ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES ADDIS

ABABA INSTITUTE OF THECHNOLOGY

DEPARPMENT OF CIVIL ENGINEERING

INVESTIGATING THE STRENGTH CHARACTERISTICS OF LATERITTIC SOIL BLENDED WITH MARBLE DUST

BY: BLEN ASSEFA

"A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in civil engineering (Geotechnical Engineering)"

ADVISOR: DR.ING. SAMUEL TADESSE

November, 2016

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Approved by Board of Examiners

Dr Samuel Tadesse	______________	______________
(Advisor)	Signature	Date
Dr Henok Fekrie	______________	______________
(External Examiner)	Signature	Date
Dr Messele Haile	______________	______________
(Internal Examiner)	Signature	Date
______________	______________	______________
(Chairman)	Signature	Date

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Acknowledgement

This study was conducted under the supervision of my Advisor Dr. Ing. Samuel Taddesse, Faculty of Technology, Addis Ababa University.

I would like to express my gratitude to my advisor Dr. Ing. Samuel Taddesse for his guidance and help throughout the study period.

I express my sincere gratitude to ERA for assisting me during the data collection and sampling.

Finally I would like to thank my family and friends for their encouragement throughout the study.

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Symbols and Abbreviations

Designation		Unit
AASHTO	American Association of State Highway & Transportation Officials	-
AD	Air drying	-
ASTM	American Society for Testing and Materials	-
CBR	California Bearing Ratio	%
LL	Liquid Limit	%
MDD	Maximum Dry Density	g/cm^3
NMC	Natural Moisture Content	%
OMC	Optimum Moisture Content	%
PI	Plasticity Index	%
PL	Plastic Limit	%
q_u	Unconfined Compressive Strength	kPa
UCS	Unconfined Compressive Strength	kPa
USCS	Unified Soil Classification System	-
ω	Moisture content	%

Abstract

The purpose of this study is to investigate the strength characteristics of a stabilized lateritic soil with marble dust. The sample of the residual lateritic soil used in the study is taken from Mekanejo area. The soil is classified as A-7-5 according to AASHTO classification. The material could possibly termed true laterite, since silica-sesquioxide ratio is Less than 1.33.

An attempt has been made in the study to improve the index and engineering properties of the lateritic soil by stabilization using an industrial waste, marble-dust. This method is both low-cost and ecofriendly. Accordingly, the lateritic soil was treated with marble-dust of 4%, 8%, 12%, 16% and 20% by dry weight of soil, and various tests have been carried out on the marble-stabilized soil to assess alterations in its strength characteristics.

The lateritic soil responded very well to the marble-dust treatment, as exhibited in improvement of its strength, and its increased resistance to softening by water.

20% marble dust is the optimum quantity in terms of improving plasticity index, maximum dry density and soaked and unsoaked CBR properties but for unconfined compressive value, the optimum marble dust content is 8%.

The addition of marble-dust to the lateritic soil has beneficial effects on its engineering properties, including reduction in plasticity, improved workability, increased strength, more resistance to moisture effect, and enhanced durability. Besides, a trial pavement design revealed that lateritic subgrade stabilization results in thinner pavement structures, and hence reduces costs of road construction.

CHAPTER 1: Introduction

1.1 GENERAL

Soil strength is the capacity of a soil to resist force without failure. We can determine the strength characteristics of a soil by conducting unconfined compressive strength test, California Bearing Ratio test and Compaction test. Three strengths are usually considered for a material: *compressive strength*, *tensile strength*, and *shear strength*. The tensile mode of failure does not often control the behavior of soils. All failures in soil mass are shear failures. It cannot withstand tension stress, and compression leads to shear. We interpret soil failure using *failure criteria* such as *Coulomb, Mohr–Coulomb, Tresca,* or *Taylor*.

In construction, a good quality material is required to support the imposed loads during usage and loads from construction equipment. This material has to support these superimposed loads without failure. Moreover, the selection of any construction material has to be economical in terms of availability.

Lateritic soils are important residual soils that have been used for road pavement construction in humid tropical and sub-tropical countries. In Ethiopia, lateritic gravels have been used as subgrade material, subbbase, and as gravel wearing course in low-volume unpaved roads in many parts of the country (for instance, in *Wollega*, *Arsi* and *Bale* regions). Lateritic gravels are also used as backfill material around drainage and earth-supporting structures.

Lateritic soils, especially those containing excess fines, are possibly weak in strength. If these soils are encountered in the subgrade, thicker pavement structures are needed. If the pavement structures are too thin for a particular class of subgrade (based on its CBR or resilient modulus), large permanent deformations accumulate over time and affect the performance of the pavement. For use in road works, lateritic soils may fall short to satisfy specification requirements, especially subbase or base material specification. Because lateritic material is cheap and abundantly available in tropical areas, its use as *in situ subgrade* (instead of undercutting, capping layer, etc.) or *subbase* (instead of select material or crushed rock) or *base* (instead of crushed rock), will significantly reduce construction costs.

To this end, a low-cost method of improving the mechanical behavior and strength of lateritic soils is desirable. It has been found that lateritic soils respond to cement stabilization and, in some cases, lime stabilization (Townsend F. C., 1985). However, both cement and lime stabilization methods are expensive. In this study, an assessment of strength of lateritic soil, treated with lime dust, which is a waste product from marble manufacturing, has been made. This method is both low-cost and ecofriendly.

As noted by InfraAfrica, Netterberg, CSIR (2014), despite its non-compliance with traditional specifications, lateritic material has been successfully used in the upper layers of both low and high-volume roads in a number of Southern and Eastern African countries, such as Angola, Botswana, Kenya, Malawi, Mozambique, Zambia and Zimbabwe. Thus, lateritic materials deserve further study, for wider use as subbase and base material of paved, low-volume roads.

Laterites and Lateritic Soils

Laterite is a group of highly weathered soils formed by concentration of hydrated oxides of iron and aluminum (Thagesen, 2004). The soil name laterite was coined from a Latin word ‘later’ meaning brick. Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine grained residual soil of light texture and cemented soils (Lamb & Whitman, 1979).

Most laterites are encountered in an already hardened state. When the laterite is exposed to air or dried out by lowering the ground water table, irreversible hardening occurs producing a material suitable for use as a building or road stone. The lateritic soils behave more like fine grained sands, gravels, and soft rocks. The laterite typically has a porous or vesicular appearance which may be self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel.

The behavior of laterite soils in pavement structure has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions (Gidigasu, 1976).

Well-graded laterite gravels perform satisfactorily as unbound road foundations. However, their tendency to be gap-graded with depleted sand-fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which may breakdown limits their usefulness as pavement materials on roads with heavy traffic (Thagesen, 2004).

Stabilization of Lateritic Soils

Well-graded laterite gravels perform satisfactorily as unbound road foundations. However, their tendency to be gap-graded with depleted sand-fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which may break down, limits their usefulness as pavement materials on roads with heavy traffic (Thagesen. 1996).

Studies have been trying to find practical results for the appropriate utilization of these locally available lateritic soils. In the recent past, some investigations have also been made on lateritic soils in order to utilize this local material in the building industry and highway construction.

OBJECTIVES OF THE RESEARCH

1.2.1 General Objective

The objective of this thesis work is to study the effect of marble dust on stabilization of lateritic soil on the strength characteristics. This study aims to assess the potential improvement in strength and decrease in plasticity of soils by application of marble dust at various curing durations.

1.2.2 Specific Objective

1. Make detailed investigation of index properties and classify the soil.
2. Investigate the effect of marble dust on strength characteristics of the soil sample taken from mekenajo area by conducting laboratory tests including Proctor test, California Bearing Ratio test and Unconfined Compression test.

1.2 METHODOLOGY

Sample preparation of the experimental work involved air drying and sieving of soil to the required particle size. Soil Classification was performed on the sample by conducting index property and grain size analysis tests in accordance with ASTM (American Society for Testing and Materials), known since 2001 as *ASTM International*, and AASHTO (American Association of State Highway and Transportation Officials). Index property tests conducted include moisture content determination, atterberg limit test, grain size analysis and Specific Gravity testing. The strength development of the soil was studied using California Bearing Ratio (CBR) test, Compaction test and Unconfined Compressive Strength test.

The lateritic soil was first tested and studied in its natural form and then again studied to see the change in the strength characteristics of the soil when treated with marble dust.

The natural soil was treated at mixing ratio of 0%, 4%, 8%, 12%, 16% and 20% of marble dust by dry weight of the soil and curing the samples at 7 and 14 days for all tests.

1.3 ORGANIZATION OF THE THESIS

The presentation of this thesis work is organized into eight chapters. The first chapter gives a brief introduction of the thesis, objectives, scope of the experimental program. The second chapter explains the origin, formation, classification, mineralogy and the different characteristics of residual soils. The third chapter discusses the need for stabilization and stabilization process briefly. The fourth chapter briefly describes the topography, location, climate, mineralogy and geology of the site where samples are taken from. The fifth chapter explains characterization of materials used for the study, experimental design and standardized testing procedures followed and reports the test results obtained. Discussion of test results with respect to the theoretical aspects and findings of previous studies is made in chapter six.

Finally, conclusions and recommendations drawn from the study are presented in chapter six. References and Appendix are presented at the end of the thesis.

CHAPTER 2: Literature Review

2.1 GENERAL

In many countries of Africa and Asia, lateritic soils are the traditional material for road and airfield construction. There has generally been very little discussion on the engineering behavior of laterites. The engineering investigations have been isolated studies. This has been due to the absence of uniform methods for the preparation of samples and testing and the variable nature of lateritic soils. As a consequence, the drawing of any rational conclusions on the engineering properties of lateritic soils has been very difficult.

The perusal of the available data on lateritic soils gives the impression that the red color seems to have been accepted by most authors as the most important property by which these soils could be identified. Other obviously significant basic physical properties such as texture, structure, consistency, etc., often were ignored. It is also noted that lack of uniformity in pretreatment and testing procedures (resulting from association with different standards in different parts of Africa) makes it difficult to compare even textural data on the same soils. It is noted that three major factors influence the engineering properties and field performance of lateritic soils. They are:

1) Soil forming factors (e.g. parent rock, climatic, vegetation conditions, topography and drainage conditions).
2) Degree of weathering (degree of laterization) and texture of soils, genetic soil type, the predominant clay mineral type and depth of sample.
3) Pretest treatments and laboratory test procedures as well as interpretation of test results (Lyon Associates Inc., 1971).

2.2 FORMATION OF LATERITIC SOILS

Laterite soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm, (usually in areas with a significant dry season) on a variety of different types of rocks with high iron content.

Laterite is a highly weathered material rich in secondary oxides of Iron, Aluminum or both. It is nearly void of bases and primary silicates but it may contain large amounts of quartz and kaolinite. It is either hard, or capable of hardening on exposure to wetting and drying (Alexander & Cady, 1962).

The laterisation process appears to take place in three stages. Initially, breakdown of primary rock-forming minerals occurs, and this results in the release or formation of clay minerals, mainly kaolinite, and constituent elements such as silica, Alumina, Iron Oxides and oxides of other elements' such as Calcium and Magnesium. In the second stage, the silica and alkalis (Calcium and Magnesium Oxides, among others) are leached and accumulation of sesquioxides takes place. Leaching occurs during the wet season due to infiltrating water and its extent depends on the pH of the ground water and drainage conditions (Gidigasu, 1976).

Iron is usually carried in ferrous form by the water. Ferrous ions are mobile until they are oxidized to Ferric ions. Following the dry season, evaporation leads to upward migration of ferrous ions and the opportunity for oxidation by atmospheric Oxygen. Iron then precipitates as hydrated Ferric oxide gel. Aluminium moves in solution until precipitated as an Alumina gel by dehydration or a change in pH (Umarany & Williams, 1990).

The Sesquioxides (hydrated Ferric oxide gel and Alumina gel) are adsorbed on the surfaces of the clay minerals. This adsorption occurs through the interaction of positively charged Sesquioxides and negatively charged clay particles (Townsend, Phillip, & Parcher, 1969). At the third stage, partial or complete dehydration of hydrated colloidal Sesquioxides occurs. Dehydration is accompanied by crystallisation of amorphous iron colloids into dense crystalline forms in the sequence of Limonite, Goethite, and Haematite. This is accompanied by a change in colour from yellow or yellow-brown to red. Gelatinous, free Iron oxide first coats the soil particles, exerting a cementing effect upon the clay, silt and sand size fractions. On dehydration, larger particles and nodules are formed (Gidigasu, 1972).

The hardening process has been explained by Humbert (1948) from field observations and microscopic studies. Initially, the soil has a large specific surface area, reflected by the amount of absorbed water present. On dehydration, the amorphous iron oxide loses its water and changes to the crystalline form resulting in high liquid limit. Terzaghi explained this anomalous behavior by assuming that the clay existed in clusters of interconnected clay particles. The clay was considered strongly aggregated, a state unlikely to change during construction.

The aggregating effect of the Iron oxide in the Sasumua clay was later demonstrated by Newill (1961). He removed the iron chemically and found the clay aggregations had been dispersed. These did not reform as had been the case after mechanical manipulation. The Atterberg Limits were determined before and after chemically removing the free iron oxide. The liquid limit and plasticity index increased considerably.

The dehydration of other clay materials also causes changes in properties. Variations in the values of maximum density tests depend on whether the tests were performed after air drying or without air drying, or by determining the points backward along the moisture-density curve as the soil dries. In well-drained soils, therefore, the resulting residual soils often have characteristically high contents of aluminum and Iron oxides and a loss of Silica and bases from leaching which is referred to as laterization these highly weathered tropical materials may irreversibly change properties when dried, and even simply remolding the material may cause significant change in properties.

This irreversible change in engineering properties on drying or remolding means conventional laboratory testing that relies on disturbed bulk sampling and usually oven-dried material before testing will give erroneous estimates of in-situ properties. Consequently, laboratory testing procedures, specifications, and construction techniques based on temperate climate experiences the need of modification for lateritic materials. The self-hardening properties that some lateritic materials possess are probably too difficult to reliably ascertain and use for most engineering purposes.

As a part of the lateritic weathering process, deposits containing hardened sand and gravel size particles or even massive hardened boulders or extensive rock may form. These lateritic gravel particles or rock are cemented by various Iron and sometimes Aluminum oxide and hydroxide weathering products. These may provide a useful or even the only source of construction aggregate in some areas. Conditions favoring their formation include:

1) Parent materials rich in Iron and Aluminum bearing minerals and prone to reasonably rapid weathering (e.g., Basalts or Granodiorites).
2) Warm climate with alternating wet and dry seasons.
3) Topography that provides a well-drained regime that aids leaching.
4) The Quartz content of the parent rock. Where Quartz is a substantial component of the original rock, it may remain as Quartz grains.

Hence, *lateritic gravels* tend to be found on slopes (also commonly referred to as *ridge gravels*), to a lesser extent on uplands and not in low poorly drained areas. Laterite gravels are an important source of pavement construction materials in many parts of the world (Sharp, et al., 2001).

Based on the above discussion, the three major processes responsible for the formation of laterites can therefore be summarized as follows:

Decomposition: physico-chemical breakdown of primary minerals and the release of constituent elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, etc), which appear in simple ionic forms.

Laterization: leaching under appropriate conditions, of combined silica and bases and the relative accumulation or enrichment of Oxides and Hydroxides of Sesquioxides (Fe_2O_3, Al_2O_3, and TiO_2). The soil conditions under which the various elements are rendered soluble and removed through leaching or combination with other substances depend mainly on the pH of the ground water and the drainage conditions.

The level to which the second stage is carried depends on the nature and the extent of the chemical weathering of the primary minerals. Under conditions of low chemical and soil-forming activity, the physico-chemical weathering does not continue beyond the clay-forming stage, and tends to produce end products consisting of clay minerals predominantly represented by Kaolinite and occasionally by hydrated or hydrous oxides of Iron and Aluminium.

Desiccation: desiccation or dehydration involves partial or complete dehydration (sometimes involving hardening) of the Sesquioxide rich materials and secondary minerals. The dehydration of colloidal hydrated Iron oxide involves loss of water and the concentration and crystallization of the amorphous Iron colloids into dense crystals, in the sequence; Limonite, Goethite with Hematite to Hematite (Hamilton, 1964).

Dehydration may be caused by climatic changes, upheaval of the land, or may also be induced by human activities, for example by clearing of forests.

Under conditions favorable to tropical weathering, the weathering processes may be so intense and may continue so long that even the clay minerals, which are primarily hydrous aluminum silicates, are destroyed; in the continued weathering the silica is leached and the remainder consists merely of aluminum oxide such as gibbsite, or of hydrous iron oxide such as limonite or goethite derived from the iron. This process is known as laterization. The extent to which a residual soil has been laterized may be measured by the ratio of silica, SiO_2, remaining in the soil to the amount of Fe_20_3 and Al_20_3 that has accumulated (Lyon Associates Inc., 1971).

As far as the chemical characteristic is concerned, lateritic soils exist in various stages of weathering (laterization, desiccation and decomposition) which is known to have profound influence on their geotechnical properties. Silica has got a chemical formula of SiO_2 and Sesquioxide is a combination of Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3), designated as R_2O_3.

Accordingly, if the ratio, R, of Silica/ Sesquioxide is less than or equal to 1.33, this indicates true laterites. If $1.33 < R < 2$ then the soil is said to be lateritic. Non-laterites have a ratio of $R > 2$. (Lyon Associates Inc., 1971; Hunt, 2005).

2.3 CHEMICAL AND MINERALOGICAL CHARACTERISTICS

A distinctive feature of laterite and lateritic soils is the higher proportion of sesquioxides of iron and/or aluminum relative to the other chemical components. The amount of alumina or iron oxides is an important factor in differentiating aluminous and ferruginous varieties. The base other common lateritic constituents are manganese, titanium, and chromium oxides. Chemical analyses do not usually reveal the origin, nature or even the composition of laterites or lateritic soils. For example, physically similar laterites may have different chemical composition and chemically similar laterites may display different physical properties (Maignien, 1966).

The mineralogical composition is considered to be more important in explaining the physical properties of indurate laterite and lateritic soil. Maignien (1966) has divided the mineralogical constituents into major elements, which are essential to laterization, and minor elements which do not affect the laterization process. The major constituents are oxides and hydroxides of aluminum and iron, with clay minerals and, to a lesser extent, manganese, titanium and silica.

The clay mineral most common in lateritic soils is kaolinite. Illite and montmorillonite are rare. A study of some unpublished information and results of analyses at the Ghana Geological Survey Department indicate that due to intense chemical weathering processes almost all the unstable primary minerals are either partially or completely broken down and transformed into secondary minerals. The most common primary minerals encountered are quartz, mica (muscovite) feldspar (microcline) and hornblende. The particular mineral available depends upon the parent rock type. The chief clay mineral generally observed is kaolinite, with some mica, sericite and illite. The secondary minerals resulting mainly from the laterization processes are gibbsite, goethite, limonite and hematite. Neither manganese nor titanium minerals were observed in significant amounts (Lyon Associates Inc., 1971).

2.4 PHYSICAL AND ENGINEERING PROPERTIES

Texture

Experience with soils in stable temperate zones has revealed that particle-size distribution exerts great influence on the engineering properties of soils. It is also one of the most important properties by which soils can be easily identified and classified on the basis of simple field and laboratory tests. Consequently great importance has also been accorded to particle-size distribution in dealing with lateritic soils an interesting lithological classification of lateritic soils as follows:

Lateritic clays <0.002 mm

Lateritic silts =0.002 - 0.06 mm

Lateritic sands =0.06- 2 mm

Lateritic gravel =2 - 60 mm

Laterite stones and cuirasse > 60 mm

One of the main characteristics of lateritic gravels and gravelly soils is the high content of fines. Studies on lateritic gravels by de Graft-Johnson et al. (1969) among others, have shown that the grading, though important for identification purposes, cannot alone form the basis for grouping lateritic gravels in terms of mechanical properties. The strength of the aggregates was found to be an important factor. On the basis of studies of lateritic aggregates in Nigeria, Ackroyd (1960) distinguished hard, medium and weak lateritic gravels. It was also established that the strength of the aggregates is mainly a function of the degree of maturity of the lateritic concretionary particles and the predominant sesquioxide in the aggregates.

Structure

One major characteristic of all soils which influences other engineer properties is the structure. By virtue of the processes of laterization, lateritic soils have acquired peculiar structural characteristics. Lateritic soils may be on the whole more concretionary than most temperate zone soils. The concretionary nature of the lateritic soils may be explained in terms of their genesis.

The available literature on the genesis of lateritic soils has emphasized the physical (hardening) and mineralogical aspects of the laterization processes, but has almost completely ignored the physico-chemical aspects which involves the coating of the soil particles by iron oxide and alumina. The soil particles later coagulate into large clusters with subsequent reduction of specific surface. It seems that much of the differences between temperate-zone and lateritic soils may be explained on the basis of this coating and coagulation of the soil particles.

2.4 CLASSIFICATION OF RESIDUAL SOILS

Special classification system is required for residual soils because of the following:

1) Unusual clay mineralogy of some tropical and subtropical soils.
2) The soil mass in situ may display a sequence of material ranging from true soil to soft rock depending on degree of weathering.
3) Conventional soil classification systems focus primarily on the properties of the soil in its remolded state.

The first step in the grouping of residual soils is to divide them into groups on the basis of mineralogical composition alone, without referring to their undisturbed state. The following three groups are often suggested (Wesley, 2010):

I. **Group A:** Soils without a strong mineralogical influence, e.g., Saprolites (Residual soil with clear structural feature inherited from its parent rock).
II. **Group B:** Soils with a strong mineralogical influence deriving from clay minerals, example of this group are Black Cotton Soils.

III. **Group C:** Residual Soils strongly influenced by special clay Minerals not found in Sedimentary Soils. The most important minerals in this group are: Halloysite soils, Allophane soils, and Sesquioxides.

Group C can be classified into the following sub-groups (Wesley, 2010):

A) Halloysite soils: The principal influence of halloysite appears to be that the engineering properties of the soil are good, despite a high clay fraction, and fairly high values of natural water content in terms of Atterberg Limits.

B) Allophanic soils: Allophanic soils are probably the most distinctive of all residual soils due to the very unusual properties of the amorphous mineral Allophane. Allophane soils have a natural moisture content ranging from about 80% to 250%, but which still perform satisfactorily as a construction material. They are frequently much superior to soils with water contents only a fraction of the above values.

C) Soils Influenced by the presence of Sesquioxides: The principal role of sesquioxides appears to act as cementing agents, which bind the other mineral constituents in to clusters or aggregations. With sufficient concentration of sesquioxides, the hard concretionary material called laterite will be formed. This sub groups perhaps be termed as Lateritic group.

Generally, classification of laterites is also possible according to its genesis basis and size of particle. Besides the suggested grouping system presented, an additional item of formation which is usually of major importance in influencing the properties of residual tropical soils is the type of the parent rock and should always be included in the grouping processes. It was found during the recent study that most of the tropically weathered soils of Africa could be divided in to three groups on a genetic basis, determined by the soil-forming factors.

The three major groups of significance have been defined by D'hoore (1964) (Lyon Associates Inc., 1971). These are:

i) Ferruginous Soils: These occur in extremely arid conditions for lateritic soils, in areas with pronounced dry seasons. Ferruginous soils are common they are hard and durable. Marked separation of iron oxide is frequently observed which may be leached or precipitated with the profile. Kaolinite is the predominant clay mineral in this type. It requires an average annual rainfall of 600-1800mm for its formation.

ii) Ferralitic soils: These occur in more humid areas for lateritic soils and in areas with dense vegetation cover. Gibsite is the most common clay mineral observed and other hydrated forms of alumina occur as well as hydrated iron minerals. Halloysite is fairly common over volcanic rocks. The annual average rainfall requirement for its formation is 1500- 4000mm. Both of the above soils are classified either as lateritic or laterite soils.

iii) Ferralsols: These are formed over all types of rocks in intermediate to high rainfall areas where erosion has kept the place with profile development. They have similar profiles to ferralitic soils, but with few weatherable minerals remaining. The entire clay fraction comprises Kaolinite and amorphous oxides of iron and aluminum. These are developed at deeper levels due to the surface erosion, and occur in regions of annual average rainfall of 1250-2750mm. According to Morin W.J. and Todor P.C., Ethiopian laterites fall under this group (Blight, 1997). Moreover, based on soil forming factors, climate, topography, vegetation and parent rock, tropical soils may be classified as Latosols, Andosols and Saprolites in addition to the above three groups (Lyon Associates Inc., 1971).

I) Latosols and Andosols: These are generally formed from weathering of volcanic rocks under humid tropical conditions. Halloysite and Allophane are common clay minerals and these soils have usually high moisture content.

II) Saprolite soils: They are residual soils with clear structural features inherited from its parent rock. These soils have fragial character in grain size and the bond could be strongly affected when pulverizing**.** Moreover, (Anthony Young, 1976), (Lyon, 1997) has distinguished the following main types and sub-divisions of laterite:

1) Massive laterite: Possesses a continuous hard fabric, subdivided in to:

(a) Cellular laterite: - with cavities approximately rounded.

(b) Vascular laterite: - With cavities approximately tubular.

2) Nodular laterite: - Consists of individual particles approximately rounded (also called Pisolithic laterite) subdivided in to:

(a) Cemented nodular laterite: Individual concretions can be seen but are strongly joined together by the same iron stone material.

(b) Partially cemented nodular laterite.

(c) Non-cemented nodular laterite: Concretions from over 60 percent by weight of the total soil.

(d) Iron concretions: Are separated by soil-but forms less than 60 percent by weight of the total horizon.

3) Recemented laterite: This contains fragments of massive laterite or ferrugnized rock, broken and wholly or partly cemented.

4) Ferruginized rock: Here, rock structure is still visible, but with substantial isomorphous replacement by iron.

5) Soft laterite: Mottled iron-rich clay, which hardens irreversibly on exposure to air to, repeated wetting and drying.

2.6 STABLIZATION

2.6.1 THE NEED FOR SOIL STABILIZATION

Certain residual soils are unsuitable for construction because of inadequate strength or excessive change of volume with varying water content or because of loss of strength on wetting (Blight, 1997).

Soil stabilization aims at improving the soil strength and increase the soil resistance to softening by water by bonding the soil particles together, water proofing the soil or combination of the two (Sherwood, 1993).

Many natural materials can be stabilized to make them suitable for road pavements but this process is only economical when the cost of overcoming a deficiency in one material is less than the cost of importing another material which is satisfactory without stabilization (TRL, 1993).

According to TRL (1993) stabilization can enhance the properties of road materials and pavement layers in the following ways:

- A substantial proportion of their strength is retained when they become saturated with water.
- Surface deflections are reduced.
- Resistance to erosion is increased.
- Materials in the supporting layer cannot contaminate the stabilized layer.
- The effective elastic moduli of granular layers constructed above stabilized layers are increased.
- Lime-stabilized material is suitable for use as a capping layer or working platform when the in situ material is excessively wet or weak and removal is not economical.

Stabilization is a process by which the property of soils are improved so as to meets the construction requirement. Soil stabilization may be broadly classified as chemical and mechanical stabilization (Teferra & Leikun, 1999).

2.6.2 MECHANICAL STABILIZATION

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil (Molenaar, 2005). (These include compaction, excavation and replacement and mixing of different soils.

2.6.3 CHEMICAL STABILIZATION

In chemical stabilization soil is stabilized by adding different chemicals or other materials. In this category, soil stabilization depends mainly on chemical reactions between stabilizer and soil mineral to achieve the desired effect (Makusa, 2012).

Soil improvement by chemical stabilization can be grouped in to three chemical reactions: cation exchange, flocculation-agglomeration, and pozzolanic reaction.

2.6.3.a Cation Exchange

The excess of ions of opposite charge (to those of the surface) over those of like charge present in the diffused double layer are called exchangeable ions. These ions can be replaced by a group of different ions having the same total charge by altering the chemical composition of the equilibrium electrolyte solution (Winterkorn & Pamukcu, 1990).

Negatively charged clay particles absorb cations of specific type and amount. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of hydrated ions becomes very important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations.

A typical replaceability series is

$Na^{+}<Li^{+}<K^{+}<Rb^{+}<Cs^{2+}<Mg^{2+}<Ca^{2+}<Ba^{2+}<Cu^{2+}<Al^{3+}<Fe^{3+}<Th^{4+}$

Na^{+} up to Rb^{+} ions have the same valance therefore replaceability depends on the size of hydration ion so Rb^{+} is larger ion than Na^{+} that means Rb^{+} has larger replaceability potential and when comparing Na^{+} to Th^{4+} because Th^{4+} is higher balance cation than Na^{+} replaceaility potential of Th^{4+} is higher than Na^{+}.

example of the cation exchange

$Ca^{2+} + Na^{+}clay \rightarrow Ca^{2+}\ clay + (Na^{+})$

The above example shows lower valance cation that is Na^{+} is replaced by higher valance cation Ca^{2+}.

2.6.3.b Flocculation and Agglomeration

Cation exchange reactions result in the flocculation and agglomeration of the soil particles with consequent reaction in the amount of clay size materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity (Terzaghi, Peck, & Mesri, 1996). Due to change in texture, a significant reduction in the swelling of the soil occurs.

2.6.3.c Pozzolanic Reaction

Time dependent pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil particles (Show et al., 2003). Pozzolanic constituents produce calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{2+} + 2(OH)^{-} + SiO_2$ (Clay Silica) $\rightarrow$ CSH

$Ca^{2+} + 2(OH)^{-} + Al_2O_3$ (Clay Alumina) $\rightarrow$ CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure; thus, strength of the soil increases (Sivapullaiah, 2006).

Marble has high lime (CaO) content. Thus, stabilization characteristics of marble dust is mainly due to their high lime (CaO) content (Onur, 2009).

2.6.4 LIME STABILIZATION

The addition of lime to reactive fine-grained soils has beneficial effects on their engineering properties, including reduction in plasticity and swells potential, improved workability, increased strength and stiffness, and enhanced durability. In addition, lime has been used to improve the strength and stiffness properties of unbound base and sub base materials.

The percentage of lime used for any project depends on the type of soil being stabilized. The determination of the quantity of lime is usually based on an analysis of the effect that different lime percentages have on the reduction of plasticity and the increase in strength of the soil. However, most fine-grained soil can be effectively stabilized with 3% -10% of lime, based on the dry weight of the soil. Lime is used extensively to change the engineering properties of fine-grained soils and the fine-grained fractions of more granular soils. It is most effective in treating plastic clays capable of holding large amounts of water. The particles of such clays have highly negative-charged surfaces that attract free cations (i.e., positive charged ions) and water dipoles. The addition of lime to a fine-grained soil in the presence of water initiates several reactions. The two primary reactions, cation exchange and flocculation agglomeration, take place rapidly and produce immediate improvements in soil plasticity, workability, uncured strength, and load-deformation properties (Amu, Bamisaye, & Komolafe, 2011).

The effects of lime treatment or stabilization on pertinent soil properties can be classified as immediate and long-term. Immediate modification effects are achieved without curing and are of interest primarily during the construction stage. They are attributed to the cation exchange and flocculation–agglomeration reactions that take place when lime is mixed with soil. Long-term stabilization effects take place during and after curing, and are important from a strength and durability standpoint. While these effects are generated to an extent by cation exchange and flocculation–agglomeration, they are primarily the result of pozzolanic strength gain (Mallela, Quintus, & Smith, 2004).

