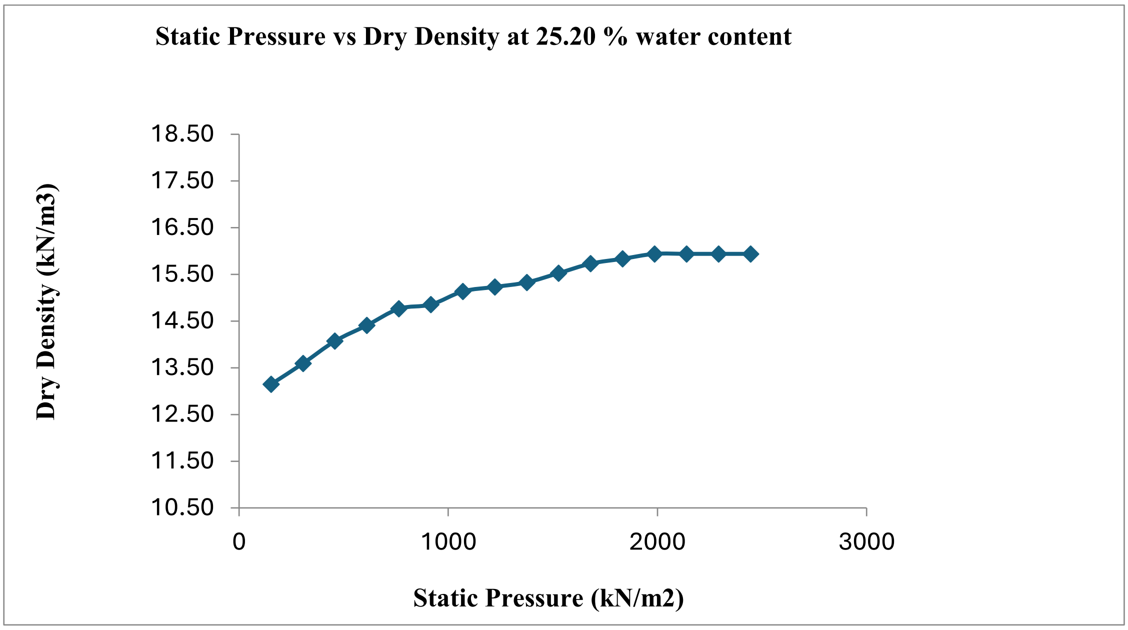

Figure 3.46: Static pressure vs Dry unit weight curve of Red soil at 25.20% water content

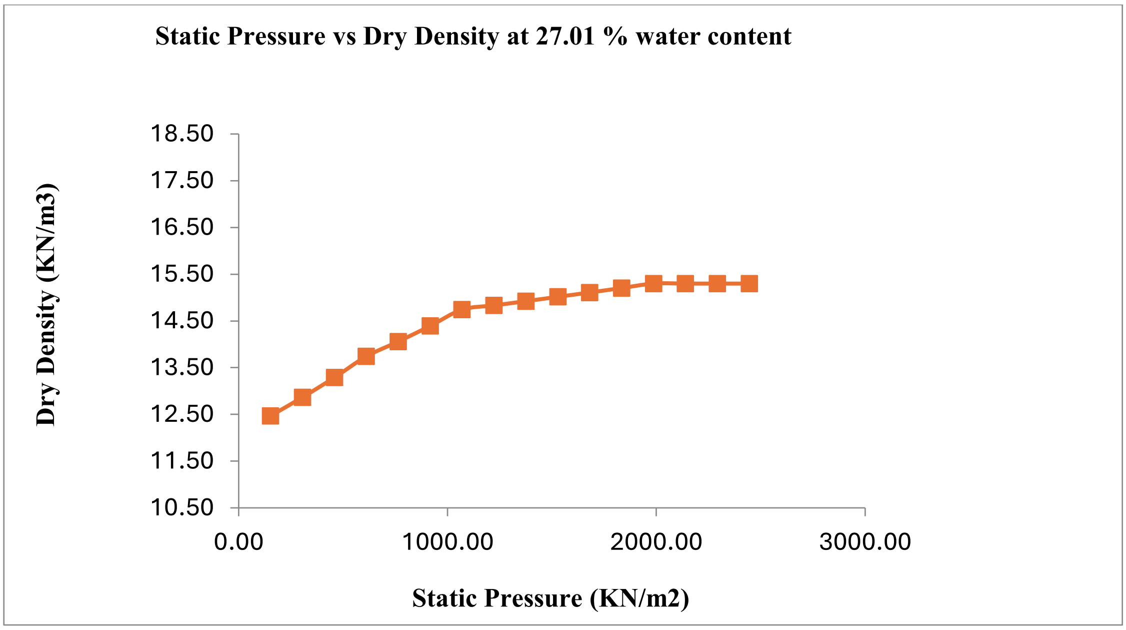

Figure 3.47: Static pressure vs Dry unit weight curve of Red soil at 27.01% water content

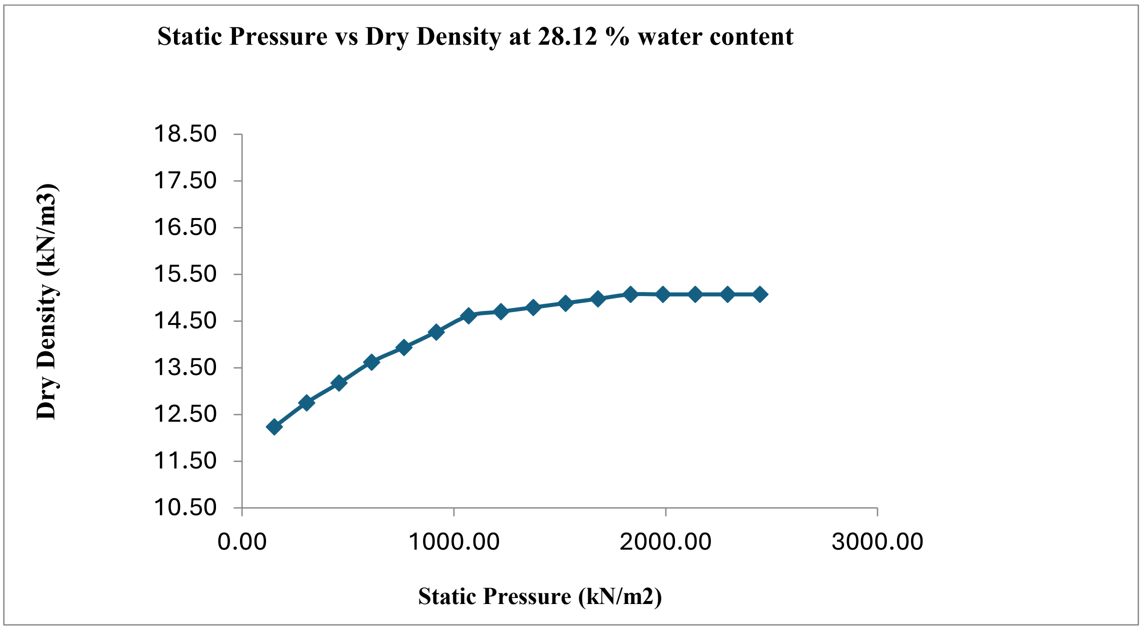

Figure 3.48: Static pressure vs Dry unit weight curve of Red soil at 28.12% water content

