CONSOLIDATION PROPERTIES ON MODIFIED SOIL USING COMMERCIALLY AVAILABLE STABILIZER

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Submitted by:

JENINA YASHMIN

M.TECH 4TH Semester

Roll No: PG-CE-22/06

ASTU Registration No: 114402116

Under the guidance of:

DR. SASANKA BORAH

Assistant Professor, Assam Engineering College

Department of Civil Engineering

ASSAM ENGINEERING COLLEGE

JALUKBARI, GUWAHATI-13, ASSAM

CANDIDATE DECLARATION

I hereby declare that the work presented in this report entitled "Consolidation Properties On Modified Soil using commercially available stabilizer" in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science and Technology University, is a work carried out in the said college under the supervision of Dr. Sasanka Borah, Assistant Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, Assam. Whatever I have presented in this report has not been submitted by me for the award of any other degree or diploma.

Date :

Place : Guwahati

JENINA YASHMIN

M.Tech 4th Semester

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati-781013

CERTIFICATE OF SUPERVISION

This is to certify that the work presented in this report entitled — "Consolidation Properties on Modified Soil using commercially available stabilizer" is carried out by Jenina Yashmin, Roll No:PG-CE-22/06, a student of M.Tech 4th semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Date :

Place : Guwahati

DR. Sasanka Borah
Assistant Professor
Department Of Civil Engineering
Assam Engineering College
Jalukbari, Guwahati-781013

CERTIFICATE OF APPROVAL

This is to certify that the following student of M.Tech 4th semester of Civil Engineering Department (Geotechnical Engineering), Assam Engineering College, has submitted her project on — “Consolidation Properties On Modified Soil using commercially available stabilizer” in partial fulfillment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Name: JENINA YASHMIN

College Roll No: PG-C-22/06

ASTU Roll No: 220620062006

ASTU Registration No: **114402116**

Date :

Place: Guwahati

DR. JAYANTA PATHAK
Professor & Head of the Department
Department of Civil Engineering
Assam Engineering College
Guwahati-781013

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Date :

Place :Guwahati

JENINA YASHMIN

M.Tech 4th Semester

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati-781013

ABSTRACT

Expansive soils denote soft clayey soils that possess the tendency of increase or decrease in volume in the presence of moisture content changes. These seasonal shifts from monsoon to summer may be the cause of these changes in the moisture content of these soils. It results in the soil being too fragile to sustain the infrastructure, which leads to consequences of various failures. This work looks into using nanomaterials to treat locally available in situ materials in order to improve their engineering performances. This paper presents the results of study on consolidation characreteristics in terms of compressibility, rate of consolidation and permeability of both unstabilized soil and soil stabilized with nanomaterial named zycobond using oedometer test. Oedometer specimen of 60mm diameter and 20mm height were tested for untreated soil sample and then soil treated with various dosage of zycobond (0.5kg/m^3, 0.75kg/m^3 and 1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) added with 3% and 5% cement respectively based on dry weight. The soil applied for the testing was collected from Assam Engineering College campus, Hostel 6 . From the test results it is discovered that stabilization with zycobond has caused the reduction in compression index and compressibility of the soil upto an optimum dose of 1kg/m^3. Also it has been found that rate of consolidation is reduced which also reduces the permeability.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Natural clayey soils rarely satisfy the foundational bearing capacity specifications of contemporary geotechnical engineering projects. Geotechnical engineering procedures urgently needs to improve the strength and stiffness of a natural clay foundation since large, high-rise buildings and other big structures are being constructed in emerging nations. Generally, foundation soils can have their strength and deformation qualities altered or improved by adding a range of reinforcing or treatment materials. The pattern of land use is changing, resulting in the laying of pavement on unfavorable ground and the stabilization of soil with locally accessible materials. In certain locations, the local building materials might not be available which increases the construction cost and accelerates the depletion of natural resources. In general, foundation soils can have their strength and deformation qualities altered or improved by adding a range of reinforcing or treatment materials. These compounds fall into three categories: composite curing agents, ionic soil stabilizing agents, and inorganic binders. Inorganic binders, such as cement, lime, fly ash, and their mixes, are frequently utilized for chemically altering soils. Ion exchange, hydration, and hydrolysis take place in the soil when inorganic binders are combined with it. For example, adding cement will improve the structural strength by increasing the cohesion between soil particles and reducing the void ratio significantly. But the manufacturing of cement is a high-carbon emission process with detrimental effects on the environment. Soil treated with lime has a slow rate of strength development and comparatively low water stability. An additional significant drawback of this approach is that it makes the soil more fragile. The strength of soil that has been treated with lime-fly ash is low at early stage, which has a direct impact on the development and quality of building. It takes at least 28 days to get a relatively high strength, and longer the time available, the higher the strength that is achieved. It can be concluded that the traditional soil modification materials have certain disadvantages and cannot fully meet engineering needs.

Nano chemical (zycobond) can be used to treat soils in order to improve their workability and load bearing characteristics in a number of situations. Nano chemical (zycobond) can substantially increase the stability, impermeability, and load bearing capacity of the subgrade. Application of nano chemical (zycobond) to subgrades can provide significantly improved engineering properties. Applying small amount of nano chemical can enhance the soil properties and can be effectively used for soil stabilization. Various research and investigation is going on soils to check the effect of nanomaterials on soil geotechnical properties. These are cost effective compared to tradition soil modification materials.

1.2 NANOCHEMICALS

Particles with an interfacial layer around them and sizes ranging from 1 and 100 nanometres (nm) in size are known as nanoparticles. The interfacial layer is an essential component of nanoscale matter that has a important effect on every property of the material.

Ions, inorganic and organic molecules make up the interfacial layer in most cases. Stabilizers, capping agents, and passive agents are the names given to organic compounds that envelop inorganic nanoparticles. The expansion of Nanoparticles to locally accessible soil as an external factor, as a result of which the soil is treated at the molecular or atomic level, affecting its quality, porosity indices, compressibility, and permeability qualities.

The product based on nanotechnology that can offer solutions to stop moisture migration and process strong bonding in pavement layers is the inclusion of nano compounds. When nanoparticles are introduced as an external component into locally available soil, the soil is treated at the atomic or molecular level. This affects the soil's strength, permeability indices, compressibility, and permeability qualities. These days, the use of nanochemical agents is expanding across a range of applications; improving the soft clay soils is very important before building an embankment, paving a road, or designing a foundation for any kind of infrastructure. Despite the availability of numerous conventional ground improvement procedures, the use of very low dosages of nanochemical agent in the soil treated with nanochemicals proven to make the treatment more affordable. Additionally, this nanochemical serves as a water barrier, maintaining the strength over time. As a result, the current study looks at the permeability and compressibility of soil treated with nanochemicals, which directly affect the treated soil's strength.

Zycobond is a cement concrete waterproofing solution that is simple to use. Zycobond is a co-polymer dispersion of acrylic that is sprayed on compacted soils to strengthen the soil layer and improve waterproofing. Zycobond reduces dust on dirt roads, minimizes soil erosion, speeds up the drying of soil layers and muddy roads after rain, and requires little maintainance. There has been some work done on stabilizing clayey soil with lime, cement, and pozzolanas, but not much has been documented with nanochemical stabilization. Stabilization using maximum strength cement comes at a significant expense. Alternative materials, such as nanochemicals, are taken into account to cut costs. Thus, the purpose of this study is to examine how nanochemicals affect the compressibility behaviour of clayey soils.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nanochemicals enhance soil stabilization by interacting at the molecular level, forming strong chemical bonds with soil particles, resulting in a more stable and uniform soil structure. Their nanoscale size provides a larger surface area for improved reactivity and bonding efficiency, leading to higher strength and better load-bearing capacity. This results in faster stabilization processes compared to traditional methods. Additionally, nanochemicals often require smaller quantities and less labor for application, making them cost-effective. They also improve durability, offering greater resistance to environmental factors such as water infiltration and erosion. Furthermore, many nanochemicals are designed to be environmentally friendly, reducing harmful byproducts and overall environmental impact.

2.2 BRIEF REVIEW OF PREVIOUS WORKS

Olaniyan and Ajileye (2018) investigated weak laterites' geotechnical characteristics. stabilized by nanoparticle materials (Zycobond and Terrasil). One important component used in road construction is laterite. However, it is costly and widely documented to stabilize weak laterite using cement or lime. Samples of lateritic soil were taken from Samples A and B, two distinct burrow pits. Weight measurements were made for zycobonds and terrasils to stabilize the laterites at 5,10,15, and 20%, respectively. Both stabilized and unstabilized materials were subjected to geotechnical testing, which included Particle Size Analysis, Liquid Limit (LL), Plastic Limit (PL), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR).After stabilizing the lateritic soil with increasing percentage of nanochemicals (Terrasil and Zycobond), it has been found that there is an increase in Liquid Limit and Plastic Limit which indicates that the soil was more clayish and MDD is reduced with increase in nanochemicals, which proves that the soil was loosely packed also there is increase in OMC as a result of an increase in surface area caused by the high amount of Nano chemicals. With increased percentage of nano chemicals The CBR value of the samples is increased. The results show that 15% Nano chemicals (Terrasil and Zycobond) gives maximum strength for California Bearing Ratio (CBR)

Meeravali et al. (2020) investigated how applying nanomaterials to locally accessible in situ materials could improve their engineering performances. Soft clay coated with nanomaterials is examined for engineering properties including compressibility and permeability. The soil mixtures are created by combining various amounts of soft clay with Terrasil, a nanochemical. Permeability, compaction, and consolidation strength parameters have been obtained by the execution of experiments on produced soil combinations. Additional studies were conducted on various soil combinations using Unconfined Compression Strength (UCS) to determine the ideal chemical dosage that corresponds to peak strength. According to the experiment's findings, adding nanochemicals to soft clay enhances its permeability and UCS while decreasing its compressibility. The final goal of this investigation is to determine how long a nanochemical can be used to repair soft ground while also determining the best stabilizer dosage to guarantee maximum strength, control compressibility, and permeability properties. Terrasil is introduced into the clay soil from 0.02 to 0.07% of the dry weight of soil. After treatment, the plasticity index dropped from 31.91% to 22.24%. It says that when an ideal amount of 0.03% nanochemical is added to clay soil, the soil becomes less plastic.So it is proved that the Terrasil stiffens the soil more. Clay soil has been mixed with terrasil between the dose of 0.02 to 0.15% weight of the soil. The UCS of untreated soil sample was 31.3 kpa and it increased to 75.7 kpa (for optimum terrasil at the end of 28 days of curing). Soil mixed with optimum dosage of 0.03% terrasil chemical, The UCS is found to improve about 2.5% higher than that of the clay soil. This improve in UCS is due to the reaction of the chemical with the soil particle. It results in restricting the entry of water into the surface. For every curing period, The soil is found impermeable at the optimum dosage of terrasil. The coefficient of consolidation is found to increase (from 0.0014 to 0.0322 cm2/min). There is reduction in the soil settlement i.e (from 3.345 to 0.82 mm) significantly for nano chemical treated soil while compared to untreated soil sample. At optimum dosage of 0.03% terrasil mixed into the soil sample results in improvement of the California Bearing Ratio strength value. It is improved about three times the California Bearing Ratio strength value of untreated clay soil.

Zahoor1 and Jassal2(2020) investigated the stability of alluvial soil using products based on nanotechnology (Terrasil and Zycobond) in order to get better results for soil compaction. Cost of construction increases for some places where local materials are not easily available also depletion of natural resources increases. An experimental study is done to determine the impact of nanoparticles (Zycobond and Terrasil) on compaction, CBR both in soaked (4 days) and unsoaked conditions. Permeability testing was also done to determine the underlying process. Various dosages of nanoparticles (0.6 kg/m3, 0.9 kg/m3, and 1.3 kg/m3)were added to the soil. It is found that that adding nanoparticles (Zycobond and Terrasil) to the alluvial soil decreases permeability and compressibility while simultaneously raising the CBR value in both cases.The results of the experiments led the author to the conclusion that the CBR value of alluvial soil increased from 9.98% to 12.67% in an unsoaked condition when combined with Terrasil and Zycobond. There was a minor decrease in the results from 10 to 20 during the stabilization phase when the soil was soaked for four days. When soil is combined with Terrasil and Zycobond, OMC and MDD also rise. The conclusion states that Zycobond and Terrasil when mixed to soil at a dose of 0.9 kg/m^3 , both the CBR values are found to improve significantly. Soil loses its permeability and becomes impenetrable when mixed with Terrasil and Zycobond.

Khalaf1 et al. (2020) examined the majority of studies conducted in the previous ten years. Enhancement of soil geotechnical qualities requires the application of nanomaterials in soil improvement techniques. The discipline of geotechnical engineering has made a number of advancements in recent years to enhance the qualities of poor soil through the application of nanomaterials. Numerous studies have been conducted using various soil tests to determine the impact of nanomaterials on the geotechnical qualities of soil. All of the results demonstrated that adding nanomaterial to soil improved its mechanical and physical qualities; however, the degree of improvement varied depending on the type, quality, and nano-ratio of the nanomaterial added as well as the features of the native soil. This study reports on earlier investigations on the use of nanoadditives for soil stabilization.

The author made Several conclusions from them:

(1) Because of their unique characteristics, such as their smaller size and higher specific area, the nanomaterials react strongly with the soil matrix's particle.

(2) The geotechnical properties of soil can be significantly impacted by the presence of small amount of nanomaterials. It enhances the soil characteristics.

(3) The impact of different type of nanomaterials depends on the type of particle, percentage, and soil mixed.

(4) An excessive concentration of nanoparticles damages the soil's geotechnical qualities by causing particle aggregation.

(5) There is great increase in compaction effort, strength, shear strength, consistency limit, compressibility, and permeability of the soil mixture when nanomaterials are added.

(6) There is decrease in plasticity which indicates that soil is improved.

Cheng1,2 et al. (2020) investigated the stabilizing effect of nano-bentonite on the consolidation qualities of soil. This paper presents the results of laboratory tests conducted to examine the one-dimensional consolidation features of nano-bentonite mixed clayey soil. Analysis was done on the effects of the nano-bentonite mixing content on the permeability coefficient, consolidation coefficient, secondary consolidation coefficient, and compression coefficient. A series of one-dimensional odometer tests has been performed on a clayey soil with varying nano-bentonite mixing contents (i.e., 0.5%, 1%, 1.5%, and 2%). The author came to the conclusion that adding 0.5% to 2% of nano-bentonite to clayey soil had little impact on the consolidation properties at first. The test soil exhibits a larger permeability coefficient under high pressure, indicating that the addition of nano-bentonite accelerates the drainage consolidation of the clayey soil. However, when the consolidation pressure increases gradually, the final settlement, coefficient of secondary consolidation, and coefficient of consolidation of the clayey soil with the addition of nano-bentonite all show an increasing trend. Once a little amount of nano-bentonite is added, the consolidation characteristics of the clayey soil change. The final void ratio is lowest and the final settlement reaches its highest at 0.5% of the nano-bentonite mixing component. The consolidation and permeability coefficients rise under high pressure circumstances as the amount of nano-bentonite added increases. This suggests that the permeability and consolidation properties of clay have been altered by nano-bentonite. The cementation filling effect of nano-bentonite is the primary manifestation of the consolidation and permeability mechanism of the mixed soil containing nano-bentonite. The adhesion and bonding between clay particles are altered by the addition of nano-bentonite. Simultaneously, the size of the spaces and their quantity between clay particles decrease. The microstructure of the clayey soil is rearranged by the new cementation between clay particles. Consequently, the clayey soil's resistance to compressive deformation is enhanced. The test results indicate that nano-bentonite can facilitate internal cementation of soil particles, which effectively reduces the compressibility of clayey soil.

Singh et al. (2008) investigated the settling properties of clayey soils contaminated with petroleum hydrocarbons. The study used engine oil, diesel, gasoline, and kerosene—the four most common petroleum hydrocarbons—as pollutants. The investigation used two different types of clay: high compressibility (CH) and low compressibility (CL). While the high compressibility (CH) soil used for the study was created by combining kaolinite and montmorillonite in a weight-ratio of 85:15, the low compressibility (CL) soil was found naturally. In order to compare the consolidation characteristics before and after contamination, laboratory studies for index properties and consolidation tests were carried out on virgin (uncontaminated) soil samples and soil samples simulated to varying degrees of contamination (i.e., 3%, 6%, and 9% expressed as a dry weight of soil w/w). Soil consolidation behavior changed as a result of pollution. An increase in the compression index value was the cause of the larger settlement in the polluted soil (apart from that involving kerosene oil). For the polluted soils, the consolidation coefficient dropped. A modified formula was put out to forecast the polluted soils' compression index. The author deduced from the experiments that an increase in the value of the compression index (Cc) led to a rise in consolidation settlement for soils contaminated with petroleum hydrocarbons (apart from kerosene). For fine-grained soils, the percentage increase in consolidation settlement varies from 35% to 50%. The soil polluted with U.E.O. shows the highest increase in the value of Cc with respect other pollutants. As contamination rises, the consolidation co-efficient (Cv) falls. A decline in CV value indicates that the consolidation process will take longer to finish. Skempton's relationship between the liquid limit and the compression index has been adjusted to include contaminated soil. The altered formula is provided as

$$Cc = 0.007(1+0.12 \log \mu cf/\mu w)(WL - 10)$$

Kassim and Huey (2000) presented the oedometer test findings on the consolidation properties of both unstabilized and lime-stabilized soil samples. A 50 mm diameter and 20 mm height oedometer specimen was evaluated at 0, 7, 14, and 28 days of age, and at 0, 200, 400, 800, and 1600 kpa of effective stress. For this experiment, three different types of soil were chosen and examined: tapah kaolin, sungai buloh clay, and UTM clay. Based on the test findings, it is shown that lime stabilization enhanced consolidation properties and decreased unstabilized clay settlement with age, particularly when the stabilization phase is completed, or after 14 days. It has been noted that at ages under 14 days, the majority of soil parameters exhibit inconsistent behavior. This shows that the bonding that has formed in the soil structure is still weak, indicating that the clay-lime mechanism is still in the modification phase below 14 days. A strong and long-lasting connection has been formed during the long-term response, or stabilization phase, which is the reason for the notable improvement in consolidation characteristics after 14 days. Overall, lime stabilization considerably increased the consolidation properties, or the untreated clay's rigidity. When soils were stabilized with lime, settlement decreased by around 60% after 28 days. With aging, stabilized soil becomes less permeable as a result of the gel that forms during the pozzolanic process. However, compared to unstabilized soil, the stabilized soil had greater permeability in its early age. Combining a surcharge with a lime-stabilized column could result in a practical application that benefits from increased permeability in the early stages and stiffer soil conditions over time as a result of pozzolanic reaction.

