CONSOLIDATION BEHAVIOUR OF GEOTEXTILE REINFORCED BLACK COTTON SOIL

A

THESIS

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

of

BACHELOR OF TECHNOLOGY

IN

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Under the supervision

of

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MAY – 2019

STUDENT'S DECLARATION

I hereby declare that the work presented in the project report entitled **"Consolidation Behaviour of Geotextile Reinforced Black Cotton Soil"** submitted for partial fulfilment of the requirements for the degree of bachelor of technology in civil engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Saurabh Rawat**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"Consolidation Behaviour of Geotextile Reinforced Black Cotton Soil"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ishan Uniyal (151673), Saksham Kumar Sharma (151693)** during a period from August, 2018 to November, 2018 under the supervision of **Dr Saurabh Rawat** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat. The above statement is correct to the best of our knowledge.

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ABSTRACT

In a developing nation like India, fast boom of population, speedy urbanization and further the construction of buildings and other structures has brought about depletion of precise high-quality present land. This creates a limitation and hence people have no choice, except to use soft and fragile soils around for building activities. Such soil is weak in shear strength and possesses high swelling & shrinkage. The geotechnical properties of these soils have to be improved by providing stabilization and reinforcement techniques to make it acceptable for construction activities. Black cotton soil is one of the key issues faced by engineers in India. When this soil is subjected to variation in moisture content it undergoes high swelling and shrinkage making it more complicated for engineering point of view.

Use of any waste materials in soil stabilization is both environmental and engineering favourable. These solid wastes are gradually increasing in India, which is not environmental friendly and hence have to be recycled. Copper slag is one of the waste materials that are being produced in abundance. Copper slag can be classified as a non-hazardous by-product. The porosity of copper slag is more and, thus, its particle size is similar to that of the coarse sand.

To attempt to provide solution to this problem, this project will investigate the use of copper slag and geotextile on the compressibility and strength characteristics of the black cotton soil. Experimental work will be carried out with the addition of Copper Slag in an increment of 5%, starting from 20% up to 60% by weight of black cotton soil. Further the most efficient location of geotextile with respect to strength parameters of copper slag mixed black cotton soil are to be found out. Samples of black cotton soil were collected from Visakhapatnam a district in state of Andhra Pradesh in India. The basic properties of soil were tested and determined. Changes in various soil properties like Particle Size Distribution, Atterbergs Limits, Maximum Dry Density, Strength parameters, Swelling characteristics and Consolidation characteristics were analyzed.

Keywords: Black cotton soil, soil stabilization, waste materials, copper slag, geotextile, strength, consolidation characteristics

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ρ	Bulk Density
a_v	Coefficient of compressibility
c_v	Coefficient of consolidation
C_c	Coefficient of Curvature
κ	Coefficient of permeability
C_u	Coefficient of Uniformity
m_v	Coefficient of volume change
c_c	Compression Index
σ	Compressive stress
I_f	Flow Index
μm	micrometer
I_p	Plasticity Index
δ	Settlement
S_u	Shear strength
G	Specific gravity
$\in$	Strain
t_{90}	Time at which 90% of primary consolidation is completed
I_t	Toughness Index
q_u	Unconfined Compressive Strength
e	Void ratio

LIST OF ACRONYMS & ABBREVATIONS

BCS	Black Cotton Soil
CBR	California Bearing Ratio
CS	Copper Slag
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
Pyc	Pycnometer
SR	Shrinkage Ratio
UCS	Unconfined Compressive Strength
w.r.t	with respect to
w/w	weight to weight
W_s	Weights of solids

CHAPTER 1

INTRODUCTION

1.1 GENERAL

This chapter describes the need for present research work, to improve the geotechnical properties of expansive soils using waste as a stabilizing agent. It also provides the basic knowledge about the materials used in the research work.

1.2 BACKGROUND

Black cotton soils are inorganic clay of medium to high compressibility and form a major soil group of India. The black colour in black cotton soil is due to the presence of Ferric oxide in small concentration. The Black cotton soil has a percentage of clay which is predominantly montmorillonite structures and black or blackish grey in colour. They are characterized by high shrinkage, low bearing capacity and swelling properties. Because of these properties, the Black cotton soil has been challenge to the high way engineers. Black cotton soils are very hard when it dry but loses its strength completely when it wet condition. Soft clays, expensive soils, weak soils, sand and organic deposits are unsuitable for all construction work due to bare engineering properties.

Soil stabilization improves the engineering properties of soils and thus making it more stable. It is essential when the soil accessible for construction is not suitable for the anticipated purpose. The term stabilization is generally restricted to the process which alter the soil material itself for improvement of is properties a solid wastes or chemicals are added to a natural soil for the purpose of stabilization.

The use of by-product materials to improve the soil properties varies with economic, environmental and technical points. In this study, the solid waste such as copper slag and the reinforcement of optimised Black Cotton Soil + Copper Slag with geotextile are utilized as material for the stabilization of Black cotton soil.

1.3 NEED OF STUDY

Rapid urbanization coupled with large scale industrialization of the modern era has created an unprecedented swell in the demand of infrastructure development in the country. This has practically left the construction sector with no choice but to undertake construction activities on whatever land is available irrespective of suitability. Thus the situation has warranted development of land, if found unsuitable, by use of sound and cost effective engineering techniques. In the process hither to unsuitable land (characterized by soft compressive clay, expansive clay, deformable sub-soil etc.) harmful to typical foundation, could be utilized for construction purposes after appropriate modification of its engineering properties. The modification of the engineering properties of such soil is termed as soil stabilization.

The term soil stabilization means the improvement of the stability or bearing power of a poor soil by the use of controlled compaction; proportioning and the addition of suitable admixtures or stabilizers. Soil stabilization deals with mechanical, physico-chemical and chemical methods to make the stabilized soil serve its purpose. The stabilization process, essentially involve excavation of the in-situ soil, treatment to the in-situ soil and compacting the treated soil. As the stabilization process involve excavation of the in-situ soil, this technique is ideal for improvement of soil in shallow depths such as pavements.

Methods of stabilization may be grouped under two main types: (a) modification or improvement of a soil property of the existing soil without using any admixture and (b) modification of the properties with the help of admixture. The examples of the first type are compaction and drainage, which improve the inherent shear strength of soil. The examples of the second type are stabilization with admixtures like cement, lime, bitumen, fly ash and chemicals. The use of lime, cement and bitumen has become common as stabilizing agents. The soil chosen for the purpose of the present study is a Black Cotton soil and the stabilizers used are Geotextile and Copper Slag.

The disposal of waste materials is a big problem in the developing country like India. Due to lack of land required for disposal technique. The substitution of these waste materials in the form of stabilizing agent in the soil stabilization is a modern approach by which waste materials can be advantageously used. The idea behind the technique of soil stabilization used in this study is that the finer particles of soil are replaced with coarser particles of stabilizing material so that a composite having the interlocking between the particles forms resulting in a material with better geotechnical properties.

1.4 BLACK COTTON SOIL

Expansive soils are produced from the break-down of basic igneous rocks where seasonal variation of weather is extreme. In India, these soils are normally derived from the weathering of basalt rocks. Also, these soil deposits are derived from various other types of rocks including very old sedimentary deposits. The minerals present in clay fraction are montmorillonite and a combination of montmorillonite and illite.

Black soil is also known as 'regur' which is derived from a Telugu word 'reguda'. Black soil is also known as Black Cotton Soil (BCS) as cotton is an important crop which is grown in this type of soil. Black cotton soils are found in various colours, starting from mild grey to dark grey and black. The mineralogy of this soil is ruled by the presence of montmorillonite that's characterized via large changes in volume from wet to dry seasons and vice versa. BCS, covering an area of 0.8 million square kilometres, which is about 20% of total land area. It is mostly found in areas such as Gujarat, Madhya Pradesh and Maharashtra. It is also found in states like Tamil Nadu, Andhra Pradesh and Karnataka. Black soil is extremely fine and clayey and has the capacity to hold a lot of moisture. It becomes sticky in the rainy season and develops cracks when dry. Black soil is good for producing cotton, oilseeds, wheat, linseed and millets.

Fig 1.1: Black Cotton Soil

1.4.1 MONTMORILLONITE CLAY MINERAL

It was formerly known as smectite. Smectite has the ability to absorb large amounts of water, forming a water-tight barrier. It is used extensively in the oil drilling industry, civil and environmental engineering (where it is known as bentonite), and the chemical industry. This clay mineral has a general molecular formula as given in equation (1):

$$(OH)_4Si_8Al_4O_{20} \cdot nH_2O \qquad (1)$$

The montmorillonite clay structure consists of octahedral sheet and tetrahedral sheet layer sheet formed and stacked one above the other and the bonding between successive layers is by vander Waals forces and by cation that may be present to balance charge deficiencies in the structure. These bonds are however, weak and easily separated by cleavage or adsorption of water and other liquids. There is an extensive isomorphous substitution for aluminium and silicon with its lattice which gives the clay a net negative charge resulting in the water absorbing tendencies and an attraction for hydroxyl ions and water molecules to the clay surface.

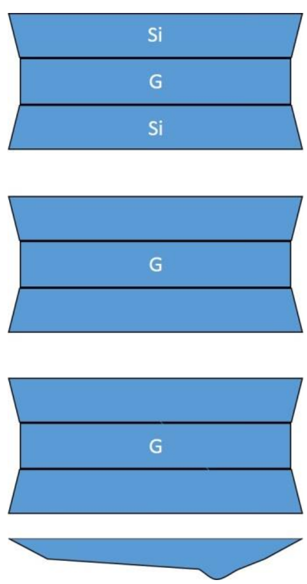

Fig 1.2: Structure of Montmorillonite clay mineral

1.4.2 PROBLEMS ASSOCIATED WITH BCS

The stability of structures based on soil relies to a large extent on the interplay of the stated soil with moisture. Some soils of the tropics (e.g., black cotton soil), take in big quantity of water throughout the rainy seasons and do not allow clean passage of such water. This therefore results in a large extent of volume swell which substantially reduces during the dry season. This phenomenon has massive effect on systems founded on such soils as there is deferential settlement in the structure founded on them. This results the structural damage in the form of micro cracks on its surface. Additionally, road bases constructed with soils that aren't effortlessly drained are laid low with the improvement of pore water pressures which causes the formation of potholes and, sooner or later, the overall failure of such roads. In an try and reduce those effects, such soils are subjected to treatments geared toward either disallowing water into them or permitting smooth passage (drainage) of water to prevent the pore water pressure from building up. Intricate soils such as expansive soils are commonly encountered in engineering designs for foundation, highways, embankments, retaining walls, backfills, and so on.

BCS is an expansive soil. It is a dark grey to black soil with an excessive content of clay, normally over 50 % in which montmorillonite is the primary clay mineral and is usually expansive. They have the tendency to swell and shrink with changes in moisture and have considerable plasticity because of the clay fraction. BCS show a general pattern of cracks all through the dry season of the year. Cracks measuring 70 mm huge and over 1 m deep had been observed. These soils are poor materials to employ for motorway or airfield creation because they include excessive probabilities of plastic clay.

Fig 1.3 (a): Heaving of interior floor causing cracking of floor tiles

(b): Heaving of interior floor causing cracking of slab

Fig 1.4: Pavement damage due to settling of sub-grade soil.

1.5 COPPER SLAG

Pure copper is rarely found in nature, but is usually combined with other chemicals in the form of copper ores. Once the waste materials have been physically removed from the ore, the remaining copper concentrate must undergo several chemical reactions to remove the iron and sulphur. This process is called smelting. Copper slag (CS) is a waste product which comes out from the smelting process. For every tonne of metal production about 2.2 tonnes of slag is generated. CS, upon mixing with soil, can be used as an effective stabilizing agent for the improvement of problematic soils.

CS has high angularity and friction angle (up to 52˚) of aggregates contribute to the stability and load bearing capacity. Also copper slag aggregates tend to be free draining and are not frost-susceptible.

Fig 1.5: Copper Slag

1.5.1 COPPER SLAG UTILIZATION

It has found its applicability in various ways:

- CS, upon mixing with soil, can be used as an effective stabilizing agent for the improvement of problematic soils for use in highway embankments, sub-grades and sub-bases.
- CS mixed with fly ash, can be used as a suitable material for embankment fill.
- The behaviour of CS is similar to that of medium sands and can be used as a construction material in place of sands, such as backfill of retaining walls and landfill for the construction of shallow foundations.
- CS can be used as an alternative aggregate in bituminous mixes.

However, mass utilization of CS for construction and land filling activities yet need proper investigation through carrying various laboratory and field experiments.

1.6 GEOTEXTILE

Geotextiles are permeable synthetic material, which are used in combination with the soil mass. They're typically made from polymers such as polypropylene or polyester. They're typically available in three forms – woven fabrics, non woven fabrics, knitted fabrics.

- **Woven Geotextiles -** Woven Geotextiles are prepared using the technique of weaving. Its appearance can be divided into two characteristic yarns. The yarn running parallel to the length is called wrap and the other one perpendicular is called weft. Individual threads (monofilaments, fibrillated yarns, silt films) are woven together to form a large, uniform piece. This method provides a high load capacity to the geotextile and makes them a suitable fit for road constructions.
- **Non Woven Geotextiles –** Non Woven Geotextiles are manufactured using short staple fibre or continuous filament yarn. Rather than weaving, these geotextiles are manufactured by bonding them together using thermal, chemical or mechanical techniques. Thermally bonded non woven contain wide range of opening sizes and a typical thickness of about 0.5 – 1 mm while chemically bonded non wovens are comparatively thick usually in the order of 3 mm. On the other hand mechanically

bonded non wovens have a typical thickness in the range of 2 -5 mm and also tend to be comparatively heavy because a large quantity of polymer filament is required to provide sufficient number of entangled filament cross wires for adequate bonding. Non woven geotextiles are not suited for stabilization or reinforcement projects.

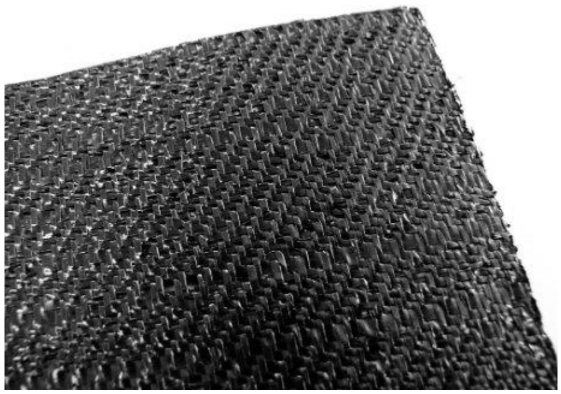

Fig 1.6 (a): Woven Geotextiles **(b)**: Non Woven Geotextile

- **Knitted Fabrics –** As the name implies, the adopted method for knitted geotextiles is knitting. A series of loops of yarn are interlocked together to produce the geotextile.

Fig 1.6 (c): Knitted Geotextile

1.7 STRUCTURE OF PROJECT REPORT

The project report consists of five chapters. The brief description of the chapter is presented below.

Chapter 1: *Introduction* which indicates the needs for present research.

Chapter 2: *Review of literature*. This gives an idea for the recent research. This chapter includes the findings of recent past research on similar type of works done by other researchers.

Chapter 3: *Methodology*. In this chapter the materials used and their characteristics followed by experimental programme in details and the method adopted in the investigation has been presented. Further, the details of sample preparation and the standard of test procedures followed for various tests are also explained.

Chapter 4: *Results and discussions*. The findings of different tests on BCS and CS stabilized soil mix are discussed in this chapter. This chapter also describes the reasons for change of geotechnical/engineering properties of expansive soil by the addition of CS.

Chapter 5: *Conclusion.* This chapter provides a study and comparison of the results of the experiments conducted in the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter deals with the already done research work on the use of waste products to improve the geotechnical properties varying with economic, environmental and technical points. In this study, the solid wastes such as fly ash, copper slag, saw dust ash, quarry dust, stone dust, steel slag and brick dust are utilized as cementitious material are used for stabilizing the Black cotton soil, providing the basic knowledge of the work to be conducted in the present study.

2.2 LITERATURE REVIEW CONCLUSIONS:

S.Elayaraja (2009) had investigated about the behavior of black cotton soil reinforced with geotextile. He concluded that due to the addition of geotextile the shear strength of BCS increases. The shear strength was found using Unconfined Compression test (UCS), Triaxial Test, Vane Shear and Direct Shear Test. Especially due to the introduction of non woven geotextiles the shear parameters increase in all type of shear testing.

Yogendra K Tandel (2009) on the basis of his research he concluded that copper slag can be recommended as an effective stabilizing agent for the improvement of soils for highway embankments. The use of copper slag as a stabilizing agent can be economically attractive in regions near the slag source areas. Utilization of copper slag in this manner also has the advantage of reusing an industrial waste by-product without adversely affecting the environment or potential land use.

C.Lavanya (2011) had studied about utilization of copper slag in geotechnical applications. In this paper, she investigated about the Index properties, free swell index, compaction properties, CBR and UCC. She concluded that the partial replacement of copper slag from 30% to 50% with black cotton soils, considerably showed the increase in properties of the soil. She also concluded that partial replacement of copper slag with black cotton soil resulted in utilization of such soils in sub grade, sub base and embankment of roads and it was also improved the sub grade soil condition.

Ashwani Jain (2013) has been conducted One-dimensional consolidation tests to study the effect of addition of various percentages of rice husk ash on compressibility characteristics of highly plastic clay soil. It has been observed due to the addition of rice husk ash to the parent clay, Compression index (Cc) has been found to decrease significantly with increase in percentage of rice husk ash, hence decreasing consolidation settlement of parent material. It has also been observed that the time required for achieving a given degree of consolidation decreases with increase in the percentage of rice husk ash at a particular effective stress. Overall, it has been observed that rice husk ash effectively increase one-dimensional stiffness and therefore, reduce settlement.

Tushal Baraskar (2014) had studied about California bearing ratio of Black cotton soil. He partially replaced the soil with waste copper slag in various percentages. He conducted various tests such as grain sieve analysis, compaction characteristics and CBR. He concluded that the maximum CBR value is obtained in black cotton soil with 28% replacement of copper slag. He also concluded that such soils can be effectively used as the sub base layer of road pavement.

Jinka chandrshekher (2015) had reviewed utilization of waste material “copper slag” in geotechnical applications. The soil sample was tested for specific gravity, grain size distribution, free swell index, compaction factor and CBR. The results were observed for 60% copper slag and 40% black cotton and it was concluded that the sub grade, sub base and engineering behaviour of soil was improved. And also the embankment construction, land reclamation of soil conditions was increased.

Mohammed (2015) had investigated about the improvement in soil properties of Expansive soil by using copper slag. The soil properties like Grain size analysis, liquid limit, plastic limit, plasticity index, compaction test, direct shear test and CBR were determined. He concluded that copper slag 40% and Black cotton soil 60% was optimum and it showed the increase in value of specific gravity and CBR. He finally concluded that such soil can be effectively used in road embankment sub base and sub grade.

Brajesh Mishra (2015) on the basis of his study and experimental investigations it was observed that the property of black cotton soil effectively improved by use of different percentage of lime contents. In this research varying percentage (3% and 5%) of lime was used to stabilize the black cotton soil. It was observed that on addition of 3% of lime decreases the liquid limit by 2.70% while with 5% addition of lime reflects a decrease 15.27%. M.D.D. was increased slightly by 6.29% and 5.59% at 3% and 5% lime content respectively. It was observed that there was a decrease in O.M.C. of 3.4% and 10.7% at 3% and at 5% lime content respectively. The C.B.R. value of black cotton soil improves considerably to 3.25 times and 4.76 times with 3% and 5% lime respectively. There was a decrease in swelling pressure by 28% and by 55% in Black cotton soil with 3% and 5% lime respectively.

Chayan Gupta (2016) they studied the black cotton soil modification by the application of waste materials. They considered 3 waste materials which are used for improving the engineering properties of black cotton soil. These waste materials are river sand, fly ash and marble dust. From the test results, they obtained that black cotton soil, black cotton soil with river sand, black cotton soil with fly ash and black cotton soil with marble dust are having 13%, 16.13%, 17.79% and 16.68% shrinkage limit. The test results show that there is an increase in the coefficient of consolidation after blending with waste material. Also the coefficient of volume compressibility and swelling index of black cotton soil reduces.

Ravi (2016) had studied about the characteristics of clay soil by using copper slag stabilization. In this paper, he tested the CBR and Max density, OMD relationship. He observed higher CBR values in 30% replacement of copper slag and this was also served as good conformity for the flexible pavement with simultaneous reduction in the sub base course thickness. He finally concluded that the addition of 30% copper slag with 70% BC soil was the suitable stabilization ratio which increased all characteristics of sub grade requirements.

Tiza Michael (2016) had reviewed about the stabilization using industrial solid wastes. In this paper, he studied about the replacement of different materials such as Red mud, copper slag, brick dust, polyvinyl waste, ceramic dust, sawdust and fly ash. The soil samples were tested by Atterberg limits, CBR and compaction test. He had concluded that almost all the industrial wastes have the ability to improve the expansive soil with less cost compared to conventional soil.

Rishi Srivastava (2016) had investigated that the maximum dry density value is increasing with reduction in optimum moisture content with maximum value of 1.84g/cc at 16% OMC. The CBR value of soil increases by 3.43% and 6% for geotextile placed at H/5 and 2H/5 depths from top of specimen. CBR value of soil decreases for 75mm (3H/5) and 100 mm (4H/5) depth of geotextile placement from top, which is even below the CBR value of unreinforced soil. The improvement in soil properties is seen in upper layers, this may be due to more resistance offered by geotextiles to penetration and there is improvement in load-penetration behaviour. The most optimum position of geotextile placement is at 2H/5 (50mm) depth from top of compacted specimen where maximum improvement in CBR value was seen.

A. Mohan Chand (2017) had investigated about the behavior of BCS with addition of copper slag and steel slag. The soil samples are tested by compaction test, unconfined compression test and CBR. It is concluded that CBR, optimum moisture content, maximum dry density and shear strength are increased when the soil is added with 20% of copper slag and steel slag.

Ranjendra kumar (2017) had studied about the Black cotton soil blended with copper slag and fly-ash which are added in different percentages. The soil properties like liquid limit, plastic limit, plasticity index, free swell, compaction test and CBR (unsoaked) were determined. The results indicated that the dry density, CBR values were improved and swelling was reduced due to addition of copper slag 30% and fly ash 10% (% by weight of soil) in the soil.

2.3 SUMMARY OF LITERATURE REVIEW

The above articles present an experimental study in the stabilization of Black Cotton soil.

- The stabilization of soil is achieved by the reduction of its swelling capacity and improvement of its mechanical capacities by the addition of by products and waste materials of industrial origin.

- Jinka Chandrshekhar et al [3] stated that the copper slag has high angularity (up to 52˚) and friction angle of aggregate contributing to stability and load bearing capacity. Copper slag aggregate tend to be free draining and are not frost susceptible.
- Geotextiles not only increases shear strength, it separates the soil from gravel, provides good drainage, stabilizes the soil, and controls erosion.

- The use of geotextile in soft sub grade causes reduction in thickness requirement of pavement, increases the service life and reduces the frequency of maintenance required, resulting in economical pavement design.

2.4 OBJECTIVES OF THE PRESENT STUDY

From the literature review the following objectives are:

[1] To find the optimum percentage of copper slag w.r.t strength parameters of copper slag mixed black cotton soil using unconfined compressive strength.

[2] To evaluate the swelling and shrinking behavior of optimized copper slag mixed Black Cotton soil reinforced with geotextiles under controlled-stress loading using Oedometer test.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter describes the methodology that has been developed. It gives insight about the swelling and shrinkage properties of black cotton soil, and sets out the definitions used and criteria applied. It also includes a detailed description of the methods (particle size distribution, atterberg's limits, compaction test , unconfined compression test and one dimensional consolidation test) used to implement this methodology by mixing copper slag in geotextile reinforced black cotton soil to increase the geotechnical properties of virgin black cotton soil.

3.2 MATERIALS

3.2.1 BLACK COTTON SOIL

BCS is produced from the break-down of basic igneous rocks where seasonal variation of weather is extreme. In India, these soils are normally derived from the weathering of basalt rocks. Also, these soil deposits are derived from various other types of rocks including very old sedimentary deposits. The minerals present in clay fraction are primarily montmorillonite and a combination of montmorillonite and illite. It is mostly found in areas such as Gujarat, Madhya Pradesh and Maharashtra. It is also found in states like Tamil Nadu, Andhra Pradesh and Karnataka.

Black Cotton Soil is collected from Sri. Gomata Gayatri Organics Pvt. Ltd. Visakhapatnam, Andhra Pradesh, India.

Fig 3.1: Black cotton soil

The main characteristics of black cotton soils are:

(i) Black or darkish grey to brown color.

(ii) High content of expansive clay mineral montmorillonite.

(iii) Poses the tendency to shrink and swell with change in moisture condition.

3.2.2 COPPER SLAG

CS is a waste product which comes out from the smelting process. Although CS is widely used in the sand blasting in and in the manufacturing of abrasive tools, the reminder is disposed of without any further reuse or reclamation and hence can be used as a cheap effective soil stabilizer.

Copper Slag is collected from Taj Abrasive Industries, Sikar, Rajasthan, India.

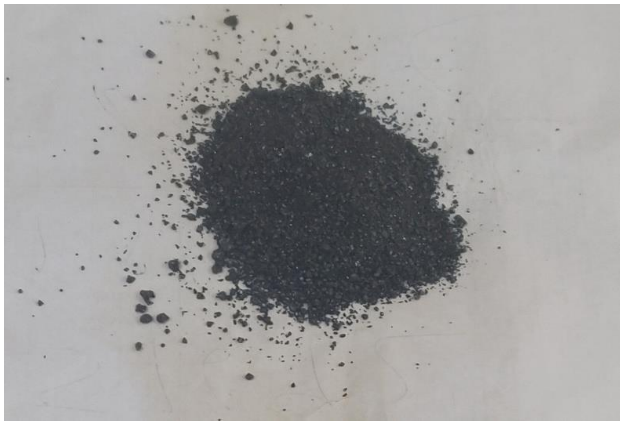

Fig 3.2: Copper Slag

3.2.2.1 CHARACTERISTICS OF COPPER SLAG

- Chemical Analysis

Table1: Chemical Analysis of CS

Element/Compound	Analysis Range (%)
Cu	0.60-0.70
FeO	42-48
SiO_2	26-30
Al_2O_3	1.0-3.0
S	0.2-0.3
CaO	1.0-2.0
MgO	0.8-1.5
Fe_3O_4	1.0-2.0

- Physical Properties
    1. Hardness on Mohr's scale = 6 – 7
    2. Specific Gravity = 3.51
    3. Bulk Density = 1.9 – 2.4 (kg/L)
    4. Granular Shape = Angular, Sharp Edges and Multi-faced
    5. Electrical Conductivity = 2 S/m

3.3 TESTING METHODOLOGY

The section deals with the testing of material used in the present study. It also outlines the experimental procedure carried out as well as the formulae used.

3.3.1. GRAIN SIZE ANALYSIS

The grain sieve analysis carried out in the present study is adopted as per IS: 2720 (part 4) [18]. The wet and dry sieve analysis and hydrometer analysis is carried out for soil classification.

Equipment and apparatus:

Balance, Sieves (4.75 mm, 2.00mm, 1.00mm, 600 µm, 425 µm, 212 µm, 150 µm, 75 µm, pan), Sieve shaker, Hydrometer, Thermometer, Glass measuring cylinder (2 of 1000 ml capacity), Stirring apparatus.

Fig 3.3 (a): Dry sieving of sand particles **(b):** Wet Sieve Analysis

Reagent:

Dispersing agent – 200 ml of sodium hexametaphosphate solution (add 8.25 g of sodium hexametaphosphate to 1.75g of sodium carbonate to make 250 ml of solution).

Procedure:

Wet sieve analysis

500 gm of oven dried soil was taken. The soil specimen was then sieved through 75 micron sieve and washed with water under tap of high pressure. The material was washed until the clean water passed through the sieve. The material retained on the sieve was dried in oven and weighed. It was then sieved through the mechanical sieve shaker for about ten minutes and retained material on each sieve was collected and weighed. The material which was retained on the pan was equal to the total mass of soil minus the sum of all the masses of material retained on all sieves. The curve for the soil was drawn in the semi-log graph and particle size distribution curve was obtained.

Hydrometer analysis

Take 50 g of air dried soil sample (passing 75 μm) obtained after wet sieve analysis. Put 100ml of dispersing agent in the soil and mix it for 4min in Stirring apparatus. Put the mixed solution in 1000ml cylindrical jar and add distilled water up to 1000ml mark. Now take another jar put 100ml of dispersing agent and fill it with distilled water up to 1000ml mark. Now take the hydrometer (very carefully) and inserted in the soil mix solution. As hydrometer is put in cylindrical jar containing soil solution, start the stopwatch and take readings at 30sec, 1, 2, 4 and 8 min. Now remove the hydrometer and put in cylindrical jar containing distilled water and dispersing agent. Repeat the above 2 steps for take readings at time interval of: 15, 30, 60min and 3, 6, 18 and 24 hour.

Formulae used:

The Coefficient of uniformity (C_u) and Coefficient of curvature (C_c) can be determined using the Eqn. (3.1) and Eqn. (3.2) respectively.

$$C_u = \frac{D_{60}}{D_{10}} \tag{3.1}$$

$$C_c = \frac{(D_{30})^2}{D_{10} \, . \, D_{60}} \tag{3.2}$$

Where,

D_{10} = Particle size (mm), such that 10% of particles are finer than this size.

D_{30} = Particle size (mm), such that 30% of particles are finer than this size.

D_{60}= Particle size (mm), such that 60% of particles are finer than this size.

Fig 3.3 (c): Hydrometer Analysis

3.3.2. SPECIFIC GRAVITY

The specific gravity test carried out in the present study is adopted as per IS: 2720 (part 3) [16]. Specific gravity of soil using pycnometer is carried out for determination of specific gravity of soils which finds application in finding out the degree of saturation and unit weight of moist soils.

Equipments and apparatus:

Weighing balance, Pycnometer, Distilled water, Sieve – 4.75 mm, Oven and Glass rod.

Procedure:

Dry the density bottle and weighs with it (W_1).Take about 200 g of oven dried soil passing through 4.75mm sieve into the density bottle and weigh again (W_2).Add water 3/4th and stir the sample with glass rod. Now fill the density bottle with distilled water to the top. Now ensure that there are no air bubbles are present and weigh it (W_3).Now clean the density bottle and wash it thoroughly. Fill the clean density bottle with distilled water up to its top with cap. Weigh the density bottle after drying it on the outside thoroughly (W_4).