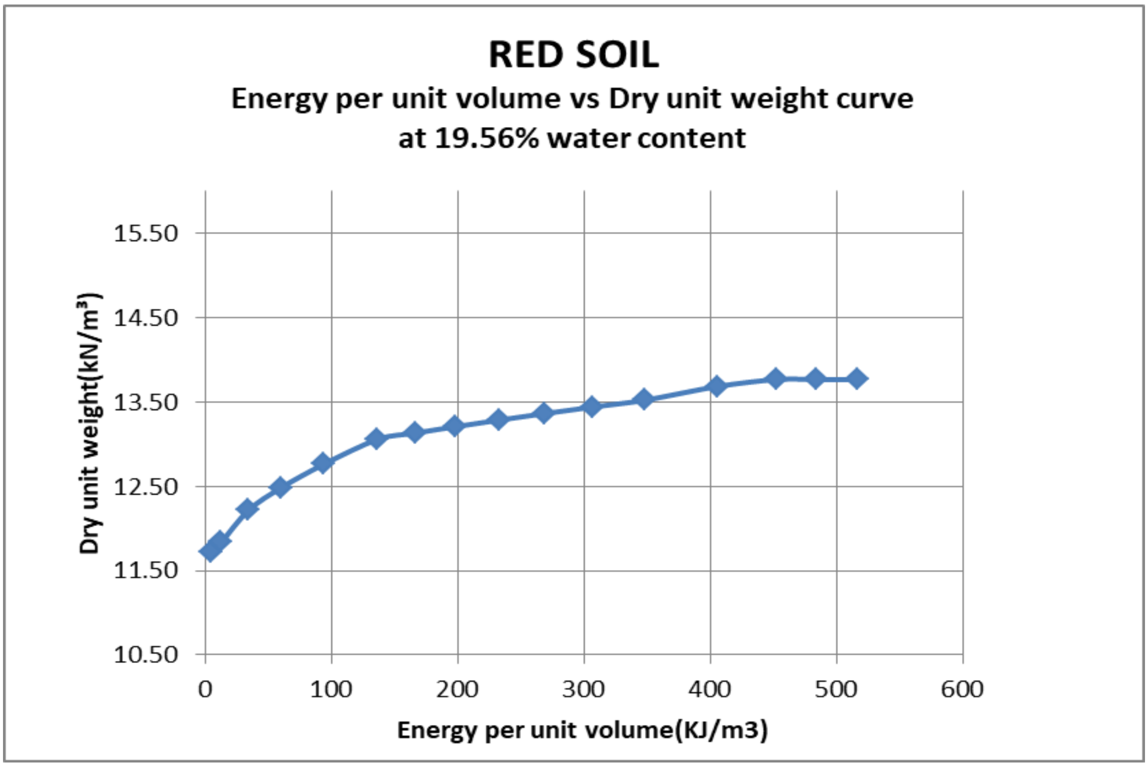

Figure 3.49: Static Energy per unit volume vs Dry unit weight curve of Red soil at 19.56% water content

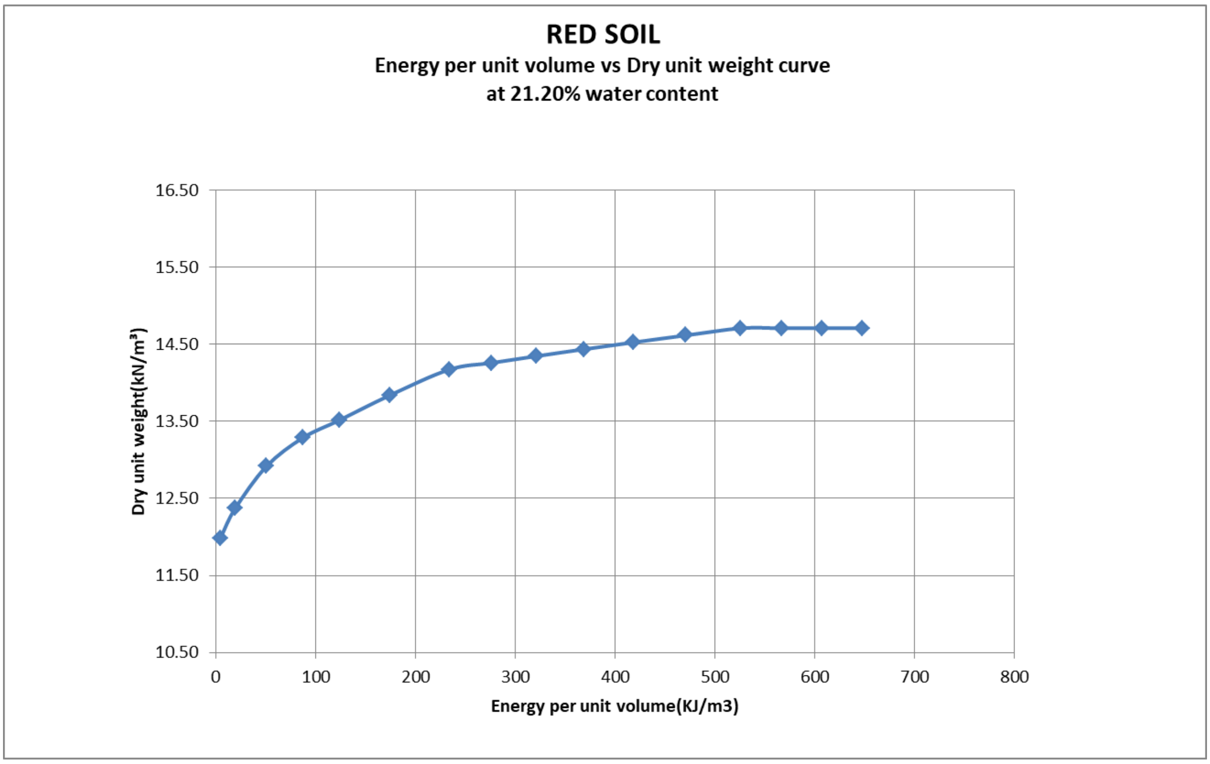

Figure 3.50: Static Energy per unit volume vs Dry unit weight curve of Red soil at 21.20% water content

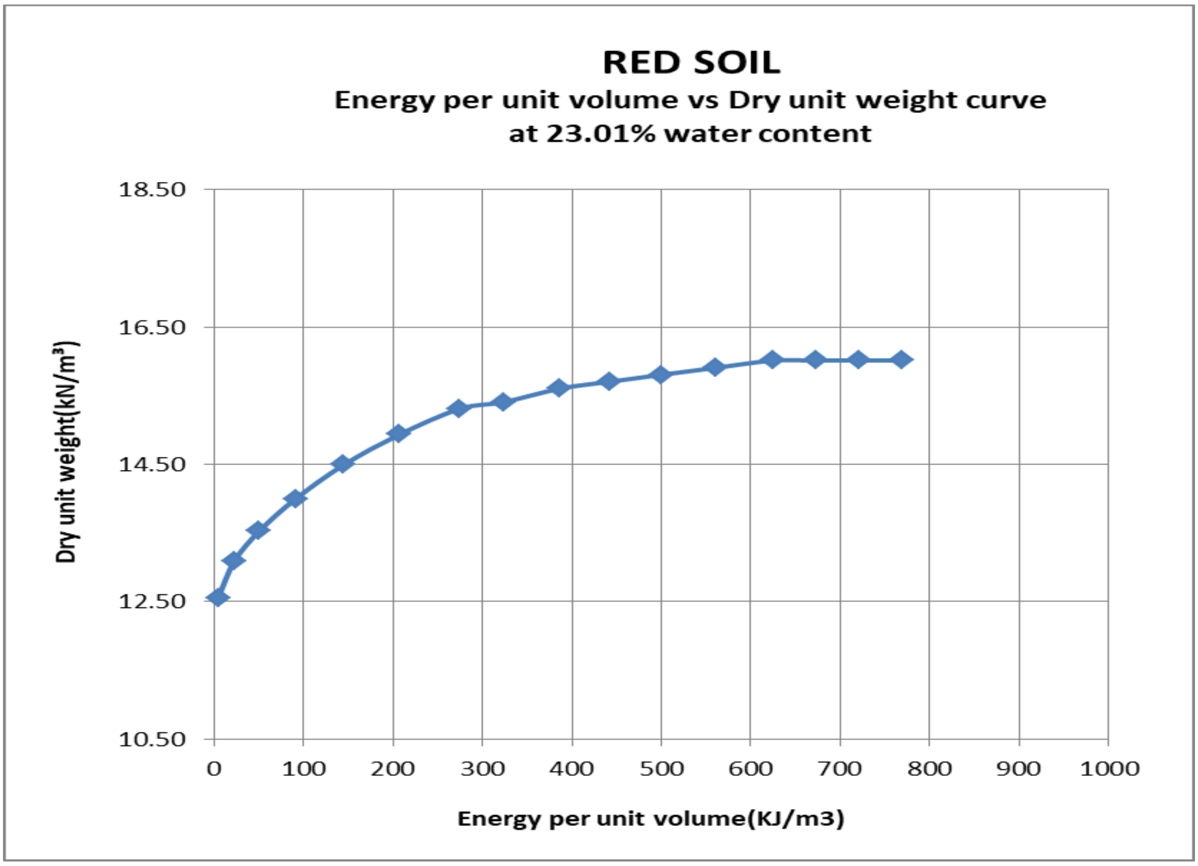

Figure 3.51: Static Energy per unit volume vs Dry unit weight curve of Red soil at 23.01% water content