Onyelowe1 and Buivan (2018) studied the application of Quarries dust (QD), crushed waste ceramics (CWC), palm bunch ash (PBA), crushed waste ceramics base geopolymer cement (CWCbGPC), and palm bunch ash base geopolymer cement (PBAbGPC) into the soil and their structural analysis is done. It is essential that the usage of supplemental cementing materials in construction projects be encouraged. This is due to the additional harm that CO2 emissions are producing and the role they play in global warming. Test soil behavior has been studied using laboratory tests in response to admixture addition. Following the preliminary investigation, it was determined that the test soil according to ASHTO classification system's was A-7 soil and according to USCS's criteria it was poorly graded soil with a high clay content (GP/CH). Consolidation settling (CS) of the treated test soil was investigated using the treatment protocol; the findings indicated that the CS decreased gradually as the cementing additives were added in different amounts. With the geopolymer cements (GPC), an even more notable improvement was noted. The outcomes also demonstrated that, according to the treatment procedure, the PBAbGPC performed better than the CWCbGPC. In addition to successfully removing solid waste from the environment, the exercise demonstrated how these waste materials could be recovered and processed into substitute cementing materials to take the place of regular Portland cement and eliminate the CO2 emissions and global warming effects that come with it.

The following conclusions can be drawn after taking into account the outcomes of the laboratory tests carried out on the test soil that was treated with QD, CWC, PBA, CWCbGPC, and PBAbGPC:

(a) The test soil underwent preliminary parameter testing; the results indicated that it was categorized as an expansive soil with a plasticity index above 17% and as highly plastic soil with an AASHTO classification system of A-7 group and USCS classification system of GP/CH.

(b) To treat the test soil under laboratory conditions, the CWC base GPC and PBAbGPC were synthesized in accordance with the guidelines provided by earlier research findings. They were then used as coupled materials, and QD, CWC, and PBA were added in the following proportions: 1, 5, 10, 15, 20, 25, 30, 35, and 40%. This allowed for the determination of the consolidation settlement behavior of the treated soil.

(c) Alkali-activated cement (NaOH + Na2SiO3) produced under dry conditions and GPC produced under alkali-activated conditions allowed for the adaptation of solid waste inorganic materials; these cements' properties are consistently superior to those of regular Portland cement (OPC). In order to counteract the possibility of an ineffective geopolymerization reaction caused by an excessive release of OH-, the concentration of NaOH was maintained below that of Na2SiO3.

(d) The above procedure's results proved that the soil treated with a cementing additive showed a considerable and consistent reduction in consolidation settlement, with the GPC performing better. The observation indicates that the stabilization protocol can effectively use the properties of GPC to produce a hydraulically bound stabilized material with superior consolidation settlement handling management capabilities, elevated temperature resistance exceeding 600°C, resilience against acid, salt, and sulfate attacks, and resistance against brittle and corrosion effects.

Wanga and Tanttub (2018) investigates the impact of chemical stabilization on the one-dimensional compression behavior of natural soft clay based on incremental loading oedometer tests. The impact of a cement-lime combination is assessed for several dosages ranging from 1 to 13% by dry mass of clay, with a curing period of 1 to 28 days. The development of cementation-induced yielding stress, which is related to the initial void ratio, position, and shape of compression curves, as well as the capacity to maintain increased effective consolidation stress, is a significant effect of cement-lime stabilization. The outcome shows how the cement-lime treatment affects the hydraulic conductivity, compression index, and consolidation coefficient. The evolution of the compression index, creep coefficient, and ratio of the compression index to the creep coefficient are examined in relation to the effect that the cement-lime dose plays. In the process of improving soft ground, this study offers a reference for analyzing the impact of cement-lime stabilization on naturally occurring soft clays.

Through a series of incremental loading oedometer tests, the one-dimensional consolidation behavior of natural soft clay and cement-lime stabilized clay was examined. The curing times were set at 1, 7, 14, and 28 days, and the cement-lime dosage ranged from 1 to 13% by dry mass of clay. The initial void ratio decreases as cement-lime dosage and curing time rise. The rise in yielding stress, which is correlated with the location and form of compression curves, is the most obvious result of chemical treatment. The compression curves change to higher effective stress levels with an increase in cement-lime dose due to the development of cementation-induced yielding stress, maintaining increased effective stress at the same void ratio. According to the results, the compression index increases significantly at low cement-lime dosages until reaching a peak value of about 3% cement-lime, after which it significantly decreases at higher cement-lime dosages. On the other hand, regardless of the binder dose, the compression index in the normally consolidated zone does not significantly alter with cement-lime addition. There is little to no noticeable change in the hydraulic conductivity as a result of chemical treatment. The addition of cement-lime combination raises the treated clay's coefficient of consolidation, which is correlated with its hydraulic conductivity and compression modulus.

CHAPTER 3
OBJECTIVE OF THE STUDY

3.1 INTRODUCTION

Enhancement of soil geotechnical properties requires the application of nanomaterials in soil improvement techniques. The discipline of geotechnical engineering has made a number of advancements in recent years to enhance the qualities of poor soil through the application of nanomaterials. Numerous studies have been conducted utilizing various soil tests to determine the impact of nanomaterials on the geotechnical qualities of soil.

Since soft soils have a high tendency for settlement and a low shear strength, they are typically found in locations with high water content, that is, areas that are getting close to the liquid limit. In order to guarantee a stable strength and deformation and to meet preconstruction and post-settlement requirements, a steady state must be reached. Numerous approaches to soil improvement have been introduced for the construction of buildings on soft soils in civil engineering projects. Research has been made on nanomaterials, to stabilize fragile soils.

The physical and chemical properties of a material can be significantly impacted by even minute numbers of nanoparticles due to their active interactions with other particles and solutions. As a result, nanoparticles have attracted a lot of attention in a wide range of technical applications.

Nanochemicals enhance soil stabilization by interacting at the molecular level, forming strong chemical bonds with soil particles, resulting in a more stable and uniform soil structure. Their nanoscale size provides a larger surface area for improved reactivity and bonding efficiency, leading to higher strength and better load-bearing capacity. This results in faster stabilization processes compared to traditional methods. Additionally, nanochemicals often require smaller quantities and less labor for application, making them cost-effective. They also improve durability, offering greater resistance to environmental factors such as water infiltration and erosion.

In this investigation, an attempt has been made to study the effect of zycobond, a chemical addictive produced by the Gujrat-based Zydex Industries. Zycobond creates a solid covalent bond between soil particles, which lowers swelling and cracking also gives better lubrication for compaction.

Traditional soil stabilization methods have several limitations compared to nanoparticle stabilization. These methods often involve bulk additives like lime or cement, which may not uniformly mix with the soil, leading to inconsistent results. The effectiveness of traditional stabilizers relies heavily on thorough mechanical mixing and compaction, which can be labor-intensive and time-consuming. Larger quantities of materials are typically needed, increasing costs and environmental impact. In contrast, nanoparticle stabilization offers more uniform bonding at the molecular level, requiring smaller quantities, providing faster and more consistent stabilization, and often being more environmentally friendly. Therefore, the main objective of this study is to investigate about the suitability of this chemical additive (zycobond) as a stabilizing agent in a properly documented manner.

CHAPTER 4
MATERIALS AND METHODOLOGY

4.1 INTRODUCTION

The soil applied for the testing program was gathered from Assam Engineering College campus, Guwahati, Assam. The soil sample was taken from the University campus, Hostel 6 . The disturbed soil (Soil changed from its natural condition by excavation, while collecting soil from the field) was taken from a depth of 2 m below the ground level in the already existing open pit for the construction of drains and was air-dried and pulverized. The water content in soil was found to be 5.4 %, the specific gravity of the soil, determined by density bottle was found to be 2.65. Table 3.1 presents all index properties of the soil.

Table 4.1 Index properties of the soil

Parameters	value
Liquid Limit (%)	42.46
Plastic Limit (%)	18.74
Specific Gravity	2.65
Silt +clay (%)	92.12
Maximum dry unit wt (g-cm^-3)	17.006
Optimum Moisture Content(%)	19.90

4.2 STABILIZERS

In soil stabilization, a stabilizer is a material added to soil to improve its physical properties, making it more stable and suitable for construction and other engineering purposes. Stabilizers can enhance various characteristics of the soil, such as its strength, load-bearing capacity, resistance to erosion, and overall durability. The type of stabilizer used depends on the specific requirements of the project and the nature of the soil being treated.

4.2.2 ZYCOBOND

Zycobond is a chemical addictive which is in liquid form made by the Zydex Industries based in Gujrat. it forms strong covalent bond between soil particles and reduce swelling and cracking and also gives better lubrication for compaction. Chemical stabilization involves mixing or injecting the soil with chemically active compounds. This study includes chemical stabilization using Zycobond. In this study zycobond has been added to the soil at different contents ($0.5kg/m^3$, $0.75kg/m^3$ and $1kg/m^3$, $1.25kg/m^3$, $1.5kg/m^3$). Chemical additives perform a great role where locally available material potentially increases the cost of the project if not available. Zycobond is a new age nano-polymer that has the almost same number of polymers particles when contrasted with soil particles. It praises ordinary adjustment strategy by granting water obstruction and adaptable attaching to the soil. It builds the contact focus for adaptable holding which improves weariness opposition of cement and lime settled soils. ZycoBond is a 80-90 nm flexible acrylic co-polymer that has a very high surface area available for bonding. The higher number of contact points ensure flexible bonding at a nano level, leading to improved fatigue resistance in stabilized soils.

Table 4.2 properties of zycobond

Parameter	Value
Colour	Milky White
Odour	No
Flash point	Above 1000C
Explosion Hazard	No
Ignition Temperature	Above 2000C
Solubility in Water	Dispersible
pH value	5-6

4.2.3 CEMENT

Cement is a binder, a chemical substance used for construction that sets, hardens and adheres to other materials to bind them together. Cement is manufactured through a closely controlled chemical combination of calcium, silicon, aluminium, iron and other ingredients. In this project, Portland pozzolana cement (PPC) grade-53 is used along with the chemical additive (zycobond). PPC is a type of blended cement . It consists of 15-35% pozzolanic material, 4% gypsum and rest is clinker. Here, cement is mixed to the soil at 3% and 5% by weight of the soil respectively.

4.3 METHODOLOGY

4.3.1 SPECIFIC GRAVITY

The specific gravity (G) of soil particles is the ratio of the mass of a given volume of soil solids at a test temperature to the mass of an equal volume of distilled water at the same temperature. It is usually determined by the principle of displacement of water by soil solids in a density bottle, volumetric flask, pycnometer or a gas jar. For fine grained soils, the density bottle is relatively more accurate. In the following study the specific gravity of the soil sample was determined with the help of density bottle as per IS: 2720 (Part III/ Sec I) – 1980.

Table 4.3 Specific gravity of the soil

Materials	**Specific Gravity**
Soil	2.65

4.3.2 PARTICLE SIZE DISTRIBUTION

The percentage of various sizes of particles in given dry soil sample is found by a particle size analysis or mechanical analysis. By mechanical analysis is meant the separation of the soil into its various different size fractions. The mechanical analysis is performed in two stages:

1. Sieve analysis

2. Sedimentation analysis or wet mechanical analysis

The first is meant for coarse grained soil only, while the second stage is performed for fine grained soils. In general, a soil sample may contain both coarse-grained particles as well as fine particles, and hence both the stages of the mechanical analysis may be necessary. The sieve analysis is, however, the true representative of grain-size distribution, since the test is not affected by temperature and other factors. In the following study, the particle grain size distribution was done as per IS 2720 (Part IV)-1985.

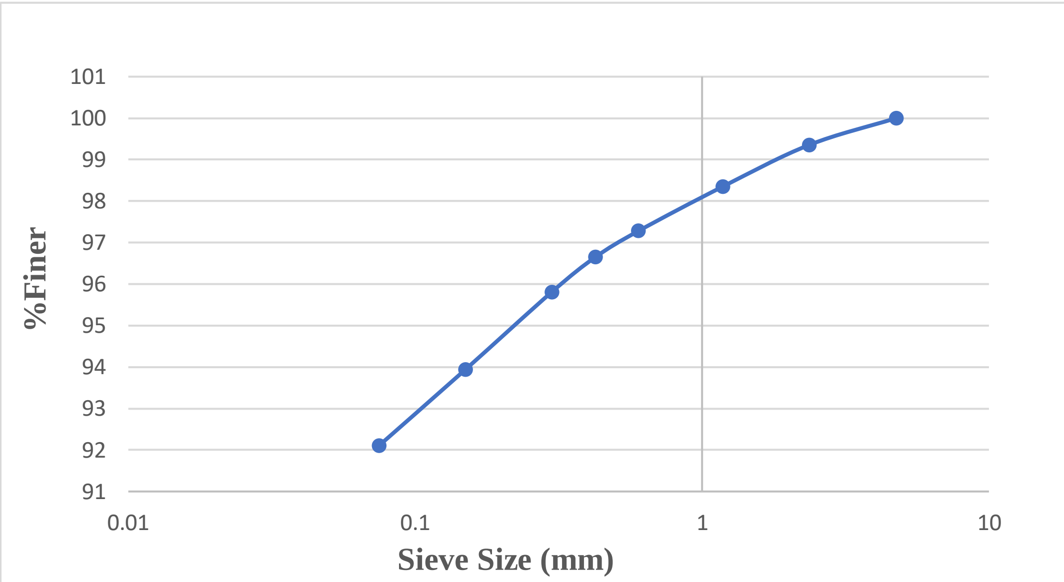


Figure 4.1: Grain Size Distribution of Test soil

4.3.3 DETERMINATION OF ATTERBERG LIMITS

In 1911, the Swedish agriculturist Atterberg divided the entire range of soil from liquid to solid state into the following four stages

(1) The liquid state

(2) The plastic state

(3) The semi-solid state

(4) The solid state

4.3.3.1 Liquid Limit (W_L)

Liquid limit is the water content corresponding to the arbitrary limit between liquid and plastic limit state of consistency of a soil. It is defined as the minimum water content at which the soil is still in the liquid state, but has an infinitesimal shearing strength against flowing, which can be measured by standard available means. In the following study, the liquid limit of the samples was determined by cone penetration method as described in IS: 2720 (Part V)-1985. 19

4.3.3.2 Plastic Limit (W_P)

Plastic limit is the water content corresponding to an arbitrary limit between plastic and semi-solid state of a soil. It is defined as the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter. About 200 g of air dried soil passing through 425 micron IS sieve, mixed with sufficient amount of water to make it plastic, is taken. Approximately 10 g of this mixture is taken with which a ball is made and rolled. The water content so adjusted that the thread just crumbles at 3 mm diameter. With this crumbled soil thread the moisture content is determined. The test is repeated atleast thrice and the average of them is taken as the plastic limit. In the following study, plastic limit of the samples were determined as per in IS: 2720 (Part V)-1985.

4.3.4 STANDARD PROCTOR TEST

The Standard Proctor Test was developed by R.R Proctor in 1933 for construction of earth fill dams in the state of California. The objective of this test is to establish a relationship between dry density and moisture content and also to determine the optimum moisture content corresponding to the maximum dry density. In the following study, the Standard Proctor Test was done as per IS: 2720 (Part VII)-1980

4.3.5 CONSOLIDATION TEST

Consolidation settlement is the vertical displacement of the surface corresponding to the volume change at any stage of the consolidation process. Consolidation settlement will result, for example, if a structure is built over a layer of saturated clay or if the water table is lowered permanently in a stratum overlying a clay layer. On the other hand, if an excavation is made in saturated clay, heaving (the reverse of settlement) will result in the bottom of the excavation due to swelling of the clay. In cases in which significant lateral strain takes place, there will be an immediate settlement due to deformation of the soil under undrained condition in addition to consolidation settlement. Immediate settlement can be easily calculated using results of elastic theory. The main purpose of the consolidation test is to obtain soil data which is used in predicting the rate and the amount of settlement of structures. The two most important properties furnished by a consolidation test are the coefficient of compressibility (av), through which one can determine the magnitude of compression and the coefficient of consolidation (Cv) which enables the determination of the rate of compression under load increment. In this study, the soil sample is completely air dried and pulverized manually. It is then sieved through 425 micron IS sieve. One dimensional consolidation test is done for untreated soil. Treated soil is prepared by mixing with various concentrations of zycobond (0.5kg/m^3, 0.75kg/m3 and 1kg/m3, 1.25kg/m^3, 1.5kg/m^3) and 3% and 5% of cement based on dry weight. samples corresponding to each above mentioned concentration of zycobond is prepared at optimum moisture content and Each sample is then subjected to one dimensional consolidation test as per the procedure mentioned in IS: 2720 (Part XV) – 1986.