2.7 PREVIOUS SIMILAR WORKS

To effectively use lateritic soil for construction works different studies have been made and are discussed below.

Lasisi (1977) reported that about 10% of cement will be needed to stabilize lateritic soils to produce blocks of the same order of magnitude of strength as for sandcrete blocks for use as masonry units in building construction. Ola (1978) also worked with cement, lime and bitumen-stabilized lateritic soils and found that these stabilized soils could be used as base and sub-base materials in highway construction. Akinmusuru (1981) investigated the crushing strength of fiber-reinforced earth blocks made from lateritic soil with pieces of locally available fiber. Lasisi (1984) worked on cement-stabilized lateritic soils to further classify the usefulness and limitations of lateritic soils. All these studies have been trying to find practical results for the appropriate utilization of these locally available lateritic soils.

Recent works includes the studies of Goswami and Mahanta (2006) entitled 'Leaching characteristics of residual lateritic soils stabilized with fly ash and lime for geotechnical applications' also Umar, Alhassan, Abdulfatah and Idris (2013) studied 'Beneficial use of Class-C Fly Ash in Improving Marginal Lateritic Soils for Road Construction'. And Amu, Bamisaye, & Komolafe, (2011) did a reaserch intitled 'The sutablity and lime stabilizatio requiremet of some lateritic soil sample as pavement ' and showed the addition of lime to the samples caused a reduction in the plasticty index of the samples.

CHAPTER 3: Site Description - Location, Topography, Climate and Geology

3.1 LOCATION AND TOPOGRAPHY

Where the samples were taken from, is located in the west Wollega Zone, in the Western part of the Oromia National Regional State.

West Wollega Zone lies between 8^0 12'N and $10^0$03'N latitudes and 34 ^{0}08' E and 36^0 10' E longitudes. Western Oromia Sub-region on the other hand extends from $07^0$13'16" to 10^0 20'10"N latitude and 34^0 08'30" to 37^0 40'53"E longitude.

West Wollega Zone is characterized by physiographic features of mountain, undulating and rolling plateaus. The proposed road route traverses through rolling hills with elevation varying between 1900m and 1500m above sea level. The topography along the route can be classified as approximately 10% escarpment, 30% mountainous, 40% rolling and 20% flat. The existing road alignment generally follows the ridge and has sharp horizontal curves and steep gradients.

3.2 CLIMATE

West Wollega zone experiences tropical climatic conditions mainly due to its location. The mean annual temperature of the zone varies from 15^0 C to over 25^0C. It has long hours of sun shine. December to February is a period of longest average sun shine (8 hours/day). The shortest sunshine hours are May to August, with average sunshine hours of around 3.8 hours/day (Source: the application CLIMWAT 2.0, developed by FAO).

Heavy rainy season in the zone is between June and September, while light rains occurs during February to May.

Climate data are obtained from three meteorological stations, at Nejo, Yubdo and Dembi-Dolo, in the vicinity of the study area. FAO claims that the database, from which the software draws, contains at least 15 years data.

Station	Nejo		Station	Yubdo		Station	Dembi-Dolo	
Altitude	1800	m	Altitude	1520	m	Altitude	1850	m
Longitude	9.5°	N	Longitude	8.95°	N	Longitude	8.5°	N
Latitude	34.48°	E	Latitude	35.45°	E	Latitude	34.76°	E

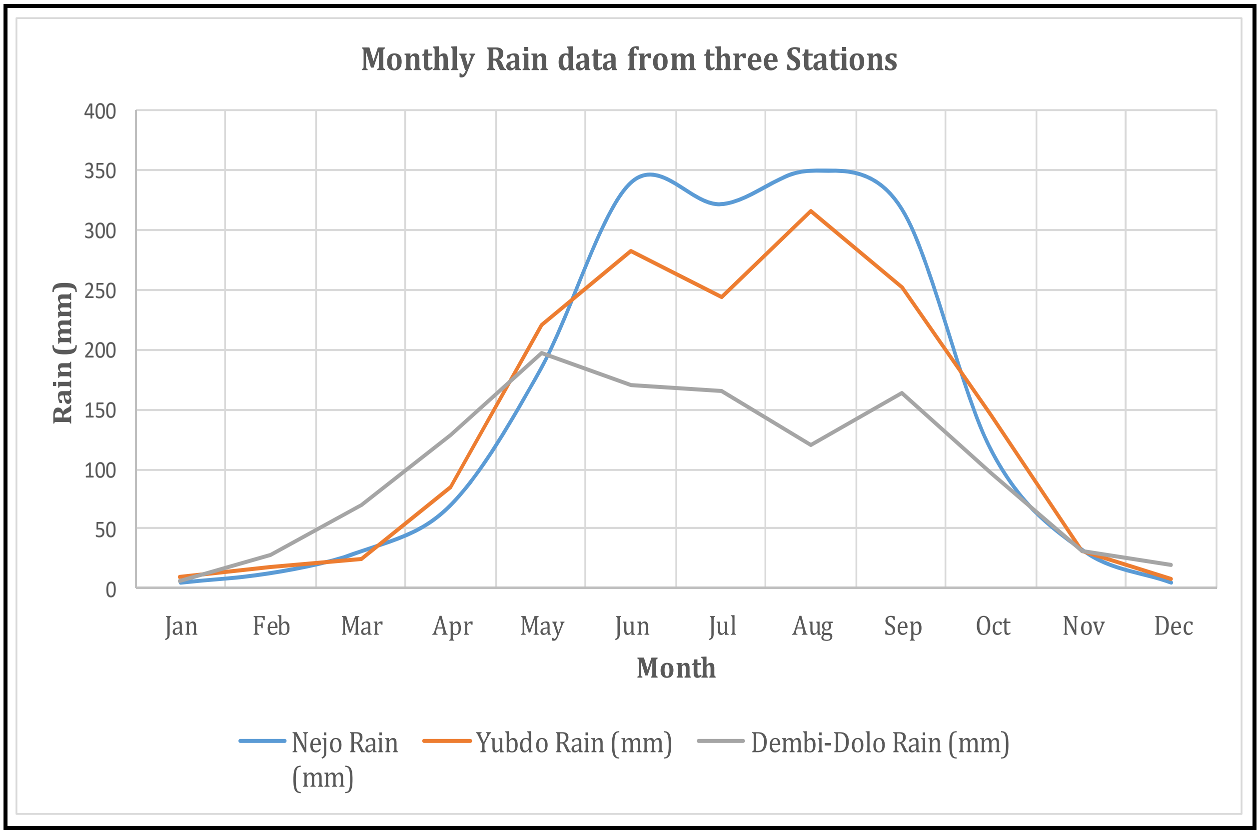


Figure 1: rain data from three nearby stations

3.3 GEOLOGY AND MINERAL DEPOSITS

The districts traversed by the road project are dominantly covered with the rocks of the Cenozoic era. The thick basalts lava rocks of the trap series that occurs in West Wollega Zone are rocks of Cenozoic era. Among the trap series of rock groups (the Ashange and The shield groups), it is the tertiary period Ashange group that is found in

West Wollega zone. The Ashange group of the trap series consists of alkali olivine basalt and tuffs with rare rhyolites and dolerite sills and gabro diabase intrusive. Intrusive igneous rocks are formed through the cooling and solidification of magma or lava below the surface .This magma can be derived from parental melts of existing rocks in either mantle or crust.

West Wollega Zone has rich mineral resources including ferrous mineral and precious metals like gold and platinum. The precamberian era rocks are sources for the ferrous, nonferrous and the precious metals, while the Cenozoic era sedimentary rocks are sources of the iron and coal. The mineral of the zone consists of coal, iron, nickel, precious metals (Gold and Platinum), non-ferrous minerals (Cobalt, molybdenum, titanium, Uranium and phosphate), and industrial and construction mineral like marble.

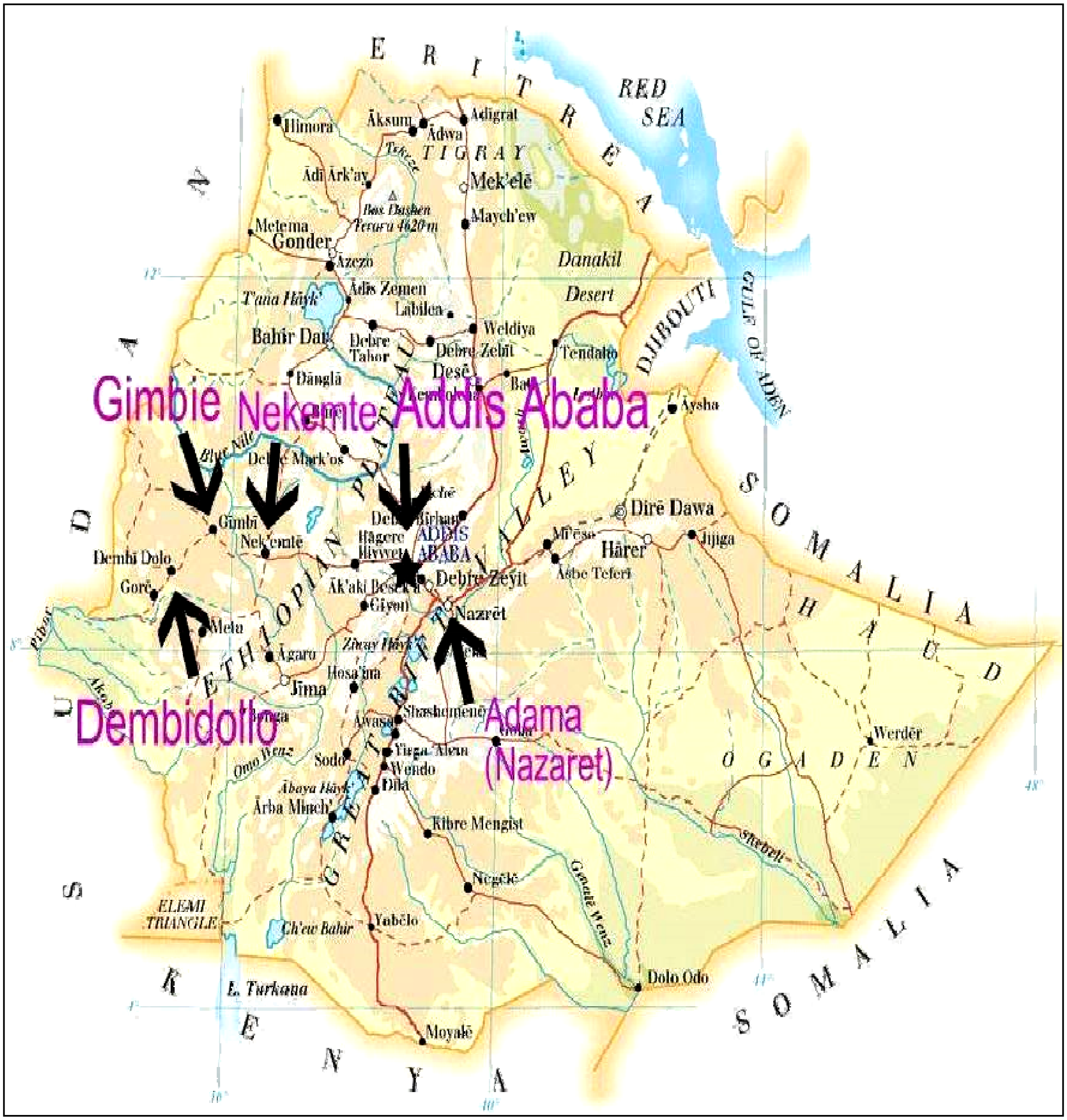


Figure 2.1: Ethiopia map showing the project area

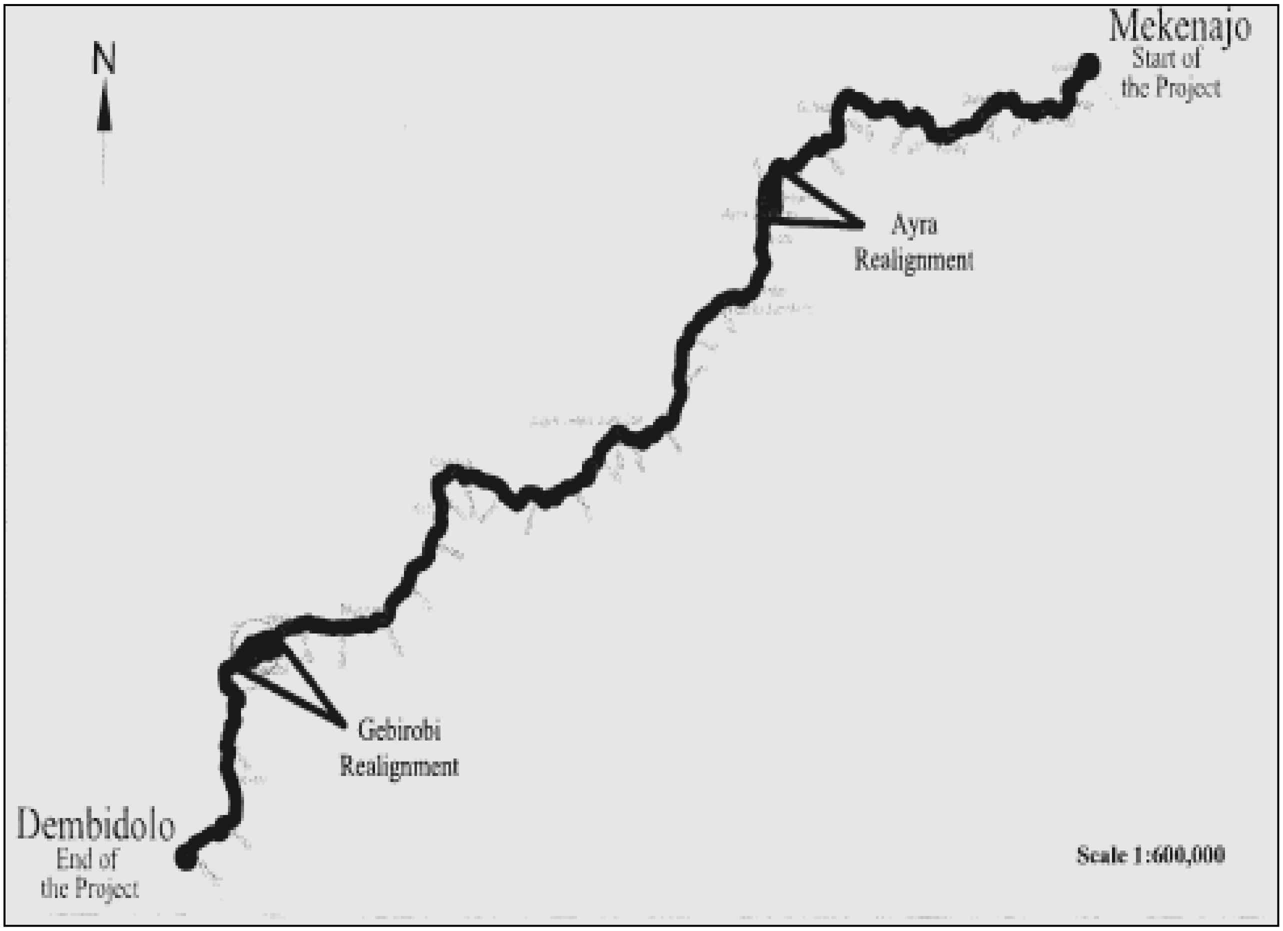


Figure 2.2: Location map of project area

Source: World Map and ERA Environmental Impact Assessment Report

CHAPTER 4: Experimental Study

4.1 PURPOSE

The purpose of this study is to investigate the strength characteristics of a stabilized lateritic soil with marble dust.

4.2 MATERIAL CHARACTERIZATION

4.2.1 Soil

The area where the sample was taken is located in western Ethiopia, in the Oromia National Regional State. Sample was collected from Mekenajo 39.45km to Dembidolo town having Latitude 09^{0}10’7”N & Longitude 35^{0}25’37.6”E. In this project, lateritic soil was used as a subgrade material.

The site of the sampling pit was approximately 1627 m above sea level, and disturbed samples were taken at 20 cm depth from natural ground level. The soil sample collected was *disturbed* sample.

Soil samples were prepared for test by air drying and sieving to the required size. Grain size analysis was determined according to ASTM D 422. Index properties of soils were determined using Atterberg limit test according to ASTM D 4318. Soil classification was made according to the AASHTO classification system (AASHTO, 2006).

Typical standard Proctor unit weight values for lateritic soils (less lateritic gravel) range from 1,281-1,682 kg/m^3, while those with gravel present may range to 2,323 kg/m^3 (Townsend, 1985). The natural soil has a dry unit weight of 1,480 kg/m^3, which indicates that it is lateritic soil with less lateritic gravel.

Mineralogical and Chemical Tests of Natural Soil

Chemical testing of the natural soil sample was carried out at the geochemical laboratory of Ethiopian Geological Survey, and the test results are presented in Table 1.

Table 1: Chemical composition of the sample lateritic soil

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LoI*	SO_3
Contents in % by mass	44	23.06	17	<0.01	<0.01	<0.01	<0.01	0.06	0.14	1.7	2.95	11.08	1.03
* LoI = Loss on Ignition													

The mineralogical composition is considered to be more important in explaining the physical properties of laterite and lateritic soil. The mineralogical constituents can be divided in to major elements, which are essential to laterization, and minor elements, which do not affect the laterization process. The major constituents are oxides and hydroxides of aluminum and iron, with clay minerals and, to a lesser extent, manganese, titanium and silica. The minor constituents are residual remainants. The result showed that major elements Al_2O_3 and Fe_2O_3 constitute 40% of total minerologial elements.

4.2.2 Marble

Marble is a metamorphic rock formed when limestone is exposed to high temperatures and pressures. Pure marble is white but marble exists in a wide variety of colors all the way through to black. The variety of colors exhibited by marble are due to minor amount of impurities being incorporated with calcite during metamorphism.

Marble is composed primary of the mineral calcite ($CaCO_3$) and usually contains other impurities such as: clay minerals, micas, quartz, pyrite, iron oxide and graphite. Dolomitic marble is produced when dolostone is subjected to heat and pressure.

Marble dust is a waste product of marble processing plants, where 20-25% of the original marble mass is lost as dust during cutting and finishing operations.

The marble dust used for this research was taken from the Bole Branch of Ethiopian Marble Processing Enterprise, one of the major marble processing plants in Ethiopia.

4.3 SAMPLE PREPARATION

The stabilization process in the lab must simulate the actual field construction operations of stabilized material in the road works. The stabilizing process involves the addition of a stabilizing agent to the soil, intimate mixing with sufficient water to achieve the optimum moisture content, compaction of the mixture, and final curing to ensure that the strength potential is realized (TRL, 1993).

Soil samples were prepared for test by air drying and sieving to the required size. For the treated samples, soil-marble mixtures were prepared with marble of 4%, 8%, 12%, 16% and 20% by dry weight of soil.

4.4 LABORATORY TESTING OF THE NATURAL SOIL

The following laboratory tests have been carried on natural lateritic soil:

- Natural moisture content
- Specific gravity
- Grain size distribution
- Atterberg limits
- Moisture-density compaction curves
- California Bearing Ratio (CBR)
- Unconfined Compression (UC) Test.

4.4.1 Moisture Content of Natural Soil

In many residual soils some moisture exists as water of crystallization within the structure of the minerals present in the solid particles. Some of this moisture may be removed by drying above the temperature (105^{o}c) i.e. not only free water is driven off. The moisture content increases significantly with drying temperature.

Therefore to see the effect, two types of moisture content determination is presented by G. E. Blight. One specimen should be oven dried at 105ºc until successive weighting show no loss of mass. The moisture content should be calculated in normal way. The second sample should be air dried (if feasible), or oven dried at a temperature of no more than 50ºc until successive weightings show no future loss of mass (Blight, 1997).

To see the existence of such water in the sample, moisture content was conducted (Table 2) by using oven drying (105ºc) and air drying till no further loss of mass.

In all the cases, it can be observed that the difference in moisture content is less than 4%; therefore, the amount of *structural water* is insignificant. Because of the above conclusion in all the tests, moisture content determinations are carried out based on the conventional drying temperatures(105 ºc).

Table 2: Moisture Contents at 50°c and 105°c

Natural moisture content at		**Difference**
50 °C	**105 °C**	
29.91%	31.32%	1.41%

4.4.2 Specific Gravity of Natural Soil

The specific gravity of solid matter in a soil particle may be defined as the ratio of the unit weight of solid matter to the unit weight of water. The specific gravity was determined in the laboratory according to ASTM D854-92. According to ASTM D854-92, specific gravity of soils is determined by means of a pycnometer. The specific gravity of the sample is found to be 2.73.

4.4.3 Grain Size Analysis of Natural Soil

Grain size analysis is an attempt to determine the relative sizes of different grain particles which makes up a soil mass. The soil samples under investigation are almost fine that the amount of particles retained on No 200 (0.075 mm) sieve was insignificant; hence, hydrometer analysis was used with sodium hexametaphosphate as dispersing agent (Das, 2010).

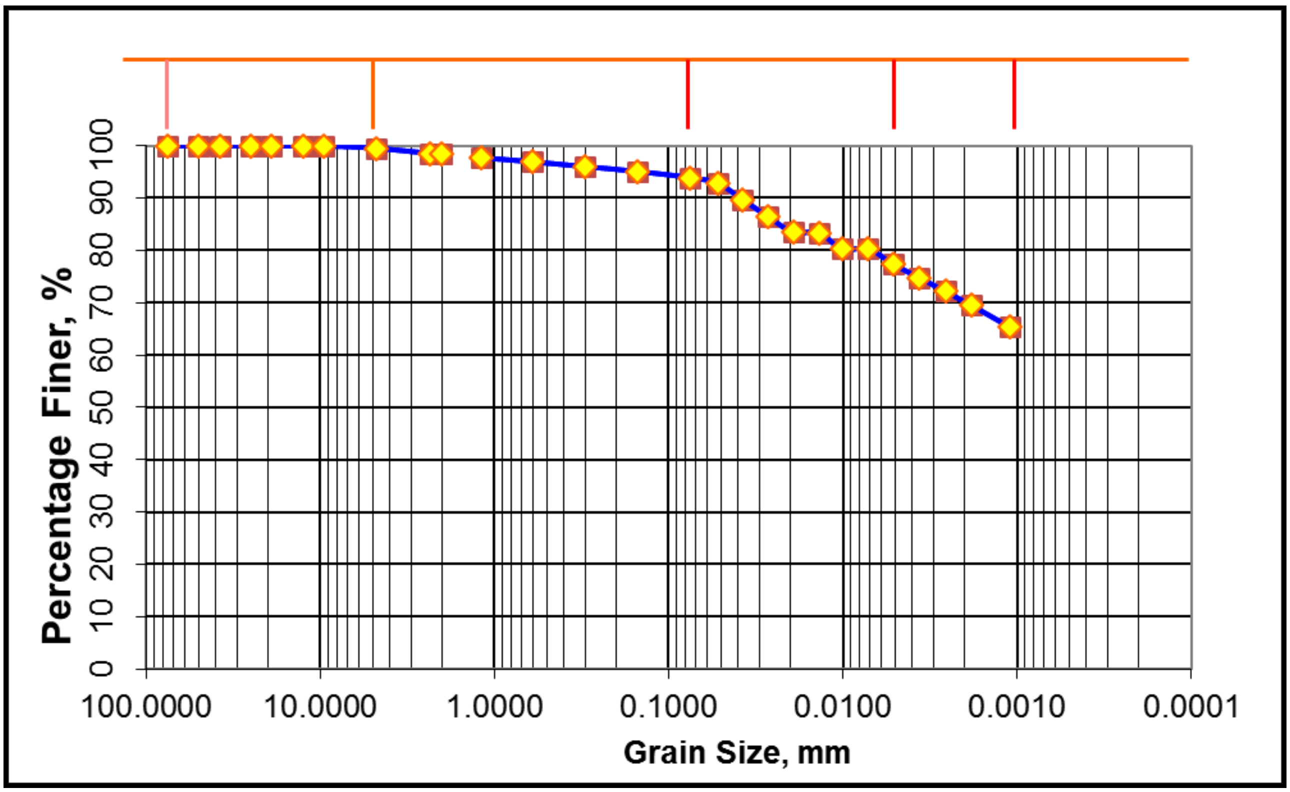


Figure 2: Grain Size Analysis Curve

4.4.4 Atterberg Limits Tests on Natural Soil

Atterberg limit tests are used to determine the plastic and liquid limits of a fine grained soil. The liquid limit (LL) is the water content at which soil in a standard cup cut by a groove of standard dimensions will flow together for a distance of 13 mm when subjected to 25 shocks dropped from 10mm at a rate of two blows per second. The plastic limit (PL) is the water content, at which a soil can no longer be deformed by rolling into 3.2 mm diameter threads without crumbling.

Atterberg limits were determined according to ASTM D 4318 on particles passing No. 40 sieve. To avoid disaggregation of the clay sized particles in the soil, the mixing time is limited to no more than 5 minutes and fresh sample was used for each moisture content point in Atterberg limit tests.

The Atterberg limits are used in estimating other engineering properties of a soil and in soil classification. Because these limit values are easily determined and simple to use, they have been used for basic soil classification or for predicting soil behavior such as strength, volume change, hydraulic, and thermal conductivity, or use for correlation of these values to other complicated soil parameters, such as tensile strength, compression index, coefficient of consolidation, cohesion, and internal friction angle (Fang & Daniels, 2006).

Table 3: Atterberg Limit Test Results of the Natural Soil

Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
58	35.9	22.1

4.4.5 Moisture-Density Relationships of Natural Soil

Moisture-density relationships were determined using Proctor test. For the given soil sample, standard compaction test was conducted according to ASTM D 629.

Fresh sample was used for each moisture content point to avoid disaggregation of the clay sized particles in the soil.

Table 4: Results from Compaction Test on the Natural Soil

Maximum Dry Density g/cm^3	Optimum Moisture Content (%)
1.48	34.2

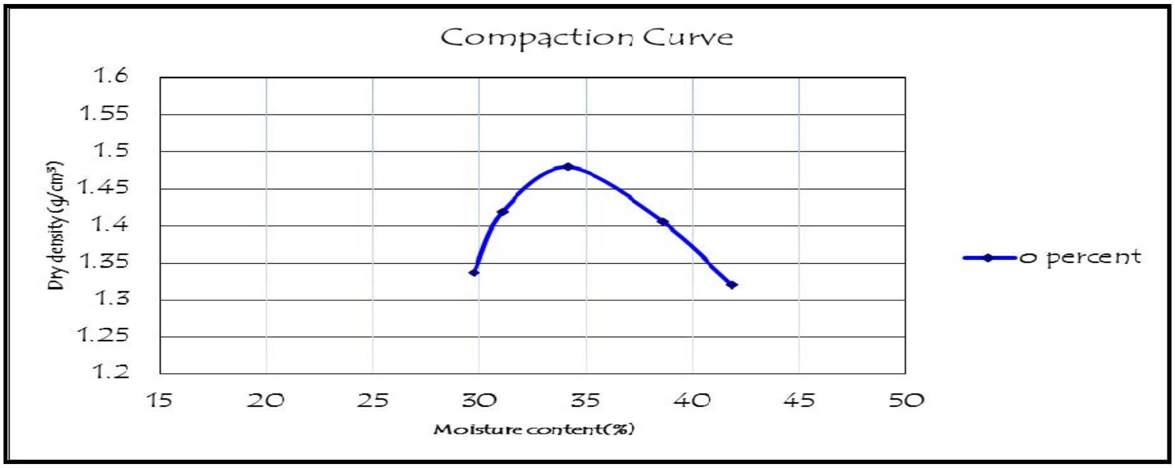


Figure 3: Dry Density-Moisture Content Relation

4.4.6 California Bearing Ratio (CBR) Test on the Natural Soil

The CBR test measures the shearing resistance of a soil under controlled moisture and density conditions. CBR value is the ratio of load required to effect a certain depth of penetration in to a soil specimen compacted at a given moisture content and dry density to the load required to obtain the same depth of penetration on a standard sample of crushed stone.

Road pavement structural design is usually based on 4-days soaked CBR values, to simulate the anticipated “worst-case” soil condition on the field.

Table 5: Results of CBR Test

CBR of Natural Soil	
Unsoaked	Soaked
5.9	2.7

4.4.7 Unconfined Compressive Strength Test on the Natural Soil

The Unconfined Compression Test is special case of the unconsolidated-undrained test (Das, 2010). No confining pressure is applied to the soil specimen throughout the test. The test can be performed by applying a load in a simple loading frame. At the start of the test, the unsaturated soil specimen has negative pore–water pressure, and pore air pressure (u_a) is assume to be atmospheric. The soil matric suction (u_a-u_w), is therefore numerically equal to pore–water pressure. The loading is applied quickly so that the porewater cannot drain from the soil; the sample is sheared at constant volume. This should apply to both pore–air and pore–water phases. The pore-air and pore–water pressures are not measured during compression (Fredlund & Rahardjo, 1993).

Table6: Results of Unconfined Compression Test on Natural Soil

Material	UCS (kPa)
Natural Soil	132.6

4.5 LABORATORY TESTING OF THE BLENDED SOIL

4.5.1 Properties of Marble Dust

From laboratory tests conducted on marble dust results showed the Atterberg limits test result is non plastic and the Specific Gravity is 2.8 .

4.5.2 Percentage of the Stabilizer

To assess the optimum percentage of the marble-dust required, soil-marble blends were prepared with marble-dust of 4%, 8%, 12%, 16% and 20% by dry weight of soil.

4.5.3 Sample Curing

For all tests, samples were prepared using soil satisfying the AASHTO or ASTM requirement and thoroughly mixed with marble dust; they were then cured for 7 and 14 days. “Covering with impermeable sheeting” was the curing technique used by applying impervious plastic to cover samples.

Proper curing, during actual construction of stabilized layers in the field, is very important for three reasons (TRL, 1993):

- It ensures that sufficient moisture is retained in the layer so that the stabilizer can continue to hydrate.
- It reduces shrinkage.
- It reduces the risk of carbonation from the top of the layer.

4.5.4 Laboratory Test Results of Blended Soil

The following tests were carried out on the marble-dust treated samples: Atterberg limits, moisture-density compaction curves, California Bearing Ratio (CBR) and Unconfined Compression (UC) Test.