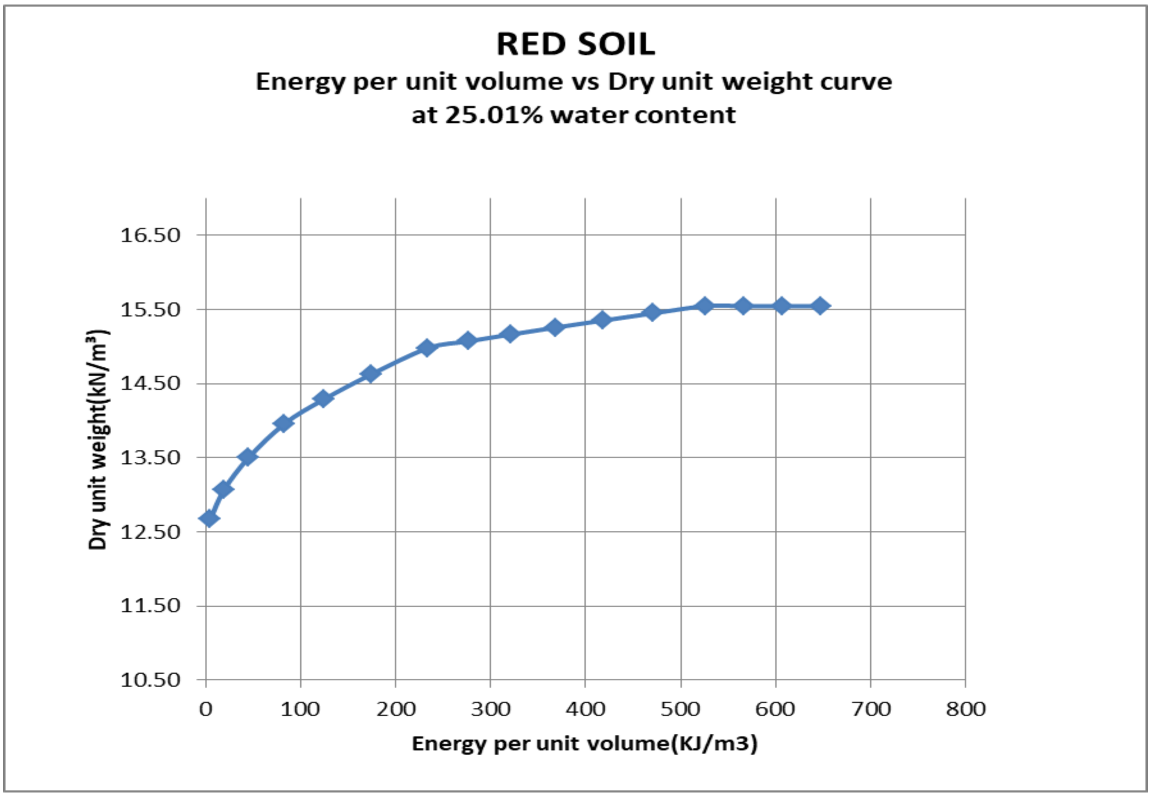

Figure 3.52: Static Energy per unit volume vs Dry unit weight curve of Red soil at 25.01% water content

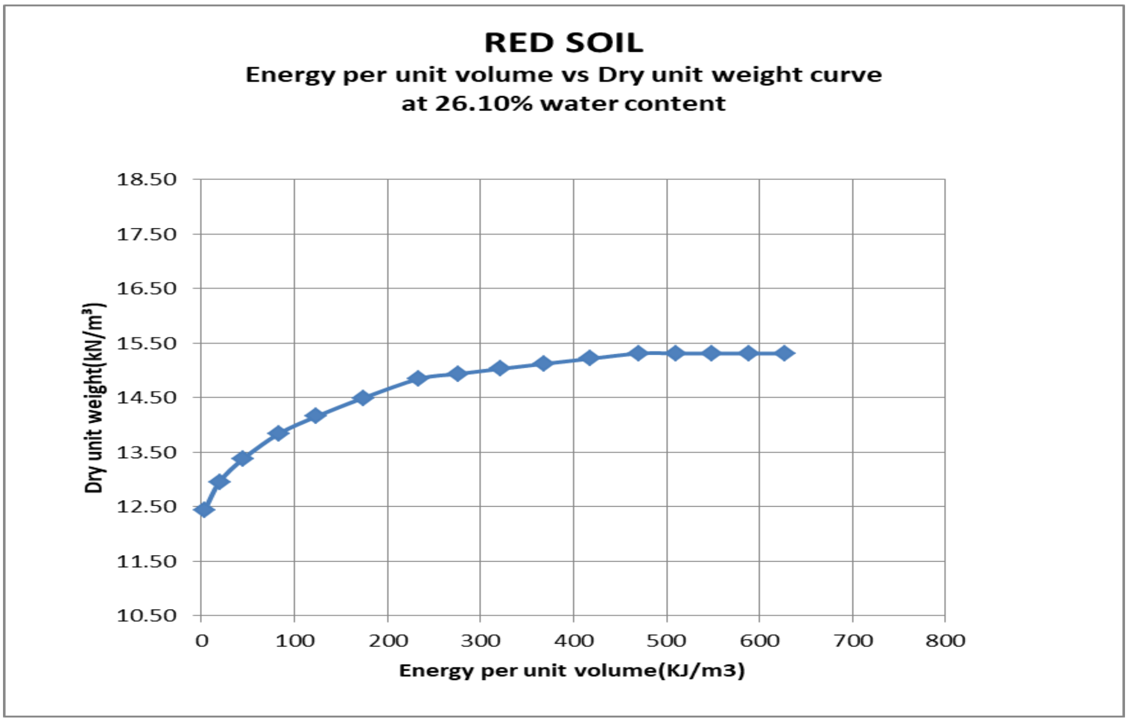

Figure 3.55: Static Energy per unit volume vs Dry unit weight curve of Red soil at 26.10% water content

Appendix 2

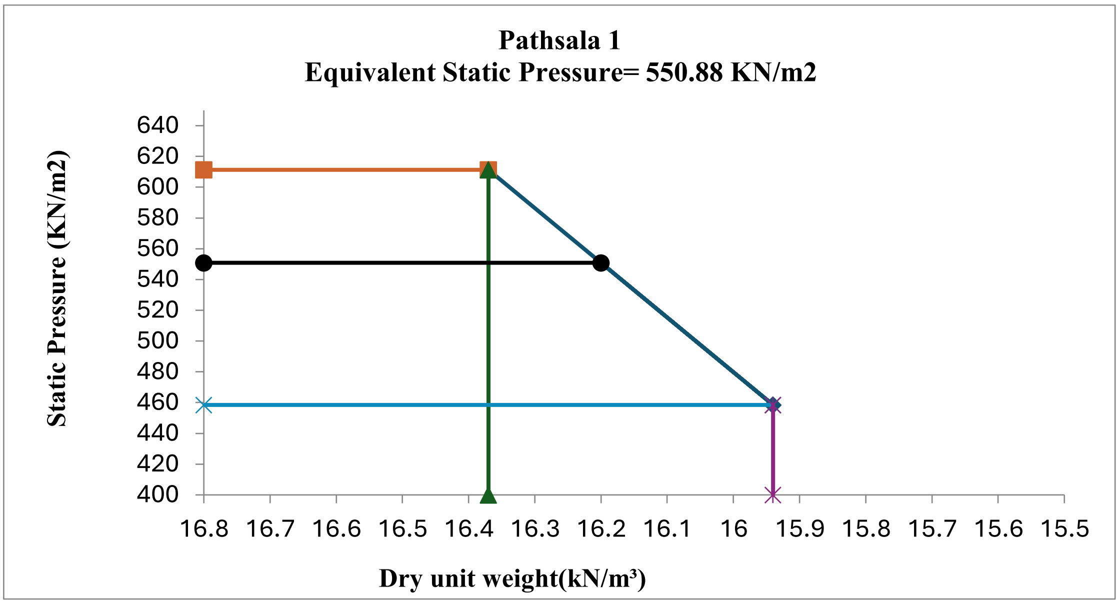

Fig4.15: Determination of Static Equivalent Pressure of Pathsala 1 sample (According to Standard Proctor)