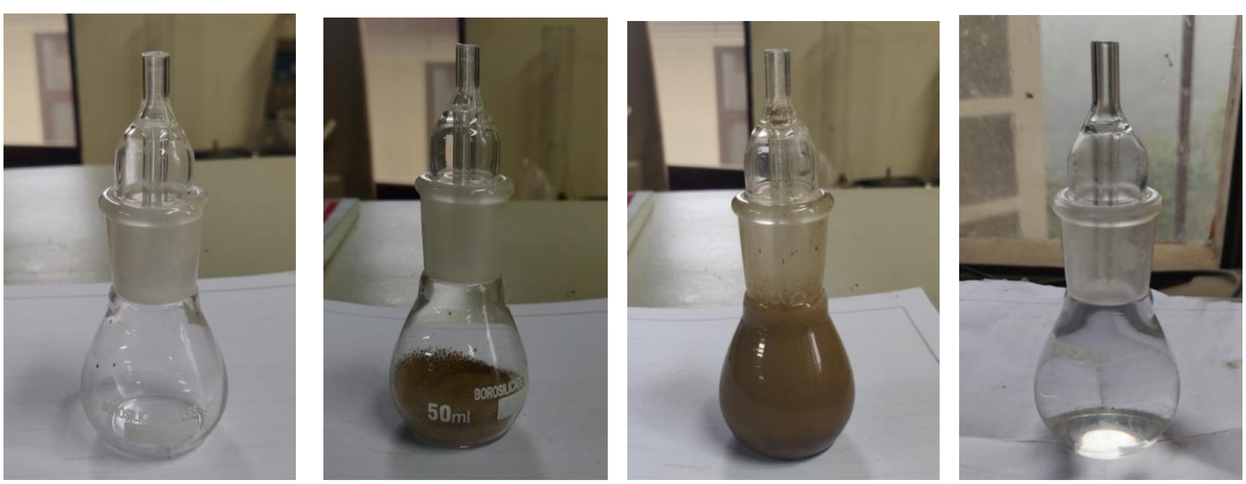

Fig 3.4(a): Empty Density Bottle
(b): Density + Dry soil Bottle
(c): Density + soil + water Bottle
(d): Density + water Bottle

Formulae used:

For the determination of Specific Gravity the given Eqn. (3.3) is used:

$$\text{Specific gravity} = \frac{(W2-W1)}{\{(W2-W1) - (W3-W4)\}} \tag{3.3}$$

3.3.3. ATTERBERG'S LIMIT

3.3.3.1. Liquid limit:

The liquid limit test carried out in the present study is adopted as per IS : 2720 (part 5) [13]. Liquid limit of soil using Cassagrande liquid limit device is carried out.

Equipment and apparatus:

Cassagrande liquid limit device, Grooving tool, Spatula, Distilled water, Oven, Weighing balance (0.01g accuracy).

Procedure:

About 120 gm of soil sample passing through 425 microns sieve was taken and mixed thoroughly with distilled water in the evaporating dish. After the formation of uniform paste a portion of paste was placed in the cup and was levelled so as to have maximum depth of 10 mm. A groove cut was made in the soil in the cup using grooving tool. The handle was rotated at the rate of 2 revolutions per second and number of blows necessary to close the groove for a distance of 13 mm was noted. Soil near the closed groove was taken to determine its water content. A graph was plotted between number of blows, N on a logarithmic scale and water content, W on the natural scale. From the graph the liquid limit was determined by reading the water content corresponding to 25 blows on the flow curve.

Formulae used:

The flow index or the slope of the curve can be determined from Eqn. (3.4)

$$\text{Flow Index } (I_f) = \frac{W_1 - W_2}{\log_{10}\frac{n_2}{n_1}} \tag{3.4}$$

Fig 3.5: Cassagrande Apparatus

3.3.3.2. Shrinkage limit:

The shrinkage limit test carried out in the present study is adopted as per IS : 2720 (part 6) [14]. Shrinkage limit of soil is carried out.

Equipment and apparatus:

Three circular shrinkage dishes, one glass plate with three prongs, one glass or stainless steel cup, Mercury, 425 microns sieve, Oven, Weighing balance, Spatula.

Procedure:

About 100g of soil sample was taken in a large evaporating dish. It was mixed with distilled water (more than liquid limit) to make a paste. Shrinkage dish was cleaned and mass was determined. The mercury was filled in the shrinkage dish and excess mercury was removed by pressing the plain glass plate over the top of the shrinkage dish. And no air was allowed to entrap. Inside portion of the shrinkage dish was coated with a thin layer of grease. The soil specimen was placed in the centre of the shrinkage dish. The dish was filled with soil and weighed. Then the dish was placed in the oven for 24 hours at 110C.The dish with the dry soil was weighed. Volume of dry soil pat was determined by placing the soil pat in glass cup full of mercury. On placing the soil pat in the glass of full of mercury and forcing the pat under the mercury by means of glass plate, the mercury was displaced. The displaced mercury was weighed and its volume was determined. The obtained volume was the volume of the dry soil pat.

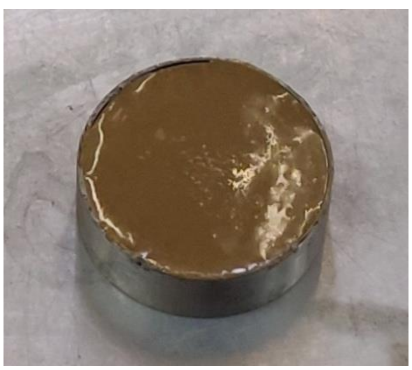

Fig 3.6 **(a):** Wet soil pat **(b):** Dry soil pat (c): Volume of mercury displace by dry soil pat

Formulae used:

The shrinkage limit is determined from Eqn. (3.5).

The shrinkage ratio of a soil is the mass specific gravity of the soil in dry state, determined by Eqn. (3.6).

$$\text{Shrinkage limit} = \left[w_1 - \frac{(V_1 - V_2)\ .\ \rho_w}{M_d}\right] * 100 \tag{3.5}$$

$$\text{Shrinkage ratio (SR)} = \frac{\frac{V_1 - V_2}{V_d} * 100}{w_1 - w_2} \tag{3.6}$$

3.3.3.3. PLASTIC LIMIT

The plastic limit test carried out in the present study is adopted as per IS: 2720 (part 5) [13]. Plastic limit of soil is carried out.

Equipment and apparatus:

Porcelain evaporating dish**,** Flat glass plate**,** Spatula**,** Weighing balance**,** Oven**,** Rod 3mm in diameter.

Procedure:

Take 20g of oven dried sample passing 425 micron IS Sieve. Mix thoroughly with distilled water in an evaporating dish till the soil mass becomes plastic enough to be easily moulded with fingers. Form a ball with about 8g of the soil mass and roll between the glass plate and the fingers with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. Continue the rolling until the thread crumbles at 3 mm diameter. If the soil doesn’t crumbles at 3mm knead the soil together to a uniform mass and roll it again. Repeat these steps of rolling and kneading until thread crumbles at 3mm diameter. Collect the pieces of crumbled soil thread in container and determine its moisture content.

Fig 3.7: Soil thread crumbles at 3 mm diameter

Formulae used:

The range of consistency within which a soil exhibit plastic properties is called plasticity index and can be determined from Eqn. (3.7).

Ratio of the plasticity index to flow index is known as toughness index and can be determined from Eqn. (3.8).

$$\text{Plasticity Index } (I_p) = \text{Liquid limit } (W_l) - \text{Plastic limit } (W_p) \quad (3.7)$$

$$\text{Toughness Index } (I_T) = \frac{I_P}{I_F} \quad (3.8)$$

3.3.4. FREE SWELL INDEX

The free swell index test carried out in the present study is adopted as per IS : 2720 (part 40) [15]. Free swell index of soil using is carried out.

Equipment and apparatus:

Weighing balance, IS Sieve – 425 µm, Oven, Glass cylinder of 100ml capacity, Kerosene and distilled water, Glass rod.

Procedure:

Take 2 specimens of 10g each oven dried soil passing through 425μm sieve. Pour each soil specimen in glass cylinder of 100ml capacity. Pour distilled water in one and kerosene in the other cylinder upto 100ml mark. Remove entrapped air by gently shaking or stirring with glass rod. Allow the suspension to attain the state of equilibrium. Final volume of soil in each of the cylinder is noted.

Fig 3.8: Final volume change of sample

Formulae used:

Free Swell Index can be determined using the Eqn. (3.9)

$$\text{Free Swell Index} = \frac{(V_2 - V_1)}{V_1} \; x \; 100 \tag{3.9}$$

Where,

V_1 = Volume of soil in kerosene

V_2 = Volume of soil in Distilled water

3.3.5. COMPACTION TEST

The compaction/proctor test carried out in the present study is adopted as per IS: 2720 (part 7) [17]. Proctor test of soil using proctor mould is carried out to determine the proper amount of mixing water to be used, when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at optimum moisture content.

Equipment and Apparatus:

Compaction mould of capacity of 999.305cc, Rammer of 5.08 cm diameter face and a weight of 2.5 kg, A balance, Sample extruder, mixing tools and spatula, IS Sieve – 4.75mm

Fig 3.9: Compaction test apparatus

Procedure:

An oven dried soil passing 4.75mm of about 3 kg was taken and was thoroughly mixed with sufficient amount of water to dampen it with approximate water content. The compaction mould was weighed with base plate only. The collar was then fixed. The soil was then filled in three layers giving 25 blows after each layer. The blows should be uniformly distributed over the surface. Collar was removed and then trimmed to make the surface level using straight edge and then weighed. The weight of the compacted soil was divided by the volume to get the bulk density. The sample was removed thoroughly and a small sample was taken for water content calculations. The water should was added in a manner so that water content was increased. This process was continued until the density of the sample started to decrease or become constant.

Formulae used:

$$Bulk\ Density\ (\rho) = \frac{M}{V} \tag{3.10}$$

$$Maximum\ Dry\ Density\ (MDD) = \frac{\rho}{(1 + \omega)} \tag{3.11}$$

Where,

M = Mass of the compacted soil in mould

V = Volume of Compaction mould (999.305 cc)

ω = Water content of compacted soil

3.3.6. UNCONFINED COMPRESSION TEST

The Unconfined compression test carried out in the present study is adopted as per IS: 2720 (part 10) [17]. The Unconfined compression describes the method for determining the shear strength of clayey soil (remoulded), using controlled rate of strain.

Equipment and Apparatus:

Unconfined compression apparatus, Proving ring, Dial gauge, Weighing balance, Oven, Stop watch, Sampling tube, Sample extractor, Knife.

Procedure:

Compact the sampling soil specimen at the optimum water content and density in the compaction mould. Push the sampling tube coated lightly with a thin layer of grease into the mould and remove the sampling tube filled with the soil. Extrude the sample out of the sampling tube, using the sample extractor and the knife. Trim the two ends of the specimen in the detachable collar. Remove the specimen from the collar. Measure the length and diameter of the specimen. Place the specimen on the bottom plate of the compression machine. Adjust the upper plate to make contact with the specimen. Apply the compression load to cause an axial strain at the rate of 1.25 mm/min. Record the displacement and stress readings for every thirty seconds. Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached.

Fig 3.10: Unconfined compression test apparatus

Formulae used:

$$Strain\ (\epsilon) = \frac{\Delta L}{L_\circ} \tag{3.12}$$

$$Corrected\ Area\ (A) = \frac{A_\circ}{(1 - \epsilon)} \tag{3.13}$$

$$Compressive\ Stress\ (\sigma) = \frac{P}{A} \tag{3.14}$$

$$Shear\ Strength\ (S_u) = \frac{q_u}{2} \tag{3.15}$$

Where,

q_u = Unconfined Compressive strength of soil

L_o = Initial length of the specimen

A_o = Initial area of the specimen

3.3.7. CONSOLIDATION

The determination of consolidation properties carried out in the present study are adopted as per IS: 2720 (part 15) [17].

Equipment and Apparatus:

Consolidometer, Loading device (Jack or lever system), Ring of non-corrosive material, Porous stone, Water reservoir, Soil trimming tool, Balance, Dial gauge, Oven, Desiccators, moisture content cans, Stopwatch, Scale.

Procedure:

Clean the ring and weigh it empty. Measure the height and diameter of the consolidation ring. For a remolded soil specimen, compact the soil at its required moisture content in the compaction mold. Then insert the ring in the soil mass by pressing with hand and remove the material around the ring. The soil specimen so cut should project about one centimeter on either side of the ring.

Trim the specimen from the top and bottom of the ring. Remove any soil sticking outside of the ring and weight the ring with the soil specimen. Assemble the consolidometer with the ring having the soil specimen and saturated porous stones on top and bottom of the specimen. Place the filter paper between the soil specimen and the porous stone. Mount the assembly on the loading frame and the dial gauge is set in position. Now inundate the soil specimen and note the initial reading of the dial gauge. Apply the normal load which should not allow any swelling in the soil. In general 5 kN/m^2 initial load applied. Note the dial gauge reading at elapsed times of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 16, 30 minutes and 1, 2, 4, 8, 24 hours from the instant of application of load. The dial gauge readings are taken until 90% consolidation is reached or at least for 24 hours. Increase the normal load to 10 kN/m^2. On successive days, apply the loads to give the pressure of 25, 50, 100, 200, 400 and 800 kN/m^2 for the desired pressure intensity. Dismantle the consolidation ring and weigh it after gently removing any surface water present. Dry the specimen in the oven for 24 hours and weigh the dry soil specimen.

Fig 3.11: Consolidation test apparatus

Formulae used:

$$Height\ of\ solids\ (\mathrm{Hs}) = \frac{\mathrm{Ws}}{G.\gamma_w.A} \tag{3.16}$$

$$Height\ of\ voids\ (\mathrm{Hv}) = H - \mathrm{Hs} \tag{3.17}$$

$$Void\ Ratio\ (\mathrm{e}) = \frac{\mathrm{Hv}}{\mathrm{Hs}} \tag{3.18}$$

$$Coefficient\ of\ compressibility\ (a_v) = -\frac{\Delta \mathrm{e}}{\Delta \sigma} \tag{3.19}$$

$$Coefficient\ of\ volume\ change\ (m_v) = -\frac{\Delta e}{1+e} . \frac{1}{\Delta\sigma} \tag{3.20}$$

$$Compression\ Index\ (C_c) = \frac{-\Delta e}{log\,\frac{(\sigma_\circ - \Delta\sigma)}{\sigma_\circ}} \tag{3.21}$$

$$Coefficient\ of\ consolidation\ (c_v) = 0.112\,\frac{d^2}{t_{90}} \tag{3.22}$$

$$Settlement\ (\delta) = \frac{C_c}{1+e_\circ} . H . \log\frac{(\sigma_\circ + \Delta\sigma)}{\sigma_\circ} \tag{3.23}$$

$$Coefficient\ of\ permeability\ (K) = c_v\ .\ m_v . \rho_w . G \tag{3.24}$$

Where,

W_s = Weight of solids

G = Specific gravity of the soil

A = Area of the ring

d = Length of the maximum drainage path

t_{90} = Time at which 90% of primary consolidation is completed

H = Height of sample

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This section deals with the information gathered based on the above described methodologies. The result section deals with the findings of the research including any statistical analysis and their importance. The discussion section provides the findings in context to literature and previously based knowledge about the subject.

4.2 GRAIN SIZE DISTRIBUTION

4.2.1 COPPER SLAG

OBSERVATIONS

Weight of CS taken for dry sieve analysis = 50g

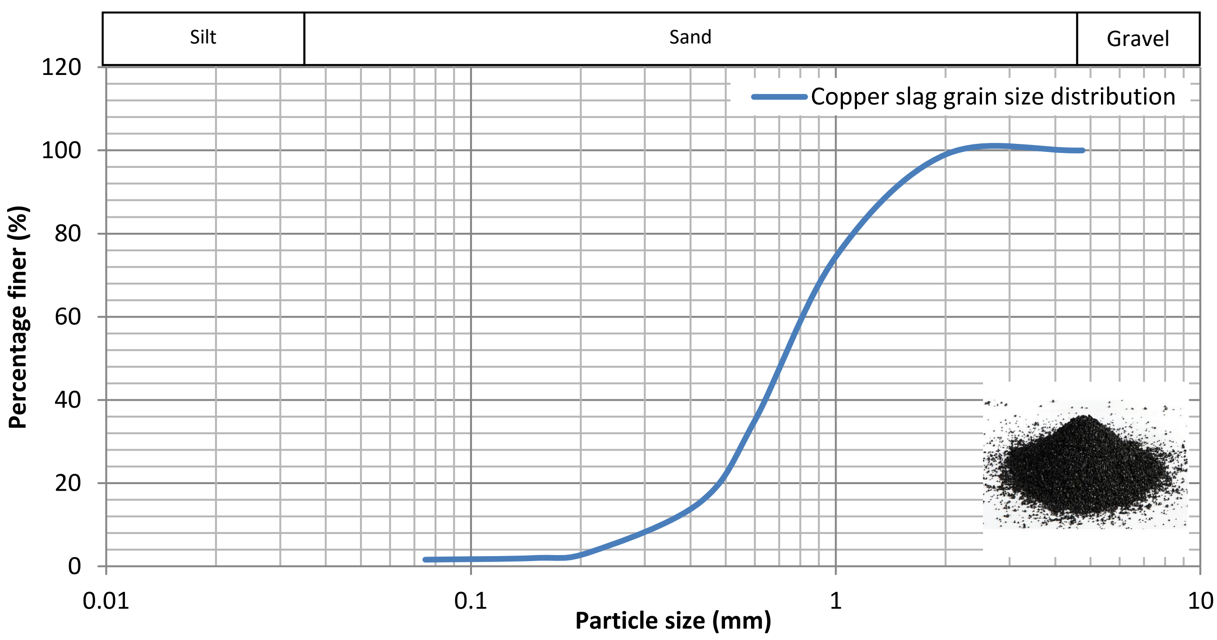

Fig 4.1: Grain size distribution curve of CS

CALCULATIONS

The calculation of coefficient of uniformity is done using Eqn. (3.1)

The coefficient of uniformity (C_u) = 2.37

The calculation of coefficient of curvature is done using Eqn. (3.2)

The coefficient of curvature (C_c) = 1.08

The particle size distribution of copper slag depicts: 1% gravel, 65% coarse sand, 14% medium sand and 20% fine sand and is therefore categorised as sand. The value of (C_u) greater than 5 represents a well-graded soil type whereas the value of (C_u) less than 3 represents a soil that is uniform in nature. The value of (C_c) lying between 0.5 and 2.0 represents a well-graded soil type whereas the value of (C_c) less than 0.1 represents a gap-graded soil type.

4.2.2 BLACK COTTON SOIL

OBSERVATIONS

Weight of BCS used = 500g

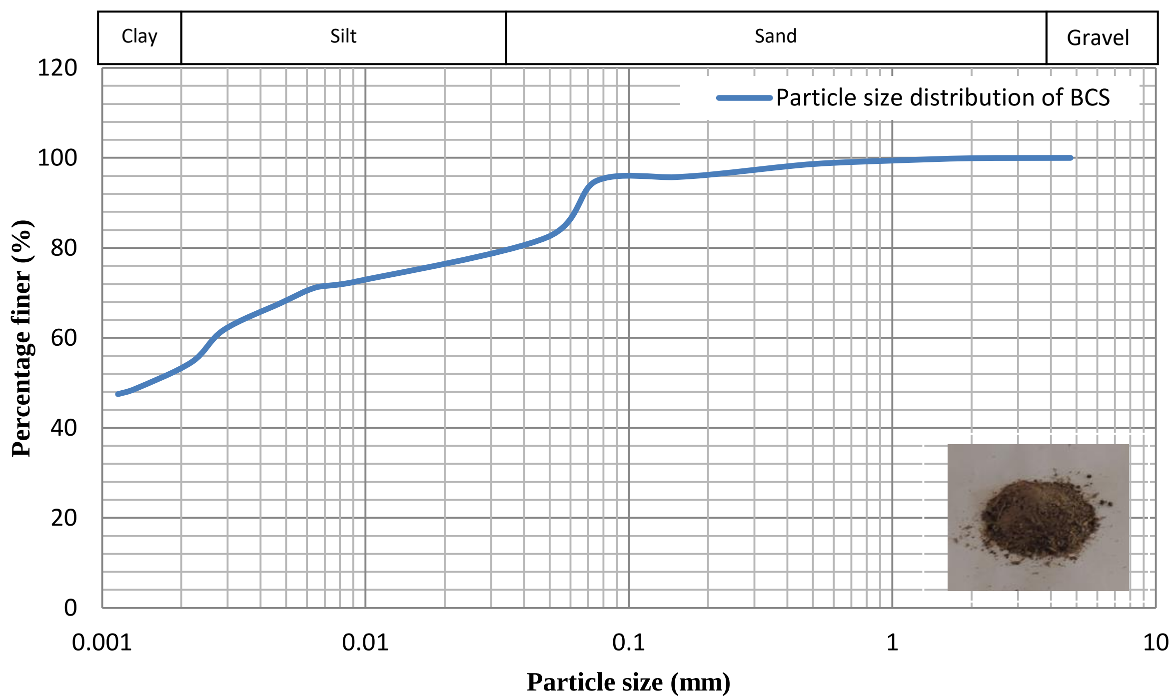

Fig 4.2: Grain size distribution curve of BCS

The particle size distribution of copper slag depicts: 0% gravel, 4% sand, 44% silt and 52% clay and hence has more than 50% clay fraction.The value of (C_u) greater than 5 represents a well-graded soil type whereas the value of (C_u) less than 3 represents a soil that is uniform in nature. The value of (C_c) lying between 0.5 and 2.0 represents a well-graded soil type whereas the value of (C_c) less than 0.1 represents a gap-graded soil type.

4.3 SPECIFIC GRAVITY

CALCULATIONS

The calculation of specific gravity is done using Eqn. (3.3)

Table 2: Variation of specific gravity with CS

Variation of waste % (w/w)	Specific Gravity
0	2.28
5	2.40
10	2.68
15	3.13
20	3.36

The specific gravity of the soil particle generally lies in the range of 2.65-2.85. The specific gravity of soils in which the presence organic matter and porous particle are there have the value of specific gravity less than 2, whereas the presence of heavy substances may result in the specific gravity greater than 3.

4.4 ATTERBERG'S LIMITS

4.4.1 LIQUID LIMIT

4.4.1.1 BLACK COTTON SOIL

OBSERVATIONS

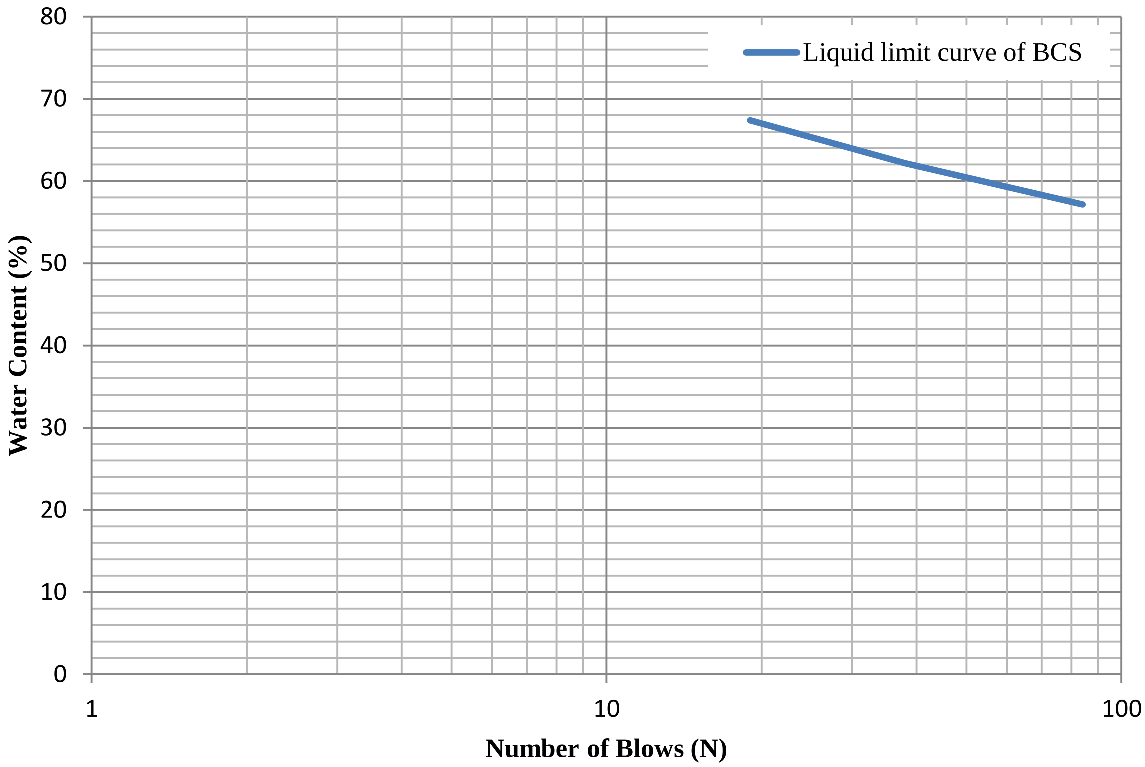

Fig 4.3: Liquid limit Fig of BCS

CALCULATIONS

The calculation of liquid limit is done using Eqn. (3.4)

The average liquid limit of BCS = 64.0%

4.4.1.2 BLACK COTTON SOIL + 5% CS

OBSERVATIONS

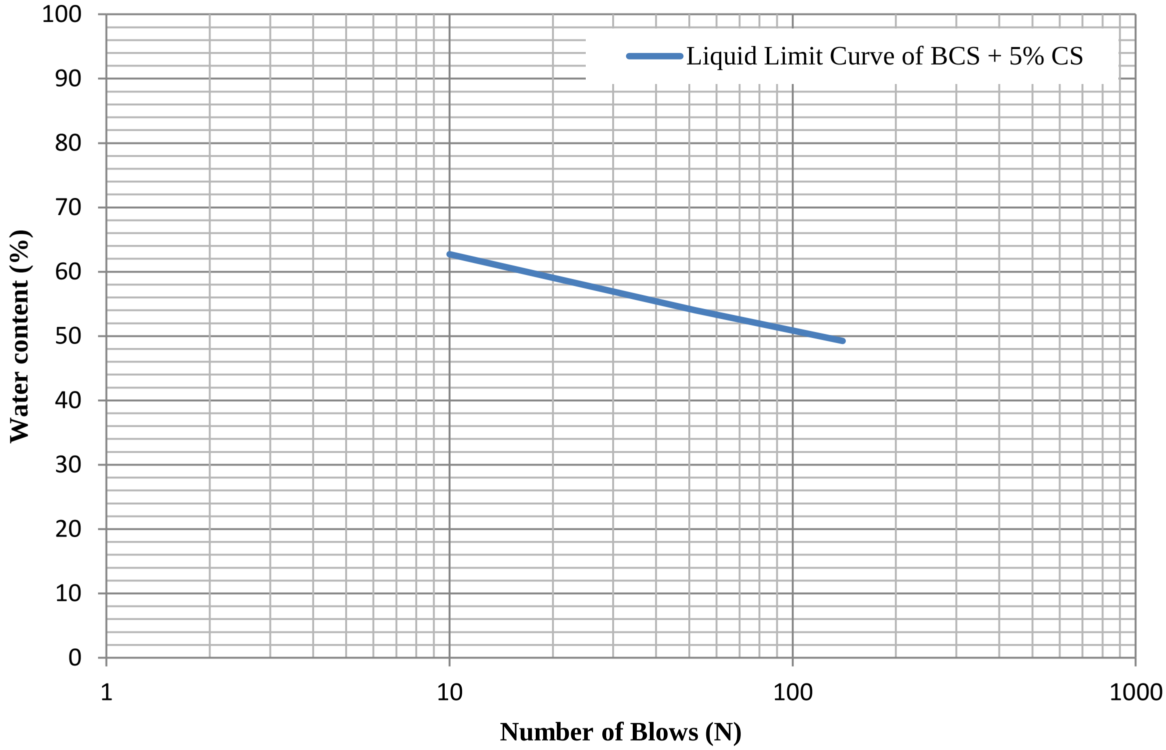

Fig 4.4: Liquid limit Fig of BCS + 5% CS

CALCULATIONS

The calculation of liquid limit is done using Eqn. (3.4)

The average liquid limit of BCS + 5% CS = 58%

4.4.1.3 BLACK COTTON SOIL + 10%CS

OBSERVATIONS

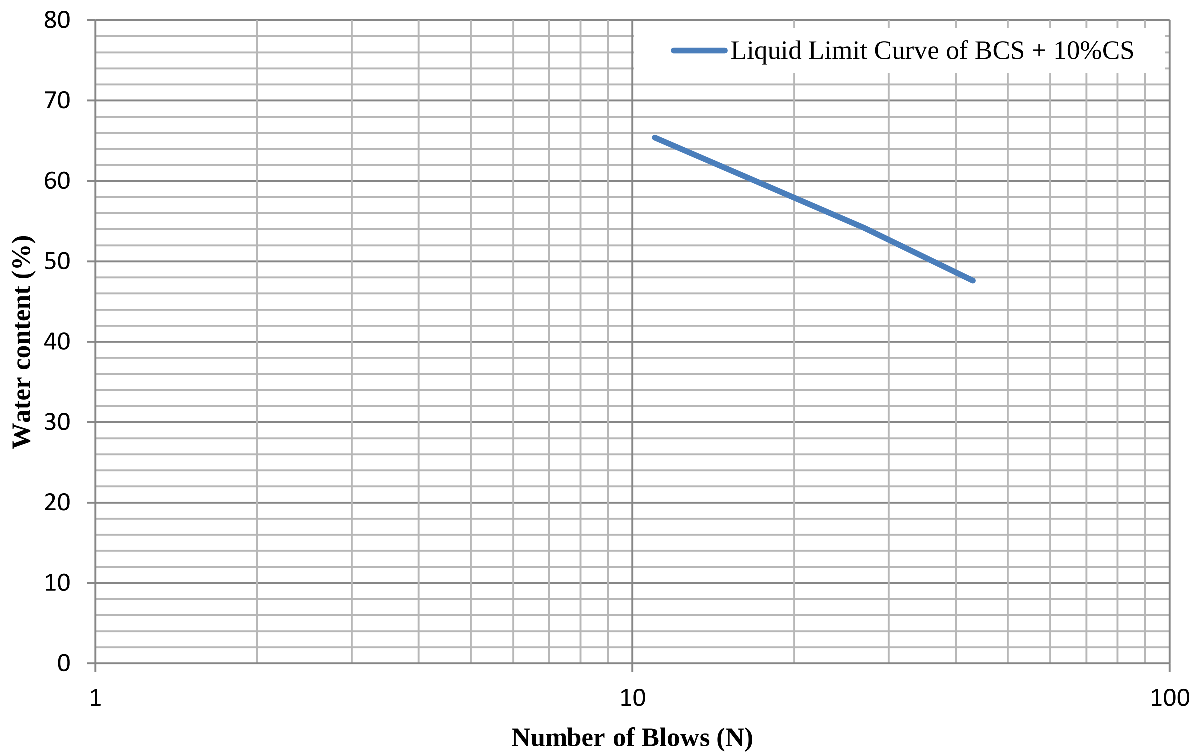

Fig 4.5: Liquid limit Fig of BCS + 10% CS

CALCULATIONS

The calculation of liquid limit is done using Eqn. (3.4)