4.5.4.1 Atterberg Limits

It is important to evaluate the changes of liquid limits, plastic limits and plasticity index with addition of marble dust to the selected soil samples. To achieve this objective, liquid limit and plastic limit tests were conducted according to consistency test of AASHTO T89 and T90, respectively. Soil samples were first air dried and then sieved with no 40 sieve. Soil passing no 40 sieve was mixed with different proportion of marble dust and kept for curing packed in plastic bags to protect loss of moisture.The proportion of marble dust used was 4%, 8%, 12%, 16% and 20%.The atterberg limits tests of marble dust-soil were determined after 7, 14 and 28 days of curing to estimate the influence of time on atterberg limit values. The test results of atterberg limits for marble dust treated soil are presented in Table 7

Table 7: Atterberg Limit Test Results on Blended Soil

Marble content (%)	*7days curing*			*14 days curing*		
	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0% marble (Natural soil)	58	35.9	22.1	58.0	35.9	22.1
4	50	33.3	16.7	49.0	32.9	16.1
8	48	31.5	16.6	48.0	31.8	16.2
12	48	31.3	16.8	48.0	32.6	15.4
16	50	33.6	16.4	47.0	30.7	16.3
20	44.9	29.0	15.9	44.2	29.0	15.2

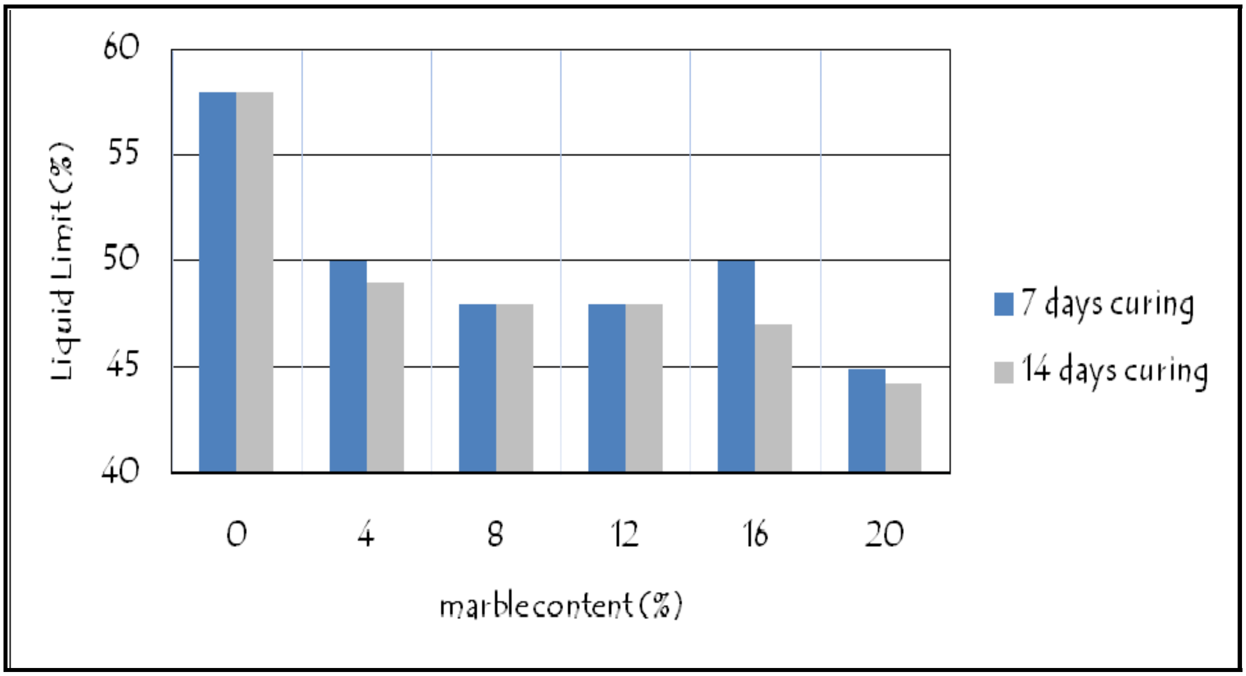


Figure 4: Liquid Limit vs Marble Dust Content

Figure 6: Plastic Limit vs Marble Dust Content

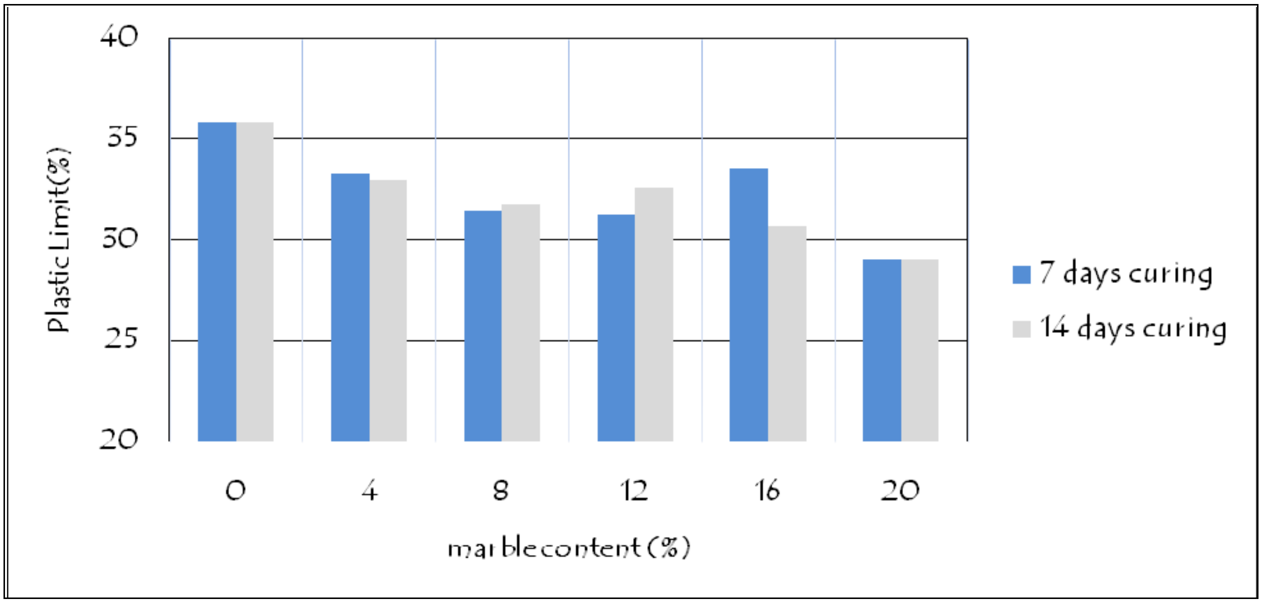
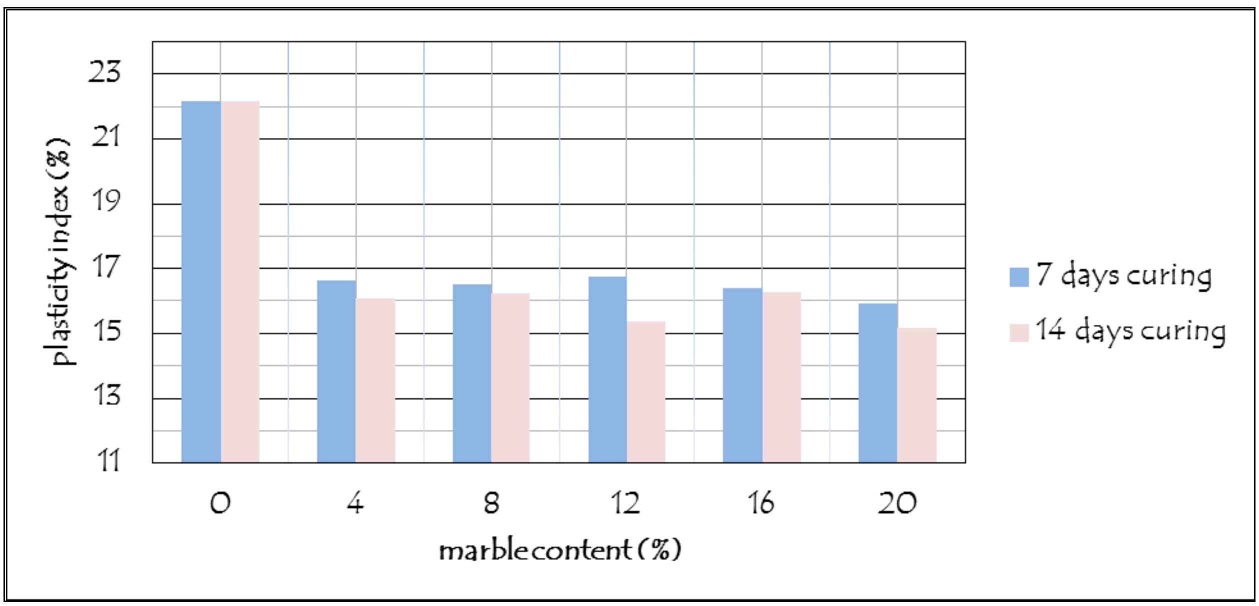


Figure 7: Plastiity index vs Marble Dust Content



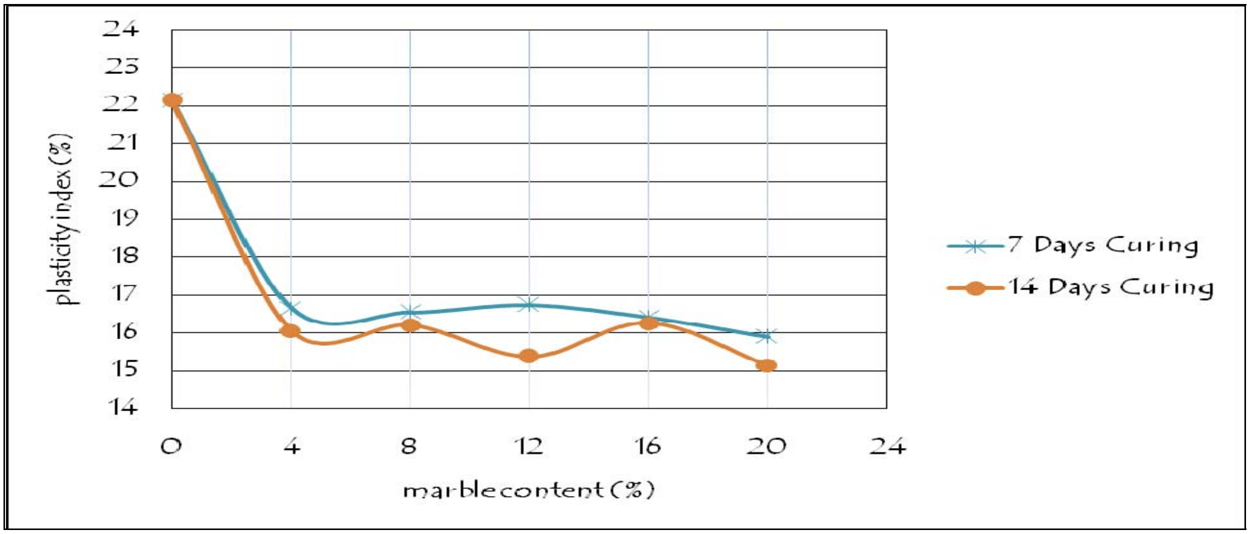


Figure 8: Plasticity Index vs Marble Dust Content

4.5.4.2 Moisture-Density Relationships

Air dried soil passing no 4 sieve was used to determine moisture density relation of the soil mixed with varying proportions of the marble dust. The soil was mixed with ratios of 4%, 8%, 12% ,6% and 20% of marble dust, and the results are presented hereunder:

Table 8: Results of Compaction Test for the Blended Soil

Marble content (%)	*7 Days Curing*		*14 Days Curing*	
	Maximum Dry Density g/cm³	**Optimum Moisture Content (%)**	**Maximum Dry Density g/cm³**	**Optimum Moisture Content (%)**
0% marble(Natural soil)	1.48	34.2	1.48	34
4	1.44	28	1.48	30
8	1.48	27.5	1.51	29.3
12	1.52	27.2	1.52	29.2
16	1.54	26.8	1.55	28.6
20	1.57	26.1	1.58	27.3

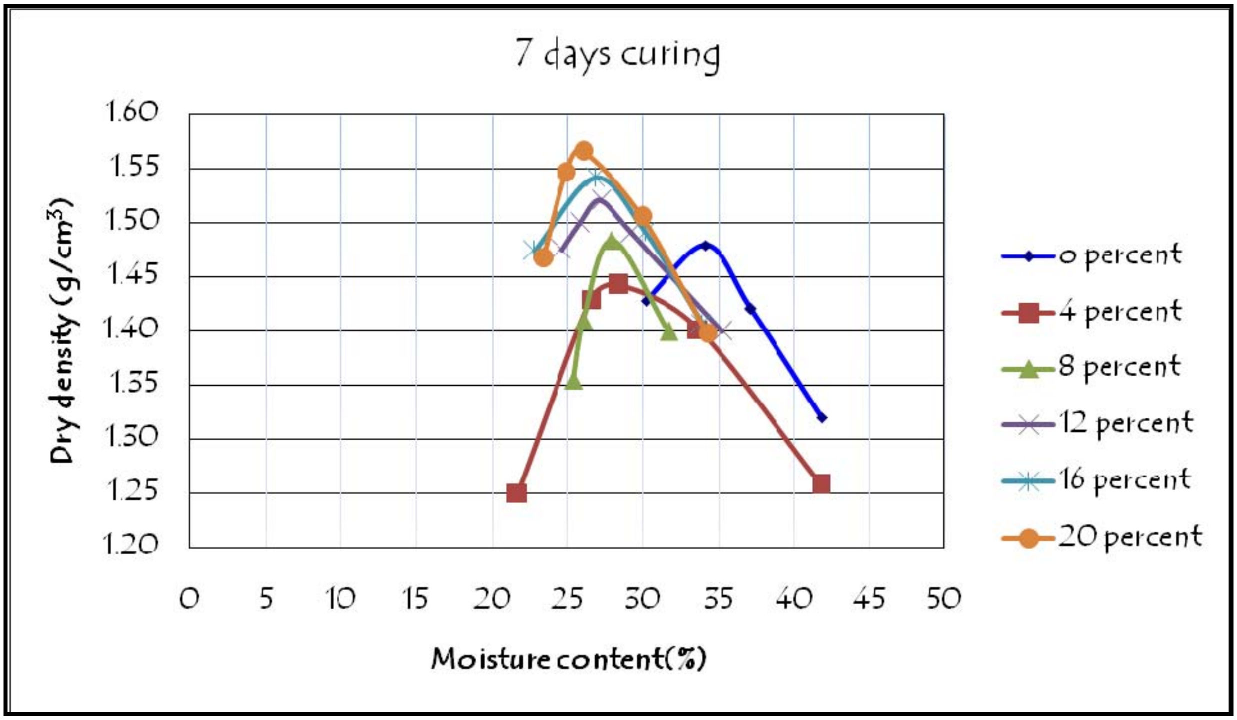


Figure 9: Dry Density-Moisture Content Relation vs Marble Dust (%), 7-days curing

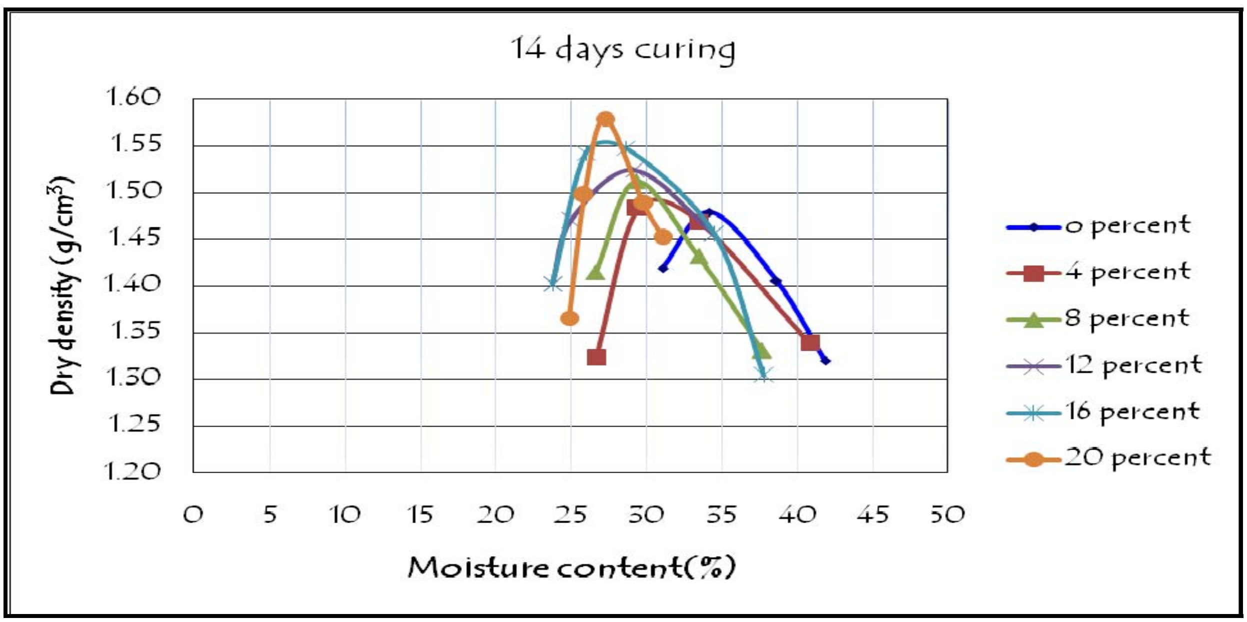


Figure 10: Dry Density-Moisture Content Relation vs Marble Dust (%), 14-days curing

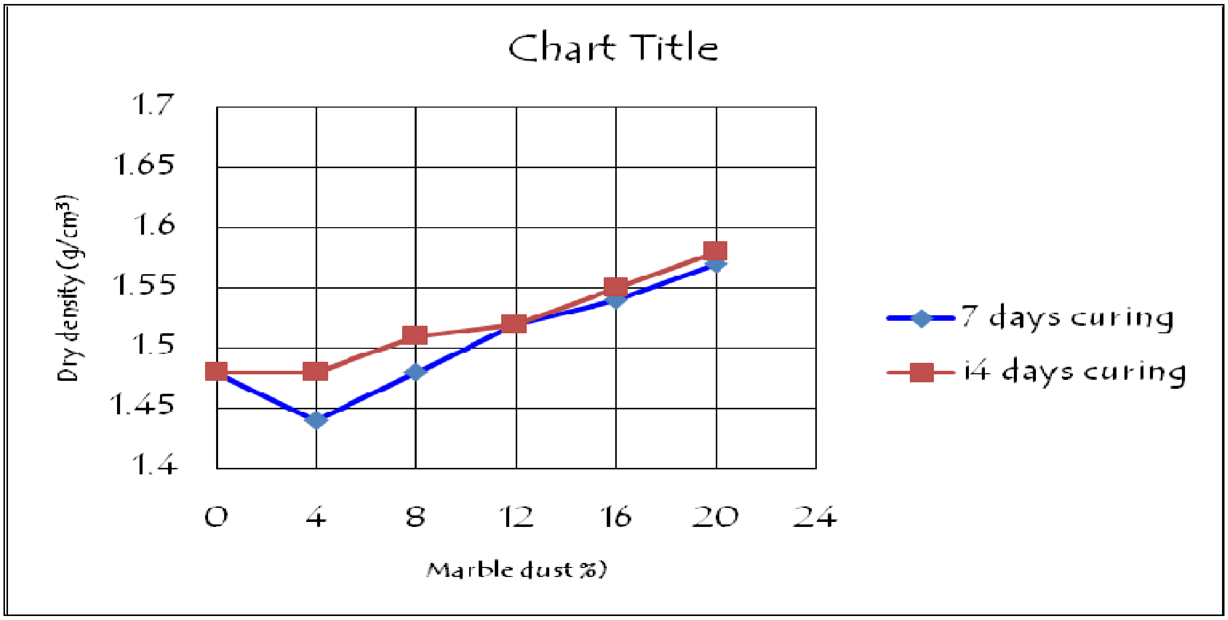


Figure 11: Dry Density vs Marble Dust

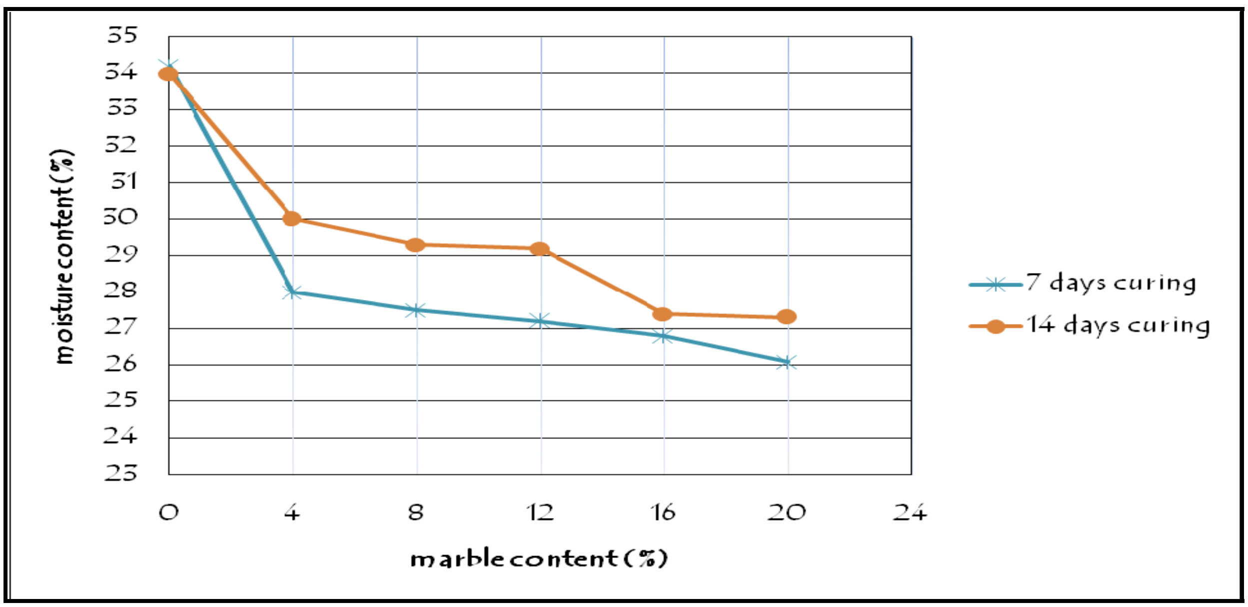


Figure 12: Optimum Moisture Content vs % of Marble Dust

4.5.4.3 California Bearing Ratio (CBR)

Soil passing no 4 sieve was mixed with marble dust at optimum moisture content and compacted in CBR molds at maximum dry density. The marble dust-soil mixtures were kept in plastic bag for 7, 14 and 28 days of curing periods to estimate the influence of time on CBR value. CBR tests were conducted after the curing periods unsocked and at the worst condition soaked for 96 hrs. soaked CBR are normally used in regions with high water tables where soaked condition are frequently met. The CBR test results are shown in Table 9.

Table 9: Results of CBR Test

Marble Content (%)	7 Days Curing		14 Days Curing	
	Unsoaked CBR (%)	Soaked CBR (%)	Unsoaked CBR (%)	Soaked CBR (%)
0% marble (Natural soil)	5.85	2.71	5.85	2.71
4	7.9	6.3	9.7	7.7
8	10.6	6.9	11.2	8.9
12	11.1	6.9	12.5	9.8
16	13.6	12.6	15.2	13.5
20	20.4	19.3	22.1	20.2

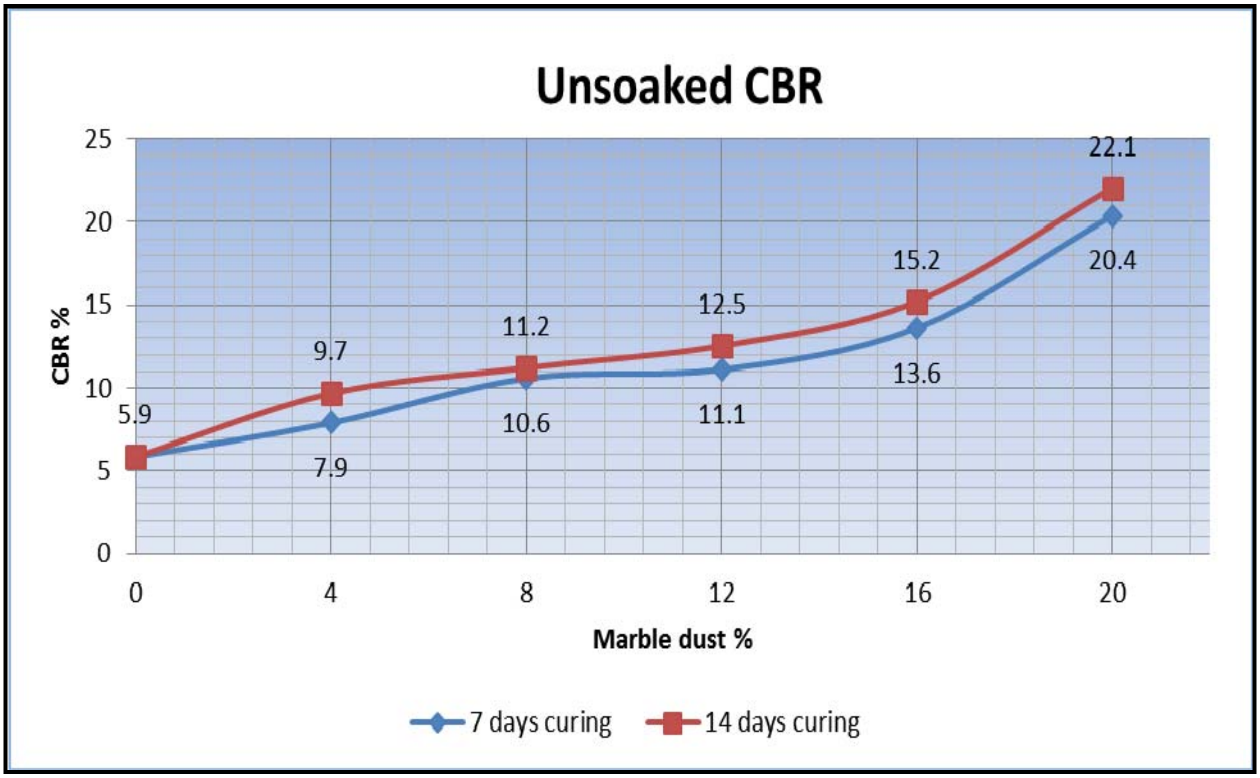


Figure 13: Unsoaked CBR vs Marble Dust Content

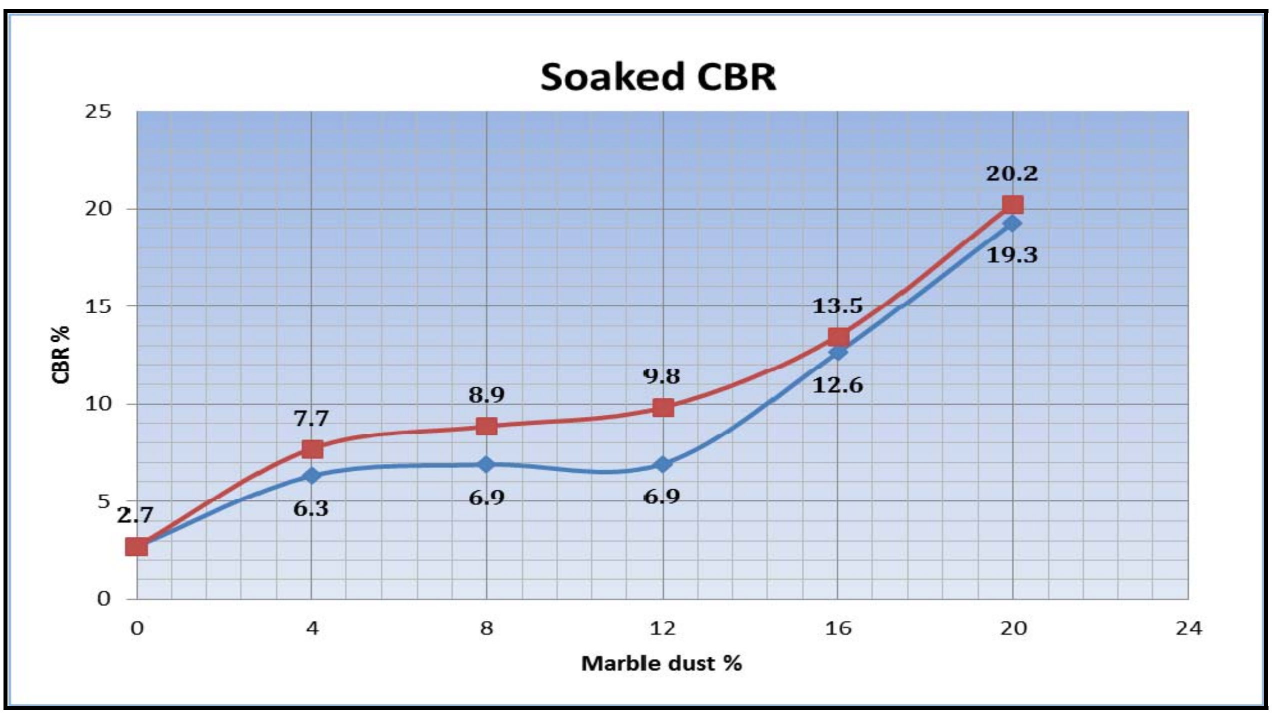


Figure 14: Soaked CBR vs Marble Dust Content

4.5.4.4 Unconfined Compression (UC) Test

The results from UC tests are used to estimate the short-term bearing capacity of fine-grained soils for foundations. The Tresca failure criterion *is used to interpret the results of the UC test. The undrained shear strength is:*

$$s_u = \frac{P_z}{2A} = \frac{1}{2}\sigma_1$$

Where, s_u = undrained shear strength, P_z = axial (plunger) load, A = sample area, and σ_1 = major principal stress

Table 10: Results of Unconfined Compression Test on Blended Soil

Marble content (%)	0% marble (Natural soil)	***4***	***8***	***12***	***16***	***20***
UCS (Kpa) 7 days curing	*132.6*	*191*	*301.6*	*212*	*187.2*	*170.2*
UCS (Kpa) 1 4days curing	*132.6*	*277.8*	*346.1*	*248.8*	*240.6*	*203.1*

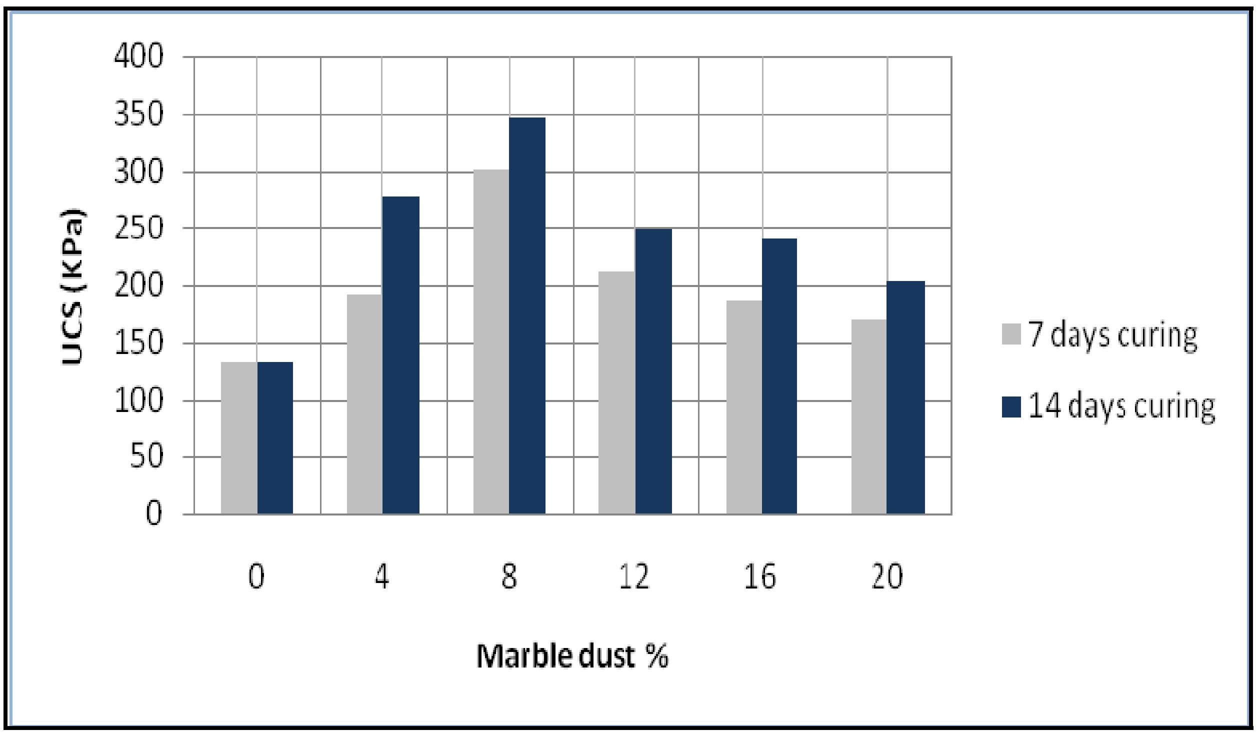


Figure 15: UCS vs % of Marble Dust

CHAPTER 5: Results and Discussion

Accordingly, the degree of laterization for the sample soil is:

Degree of laterization = SiO_2 / (Fe_2O_3 + Al_2O_3) = 44/(17+23.06) = 1.1

Since the silica-sesquioxide ratio is less than one point three, it is *indicative* that the material is a *true laterite*.