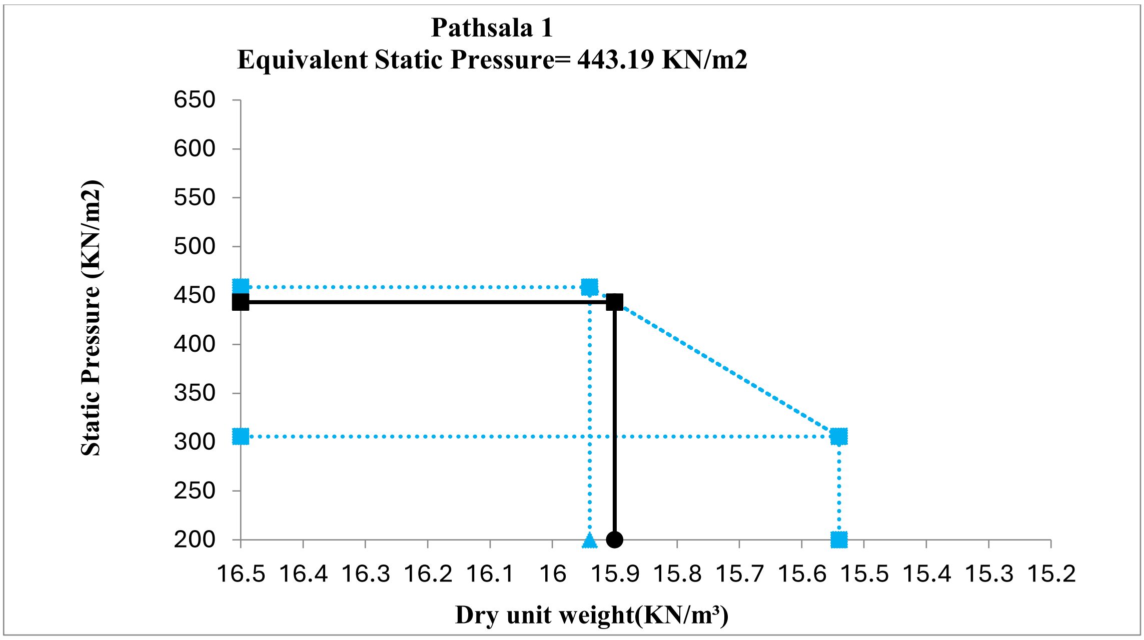

Fig4.16: Determination of Static Equivalent Pressure of Pathsala 1 sample (According to Reduced Standard Proctor)

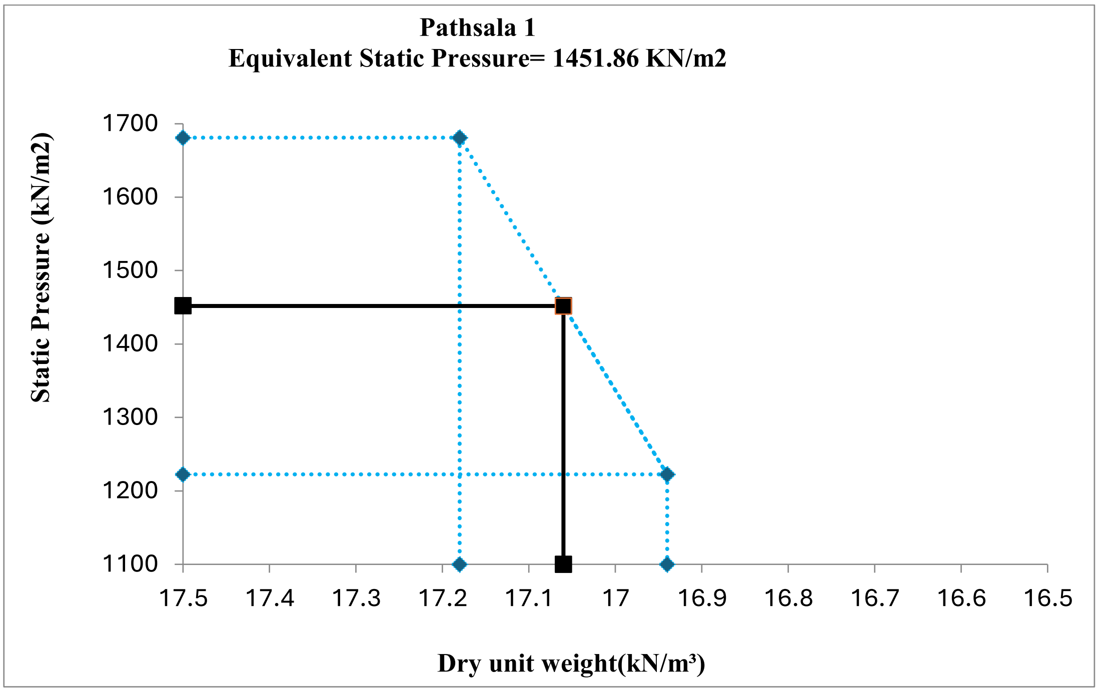

Fig4.17: Determination of Static Equivalent Pressure of Pathsala 1 sample (According to Reduced Modified Proctor)

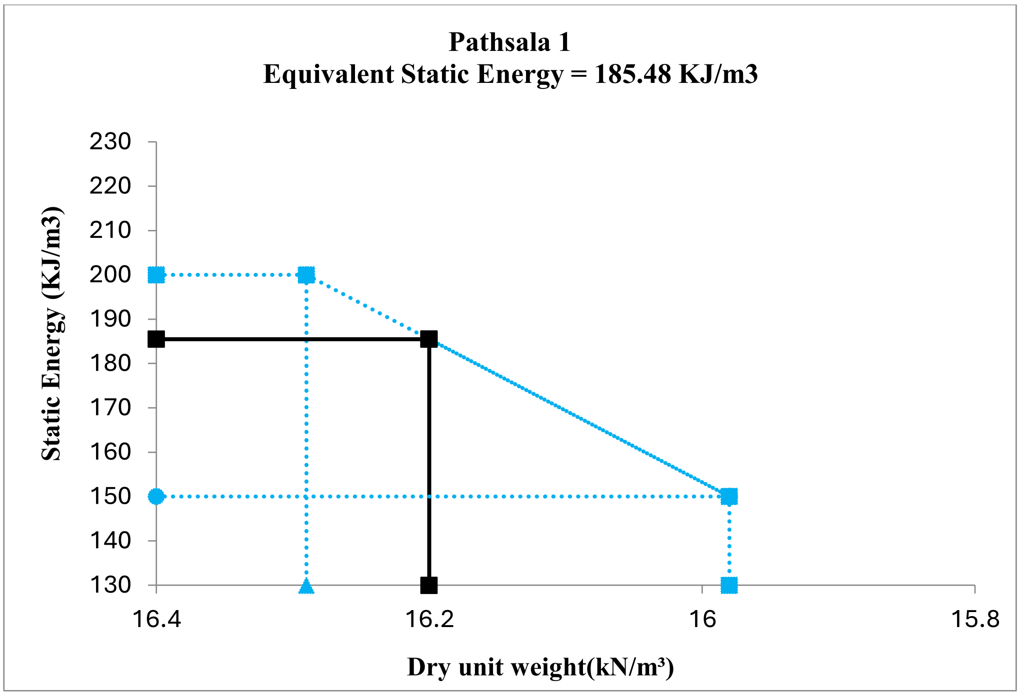

Fig4.18: Determination of Static Equivalent Energy of Pathsala 1 sample (According to Standard Proctor)