The average liquid limit of BCS + 10% CS = 54.80%

4.4.1.4 BLACK COTTON SOIL+ 15%CS

OBSERVATIONS

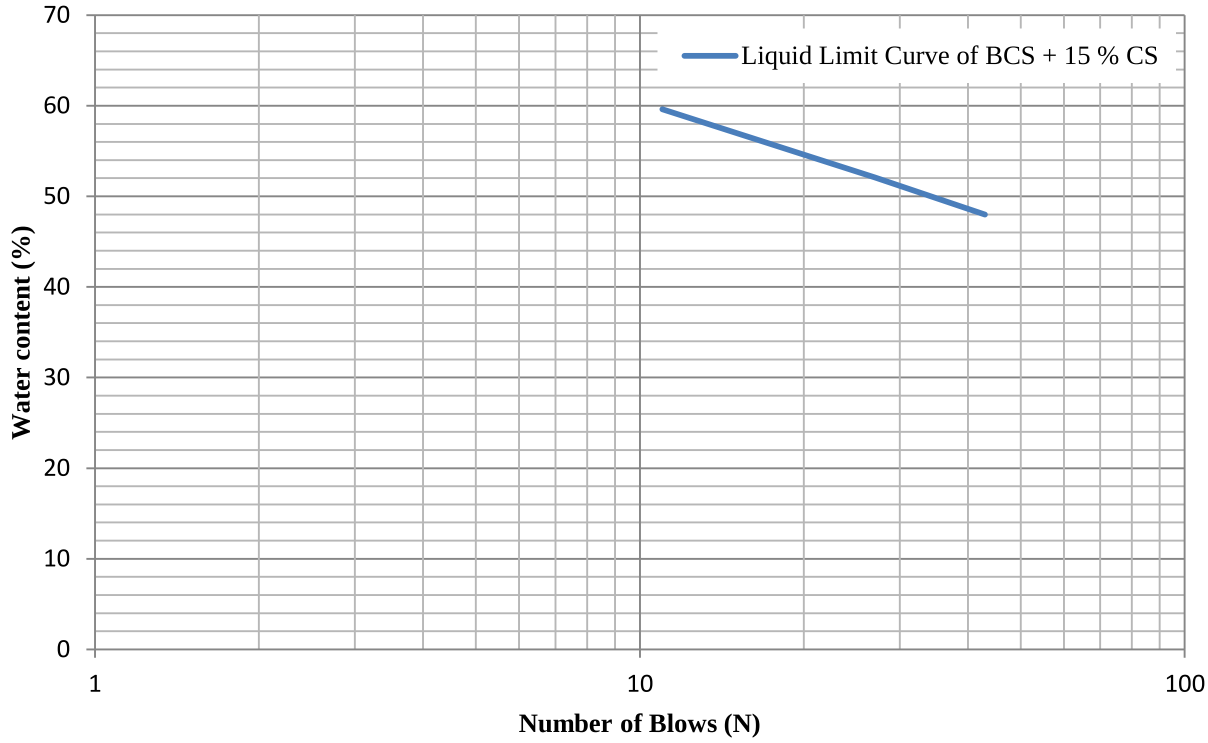

Fig 4.6: Liquid limit Fig of BCS + 15% CS

CALCULATIONS

The calculation of liquid limit is done using Eqn. (3.4)

The average liquid limit of BCS + 15% CS = 52.70%

4.4.1.5 BLACK COTTON SOIL+ 20%CS

OBSERVATIONS

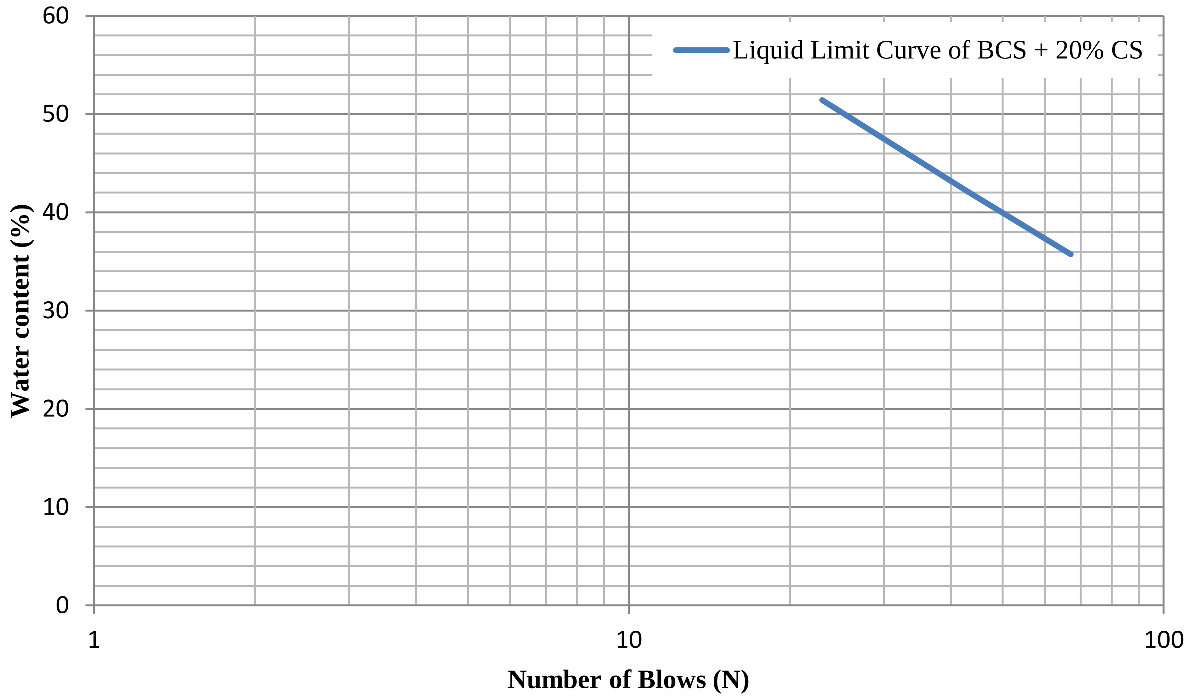

Fig 4.7: Liquid limit Fig of BCS + 20% CS

CALCULATIONS

The calculation of liquid limit is done using Eqn. (3.4)

The average liquid limit of BCS + 20% CS = 49.40%

The liquid limit of a fine grained soil is stated as percentage of moisture content at which the fine grained soil changes from its liquid state to the plastic state. It is the tendency of a soil to flow like a fluid when a very small shear force is applied at its minimum moisture content. Liquid limit is an essential property of fine soils, which is used to classify fine grained soil. It also provides the information about the state of consistency of soil and toughness index of soil.

The results from the liquid limit of plain Black cotton soil shows that it is a high shrinking and swelling clay. The addition of CS causes decreases in the liquid limit of BCS as it makes the soil a bit coarse in nature thus reducing the swelling properties of BCS

4.4.2 SHRINKAGE LIMIT

CALCULATIONS

The Shrinkage Limit was calculated from the Eqn. (3.5):

Table 3: Variation of shrinkage limit with CS

Variation of waste % (w/w)	Shrinkage Limit
0	13.61%
5	14.72%
10	15.44%
15	17.06%
20	18.53%

The shrinkage limit of soil can be stated as the amount of moisture content needed to fully fill all the voids in the soil. Shrinkage limit is the point after which the reduction of moisture content in the soil does not affect its volume whatsoever. This test provides a clue of the amount of moisture that can induce a change of volume in the soil. The analysis of shrinkage limit should be a priority when dealing with soils that have frequent wet and dry cycles. The increase in the shrinkage limit with addition of CS shows, increase in limit of moisture content causing volumetric change.

4.4.3 PLASTIC LIMIT

CALCULATIONS

Table 4: Variation of plastic limit with CS

Variation of waste % (w/w)	Plastic Limit
0	34.58%
5	28.25%
10	25.84%
15	22.87%
20	20.12%

The Plasticity Index of BCS is calculated from Eqn. (3.7)

Plasticity Index (I_P) = 28.16

The plasticity index of BCS > 17; hence it is characterised as highly plastic.

The Toughness Index of BCS is calculated from Eqn. (3.8)

Toughness Index (I_T) = 0.863

The toughness index of BCS is less than unity; hence the soil is friable at plastic limit.

The Flow Index of BCS is calculated from Eqn. (3.4)

Flow Index (I_F) = 32.62

A soil having higher value of flow index possesses lower shear strength**.**

The plastic limit of a soil is the percentage of moisture at which when the soil is rolled into threads of diameter 3mm forms cracks on its surface, a slight increase in moisture above the plastic limit decreases cohesion of the soil. The plastic limit of BCS decreases with increase in CS % (w/w) due to loss of cohesion between particles.

4.5 FREE SWELL INDEX

OBSERVATION

The weight of virgin soil sample taken = 10g

CALCULATION

The free swell index was calculated from the Eqn. (3.9):

The Free Swell Index of BCS = 63.64 %

The free swell index of BCS > 50%, hence it is a highly expansive soil.

4.6 COMPACTION TEST

4.6.1. BLACK COTTON SOIL

OBSERVATIONS

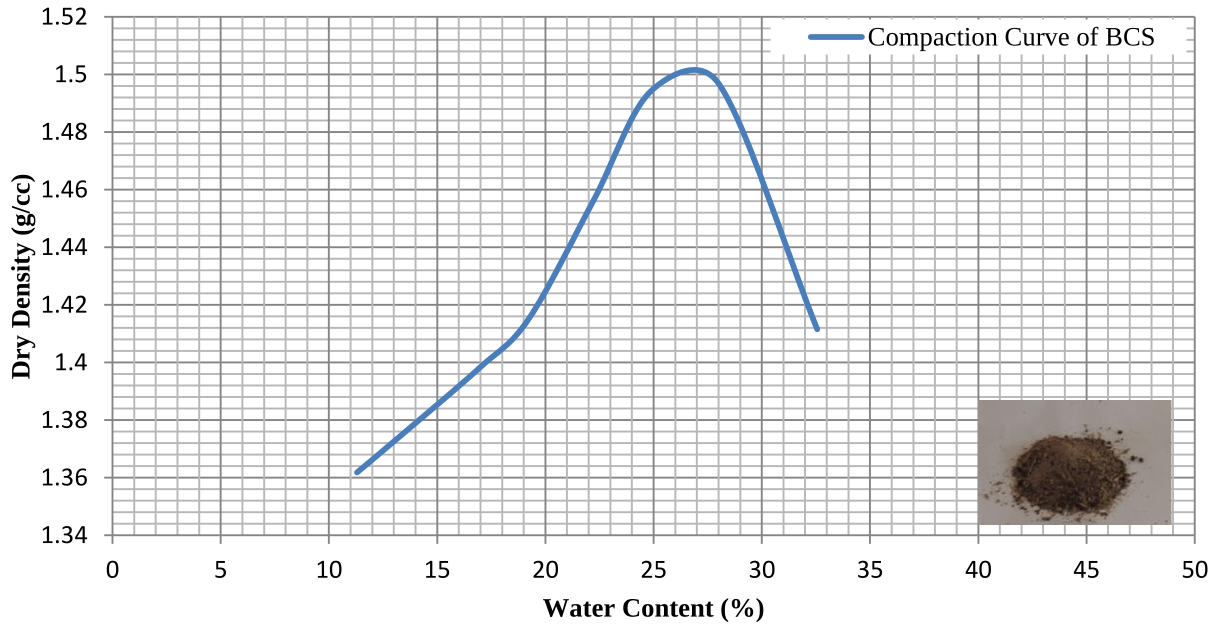

Fig 4.8: Compaction curve of BCS

CALCULATIONS

The calculation of MDD is done using Eqn. (3.11)

The MDD of BCS = 1.50 g/cc

The OMC of BCS = 26.70%

4.6.2. BLACK COTTON SOIL+ 5% CS

OBSERVATIONS

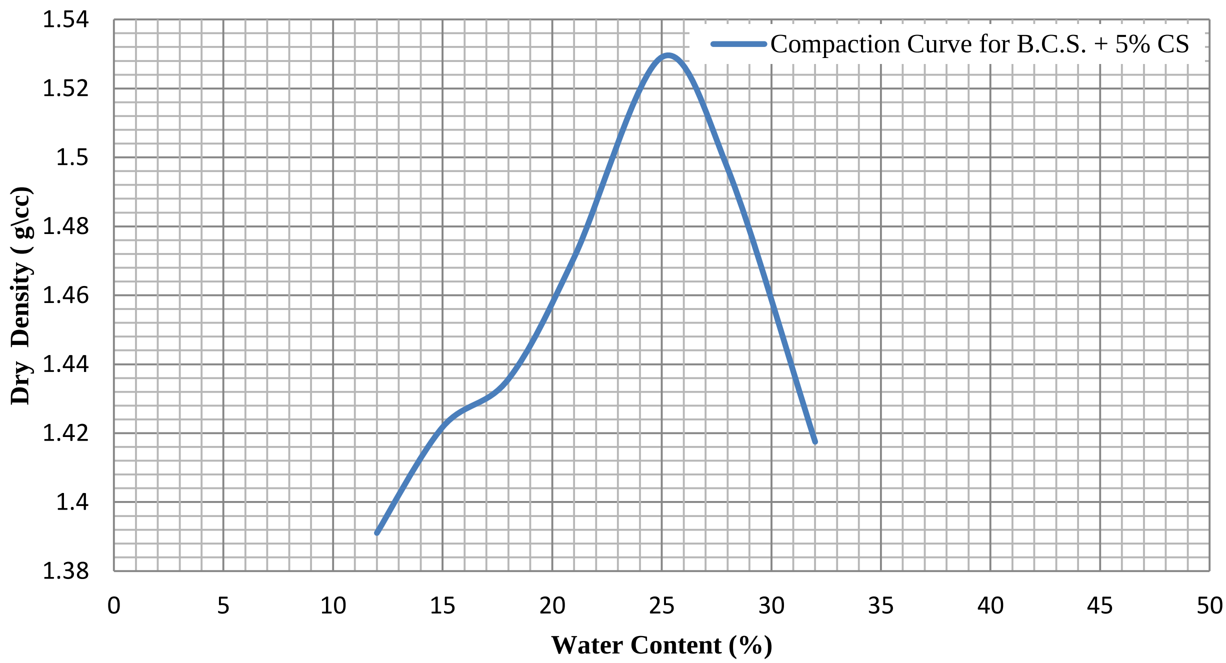

Fig 4.9: Compaction curve of BCS + 5% CS

CALCULATIONS

The calculation of MDD is done using Eqn. (3.11)

The MDD of BCS + 5% CS = 1.52 g/cc

The OMC of BCS + 5% CS = 25.20 %

4.6.3. BLACK COTTON SOIL+ 10% CS

OBSERVATIONS

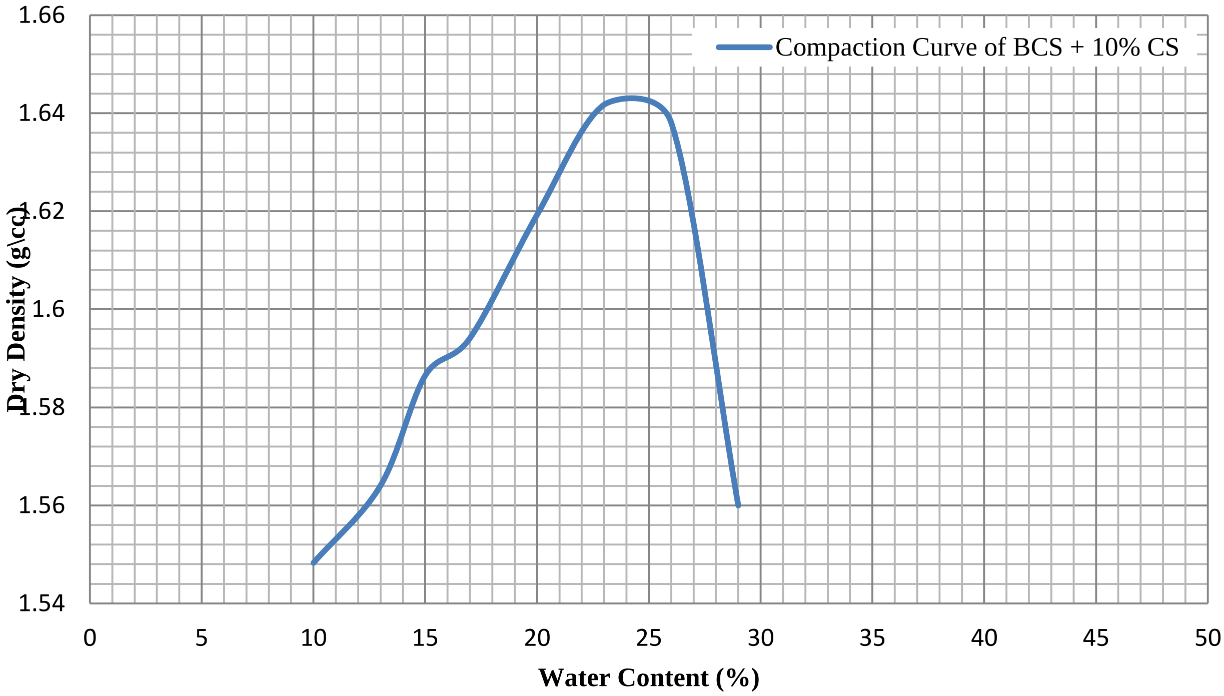

Fig 4.10: Compaction curve of BCS + 10% CS

CALCULATIONS

The calculation of MDD is done using Eqn. (3.11)

The MDD of BCS + 10% CS = 1.64 g/cc

The OMC of BCS + 10% CS = 24.3 %

4.6.4. BLACK COTTON SOIL+ 15% CS

OBSERVATIONS

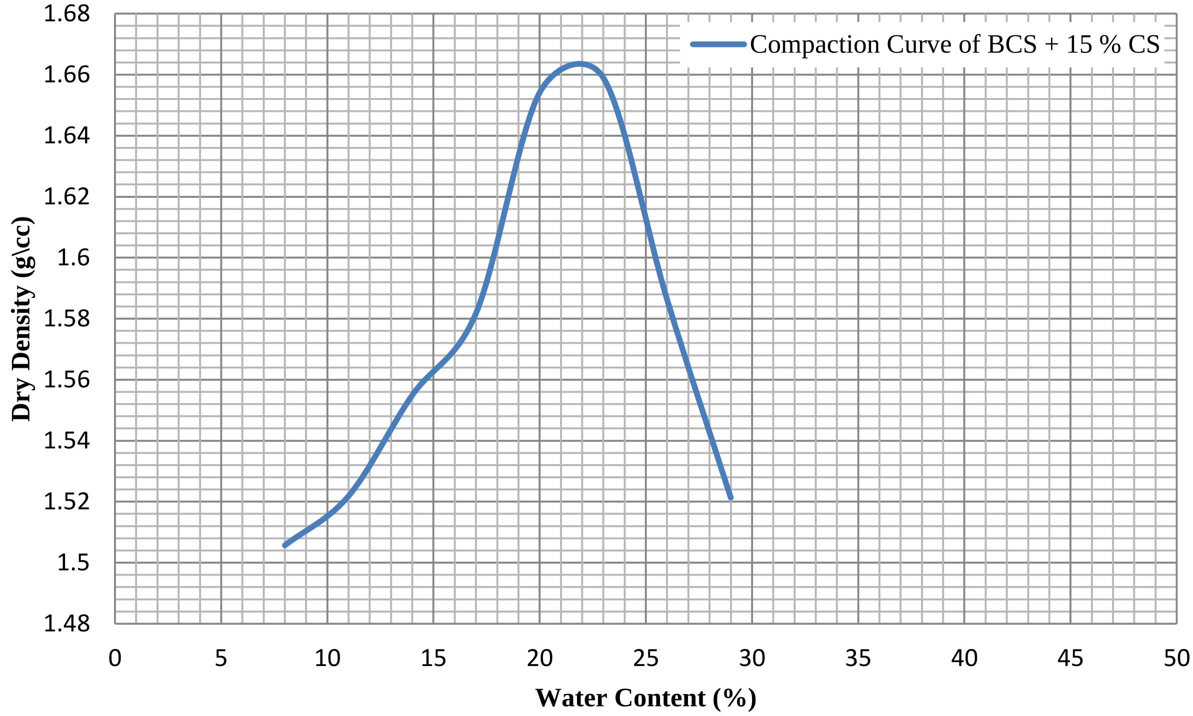

Fig 4.11: Compaction curve of BCS + 15% CS

CALCULATIONS

The calculation of MDD is done using Eqn. (3.11)

The MDD of BCS + 15% CS = 1.66 g/cc

The OMC of BCS + 15% CS = 22.0 %

4.6.5. BLACK COTTON SOIL+ 20% CS

OBSERVATIONS

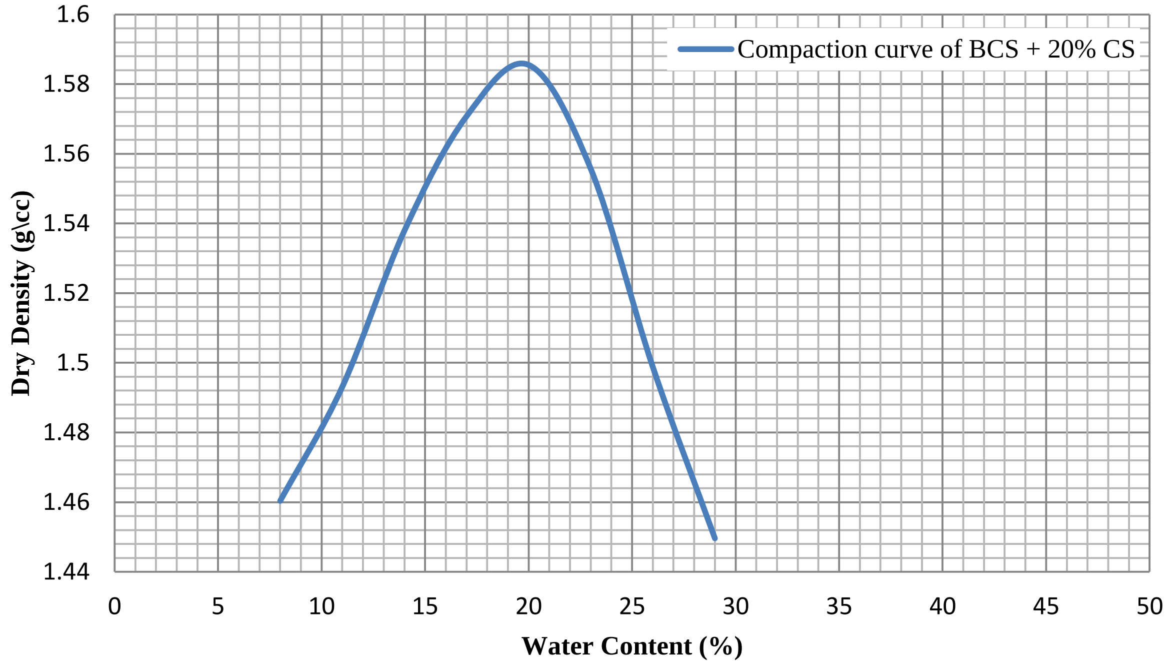

Fig 4.12: Compaction curve of BCS + 20% CS

CALCULATIONS

The calculation of MDD is done using Eqn. (3.11)

The MDD of BCS + 20% CS = 1.59 g/cc

The OMC of BCS + 20% CS = 19.6 %

The main reason for compaction of the soil is to subsequently decrease the settlement of the soil to improve its strength characteristics. The compaction of soil works on the principle that by eliminating the voids in the soil and making the penetration of water difficult as there are no interconnected voids thus, increases the shear strength. Furthermore it does not allow the build up of water pressure. This test allows the identification of maximum dry density in order to maximize the shear strength of the soil. The factors that affect compaction of soil are water content and the type of soil being compacted.

4.7 UNCONFINED COMPRESSION TEST

4.7.1 BLACK COTTON SOIL

OBSERVATIONS

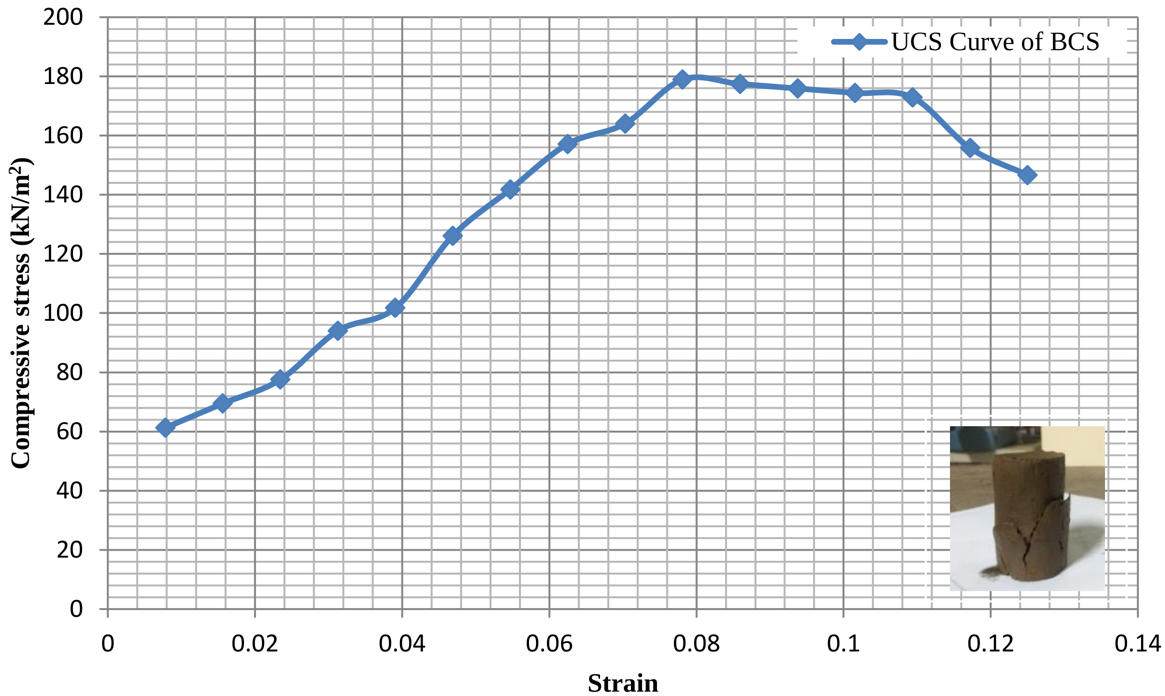

Fig 4.13: Unconfined compressive curve of BCS

CALCULATIONS

The Unconfined Compressive strength of BCS = 178.92 kN/m^2

The calculation of Shear strength is done using Eqn. (3.15)

The Shear strength of BCS = 89.46 kN/m^2

4.7.2. BLACK COTTON SOIL+ 5% CS

OBSERVATIONS

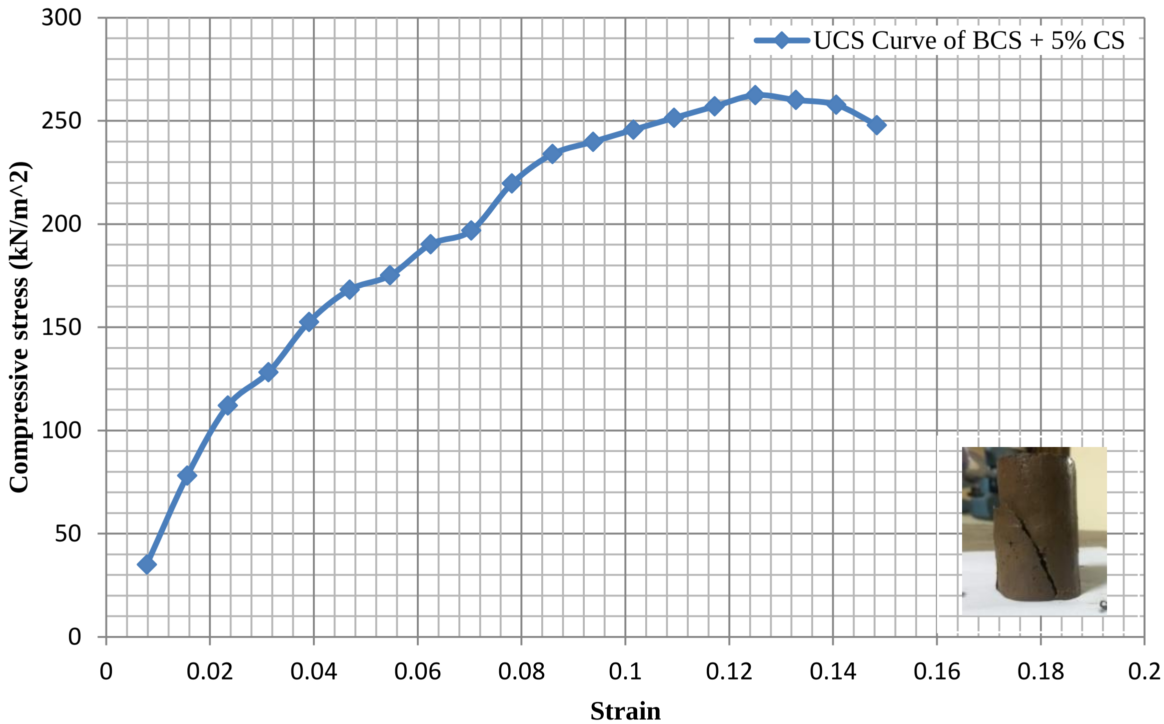

Fig 4.14: Unconfined compressive curve of BCS + 5% CS

CALCULATIONS

The Unconfined Compressive strength of BCS + 5% CS = 262.45 kN/m^2

The calculation of Shear strength is done using Eqn. (3.15)

The Shear strength of BCS + 5% CS = 131.23 kN/m^2

4.7.3. BLACK COTTON SOIL+ 10% CS

OBSERVATIONS

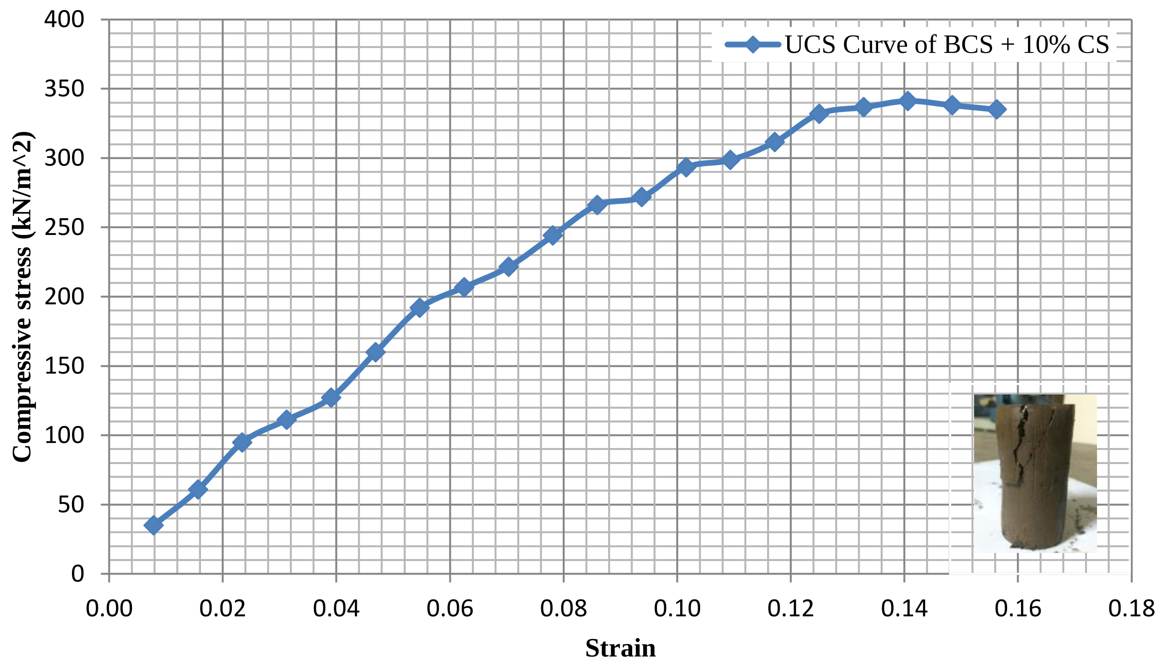

Fig 4.15: Unconfined compressive curve of BCS + 10% CS

CALCULATIONS

The Unconfined Compressive strength of BCS + 10% CS = 341.16 kN/m^2

The calculation of Shear strength is done using Eqn. (3.15)