Figure 4.2: Upper surface of consolidation sample

Figure 4.3: Lower surface of consolidation sample

Figure 4.4: Consolidometer apparatus

CHAPTER 5

TEST RESULTS AND ANALYSIS

5.1 INTRODUCTION

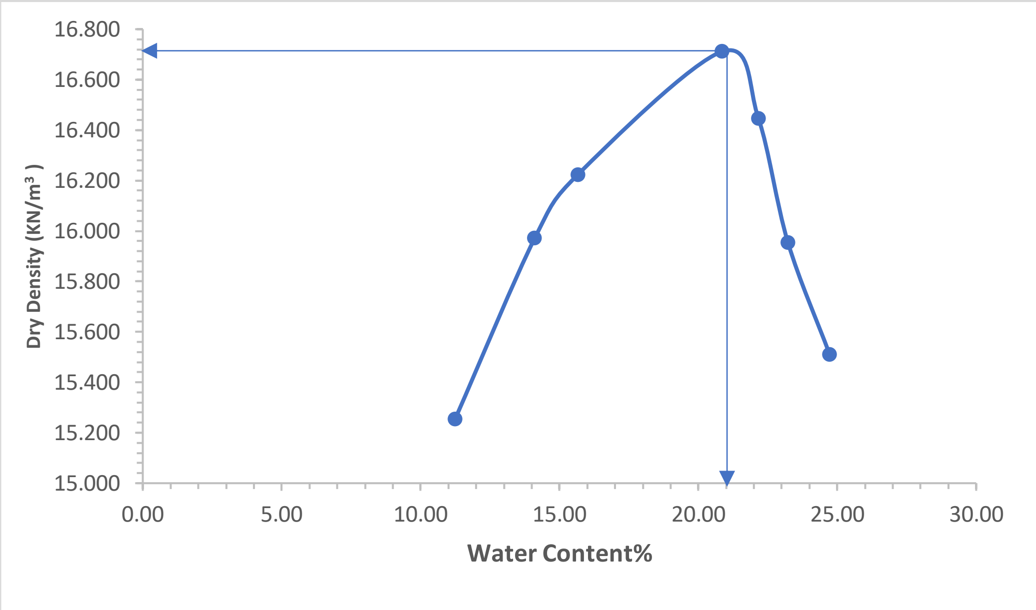
The broad process of altering natural soil to serve an engineering objective is called soil stabilization. There are various forms of stabilization, including chemical and mechanical stabilization. Chemical stabilization involves putting chemically active substances into the soil through mixing or injection. Zycobond is used in this investigation for chemical stabilization. Chemical additives are essential to a project when locally available materials are costly or difficult to obtain. By stabilizing soft clay with nanomaterials, the soil becomes impermeable and reduces plasticity index, increasing its stiffness. By adding Zycobond, the soil gains strength and stability while also becoming impermeable.

Utilizing nanomaterials for soil stabilization increases the soil's ability to support loads while also being cost-effective. (Uncontaminated) soil samples and soil samples blended with varied dosages of nano-chemical (zycobond) were subjected to laboratory investigations for index properties and consolidation tests to compare.

5.2 DETERMINATION OF COMPACTION PROPERTIES OF SOIL

The dynamic compaction method is the primary means of determining the compaction parameters of the soil in this study. A 4.75mm IS sieve was used to sieve the air-dried soil sample. Before adding water, the initial moisture content of a 2.5 kg soil sample was determined. Following the determination of the current moisture content, the appropriate amount of water was applied to the particular soil sample in order to reach the target water content. After that, the soil sample was matured for at least 24 hours by being kept within a polythene bag in an airtight container. For the remaining four samples of the same soil with varying water contents, the same procedure was carried out. Following the maturation process, the optimum moisture content that corresponds to the maximum dry unit weight was determined in a laboratory using the standard Proctor's compaction test, in accordance with IS: 2720 (Part 7) 1980.

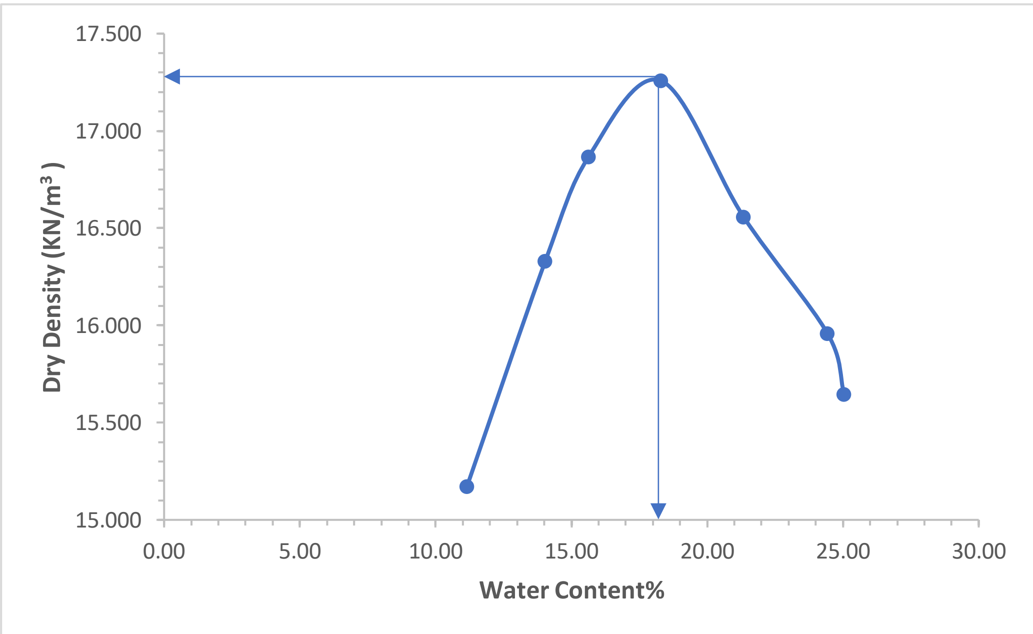
In this study standard proctor compaction test is conducted in 3 sets for the same soil sample to get more accuracy in work. Thus, 3 compaction curve has been obtained and the average of OMC and MDD is taken.



MDD=16.76

OMC=21%

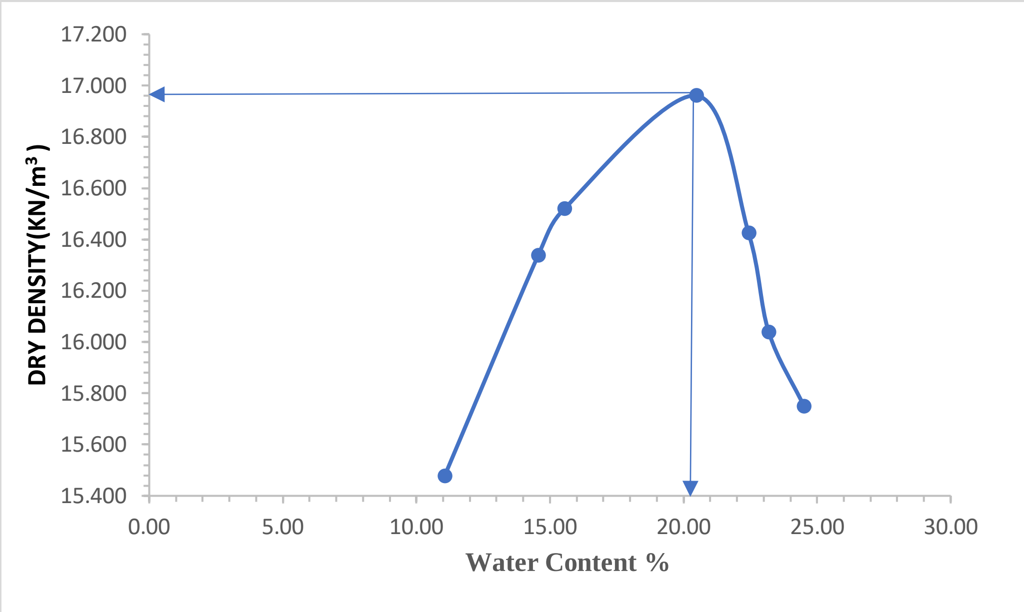
Figure 5.1: Compaction curve for set 1



MDD=17.29

OMC=18.20%

Figure 5.2: Compaction curve for set2



MDD=16.96

OMC=20.50%

Figure 5.3: Compaction curve for set3

AVG MDD=17.0066 g/cm^3

AVD OMC=19.90%

5.3 CONSOLIDATION TEST

The consolidation test was done in standard fixed-ring consolidometer using stainless steel rings of 60 mm diameter and 20mm height as according to the procedure given in IS:2720 (Part- 15) – 1986. At first the test was done in unstabilized sample and then test is done in soil sample mixed with various concentrations of zycobond (0.5kg/m^3, 0.75kg/m^3 and 1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) added with 3% and 5% cement respectively based on dry weight of soil.

5.3.1 Determination of Compression Index (C_C):

The Compression index 'C_C' is defined as the slope of the straight line portion of the void ratio versus log of effective stress for a normally consolidated clay.

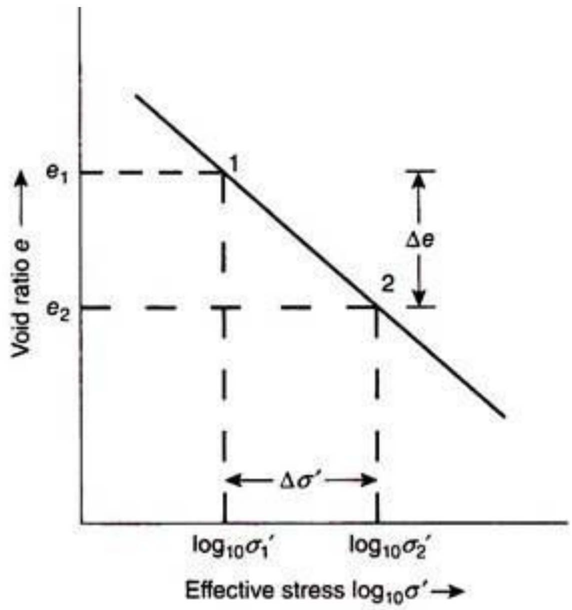


Figure 5.4: Void ratio versus log effective stress

The expression to find the compression index 'C_C' is given below-

$$C_C = \frac{(e_1 - e_2)}{\log_{10}\sigma'_2 - \log_{10}\sigma'_1} = \frac{\Delta e}{\log_{10}(\sigma'_2/\sigma'_1)}$$

Where, Δe = Change in void ratio

$\log_{10}(\sigma'_2/\sigma'_1)$ = Change in effective stress taken in log scale

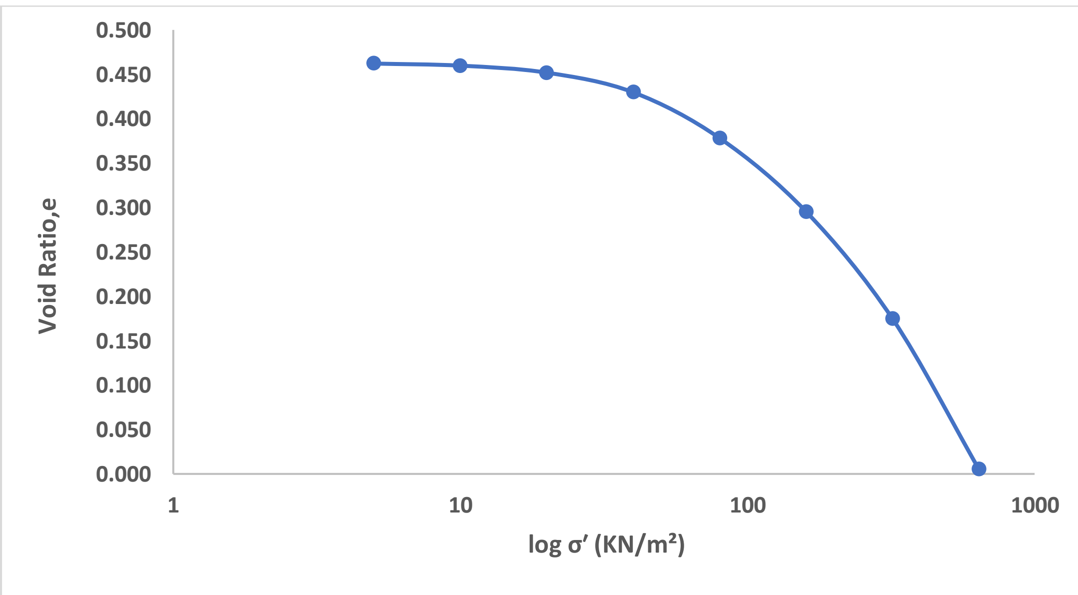


Figure 5.5: Semi-log plot of effective stress-void ratio for untreated soil.

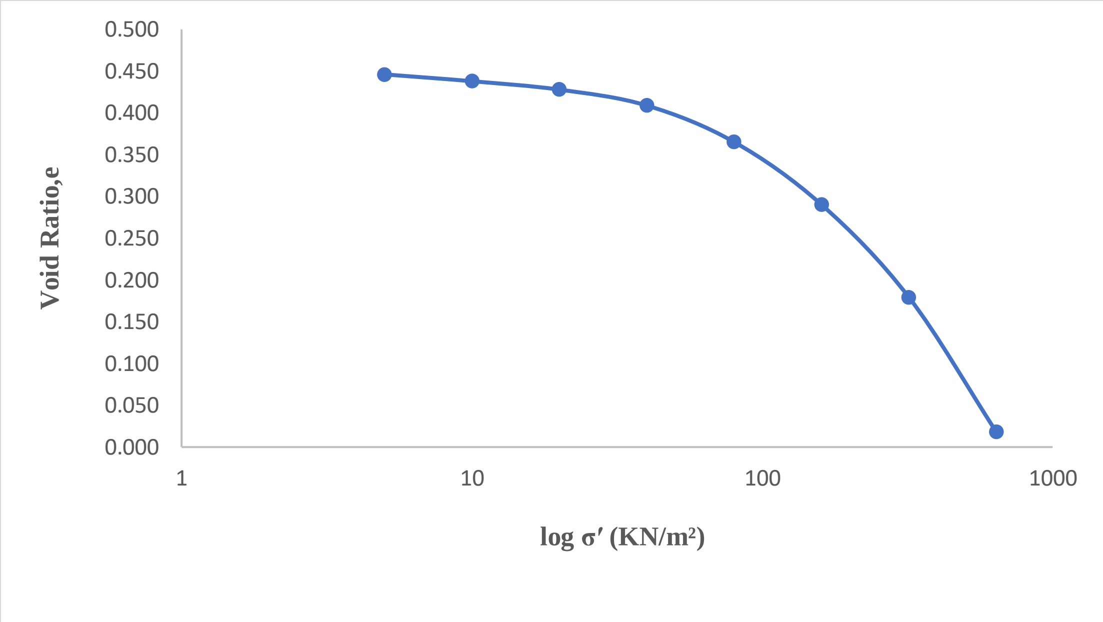


Figure 5.6: Semi-log plot of effective stress-void ratio for 3% cement and 0.5kg/m^3 zycobond

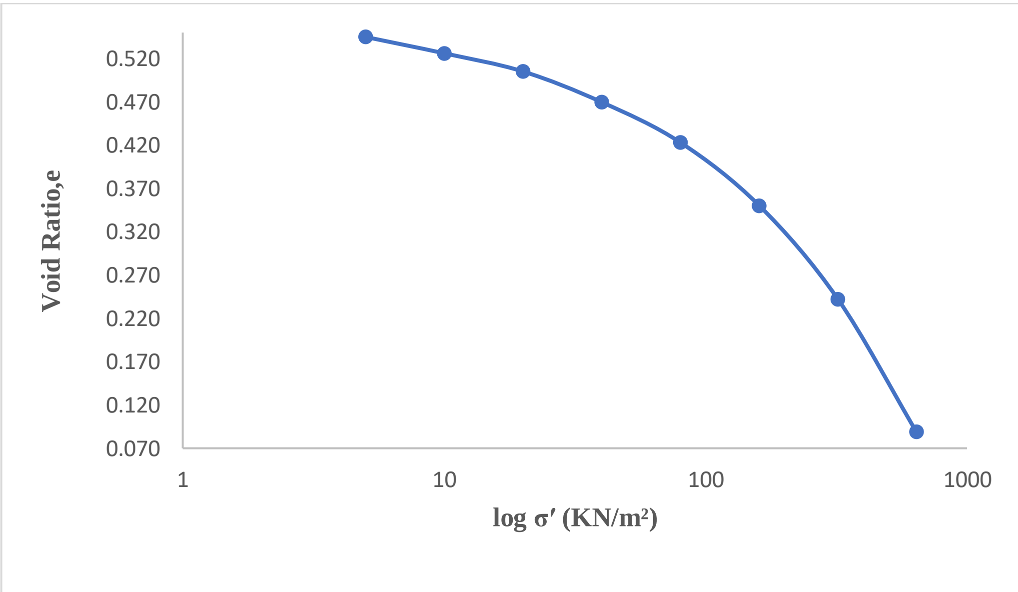


Figure 5.7:Semi-log plot of effective stress-void ratio for 3% cement and 0.75 kg/m^3 zycobond