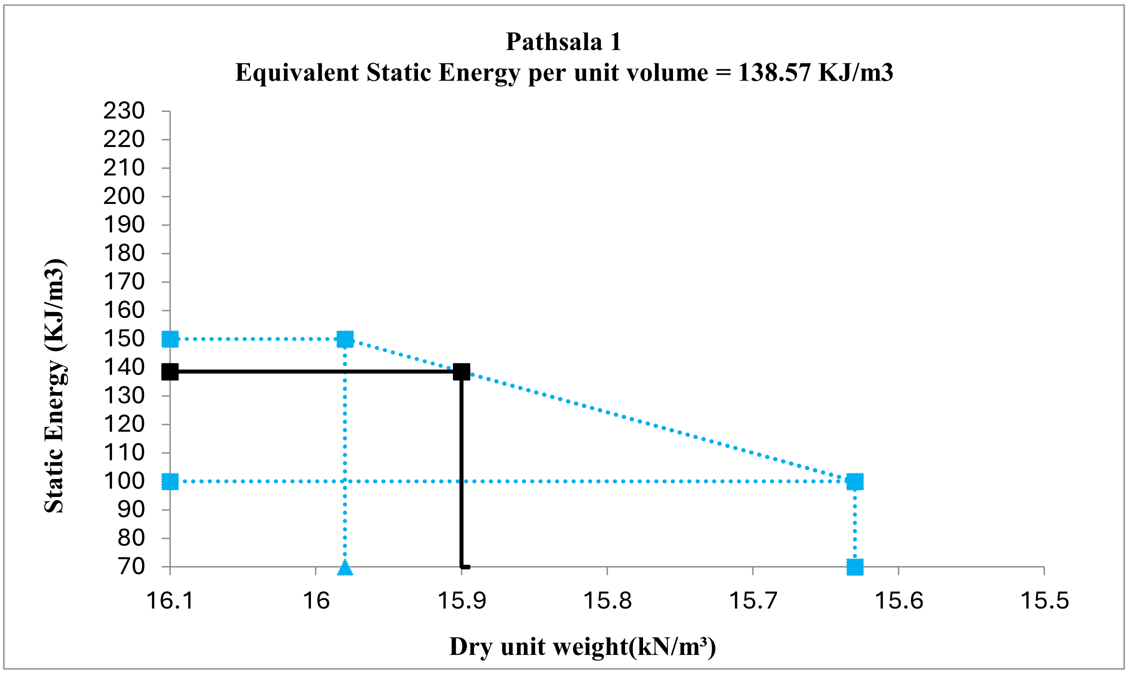

Fig4.19: Determination of Static Equivalent Energy of Pathsala 1 sample (According to Reduced Standard Proctor)

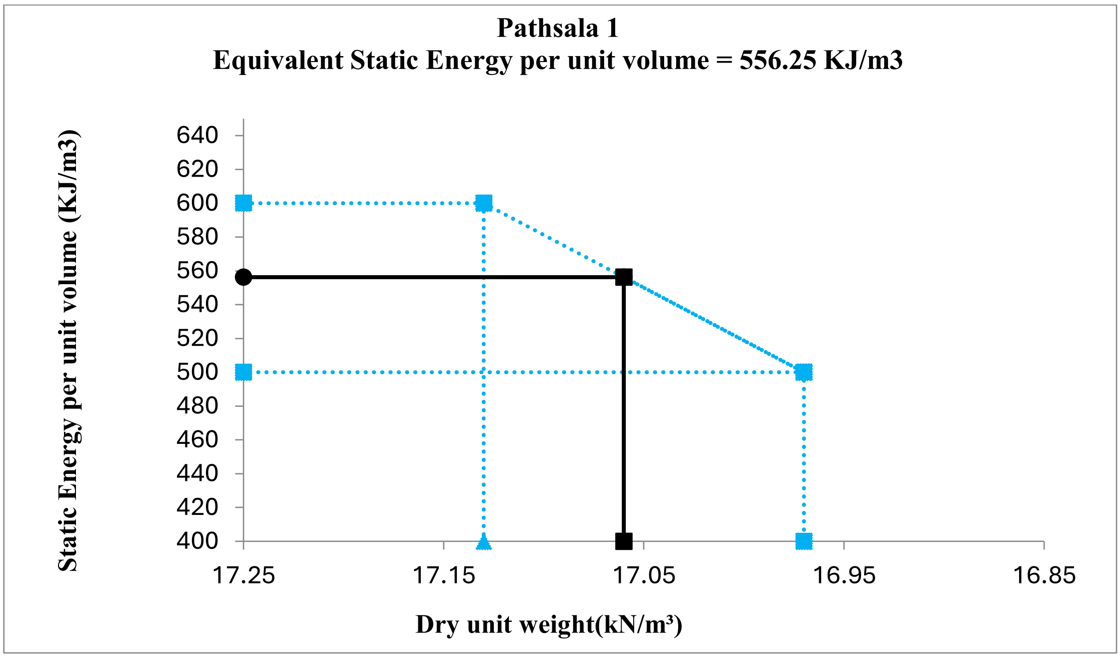

Fig4.20: Determination of Static Equivalent Energy of Pathsala 1 sample (According to Reduced Modified Proctor)

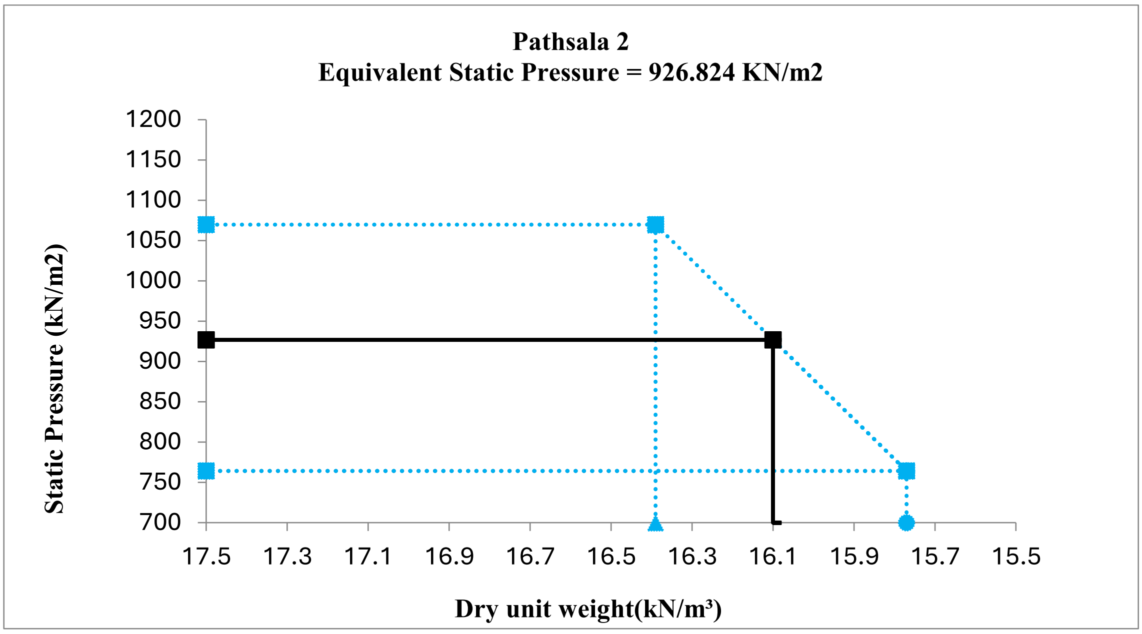

Fig4.21: Determination of Static Equivalent Pressure of Pathsala 2 sample (According to Standard Proctor)

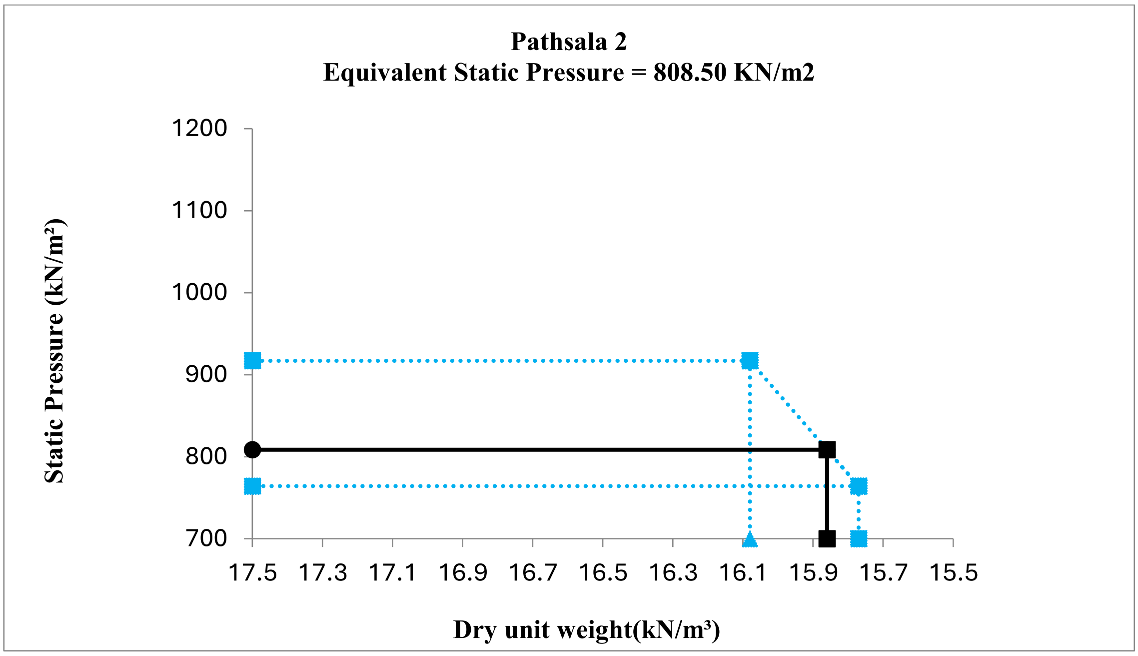

Fig4.22: Determination of Static Equivalent Pressure of Pathsala 2 sample (According to Reduced Standard Proctor)