CBR and MDD values keep on increasing with increase in marble dust content. Because the soil is unconfined in UCS test the result increases up to 8% then decreases.

It is to be noted that the compaction curves, as shown in Figure 10 and Figure 11, are bell-shaped, which is typical of most clayey soils (Das, 2010).

At 4% the MDD decreases because during laboratory testing process like mixing the soil and the stabilizer the bond between the soil particles are disturbed .But starting from 8% as Sabat (2012) spotlighted, the maximum dry density increases when the amount of stabilizer is increased, the reason for such behavior is due to replacement of soil particles having low specific gravity with stabilizer particles having higher specific gravity. The specific gravities of the soil and marble dust are 2.73 and 2.8, respectively. Townsend (1985) highlights that lateritic soils have high specific gravities (Gs, 2.7-3.5).

The optimum moisture content decreased as percentage of marble dust increased, because marble dust absorbs less water than the soil, so less water was needed to lubricate the marble dust-soil blend.

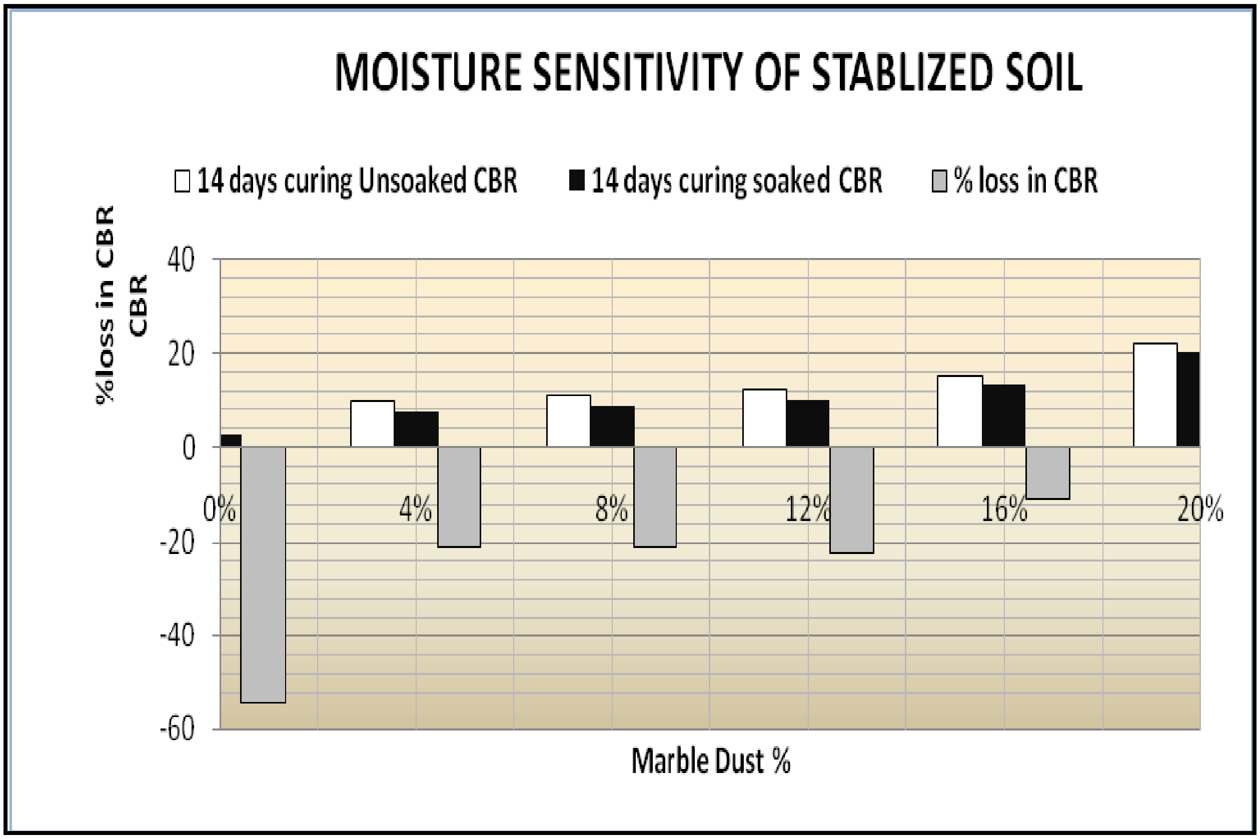


Figure 16 : % Loss in CBR between Unsoaked and Soaked Samples

The bearing capacity of the soil markedly improved due to treatment by marble-dust, as verified by the increase in CBR. For instance, the CBR of soaked natural soil increased from 2.7 to 8.9 (soaked CBR) at 8% marble-dust treatment, which is a 230% increase. Improvement in CBR value is attributed to better compaction and packing of the mix particles with addition of marble dust.

Clay soil responds to marble-dust stabilization due to the effect of pozzolanic reaction between lime present in marble-dust and the soil (Sabat & Nanda, 2011).

Thus, the addition of lime to a soil causes an immediate increase in the pH of the molding water due to the partial dissociation of the calcium hydroxide. The calcium ions in turn combine with the reactive silica or alumina or both, present at soil surfaces, to form insoluble calcium silicates or aluminates or both which harden on curing to stabilize the soil. This process continues for some months. This then is responsible for the increase in strength with time of lime-stabilized soils (Ola, 1977).

In unstabilized state, the difference between the unsoaked and soaked CBR values of the soils is quite large compared to the values in lime stabilized conditions. This is mainly due to the fact that in their natural states, water could still percolate into the interstitial spaces of the soil thereby weakening them. However, this is reduced in their optimum-lime stabilized states as the lime has effectively bonded the soil particles to form a closely packed mass that resists the ingress of water.

Figure 16 show that the CBR values of the unsoaked condition of the stabilized soils reduced after soaking as a result of the absorption of water which weakened the soil. Also, the difference between the unsoaked and soaked CBR values can be associated with the PI of the stabilized soils at the respective lime contents which determines their swell potential; the higher the PI, the higher the difference between the unsoaked and soaked values (Amu, Bamisaye, & Komolafe, 2011).

UCS value increased as the amount of marble dust added to the soil and curing time increased. . For instance, the UCS of natural soil increased from 133Kpa to 346Kpa at 8% marble-dust treatment and 14 days curing, which is a 160% increase. Improvement in UCS value is attributed to better compaction and packing of the mix particles with addition of marble dust.

As noted by Sabat and Nanda (2012), the increase in UCS of the soil is because of the pozzolanic reaction of lime present in marble dust with the Amorphous Silica and Alumina present in the soil.

From the lab test a decrease in plasticity has been observed at increased marble dust content.

The decrease in liquid limit and plasticity index is connected with the pozzolanic action of the stabilizer in aiding the flocculation and aggregation of fine particles of the soil. (Umar et al.,2013).

From the lab test a decrease in plasticity has been observed at increased curing duration and marble dust content.

CHAPTER 6: Conclusions and Recommendations

6.1 CONLUSTIONS

The soil is classified as A-7-5 according to AASHTO classification. The material could possibly be termed as *lateritic soil* (instead of true laterite), Since the silica-sesquioxide ratio is greater than 1.33 the material is true laterite.

An attempt has been made in the study to improve the index and engineering properties of the lateritic soil by stabilization using an industrial waste, marble-dust. To this end, the lateritic soil was treated with marble-dust of 4%, 8%, 12%, 16% and 20% by dry weight of soil, and various tests have been carried out on the laterite-marble mix to assess alterations in its strength characteristics.

The lateritic soil responded very well to the marble-dust treatment, as exhibited in improvement of its strength and its increased resistance to softening by water.

The plasticity index of the treated soil sample at 20% marble dust content was reduced from 22% to 16% and 22% to 15% at 7 and 14 days curing days respectively , due to the flocculation and agglomeration process.

Unconfined compressive strength at 8% marble dust content significantly increased from 132.6kPa to 301.6kPa and from 132.6 kPa to 346.1 kPa at 7 and 14 days curing respectively, owing to the pozzolanic reaction process.

Unsoaked CBR of the modified soil sample at 20%marble dust content considerably increased from 5.9% to 20.4 % and increased from 5.9% to 22.1% at 7 days and 14 days curing respetively. Also the soaked CBR of the modified soil sample with 7 days and 14 days curing increased from 2.7% to 19.3% from 2.7% to 20.2%respetively by pozzolanic reaction process. From the soaked and unsoaked CBR tests, both on the natural soil and stabilized one, it can be inferred that the stabilized material is much less susceptible to moisture fluctuation than the natural soil. For instance, at marble-dust content of 20% and 14-days curing, the CBR drop between unsoaked and soaked is only 9%, as compared to 54% for the untreated natural soil.

The maximum dry density slightly increased from 1.48 g/cm^3 to 1.57 g/cm^3 and 1.58 g/cm^3 with 7 days and with 14 days curing respectively, as a result of increasing marble dust particles that have larger specific gravity than the soil.

Adding 20% marble dust is the optimum quantity in terms of improving plasticity index, maximum dry density and soaked and unsoaked CBR properties but for unconfined compressive value, the optimum marble dust content is 8%.

From the above results, one can conclude that marble dust improves the strength characteristics of the given lateritic soil. Using lime-dust, which is an industrial waste from marble factories, in the road works is not only economical but also contributes to the management of environmental waste.

6.2 RECOMMENDATIONS

From the results of the study, it is observed that the application of marble dust improves the strength characteristics of lateritic soil. Thus, the following recommendations are in order:

1) The results show that there is marked improvement in engineering properties of the soil after applying the stabilizer. Thus, before large-scale applications, the optimum mix of a given soil and curing time should be established from test results of various trials.

2) Cost benefit analysis should also be undertaken, i.e. the economic gains of using the marble-dust stabilized soil in construction works, as compared with other alternatives.

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Appendix

Laboratory Test Results

F .UNSOCKED CBR LABORATORY TEST RESULTS

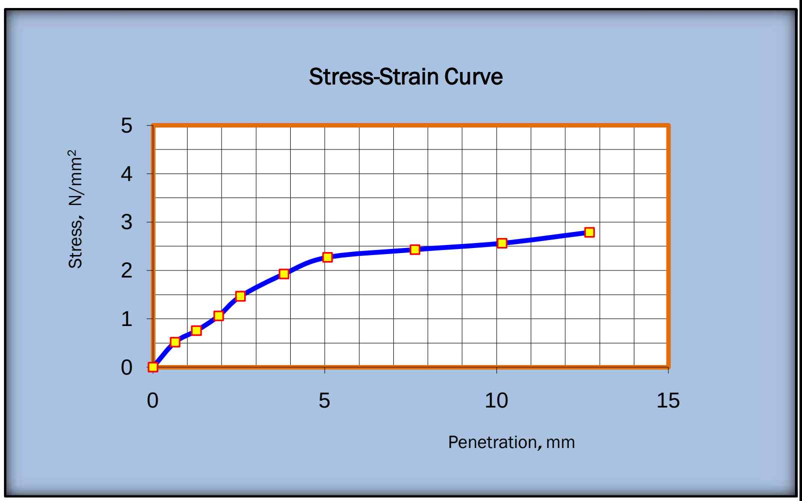
F.6) Marble Dust Content =20% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 20%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**22.06**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	39.0	1003	0.52		
1.27	57.0	1465	0.76		
1.91	80.0	2057	1.06		
2.54	110.0	2828	1.46	6.9	21.18
3.81	145.0	3728	1.93		
5.08	171.0	4396	2.27	10.3	22.06
7.62	183.0	4704	2.43		
10.16	193.0	4961	2.56		
12.70	210.0	5398	2.79		



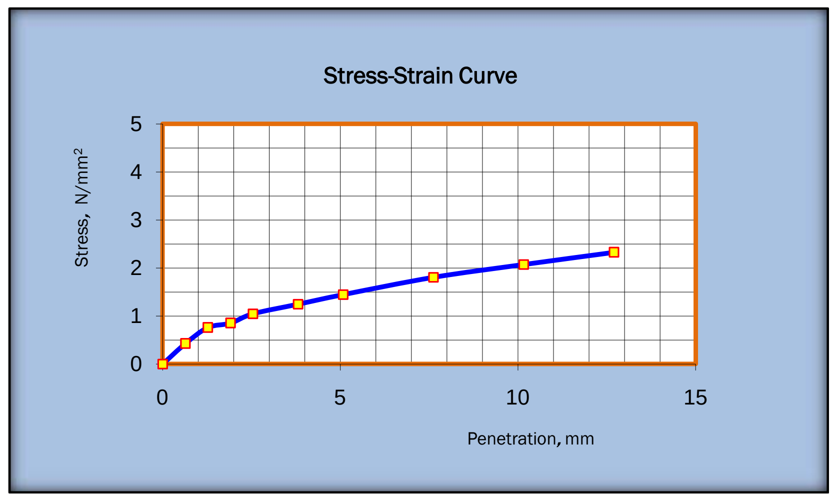
F.15 Marble Dust Content =16% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 16%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5		
Swell, %	0.00	Optimum Most. Content	17
CBR Value, %	**15.21**	Max. Dry DensityMoisture Content	1.38

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0	0	0	0		
0.64	32.0	823	0.43		
1.27	57.0	1465	0.76		
1.91	64.0	1645	0.85		
2.54	79.0	2031	1.05	6.9	15.21
3.81	94.0	2416	1.25		
5.08	109.0	2802	1.45	10.3	14.06
7.62	136.0	3496	1.81		
10.16	156.0	4010	2.07		
12.70	175.0	4499	2.32		



G .SOCKED CBR LABORATORY TEST RESULTS

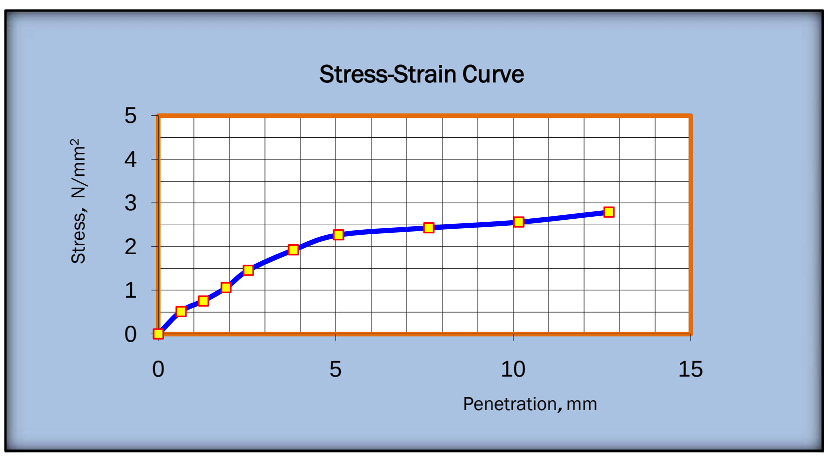
G.2) Marble Dust Content =4% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 4%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**7.70**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0		
0.64	15.0	386	0.20		
1.27	23.0	591	0.31		
1.91	28.0	720	0.37		
2.54	40.0	1028	0.53	6.9	7.70
3.81	47.0	1208	0.62		
5.08	55.0	1414	0.73	10.3	7.09
7.62	67.0	1722	0.89		
10.16	77.0	1979	1.02		
12.70	83.0	2134	1.10		



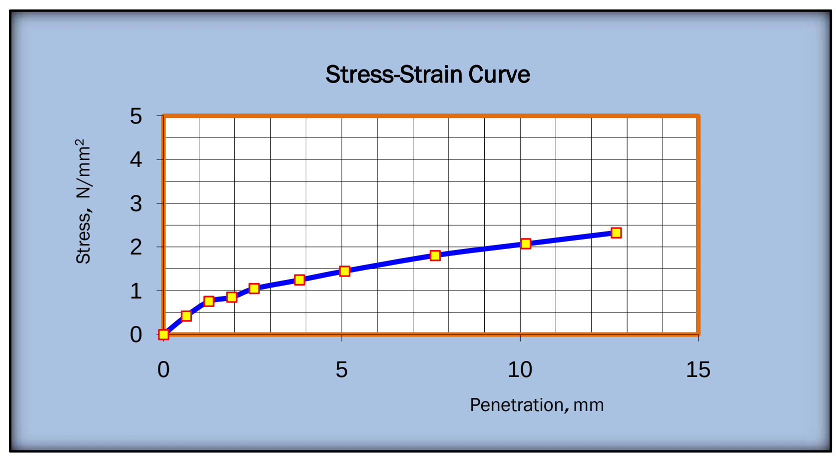
G.1) Marble Dust Content =0% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 0%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**2.89**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	5.0	129	0.07		
1.27	7.0	180	0.09		
1.91	10.0	257	0.13		
2.54	15.0	386	0.20	6.9	2.89
3.81	21.0	540	0.28		
5.08	21.0	540	0.28	10.3	2.71
7.62	38.0	977	0.50		
10.16	45.0	1157	0.60		
12.70	50.0	1285	0.66		



G .SOCKED CBR LABORATORY TEST RESULTS

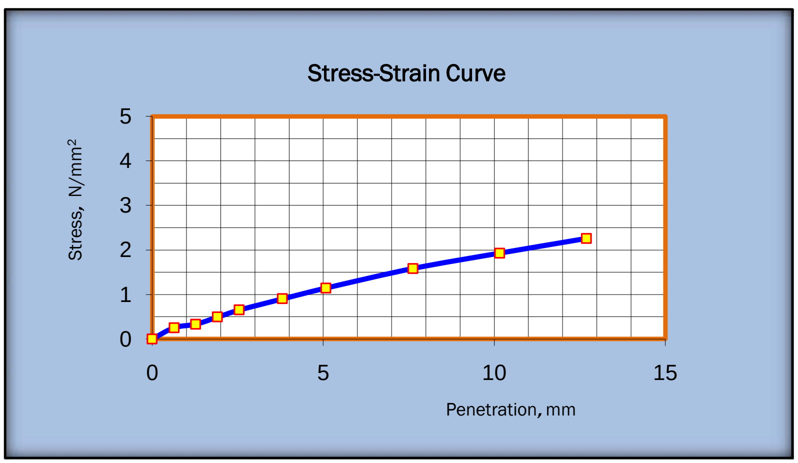
G.3) Marble Dust Content =12% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 12%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54
		swell reading, x 100	0.16
		Original Height,mm	127
		swell ,%	0.13

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.13
CBR Value, %	**9.82**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	23.0	591	0.31		
1.27	37.0	951	0.49		
1.91	45.0	1157	0.60		
2.54	51.0	1311	0.68	6.9	9.82
3.81	58.0	1491	0.77		
5.08	67.0	1722	0.89	10.3	8.64
7.62	79.0	2031	1.05		
10.16	90.0	2314	1.20		
12.70	101.0	2596	1.34		



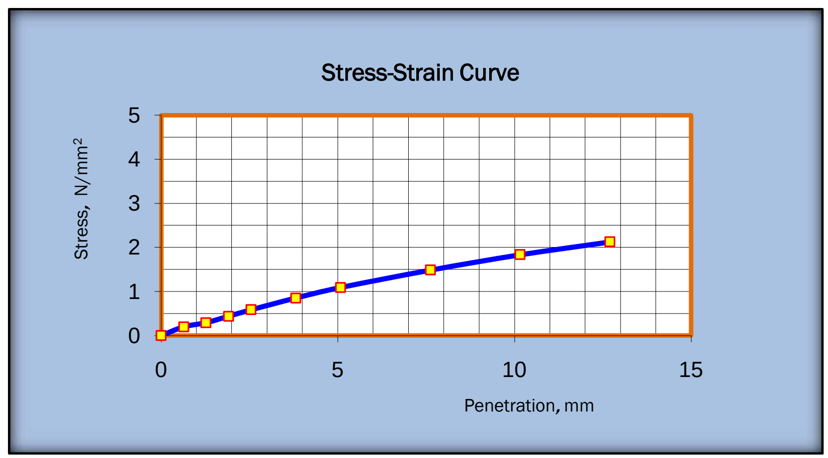
G.14 Marble Dust Content =8% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 8%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**8.86**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	20.0	514	0.27		
1.27	35.0	900	0.46		
1.91	43.0	1105	0.57		
2.54	46.0	1183	0.61	6.9	8.86
3.81	52.0	1337	0.69		
5.08	58.0	1491	0.77	10.3	7.48
7.62	68.0	1748	0.90		
10.16	82.0	2108	1.09		
12.70	93.0	2391	1.24		



G .SOCKED CBR LABORATORY TEST RESULTS

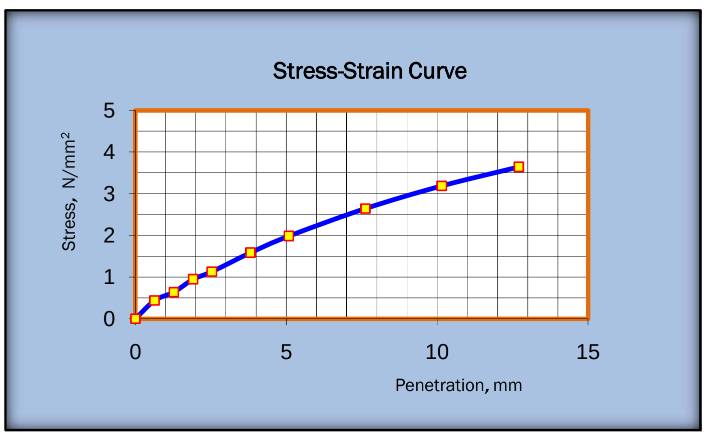
G.5) Marble Dust Content =20% ,Curing Day=14

		Ring Calibration Factoı	25.707
curing day,marble%	14days , 20%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/miı	1.27
Station:	0+200	Rammer wt. (kg)	4.54
		swell reading, x 100	0.16
		Original Height,mm	127
		swell ,%	0.13

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.13
CBR Value, %	**19.99**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	35.0	900	0.46		
1.27	59.0	1517	0.78		
1.91	77.0	1979	1.02		
2.54	105.0	2699	1.39	6.9	20.22
3.81	135.0	3470	1.79		
5.08	155.0	3985	2.06	10.3	19.99
7.62	192.0	4936	2.55		
10.16	200.0	5141	2.66		
12.70	210.0	5398	2.79		



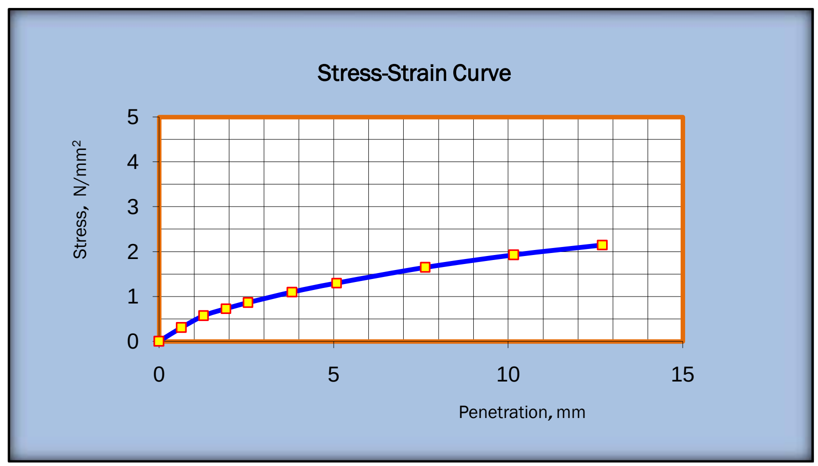
G.6) Marble Dust Content =16% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 16%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**13.48**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	30.0	771	0.40		
1.27	47.0	1208	0.62		
1.91	58.0	1491	0.77		
2.54	70.0	1799	0.93	6.9	13.48
3.81	74.0	1902	0.98		
5.08	83.0	2134	1.10	10.3	10.71
7.62	95.0	2442	1.26		
10.16	108.0	2776	1.43		
12.70	123.0	3162	1.6		



E .SOCKED CBR LABORATORY TEST RESULTS

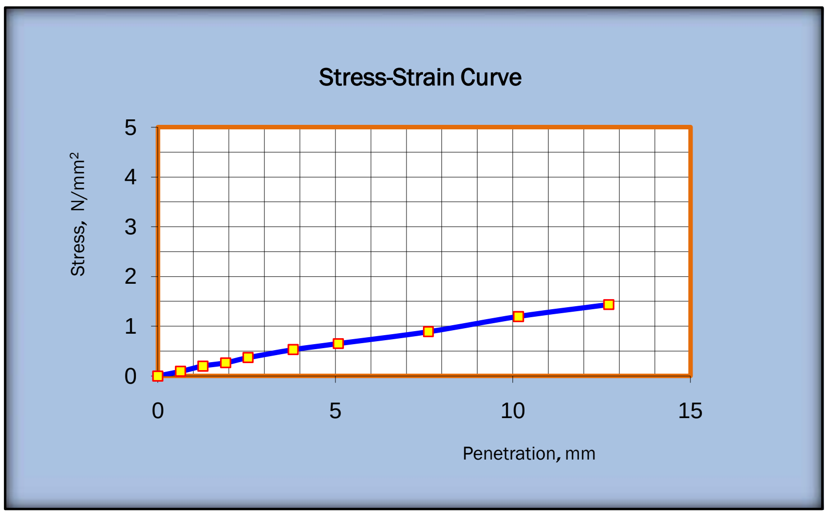
E.2) Marble Dust Content =4% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 4%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**6.32**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress	CBR (%)
0.00	0.0	0	0.00		
0.64	7.0	180	0.09		
1.27	15.0	386	0.20		
1.91	20.0	514	0.27		
2.54	28.0	720	0.37	6.9	5.39
3.81	40.0	1028	0.53		
5.08	49.0	1260	0.65	10.3	6.32
7.62	67.0	1722	0.89		
10.16	90.0	2314	1.20		
12.70	108.0	2776	1.43		



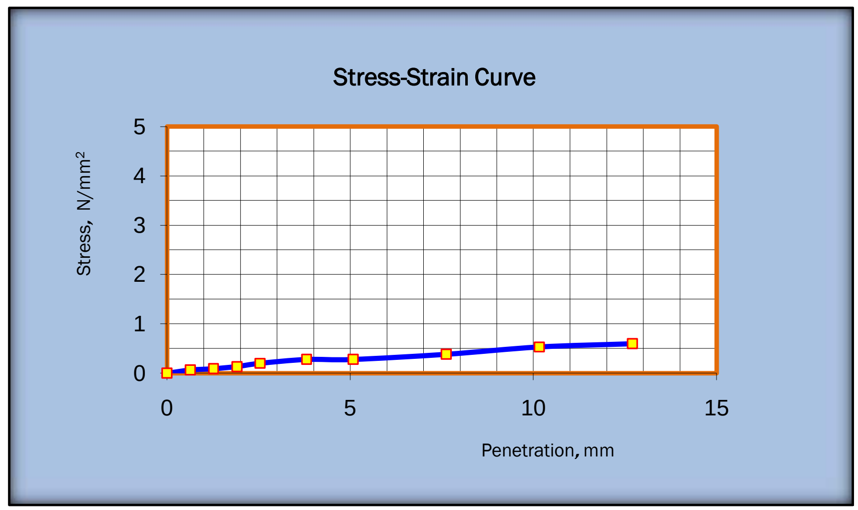
E.1) Marble Dust Content =0% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 0%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**2.89**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	5.0	129	0.07		
1.27	7.0	180	0.09		
1.91	10.0	257	0.13		
2.54	15.0	386	0.20	6.9	2.89
3.81	21.0	540	0.28		
5.08	21.0	540	0.28	10.3	2.71
7.62	29.0	746	0.39		
10.16	40.0	1028	0.53		
12.70	45.0	1157	0.60		



E .SOCKED CBR LABORATORY TEST RESULTS

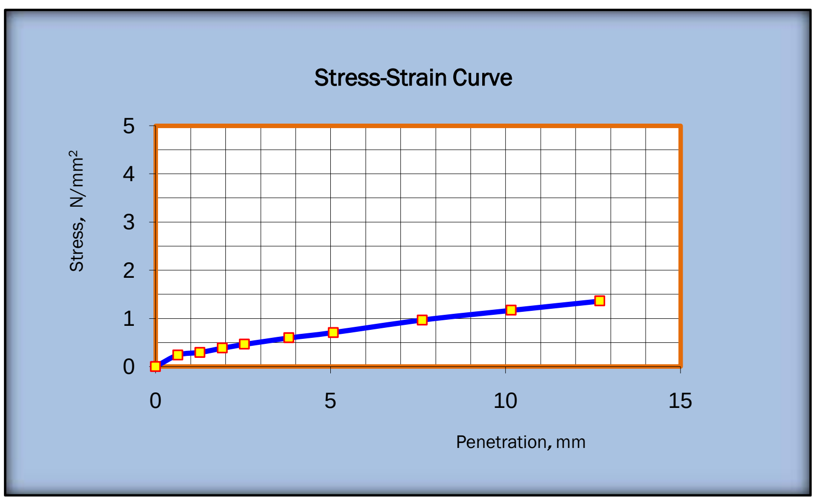
E.3) Marble Dust Content =4% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 8%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**6.86**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	18.0	463	0.24		
1.27	22.0	566	0.29		
1.91	29.0	746	0.39		
2.54	34.8	895	0.46	6.9	6.70
3.81	45.0	1157	0.60		
5.08	53.2	1368	0.71	10.3	6.86
7.62	72.8	1871	0.97		
10.16	88.0	2262	1.17		
12.70	102.5	2635	1.36		