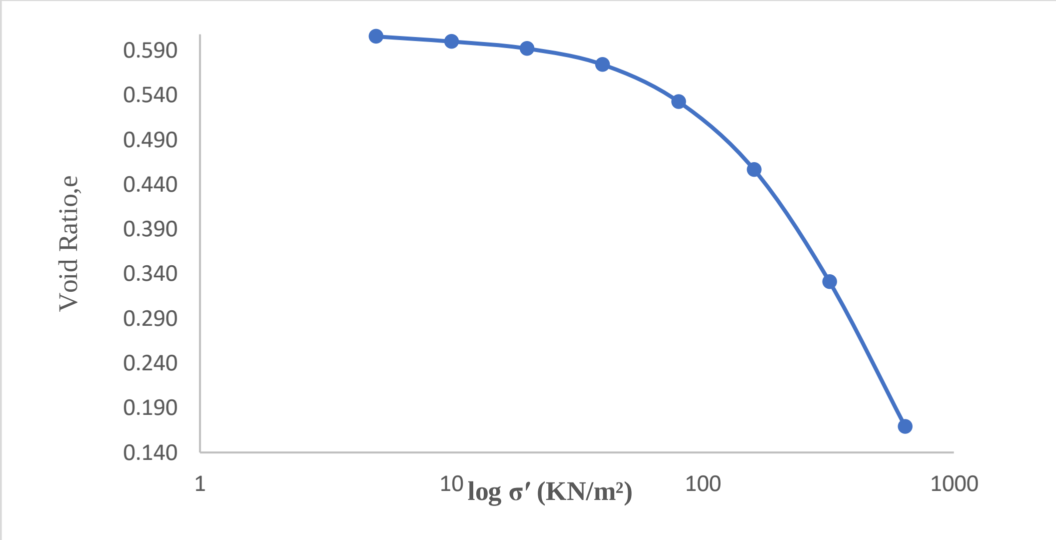


Figure 5.8: Semi-log plot of effective stress-void ratio for 3% cement and 1 kg/m^3 zycobond

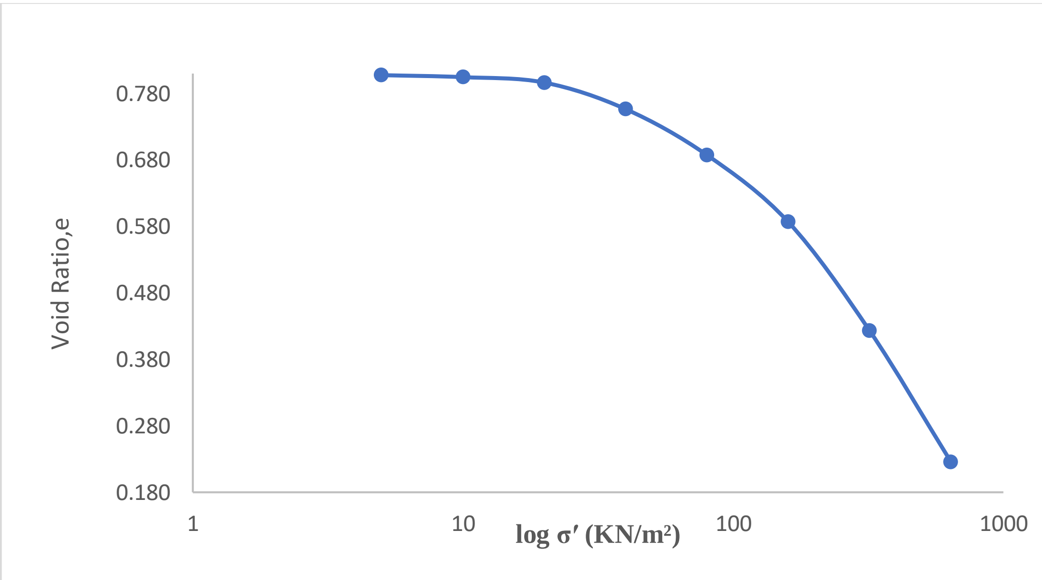


Figure 5.9:Semi-log plot of effective stress-void ratio for 3% cement and 1.25 kg/m^3 zycobond

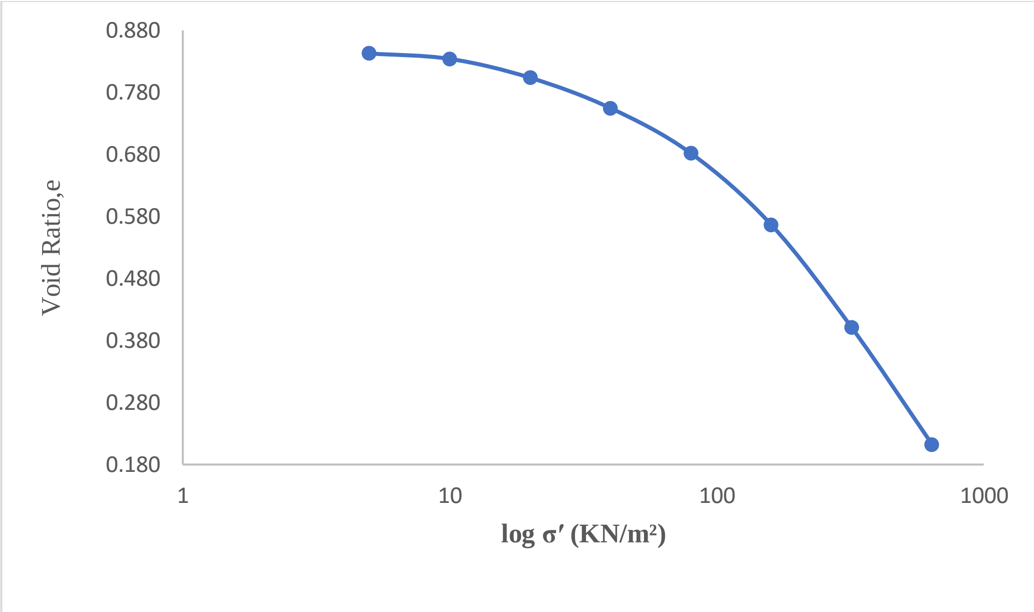


Figure 5.10:Semi-log plot of effective stress-void ratio for 3% cement and 1.5 kg/m^3 zycobond

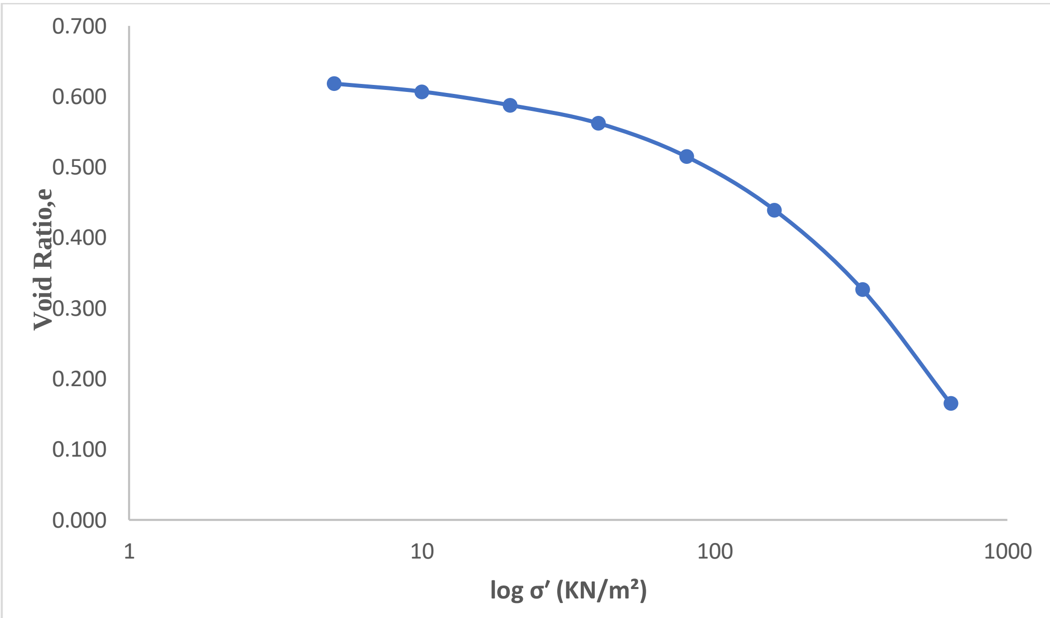


Figure 5.11: Semi-log plot of effective stress-void ratio for 5% cement and 0.5 kg/m^3 zycobond

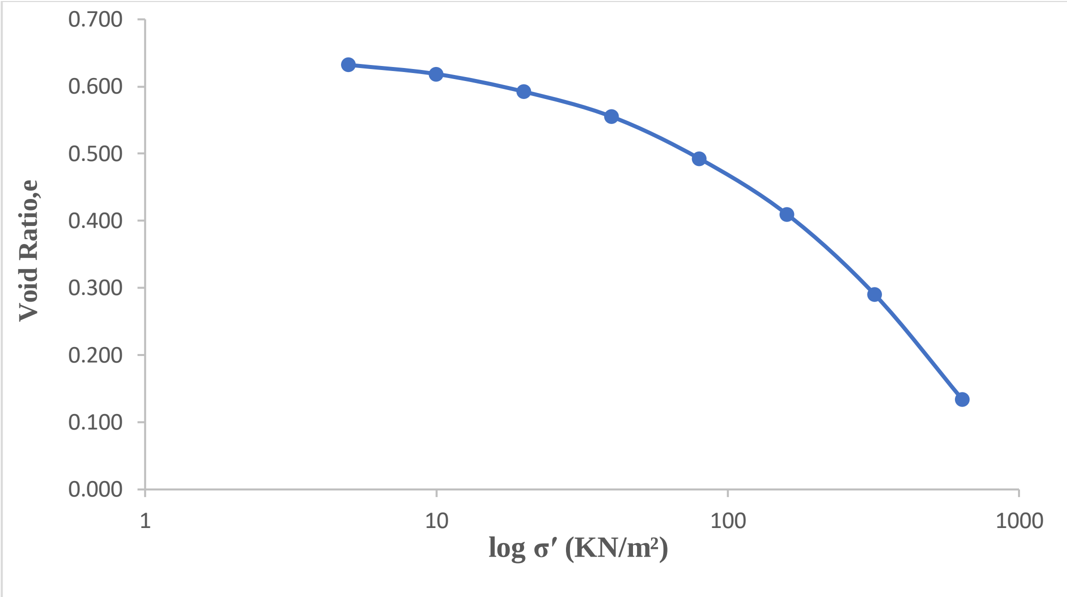


Figure 5.12:Semi-log plot of effective stress-void ratio for 5% cement and 0.75 kg/m^3 zycobond

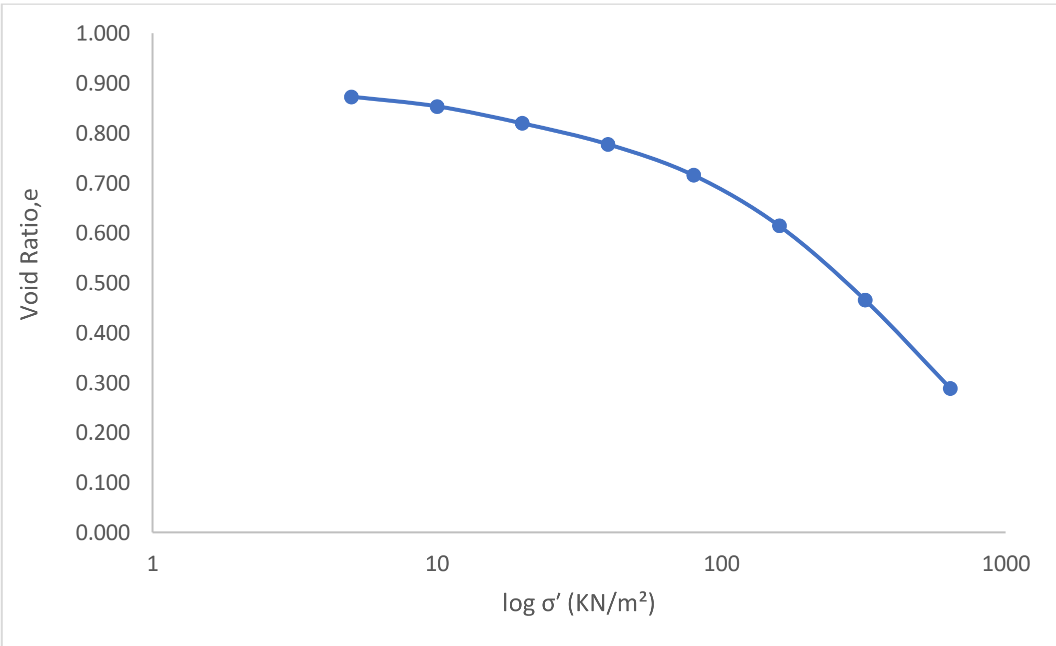


Figure 5.13: Semi-log plot of effective stress-void ratio for 5% cement and 1 kg/m^3 zycobond

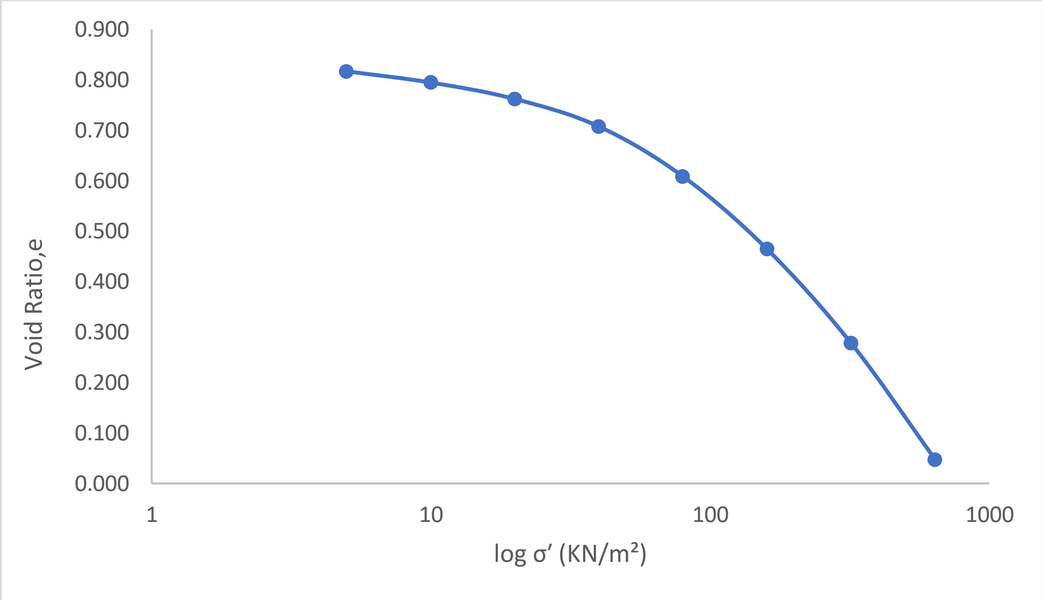


Figure 5.14: Semi-log plot of effective stress-void ratio for 5% cement and 1.25 kg/m^3 zycobond

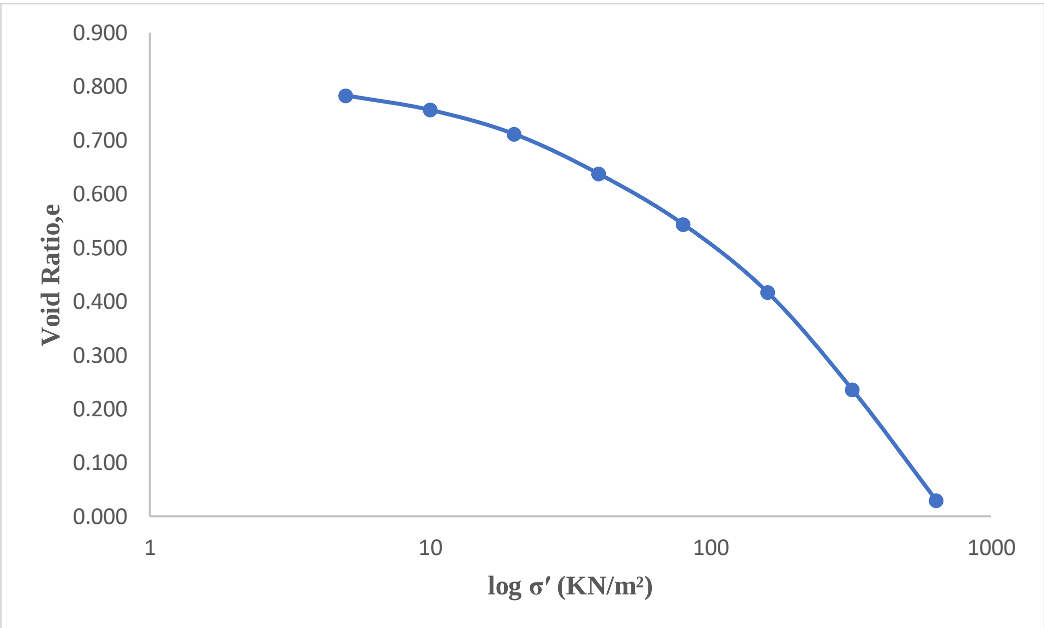


Figure 5.15: Semi-log plot of effective stress-void ratio for 5% cement and 1.5 kg/m^3 zycobond

Compression curves (e vs.log σ') is used to study about the effect of nanochemicals on the compressibility characteristics of the given sample. From the test results, it has been found that with increase in the concentration of zycobond the Compression Index (C_c) of the soil decreases upto the concentration of 1kg/m^3 and further goes on increasing till dosage of 1.5kg/m^3 from that of untreated sample. The values of compression index of the untreated soil and that of soil treated with 3% and 5% cement and varying dosage of zycobond (0.5kg/m^3, 0.75kg/m^3 and 1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) has been given below in the tabular form.