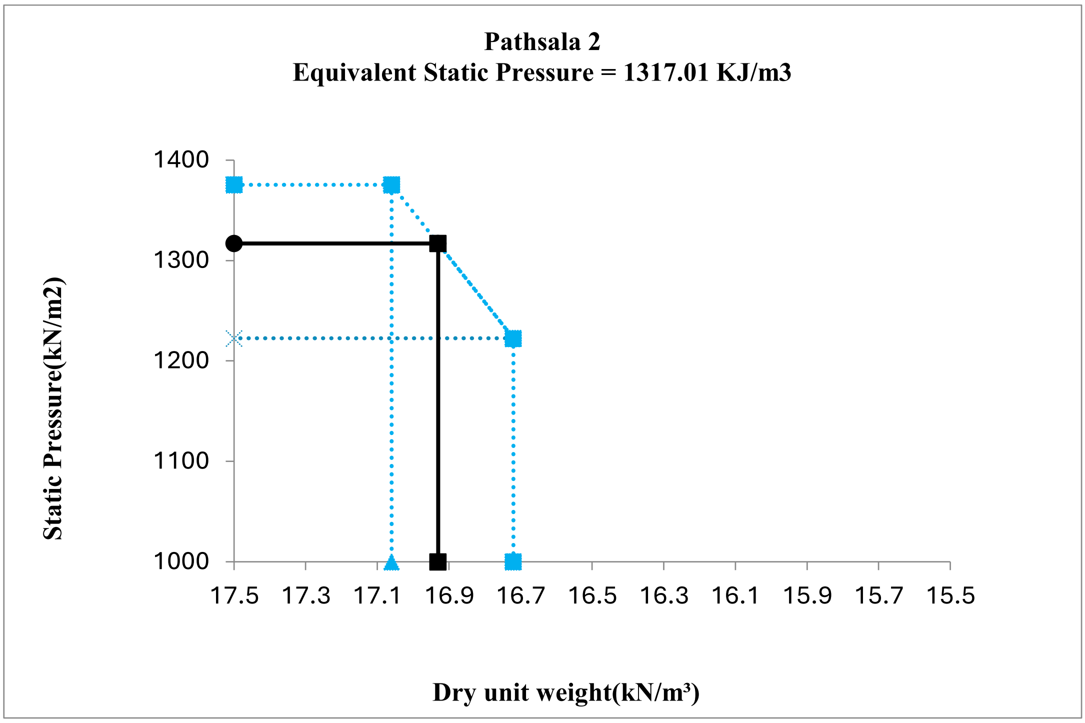

Fig4.23: Determination of Static Equivalent Pressure of Pathsala 2 sample (According to Reduced Modified Proctor)

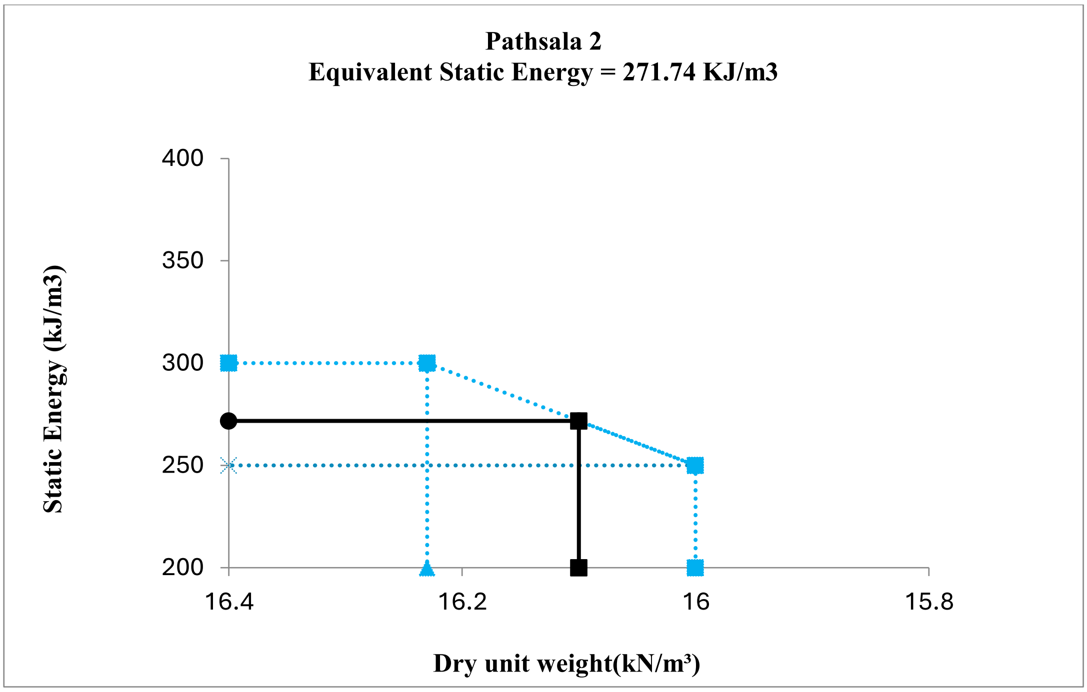

Fig4.24: Determination of Static Equivalent Energy of Pathsala 2 sample (According to Standard Proctor)

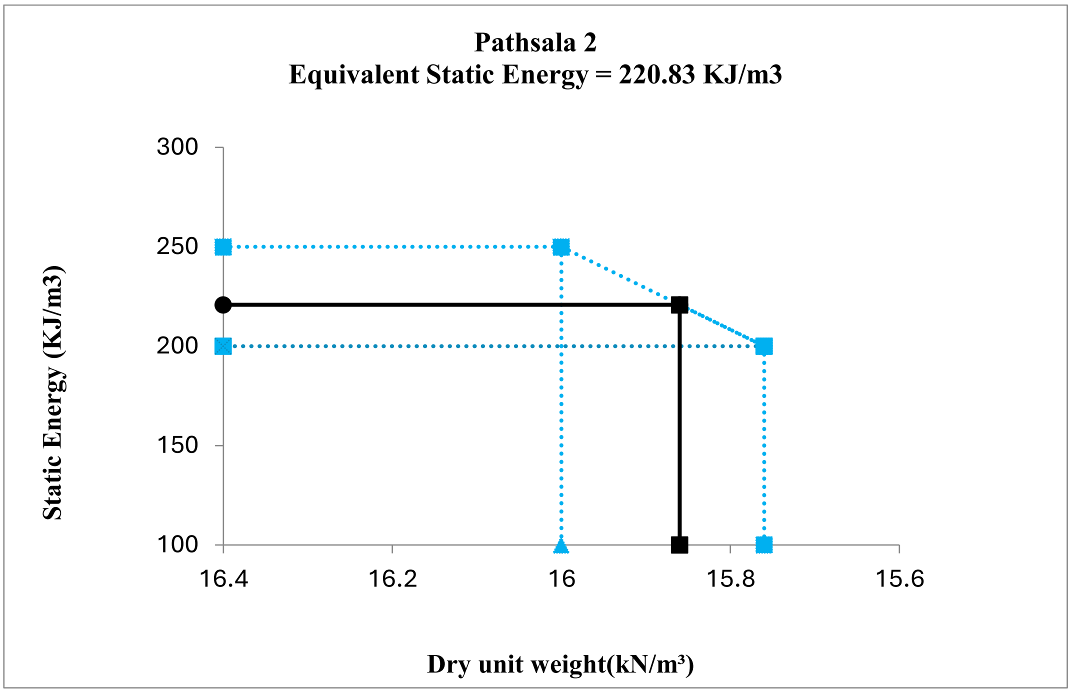

Fig4.25: Determination of Static Equivalent Energy of Pathsala 2 sample (According to Reduced Standard Proctor)