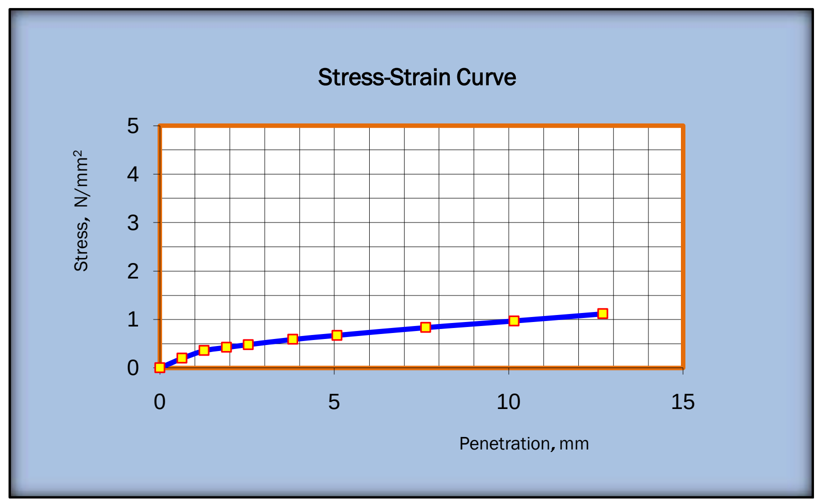
E.4) Marble Dust Content =0% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 12%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**6.93**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	15.0	386	0.20		
1.27	26.8	689	0.36		
1.91	31.8	817	0.42		
2.54	36.0	925	0.48	6.9	6.93
3.81	44.2	1136	0.59		
5.08	50.5	1298	0.67	10.3	6.51
7.62	62.8	1614	0.83		
10.16	73.0	1877	0.97		
12.70	84.0	2159	1.12		



E .SOCKED CBR LABORATORY TEST RESULTS

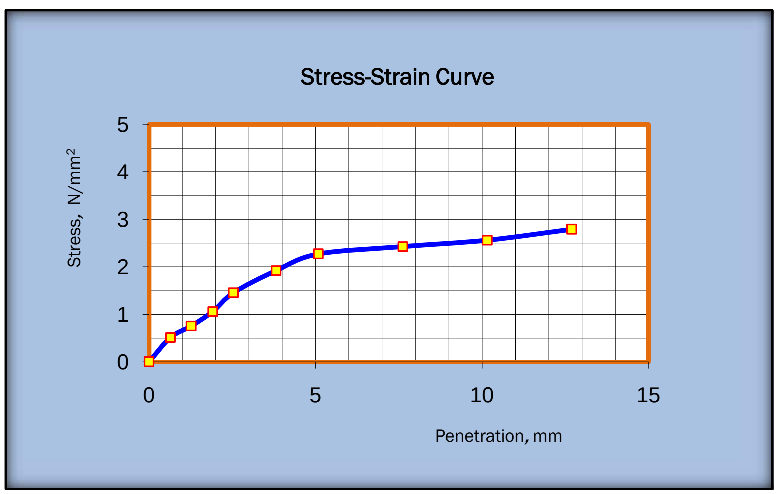
E.6) Marble Dust Content =20% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 20%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**19.22**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	33.0	848	0.44		
1.27	48.0	1234	0.64		
1.91	71.0	1825	0.94		
2.54	85.0	2185	1.13	6.9	16.37
3.81	119.0	3059	1.58		
5.08	149.0	3830	1.98	10.3	19.22
7.62	199.0	5116	2.64		
10.16	240.0	6170	3.19		
12.70	274.0	7044	3.64		



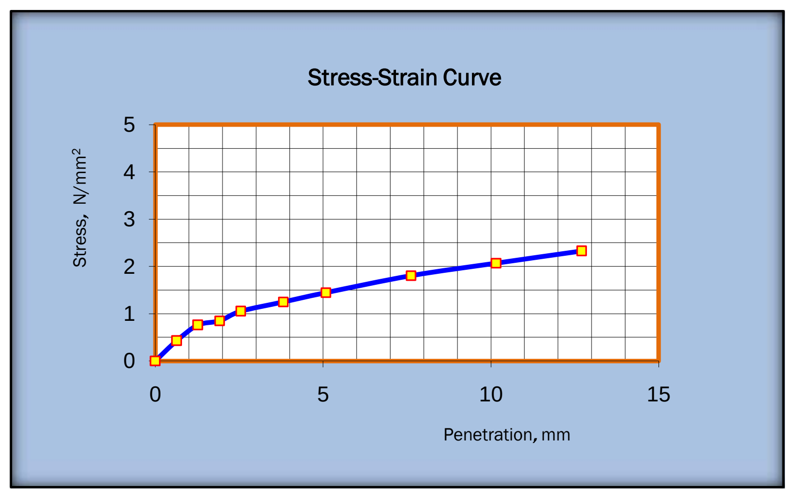
E.5) Marble Dust Content =16% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 16%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**12.64**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	23.0	591	0.31		
1.27	43.0	1105	0.57		
1.91	55.0	1414	0.73		
2.54	65.0	1671	0.86	6.9	12.52
3.81	83.0	2134	1.10		
5.08	98.0	2519	1.30	10.3	12.64
7.62	124.0	3188	1.65		
10.16	145.0	3728	1.93		
12.70	162.0	4165	2.15		



D .UNSOCKED CBR LABORATORY TEST RESULTS

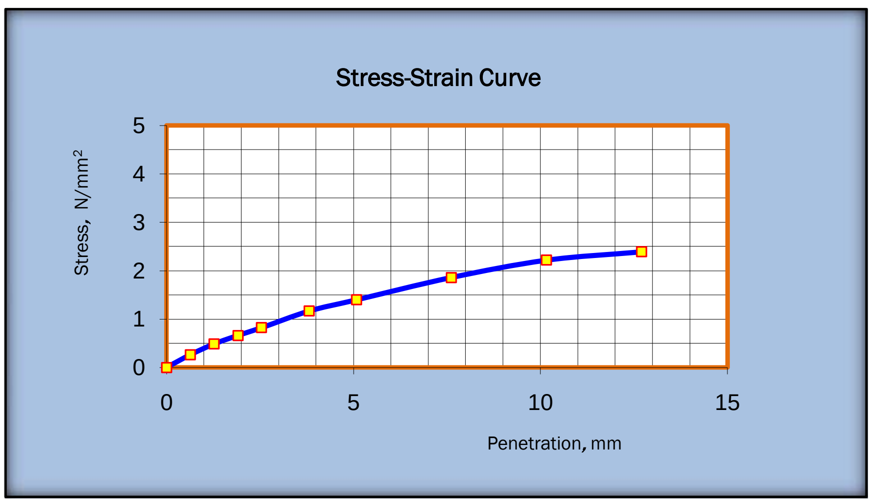
D.5) Marble Dust Content =16% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 16%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**13.61**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	20.0	514	0.27		
1.27	36.8	946	0.49		
1.91	49.8	1280	0.66		
2.54	62.0	1594	0.82	6.9	11.94
3.81	88.0	2262	1.17		
5.08	105.5	2712	1.40	10.3	13.61
7.62	140.0	3599	1.86		
10.16	167.0	4293	2.22		
12.70	180.0	4627	2.39		



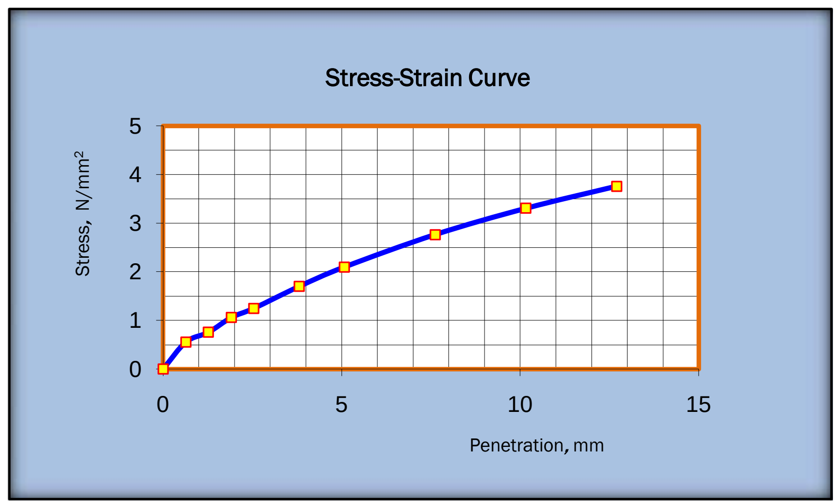
D.6) Marble Dust Content =20% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 20%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**20.38**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	42.0	1080	0.56		
1.27	57.0	1465	0.76		
1.91	80.0	2057	1.06		
2.54	94	2416	1.25	6.9	18.10
3.81	128	3290	1.70		
5.08	158.0	4062	2.10	10.3	20.38
7.62	208.0	5347	2.76		
10.16	249.0	6401	3.31		
12.70	283.0	7275	3.76		



D . UNSOCKED CBR LABORATORY TEST RESULTS

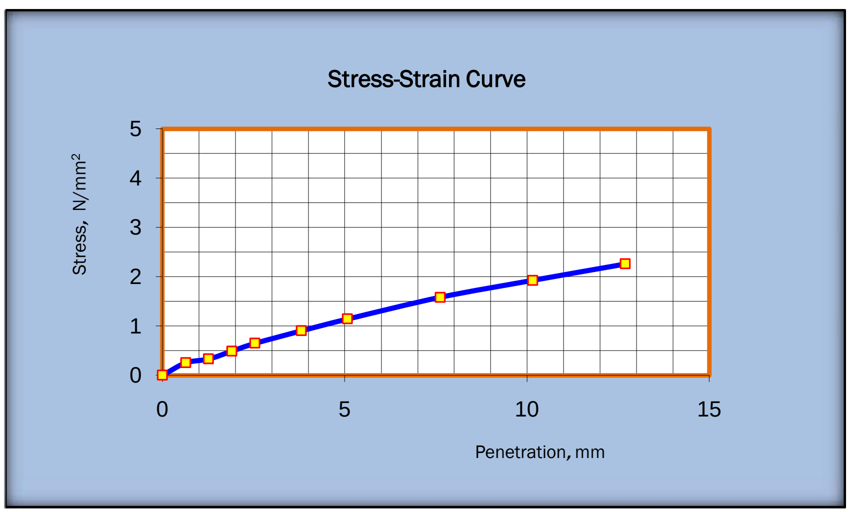
D.4) Marble Dust Content = 12 % ,Curing Day = 7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 12%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**11.09**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	19.0	488	0.25		
1.27	25.0	643	0.33		
1.91	37.0	951	0.49		
2.54	49.0	1260	0.65	6.9	9.43
3.81	68.0	1748	0.90		
5.08	86.0	2211	1.14	10.3	11.09
7.62	119.0	3059	1.58		
10.16	145.0	3728	1.93		
12.70	170.0	4370	2.26		



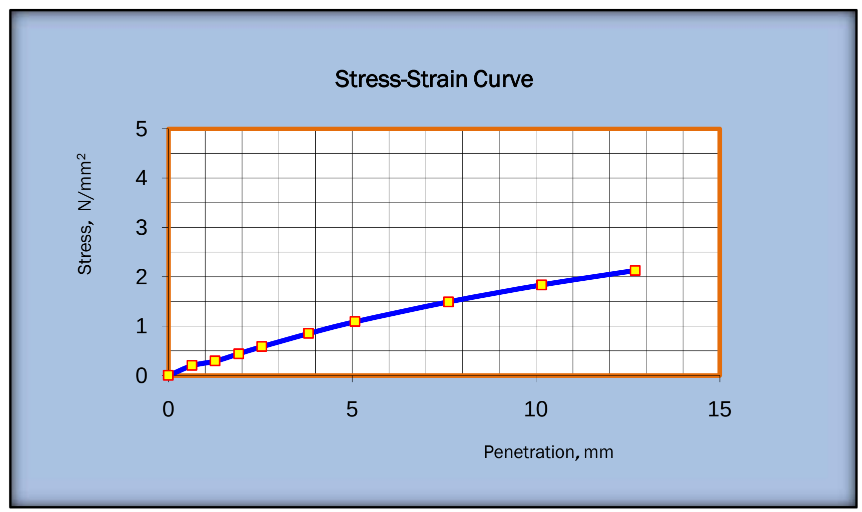
D.3) Marble Dust Content = 8 % ,Curing Day = 7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 8%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**10.58**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	15.0	386	0.20		
1.27	22.0	566	0.29		
1.91	33.0	848	0.44		
2.54	44.0	1131	0.58	6.9	8.47
3.81	64.0	1645	0.85		
5.08	82.0	2108	1.09	10.3	10.58
7.62	112.0	2879	1.49		
10.16	138.0	3548	1.83		
12.70	160.0	4113	2.13		



D .UNSOCKED CBR LABORATORY TEST RESULTS

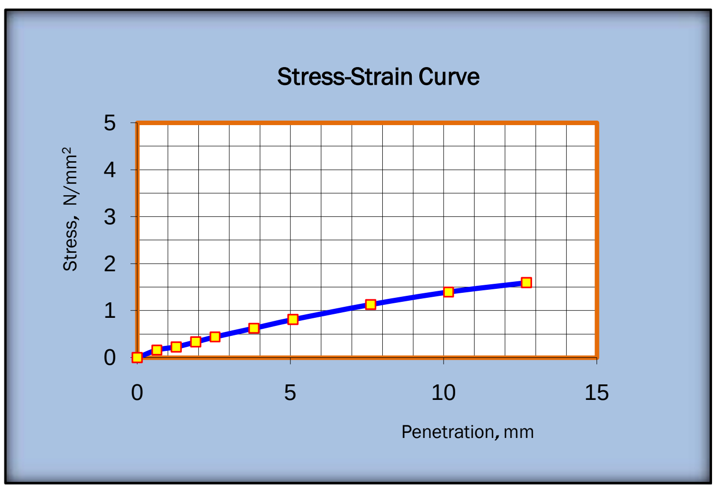
D.2) Marble Dust Content =4% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 4%	Plunger Area, mm²	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**7.87**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm²)	Standard (N/mm²)	CBR (%)
0.00	0.0	0	0.00		
0.64	12.0	308	0.16		
1.27	17.0	437	0.23		
1.91	25.0	643	0.33		
2.54	33.0	848	0.44	6.9	6.35
3.81	47.0	1208	0.62		
5.08	61.0	1568	0.81	10.3	7.87
7.62	85.0	2185	1.13		
10.16	105.0	2699	1.39		
12.70	120.0	3085	1.59		



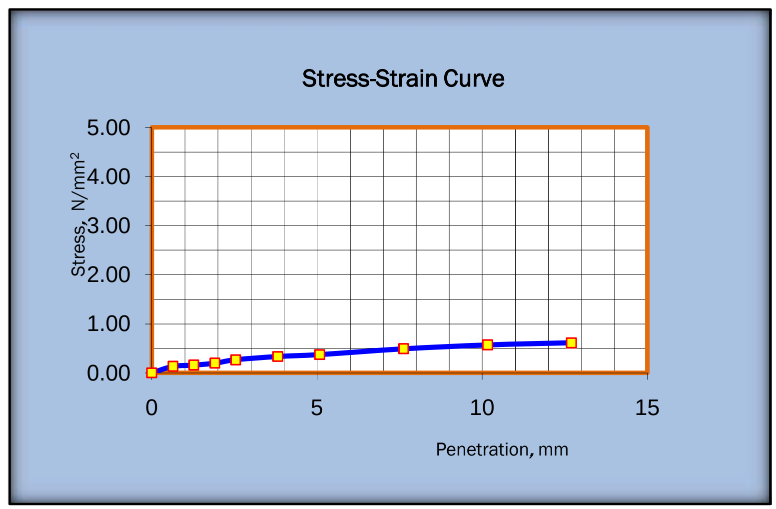
D.1) Marble Dust Content =0% ,Curing Day=7

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	7days , 0%	Plunger Area, mm²	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**3.85**

Penet. (mm)	Ring (Div.)	Load N	Stress (N/mm²)	Standard stress (N/mm²)	CBR (%)
0.00	0.0	0	0.00		
0.64	10.0	257.07	0.13		
1.27	12.0	308.484	0.16		
1.91	15.0	385.605	0.20		
2.54	20.0	514.14	0.27	6.9	3.85
3.81	25.0	642.675	0.33		
5.08	28.0	719.796	0.37	10.3	3.61
7.62	37.0	951.159	0.49		
10.16	43.0	1105.401	0.57		
12.70	46.0	1182.522	0.61		



F .UNSOCKED CBR LABORATORY TEST RESULTS

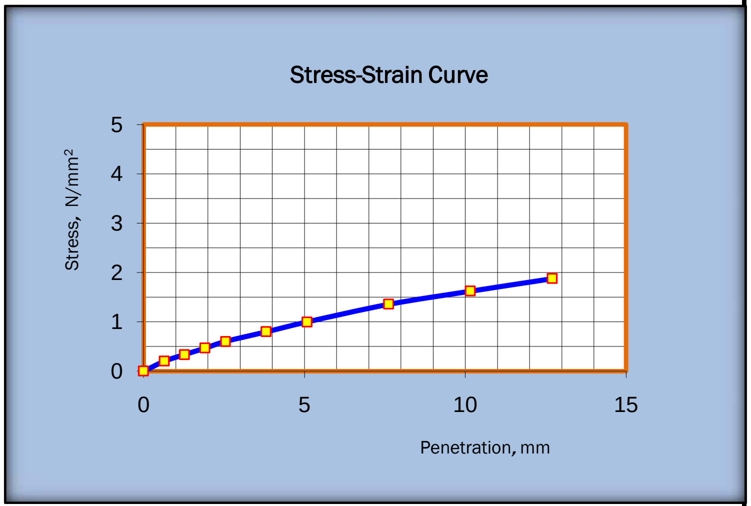
F.2) Marble Dust Content =4% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 4%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/mir	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**9.67**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	15.0	386	0.20		
1.27	25.0	643	0.33		
1.91	35.0	900	0.46		
2.54	45.0	1157	0.60	6.9	8.66
3.81	60.0	1542	0.80		
5.08	75.0	1928	1.00	10.3	9.67
7.62	102.0	2622	1.36		
10.16	122.0	3136	1.62		
12.70	141.0	3625	1.87		



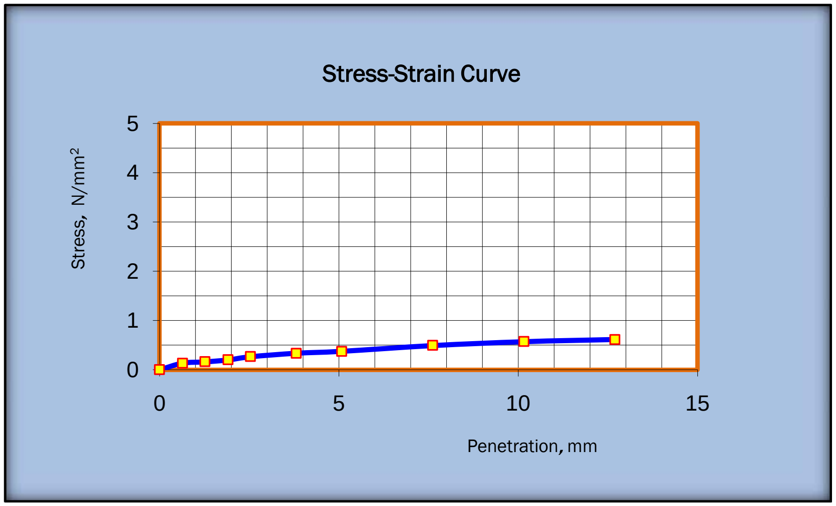
F.1) Marble Dust Content =0% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 0%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5		
Swell, %	0.00	Optimum Most. Content	17
CBR Value, %	**3.85**	Max. Dry DensityMoisture Content	1.38

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	10.0	257	0.13		
1.27	12.0	308	0.16		
1.91	15.0	386	0.20		
2.54	20.0	514	0.27	6.9	3.85
3.81	25.0	643	0.33		
5.08	28.0	720	0.37	10.3	3.61
7.62	37.0	951	0.49		
10.16	43.0	1105	0.57		
12.70	46.0	1183	0.61		



F .UNSOCKED CBR LABORATORY TEST RESULTS

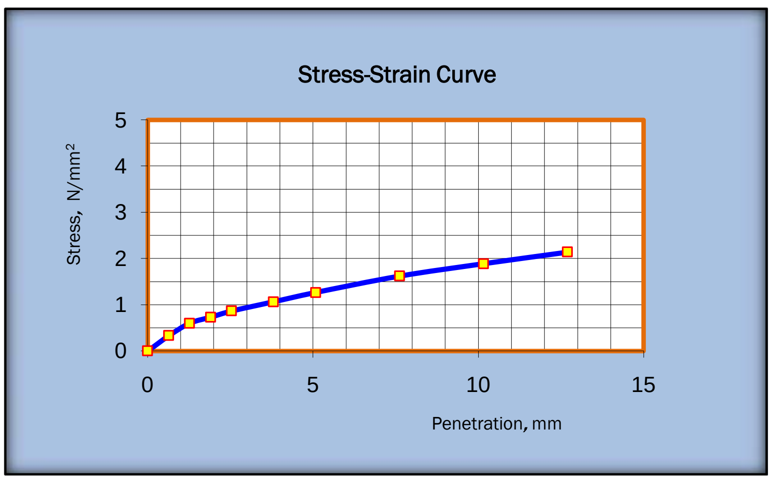
F.3) Marble Dust Content =12% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 12%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5
Swell, %	0.00
CBR Value, %	**12.25**

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	25.0	643	0.33		
1.27	45.0	1157	0.60		
1.91	55.0	1414	0.73		
2.54	65.0	1671	0.86	6.9	12.52
3.81	80.0	2057	1.06		
5.08	95.0	2442	1.26	10.3	12.25
7.62	122.0	3136	1.62		
10.16	142.0	3650	1.89		
12.70	161.0	4139	2.14		



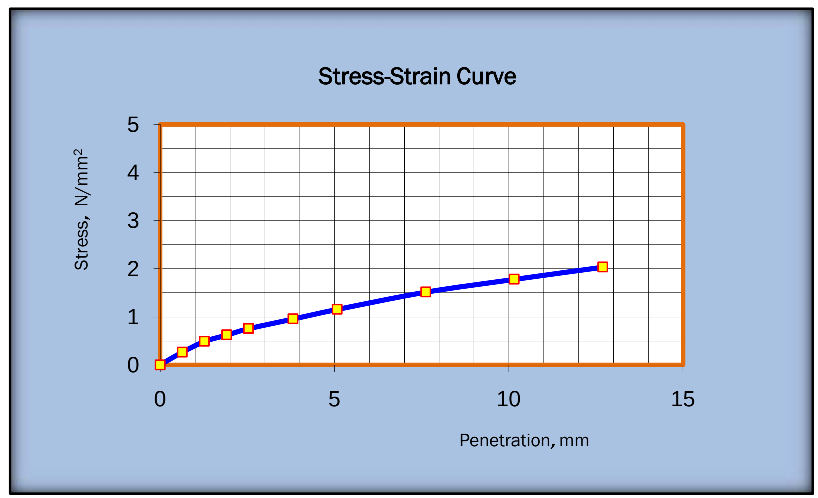
F.4) Marble Dust Content =8% ,Curing Day=14

		Ring Calibration Factor,N/Div	25.707
curing day,marble%	14days , 8%	Plunger Area, mm^2	1935
Material Desc.	Subgrade	Rate of strain ,mm/min	1.27
Station:	0+200	Rammer wt. (kg)	4.54

CBR Computation Table

Blow/ Layer	56/5		
Swell, %	0.00	Optimum Most. Content	17
CBR Value, %	**11.22**	Max. Dry DensityMoisture Content	1.38

Penet. (mm)	Ring (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	20.0	514	0.27		
1.27	37.0	951	0.49		
1.91	47.0	1208	0.62		
2.54	57.0	1465	0.76	6.9	10.97
3.81	72.0	1851	0.96		
5.08	87.0	2237	1.16	10.3	11.22
7.62	114.0	2931	1.51		
10.16	134.0	3445	1.78		
12.70	153.0	3933	2.03		



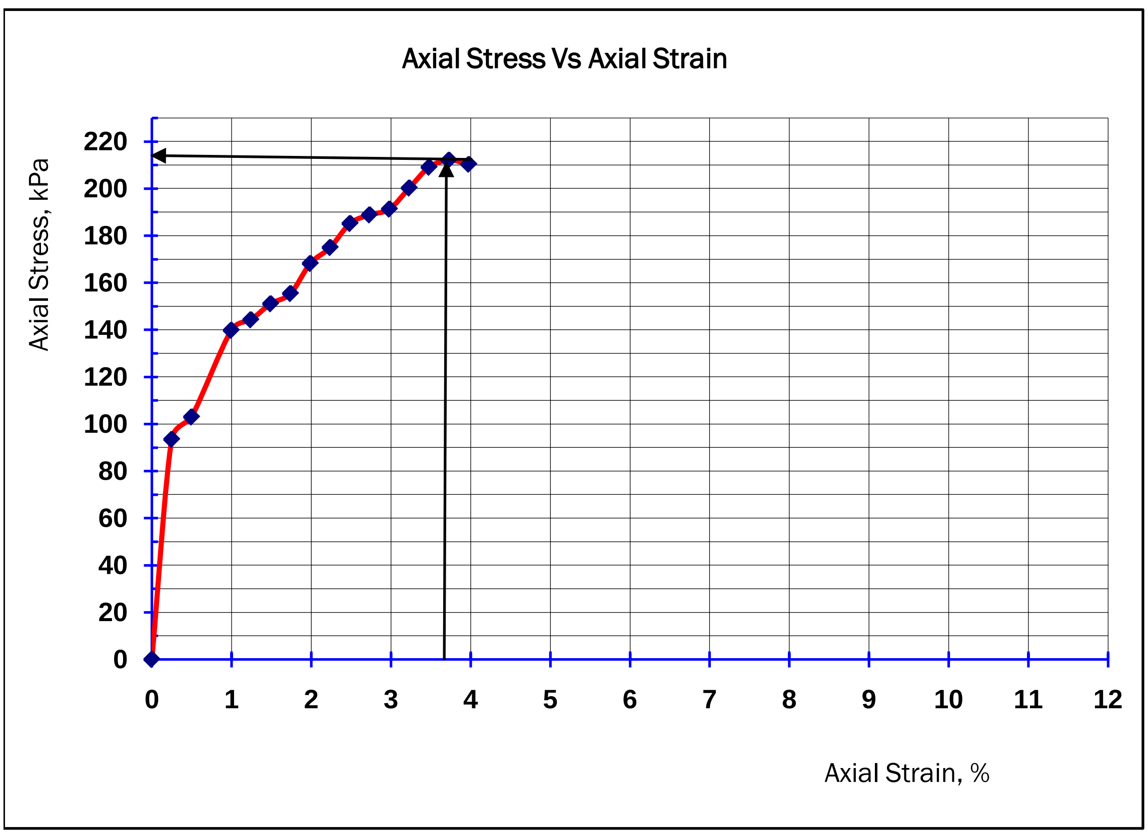
B) Unconfined Compressive Strength Laboratory Test Results

B.4) Marble Dust Content =12 % ,Curing Day=7

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	80.5	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.25	77	0.1063	0.001137	93.46
0.40	0.50	85	0.1173	0.001140	102.91
0.80	0.99	116	0.1601	0.001145	139.75
1.00	1.24	120	0.1656	0.001148	144.20
1.20	1.49	126	0.1739	0.001151	151.03
1.40	1.74	130	0.1794	0.001154	155.43
1.60	1.99	141	0.1946	0.001157	168.16
1.80	2.24	147	0.2029	0.001160	174.87
2.00	2.48	156	0.2153	0.001163	185.11
2.20	2.73	159.5	0.2201	0.001166	188.78
2.40	2.98	162	0.2236	0.001169	191.25
2.60	3.23	170	0.2346	0.001172	200.18
2.80	3.48	178	0.2456	0.001175	209.06
3.00	3.73	181	0.2498	0.001178	212.03
3.20	3.98	180	0.2484	0.001181	210.32

Unconfined Compressive Strength , kPa = 212

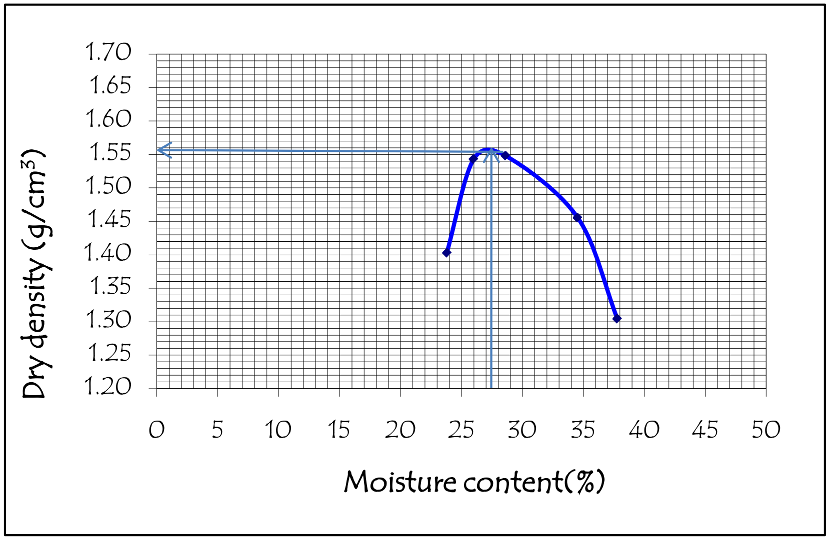


A.12) Marble Dust Content =16 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4	5
Mass of Mold, g	4399.3	4399.3	4399.3	4399.3	4480
Mass of mold+ Compacted Soil, g	6038.5	6234.1	6278.8	6247.5	6176.4
Mass of Compacted soil, g	1639.2	1834.8	1879.5	1848.2	1696.4
Volume of Mold,cm3	944.0	944.0	944.0	944.0	944.0
Bulk density, g/cm3	1.7	1.9	2.0	2.0	1.8
Water Contenet, %	23.8	26.0	28.6	34.5	37.8
Dry density, g/cm3	1.40	1.54	1.55	1.46	1.30

Max.dry dernsity,(g/cm3) = 1.55 Opt. moisture content, %(omc)= 28.6



Water Content

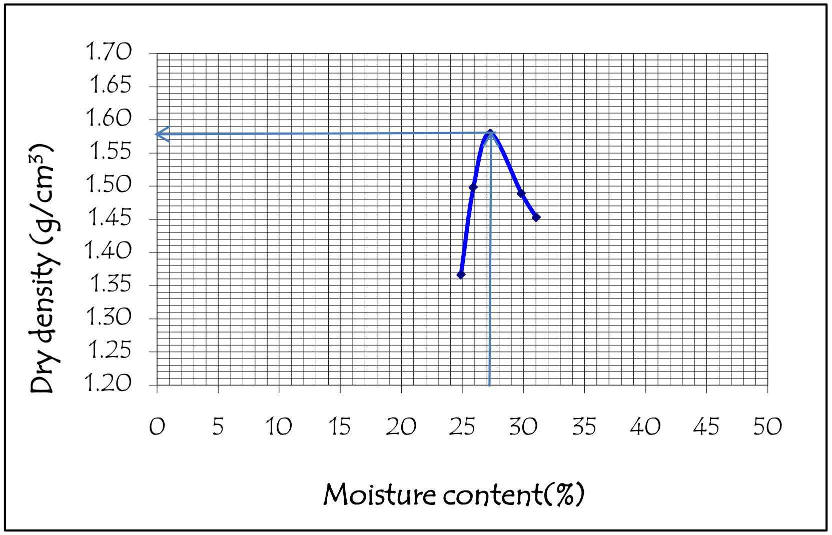
Conatainer No	1	2	3	4	5
Mass of container, g	13.8	15.7	15.7	15.8	15.7
Mass of container + wet soil, g	47.1	54.0	59.3	53.6	40.5
Mass of ontainer + Dry soil, g	40.7	46.1	49.6	43.9	33.7
Mass of Water, g	6.4	7.9	9.7	9.7	6.8
Mass of Dry soil, g	26.9	30.4	33.9	28.1	18.0
Water content, %	23.8	26.0	28.6	34.5	37.8
Dry Unit Weight, g/cm3	1.40	1.54	1.55	1.46	1.30