Table 5.1`: Compression Index of untreated soil and that of soil treated with 3% cement and varying dosage of zycobond (0.5kg/m^3, 0.75kg/m^3 and 1kg/m^3, 1.25kg/m^3, 1.5kg/m^3)

Sample	**Compression Index (C_c)**
Untreated soil	0.564
soil + 3% cement + 0.5kg/m^3 zycobond	0.534
soil + 3% cement + 0.75kg/m^3 zycobond	0.511
soil + 3% cement + 1kg/m^3 zycobond	0.478
soil + 3% cement + 1.25kg/m^3 zycobond	0.599
soil + 3% cement + 1.5kg/m^3 zycobond	0.624

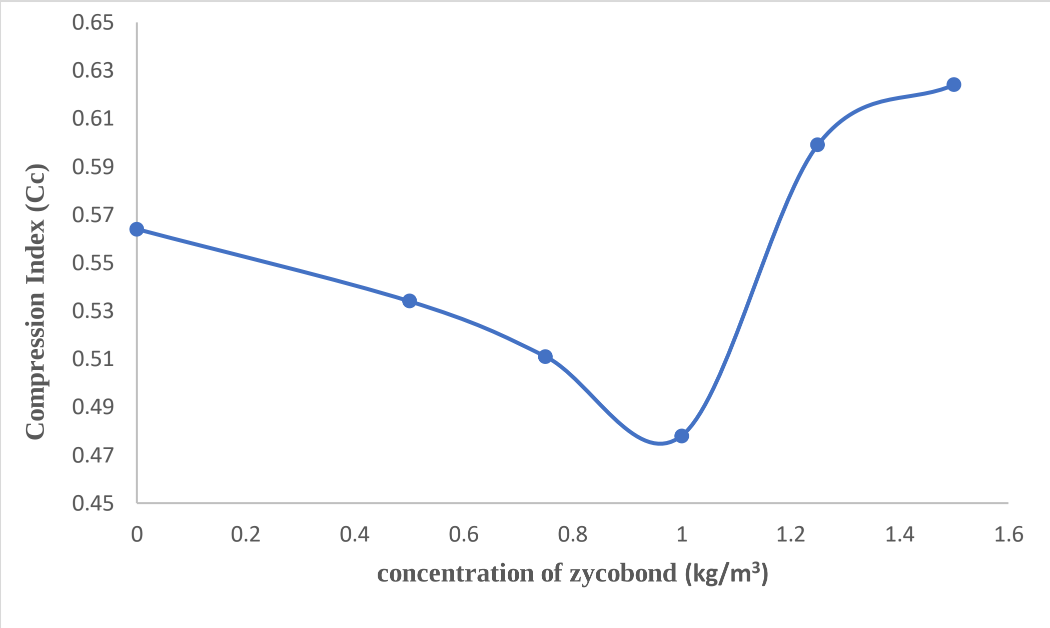


Figure 5.16: Variation in Compression Index (C_c) of soil with increasing concentration of Zycobond and 3% cement.

Table 5.2: Compression Index of untreated soil and that of soil treated with 5% cement and varying dosage of zycobond (0.5kg/m^3, 0.75kg/m^3 and 1kg/m^3, 1.25kg/m^3, 1.5kg/m^3)

Sample	Compression Index (C_c)
Untreated soil	0.564
soil + 5% cement + 0.5kg/m^3 zycobond	0.534
soil + 5% cement + 0.75kg/m^3 zycobond	0.518
soil + 5% cement + 1kg/m^3 zycobond	0.491
soil + 5% cement + 1.25kg/m^3 zycobond	0.617
soil + 5% cement + 1.5kg/m^3 zycobond	0.64

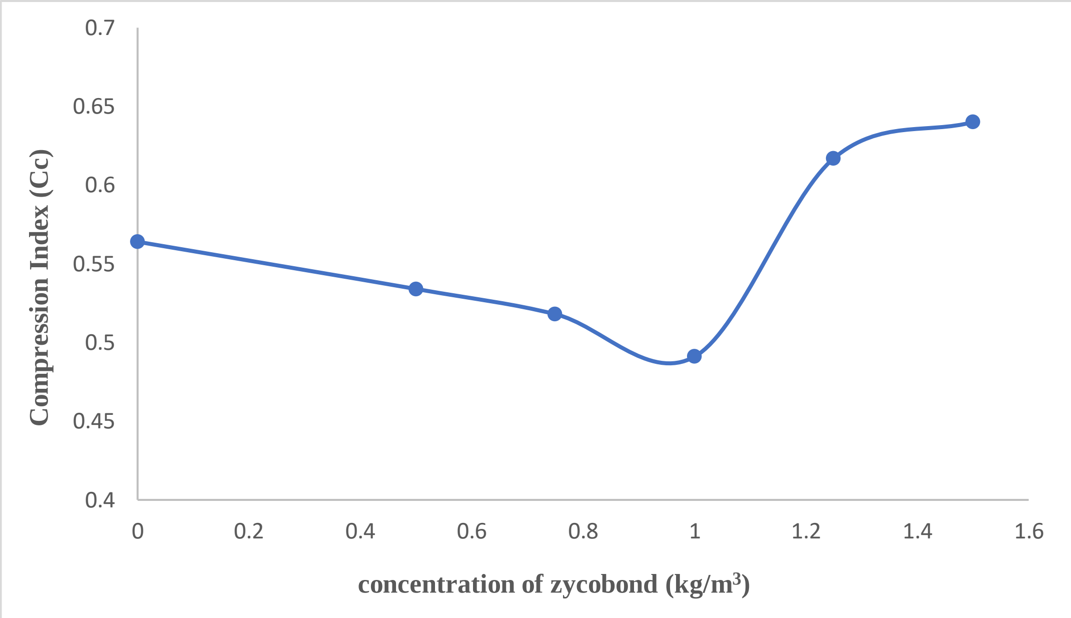


Figure 5.17: Variation in Compression Index (C_c) of soil with increasing concentration of Zycobond and 5% cement.

5.3.2 Determination of Coefficient of consolidation (C_V): The coefficient of consolidation, or "CV," is a metric that quantifies how quickly saturated soil or clay consolidates or becomes compacted in response to pressure increases. Typically, they are expressed in square centimeters per second.

The coefficient of consolidation in this study has been determined using the square root of time approach, in accordance with IS: 2720 (Part XV)-1986. After plotting the dial gauge reading vs. √t for a load increment of 320 KN/m^2 , a smooth curve connecting the spots is created. A straight line has to be drawn passing through the primary consolidation zone. Another straight line is drawn with a slope 1.15 times of the previous line. This line meets the curve at a point and the x-coordinate of that point gives the value of $\sqrt{t_{90}}$. The coefficient of consolidation 'C_V' can be calculated by the following equation-

$$C_V = \frac{(T_V \times d^2)}{t_{90}}$$

Where, $\sqrt{t_{90}}$ is obtained from the curves.

$(T_V)_{90}$ = Time factor corresponding to 90% degree of consolidation = 0.848 (from table)

d = Average drainage path for the pressure increment = $(H_i + H_f) / 4$

H_i = Initial height

H_f = Final height obtained by height of soilds method for a given pressure increment.

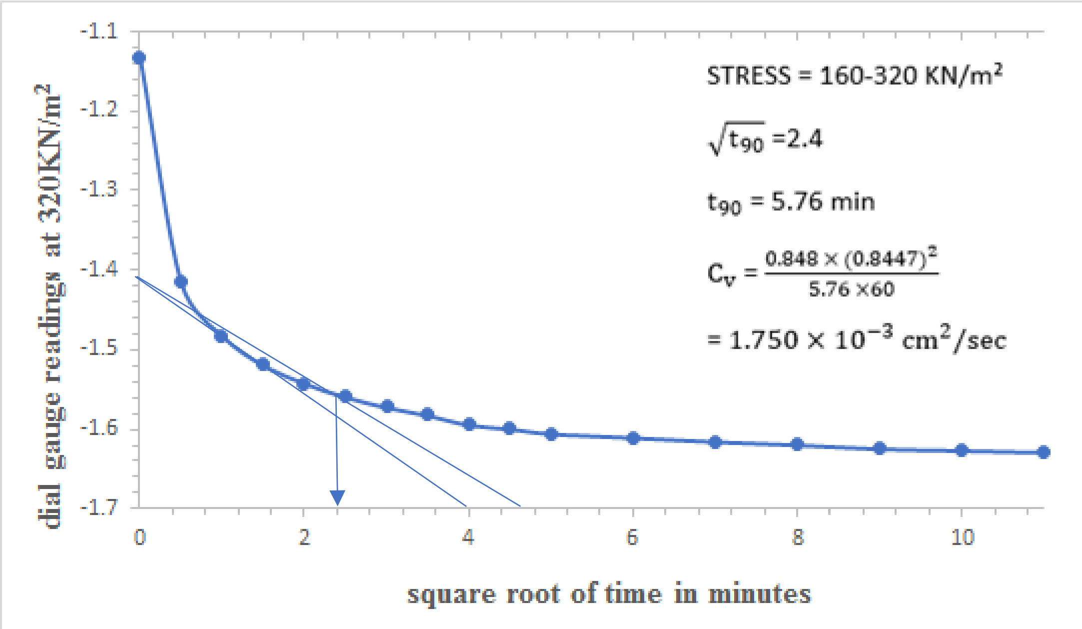


Figure 5.18: Time-consolidation curve for untreated soil

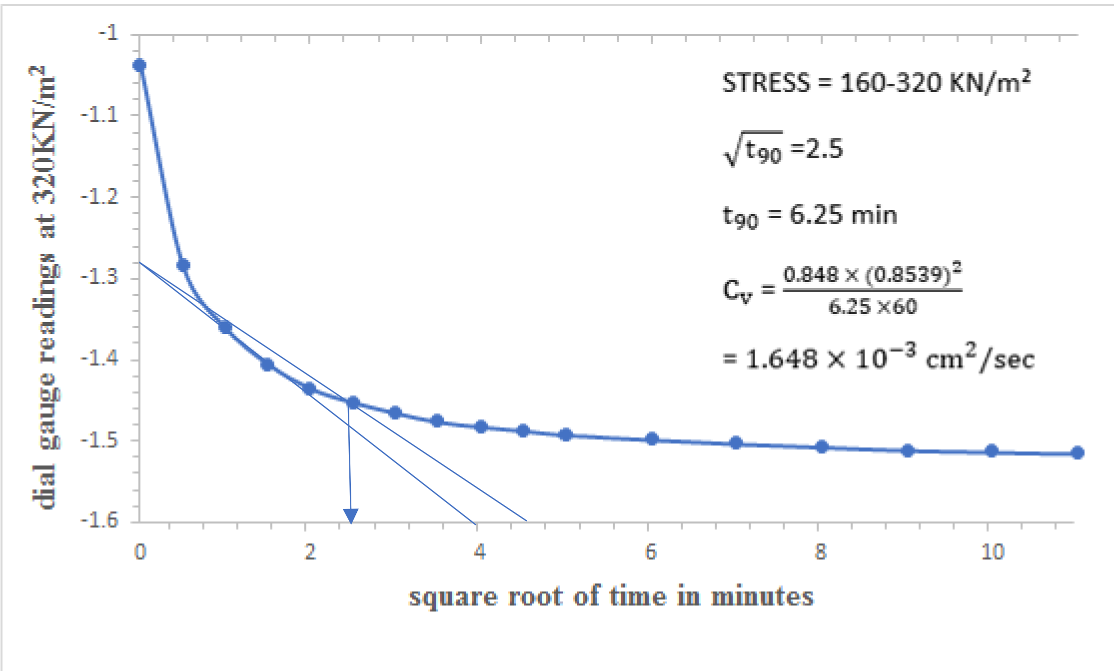


Figure 5.19: Time-consolidation curve for soil treated with 3 % and 0.5kg/m^3 zycobond

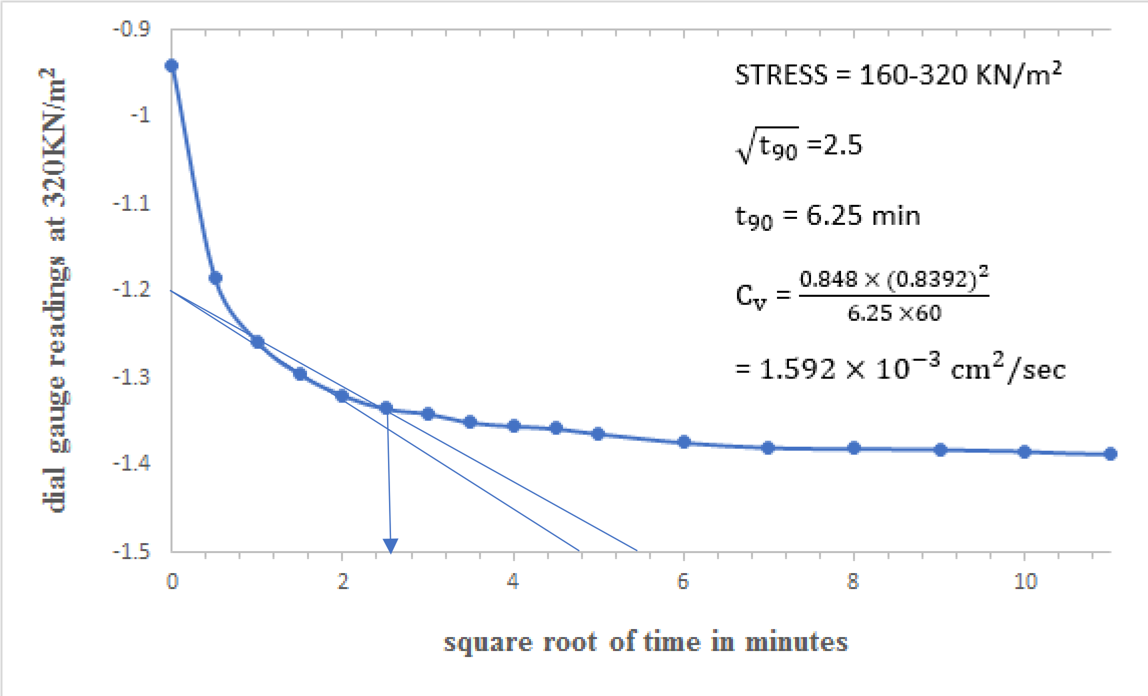


Figure 5.20: Time-consolidation curve for soil treated with 3 % cement and 0.75kg/m^3 zycobond

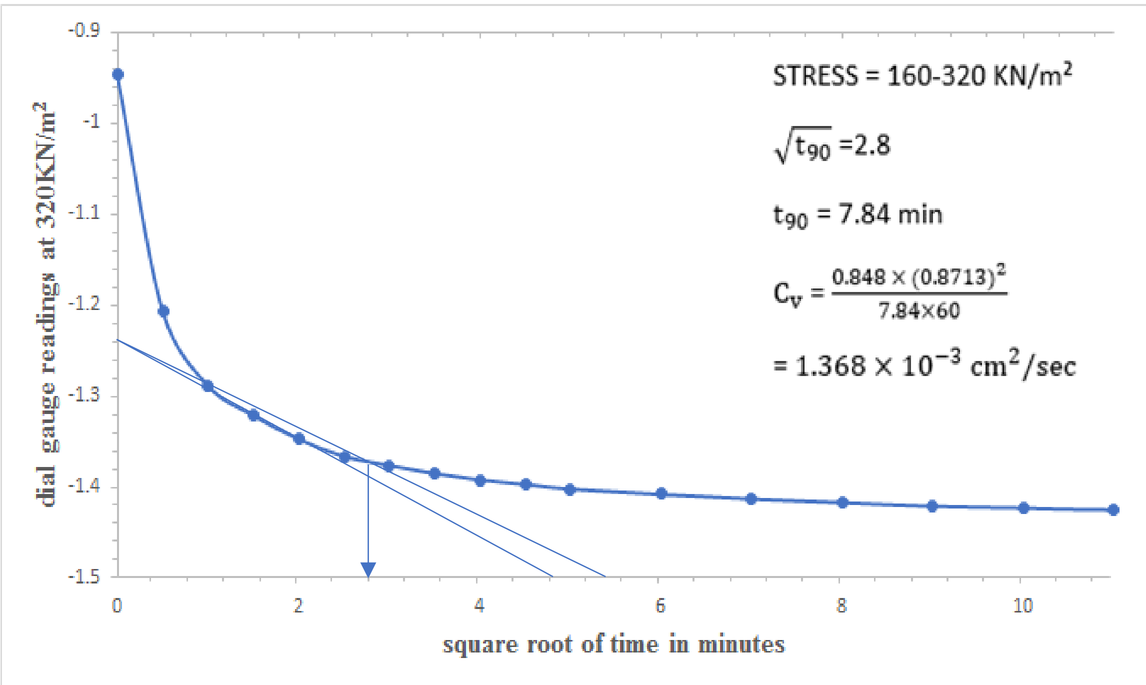


Figure 5.21: Time- consolidation curve for soil treated with 3 % cement and 1kg/m^3 zycobond