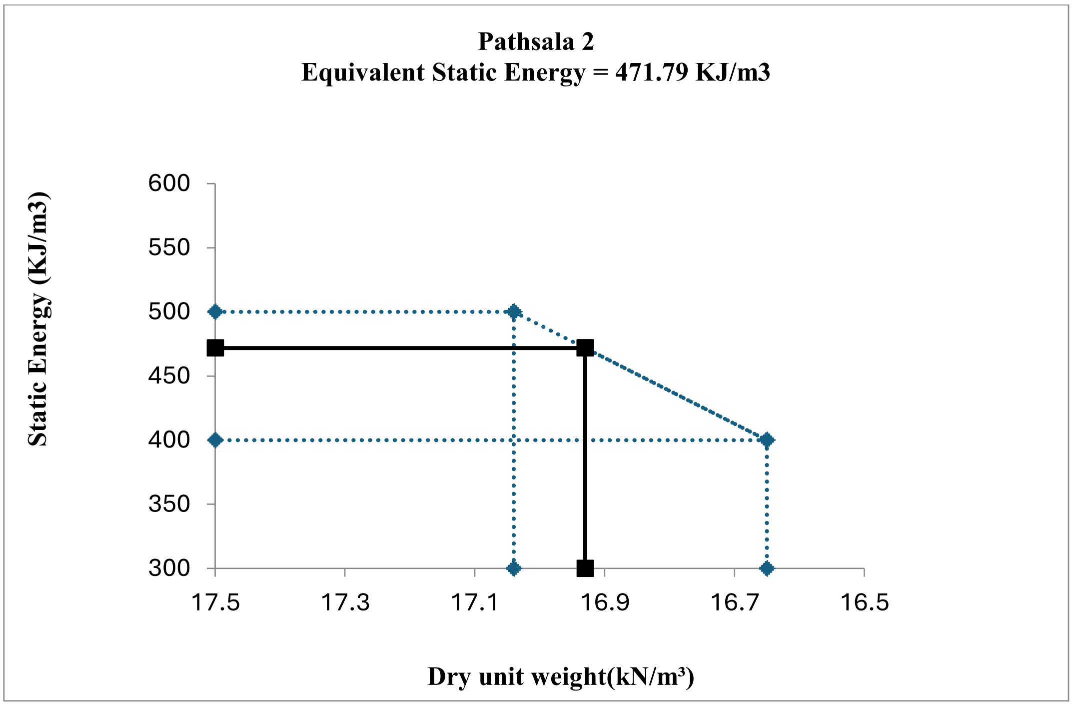

Fig4.26: Determination of Static Equivalent Energy of Pathsala 2 sample (According to Reduced Modified Proctor)

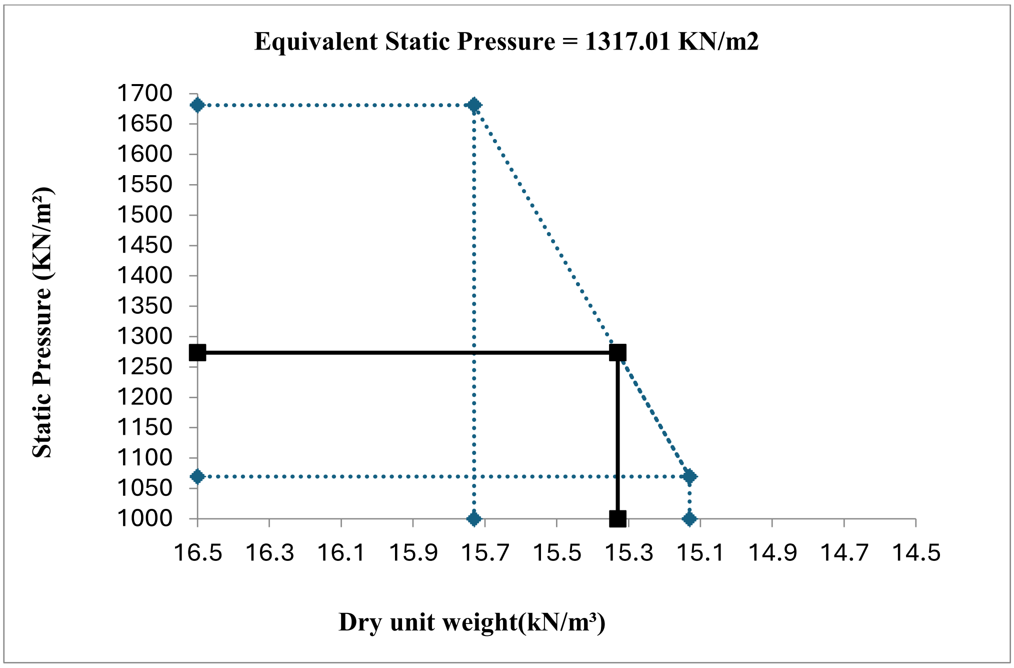

Fig4.27: Determination of Static Equivalent Pressure of Red Soil sample (According to Standard Proctor)

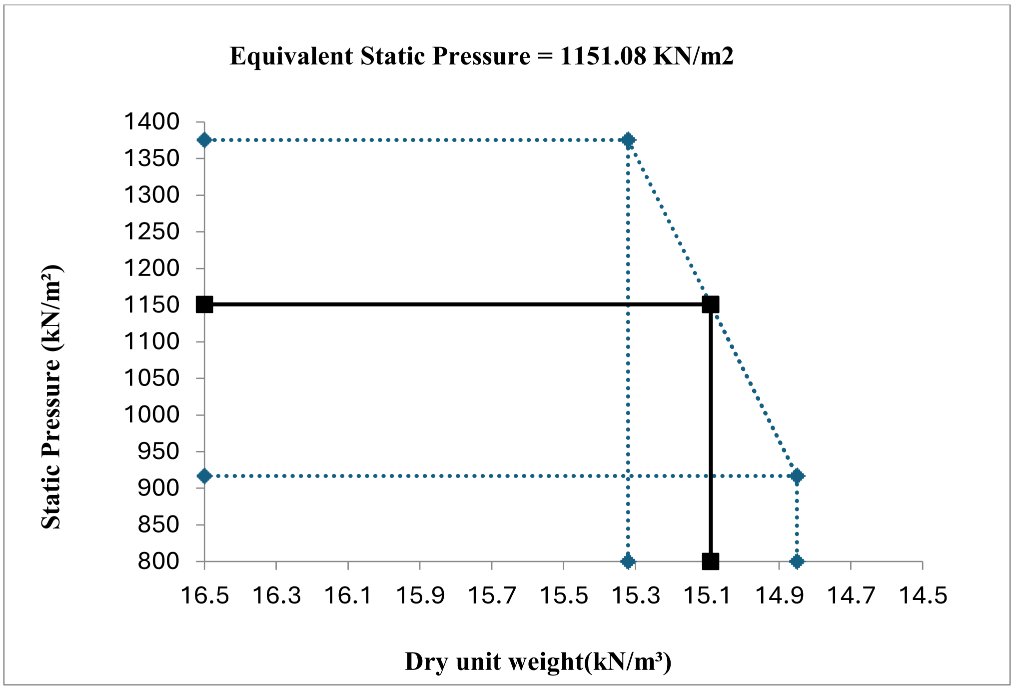

Fig4.28: Determination of Static Equivalent Pressure of Red Soil sample (According to Reduced Standard Proctor)