A.13) Marble Dust Content =20 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4	5
Mass of Mold, g	3152.7	3152.7	3152.7	3152.7	3152.7
Mass of mold+ Compacted Soil, g	4763.5	4932.8	5050.4	4977.3	4949.8
Mass of Compacted soil, g	1610.8	1780.1	1897.7	1824.6	1797.1
Volume of Mold,cm3	944.0	944.0	944.0	944.0	944.0
Bulk density, g/cm3	1.7	1.9	2.0	1.9	1.9
Water Contenet, %	24.9	25.9	27.3	29.8	31.1
Dry density, g/cm3	1.37	1.50	1.58	1.49	1.45

Max.dry dernsity,(g/cm3) = 1.58 Opt. moisture content, %(omc)= 27.3



Water Content

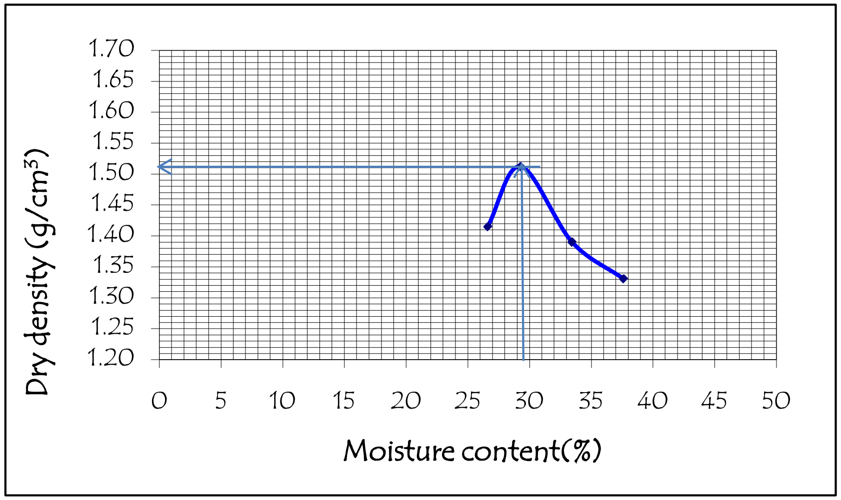
Conatainer No	1	2	3	4	5
Mass of container, g	15.6	15.8	15.7	15.4	15.7
Mass of container + wet soil, g	44.2	54.7	40.9	52.4	56.2
Mass of ontainer + Dry soil, g	38.5	46.7	35.5	43.9	46.6
Mass of Water, g	5.7	8.0	5.4	8.5	9.6
Mass of Dry soil, g	22.9	30.9	19.8	28.5	30.9
Water content, %	24.9	25.9	27.3	29.8	31.1
Dry Unit Weight, g/cm3	1.37	1.50	1.58	1.49	1.45

A.9) Marble Dust Content =8 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	4399.3	4350.3	4399.3	4399.3
Mass of mold+ Compacted Soil, g	6090.7	6195.8	6203.3	6128.4
Mass of Compacted soil, g	1691.4	1845.5	1804	1729.1
Volume of Mold,cm3	944	944	944	944
Bulk density, g/cm3	1.79	1.95	1.91	1.83
Water Contenet, %	26.6	29.3	33.5	37.6
Dry density, g/cm3	1.41	1.51	1.43	1.33

Max.dry dernsity,(g/cm3) = 1.51 opt.moisture content,%(omc)= 29.3



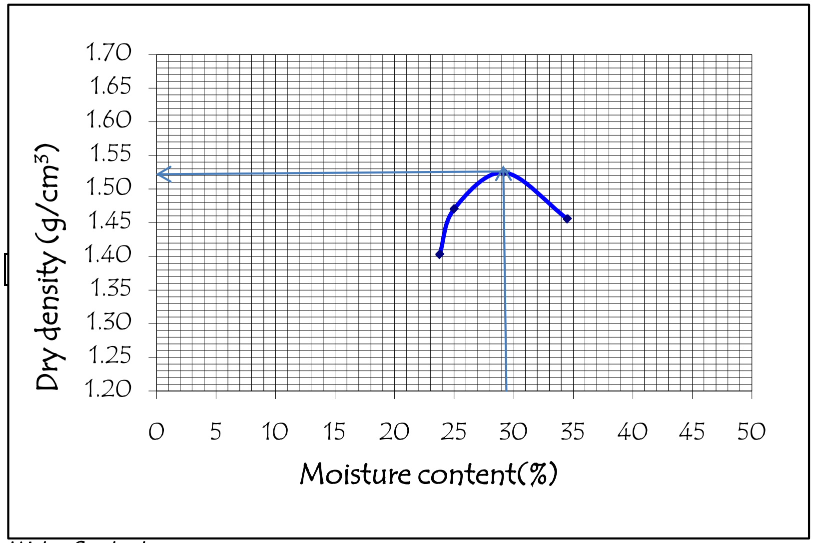
Water Content				
Conatainer No	1	2	3	4
Mass of container, g	15.8	15.7	15.8	15.8
Mass of container + wet soil, g	60.5	48.0	53.1	70.3
Mass of ontainer + Dry soil, g	51.1	40.7	44.0	55.4
Mass of Water, g	9.4	7.3	11.1	14.9
Mass of Dry soil, g	35.3	25.0	32.3	39.6
Water content, %	26.6	29.3	33.5	37.6
Dry Unit Weight, g/cm3	1.41	1.51	1.39	1.33

A.10) Marble Dust Content =12 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	4399.3	4399.3	4399.3	4399.3
Mass of mold+ Compacte	6038.5	6134.1	6258.8	6247.5
Mass of Compacted soil, g	1639.2	1734.8	1859.5	1848.2
Volume of Mold,cm3	944	944	944	944
Bulk density, g/cm3	1.74	1.84	1.97	1.96
Water Contenet, %	23.8	25.0	29.2	34.5
Dry density, g/cm3	1.40	1.47	1.52	1.46

Max.dry dernsity,(g/cm3) = 1.52 Opt. moisture content, %(omc)= 29.2



Water Content

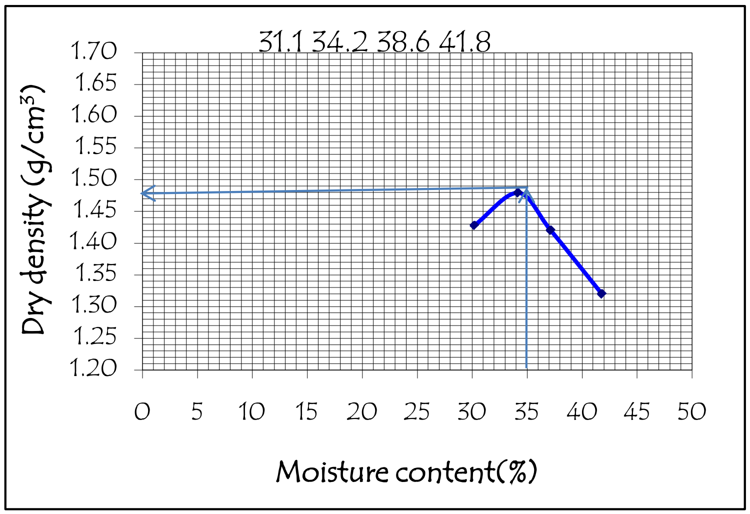
Conatainer No	1.0	2.0	3.0	4.0
Mass of container, g	13.8	15.7	15.7	15.8
Mass of container + we	47.1	53.7	59.5	53.6
Mass of ontainer + Dry	40.70	46.10	49.60	43.90
Mass of Water, g	6.4	7.6	9.9	9.7
Mass of Dry soil, g	26.9	30.4	33.9	28.1
Water content, %	23.8	25.0	29.2	34.5
Dry Unit Weight, g/cm	1.40	1.47	1.52	1.46

A.7) Marble Dust Content =0 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	5
Mass of Mold, g	3007.2	3007.2	3007.2	3007.2
Mass of mold+ Compacted Soil, g	4763.0	4881.0	4848.3	4774.4
Mass of Compacted soil, g	1755.8	1873.8	1841.1	1767.2
Volume of Mold,cm3	944	944	945	944
Bulk density, g/cm3	1.86	1.98	1.95	1.87
Water Contenet, %	31.1	34.2	38.6	41.8
Dry density, g/cm3	1.42	1.48	1.41	1.32

Max.dry dernsity,(g/cm3) = 1.48 pt. moisture content, %(omc)= 34.0



Water Content

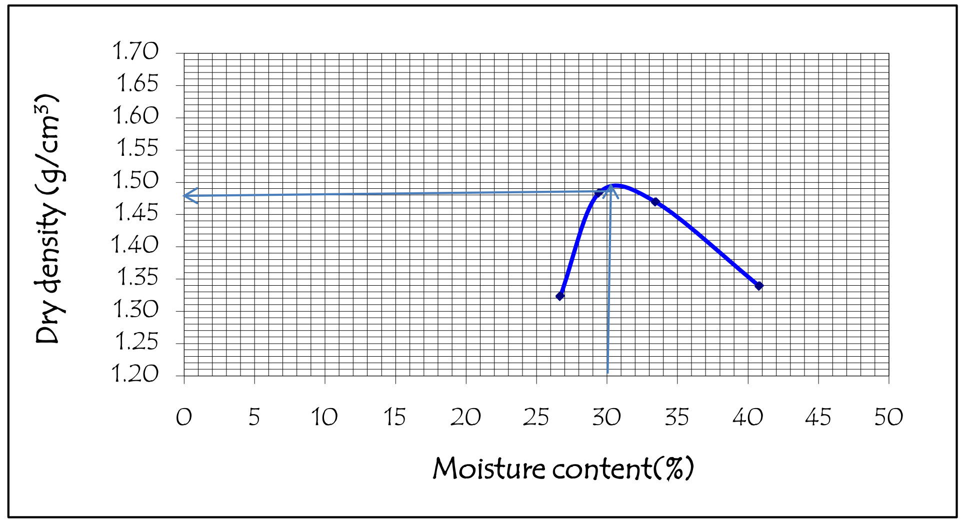
Conatainer No	1	2	3	4
Mass of container, g	20.1	24.5	15.8	15.5
Mass of container + wet soil, g	35.5	46.1	35.2	40.6
Mass of ontainer + Dry soil, g	31.85	40.6	29.8	33.2
Mass of Water, g	3.65	5.5	5.4	7.4
Mass of Dry soil, g	11.75	16.1	14	17.7
Water content, %	31.1	34.2	38.6	41.8
Dry Unit Weight, g/cm3	1.42	1.48	1.41	1.32

A.8) Marble Dust Content =4 % ,Curing Day=14

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	4399.3	4399.3	4399.3	4399.3
Mass of mold+ Co	5981.5	6211.8	6250.6	6179.3
Mass of Compacted	1582.2	1812.5	1851.3	1780
Volume of Mold,cm	944	944	944	944
Bulk density, g/cm	1.68	1.92	1.96	1.89
Water Contenet, %	26.7	29.4	33.5	40.8
Dry density, g/cm3	1.32	1.48	1.47	1.34

Max.dry dernsity,(g/cm3) = 1.48 Opt. moisture content, %(omc)= 29.4



Water Content

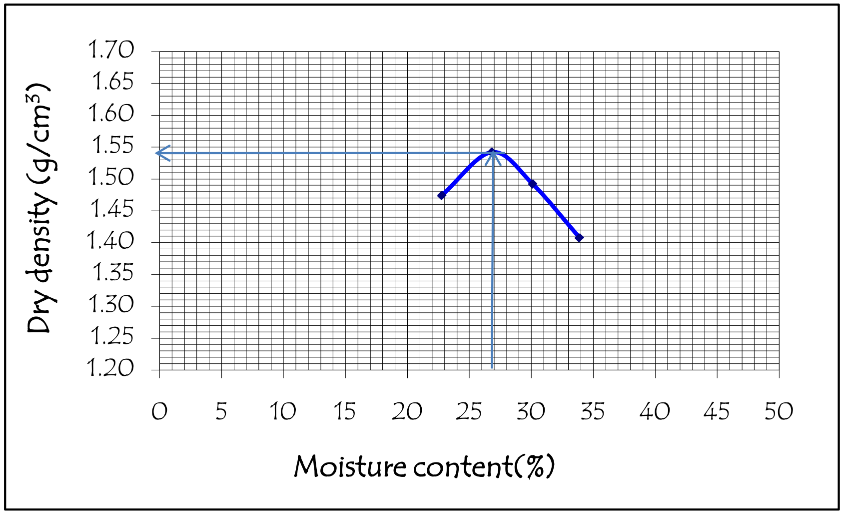
Conatainer No	1	2	3	4
Mass of containe	15.8	15.7	15.6	15.5
Mass of containe	62.8	52.2	51.9	50
Mass of ontainer	52.9	43.9	42.8	40.0
Mass of Water, g	9.9	8.3	9.1	10
Mass of Dry soil,	37.1	28.2	27.2	24.5
Water content, %	26.7	29.4	33.5	40.8
Dry Unit Weight,	1.32	1.48	1.47	1.34

A.5) Marble Dust Content =16% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	4397.3	4397.3	4397.3	4397.3
Mass of mold+ Compacted Soil, g	6105.9	6243.0	6230.1	6176.4
Mass of Compacted soil, g	1708.6	1845.7	1832.8	1779.1
Volume of Mold,cm3	944.0	944.0	944.0	944.0
Bulk density, g/cm3	1.8	2.0	1.9	1.9
Water Contenet, %	22.8	26.8	30.1	33.9
Dry density, g/cm3	1.47	1.54	1.49	1.41

Max.dry dernsity,(g/cm3) = 1.54 Opt. moisture content, %(omc)= 26.8



Water Content

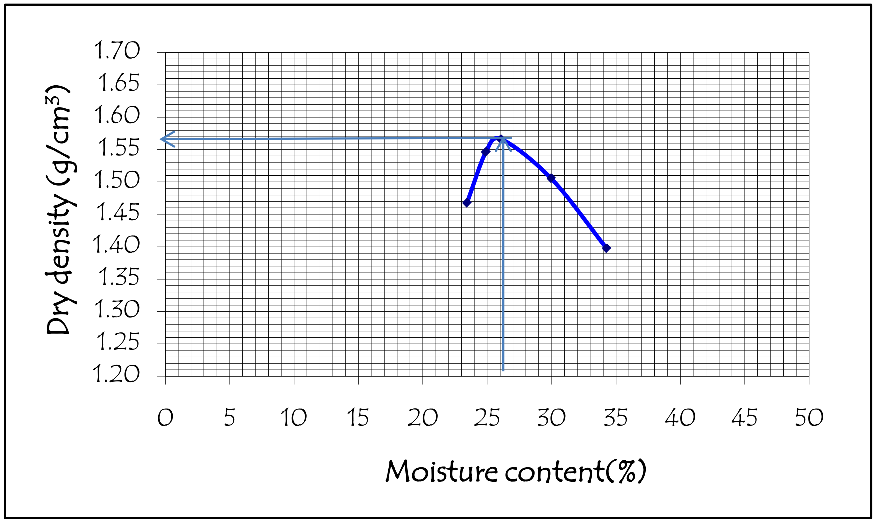
Conatainer No	1	2	3	4
Mass of container, g	15.5	15.6	11.4	15.7
Mass of container + wet soil, g	44.6	40.2	46.4	39.8
Mass of ontainer + Dry soil, g	39.2	35.0	38.3	33.7
Mass of Water, g	5.4	5.2	8.1	6.1
Mass of Dry soil, g	23.7	19.4	26.9	18.0
Water content, %	22.8	26.8	30.1	33.9
Dry Unit Weight, g/cm3	1.47	1.54	1.49	1.41

A.6) Marble Dust Content =20% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4	5
Mass of Mold, g	4397.3	4397.3	4397.3	4397.3	4397.3
Mass of mold+ Compa	6107.3	6220.3	6261.2	6244.5	6168.6
Mass of Compacted soi	1710.0	1823.0	1863.9	1847.2	1771.3
Volume of Mold,cm3	944.0	944.0	944.0	944.0	944.0
Bulk density, g/cm3	1.8	1.9	2.0	2.0	1.9
Water Contenet, %	23.4	24.9	26.1	30.0	34.3
Dry density, g/cm3	1.47	1.55	1.57	1.51	1.40

Max.dry dernsity,(g/cm3) = 1.57 Opt. moisture content, %(omc)= 26.1



Water Content

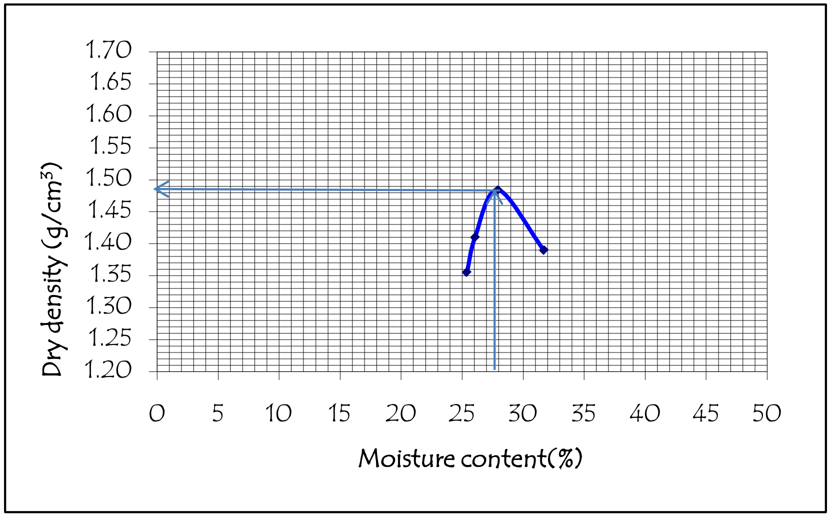
Conatainer No	1	2	3	4	5
Mass of container, g	13.8	15.3	15.6	10.9	15.4
Mass of container +	41.2	44.9	33.5	43.0	58.9
Mass of ontainer + [	36.0	39.0	29.8	35.6	47.8
Mass of Water, g	5.2	5.9	3.7	7.4	11.1
Mass of Dry soil, g	22.2	23.7	14.2	24.7	32.4
Water content, %	23.4	24.9	26.1	30.0	34.3
Dry Unit Weight, g/	1.47	1.55	1.57	1.51	1.40

A.3) Marble Dust Content =8% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	4396.7	4396.7	4396.7	4396.7
Mass of mold+ Compacted Soil, g	6001	6074.4	6189	6144.8
Mass of Compacted soil, g	1604.3	1677.7	1792.3	1748.1
Volume of Mold,cm3	944	944	944	944
Bulk density, g/cm3	1.70	1.78	1.90	1.85
Water Contenet, %	25.4	26.1	27.9	31.7
Dry density, g/cm3	1.36	1.41	1.48	1.40

Max.dry dernsity,(g/cm3) = 1.48 27.5



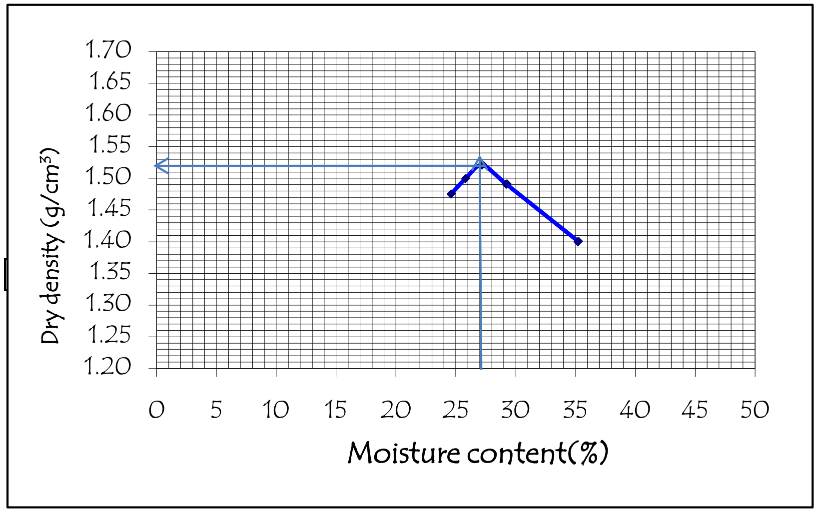
Water Content				
Conatainer No	1	2	3	4
Mass of container, g	15.7	15.6	15.4	15.1
Mass of container + wet soil, g	39.9	54.3	43.8	51.0
Mass of ontainer + Dry soil, g	35.0	46.3	37.6	41.5
Mass of Water, g	4.9	8.0	6.2	8.5
Mass of Dry soil, g	19.3	30.7	22.2	26.4
Water content, %	25.4	26.1	27.9	31.7
Dry Unit Weight, g/cm3	1.36	1.41	1.48	1.39

A.4) Marble Dust Content =12% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4	5
Mass of Mold, g	4401.2	4401.2	4401.2	4401.2	4401.2
Mass of mold+ Compacte	6136.9	6182.4	6228	6220	6188.8
Mass of Compacted soil, g	1735.7	1781.2	1826.8	1818.8	1787.6
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.84	1.89	1.94	1.93	1.89
Water Contenet, %	24.6	25.8	27.2	29.3	35.3
Dry density, g/cm3	1.48	1.50	1.52	1.49	1.40

Max.dry dernsity,(g/cm3) = 1.52 Opt. moisture content, %(omc)= 27.2



Water Content

Conatainer No	1	2	3	4	5
Mass of container, g	15.6	15.5	15.2	15.2	15.1
Mass of container + we	31.8	46.2	28.1	34.2	33.9
Mass of ontainer + Dry	28.6	39.9	25.3	29.9	29.0
Mass of Water, g	3.2	6.3	2.8	4.3	4.9
Mass of Dry soil, g	13.0	24.4	10.1	14.7	13.9
Water content, %	24.6	25.8	27.2	29.3	35.3
Dry Unit Weight, g/cm	1.48	1.50	1.52	1.49	1.40

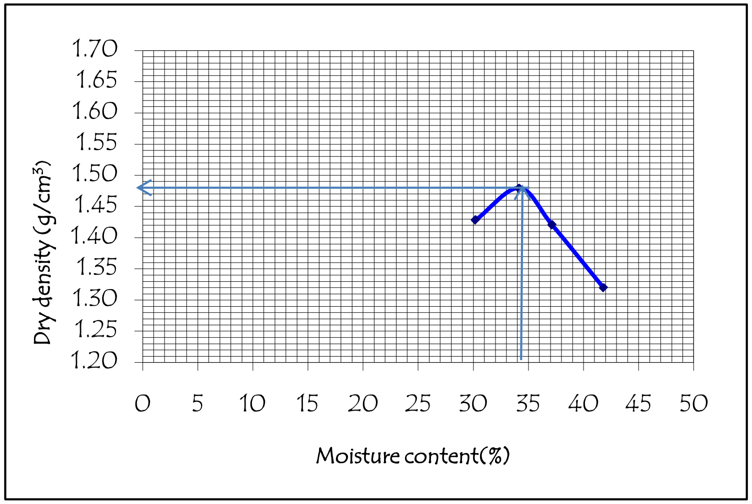
A .COMPATION LABORATORY TEST RESULTS

A.1) Marble Dust Content =0% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4
Mass of Mold, g	3007.2	3007.2	3007.2	3007.2
Mass of mold+ Compacted Soil, g	4763.0	4881.0	4848.3	4774.4
Mass of Compacted soil, g	1755.8	1873.8	1841.1	1767.2
Volume of Mold,cm3	944	944	945	944
Bulk density, g/cm3	1.86	1.98	1.95	1.87
Water Contenet, %	30.2	34.2	37.1	41.8
Dry density, g/cm3	1.43	1.48	1.42	1.32

Max.dry dernsity,(g/cm3) = 1.48)pt. moisture content, %(omc)= 34.0



Water Content

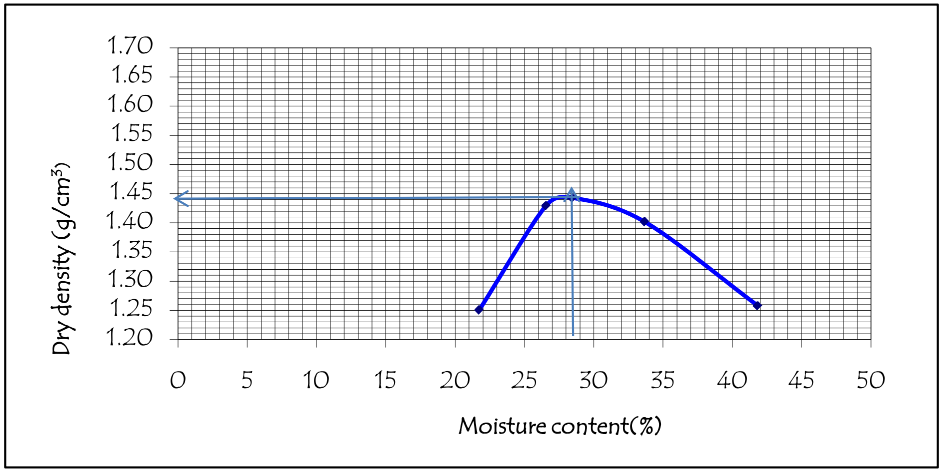
Conatainer No	1	2	3	4
Mass of container, g	20.1	24.5	15.8	15.5
Mass of container + wet soil, g	35.4	46.1	35	40.6
Mass of ontainer + Dry soil, g	31.85	40.6	29.8	33.2
Mass of Water, g	3.55	5.5	5.2	7.4
Mass of Dry soil, g	11.75	16.1	14	17.7
Water content, %	30.2	34.2	37.1	41.8
Dry Unit Weight, g/cm3	1.43	1.48	1.42	1.32

A.2) Marble Dust Content =4% ,Curing Day=7

Moisture content Vs dry density comp. table

Determination No.	1	2	3	4	5
Mass of Mold, g	3122	3122	3122	3122	3122
Mass of mold+ Comp	4558.9	4829.6	4871.2	4890.6	4806
Mass of Compacted so	1436.9	1707.6	1749.2	1768.6	1684
Volume of Mold,cm3	944	944	944	944	944
Bulk density, g/cm3	1.52	1.81	1.85	1.87	1.78
Water Contenet, %	21.7	26.6	28.4	33.7	41.8
Dry density, g/cm3	1.25	1.43	1.44	1.40	1.26

Max.dry dernsity,(g/cm3) = 1.44 Opt. moisture content, %(omc)= 28.0



Water Content

Conatainer No	1	2	3	4	5
Mass of container,	15.3	15.7	14.9	15.4	15.5
Mass of container +	45	38.1	57.8	42.8	38.9
Mass of ontainer +	39.7	33.4	48.3	35.9	32
Mass of Water, g	5.3	4.7	9.5	6.9	6.9
Mass of Dry soil, g	24.4	17.7	33.4	20.5	16.5
Water content, %	21.7	26.6	28.4	33.7	41.8
Dry Unit Weight, g	1.25	1.43	1.44	1.40	1.26

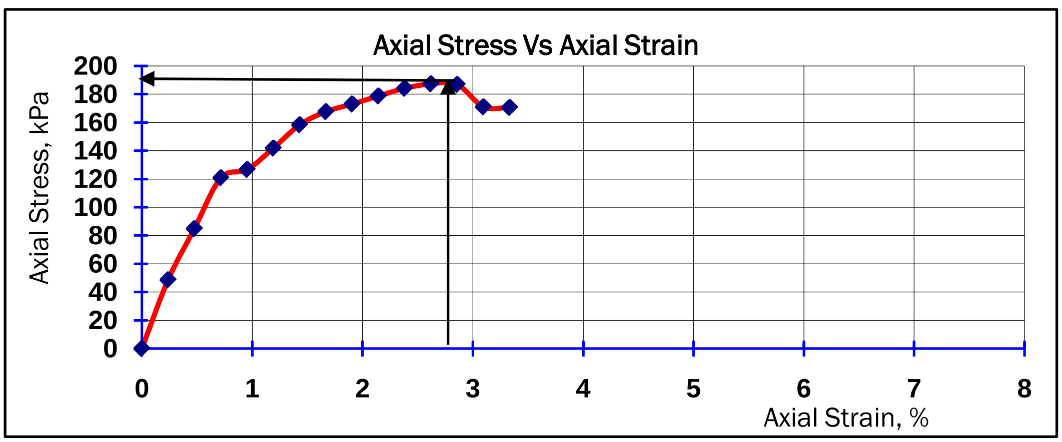
B) Unconfined Compressive Strength Laboratory Test Results

B.5) Marble Dust Content =16 % ,Curing Day=7

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	84	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.24	40	0.0552	0.001137	48.56
0.40	0.48	70	0.0966	0.001140	84.77
0.60	0.71	100	0.1380	0.001142	120.81
0.80	0.95	105	0.1449	0.001145	126.55
1.00	1.19	118	0.1628	0.001148	141.87
1.20	1.43	132	0.1822	0.001151	158.32
1.40	1.67	140	0.1932	0.001153	167.51
1.60	1.90	145	0.2001	0.001156	173.08
1.80	2.14	150	0.2070	0.001159	178.61
2.00	2.38	155	0.2139	0.001162	184.11
2.20	2.62	158	0.2180	0.001165	187.22
2.40	2.86	158	0.2180	0.001167	186.76
2.60	3.10	145	0.2001	0.001170	170.98
2.80	3.33	145	0.2001	0.001173	170.56

Unconfined Compressive Strength , kPa = 187



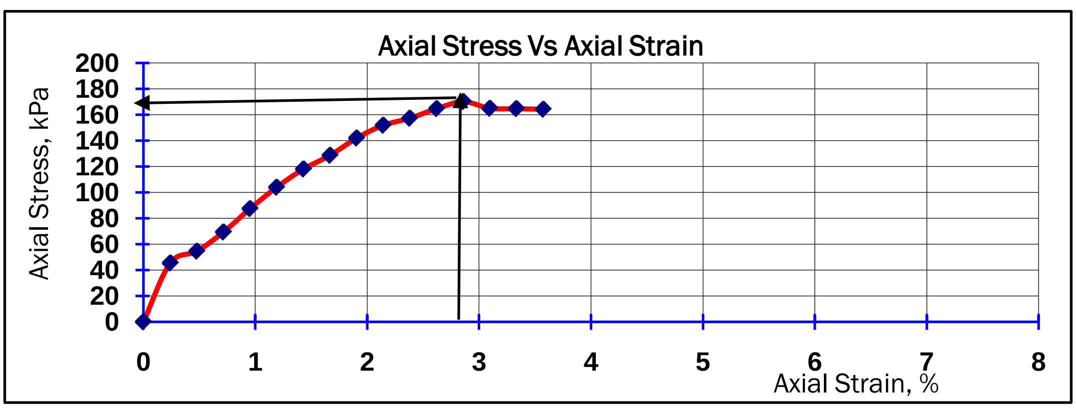
B) Unconfined Compressive Strength Laboratory Test Results