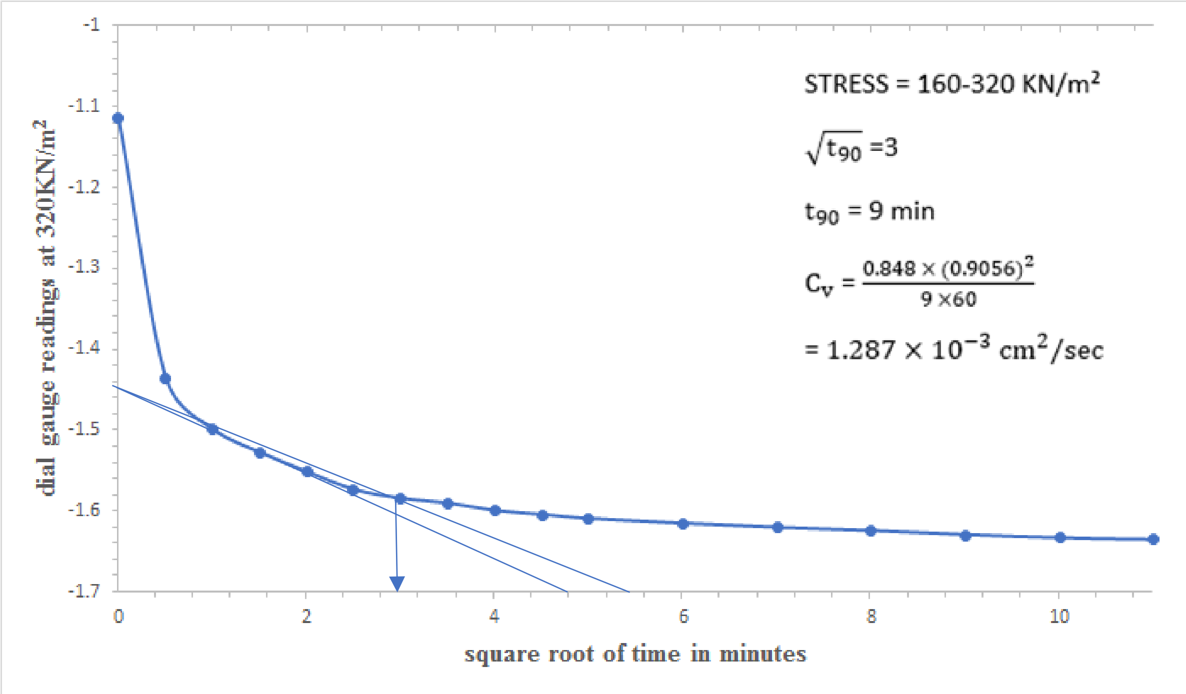


Figure 5.22: Time-consolidation curve for soil treated with 3 % cement and 1.25kg/m^3 zycobond

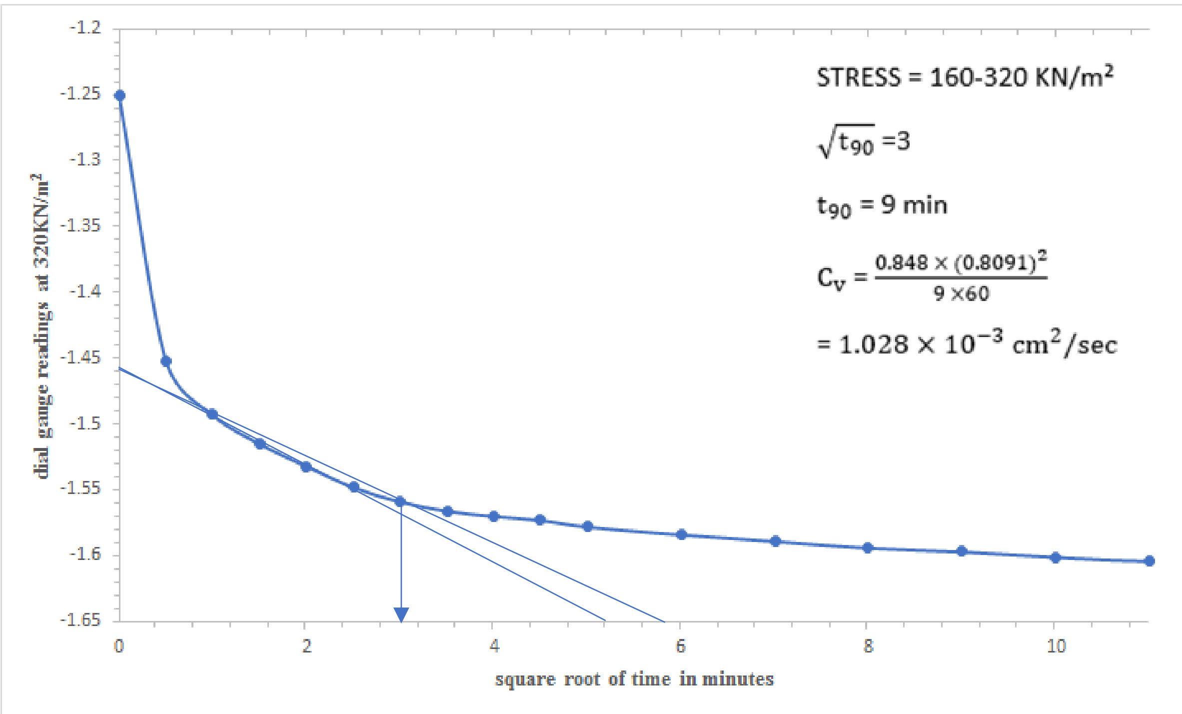


Figure 5.23: Time-consolidation curve for soil treated with 3 % cement and 1.5kg/m^3 zycobond

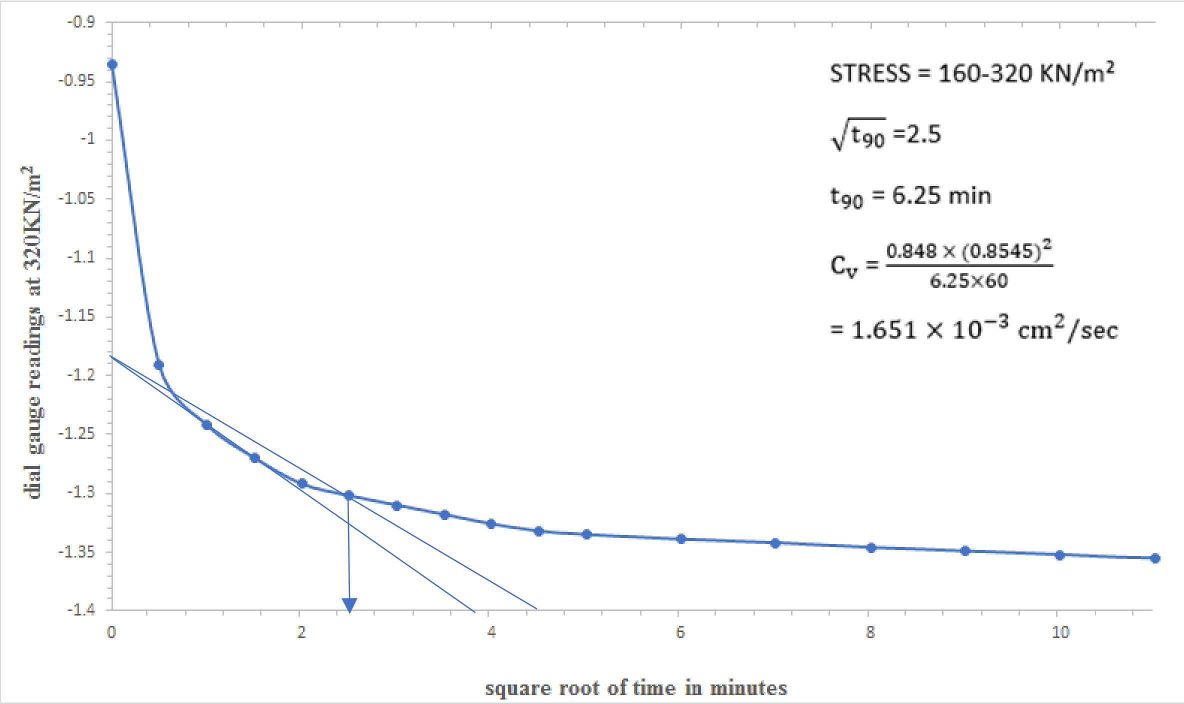


Figure 5.24: Time-consolidation curve for soil treated with 5 % cement and 0.5kg/m^3 zycobond

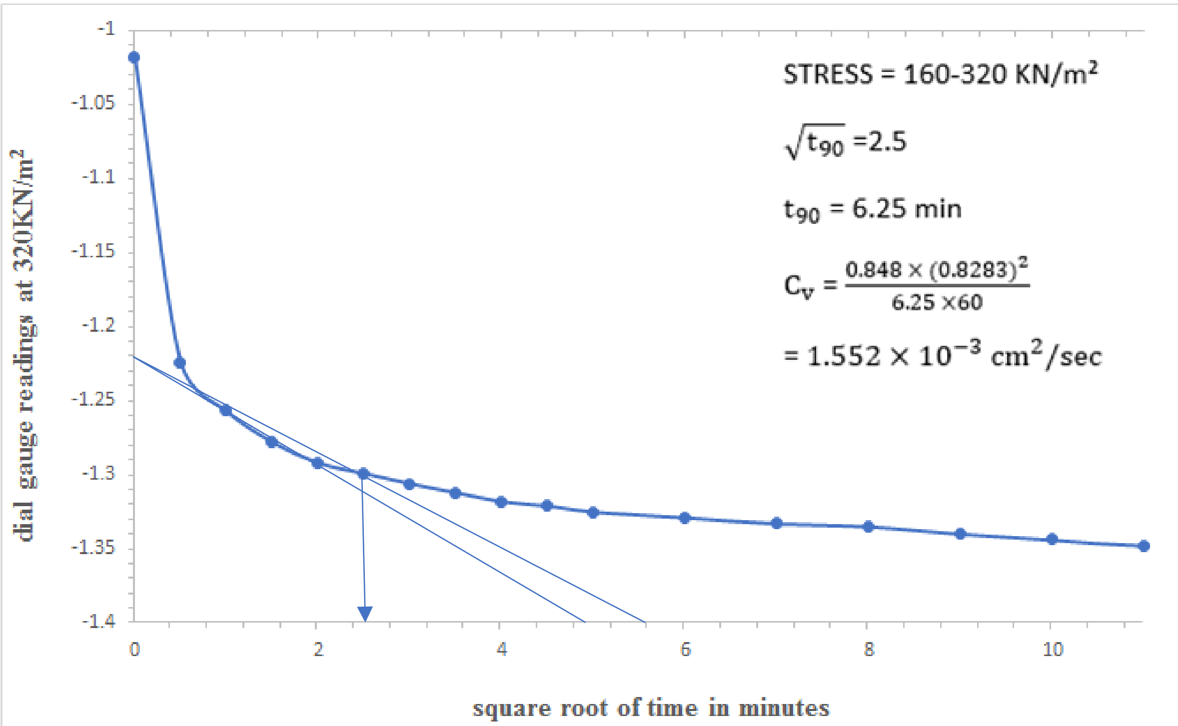


Figure 5.25: Time-consolidation curve for soil treated with 5 % cement and 0.75kg/m^3 zycobond

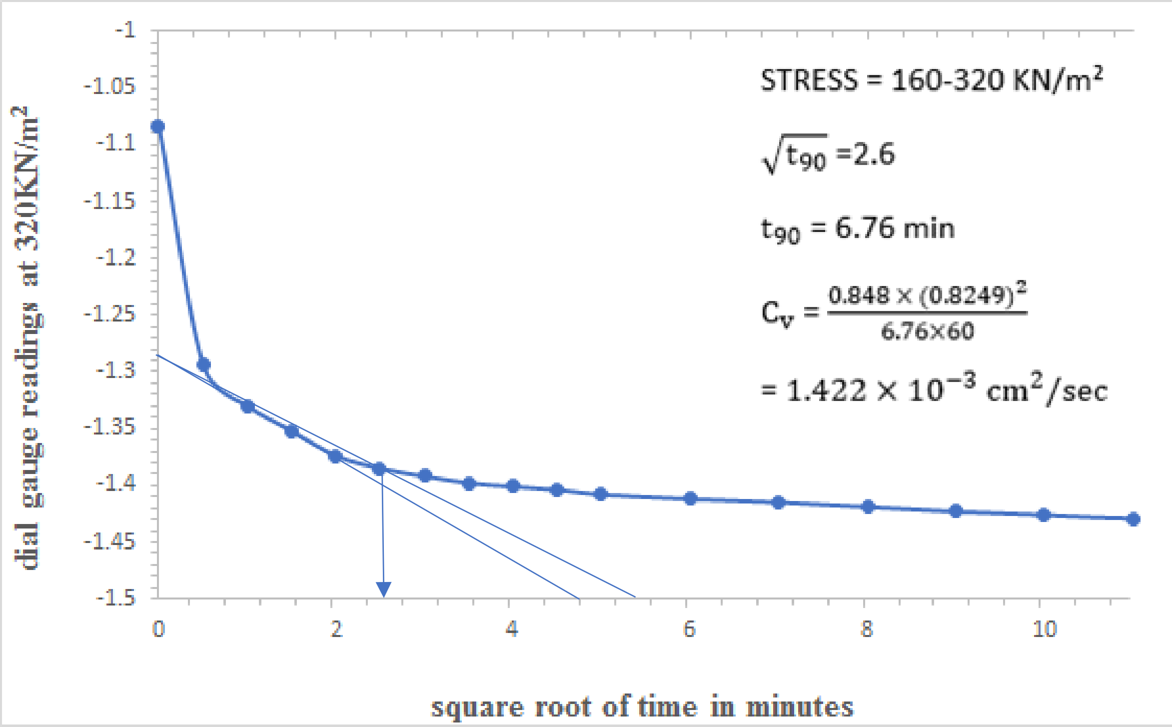


Figure 5.26: Time-consolidation curve for soil treated with 5 % cement and 1kg/m³ zycobond

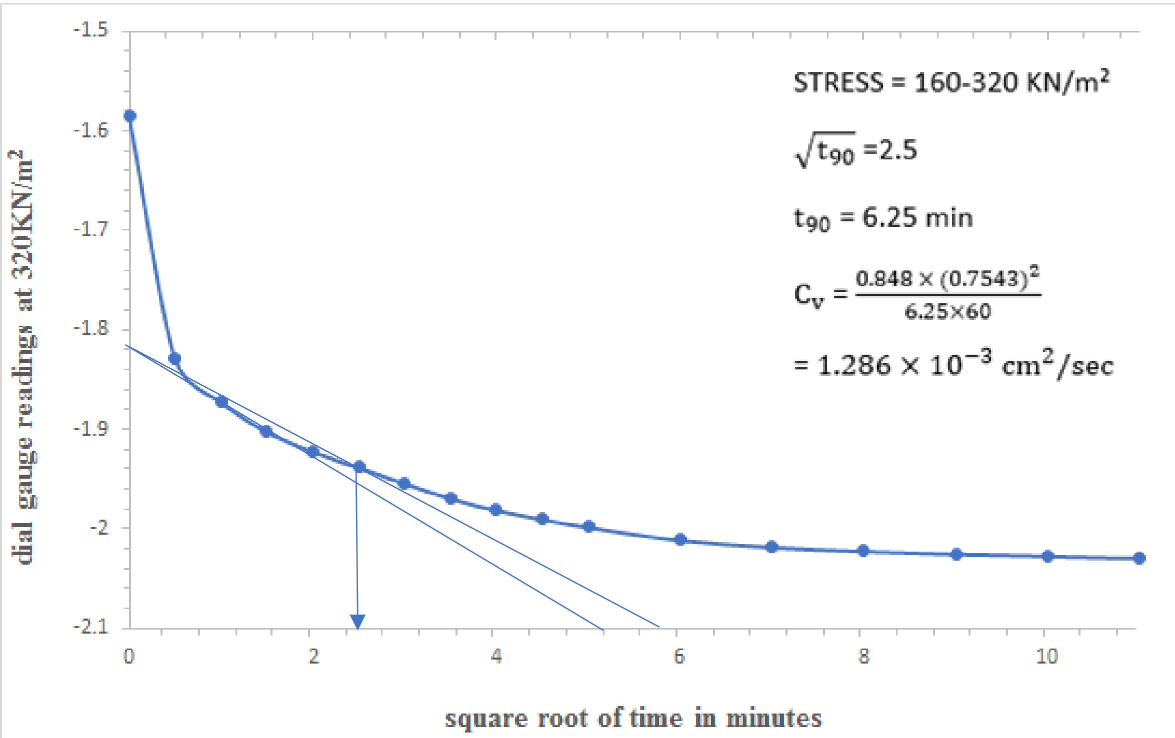


Figure 5.27: Time-consolidation curve for soil treated with 5 % cement and 1.25 kg/m³ zycobond

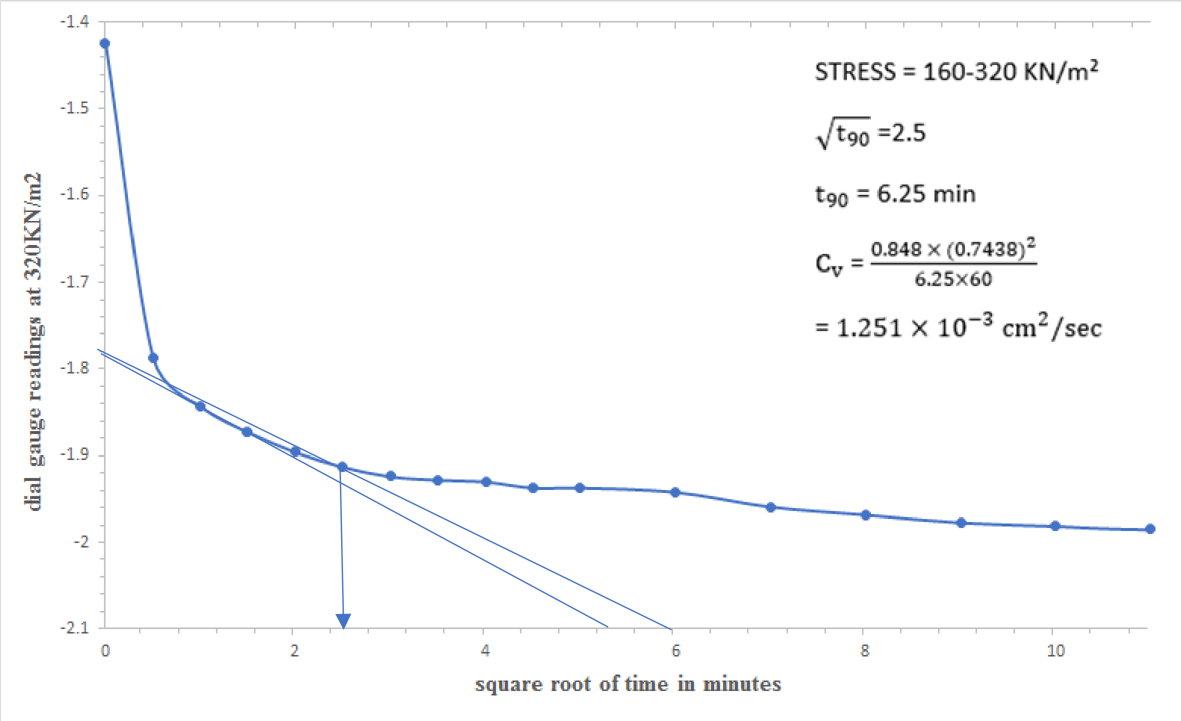


Figure 5.28: Time-consolidation curve for soil treated with 5 % cement and 1.5 kg/m^3 zycobond

Table 5.3: Coefficient of consolidation of untreated soil and that of soil treated with 3% cement and (0.5kg/m^3, 0.75kg/m^3 ,1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) of zycobond.