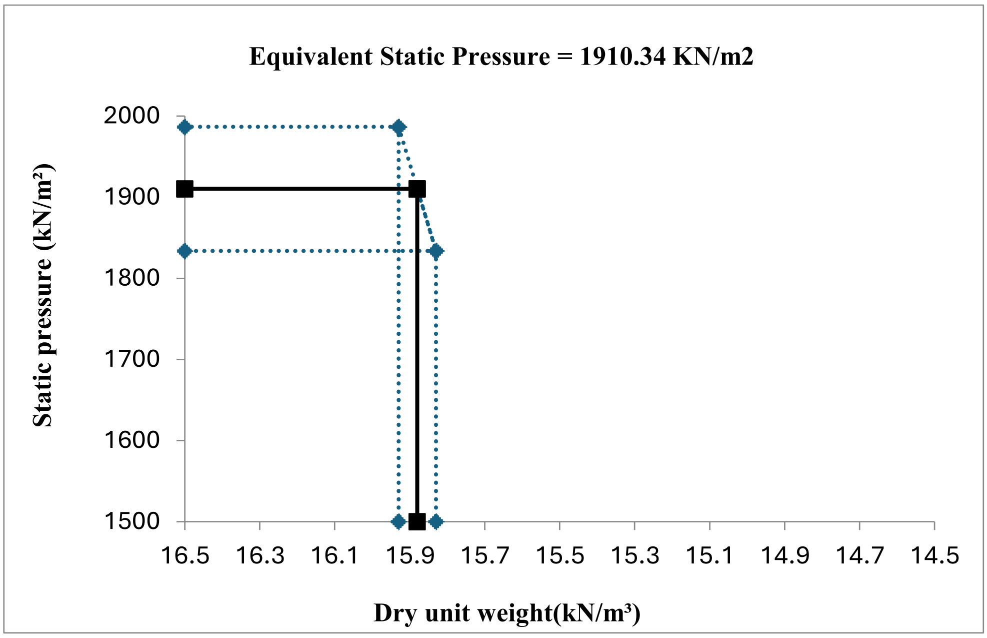

Fig4.29: Determination of Static Equivalent Pressure of Red Soil sample (According to Reduced Modified Proctor)

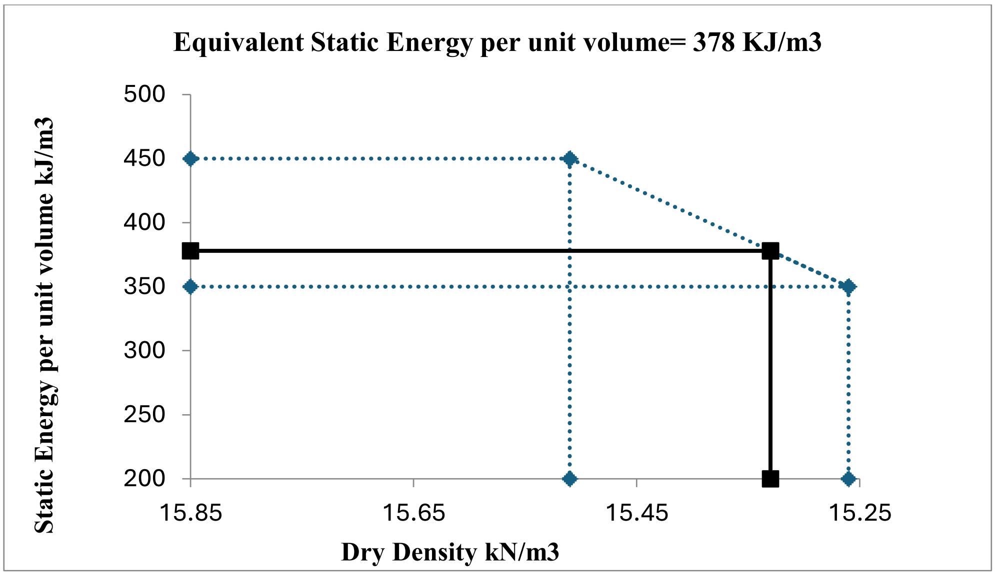

Fig4.30: Determination of Static Equivalent Energy of Red Soil sample (According to Standard Proctor)

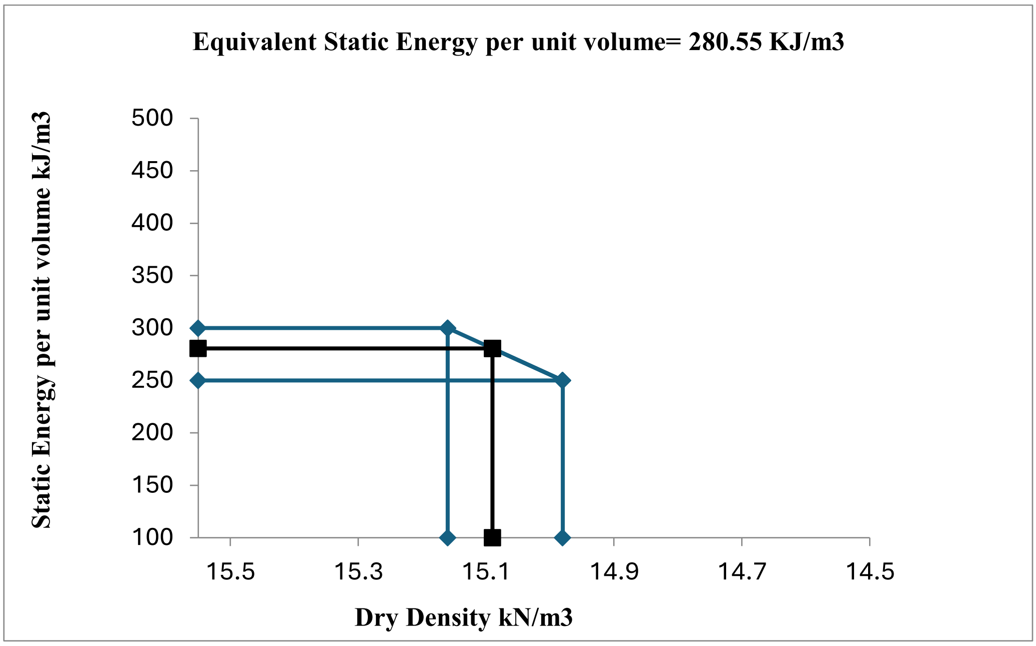

Fig4.31: Determination of Static Equivalent Energy of Red Soil sample (According to Reduced Standard Proctor)

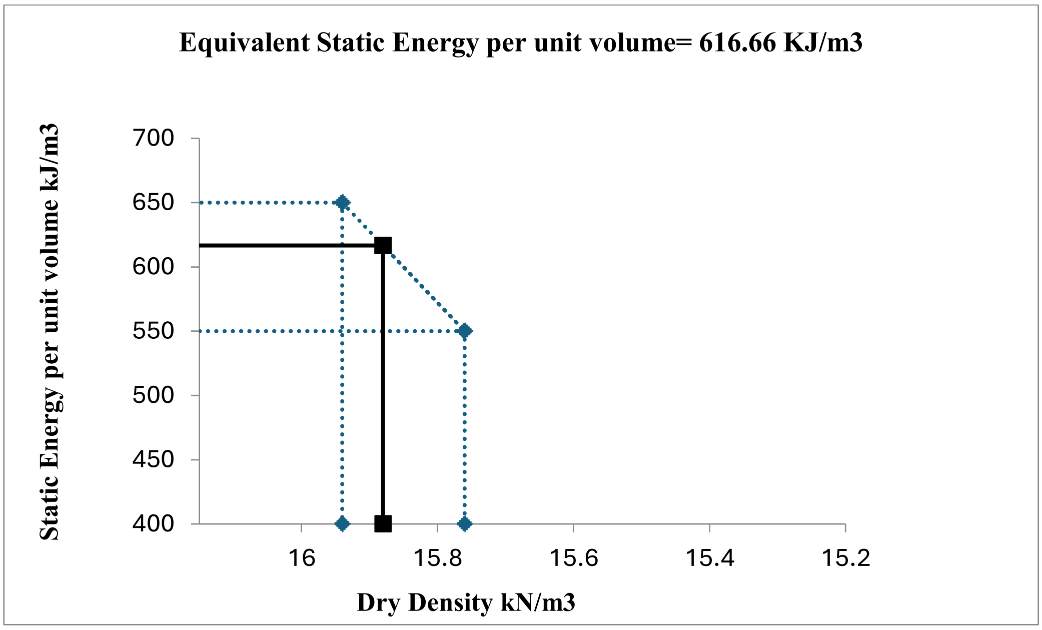

Fig4.32: Determination of Equivalent Static Energy of Red Soil sample (According to Reduced Modified Proctor)