The Shear strength of BCS + 10% CS = 170.58 kN/m^2

4.7.4. BLACK COTTON SOIL+ 15% CS

OBSERVATIONS

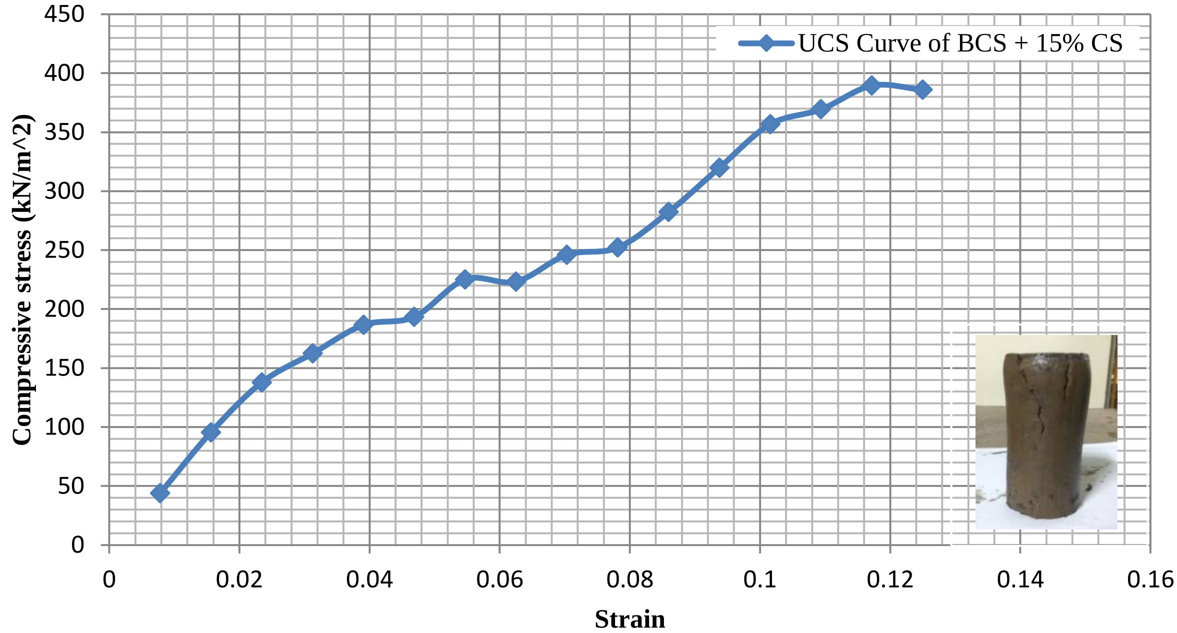

Fig 4.16: Unconfined compressive curve of BCS + 15% CS

CALCULATIONS

The Unconfined Compressive strength of BCS + 15% CS = 389.41 kN/m^2

The calculation of Shear strength is done using Eqn. (3.15)

The Shear strength of BCS + 15% CS = 194.71 kN/m^2

4.7.5. BLACK COTTON SOIL+ 20% CS

OBSERVATIONS

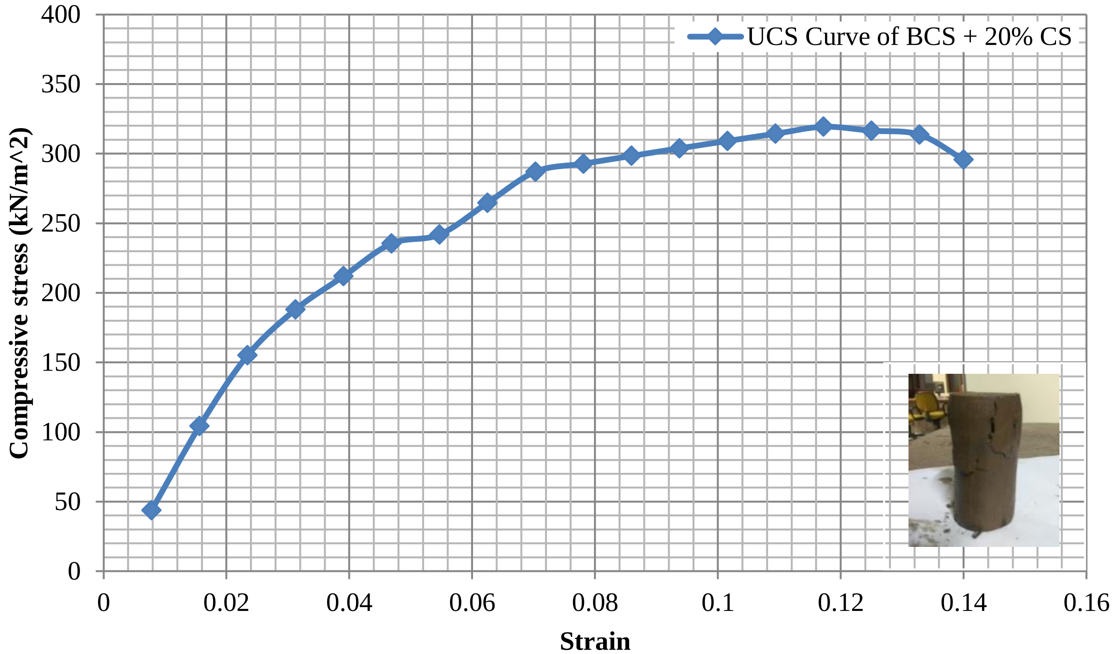

Fig 4.17: Unconfined compressive curve of BCS + 20% CS

CALCULATIONS

The Unconfined Compressive strength of BCS + 20% CS = 316.49 kN/m^2

The calculation of Shear strength is done using Eqn. (3.15)

The Shear strength of BCS + 20% CS = 158.25 kN/m^2

The unconfined compression test is a measure of the shear strength and provides a relation between the stress – strain characteristics of cohesive soils. This is a parameter for soil is important as it is the maximum capacity of the soil to resist failure when on soil some forces are applied.

4.8 CONSOLIDATION

4.8.1 BLACK COTTON SOIL

OBSERVATIONS

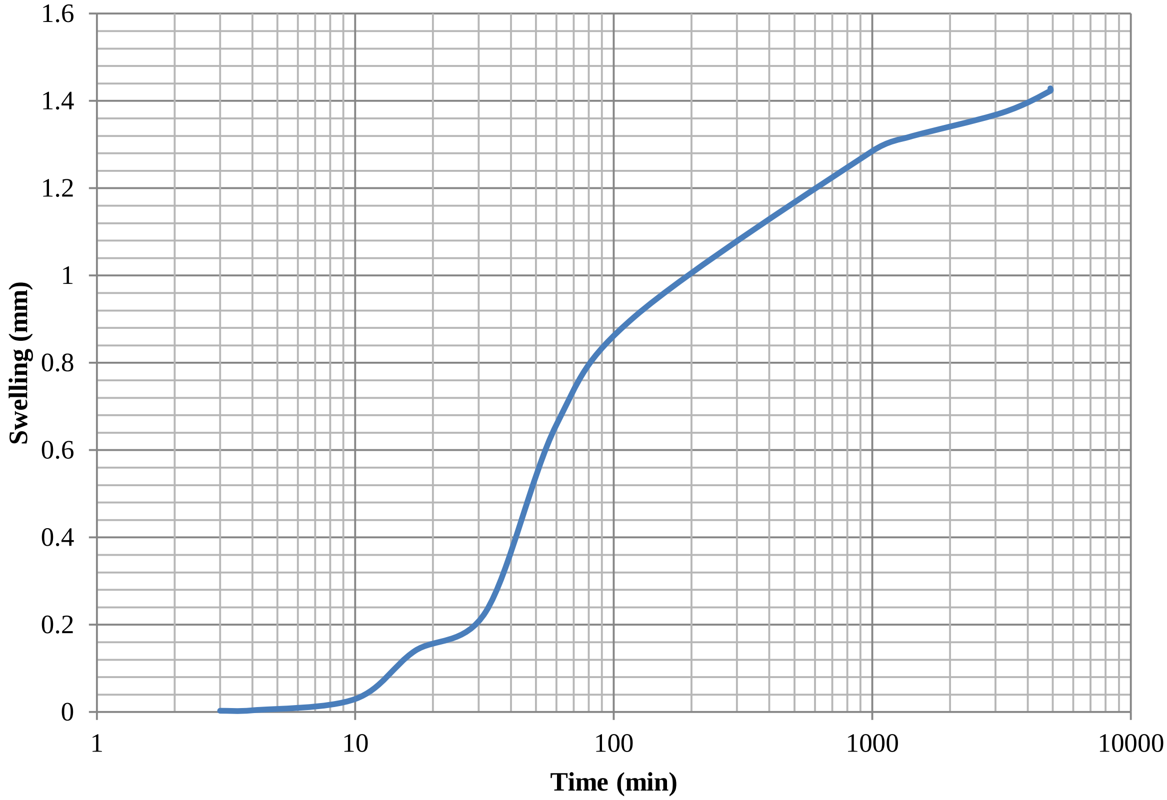

Fig 4.18: Log time/Settlement curve of BCS

CALCULATIONS

The total swelling of BCS obtained = 1.429 mm

OBSERVATIONS

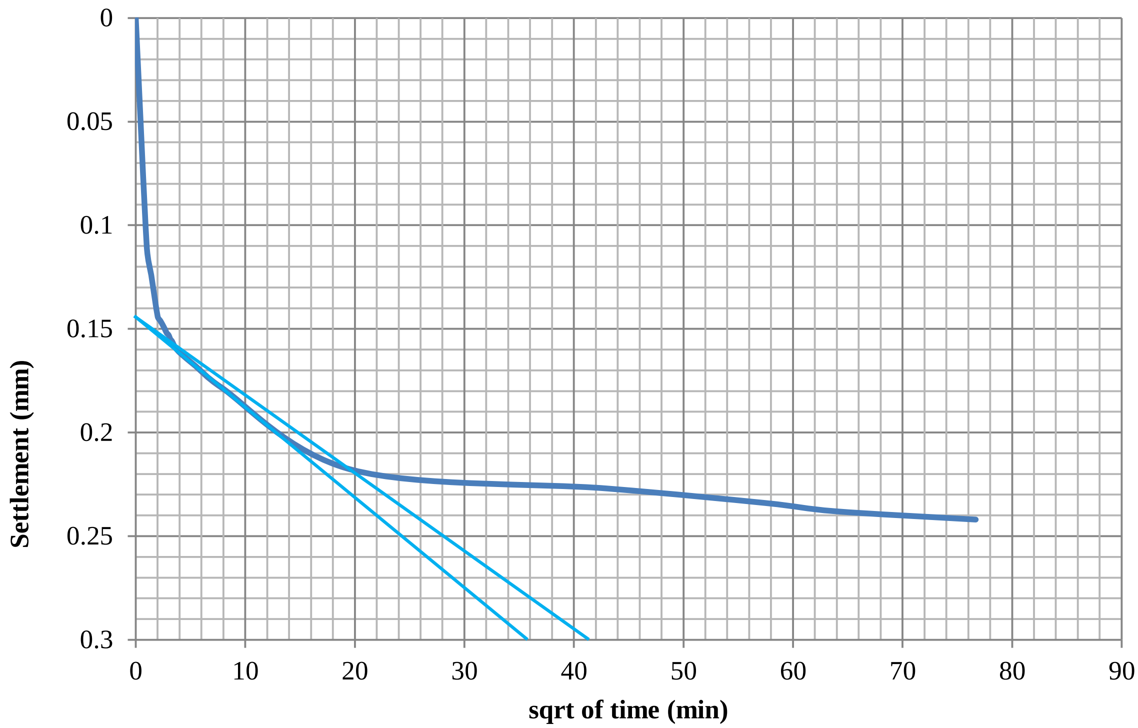

Fig 4.19: Sqrt time/Settlement curve of BCS at 25kN load

CALCULATIONS

From the Fig the value of t_{90} = 1713.9 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.026

OBSERVATIONS

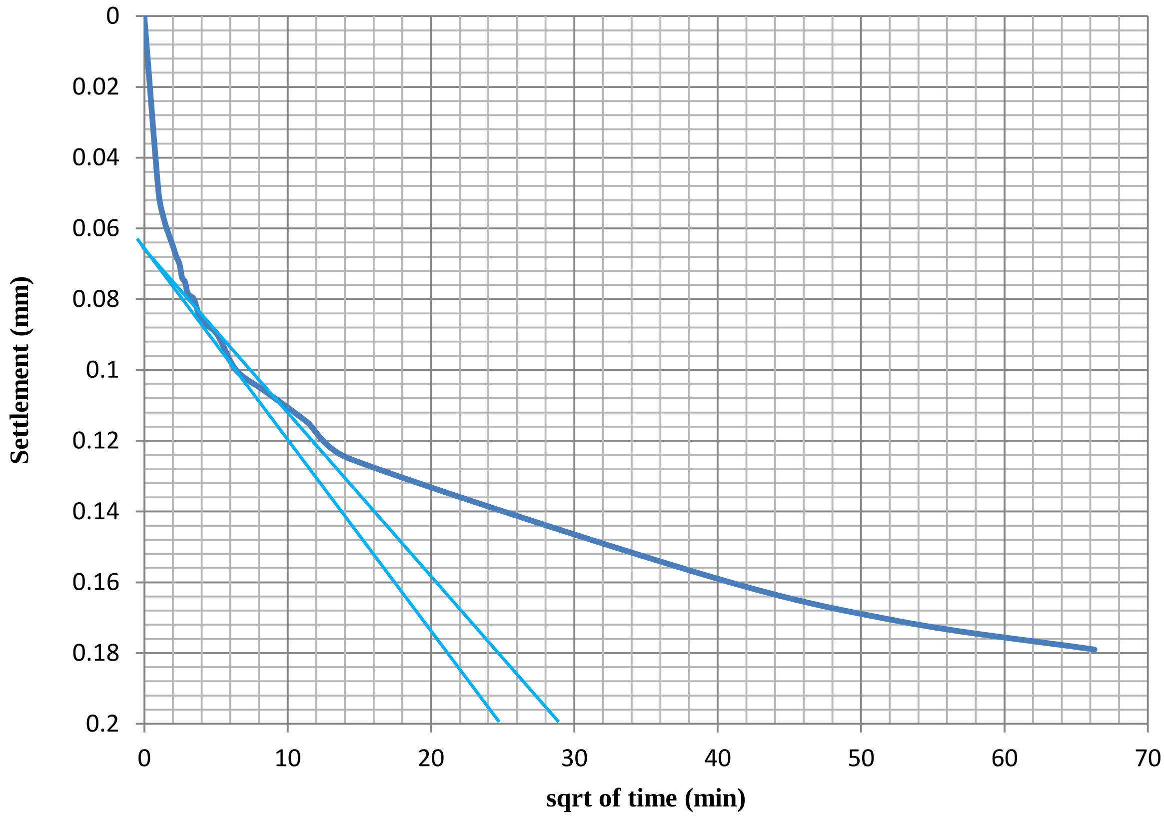

Fig 4.20: Sqrt time/Settlement curve of BCS at 50kN load

CALCULATIONS

From the Fig the value of t_{90} = 825 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.054

OBSERVATIONS

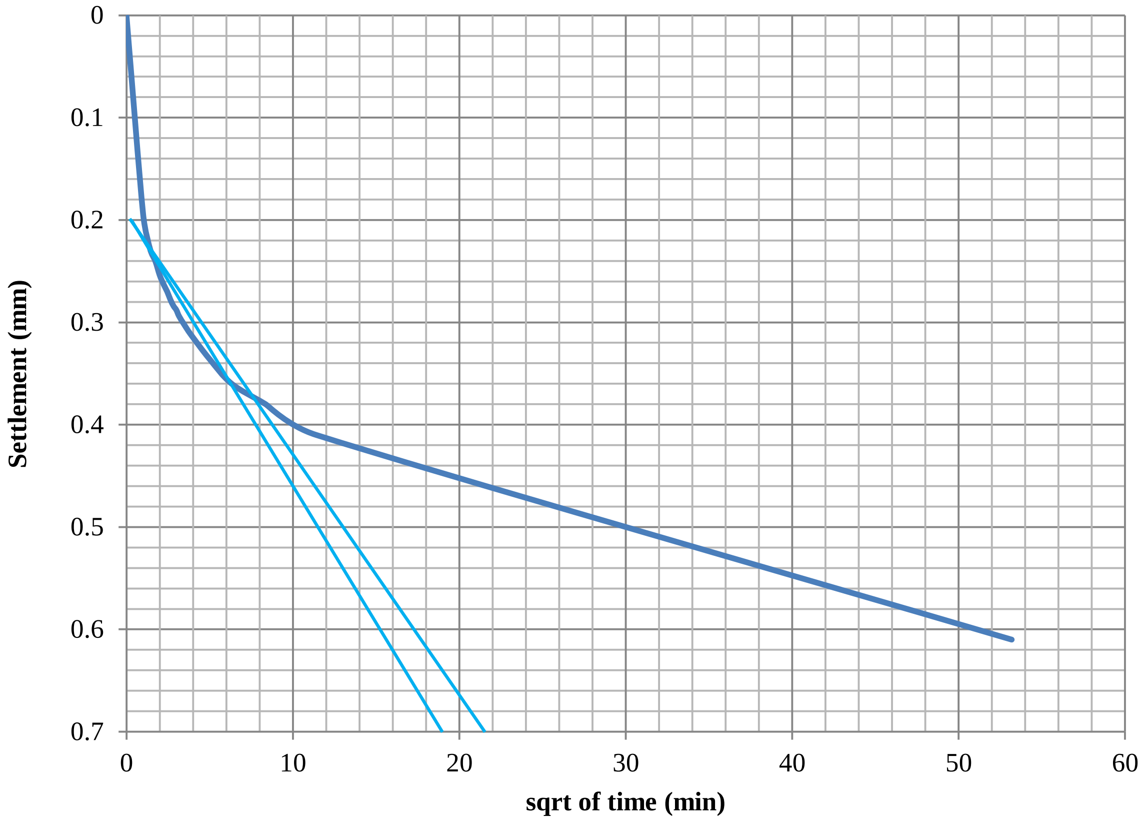

Fig 4.21: Sqrt time/Settlement curve of BCS at 100kN load

CALCULATIONS

From the Fig the value of t_{90} = 429 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.104

OBSERVATIONS

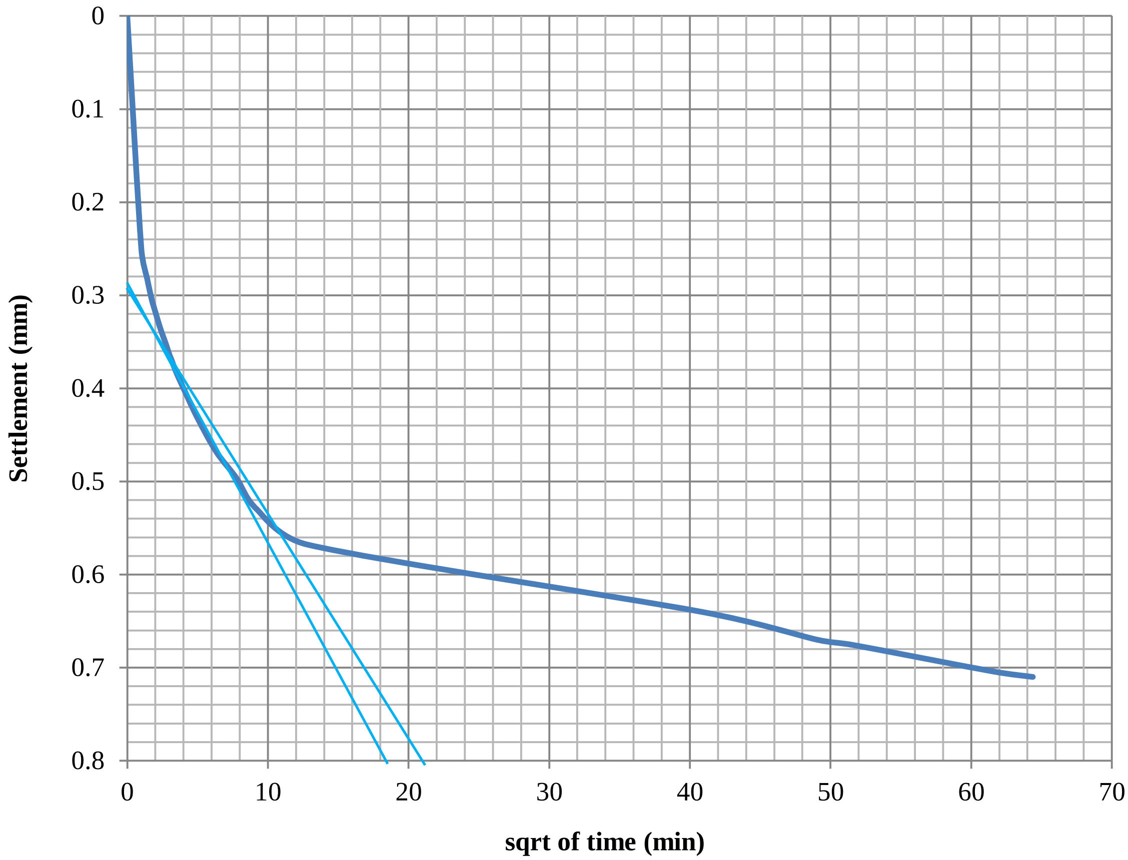

Fig 4.22: Sqrt time/Settlement curve of BCS at 200kN load

CALCULATIONS

From the Fig the value of t_{90} = 429 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.104

OBSERVATIONS

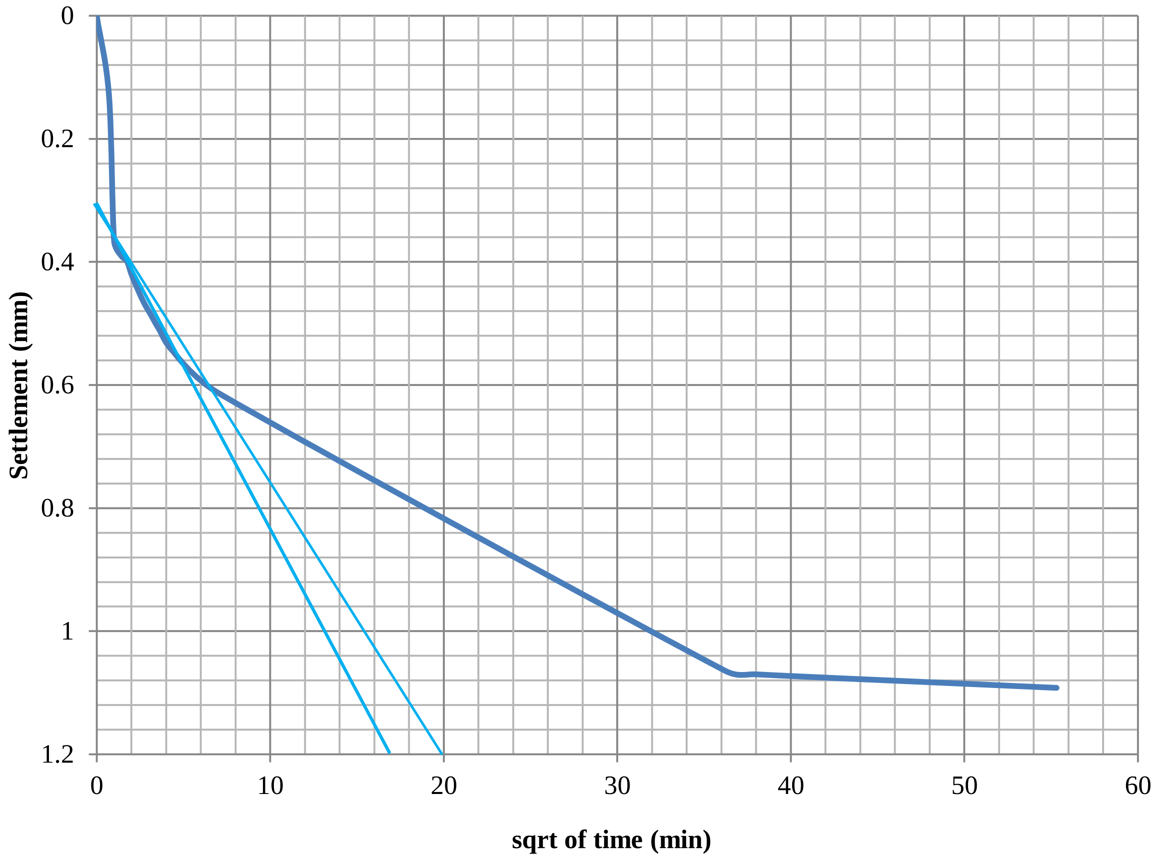

Fig 4.23: Sqrt time/Settlement curve of BCS at 400kN load

CALCULATIONS

From the Fig the value of t_{90} = 382 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.117

OBSERVATIONS

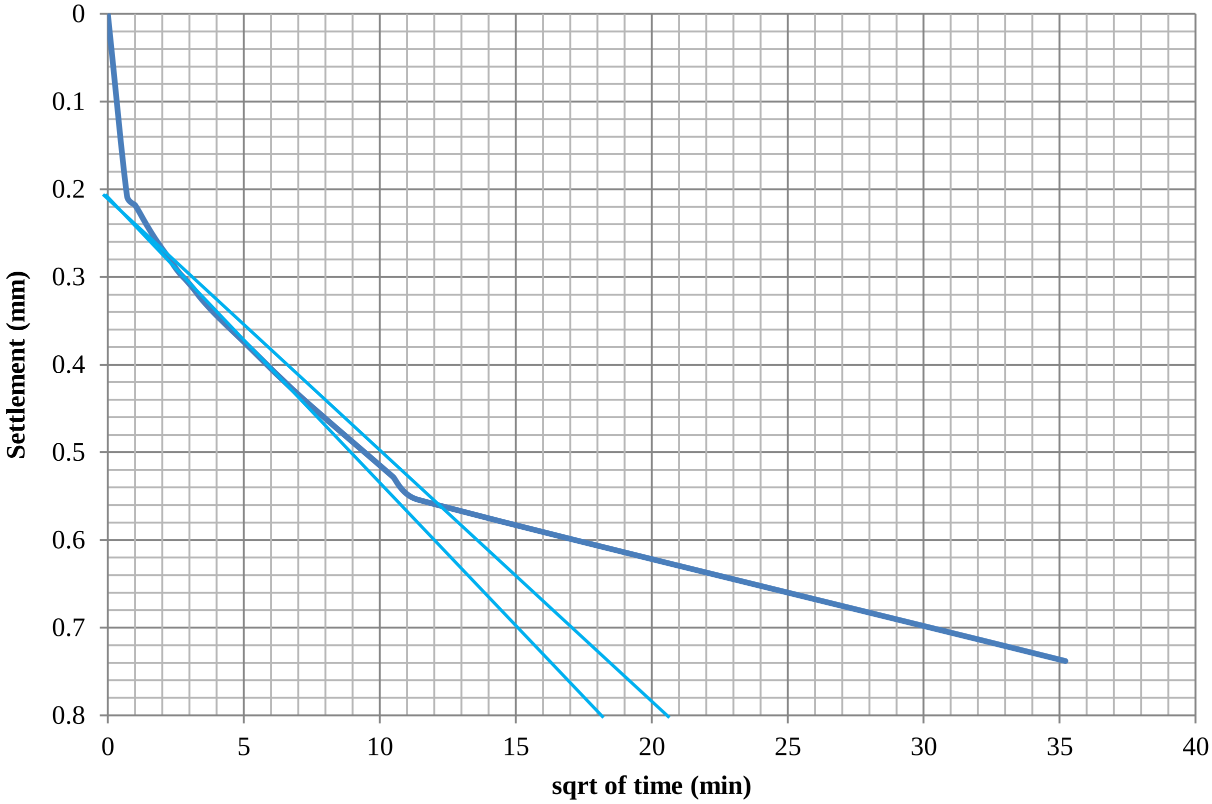

Fig 4.24: Sqrt time/Settlement curve of BCS at 800kN load

CALCULATIONS

From the Fig the value of t_{90} = 429 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.104

OBSERVATIONS

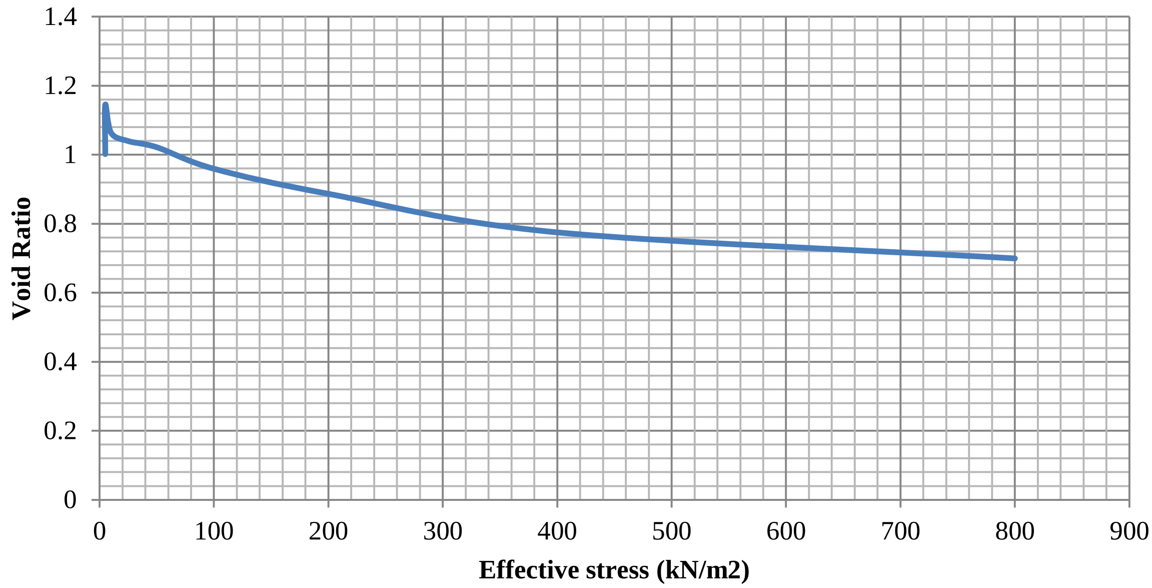

Fig 4.25: Effective stress/Void ratio curve of BCS

CALCULATIONS

The calculation of Coefficient of compressibility (a_v) is done using Eqn. (3.19)

The calculation of Coefficient of volume change (m_v) is done using Eqn. (3.20)