B.6) Marble Dust Content =20 % ,Curing Day=7

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	84	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.24	37.5	0.0518	0.001137	45.52
0.40	0.48	45	0.0621	0.001140	54.50
0.60	0.71	57.5	0.0794	0.001142	69.47
0.80	0.95	72.5	0.1001	0.001145	87.38
1.00	1.19	86.5	0.1194	0.001148	104.00
1.20	1.43	98.5	0.1359	0.001151	118.14
1.40	1.67	107.5	0.1484	0.001153	128.63
1.60	1.90	119	0.1642	0.001156	142.04
1.80	2.14	127.5	0.1760	0.001159	151.82
2.00	2.38	132.5	0.1829	0.001162	157.39
2.20	2.62	139	0.1918	0.001165	164.71
2.40	2.86	144	0.1987	0.001167	170.21
2.60	3.10	140	0.1932	0.001170	165.08
2.80	3.33	140	0.1932	0.001173	164.67
3.00	3.57	140	0.1932	0.001176	164.27

Unconfined Compressive Strength , kPa = 170



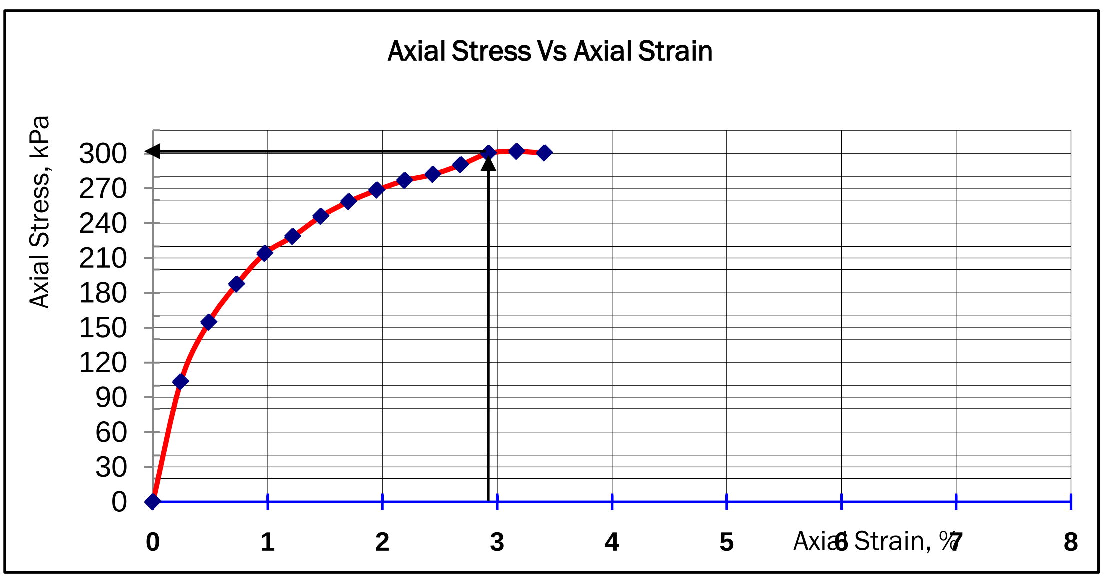
B) Unconfined Compressive Strength Laboratory Test Results

B.3) Marble Dust Content =8 % ,Curing Day=7

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	82	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.24	85	0.1173	0.001137	103.18
0.40	0.49	127.5	0.1760	0.001140	154.39
0.60	0.73	155	0.2139	0.001142	187.23
0.80	0.98	177.5	0.2450	0.001145	213.88
1.00	1.22	190	0.2622	0.001148	228.37
1.20	1.46	205	0.2829	0.001151	245.80
1.40	1.71	216	0.2981	0.001154	258.34
1.60	1.95	225	0.3105	0.001157	268.44
1.80	2.20	232.5	0.3209	0.001160	276.70
2.00	2.44	237.5	0.3278	0.001162	281.94
2.20	2.68	245	0.3381	0.001165	290.12
2.40	2.93	254	0.3505	0.001168	300.02
2.60	3.17	256	0.3533	0.001171	301.63
2.80	3.41	255.5	0.3526	0.001174	300.28
3.00	3.66	255	0.3519	0.001177	298.93

Unconfined Compressive Strength , kPa = 302



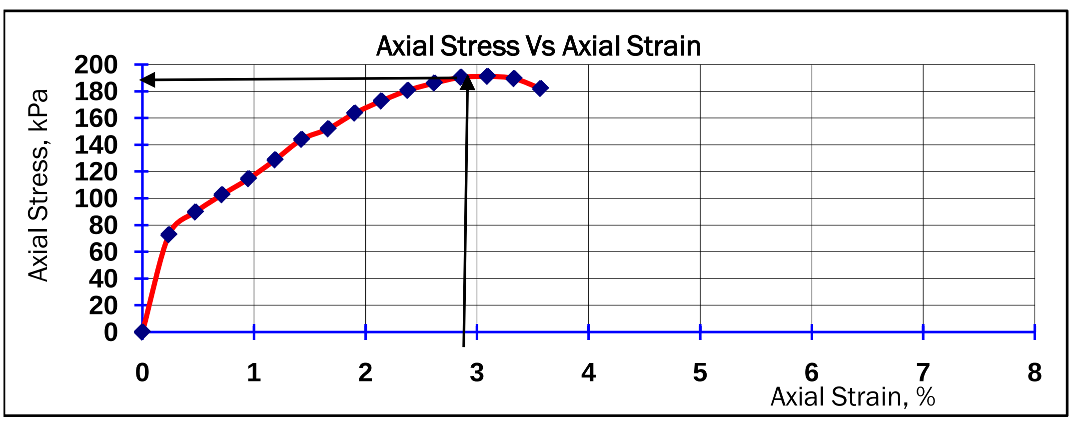
B) Unconfined Compressive Strength Laboratory Test Results

B.2) Marble Dust Content =4 % ,Curing Day=7

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	84	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.24	60	0.0828	0.001137	72.83
0.40	0.48	74	0.1021	0.001140	89.62
0.60	0.71	85	0.1173	0.001142	102.69
0.80	0.95	95	0.1311	0.001145	114.50
1.00	1.19	107	0.1477	0.001148	128.65
1.20	1.43	120	0.1656	0.001151	143.93
1.40	1.67	127	0.1753	0.001153	151.96
1.60	1.90	137	0.1891	0.001156	163.53
1.80	2.14	145	0.2001	0.001159	172.66
2.00	2.38	152	0.2098	0.001162	180.55
2.20	2.62	157	0.2167	0.001165	186.04
2.40	2.86	161	0.2222	0.001167	190.31
2.60	3.10	162	0.2236	0.001170	191.02
2.80	3.33	161	0.2222	0.001173	189.38
3.00	3.57	155	0.2139	0.001176	181.87

Unconfined Compressive Strength , kPa = 191

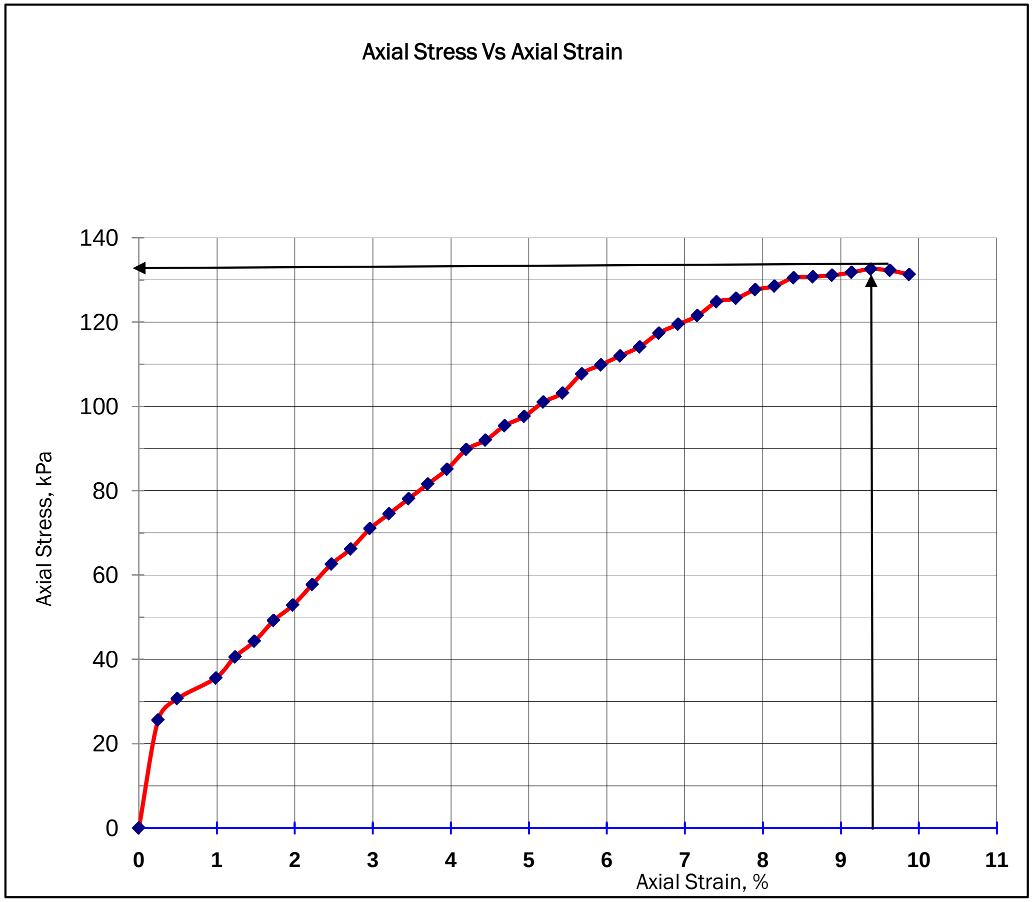


B) Unconfined Compressive Strength Laboratory Test Results

B.1) Marble Dust Content =0 % ,Curing Day=7

Diameter of sample , mm	37	**Cross- Sectional Area , m^2**	**0.001075**
Length of sample , mm	81	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001075	0
0.20	0.25	20	0.0276	0.001078	25.61
0.40	0.49	24	0.0331	0.001081	30.65
0.80	0.99	28	0.0386	0.001086	35.58
1.00	1.23	32	0.0442	0.001089	40.56
1.20	1.48	35	0.0483	0.001091	44.26
1.40	1.73	39	0.0538	0.001094	49.19
1.60	1.98	42	0.0580	0.001097	52.84
1.80	2.22	46	0.0635	0.001100	57.73
2.00	2.47	50	0.0690	0.001102	62.59
2.20	2.72	53	0.0731	0.001105	66.18
2.40	2.96	57	0.0787	0.001108	70.99
2.60	3.21	60	0.0828	0.001111	74.54
2.80	3.46	63	0.0869	0.001114	78.06
3.00	3.70	66	0.0911	0.001117	81.57
3.20	3.95	69	0.0952	0.001119	85.06
3.40	4.20	73	0.1007	0.001122	89.76
3.60	4.44	75	0.1035	0.001125	91.98
3.80	4.69	78	0.1076	0.001128	95.41
4.00	4.94	80	0.1104	0.001131	97.61
4.20	5.19	83	0.1145	0.001134	101.00
4.40	5.43	85	0.1173	0.001137	103.17
4.60	5.68	89	0.1228	0.001140	107.74
4.80	5.93	91	0.1256	0.001143	109.87
5.00	6.17	93	0.1283	0.001146	111.99
5.20	6.42	95	0.1311	0.001149	114.10
5.40	6.67	98	0.1352	0.001152	117.39
5.60	6.91	100	0.1380	0.001155	119.47
5.80	7.16	102	0.1408	0.001158	121.54
6.00	7.41	105	0.1449	0.001161	124.78
6.20	7.65	106	0.1463	0.001164	125.63
6.40	7.90	108	0.1490	0.001167	127.66
6.60	8.15	109	0.1504	0.001171	128.50
6.80	8.40	111	0.1532	0.001174	130.51
7.00	8.64	111.5	0.1539	0.001177	130.74
7.20	8.89	112.1	0.1547	0.001180	131.09
7.40	9.14	113	0.1559	0.001183	131.78
7.60	9.38	114	0.1573	0.001187	132.59
7.80	9.63	114	0.1573	0.001190	132.23
8.00	9.88	113.5	0.1566	0.001193	131.29



Unconfined Compressive Strength , kPa = 133

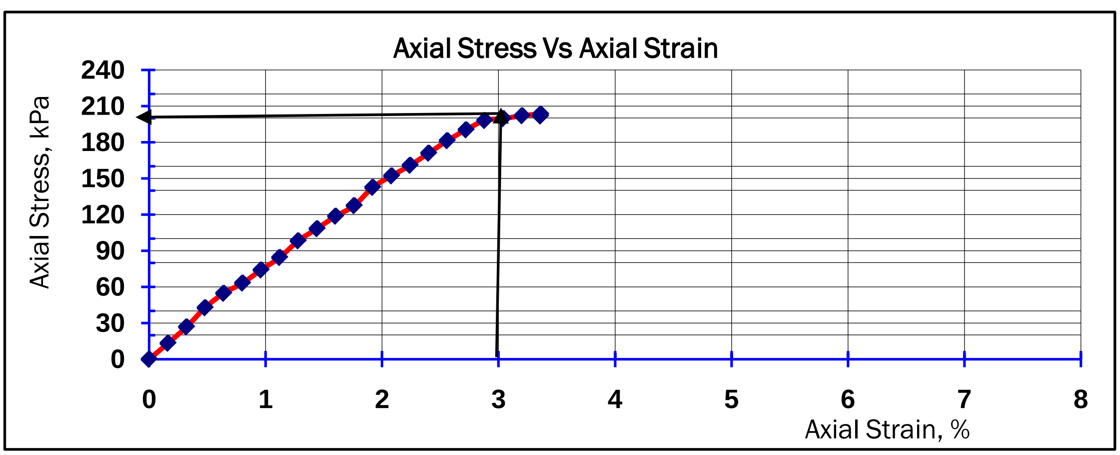
B) Unconfined Compressive Strength Laboratory Test Results

B.11) Marble Dust Content =20 % ,Curing Day=14

Diameter of sample , mm	100	**Cross- Sectional Area , m^2**	**0.007854**
Length of sample , mm	125	Ring Calibration Factor, kN/div	0.00396
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.007854	0
0.20	0.16	26	0.1030	0.007867	13.09
0.40	0.32	53	0.2099	0.007879	26.64
0.60	0.48	85	0.3366	0.007892	42.65
0.80	0.64	109	0.4316	0.007905	54.61
1.00	0.80	126	0.4990	0.007917	63.02
1.20	0.96	148	0.5861	0.007930	73.91
1.40	1.12	169	0.6692	0.007943	84.26
1.60	1.28	197	0.7801	0.007956	98.06
1.80	1.44	218	0.8633	0.007969	108.33
2.00	1.60	239	0.9464	0.007982	118.58
2.20	1.76	257	1.0177	0.007995	127.30
2.40	1.92	288	1.1405	0.008008	142.42
2.60	2.08	308	1.2197	0.008021	152.06
2.80	2.24	326	1.2910	0.008034	160.69
3.00	2.40	347	1.3741	0.008047	170.76
3.20	2.56	369	1.4612	0.008060	181.29
3.40	2.72	388	1.5365	0.008074	190.31
3.60	2.88	404	1.5998	0.008087	197.83
3.80	3.04	408	1.6157	0.008100	199.46
4.00	3.20	414	1.6394	0.008114	202.06
4.20	3.36	417	1.6513	0.008127	203.19
4.20	3.36	414	1.6394	0.008127	201.73

Unconfined Compressive Strength , kPa = 203



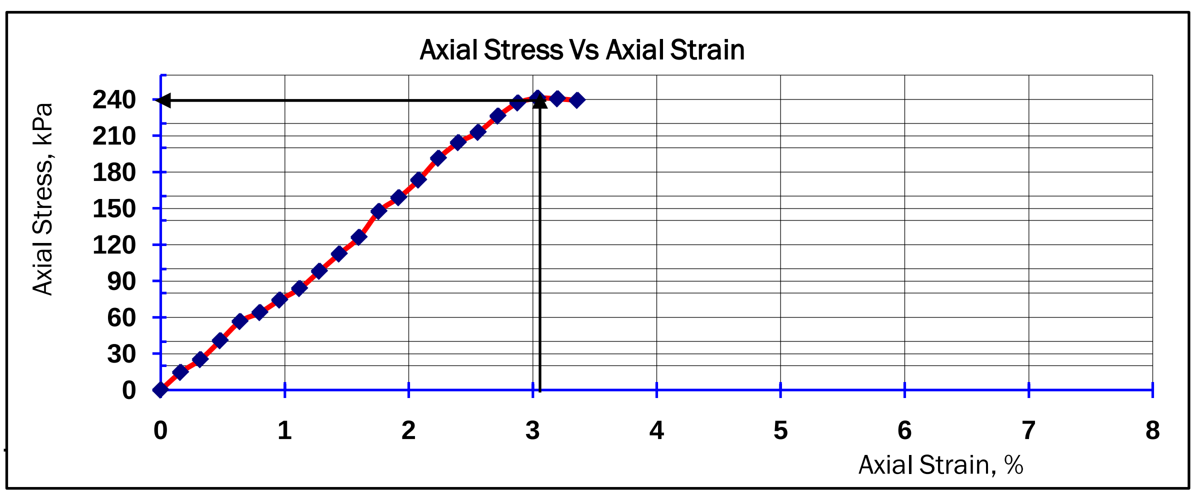
B) Unconfined Compressive Strength Laboratory Test Results

B.10) Marble Dust Content =16% ,Curing Day=14

Diameter of sample , mm	100		**Cross- Sectional Area , m^2**	**0.007854**
Length of sample , mm	125		Ring Calibration Factor, kN/div	0.00396
			Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.007854	0
0.20	0.16	29	0.1148	0.007867	14.60
0.40	0.32	50	0.1980	0.007879	25.13
0.60	0.48	81	0.3208	0.007892	40.64
0.80	0.64	113	0.4475	0.007905	56.61
1.00	0.80	128	0.5069	0.007917	64.02
1.20	0.96	149	0.5900	0.007930	74.41
1.40	1.12	168	0.6653	0.007943	83.76
1.60	1.28	197	0.7801	0.007956	98.06
1.80	1.44	226	0.8950	0.007969	112.31
2.00	1.60	254	1.0058	0.007982	126.02
2.20	1.76	298	1.1801	0.007995	147.61
2.40	1.92	321	1.2712	0.008008	158.74
2.60	2.08	351	1.3900	0.008021	173.29
2.80	2.24	388	1.5365	0.008034	191.25
3.00	2.40	415	1.6434	0.008047	204.22
3.20	2.56	433	1.7147	0.008060	212.73
3.40	2.72	461	1.8256	0.008074	226.12
3.60	2.88	484	1.9166	0.008087	237.01
3.80	3.04	493	1.9523	0.008100	241.02
4.00	3.20	493	1.9523	0.008114	240.62
4.20	3.36	491	1.9444	0.008127	239.25

Unconfined Compressive Strength , kPa = 240.6



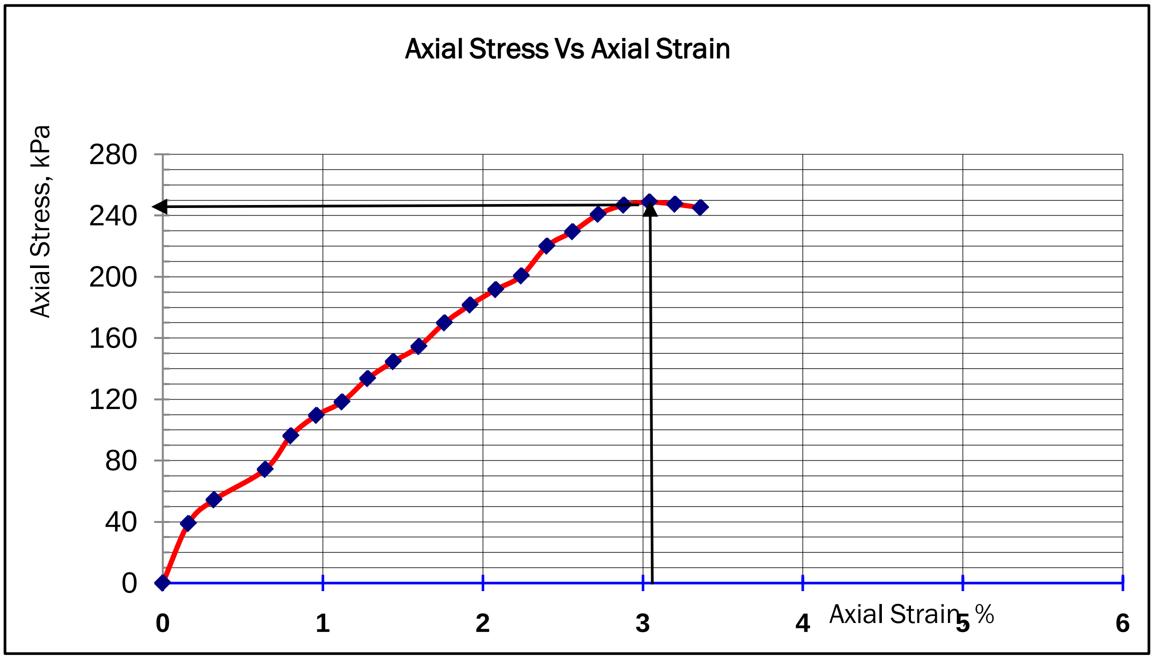
B) Unconfined Compressive Strength Laboratory Test Results

B.9) Marble Dust Content =12 % ,Curing Day=14

Diameter of sample , mm	100	Cross- Sectional Area , m^2	**0.007854**
Length of sample , mm	125	Ring Calibration Factor, kN/div	0.00396
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.007854	0
0.20	0.16	77	0.3049	0.007867	38.76
0.40	0.32	108	0.4277	0.007879	54.28
0.80	0.64	148	0.5861	0.007905	74.14
1.00	0.80	192	0.7603	0.007917	96.03
1.20	0.96	219	0.8672	0.007930	109.36
1.40	1.12	237	0.9385	0.007943	118.16
1.60	1.28	268	1.0613	0.007956	133.40
1.80	1.44	291	1.1524	0.007969	144.61
2.00	1.60	311	1.2316	0.007982	154.30
2.20	1.76	343	1.3583	0.007995	169.90
2.40	1.92	367	1.4533	0.008008	181.49
2.60	2.08	388	1.5365	0.008021	191.56
2.80	2.24	407	1.6117	0.008034	200.61
3.00	2.40	447	1.7701	0.008047	219.97
3.20	2.56	467	1.8493	0.008060	229.43
3.40	2.72	491	1.9444	0.008074	240.83
3.60	2.88	504	1.9958	0.008087	246.80
3.80	3.04	509	2.0156	0.008100	248.84
4.00	3.20	507	2.0077	0.008114	247.45
4.20	3.36	503	1.9919	0.008127	245.09

Unconfined Compressive Strength , kPa = 248.8



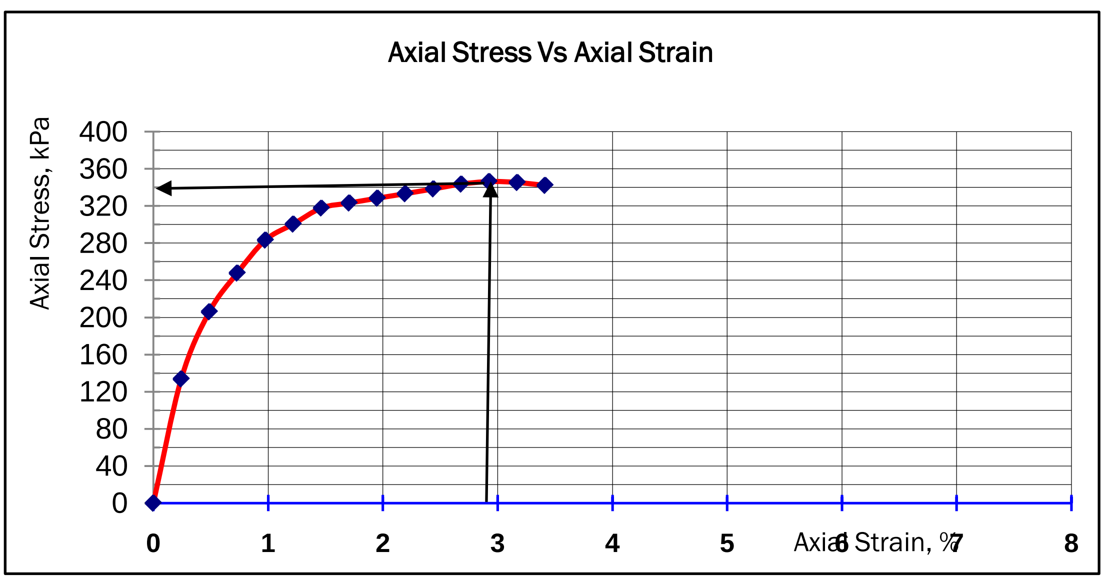
B) Unconfined Compressive Strength Laboratory Test Results

B.8) Marble Dust Content =8 % ,Curing Day=14

Diameter of sample , mm	38	**Cross- Sectional Area , m^2**	**0.001134**
Length of sample , mm	82	Ring Calibration Factor, kN/div	0.00138
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.24	110	0.1518	0.001137	133.52
0.40	0.49	170	0.2346	0.001140	205.85
0.60	0.73	205	0.2829	0.001142	247.62
0.80	0.98	235	0.3243	0.001145	283.16
1.00	1.22	250	0.3450	0.001148	300.49
1.20	1.46	265	0.3657	0.001151	317.74
1.40	1.71	270	0.3726	0.001154	322.93
1.60	1.95	275	0.3795	0.001157	328.09
1.80	2.20	280	0.3864	0.001160	333.23
2.00	2.44	285	0.3933	0.001162	338.33
2.20	2.68	290	0.4002	0.001165	343.41
2.40	2.93	293	0.4043	0.001168	346.09
2.60	3.17	293	0.4043	0.001171	345.22
2.80	3.41	291	0.4016	0.001174	342.00

Unconfined Compressive Strength , kPa = 346.1



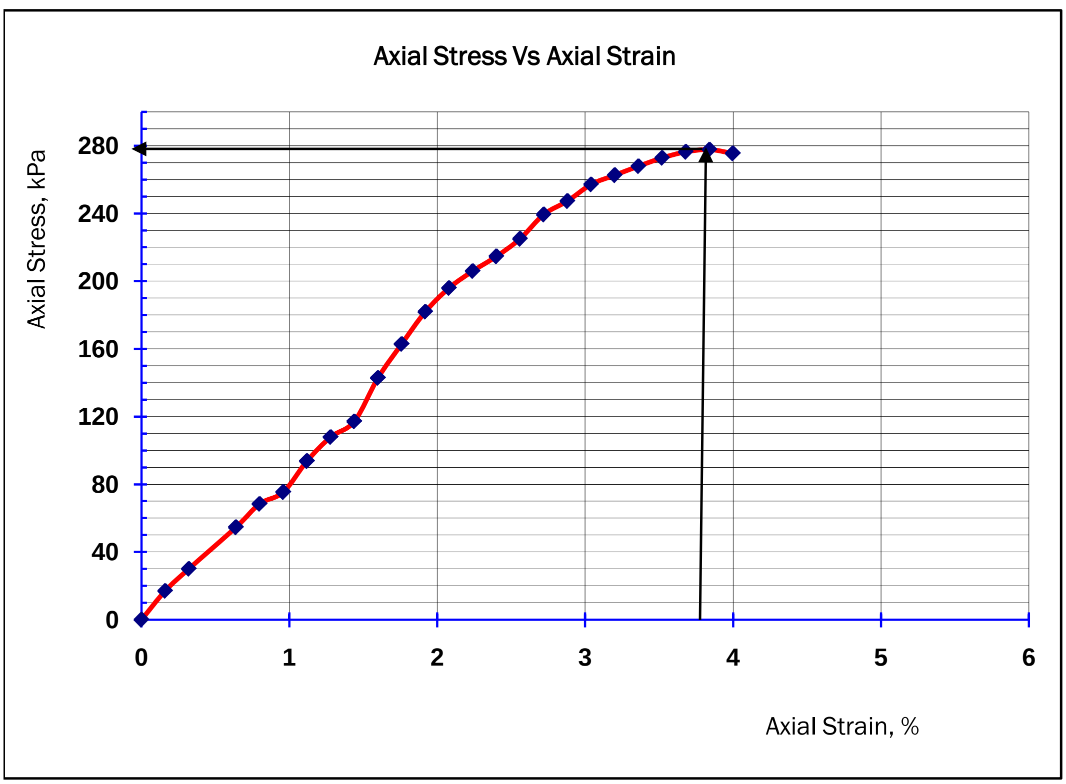
B) Unconfined Compressive Strength Laboratory Test Results

B.7) Marble Dust Content =4 % ,Curing Day=14

Diameter of sample , mm	100	**Cross- Sectional Area , m^2**	**0.007854**
Length of sample , mm	125	Ring Calibration Factor, kN/div	0.00396
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.007854	0
0.20	0.16	34	0.1346	0.007867	17.12
0.40	0.32	60	0.2376	0.007879	30.16
0.80	0.64	109	0.4316	0.007905	54.61
1.00	0.80	137	0.5425	0.007917	68.52
1.20	0.96	151	0.5980	0.007930	75.40
1.40	1.12	188	0.7445	0.007943	93.73
1.60	1.28	217	0.8593	0.007956	108.01
1.80	1.44	236	0.9346	0.007969	117.28
2.00	1.60	288	1.1405	0.007982	142.89
2.20	1.76	329	1.3028	0.007995	162.96
2.40	1.92	368	1.4573	0.008008	181.98
2.60	2.08	397	1.5721	0.008021	196.01
2.80	2.24	418	1.6553	0.008034	206.04
3.00	2.40	436	1.7266	0.008047	214.56
3.20	2.56	458	1.8137	0.008060	225.01
3.40	2.72	488	1.9325	0.008074	239.36
3.60	2.88	505	1.9998	0.008087	247.29
3.80	3.04	526	2.0830	0.008100	257.15
4.00	3.20	538	2.1305	0.008114	262.58
4.20	3.36	550	2.1780	0.008127	267.99
4.40	3.52	561	2.2216	0.008141	272.90
4.60	3.68	569	2.2532	0.008154	276.33
4.80	3.84	573	2.2691	0.008168	277.81
5.00	4.00	569	2.2532	0.008181	275.42

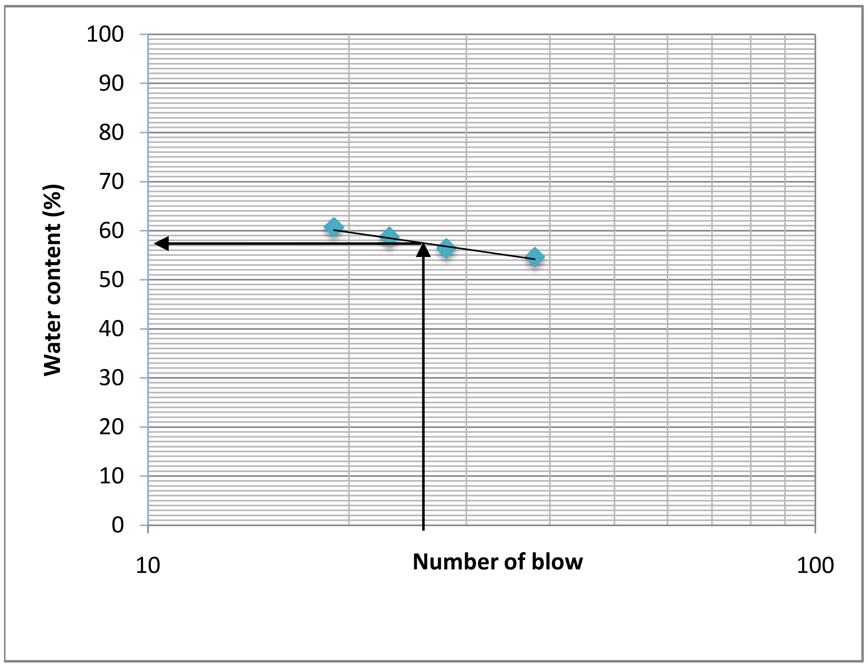
Unconfined Compressive Strength , kPa = 277.8