Sample	Coefficient of consolidation (C_v) (cm^2/s)
Untreated soil	1.750×10^{-3}
soil + 3% cement + 0.5kg/m^3 zycobond	1.648×10^{-3}
soil + 3% cement + 0.75kg/m^3 zycobond	1.592×10^{-3}
soil + 3% cement + 1kg/m^3 zycobond	1.368×10^{-3}
soil + 3% cement + 1.25kg/m^3 zycobond	1.287×10^{-3}
soil + 3% cement + 1.5kg/m^3 zycobond	1.028×10^{-3}

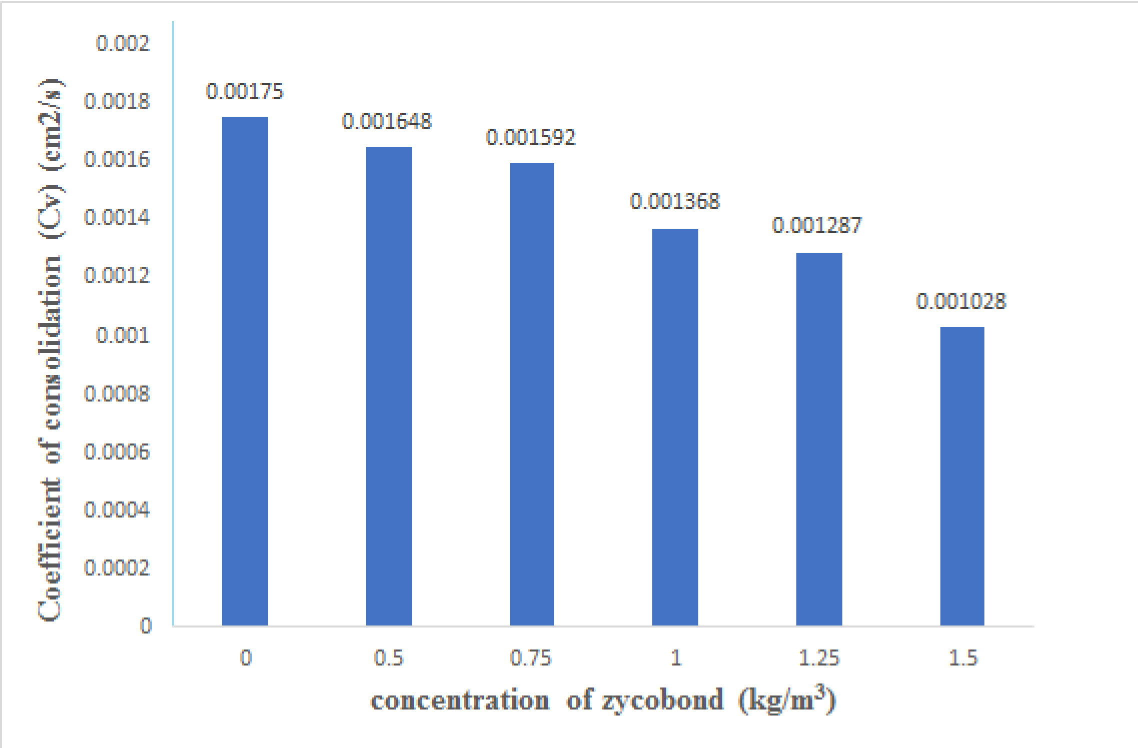


Figure 5.29: Variation of Coefficient of consolidation with respect to concentration of zycobond

Table 5.4: Coefficient of consolidation of untreated soil and that of soil treated with 5% cement and ($0.5kg/m^3$, $0.75kg/m^3$,$1kg/m^3$, $1.25kg/m^3$, $1.5kg/m^3$) of zycobond.

Sample	**Coefficient of consolidation (C_v) (cm^2/s)**
Untreated soil	1.750×10^{-3}
soil + 5% cement + $0.5kg/m^3$ zycobond	1.651×10^{-3}
soil + 5% cement + $0.75kg/m^3$ zycobond	1.552×10^{-3}
soil + 5% cement + $1kg/m^3$ zycobond	1.422×10^{-3}
soil + 5% cement + $1.25kg/m^3$ zycobond	1.286×10^{-3}
soil + 5% cement + $1.5kg/m^3$ zycobond	1.251×10^{-3}

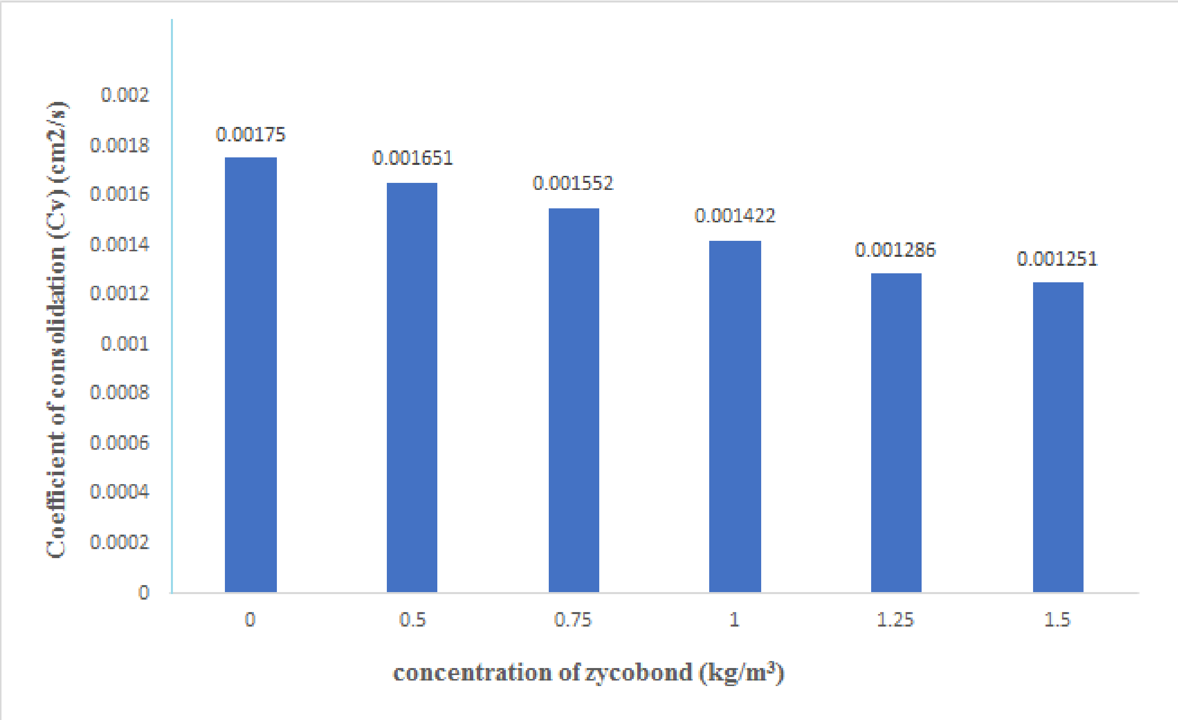


Figure 5.30: Variation of Coefficient of consolidation with respect to concentration of zycobond

From the Figure 5.29 and Figure 5.30, it has been observed that the coefficient of consolidation decreases with increase in concentration of zycobond. Coefficient of consolidation has a unique relationship between the permeability (k) and coefficient of volume compressibility (m_v). C_v is a function of k/m_v. As C_v is found to decrease, permeability which is directly proportional to C_v will also reduce.

5.3.3 Determination of Coefficient of Compressibility (a_v) :

The coefficient of compressibility (a_v) is defined as the decrease in voids ratio per unit increase in pressure. It can be calculated from the relation

$$a_v = -\Delta e/\Delta\sigma'$$

where, Δe represents the change in void ratio and $\Delta\sigma'$ represents the change in pressure increment. In this study, the coefficient of compressibility of soil sample treated different dosage of zycobond (0.5kg/m^3, 0.75kg/m^3 ,1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) corresponding to a pressure increment of 160 KN/m^2 has been taken.

Table 5.5: Coefficient of compressibility of untreated soil and that of soil treated with 3% cement and (0.5kg/m^3, 0.75kg/m^3 ,1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) of zycobond.

Sample	**Coefficient of compressibility (a_v) (m^2/KN)**
Untreated soil	1.038×10^{-3}
soil + 3% cement + 0.5kg/m^3 zycobond	0.938×10^{-3}
soil + 3% cement + 0.75kg/m^3 zycobond	0.913×10^{-3}
soil + 3% cement + 1kg/m^3 zycobond	0.909×10^{-3}
soil + 3% cement + 1.25kg/m^3 zycobond	1.250×10^{-3}
soil + 3% cement + 1.5kg/m^3 zycobond	1.438×10^{-3}

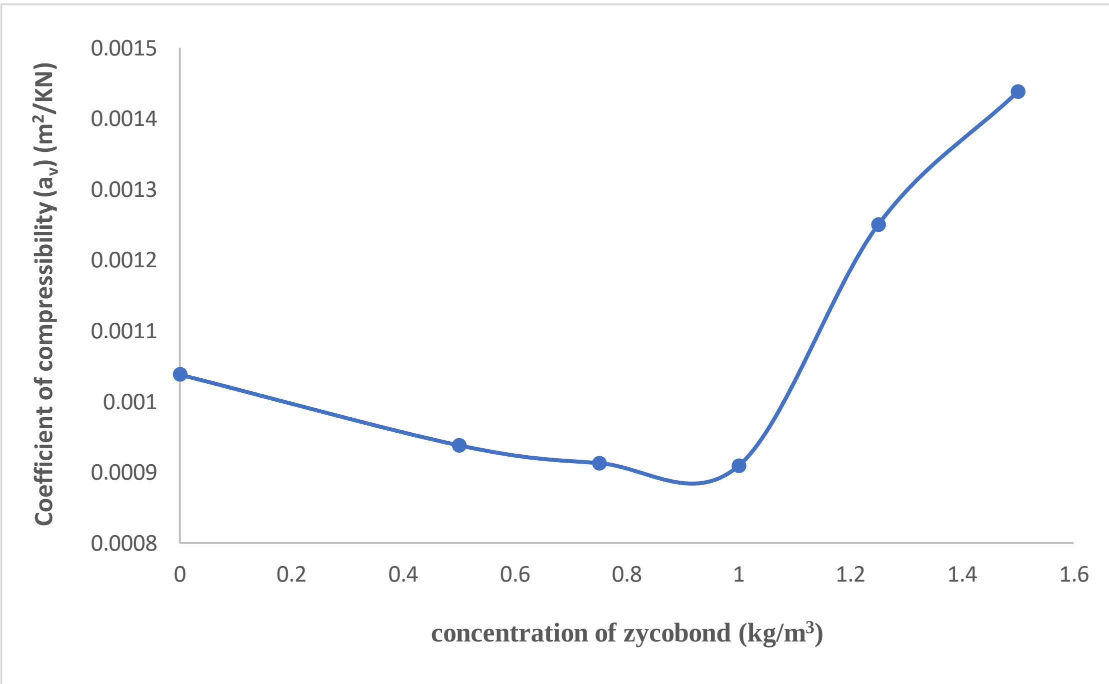


Figure 5.31: Variation of Coefficient of compressibility with respect to concentration of zycobond

Table 5.6: Coefficient of compressibility of untreated soil and that of soil treated with 5% cement and (0.5kg/m^3, 0.75kg/m^3 ,1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) of zycobond.

Sample	**Coefficient of compressibility (a_v) (m^2/KN)**
Untreated soil	1.038×10^{-3}
soil + 5% cement + 0.5kg/m^3 zycobond	0.950×10^{-3}
soil + 5% cement + 0.75kg/m^3 zycobond	0.935×10^{-3}
soil + 5% cement + 1kg/m^3 zycobond	0.921×10^{-3}
soil + 5% cement + 1.25kg/m^3 zycobond	1.234×10^{-3}
soil + 5% cement + 1.5kg/m^3 zycobond	1.588×10^{-3}

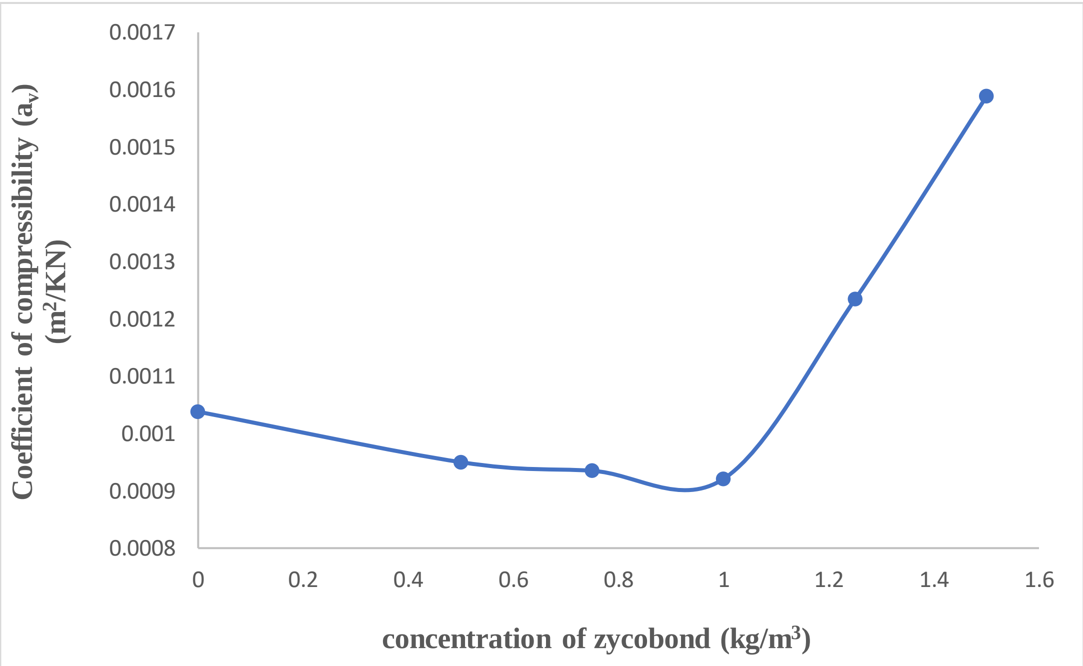


Figure 5.32: Variation of Coefficient of compressibility with respect to concentration of zycobond

From the Figure 5.31 and Figure 5.32, it is evident that the coefficient of compressibility decreases with increase in concentration of zycobond upto the dosage of 1kg/m^3 zycobond. It can also be observed that the coefficient of compressibility increases from the concentration of 1.25kg/m^3. Hence it can be concluded that the magnitude of compression decreases with increase in concentration of zycobond upto a optimum dose of 1kg/m^3.

CHAPTER 6
CONCLUSION

In this work consolidation test has been carried out in unstabilized soil and soil treated with nano-chemical (zycobond) with different dosage (0.5kg/m^3, 0.75kg/m^3 ,1kg/m^3, 1.25kg/m^3, 1.5kg/m^3) also mixed with 3% and 5% cement respectively based on dry weight of soil.

physical properties has been tested for the soil sample. This study is mainly about the test on the soil sample stabilized with nano chemicals namely zycobond. The test results will be compared between the stabilized and unstabilized soil. The consolidation behaviour of the soil is tested and analysis is done for untreated soil and the soil treated with nano-particles.

1) Liquid limit and plastic limit has been found to be 42.034% and 18.747% respectively. Specific gravity of the untreated soil has been found as 2.65, also from grain size distribution curve (silt & clay) % has been found as 92.12%.
2) Maximum dry unit wt and optimum moisture content has been found as 17.006 g/cm^3 and 19.90% respectively.
3) Consolidation test was performed for unstabilized soil and soil stabilized with nano-chemical. It has been found that with increase in the concentration of zycobond the Compression Index (Cc) of the soil decreases upto the concentration of 1kg/m^3 and further goes on increasing till dosage of 1.5kg/m^3 from that of untreated sample. This implies that the soil becomes less compressible with addition of zycobond upto a optimum dose of 1kg/m^3. Compressibility of the soil increases from 1.25kg/m^3 to 1.5kg/m^3. There is a decrement of 15% in the compressibility of the soil as compared to untreated soil at the optimum dose of 1kg/m^3 added with 3% of cement. Also a decrement of 12% is seen in compressibility at optimum dose added with 5% cement. The consolidation settlement depends upon the value of compression index (Cc) of the soil. A decrease in the value of compression index results in lowering consolidation settlement.
4) Consolidation settlement decreases compared to untreated soil upto the optimum dose of 1kg/m^3 of zycobond mixed to the soil. Settlement increases with further increase in concentration of zycobond.