The calculation of Coefficient of permeability (K) is done using Eqn. (3.24)

Table 5: Parameters from oedometer test of BCS

Parameters	**25 kN**	**50 kN**	**100 kN**	**200 kN**	**400 kN**	**800 kN**
$\mathbf{a_v}$	0.00097	0.00072	0.001	0.00073	0.00056	0.00019
$\mathbf{m_v}$	0.469	0.351	0.617	0.371	0.296	0.106
K	0.0038×10^{-9}	0.006×10^{-9}	0.02×10^{-9}	0.012×10^{-9}	0.011×10^{-9}	0.0034×10^{-9}

OBSERVATIONS

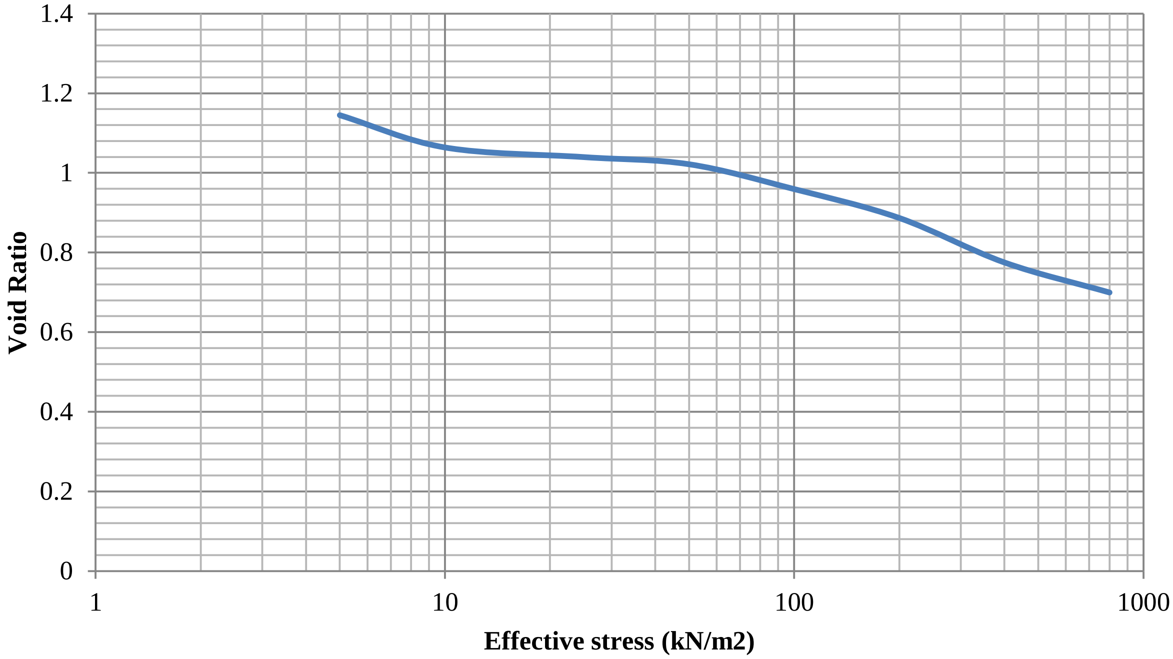

Fig 4.26: log Effective stress/Void ratio curve of BCS

CALCULATIONS

The calculation of Compression index (C_c) is done using Eqn. (3.21)

Compression index (C_c) for BCS = 0.22

The calculation of Settlement (δ) is done using Eqn. (3.23)

Settlement (δ) for BCS = 5.081 mm

4.8.2. BLACK COTTON SOIL+ 15% CS

OBSERVATIONS

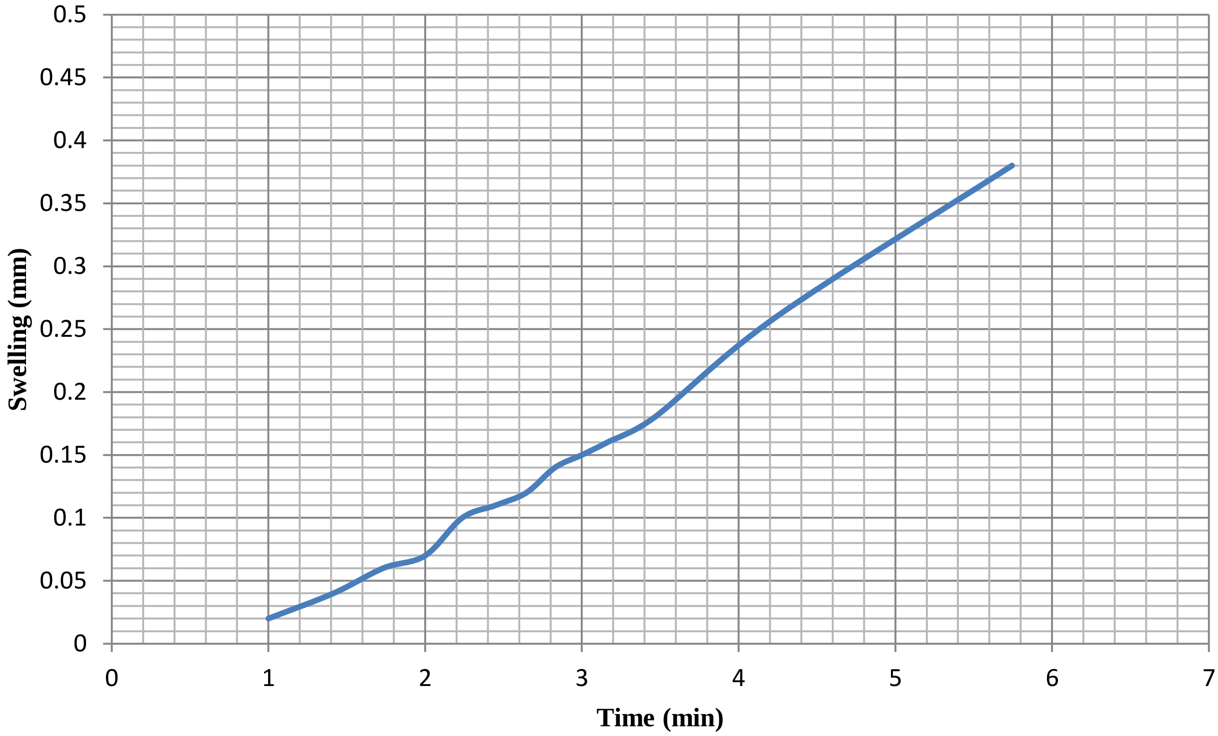

Fig 4.27: Log time/Settlement curve of BCS +15% CS

CALCULATIONS

The total swelling of BCS + 15% CS obtained = 3.3 mm

OBSERVATIONS

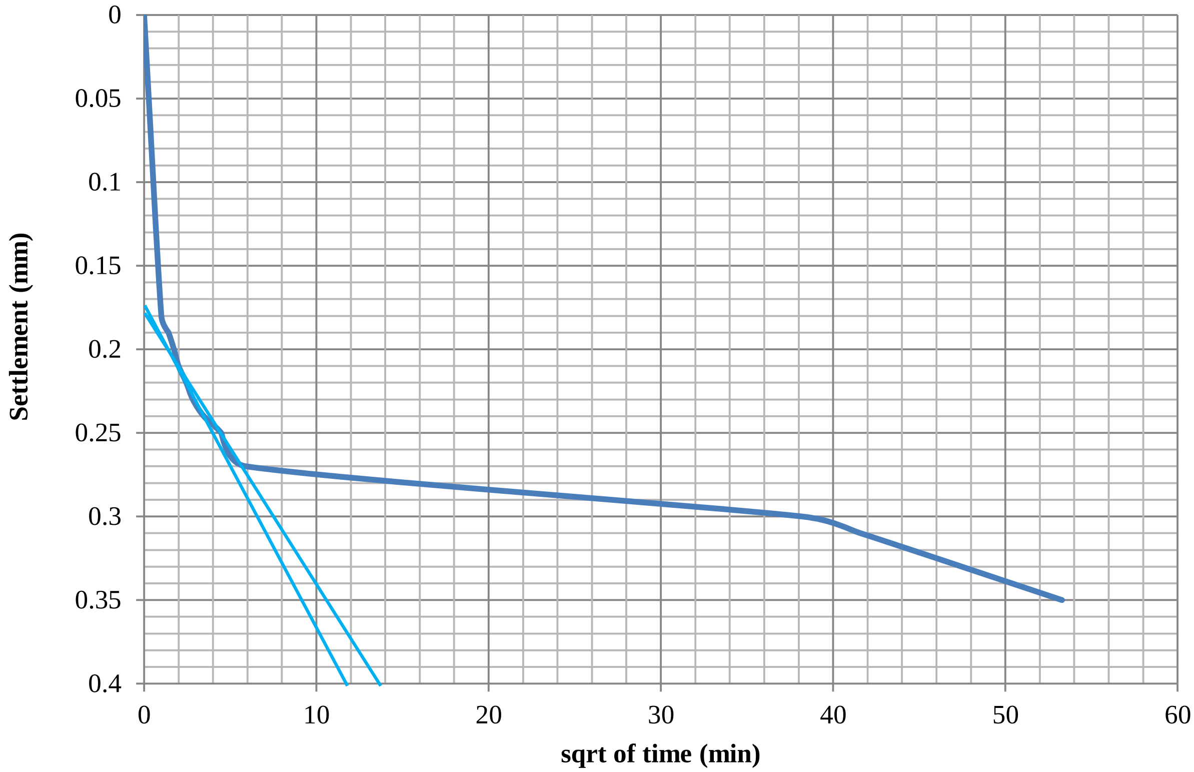

Fig 4.28: Sqrt time/Settlement curve of BCS + 15% CS at 25kN load

CALCULATIONS

From the Fig the value of t_{90} = 190 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.236

OBSERVATIONS

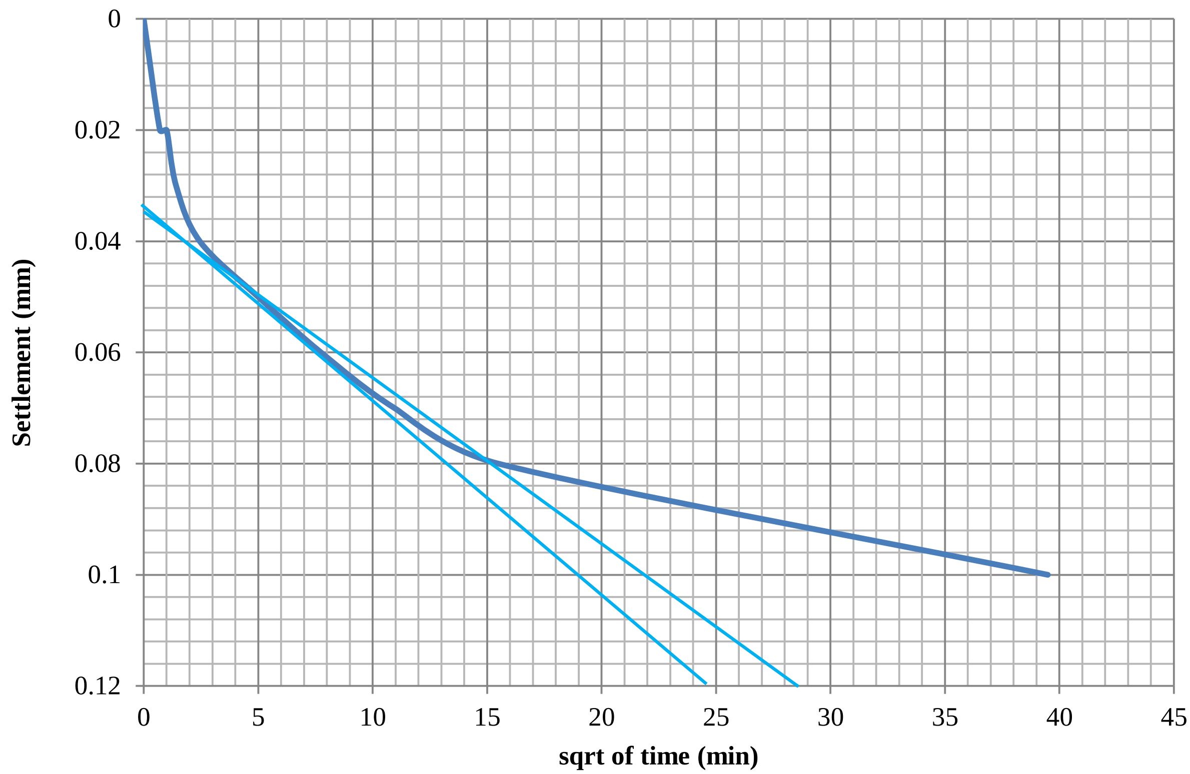

Fig 4.29: Sqrt time/Settlement curve of BCS + 15% CS at 50kN load

CALCULATIONS

From the Fig the value of t_{90} = 794 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.056

OBSERVATIONS

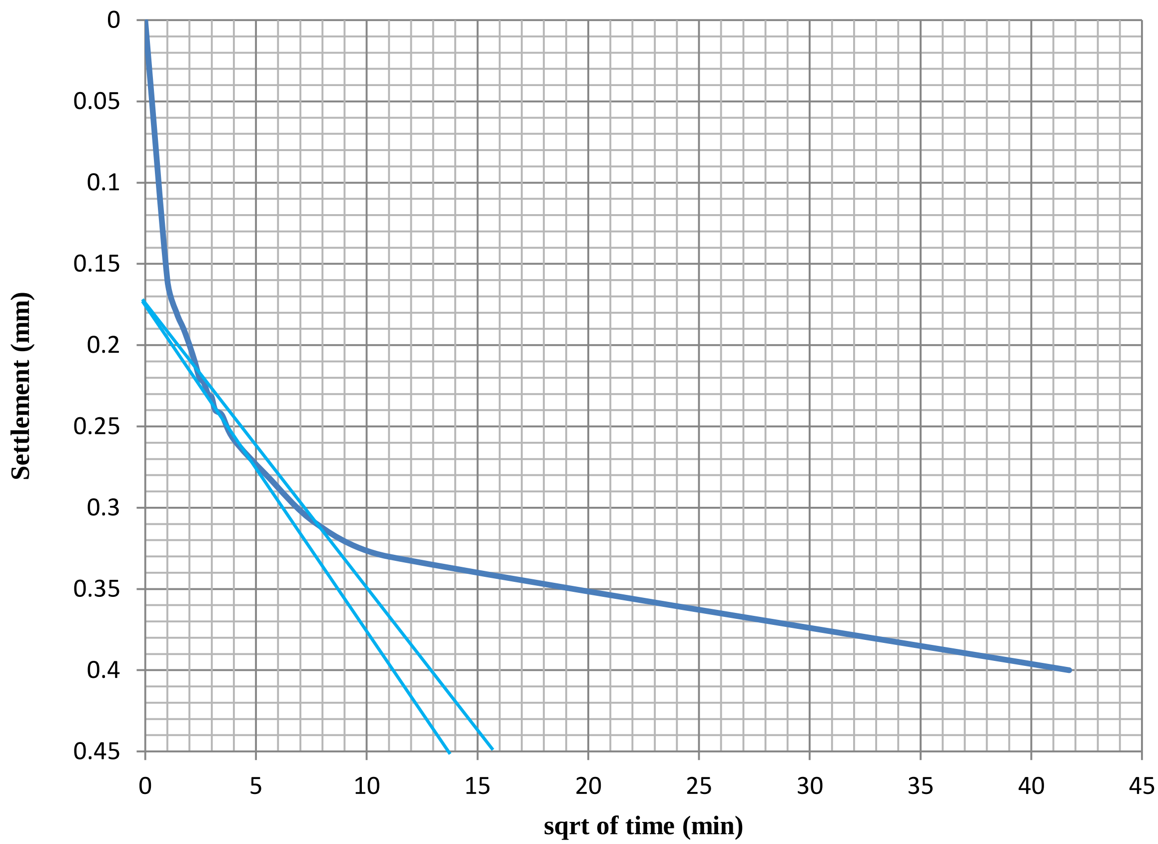

Fig 4.30: Sqrt time/Settlement curve of BCS + 15% CS at 100kN load

CALCULATIONS

From the Fig the value of t_{90} = 260 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.172

OBSERVATIONS

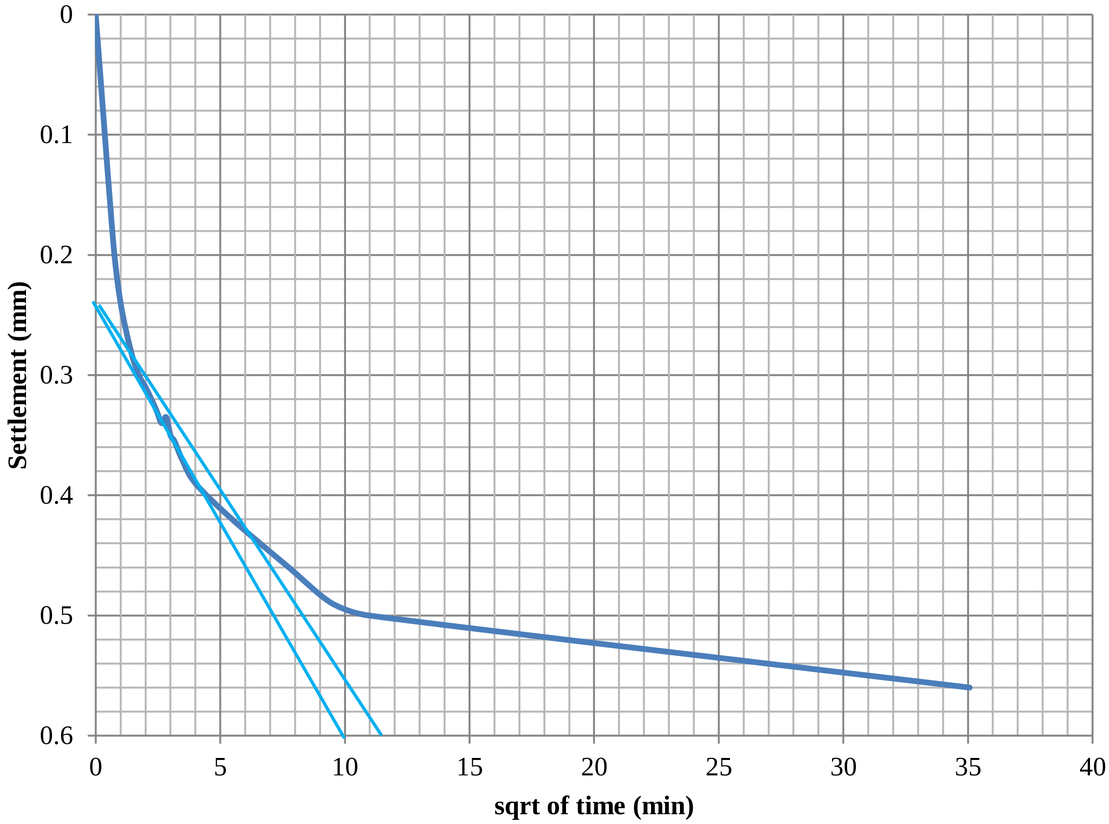

Fig 4.31: Sqrt time/Settlement curve of BCS + 15% CS at 200kN load

CALCULATIONS

From the Fig the value of t_{90} = 132.25 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.338

OBSERVATIONS

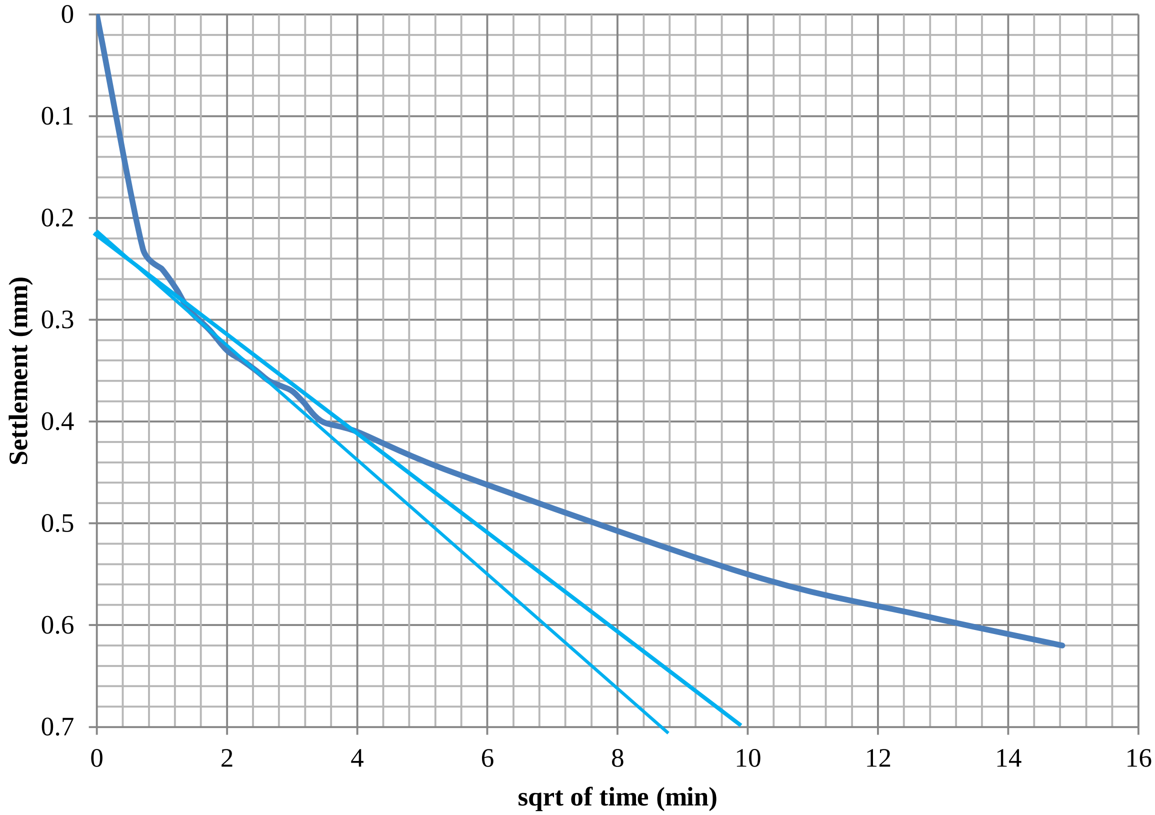

Fig 4.32: Sqrt time/Settlement curve of BCS + 15% CS at 400kN load

CALCULATIONS

From the Fig the value of t_{90} = 102.4 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.437

OBSERVATIONS

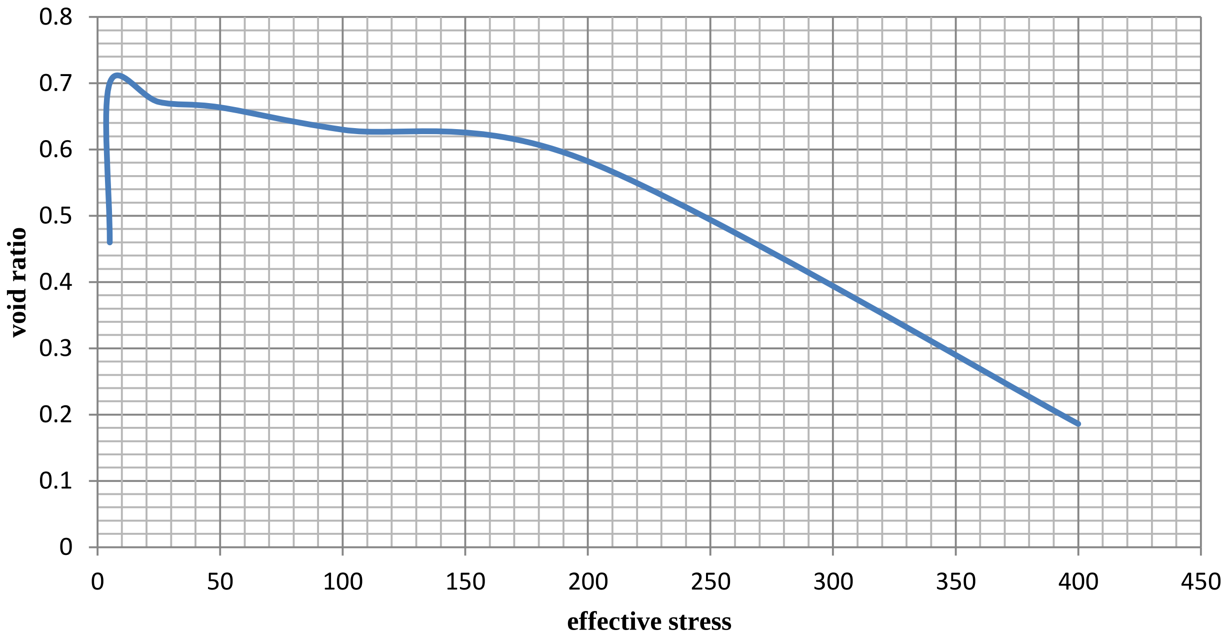

Fig 4.33: Effective stress/Void ratio curve of BCS + 15% CS

CALCULATIONS

The calculation of Coefficient of compressibility (a_v) is done using Eqn. (3.19)

The calculation of Coefficient of volume change (m_v) is done using Eqn. (3.20)

The calculation of Coefficient of permeability (K) is done using Eqn. (3.24)

Table 6: Parameters from oedometer test of BCS + 15% CS

Parameters	**25 kN**	**50 kN**	**100 kN**	**200 kN**	**400 kN**
a_v	0.028	0.027	0.013	0.006	0.0003
m_v	16.48	16.08	7.98	3.86	0.17
K	1.204×10^{-9}	0.28×10^{-9}	0.426×10^{-9}	0.406×10^{-9}	0.023×10^{-9}

OBSERVATIONS

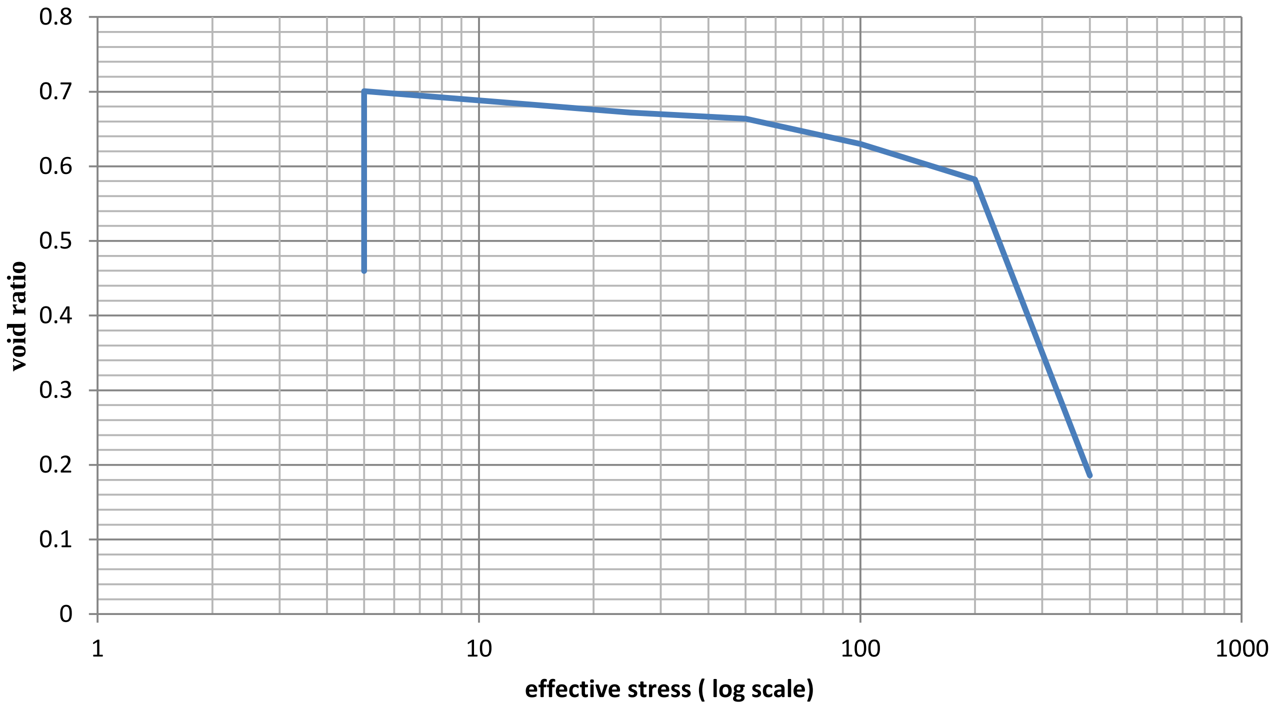

Fig 4.34: log Effective stress/Void ratio curve of BCS + 15% CS

CALCULATIONS

The calculation of Compression index (C_c) is done using Eqn. (3.21)

Compression index (C_c) for BCS + 15% CS = 0.04

The calculation of Settlement (δ) is done using Eqn. (3.23)

Settlement (δ) for BCS + 15% CS = 3.87 mm

4.8.3. BLACK COTTON SOIL+ 15% CS + GEOTEXTILE (at H/2)

OBSERVATIONS

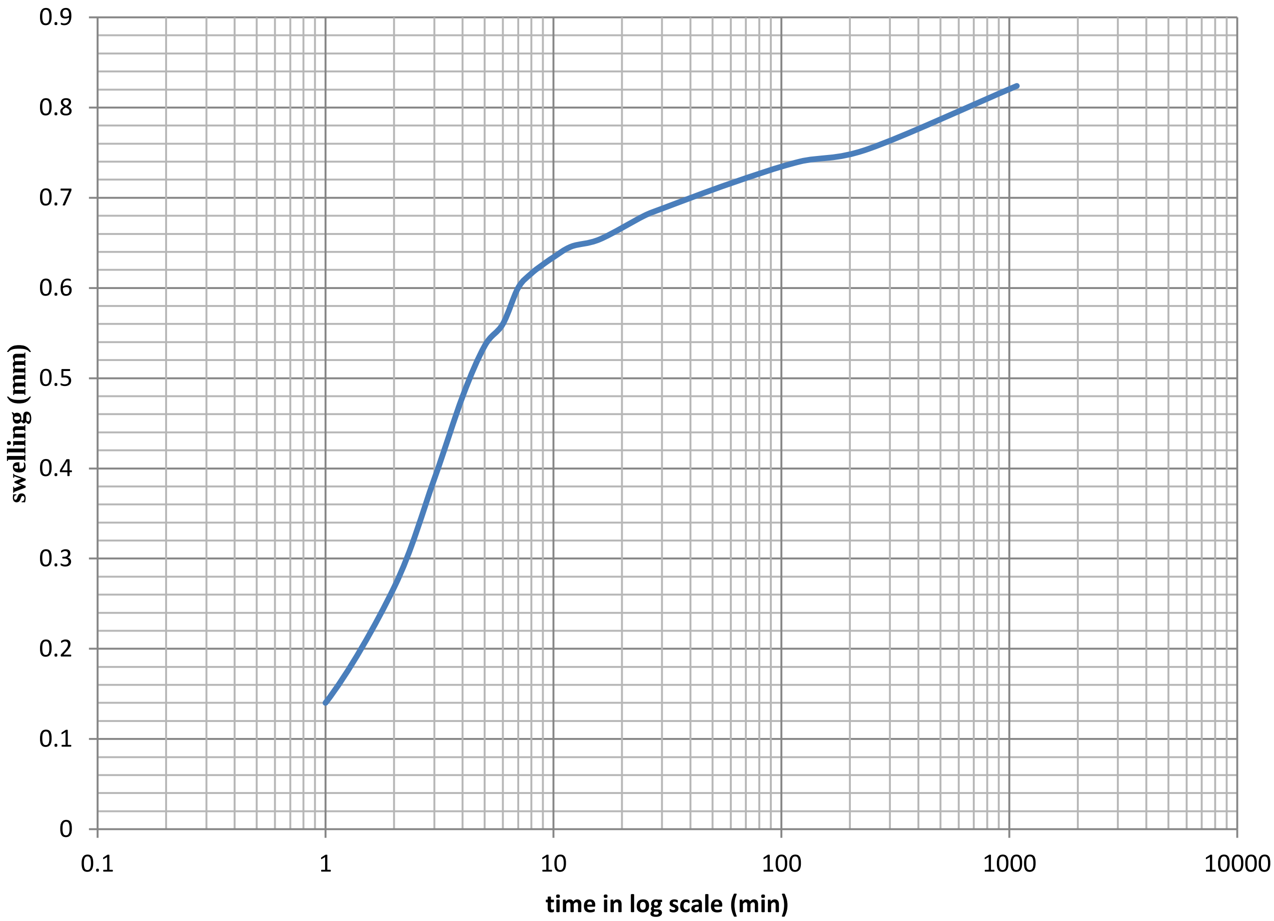

Fig 4.35: Log time/Settlement curve of BCS +15% CS + Geotextile (H/2)