C.5) Marble Dust Content =16% ,Curing Day=7

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	5		D32	13	B4	M1
Mass of can(g)	11.4	15.7	15.5	10.9	15.8	15.6
Mass of can + wet soil (g)	27.9	33.1	30.8	26.3	22	22.2
Mass of can + dry soil (g)	22.3	27.3	25.7	21.2	20.3	20.7
Mass of water (g)	5.6	5.8	5.1	5.1	1.7	1.5
Mass of dry soil(g)	10.9	11.6	10.2	10.3	4.5	5.1
water content (%)	51.4	50.0	50.0	49.5	37.8	29.4
No. blows	11	26	29	32		

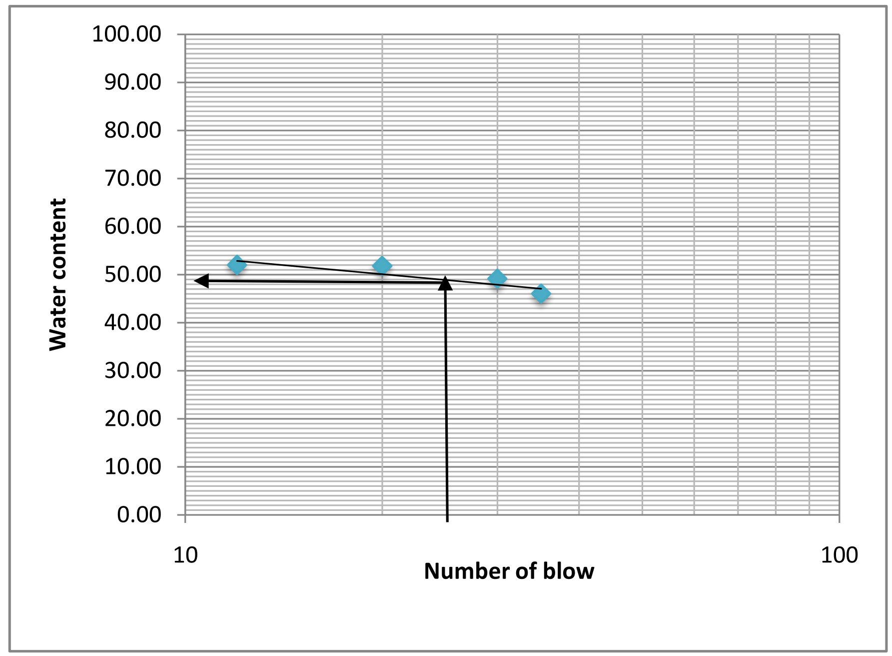
Liquid Limit, % = 50 Plastic Limit, % = 33.6 PI, %= 16.4



C.6) Marble Dust Content =20 % ,Curing Day=7

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	12	A5	1		15.5	17
Mass of can(g)	15.6	15.7	15.7	15.6	15.5	14.8
Mass of can + wet soil (g)	36.9	33.45	35.5	33.8	21.7	22.4
Mass of can + dry soil (g)	30.2	27.9	29.3	28.2	20.3	20.7
Mass of water (g)	6.7	5.55	6.2	5.6	1.4	1.7
Mass of dry soil(g)	14.6	12.2	13.6	12.6	4.8	5.9
water content (%)	45.9	45.5	45.6	44.4	29.2	28.8
No. blows	11	23	27	31		

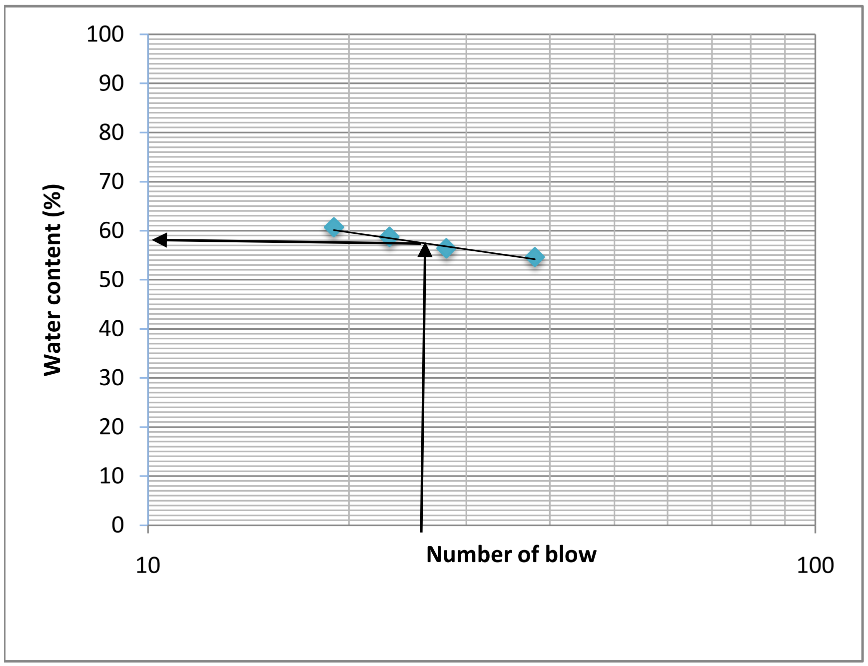
Liquid Limit, % = 44.9 Plastic Limit, % = 29.0 PI, %= 15.9



C.3) Marble Dust Content =8% ,Curing Day=7

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	5	1	D32	13	B4	M1
Mass of can(g)	15.3	11	15.6	15.4	14.5	14.8
Mass of can + wet soil (g)	32.3	26.6	32.4	35.5	22.7	22.9
Mass of can + dry soil (g)	26.5	21.3	26.5	28.4	20.9	20.8
Mass of water (g)	5.8	5.3	5.9	7.1	1.8	2.09
Mass of dry soil(g)	11.2	10.3	10.9	13	6.4	6.01
water content (%)	51.8	51.5	54.1	54.6	28.1	34.8
No. blows	19	23	27	34		

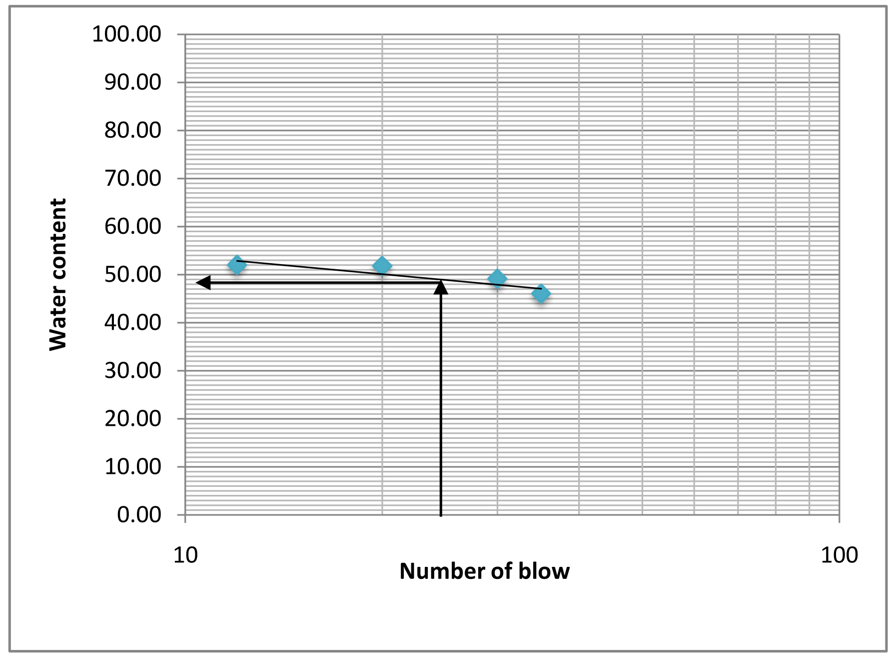
Liquid Limit, % = 48 **Plastic Limit, % = 31.5** **PI, %= 16.5**



C.4) Marble Dust Content =12 % ,Curing Day=7

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.		1	D32	13	B4	M1
Mass of can(g)	29.1	15	15.6	15.7	15.6	15.7
Mass of can + wet soil (g)	44.4	33.6	32.1	32.3	22.4	21.9
Mass of can + dry soil (g)	39.3	27.5	26.7	26.9	20.7	20.5
Mass of water (g)	5.1	6.1	5.4	5.4	1.7	1.4
Mass of dry soil(g)	10.2	12.5	11.1	11.2	5.1	4.8
water content (%)	50.0	48.8	48.6	48.2	33.33	29.17
No. blows	17	26	29	32		

Liquid Limit, % = 48 **Plastic Limit, % = 31.3** **PI, %= 16.8**

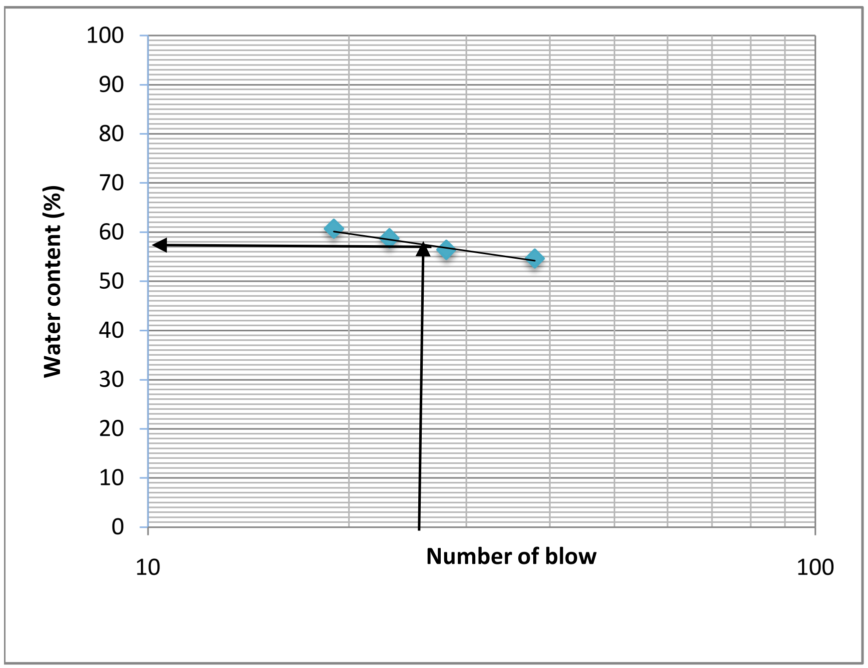


C) Atterberg Limit Laboratory Test Results

C.1) Marble Dust Content =0% ,Curing Day=7

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	T2	2T1L9	TAP3	TA2	CP1	DAS1
Mass of can(g)	13.8	15.8	15.4	15.5	15.6	15.7
Mass of can + wet soil (g)	27.3	28.5	27.6	28.8	21.4	20.9
Mass of can + dry soil (g)	22.2	23.8	23.2	24.1	19.9	19.5
Mass of water (g)	5.1	4.7	4.4	4.7	1.5	1.4
Mass of dry soil(g)	8.4	8	7.8	8.6	4.3	3.8
water content (%)	60.7	58.8	56.4	54.7	34.9	36.8
No. blows	19	23	28	38		

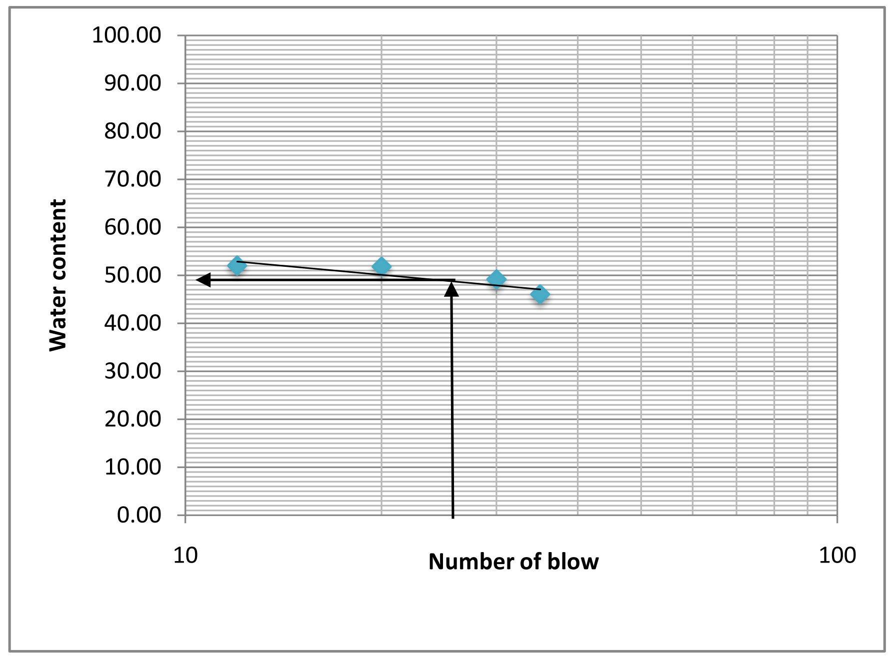
Liquid Limit, % = **58** Plastic Limit, % = **35.9** PI, %= **22.1**



C.2) Marble Dust Content =4 % ,Curing Day=7

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	12	2	A5	1	8	17
Mass of can(g)	15.7	20.7	14.9	16	15.4	15.4
Mass of can + wet soil (g)	35.9	40.6	33.2	31.5	22.5	22.7
Mass of can + dry soil (g)	29.1	34	27	26.3	20.7	20.9
Mass of water (g)	6.8	6.6	6.2	5.2	1.8	1.8
Mass of dry soil(g)	13.4	13.3	12.1	10.3	5.3	5.5
water content (%)	51	49.6	51.2	50.5	34.0	32.7
No. blows	14	22	27	31		

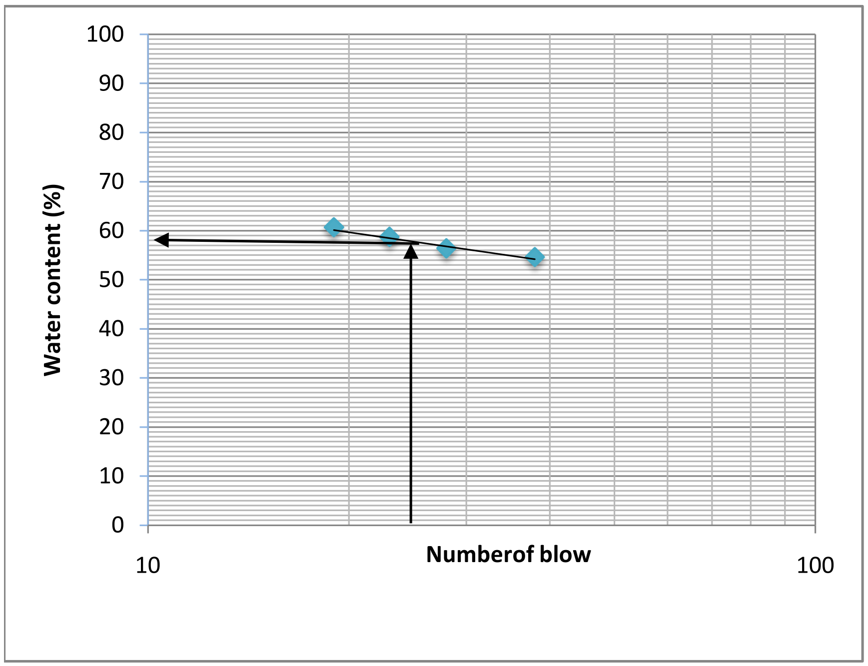
Liquid Limit, % = **50** Plastic Limit, % **33.3** PI, %= **16.7**



C.11) Marble Dust Content =16% ,Curing Day=7

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	5	BB	D32	13	B4	M1
Mass of can(g)	15.7	20.5	15.5	15.6	15.8	15.7
Mass of can + wet soil (g)	31	37.9	30.5	31.2	22	21.4
Mass of can + dry soil (g)	25.9	32.3	25.7	26.3	20.5	20.1
Mass of water (g)	5.1	5.6	4.8	4.9	1.5	1.3
Mass of dry soil(g)	10.2	11.8	10.2	10.7	4.7	4.4
water content (%)	50.0	47.5	47.1	45.8	31.9	29.5
No. blows	10	22	29	37		

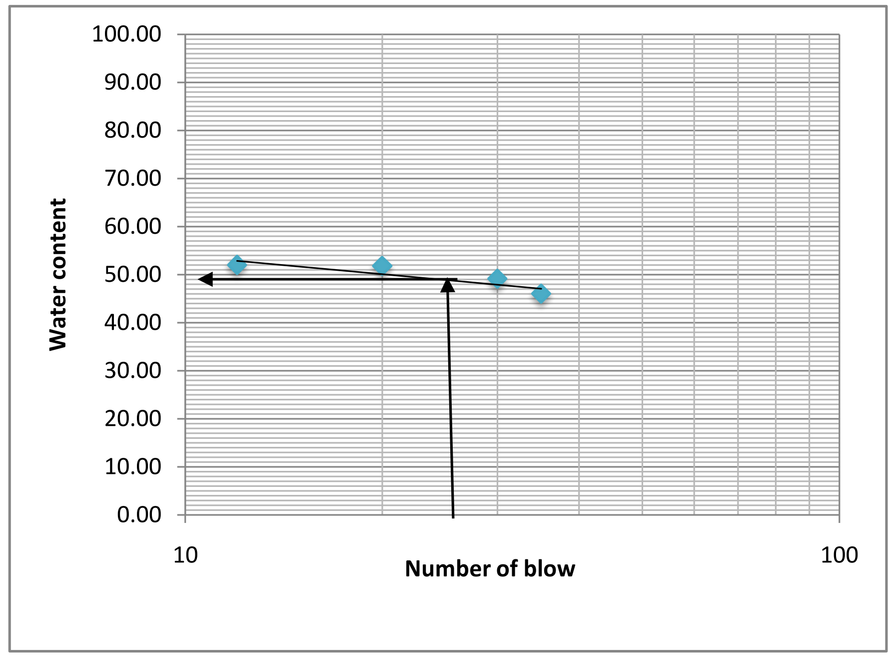
Liquid Limit, % = 47 **Plastic Limit, % = 30.7** **PI, %= 16.3**



C.12) Marble Dust Content =20 % ,Curing Day=7

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	12	A5	1		15.5	17
Mass of can(g)	15.6	15.1	13.8	15.5	15.4	15.6
Mass of can + wet soil (g)	37.4	27.5	34.3	34.6	22	22.6
Mass of can + dry soil (g)	30.3	23.7	28	29.1	20.5	21.04
Mass of water (g)	7.1	3.8	6.3	5.5	1.5	1.56
Mass of dry soil(g)	14.7	8.6	14.2	13.6	5.1	5.44
water content (%)	48.3	44.2	44.4	40.4	29.4	28.7
No. blows	10	25	30	34		

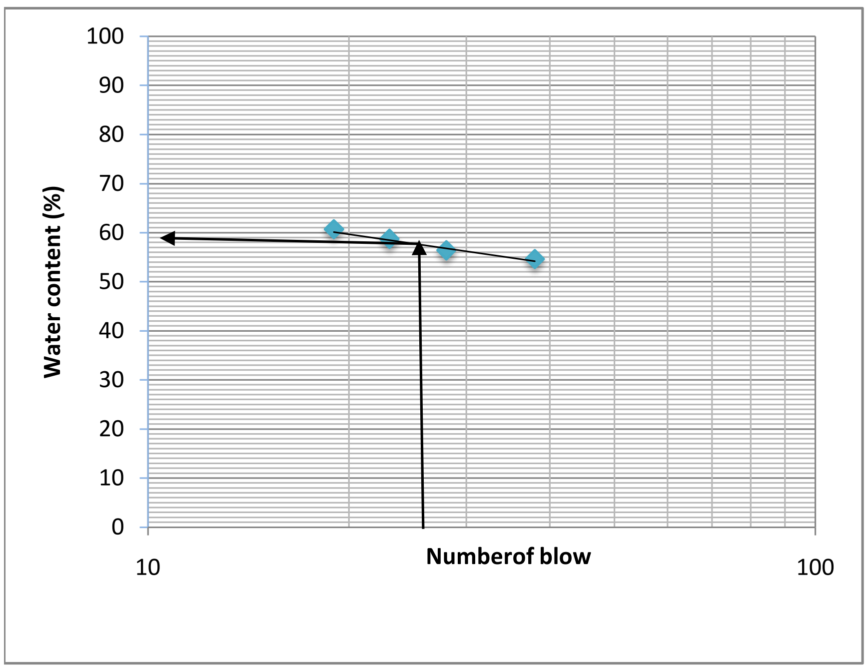
Liquid Limit, % = 44.2 **Plastic Limit, % = 29.0** **PI, %= 15.2**



C.9) Marble Dust Content =8% ,Curing Day=14

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	5	1	D32	AA	B4	M1
Mass of can(g)	15.6	10.9	15.6	15.5	15.7	15.7
Mass of can + wet soil (g)	32.5	27.5	31.8	31.4	21.8	21.2
Mass of can + dry soil (g)	26.8	22	26.6	26.3	20.3	19.9
Mass of water (g)	5.7	5.5	5.2	5.1	1.5	1.3
Mass of dry soil(g)	11.2	11.1	11	10.8	4.6	4.2
water content (%)	50.9	49.5	47.3	47.2	32.6	31.0
No. blows	20	23	37	40		

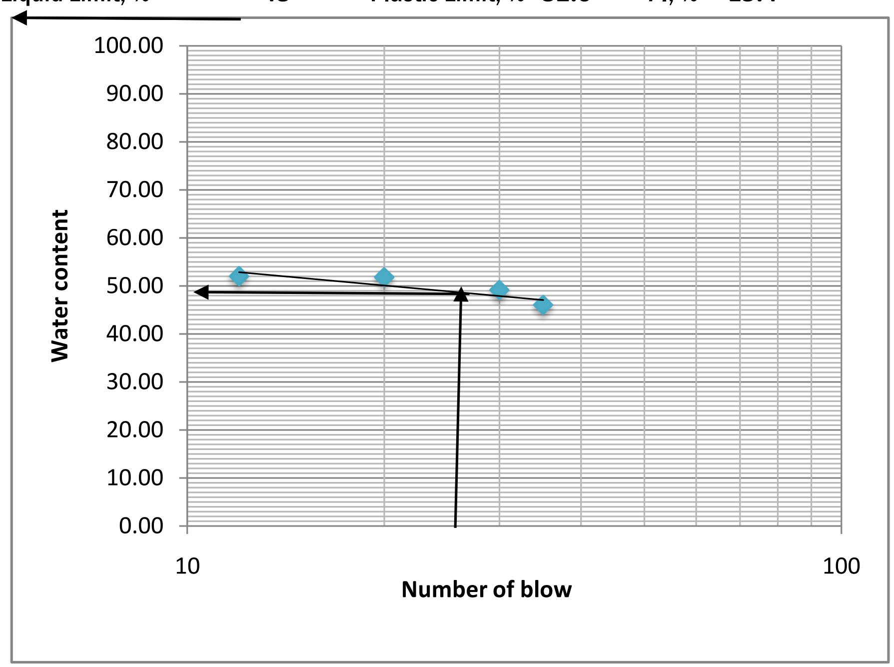
Liquid Limit, % = 48 **Plastic Limit, % = 31.8** **PI, %= 16.2**



C.10) Marble Dust Content =12 % ,Curing Day=14

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.		1	D32	13	B4	M1
Mass of can(g)	15.4	15.8	15.7	15.4	15.8	15.5
Mass of can + wet soil (g)	33.2	31.5	32.9	29.2	22	21.5
Mass of can + dry soil (g)	27.2	26.2	27.4	24.8	20.4	20.1
Mass of water (g)	6	5.3	5.5	4.4	1.6	1.4
Mass of dry soil(g)	11.8	10.4	11.7	9.4	4.6	4.6
water content (%)	50.8	51.0	47.0	46.8	34.8	30.4
No. blows	16	23	27	33		

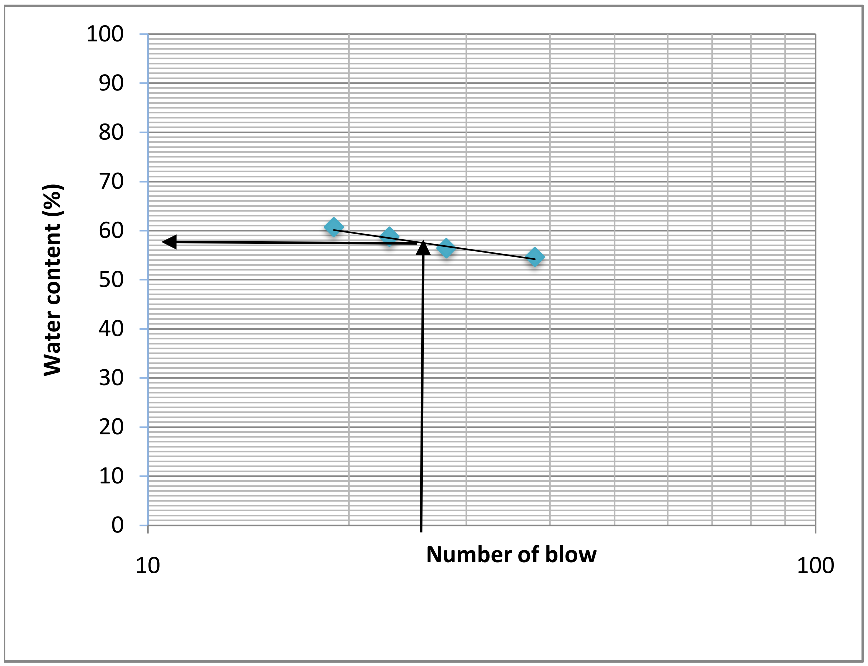
Liquid Limit, % = 48 **Plastic Limit, % 32.6** **PI, %= 15.4**



C.7) Marble Dust Content =0% ,Curing Day=14

	Liquid limit (%)				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	T2	2T1L9	TAP3	TA2	CP1	DAS1
Mass of can(g)	13.8	15.8	15.4	15.5	15.6	15.7
Mass of can + wet soil (g)	27.3	28.5	27.6	28.8	21.4	20.9
Mass of can + dry soil (g)	22.2	23.8	23.2	24.1	19.9	19.5
Mass of water (g)	5.1	4.7	4.4	4.7	1.5	1.4
Mass of dry soil(g)	8.4	8	7.8	8.6	4.3	3.8
water content (%)	60.7	58.8	56.4	54.7	34.9	36.8
No. blows	19	23	28	38		

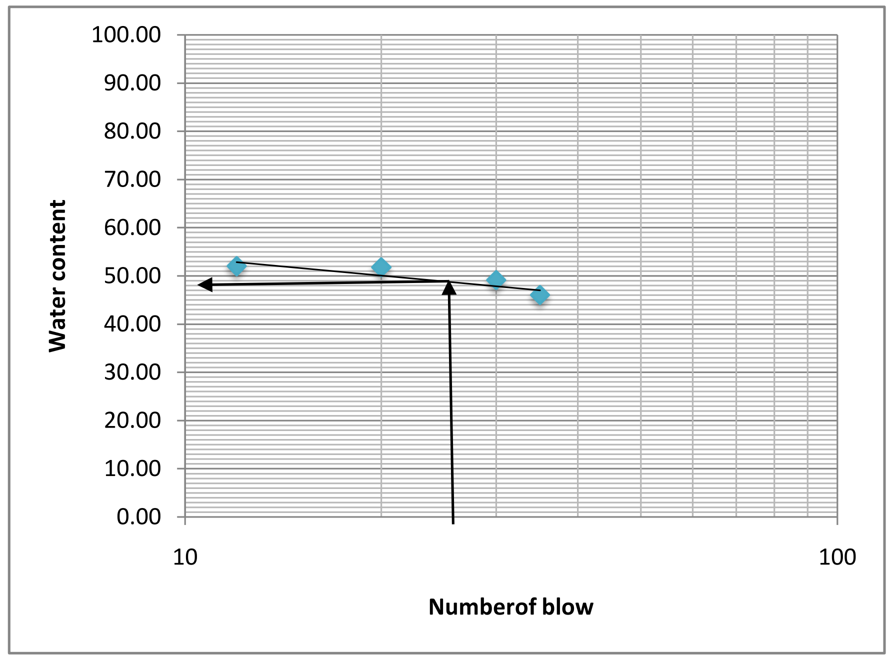
Liquid Limit, % = 58 Plastic Limit, % = 35.9 PI, %= 22.1



C.8) Marble Dust Content =4% ,Curing Day=14

	Liquid limit				Plastic limit(%)	
Trial No.	1	2	3	3	1	2
Can No.	12	2	A5	1	8	17
Mass of can(g)	15.6	15.4	15.7	15.8	29.1	15.4
Mass of can + wet soil (g)	30.5	32.1	33.9	26.9	35.4	21.2
Mass of can + dry soil (g)	25.4	26.4	27.9	23.4	33.8	19.8
Mass of water (g)	5.1	5.7	6	3.5	1.6	1.4
Mass of dry soil(g)	9.8	11	12.2	7.6	4.7	4.4
water content (%)	52.0	51.8	49.2	46.1	34.0	31.8
No. blows	12	20	30	35		

Liquid Limit, % = 49 Plastic Limit, % = 32.9 PI, %= 16.1



1) Grain Size Analysis Laboratory Test Results

Wet Sieve Analysis

Total mass of sample, g 442.1

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	ass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	n. Percentage Retained (%)	Perc. Passing (%)
3''	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2''	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4''	19.0	1443.0	1443.0	0.0	0.0	0.0	100.0
1/2"	12.5	1242.0	1242.0	0.0	0.0	0.0	100.0
3.8"	9.5	461.6	463.3	1.7	0.4	0.4	99.6
No 4	4.75	427.0	432.0	5.0	1.1	1.5	98.5
No 8	2.36	415.2	419.3	4.1	0.9	2.4	97.6
No 10	2	0.0	0.0	0.0	0.0	2.4	97.6
No 16	1.18	362.8	367.8	5.0	1.1	3.6	96.4
No 30	0.6	325.8	229.9	-95.9	-21.7	-18.1	118.1
No 40	0.425	0.0	0.0	0.0	0.0	-18.1	118.1
No 50	0.3	301.4	305.7	4.3	1.0	-17.1	117.1
No 100	0.15	276.9	283.1	6.2	1.4	-15.7	115.7
No 200	0.075	0.0	0.0	0.0	0.0	-15.7	115.7
pan	-------	422.6	262.1	-160.5	-36.3	-52.0	-------