5) Coefficient of consolidation decreases with increasing concentration of zycobond added with both 3% and 5% cement. This implies that the rate of consolidation decreases with increasing content of zycobond. C_v can be expressed as k/mv. As c_v decreases, permeability (k) of the soil also decreases. The reason for decrease in permeability, compressibility and rate of consolidation is the use of Zycobond, which is a cement concrete waterproofing solution that can offer solutions to stop moisture migration and process strong bonding in pavement layers as a result of which the soil is treated at the molecular or atomic level, affecting its quality, porosity indices, compressibility, and permeability qualities.

6) coefficient of compressibility(a_v) decreases with increase in concentration of zycobond upto the optimum dose of $1kg/m^3$ as compared to untreated soil. Hence it can be concluded that the magnitude of compression is lowest at optimum dosage of $1kg/m^3$ zycobond. This nanochemical serves as a water barrier, maintaining the strength over time. strong bonding in pavement layers is achieved when treated with zycobond. When nanoparticles are introduced as an external component into locally available soil, the soil is treated at the atomic or molecular level. This is the reason that its treatment improves soil's strength, compressibility, and permeability qualities.

CHAPTER-7

SCOPE FOR FURTHER STUDIES

7.1 LIMITATIONS OF THE STUDY

The present study is carried out to get a preliminary insight into the effects of nanoparticle named zycobond on some of the geotechnical properties of soil. This study does not take into account the variation of all the geotechnical properties, physical properties and chemical properties; it is just a minute step ahead of large research area of laboratory investigation in the field of soil mechanics. Due to time constraints, this study is limited to some of the geotechnical properties only. Although zycobond has given promising results regarding stabilization of soil considered, the study has some limitations, some of them are:

1. Only one type of soil has been considered for the study.
2. The effect of zycobond on shear parameters of the soil has not been studied.
3. The effect of zycobond on the unconfined compressive strength of the soil has not been studied.
4. The effect of zycobond on the California Bearing Ratio (CBR) has not been studied.

7.2 SOME OTHER POSSIBLE STUDIES ON THE SAME LINE

Due to the above limitation, some possible courses for further studies that can be carried out on the same line are:

1. The effect of zycobond stabilization on the unconfined compressive strength of soil.
2. The effect of zycobond on shear parameters of soil.
3. The effect of zycobond on CBR properties of soil etc.

REFERENCES

1.Zahoor, S. A. R. V. E. R., & Jassal, K. S. H. I. T. I. J. (2020). Nanotechnology mediated enhancement in engineering properties of alluvial soil. *International Journal of Mechanical and Production Engineering Research and Development*, *10*(3), 12881-12888.

2.Olaniyan, O. S., & Ajileye, V. O. (2018). Strength characteristics of lateritic soil stabilized with terrasil and zycobond nanno chemicals. *International Academy of Engineering and Technology Science*, *7*(2).

3. Khalaf, F. K., Hafez, M. A., Fattah, M. Y., & Al-Shaikli, M. S. (2020). A review study on the optimizing the performance of soil using nanomaterials. *Advances in Industrial Engineering and Management (AIEM)*, *9*(2), 1-10.

4. Meeravali, K., Ruben, N., & Rangaswamy, K. (2020). Stabilization of soft-clay using nanomaterial: Terrasil. *Materials Today: Proceedings*, *27*, 1030-1037.

5. Cheng, G., Zhu, H. H., Wen, Y. N., Shi, B., & Gao, L. (2020). Experimental investigation of consolidation properties of nano-bentonite mixed clayey soil. *Sustainability*, *12*(2), 459.

6. Singh, S. K., Srivastava, R. K., & John, S. (2008). Settlement characteristics of clayey soils contaminated with petroleum hydrocarbons. *Soil & sediment contamination*, *17*(3), 290-300.

7. Sebastian Bryson, L., Mahmoodabadi, M., & Adu-Gyamfi, K. (2017). Prediction of consolidation and shear behavior of fly ash–soil mixtures using mixture theory. *Journal of Materials in Civil Engineering*, *29*(11), 04017222.

8. Zheng, J., Yang, Z., Gao, H., Lai, X., Wu, X., & Huang, Y. (2022). Experimental study on microstructure characteristics of saturated remolded cohesive soil during consolidation. *Scientific Reports*, *12*(1), 18378.

9.Kassim, K. A., & Uuey, C. S. (2000). Consolidation characteristics of lime stabilised soil. *Malaysian Journal of Civil Engineering*, *12*(1).

10. Onyelowe, K., & Van, D. B. (2018). Structural analysis of consolidation settlement behaviour of soil treated with alternative cementing materials for foundation purposes. *Environmental Technology & Innovation*, *11*, 125-141.

11. Wang, D., & Korkiala-Tanttu, L. (2020). 1-D compressibility behaviour of cement-lime stabilized soft clays. *European Journal of Environmental and Civil Engineering*, *24*(7), 1013-1031.

12. Bureau of Indian Standards (1980) Methods of test for soils: Determination of liquid limit and plastic limit, IS 2720-5, New Delhi, India.

13. Bureau of Indian Standards (1986) Methods of test for soils: Determination of consolidation properties, IS 2720-15, New Delhi, India.

APPENDIX A: DETERMINATION OF THE CONSOLIDATION PARAMETERS OF THE SOIL

A.1 CONSOLIDATION PARAMETERS FOR UNTREATED SOIL

Initial height of the specimen =20 mm

Diameter of the specimen =60 mm

Height of solids (Hs) =13.679 mm

A.1.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.1.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.132
0.25	0.5	-1.415
1	1	-1.482
2.25	1.5	-1.519
4	2	-1.542
6.25	2.5	-1.559
9	3	-1.572
12.25	3.5	-1.582
16	4	-1.594
20.25	4.5	-1.599
25	5	-1.605
36	6	-1.61
49	7	-1.615
64	8	-1.619
81	9	-1.624
100	10	-1.626
121	11	-1.628
1440	37.95	-1.649

A.1.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.1.2: Calculation of void ratios by Height of Solids methods

Applied pressure	Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa	(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5		20	6.321	0.462
10	-0.032	19.968	6.289	0.460
20	-0.108	19.86	6.181	0.452
40	-0.303	19.557	5.878	0.430
80	-0.706	18.851	5.172	0.378
160	-1.132	17.719	4.040	0.295
320	-1.649	16.07	2.391	0.175
640	-2.32	13.75	0.071	0.005

A.2 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 3% CEMENT AND 0.5 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 13.830 mm

A.2.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.2.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.037
0.25	0.5	-1.284
1	1	-1.36
2.25	1.5	-1.405
4	2	-1.435
6.25	2.5	-1.452
9	3	-1.465
12.25	3.5	-1.476
16	4	-1.482
20.25	4.5	-1.487
25	5	-1.492
36	6	-1.498
49	7	-1.503
64	8	-1.507
81	9	-1.511
100	10	-1.513
121	11	-1.515
1440	37.95	-1.534

A.2.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.2.2: Calculation of void ratios by Height of Solids methods

Applied pressure	Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa	(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5		20	6.170	0.446
10	-0.113	19.887	6.057	0.438
20	-0.139	19.748	5.918	0.428
40	-0.263	19.485	5.655	0.409
80	-0.604	18.881	5.051	0.365
160	-1.037	17.844	4.014	0.290
320	-1.534	16.31	2.480	0.179
640	-2.229	14.081	0.251	0.018

A.3 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 3% CEMENT AND 0.75 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 12.945 mm

A.3.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.3.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-0.941
0.25	0.5	-1.185
1	1	-1.258
2.25	1.5	-1.296
4	2	-1.32
6.25	2.5	-1.335
9	3	-1.341
12.25	3.5	-1.351
16	4	-1.355
20.25	4.5	-1.358
25	5	-1.364
36	6	-1.374
49	7	-1.38
64	8	-1.381
81	9	-1.382
100	10	-1.384
121	11	-1.387
1440	37.95	-1.397

A.3.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.3.2: Calculation of void ratios by Height of Solids methods

Applied pressure	Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa	(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5		20	7.055	0.545
10	-0.245	19.755	6.810	0.526
20	-0.271	19.484	6.539	0.505
40	-0.458	19.026	6.081	0.470
80	-0.603	18.423	5.478	0.423
160	-0.941	17.482	4.537	0.350
320	-1.397	16.085	3.140	0.243
640	-1.989	14.096	1.151	0.089

A.4 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 3% CEMENT AND 1 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 12.457 mm

A.4.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.4.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-0.947
0.25	0.5	-1.206
1	1	-1.288
2.25	1.5	-1.321
4	2	-1.347
6.25	2.5	-1.366
9	3	-1.376
12.25	3.5	-1.385
16	4	-1.392
20.25	4.5	-1.397
25	5	-1.402
36	6	-1.408
49	7	-1.413
64	8	-1.417
81	9	-1.421
100	10	-1.423
121	11	-1.425
1440	37.95	-1.444

A.4.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.4.2: Calculation of void ratios by Height of Solids methods

Applied pressure kPa	Dial change, ΔH (mm)	Specimen height H=H1 - ΔH (mm)	Height of voids H-Hs (mm)	Void Ratio e=(H-Hs/Hs)
5		20	7.543	0.606
10	-0.071	19.929	7.472	0.600
20	-0.098	19.831	7.374	0.592
40	-0.223	19.608	7.151	0.574
80	-0.514	19.094	6.637	0.533
160	-0.947	18.147	5.690	0.457
320	-1.444	16.703	4.246	0.331
640	-2.139	14.564	2.107	0.169

A.5 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 3% CEMENT AND 1.25 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 11.065 mm

A.5.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.5.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.115
0.25	0.5	-1.436
1	1	-1.499
2.25	1.5	-1.528
4	2	-1.552
6.25	2.5	-1.574
9	3	-1.585
12.25	3.5	-1.591
16	4	-1.6
20.25	4.5	-1.605
25	5	-1.61
36	6	-1.616
49	7	-1.621
64	8	-1.625
81	9	-1.63
100	10	-1.634
121	11	-1.636
1440	37.95	-1.658

A.5.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.5.2: Calculation of void ratios by Height of Solids methods

Applied pressure kPa	Dial change, ΔH (mm)	Specimen height H=H1 - ΔH (mm)	Height of voids H-Hs (mm)	Void Ratio e=(H-Hs/Hs)
5		20	8.935	0.808
10	-0.033	19.967	8.902	0.805
20	-0.09	19.877	8.812	0.796
40	-0.442	19.435	8.370	0.756
80	-0.765	18.67	7.605	0.687
160	-1.115	17.555	6.490	0.587
320	-1.658	15.897	4.832	0.423
640	-2.336	13.561	2.496	0.226

A.6 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 3% CEMENT AND 1.5 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 10.853 mm

A.6.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.6.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.251
0.25	0.5	-1.452
1	1	-1.493
2.25	1.5	-1.515
4	2	-1.532
6.25	2.5	-1.548
9	3	-1.559
12.25	3.5	-1.566
16	4	-1.57
20.25	4.5	-1.573
25	5	-1.578
36	6	-1.584
49	7	-1.589
64	8	-1.594
81	9	-1.597
100	10	-1.601
121	11	-1.604
1440	37.95	-1.642

A.6.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.6.2: Calculation of void ratios by Height of Solids methods

Applied pressure kPa	Dial change, ΔH (mm)	Specimen height H=H1 - ΔH (mm)	Height of voids H-Hs (mm)	Void Ratio e=(H-Hs/Hs)
5		20	9.147	0.843
10	-0.095	19.905	9.052	0.834
20	-0.33	19.575	8.722	0.804
40	-0.532	19.043	8.190	0.755
80	-0.79	18.253	7.400	0.682
160	-1.251	17.002	6.149	0.567
320	-1.642	15.36	4.507	0.401
640	-2.2	13.16	2.307	0.213

A.7 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 5% CEMENT AND 0.5 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 12.359 mm

A.7.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.7.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-0.935
0.25	0.5	-1.191
1	1	-1.242
2.25	1.5	-1.27
4	2	-1.292
6.25	2.5	-1.302
9	3	-1.31
12.25	3.5	-1.318
16	4	-1.326
20.25	4.5	-1.332
25	5	-1.335
36	6	-1.339
49	7	-1.342
64	8	-1.346
81	9	-1.349
100	10	-1.352
121	11	-1.355
1440	37.95	-1.398

A.7.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.7.2: Calculation of void ratios by Height of Solids methods

Applied pressure kPa	Dial change, ΔH (mm)	Specimen height H=H1 - ΔH (mm)	Height of voids H-Hs (mm)	Void Ratio e=(H-Hs/Hs)
5		20	7.641	0.618
10	-0.14	19.86	7.501	0.607
20	-0.238	19.622	7.263	0.588
40	-0.315	19.307	6.948	0.562
80	-0.584	18.723	6.364	0.515
160	-0.935	17.788	5.429	0.439
320	-1.398	16.39	4.031	0.326
640	-1.993	14.397	2.038	0.165

A.8 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 5% CEMENT AND 0.75 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 12.254 mm

A.8.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.8.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.018
0.25	0.5	-1.224
1	1	-1.257
2.25	1.5	-1.278
4	2	-1.292
6.25	2.5	-1.299
9	3	-1.306
12.25	3.5	-1.312
16	4	-1.318
20.25	4.5	-1.321
25	5	-1.325
36	6	-1.329
49	7	-1.333
64	8	-1.335
81	9	-1.34
100	10	-1.344
121	11	-1.348
1440	37.95	-1.414

A.8.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.8.2: Calculation of void ratios by Height of Solids methods

Applied pressure	Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa	(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5		20	7.746	0.632
10	-0.166	19.834	7.580	0.619
20	-0.323	19.511	7.257	0.592
40	-0.456	19.055	6.801	0.555
80	-0.765	18.29	6.036	0.493
160	-1.018	17.272	5.018	0.409
320	-1.414	15.858	3.604	0.290
640	-1.966	13.892	1.638	0.134

A.9 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 5% CEMENT AND 1 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 10.679 mm

A.9.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.9.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.083
0.25	0.5	-1.294
1	1	-1.33
2.25	1.5	-1.352
4	2	-1.374
6.25	2.5	-1.385
9	3	-1.392
12.25	3.5	-1.398
16	4	-1.401
20.25	4.5	-1.404
25	5	-1.408
36	6	-1.412
49	7	-1.415
64	8	-1.419
81	9	-1.423
100	10	-1.426
121	11	-1.429
1440	37.95	-1.473

A.9.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.9.2: Calculation of void ratios by Height of Solids methods

Applied pressure kPa	Dial change, ΔH (mm)	Specimen height H=H1 - ΔH (mm)	Height of voids H-Hs (mm)	Void Ratio e=(H-Hs/Hs)
5		20	9.321	0.873
10	-0.206	19.794	9.115	0.854
20	-0.366	19.428	8.749	0.819
40	-0.447	18.981	8.302	0.777
80	-0.663	18.318	7.639	0.715
160	-1.083	17.235	6.556	0.614
320	-1.473	15.762	5.083	0.466
640	-2.002	13.76	3.081	0.289

A.10 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 5% CEMENT AND 1.25 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 11.008 mm

A.10.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.10.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.585
0.25	0.5	-1.828
1	1	-1.872
2.25	1.5	-1.902
4	2	-1.922
6.25	2.5	-1.938
9	3	-1.954
12.25	3.5	-1.969
16	4	-1.981
20.25	4.5	-1.99
25	5	-1.998
36	6	-2.011
49	7	-2.018
64	8	-2.022
81	9	-2.025
100	10	-2.027
121	11	-2.029
1440	37.95	-2.052

A.10.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.10.2: Calculation of void ratios by Height of Solids methods

Applied pressure		Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa		(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5			20	8.992	0.817
10		-0.245	19.755	8.747	0.795
20		-0.359	19.396	8.388	0.762
40		-0.601	18.795	7.787	0.707
80		-1.089	17.706	6.698	0.608
160		-1.585	16.121	5.113	0.464
320		-2.052	14.069	3.061	0.278
640		-2.537	11.532	0.524	0.048

A.11 CONSOLIDATION PARAMETERS FOR TREATED SOIL WITH 5% CEMENT AND 1.5 KG/M^3 ZYCOBOND

Initial height of the specimen = 20 mm

Diameter of the specimen = 60 mm

Height of solids (Hs) = 11.216 mm

A.11.1 DETERMINATION OF COEFFICIENT OF CONSOILDATION (C_V)

Table A.11.1: Dial gauge reading for 320 KN/m^2 for different interval of time

Elapsed time, t (mins)	Square root of time, √t (mins)	Dial gauge reading (mm)
0	0	-1.424
0.25	0.5	-1.787
1	1	-1.843
2.25	1.5	-1.873
4	2	-1.896
6.25	2.5	-1.913
9	3	-1.924
12.25	3.5	-1.928
16	4	-1.93
20.25	4.5	-1.937
25	5	-1.937
36	6	-1.942
49	7	-1.959
64	8	-1.968
81	9	-1.977
100	10	-1.981
121	11	-1.985
1440	37.95	-2.023

A.11.2 DETERMINATION OF COMPRESSION INDEX (C_C)

Table A.11.2: Calculation of void ratios by Height of Solids methods

Applied pressure	Dial change, ΔH	Specimen height	Height of voids	Void Ratio
kPa	(mm)	H=H1 - ΔH (mm)	H-Hs (mm)	e=(H-Hs/Hs)
5		20	8.784	0.783
10	-0.302	19.698	8.482	0.756
20	-0.506	19.192	7.976	0.711
40	-0.829	18.363	7.147	0.637
80	-1.052	17.311	6.095	0.543
160	-1.424	15.887	4.671	0.416
320	-2.023	13.864	2.648	0.236
640	-2.324	11.54	0.324	0.029