CALCULATIONS

The total swelling of BCS + 15% CS + Geotextile (H/2) obtained = 0.824 mm

OBSERVATIONS

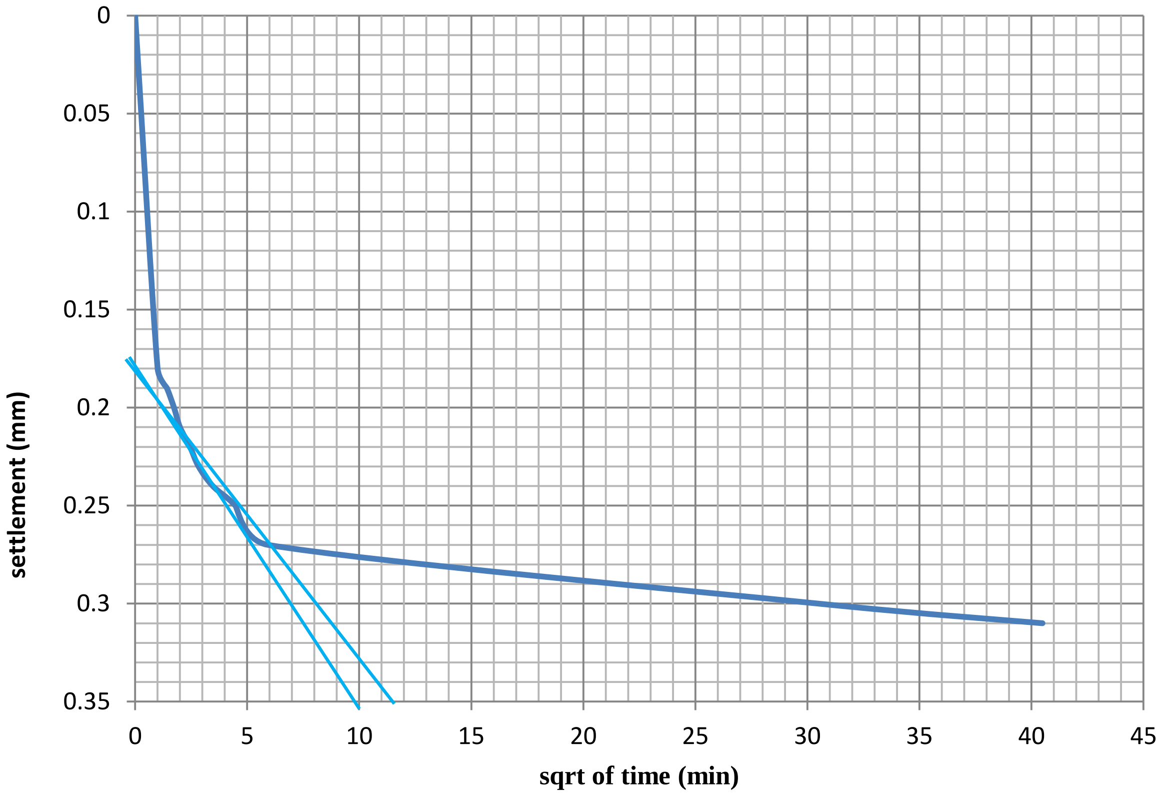

Fig 4.36: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (H/2) at 25kN load

CALCULATIONS

From the Fig the value of t_{90} = 132.5 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.338

OBSERVATIONS

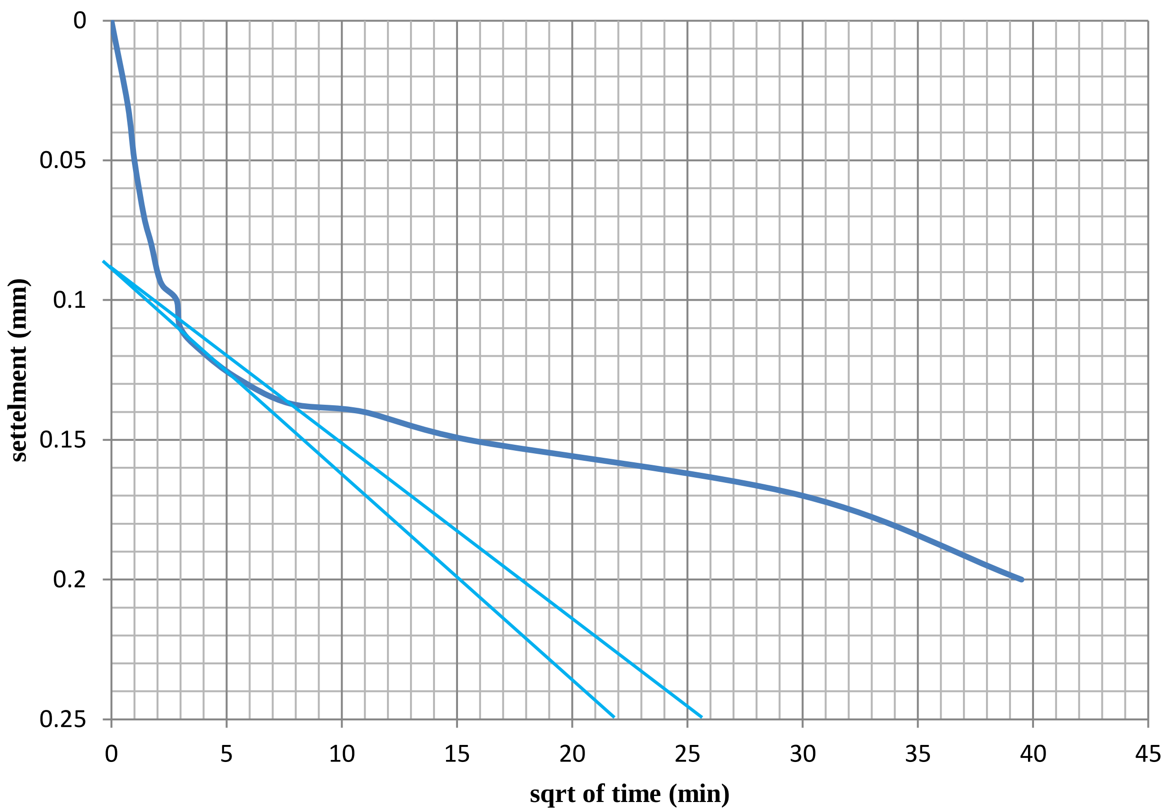

Fig 4.37: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (H/2) at 50kN load

CALCULATIONS

From the Fig the value of t_{90} = 640 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.067

OBSERVATIONS

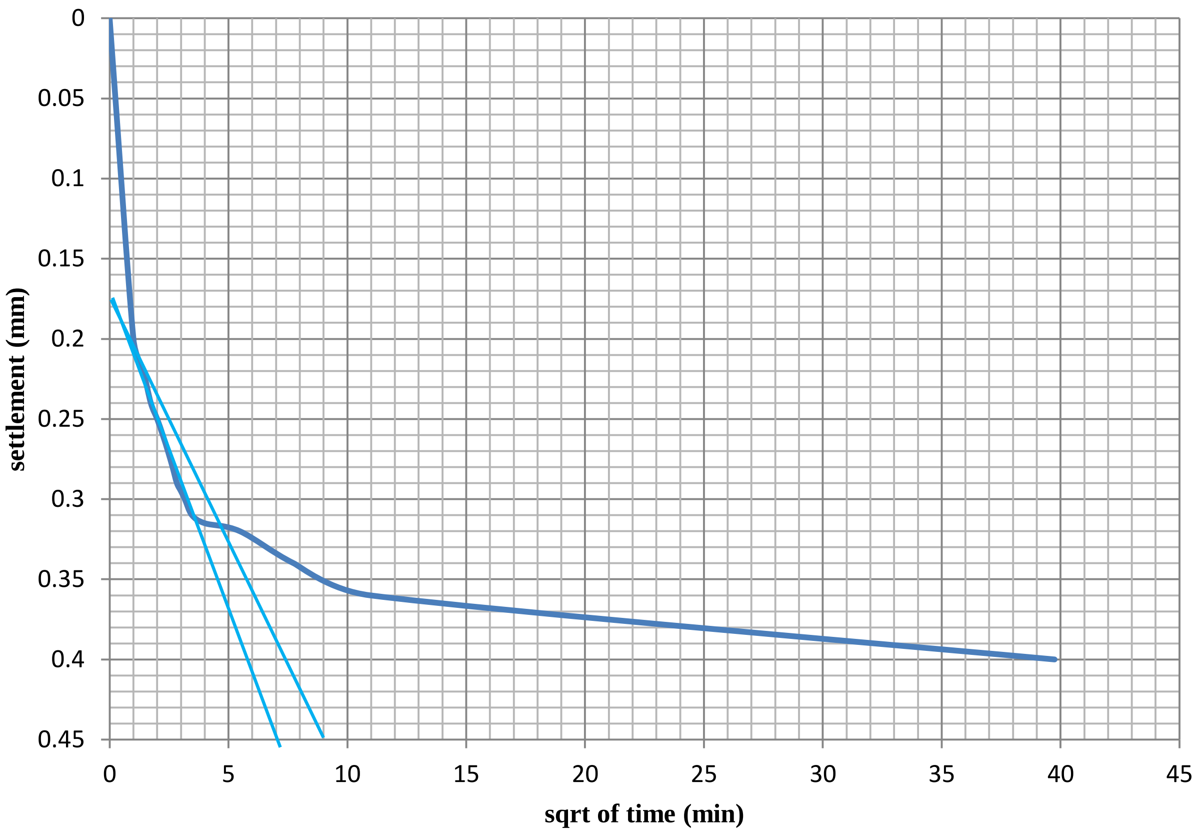

Fig 4.38: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (H/2) at 100kN load

CALCULATIONS

From the Fig the value of t_{90} = 64 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.7

OBSERVATIONS

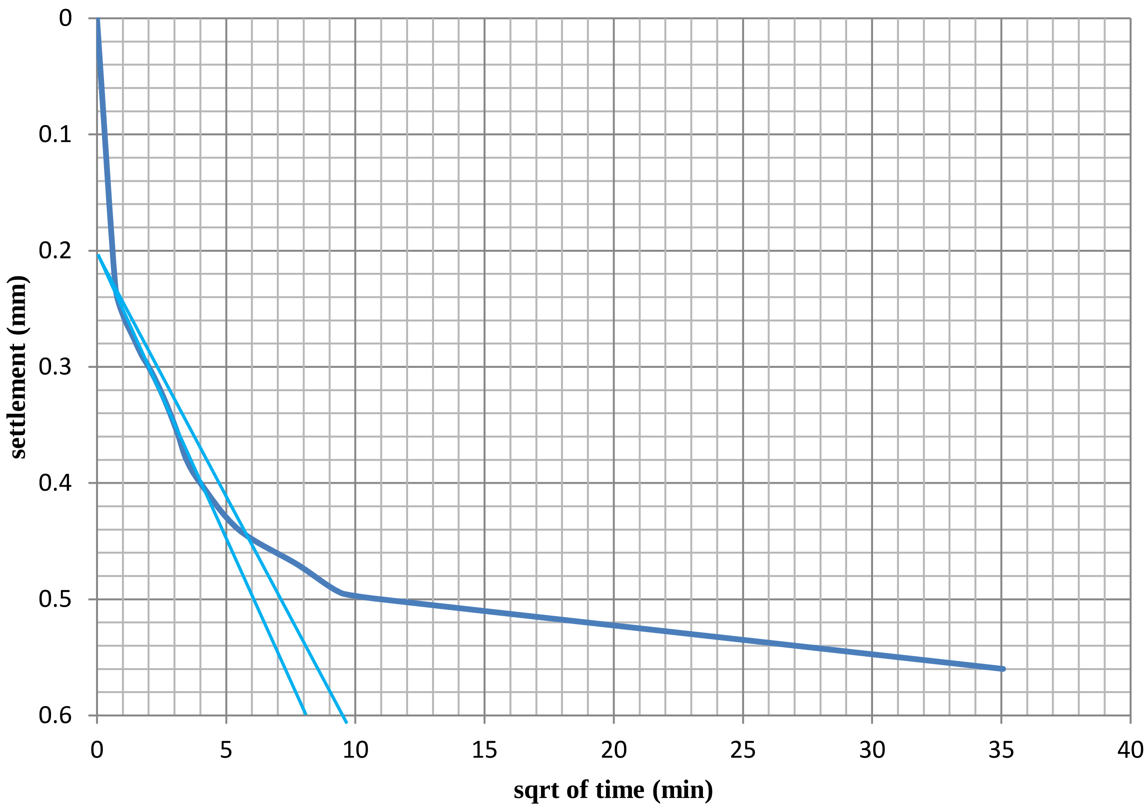

Fig 4.39: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (H/2) at 200kN load

CALCULATIONS

From the Fig the value of t_{90} = 84 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.53

OBSERVATIONS

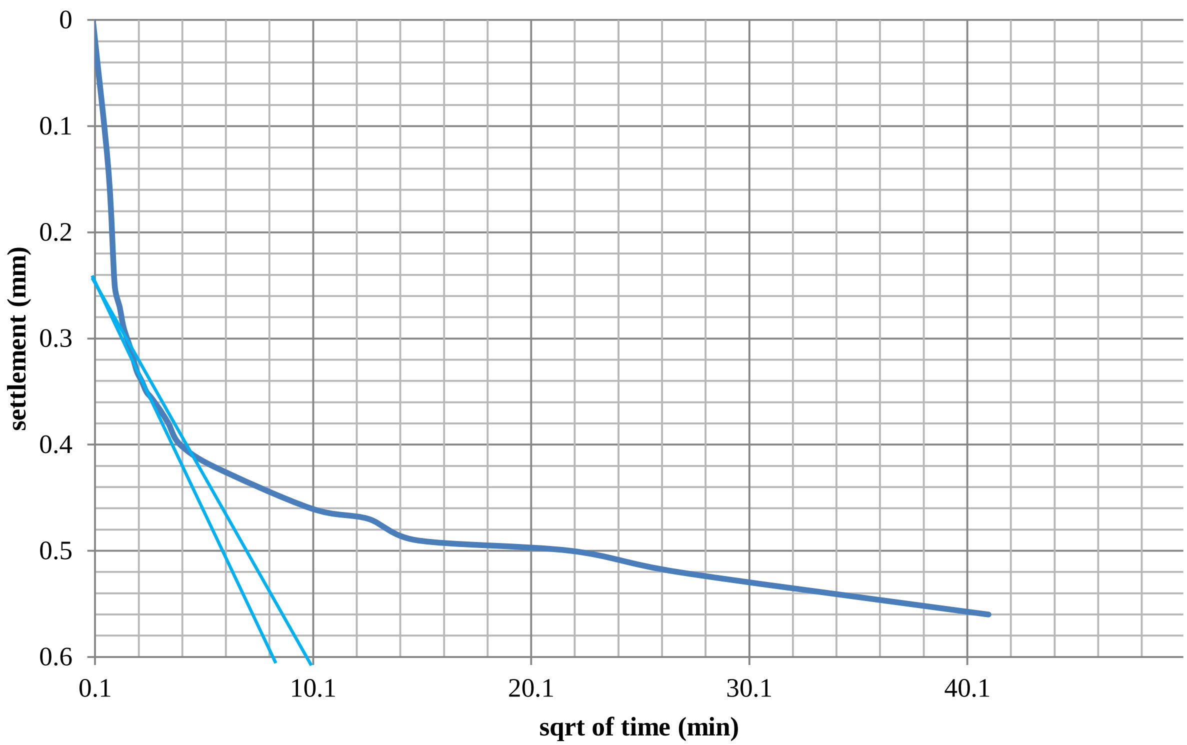

Fig 4.40: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (H/2) at 400kN load

CALCULATIONS

From the Fig the value of t_{90} = 102.4 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.437

OBSERVATIONS

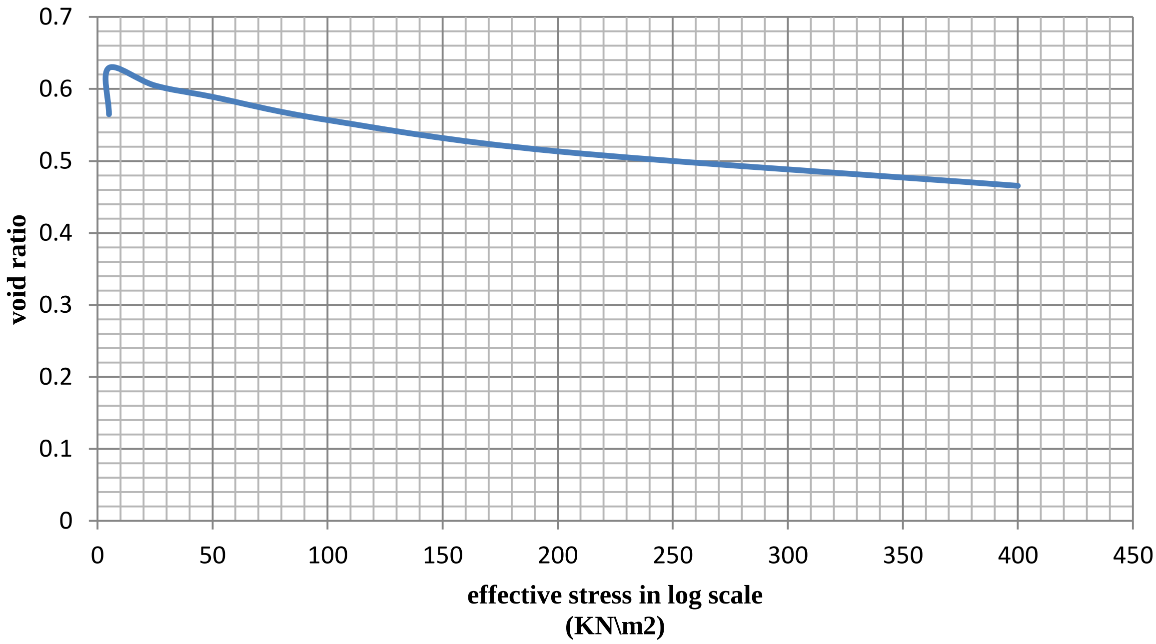

Fig 4.41: Effective stress/Void ratio curve of BCS + 15% CS + Geotextile (H/2)

CALCULATIONS

The calculation of Coefficient of compressibility (a_v) is done using Eqn. (3.19)

The calculation of Coefficient of volume change (m_v) is done using Eqn. (3.20)

The calculation of Coefficient of permeability (K) is done using Eqn. (3.24)

Table 7: Parameters from oedometer test of BCS + 15% CS + Geotextile (H/2)

Parameters	**25 kN**	**50 kN**	**100 kN**	**200 kN**	**400 kN**
a_v	0.025	0.024	0.012	0.0056	0.0002
m_v	15.45	15.07	7.42	3.57	0.133
K	1.62×10^{-9}	0.327×10^{-9}	1.6×10^{-9}	0.587×10^{-9}	0.018×10^{-9}

OBSERVATIONS

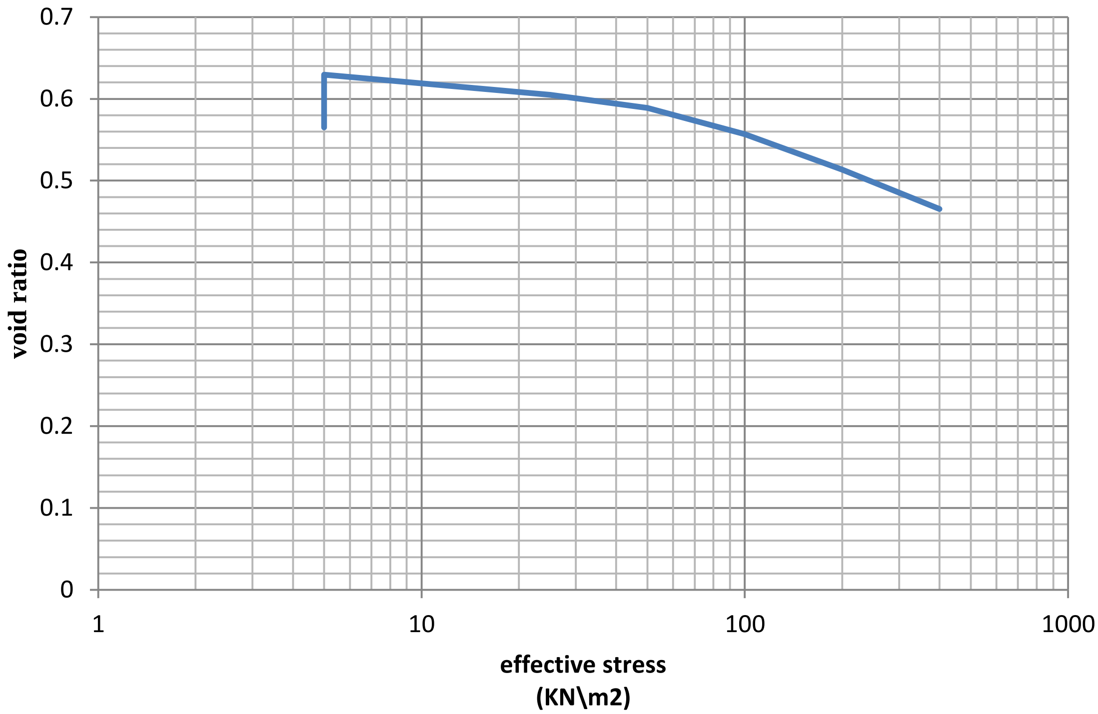

Fig 4.42: log Effective stress/Void ratio curve of BCS + 15% CS + Geotextile (H/2)

CALCULATIONS

The calculation of Compression index (C_c) is done using Eqn. (3.21)

Compression index (C_c) for BCS + 15% CS + Geotextile (H/2) = 0.07

The calculation of Settlement (δ) is done using Eqn. (3.23)

Settlement (δ) for BCS + 15% CS + Geotextile (H/2) = 2.03 mm

4.8.3. BLACK COTTON SOIL+ 15% CS + GEOTEXTILE (at 2H/5)

OBSERVATIONS

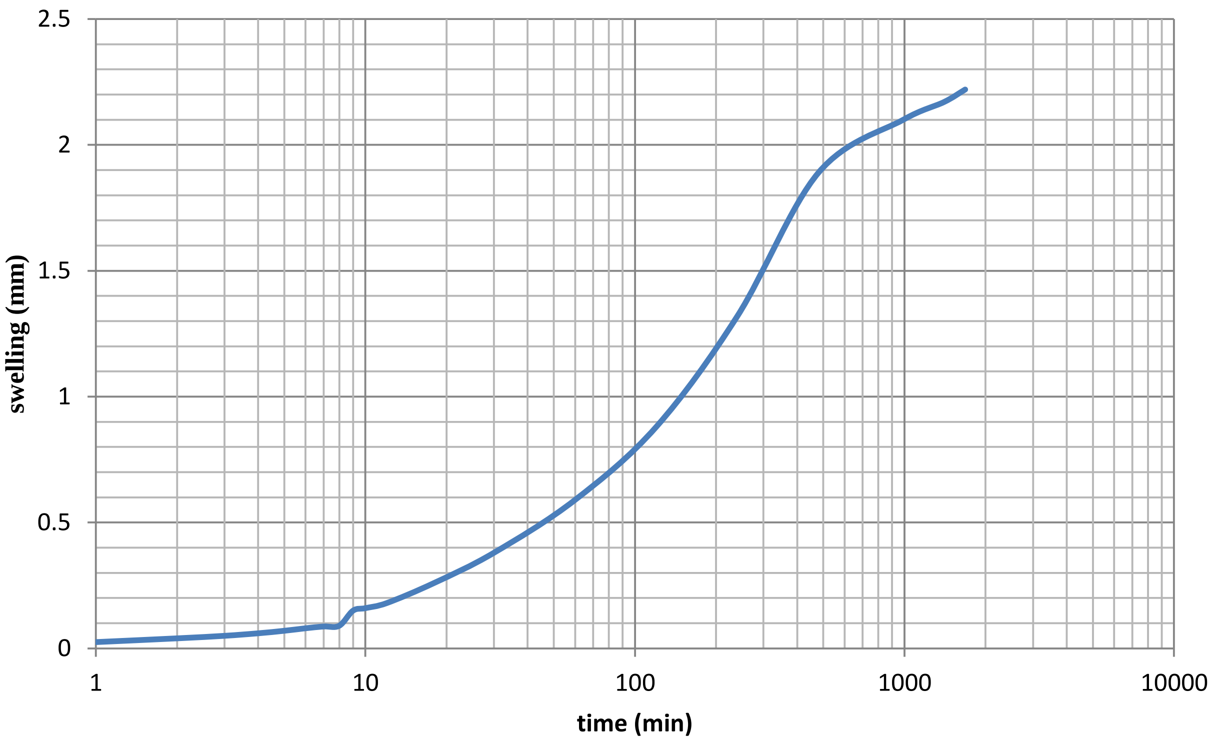

Fig 4.43: Log time/Swelling curve of BCS +15% CS + Geotextile (2H/5)

CALCULATIONS

The total swelling of BCS + 15% CS + Geotextile (2H/5) obtained = 2.22 mm

OBSERVATIONS

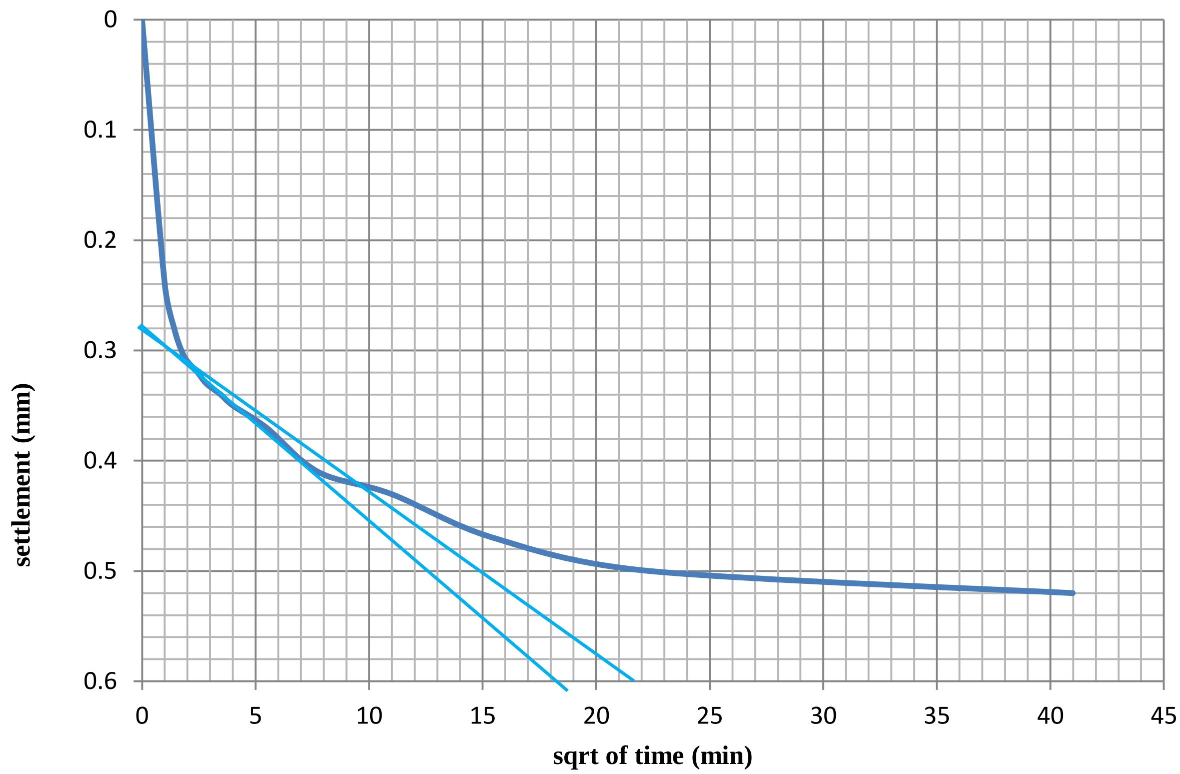

Fig 4.44: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (2H/5) at 25kN load

CALCULATIONS

From the Fig the value of t_{90} = 478 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.094

OBSERVATIONS

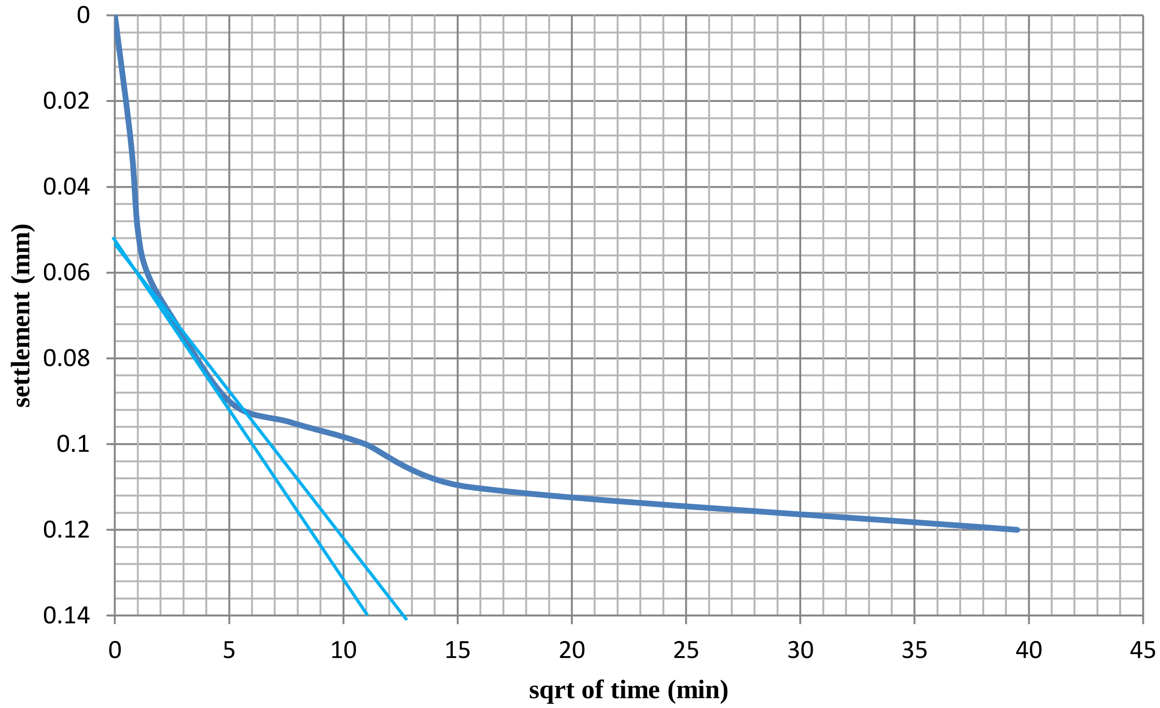

Fig 4.45: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (2H/5) at 50kN load

CALCULATIONS

From the Fig the value of t_{90} = 163 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.27

OBSERVATIONS

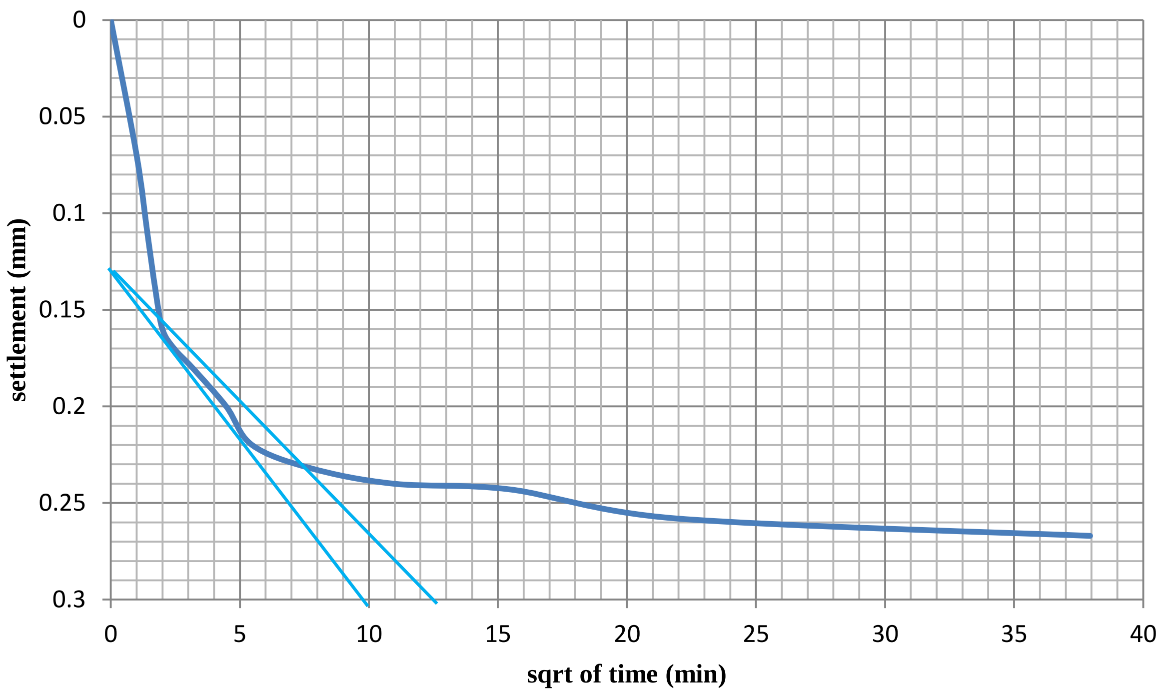

Fig 4.46: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (2H/5) at 100kN load

CALCULATIONS

From the Fig the value of t_{90} = 161 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.28

OBSERVATIONS

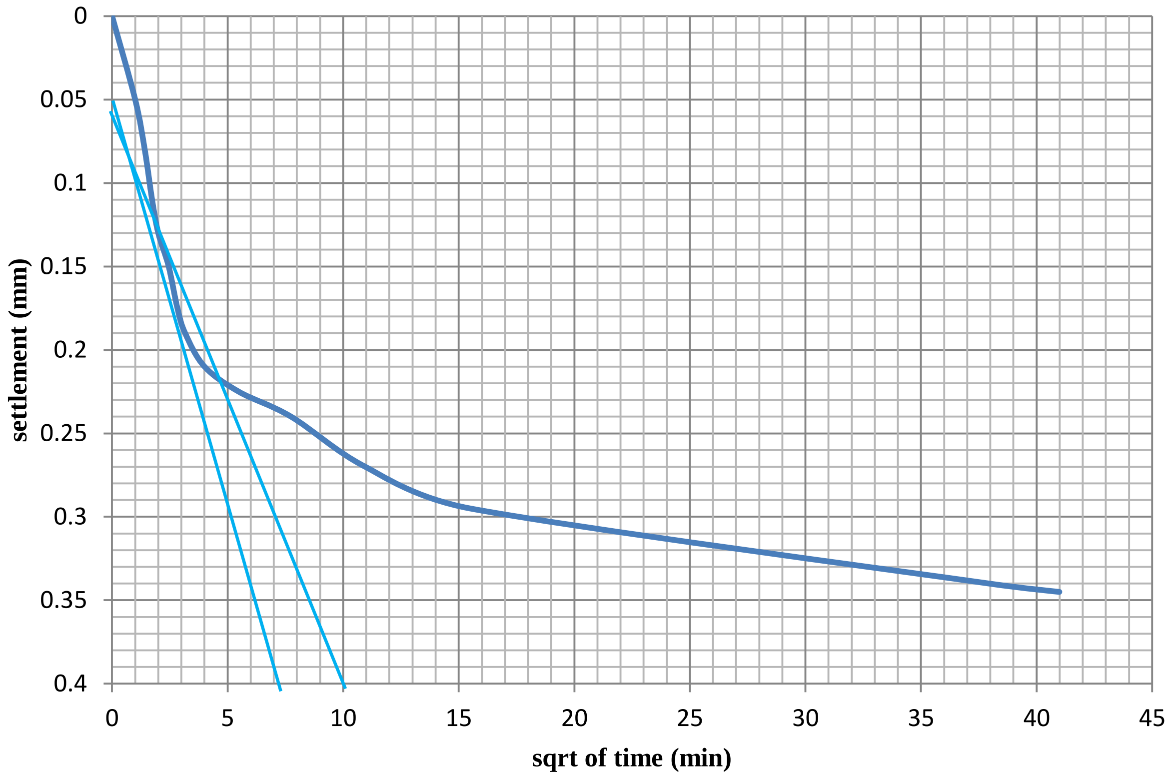

Fig 4.47: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (2H/5) at 200kN load

CALCULATIONS

From the Fig the value of t_{90} = 108 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.41

OBSERVATIONS

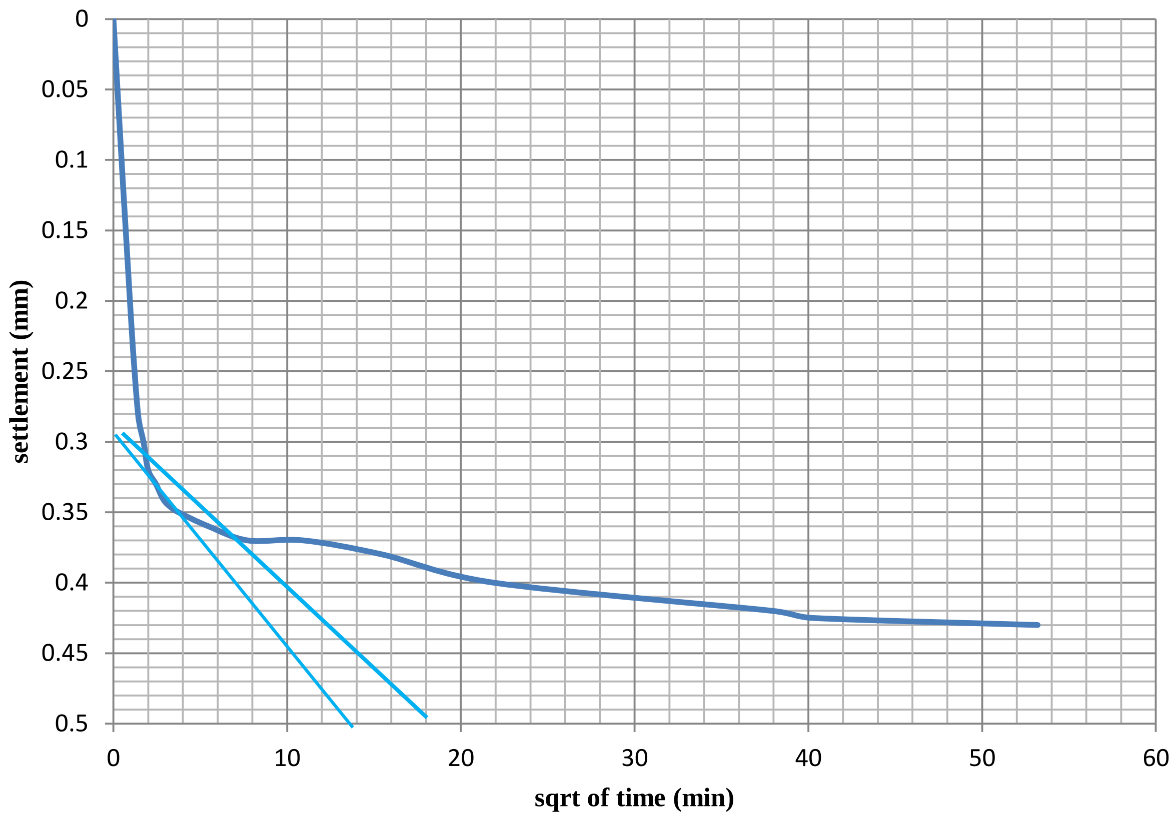

Fig 4.48: Sqrt time/Settlement curve of BCS +15% CS + Geotextile (2H/5) at 400kN load

CALCULATIONS

From the Fig the value of t_{90} = 195 min

The calculation of Coefficient of consolidation is done using Eqn. (3.22)

Coefficient of consolidation = 0.23

OBSERVATIONS

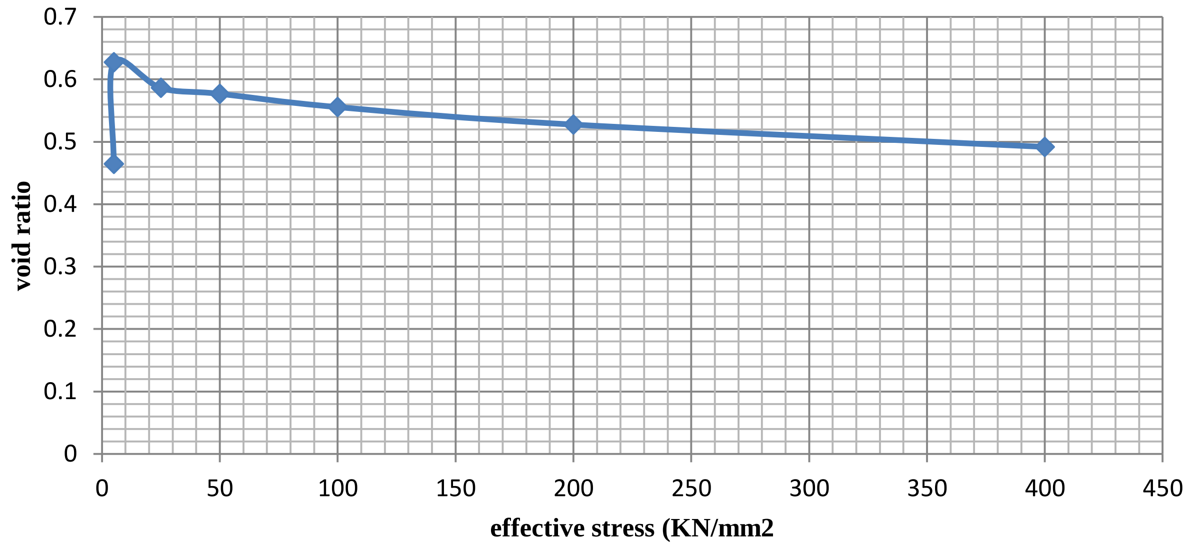

Fig 4.49: Effective stress/Void ratio curve of BCS + 15% CS + Geotextile (2H/5)

CALCULATIONS

The calculation of Coefficient of compressibility (a_v) is done using Eqn. (3.19)

The calculation of Coefficient of volume change (m_v) is done using Eqn. (3.20)

The calculation of Coefficient of permeability (K) is done using Eqn. (3.24)

Table 8: Parameters from oedometer test of BCS + 15% CS + Geotextile (2H/5)

Parameters	**25 kN**	**50 kN**	**100 kN**	**200 kN**	**400 kN**
a_v	0.025	0.023	0.011	0.0056	0.0026
m_v	15.42	14.78	7.31	3.57	1.73
K	0.448×10^{-9}	1.26×10^{-9}	0.63×10^{-9}	0.46×10^{-9}	0.123×10^{-9}

OBSERVATIONS

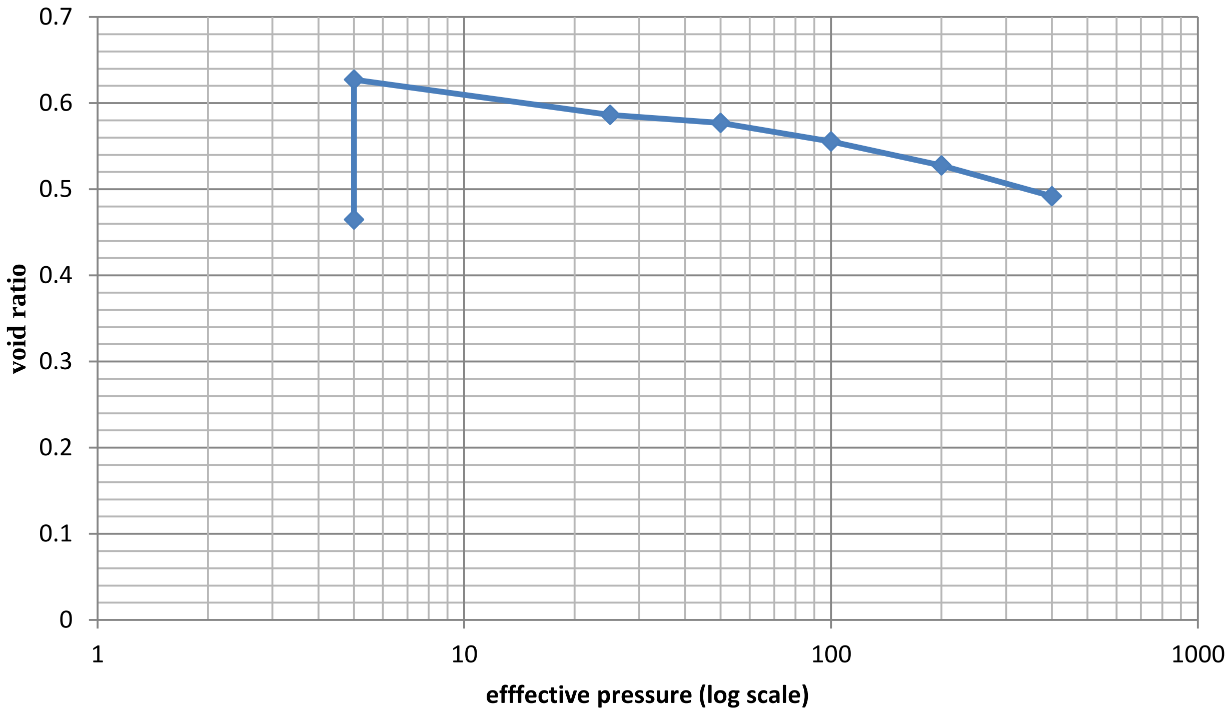

Fig 4.50: log Effective stress/Void ratio curve of BCS + 15% CS + Geotextile (2H/5)

CALCULATIONS

The calculation of Compression index (C_c) is done using Eqn. (3.21)

Compression index (C_c) for BCS + 15% CS + Geotextile (2H/5) = 0.06

The calculation of Settlement (δ) is done using Eqn. (3.23)

Settlement (δ) for BCS + 15% CS + Geotextile (2H/5) = 2.303 mm

CHAPTER 5

CONCLUSION

5.1 GENERAL

This chapter provides an insight to the results obtained from the testing methodologies for the stabilizing and improvement of the geotechnical properties of BCS with CS as a waste material and geotextiles.

5.2 CONCLUSIONS

- The CS has a well graded sandy characterization and is uniform in nature.
- The BCS is classified as organic clay having high plasticity (OH) as per IS standards.
- The BCS consists of organic matter as its specific gravity is 2.28. The specific gravity of the BCS + CS mix increases with increase in the percentage of CS due to the incorporation of heavy copper slag particles.
- The Atterberg's limits show the improvement in the geotechnical property of BCS with increase in CS % (w/w).
- The addition of CS % (w/w) of BCS, the MDD increased by 10 % of original MDD.
- The maximum shear strength of CS mixed BCS was found at **15% addition of CS** and the value of 194.71 kN/m^2. The optimum location for geotextile is at the **height of (H/2)** from the bottom of the compacted soil.

5.3 SCOPE FOR FUTURE WORK

The present work shows that the stabilization of BCS using CS as a waste material is both cost-effective and environment friendly. The addition of CS as a stabilizing agent and geotextile improves almost all the geotechnical properties of BCS, but still some investigation may be done so as to look for the most effective and efficient usage of both the materials in future:

- The methodology adopted for the optimization of CS can be done by replacement of the soil with equal percentage of CS.
- To find out the consolidation properties, the CS can be used in layer.
- Different types of geotextiles can be used and at many more different heights.
- The shear strength value can be found incorporating geotextiles at different heights.

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ANNEXURE A

ANNEXURE 1.1

Table 9: Results of sieve analysis of CS

IS Sieve size (mm)	Weight of empty sieve (g)	Weight of sieve + soil (g)	Weight of soil retained (g)	Cumulative mass of soil retained (g)	Cumulative % of soil retained (%)	Percent finer (%)
4.75	374.60	374.60	0.00	0.00	0.00	100.00
2	401.30	401.80	0.50	0.50	1.00	99.00
1	372.80	385.10	12.30	12.80	25.60	74.40
0.6	360.70	380.40	19.70	32.50	65.00	35.00
0.425	349.40	359.20	9.80	42.30	84.60	15.40
0.212	328.40	334.40	6.00	48.30	96.60	3.40
0.15	355.80	356.50	0.70	49.00	98.00	2.00
0.075	263.20	263.40	0.20	49.20	98.40	1.60
Pan	253.80	254.60	0.80	50.00	100.00	0.00

ANNEXURE 1.2

Table 10: Results of sieve analysis of BCS

IS Sieve Size (mm)	Weight of Sieve (g)	Weight of Sieve + Soil (g)	Weight of Soil Retained (g)	Retained (%)	Cumulative Retained (%)	Percent Finer (%)
4.75	374.60	374.60	0.00	0.00	0.00	100.00
2	401.50	401.90	0.40	0.08	0.08	99.92
1	372.90	375.50	2.60	0.52	0.60	99.40
0.6	361.00	363.50	2.50	0.50	1.10	98.90
0.425	349.40	352.50	3.10	0.62	1.72	98.28
0.212	328.70	338.20	9.50	1.90	3.62	96.38
0.15	353.30	356.60	3.30	0.66	4.28	95.72
0.075	263.30	267.70	4.40	0.88	5.16	94.84

ANNEXURE 1.3

Table 11: Hydrometer analysis of BCS

Size (mm)	Percent Finer (%)
0.048899898	82.35
0.009073037	72.44
0.006516645	71.25
0.004747754	67.69
0.002893516	61.75
0.002188861	54.625
0.001338789	48.69
0.001149033	47.5

ANNEXURE B

ANNEXURE 2.1

Table 12: Specific Gravity of BCS

Weight of density bottle (g)	Weight of density bottle + dry soil (g)	Weight of density bottle + wet soil (g)	Weight of density bottle + water (g)	Specific Gravity
47.30	57.30	107.30	101.50	2.38
47.50	57.20	107.80	102.40	2.26
47.40	57.60	110.30	104.70	2.22

ANNEXURE 2.2

Table 13: Specific Gravity of BCS + 5% CS

Weight of density bottle (g)	Weight of density bottle + dry soil (g)	Weight of density bottle + wet soil (g)	Weight of density bottle + water (g)	Specific gravity
47.20	52.68	104.70	101.60	2.30
47.50	53.50	103.80	100.50	2.22
47.30	52.90	105.40	101.90	2.67

ANNEXURE 2.3

Table 14: Specific Gravity of BCS + 10% CS

Weight of density bottle (g)	Weight of density bottle + dry soil (g)	Weight of density bottle + wet soil (g)	Weight of density bottle + water (g)	Specific gravity
47.30	52.40	105.20	102.00	2.68
47.50	52.60	106.00	102.80	2.68
47.30	52.10	105.60	102.60	2.67

ANNEXURE 2.4

Table 15: Specific Gravity of BCS + 15% CS

Weight of density bottle (g)	Weight of density bottle + dry soil (g)	Weight of density bottle + wet soil (g)	Weight of density bottle + water (g)	Specific gravity
47.50	54.48	107.50	102.80	3.06
47.30	54.70	106.80	101.72	3.19
47.40	52.40	105.60	102.30	2.94

ANNEXURE 2.5

Table 16: Specific Gravity of BCS + 20% CS

Weight of density bottle (g)	Weight of density bottle + dry soil (g)	Weight of density bottle + wet soil (g)	Weight of density bottle + water (g)	Specific gravity
47.30	55.50	108.00	102.20	3.42
47.50	53.80	106.60	102.30	3.15
47.30	55.40	109.50	103.70	3.52

ANNEXURE C

ANNEXURE 3.1

Table 17: Liquid Limit of BCS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Number of blows (n)	Water content (%)
7.90	22.20	17.00	84.00	57.14
8.90	20.90	16.30	38.00	62.16
8.40	31.50	22.20	19.00	67.39

ANNEXURE 3.2

Table 18: Liquid Limit of BCS + 5% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Number of blows (n)	Water content (%)
8.80	18.40	14.70	10.00	62.71
7.50	22.90	17.50	52.00	54.00
7.30	27.60	20.90	140.00	49.26

ANNEXURE 3.3

Table 19: Liquid Limit of BCS + 10% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Number of blows (n)	Water content (%)
8.30	12.60	10.90	11.00	65.38
7.70	11.40	10.10	27.00	54.17
7.80	10.90	9.90	43.00	47.62

ANNEXURE 3.4

Table 20: Liquid Limit of BCS + 15% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Number of blows (n)	Water content (%)
8.30	12.45	10.90	11.00	59.62
7.70	11.35	10.10	27.00	52.08
7.65	9.50	8.90	43.00	48.00

ANNEXURE 3.5

Table 21: Liquid Limit of BCS + 20% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Number of blows (n)	Water content (%)
7.90	13.20	11.40	23.00	51.43
7.80	13.20	11.60	43.00	42.11
7.60	11.40	10.40	67.00	35.71

ANNEXURE 3.6

Table 22: Shrinkage Limit of BCS

Weight of shrinkage dish W1(g)	Weight of shrinkage dish +wet soil W2(g)	Weight of shrinkage dish + dry soil w3(g)	Weight of dry soil Wd = (W3-W1)(g)	Weight of water Wwet = (W2-W3) (g)	Water content (%)	Volume of shrinkage dish = volume of mercury in shrinkage dish (cc)	Weight of mercury displaced (g)	Volume of dry soil = Volume of mercury displaced (cc)	Shrinkage limit
34.30	68.80	54.30	20.00	14.50	72.50	22.04	145.30	10.72	15.88
36.20	69.90	55.50	19.30	14.40	74.61	22.04	141.20	10.41	14.37
31.80	64.50	50.60	18.80	13.90	73.94	22.04	137.40	10.13	10.60

ANNEXURE 3.7

Table 23: Shrinkage Limit of BCS + 5% CS

Weight of shrinkage dish W1(g)	Weight of shrinkage dish +wet soil W2(g)	Weight of shrinkage dish + dry soil w3(g)	Weight of dry soil Wd = (W3-W1)(g)	Weight of water Wwet = (W2-W3) (g)	Water content (%)	Volume of shrinkage dish = volume of mercury in shrinkage dish (cc)	Weight of mercury displaced (g)	Volume of dry soil = Volume of mercury displaced (cc)	Shrinkage limit
34.60	68.70	54.50	19.90	14.20	71.36	22.04	146.30	10.79	14.82
34.30	68.50	54.30	20.00	14.20	71.00	22.04	143.20	10.56	13.60
33.80	66.10	51.60	17.80	14.50	81.46	22.04	140.20	10.34	15.73

ANNEXURE 3.8

Table 24: Shrinkage Limit of BCS + 10% CS

Weight of shrinkage dish W1(g)	Weight of shrinkage dish +wet soil W2(g)	Weight of shrinkage dish + dry soil w3(g)	Weight of dry soil Wd = (W3-W1)(g)	Weight of water Wwet = (W2-W3) (g)	Water content (%)	Volume of shrinkage dish = volume of mercury in shrinkage dish (cc)	Weight of mercury displaced (g)	Volume of dry soil = Volume of mercury displaced (cc)	Shrinkage limit
31.40	69.30	55.50	24.10	13.80	57.26	22.04	161.90	11.94	15.35
31.50	69.50	55.60	24.10	13.90	57.68	22.04	161.70	11.92	15.70
30.70	68.70	54.80	24.10	13.90	57.68	22.04	160.30	11.82	15.28

ANNEXURE 3.9

Table 25: Shrinkage Limit of BCS + 15% CS

Weight of shrinkage dish W1(g)	Weight of shrinkage dish +wet soil W2(g)	Weight of shrinkage dish + dry soil w3(g)	Weight of dry soil Wd = (W3-W1)(g)	Weight of water Wwet = (W2-W3) (g)	Water content (%)	Volume of shrinkage dish = volume of mercury in shrinkage dish (cc)	Weight of mercury displaced (g)	Volume of dry soil = Volume of mercury displaced (cc)	Shrinkage limit
31.70	69.30	55.50	23.80	13.80	57.98	22.04	161.90	11.94	15.54
34.20	69.50	55.60	21.40	13.90	64.95	22.04	161.70	11.92	17.69
34.30	68.70	54.80	20.50	13.90	67.80	22.04	160.30	11.82	17.96

ANNEXURE 3.10

Table 26: Shrinkage Limit of BCS + 20% CS

Weight of shrinkage dish W1(g)	Weight of shrinkage dish +wet soil W2(g)	Weight of shrinkage dish + dry soil w3(g)	Weight of dry soil Wd = (W3-W1)(g)	Weight of water in wet soil Wwet = (W2-W3) (g)	Water content (%)	Volume of shrinkage dish = volume of mercury in shrinkage dish (cc)	Weight of mercury displaced (g)	Volume of dry soil = Volume of mercury displaced (cc)	Shrinkage limit
31.70	67.50	53.70	22.00	13.80	62.73	22.04	151.30	11.16	13.26
34.20	72.40	57.80	23.60	14.60	61.86	22.04	161.50	11.91	18.94
34.30	73.60	58.10	23.80	15.50	65.13	22.04	164.20	12.11	23.40

ANNEXURE 3.11

Table 27: Plastic Limit of BCS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Weight of water (g)	Weight of dry soil (g)	Moisture Content (%)
20.30	22.60	22.10	0.50	1.80	27.78
19.30	20.40	20.10	0.30	0.80	37.50
19.30	21.10	20.60	0.50	1.30	38.46

ANNEXURE 3.12

Table 28: Plastic Limit of BCS + 5% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Weight of water (g)	Weight of dry soil (g)	Moisture Content (%)
20.30	22.90	22.30	0.60	2.00	30.00
19.30	25.50	24.10	1.40	4.80	29.17
19.30	24.70	23.60	1.10	4.30	25.58

ANNEXURE 3.13

Table 29: Plastic Limit of BCS + 10% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Weight of water (g)	Weight of dry soil (g)	Moisture Content (%)
19.90	23.40	22.70	0.70	2.80	25.00
18.90	21.70	21.20	0.50	2.30	21.74
18.70	22.10	21.30	0.80	2.60	30.77

ANNEXURE 3.14

Table 30: Plastic Limit of BCS + 15% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Weight of water (g)	Weight of dry soil (g)	Moisture Content (%)
20.10	27.40	25.80	1.60	5.70	28.07
19.90	26.50	25.40	1.10	5.50	20.00
20.50	29.30	27.80	1.50	7.30	20.55

ANNEXURE 3.15

Table 31: Plastic Limit of BCS + 20% CS

Weight of empty container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)	Weight of water (g)	Weight of dry soil (g)	Moisture Content (%)
8.70	15.20	14.10	1.10	5.40	20.37
8.00	11.50	10.80	0.70	2.80	25.00
7.60	9.90	9.60	0.30	2.00	15.00

ANNEXURE 3.16

Table 32: Free swell index of BCS

Observations	Time (hrs)	Volume of soil In kerosene (V_1) (cc)	Volume of soil In distilled water (V_2) (cc)
1	0	11	15
2	12	11	17
3	24	11	18

ANNEXURE D

ANNEXURE 4.1

Table 33: Standard Compaction of BCS

Weight of mould + base plate W1(g)	Weight of mould + base plate + compacted soil W2(g)	Weight of compacted soil =(W2-W1) (g)	Bulk density =W/v (g/cc)	Moisture content (%)	Dry density (g/cc)
3675.90	5190.50	1514.60	1.52	11.00	1.37
3675.90	5232.80	1556.90	1.56	14.00	1.37
3675.90	5309.80	1633.90	1.64	17.00	1.40
3675.90	5362.00	1686.10	1.69	20.00	1.41
3675.90	5454.50	1778.60	1.78	23.00	1.45
3675.90	5540.40	1864.50	1.87	26.00	1.48
3675.90	5590.60	1914.70	1.92	30.00	1.47
3675.90	5545.70	1869.80	1.87	33.00	1.41

ANNEXURE 4.2

Table 34: Standard Compaction of BCS + 5% CS

Weight of mould + base plate W1(g)	Weight of mould + base plate + compacted soil W2(g)	Weight of compacted soil =(W2-W1) (g)	Bulk density =W/v (g/cc)	Moisture content (%)	Dry density (g/cc)
3675.90	5232.80	1556.90	1.56	12.00	1.39
3675.90	5309.80	1633.90	1.64	15.00	1.42
3675.90	5368.80	1692.90	1.69	18.00	1.44
3675.90	5454.50	1778.60	1.78	21.00	1.47
3675.90	5585.90	1910.00	1.91	25.00	1.53
3675.90	5590.60	1914.70	1.92	28.00	1.50
3675.90	5545.70	1869.80	1.87	32.00	1.42

ANNEXURE 4.3

Table 35: Standard Compaction of BCS + 10% CS

Weight of mould + base plate W1(g)	Weight of mould + base plate + compacted soil W2(g)	Weight of compacted soil =(W2-W1) (g)	Bulk density =W/v (g/cc)	Water content (%)	Dry density (g/cc)
3660.30	5273.80	1613.50	1.70	10.00	1.55
3660.30	5334.70	1674.40	1.77	13.00	1.56
3660.30	5388.80	1728.50	1.82	15.00	1.59
3660.30	5427.30	1767.00	1.87	17.00	1.59
3660.30	5501.20	1840.90	1.94	20.00	1.62
3660.30	5573.40	1913.10	2.02	23.00	1.64
3660.30	5615.70	1955.40	2.06	26.00	1.64
3660.30	5566.80	1906.50	2.01	29.00	1.56

ANNEXURE 4.4

Table 36: Standard Compaction of BCS + 15% CS

Weight of mould + base plate W1(g)	Weight of mould + base plate + compacted soil W2(g)	Weight of compacted soil =(W2-W1) (g)	Bulk density =W/v (g/cc)	Water content (%)	Dry density (g/cc)
3660.60	5285.60	1625.00	1.63	8.00	1.51
3660.60	5348.70	1688.10	1.69	11.00	1.52
3660.60	5432.00	1771.40	1.77	14.00	1.55
3660.60	5510.00	1849.40	1.85	17.00	1.58
3660.60	5644.20	1983.60	1.98	20.00	1.65
3660.60	5699.70	2039.10	2.04	23.00	1.66
3660.60	5657.90	1997.30	2.00	26.00	1.59
3660.60	5621.70	1961.10	1.96	29.00	1.52

ANNEXURE 4.5

Table 37: Standard Compaction of BCS + 20% CS

Weight of mould + base plate W1(g)	**Weight of mould + base plate + compacted soil W2(g)**	**Weight of compacted soil =(W2-W1) (g)**	**Bulk density =W/v (g/cc)**	**Water content (%)**	**Dry density (g/cc)**
3660.60	5236.70	1576.10	1.58	8.00	1.46
3660.60	5316.80	1656.20	1.66	11.00	1.49
3660.60	5412.60	1752.00	1.75	14.00	1.54
3660.60	5497.10	1836.50	1.84	17.00	1.57
3660.60	5561.90	1901.30	1.90	20.00	1.59
3660.60	5572.80	1912.20	1.91	23.00	1.56
3660.60	5547.80	1887.20	1.89	26.00	1.50
3660.60	5529.30	1868.70	1.87	29.00	1.45

ANNEXURE E

ANNEXURE 5.1

Table 38: Unconfined Compression test of BCS

Elapsed time (minutes)	Change in length (cm)	Strain (%)	Corrected Area (cm^2)	Load (KN)	Compressive Stress (KN/m^2)
0.50	0.06	0.01	11.42	0.07	61.27
1.00	0.13	0.02	11.52	0.08	69.47
1.50	0.19	0.02	11.61	0.09	77.54
2.00	0.25	0.03	11.70	0.11	94.01
2.50	0.31	0.04	11.80	0.12	101.73
3.00	0.38	0.05	11.89	0.15	126.13
3.50	0.44	0.05	11.99	0.17	141.77
4.00	0.50	0.06	12.09	0.19	157.14
4.50	0.56	0.07	12.19	0.20	164.03
5.00	0.63	0.08	12.30	0.22	178.92
5.50	0.69	0.09	12.40	0.22	177.40
6.00	0.75	0.09	12.51	0.22	175.89
6.50	0.81	0.10	12.62	0.22	174.37
7.00	0.88	0.11	12.73	0.22	172.85
7.50	0.94	0.12	12.84	0.20	155.76
8.00	1.00	0.13	12.95	0.19	146.66

ANNEXURE 5.2

Table 39: Unconfined Compression test of BCS + 5% CS

Elapsed time (minutes)	Change in length (cm)	Strain (%)	Corrected Area (cm^2)	Load (KN)	Compressive Stress (KN/m^2)
0.50	0.06	0.01	11.42	0.04	35.01
1.00	0.13	0.02	11.52	0.09	78.16
1.50	0.19	0.02	11.61	0.13	112.00
2.00	0.25	0.03	11.70	0.15	128.19
2.50	0.31	0.04	11.80	0.18	152.59
3.00	0.38	0.05	11.89	0.20	168.17
3.50	0.44	0.05	11.99	0.21	175.13
4.00	0.50	0.06	12.09	0.23	190.22
4.50	0.56	0.07	12.19	0.24	196.84
5.00	0.63	0.08	12.30	0.27	219.58
5.50	0.69	0.09	12.40	0.29	233.85
6.00	0.75	0.09	12.51	0.30	239.85
6.50	0.81	0.10	12.62	0.31	245.70
7.00	0.88	0.11	12.73	0.32	251.42
7.50	0.94	0.12	12.84	0.33	257.01
8.00	1.00	0.13	12.95	0.34	262.45
8.50	1.06	0.13	13.07	0.34	260.11
9.00	1.13	0.14	13.19	0.34	257.77
9.50	1.19	0.15	13.31	0.33	247.91

ANNEXURE 5.3

Table 40: Unconfined Compression test of BCS + 10% CS

Elapsed time (minutes)	Change in length (cm)	Strain (%)	Corrected Area (cm^2)	Load (KN)	Compressive Stress (KN/m^2)
0.50	0.06	0.01	11.42	0.04	35.01
1.00	0.13	0.02	11.52	0.07	60.79
1.50	0.19	0.02	11.61	0.11	94.77
2.00	0.25	0.03	11.70	0.13	111.10
2.50	0.31	0.04	11.80	0.15	127.16
3.00	0.38	0.05	11.89	0.19	159.76
3.50	0.44	0.05	11.99	0.23	191.81
4.00	0.50	0.06	12.09	0.25	206.76
4.50	0.56	0.07	12.19	0.27	221.44
5.00	0.63	0.08	12.30	0.30	243.98
5.50	0.69	0.09	12.40	0.33	266.10
6.00	0.75	0.09	12.51	0.34	271.83
6.50	0.81	0.10	12.62	0.37	293.26
7.00	0.88	0.11	12.73	0.38	298.57
7.50	0.94	0.12	12.84	0.40	311.52
8.00	1.00	0.13	12.95	0.43	331.92
8.50	1.06	0.13	13.07	0.44	336.61
9.00	1.13	0.14	13.19	0.45	341.16
9.50	1.19	0.15	13.31	0.45	338.06
10.00	1.25	0.16	13.43	0.45	334.96

ANNEXURE 5.4

Table 41: Unconfined Compression test of BCS + 15% CS

Elapsed time (minutes)	Change in length (cm)	Strain (%)	Corrected Area (cm^2)	Load (KN)	Compressive Stress (KN/m^2)
0.50	0.06	0.01	11.42	0.05	43.76
1.00	0.13	0.02	11.52	0.11	95.52
1.50	0.19	0.02	11.61	0.16	137.84
2.00	0.25	0.03	11.70	0.19	162.38
2.50	0.31	0.04	11.80	0.22	186.50
3.00	0.38	0.05	11.89	0.23	193.39
3.50	0.44	0.05	11.99	0.27	225.17
4.00	0.50	0.06	12.09	0.27	223.30
4.50	0.56	0.07	12.19	0.30	246.05
5.00	0.63	0.08	12.30	0.31	252.11
5.50	0.69	0.09	12.40	0.35	282.23
6.00	0.75	0.09	12.51	0.40	319.79
6.50	0.81	0.10	12.62	0.45	356.67
7.00	0.88	0.11	12.73	0.47	369.28
7.50	0.94	0.12	12.84	0.50	389.41
8.00	1.00	0.13	12.95	0.50	385.96
8.50	1.06	0.13	13.07	0.50	382.51
9.00	1.13	0.14	13.19	0.50	379.07
9.50	1.19	0.15	13.31	0.50	375.62

ANNEXURE 5.5

Table 42: Unconfined Compression test of BCS + 20% CS

Elapsed time (minutes)	Change in length (cm)	Strain (%)	Corrected Area (cm^2)	Load (KN)	Compressive Stress (KN/m^2)
0.50	0.06	0.01	11.42	0.05	43.76
1.00	0.13	0.02	11.52	0.12	104.21
1.50	0.19	0.02	11.61	0.18	155.07
2.00	0.25	0.03	11.70	0.22	188.02
2.50	0.31	0.04	11.80	0.25	211.93
3.00	0.38	0.05	11.89	0.28	235.44
3.50	0.44	0.05	11.99	0.29	241.84
4.00	0.50	0.06	12.09	0.32	264.66
4.50	0.56	0.07	12.19	0.35	287.06
5.00	0.63	0.08	12.30	0.36	292.78
5.50	0.69	0.09	12.40	0.37	298.36
6.00	0.75	0.09	12.51	0.38	303.80
6.50	0.81	0.10	12.62	0.39	309.11
7.00	0.88	0.11	12.73	0.40	314.28
7.50	0.94	0.12	12.84	0.40	311.52
8.00	1.00	0.13	12.95	0.41	316.49
8.50	1.06	0.13	13.07	0.41	313.66
9.00	1.13	0.14	13.19	0.39	295.67

ANNEXURE F

ANNEXURE 6.1

Table 43: Swelling observation of BCS

Time	sq. root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	swelling (mm)
0	0	0	0	20	20	1.0019	0	1.0019	0
2	1.41421	0.002	0.002	20	20.002	1.0019	0.0002	1.0021	0.002
3	1.73205	0.003	0.001	20.002	20.003	1.0021	0.0001	1.0022	0.003
4	2	0.004	0.001	20.003	20.004	1.0022	0.0001	1.0023	0.004
10	3.16228	0.03	0.026	20.004	20.03	1.0023	0.0026	1.0049	0.03
17	4.12311	0.14	0.11	20.03	20.14	1.0049	0.01101	1.01591	0.14
32	5.65685	0.23	0.09	20.14	20.23	1.01591	0.00901	1.02492	0.23
60	7.74597	0.658	0.428	20.23	20.658	1.02492	0.04284	1.06776	0.658
120	10.9545	0.905	0.247	20.658	20.905	1.06776	0.02472	1.09249	0.905
1000	31.6228	1.285	0.38	20.905	21.285	1.09249	0.03804	1.13052	1.285
1380	37.1484	1.317	0.032	21.285	21.317	1.13052	0.0032	1.13373	1.317
3183	56.4181	1.373	0.056	21.317	21.373	1.13373	0.00561	1.13933	1.373
4885	69.8928	1.423	0.05	21.373	21.423	1.13933	0.005	1.14434	1.423
4889	69.9214	1.429	0.006	21.423	21.429	1.14434	0.0006	1.14494	1.429
4891	69.9357	1.427	-0.002	21.429	21.427	1.14494	-0.0002	1.14474	1.427
4892	69.9428	1.426	-0.001	21.427	21.426	1.14474	-0.0001	1.14464	1.426
4900	70	0.425	-1.001	21.426	20.425	1.14464	-0.1002	1.04444	0.425
4922	70.157	0.421	-0.004	20.425	20.421	1.04444	-0.0004	1.04404	0.421
5100	71.4143	0.419	-0.002	20.421	20.419	1.04404	-0.0002	1.04384	0.419
5160	71.8331	0.417	-0.002	20.419	20.417	1.04384	-0.0002	1.04364	0.417
6255	79.0886	0.613	0.196	20.417	20.613	1.04364	0.01962	1.06326	0.613
7740	87.9773	0.619	0.006	20.613	20.619	1.06326	0.0006	1.06386	0.619

Table 44: Settlement observation of BCS at 25kN load

Time	sqr root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.619	20.619	1.06386	0	1.06386	0
1	1	0.11	0.11	20.619	20.509	1.06386	0.01101	1.05285	-0.11
2	1.41421	0.124	0.014	20.509	20.495	1.05285	0.0014	1.05145	-0.124

4	2	0.144	0.02	20.495	20.475	1.05145	0.002	1.04945	-0.144
5	2.23607	0.146	0.002	20.475	20.473	1.04945	0.0002	1.04925	-0.146
6	2.44949	0.148	0.002	20.473	20.471	1.04925	0.0002	1.04905	-0.148
7	2.64575	0.15	0.002	20.471	20.469	1.04905	0.0002	1.04885	-0.15
8	2.82843	0.152	0.002	20.469	20.467	1.04885	0.0002	1.04865	-0.152
9	3	0.153	0.001	20.467	20.466	1.04865	0.0001	1.04855	-0.153
10	3.16228	0.155	0.002	20.466	20.464	1.04855	0.0002	1.04835	-0.155
11	3.31662	0.156	0.001	20.464	20.463	1.04835	0.0001	1.04825	-0.156
13	3.60555	0.159	0.003	20.463	20.46	1.04825	0.0003	1.04794	-0.159
17	4.12311	0.162	0.003	20.46	20.457	1.04794	0.0003	1.04764	-0.162
30	5.47723	0.168	0.006	20.457	20.451	1.04764	0.0006	1.04704	-0.168
60	7.74597	0.178	0.01	20.451	20.441	1.04704	0.001	1.04604	-0.178
390	19.7484	0.218	0.04	20.441	20.401	1.04604	0.004	1.04204	-0.218
1850	43.0116	0.227	0.009	20.401	20.392	1.04204	0.0009	1.04114	-0.227
3300	57.4456	0.234	0.007	20.392	20.385	1.04114	0.0007	1.04044	-0.234
4080	63.8749	0.238	0.004	20.385	20.381	1.04044	0.0004	1.04004	-0.238
5880	76.6812	0.242	0.004	20.381	20.377	1.04004	0.0004	1.03964	-0.242

Table 45: Settlement observation of BCS at 50kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.377	20.377	1.03964	0	1.03964	0
1	1	0.05	0.05	20.377	20.327	1.03964	0.005	1.03464	-0.05
2	1.41421	0.058	0.008	20.327	20.319	1.03464	0.0008	1.03383	-0.058
3	1.73205	0.062	0.004	20.319	20.315	1.03383	0.0004	1.03343	-0.062
4	2	0.065	0.003	20.315	20.312	1.03343	0.0003	1.03313	-0.065
5	2.23607	0.068	0.003	20.312	20.309	1.03313	0.0003	1.03283	-0.068
6	2.44949	0.07	0.002	20.309	20.307	1.03283	0.0002	1.03263	-0.07
7	2.64575	0.074	0.004	20.307	20.303	1.03263	0.0004	1.03223	-0.074
8	2.82843	0.075	0.001	20.303	20.302	1.03223	0.0001	1.03213	-0.075
9	3	0.078	0.003	20.302	20.299	1.03213	0.0003	1.03183	-0.078
10	3.16228	0.079	0.001	20.299	20.298	1.03183	0.0001	1.03173	-0.079
12	3.4641	0.08	0.001	20.298	20.297	1.03173	0.0001	1.03163	-0.08
16	4	0.086	0.006	20.297	20.291	1.03163	0.0006	1.03103	-0.086
26	5.09902	0.09	0.004	20.291	20.287	1.03103	0.0004	1.03063	-0.09
41	6.40312	0.1	0.01	20.287	20.277	1.03063	0.001	1.02963	-0.1

71	8.42615	0.106	0.006	20.277	20.271	1.02963	0.0006	1.02903	-0.106
131	11.4455	0.115	0.009	20.271	20.262	1.02903	0.0009	1.02813	-0.115
204	14.2829	0.125	0.01	20.262	20.252	1.02813	0.001	1.02713	-0.125
1534	39.1663	0.158	0.033	20.252	20.219	1.02713	0.0033	1.02382	-0.158
2774	52.6688	0.171	0.013	20.219	20.206	1.02382	0.0013	1.02252	-0.171
4394	66.2873	0.179	0.008	20.206	20.198	1.02252	0.0008	1.02172	-0.179

Table 46: Settlement observation of BCS at 100kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.767	19.767	1.02172	0	1.02172	0
1	1	0.194	0.194	19.767	19.573	1.02172	0.01984	1.00188	-0.194
2	1.41421	0.228	0.034	19.573	19.539	1.00188	0.00348	0.9984	-0.228
3	1.73205	0.24	0.012	19.539	19.527	0.9984	0.00123	0.99717	-0.24
4	2	0.254	0.014	19.527	19.513	0.99717	0.00143	0.99574	-0.254
5	2.23607	0.263	0.009	19.513	19.504	0.99574	0.00092	0.99482	-0.263
6	2.44949	0.27	0.007	19.504	19.497	0.99482	0.00072	0.99411	-0.27
7	2.64575	0.278	0.008	19.497	19.489	0.99411	0.00082	0.99329	-0.278
8	2.82843	0.284	0.006	19.489	19.483	0.99329	0.00061	0.99267	-0.284
9	3	0.288	0.004	19.483	19.479	0.99267	0.00041	0.99226	-0.288
10	3.16228	0.294	0.006	19.479	19.473	0.99226	0.00061	0.99165	-0.294
12	3.4641	0.302	0.008	19.473	19.465	0.99165	0.00082	0.99083	-0.302
15	3.87298	0.312	0.01	19.465	19.455	0.99083	0.00102	0.98981	-0.312
25	5	0.336	0.024	19.455	19.431	0.98981	0.00245	0.98735	-0.336
40	6.32456	0.36	0.024	19.431	19.407	0.98735	0.00245	0.9849	-0.36
70	8.3666	0.38	0.02	19.407	19.387	0.9849	0.00205	0.98285	-0.38
130	11.4018	0.41	0.03	19.387	19.357	0.98285	0.00307	0.97979	-0.41
2830	53.1977	0.61	0.2	19.357	19.157	0.97979	0.02046	0.95933	-0.61

Table 47: Settlement observation of BCS at 200kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.157	19.157	0.95933	0	0.95933	0
1	1	0.25	0.25	19.157	18.907	0.95933	0.02557	0.93376	-0.25
2	1.41421	0.282	0.032	18.907	18.875	0.93376	0.00327	0.93049	-0.282

3	1.73205	0.304	0.022	18.875	18.853	0.93049	0.00225	0.92824	-0.304
4	2	0.318	0.014	18.853	18.839	0.92824	0.00143	0.92681	-0.318
5	2.23607	0.33	0.012	18.839	18.827	0.92681	0.00123	0.92558	-0.33
6	2.44949	0.34	0.01	18.827	18.817	0.92558	0.00102	0.92456	-0.34
7	2.64575	0.348	0.008	18.817	18.809	0.92456	0.00082	0.92374	-0.348
8	2.82843	0.356	0.008	18.809	18.801	0.92374	0.00082	0.92292	-0.356
9	3	0.364	0.008	18.801	18.793	0.92292	0.00082	0.9221	-0.364
10	3.16228	0.37	0.006	18.793	18.787	0.9221	0.00061	0.92149	-0.37
12	3.4641	0.382	0.012	18.787	18.775	0.92149	0.00123	0.92026	-0.382
16	4	0.4	0.018	18.775	18.757	0.92026	0.00184	0.91842	-0.4
25	5	0.432	0.032	18.757	18.725	0.91842	0.00327	0.91515	-0.432
40	6.32456	0.468	0.036	18.725	18.689	0.91515	0.00368	0.91146	-0.468
60	7.74597	0.496	0.028	18.689	18.661	0.91146	0.00286	0.9086	-0.496
85	9.21954	0.53	0.034	18.661	18.627	0.9086	0.00348	0.90512	-0.53
165	12.8452	0.568	0.038	18.627	18.589	0.90512	0.00389	0.90124	-0.568
1665	40.8044	0.64	0.072	18.589	18.517	0.90124	0.00736	0.89387	-0.64
2405	49.0408	0.67	0.03	18.517	18.487	0.89387	0.00307	0.8908	-0.67
2675	51.7204	0.676	0.006	18.487	18.481	0.8908	0.00061	0.89019	-0.676
3785	61.5224	0.704	0.028	18.481	18.453	0.89019	0.00286	0.88733	-0.704
4145	64.3817	0.71	0.006	18.453	18.447	0.88733	0.00061	0.88671	-0.71

Table 48: Settlement observation of BCS at 400kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	18.447	18.447	0.88671	0	0.88671	0
0.5	0.70711	0.13	0.13	18.447	18.317	0.88671	0.0133	0.87341	-0.13
1	1	0.366	0.236	18.317	18.081	0.87341	0.02414	0.84928	-0.366
2	1.41421	0.39	0.024	18.081	18.057	0.84928	0.00245	0.84682	-0.39
3	1.73205	0.398	0.008	18.057	18.049	0.84682	0.00082	0.846	-0.398
4	2	0.42	0.022	18.049	18.027	0.846	0.00225	0.84375	-0.42
5	2.23607	0.436	0.016	18.027	18.011	0.84375	0.00164	0.84212	-0.436
6	2.44949	0.45	0.014	18.011	17.997	0.84212	0.00143	0.84069	-0.45
7	2.64575	0.462	0.012	17.997	17.985	0.84069	0.00123	0.83946	-0.462
8	2.82843	0.472	0.01	17.985	17.975	0.83946	0.00102	0.83844	-0.472
9	3	0.48	0.008	17.975	17.967	0.83844	0.00082	0.83762	-0.48
10	3.16228	0.488	0.008	17.967	17.959	0.83762	0.00082	0.8368	-0.488

11	3.31662	0.496	0.008	17.959	17.951	0.8368	0.00082	0.83598	-0.496
13	3.60555	0.51	0.014	17.951	17.937	0.83598	0.00143	0.83455	-0.51
19	4.3589	0.544	0.034	17.937	17.903	0.83455	0.00348	0.83107	-0.544
50	7.07107	0.614	0.07	17.903	17.833	0.83107	0.00716	0.82391	-0.614
1310	36.1939	1.064	0.45	17.833	17.383	0.82391	0.04602	0.77789	-1.064
1440	37.9473	1.07	0.006	17.383	17.377	0.77789	0.00061	0.77727	-1.07
3060	55.3173	1.092	0.022	17.377	17.355	0.77727	0.00225	0.77502	-1.092

Table 49: Settlement observation of BCS at 800kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	17.355	17.355	0.77502	0	0.77502	0
0.5	0.70711	0.208	0.208	17.355	17.147	0.77502	0.02127	0.75375	-0.208
1	1	0.218	0.01	17.147	17.137	0.75375	0.00102	0.75272	-0.218
2	1.41421	0.24	0.022	17.137	17.115	0.75272	0.00225	0.75047	-0.24
3	1.73205	0.256	0.016	17.115	17.099	0.75047	0.00164	0.74884	-0.256
4	2	0.268	0.012	17.099	17.087	0.74884	0.00123	0.74761	-0.268
5	2.23607	0.278	0.01	17.087	17.077	0.74761	0.00102	0.74659	-0.278
6	2.44949	0.288	0.01	17.077	17.067	0.74659	0.00102	0.74556	-0.288
7	2.64575	0.296	0.008	17.067	17.059	0.74556	0.00082	0.74475	-0.296
8	2.82843	0.302	0.006	17.059	17.053	0.74475	0.00061	0.74413	-0.302
9	3	0.308	0.006	17.053	17.047	0.74413	0.00061	0.74352	-0.308
10	3.16228	0.314	0.006	17.047	17.041	0.74352	0.00061	0.7429	-0.314
12	3.4641	0.326	0.012	17.041	17.029	0.7429	0.00123	0.74168	-0.326
16	4	0.344	0.018	17.029	17.011	0.74168	0.00184	0.73984	-0.344
25	5	0.374	0.03	17.011	16.981	0.73984	0.00307	0.73677	-0.374
50	7.07107	0.436	0.062	16.981	16.919	0.73677	0.00634	0.73043	-0.436
110	10.4881	0.528	0.092	16.919	16.827	0.73043	0.00941	0.72102	-0.528
130	11.4018	0.554	0.026	16.827	16.801	0.72102	0.00266	0.71836	-0.554
1240	35.2136	0.738	0.184	16.801	16.617	0.71836	0.01882	0.69954	-0.738

Table 50: Change in void ratio of BCS

load	Dial gauge reading	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
5	4355	0	0	20	20	1.0019	0	1.0019	0

5	3318	-1.429	-1.429	20	21.429	1.0019	-0.143	1.14494	1.429
10	3049	0.619	2.048	21.429	19.381	1.14494	0.20499	1.06386	-0.619
25	2628	0.861	0.242	19.381	19.139	1.06386	0.02577	1.03964	-0.861
50	2311	1.051	0.19	19.139	18.949	1.03964	0.02025	1.02172	-1.051
100	2110	1.112	0.061	18.949	18.888	1.02172	0.00651	0.95933	-1.112
200	1876	1.822	0.71	18.888	18.178	0.95933	0.07365	0.88671	-1.822
400	1660	2.914	1.092	18.178	17.086	0.88671	0.11334	0.77502	-2.914
800	1447	3.652	0.738	17.086	16.348	0.77502	0.07667	0.69954	-3.652

ANNEXURE 6.2

Table 51: Swelling observation of BCS + 15% CS

Time	sq. root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	swelling (mm)
0	0	0	0	20	20	0.4598	0	0.4598	0
1	1	0.02	0.02	20	20.02	0.4598	0.00146	0.46126	0.02
2	1.41421	0.04	0.02	20.02	20.04	0.46126	0.00146	0.46272	0.04
3	1.73205	0.06	0.02	20.04	20.06	0.46272	0.00146	0.46418	0.06
4	2	0.07	0.01	20.06	20.07	0.46418	0.00073	0.46491	0.07
5	2.23607	0.1	0.03	20.07	20.1	0.46491	0.00219	0.4671	0.1
6	2.44949	0.11	0.01	20.1	20.11	0.4671	0.00073	0.46783	0.11
10	3.16228	0.16	0.01	20.15	20.16	0.47075	0.00073	0.47148	0.16
12	3.4641	0.18	0.02	20.16	20.18	0.47148	0.00146	0.47294	0.18
18	4.24264	0.26	0.08	20.18	20.26	0.47294	0.00584	0.47878	0.26
33	5.74456	0.38	0.12	20.26	20.38	0.47878	0.00876	0.48754	0.38
63	7.93725	0.59	0.21	20.38	20.59	0.48754	0.01533	0.50286	0.59
123	11.0905	0.88	0.29	20.59	20.88	0.50286	0.02117	0.52403	0.88
285	16.8819	1.32	0.44	20.88	21.32	0.52403	0.03212	0.55615	1.32
1368	36.9865	1.89	0.57	21.32	21.89	0.55615	0.0416	0.59775	1.89
1453	38.1182	1.94	0.05	21.89	21.94	0.59775	0.00365	0.6014	1.94
2773	52.6593	2.17	0.23	21.94	22.17	0.6014	0.01679	0.61819	2.17
3978	63.0714	2.22	0.05	22.17	22.22	0.61819	0.00365	0.62184	2.22
4418	66.468	2.3	0.08	22.22	22.3	0.62184	0.00584	0.62768	2.3
4419	66.4756	3.3	1	22.3	23.3	0.62768	0.07299	0.70067	3.3

Table 52: Settlement observation of BCS + 15% CS at 25kN load

Time	sqr root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.619	20.619	0.70067	0	0.70067	0
1	1	0.18	0.18	20.619	20.439	0.70067	0.01485	0.68582	-0.18
2	1.41421	0.19	0.01	20.439	20.429	0.68582	0.00082	0.685	-0.19
3	1.73205	0.2	0.01	20.429	20.419	0.685	0.00082	0.68417	-0.2
4	2	0.21	0.01	20.419	20.409	0.68417	0.00082	0.68335	-0.21
6	2.44949	0.22	0.01	20.409	20.399	0.68335	0.00082	0.68252	-0.22
12	3.4641	0.24	0.01	20.389	20.379	0.6817	0.00082	0.68087	-0.24
20	4.47214	0.25	0.01	20.379	20.369	0.68087	0.00082	0.68005	-0.25
35	5.91608	0.27	0.02	20.369	20.349	0.68005	0.00165	0.6784	-0.27
1460	38.2099	0.3	0.03	20.349	20.319	0.6784	0.00247	0.67592	-0.3
1730	41.5933	0.31	0.01	20.319	20.309	0.67592	0.00082	0.6751	-0.31
2840	53.2917	0.35	0.04	20.309	20.269	0.6751	0.0033	0.6718	-0.35

Table 53: Settlement observation of BCS + 15% CS at 50kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.377	20.377	0.6718	0	0.6718	0
0.5	0.70711	0.02	0.02	20.377	20.357	0.6718	0.00164	0.67016	-0.02
1	1	0.02	0	20.357	20.357	0.67016	0	0.67016	-0.02
2	1.41421	0.03	0.01	20.357	20.347	0.67016	0.00082	0.66934	-0.03
6	2.44949	0.04	0.01	20.347	20.337	0.66934	0.00082	0.66852	-0.04
25	5	0.05	0.01	20.337	20.327	0.66852	0.00082	0.6677	-0.05
60	7.74597	0.06	0.01	20.327	20.317	0.6677	0.00082	0.66688	-0.06
120	10.9545	0.07	0.01	20.317	20.307	0.66688	0.00082	0.66606	-0.07
240	15.4919	0.08	0.01	20.307	20.297	0.66606	0.00082	0.66524	-0.08
1560	39.4968	0.1	0.02	20.297	20.277	0.66524	0.00164	0.66359	-0.1

Table 54: Settlement observation of BCS + 15% CS at 100kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.767	19.767	0.66359	0	0.66359	0

1	1	0.16	0.16	19.767	19.607	0.66359	0.01347	0.65013	-0.16
2	1.41421	0.18	0.02	19.607	19.587	0.65013	0.00168	0.64845	-0.18
3	1.73205	0.19	0.01	19.587	19.577	0.64845	0.00084	0.6476	-0.19
4	2	0.2	0.01	19.577	19.567	0.6476	0.00084	0.64676	-0.2
5	2.23607	0.21	0.01	19.567	19.557	0.64676	0.00084	0.64592	-0.21
10	3.16228	0.24	0.008	19.535	19.527	0.64407	0.00067	0.6434	-0.24
12	3.4641	0.243	0.003	19.527	19.524	0.6434	0.00025	0.64314	-0.243
16	4	0.258	0.015	19.524	19.509	0.64314	0.00126	0.64188	-0.258
30	5.47723	0.28	0.022	19.509	19.487	0.64188	0.00185	0.64003	-0.28
60	7.74597	0.31	0.03	19.487	19.457	0.64003	0.00252	0.6375	-0.31
120	10.9545	0.33	0.02	19.457	19.437	0.6375	0.00168	0.63582	-0.33
1740	41.7133	0.4	0.07	19.437	19.367	0.63582	0.00589	0.62993	-0.4

Table 55: Settlement observation of BCS + 15% CS at 200kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.157	19.157	0.62993	0	0.62993	0
0.5	0.70711	0.19	0.19	19.157	18.967	0.62993	0.01617	0.61376	-0.19
1	1	0.24	0.05	18.967	18.917	0.61376	0.00425	0.60951	-0.24
2	1.41421	0.28	0.04	18.917	18.877	0.60951	0.0034	0.60611	-0.28
3	1.73205	0.3	0.02	18.877	18.857	0.60611	0.0017	0.60441	-0.3
4	2	0.31	0.01	18.857	18.847	0.60441	0.00085	0.60355	-0.31
5	2.23607	0.32	0.01	18.847	18.837	0.60355	0.00085	0.6027	-0.32
10	3.16228	0.355	0.005	18.807	18.802	0.60015	0.00043	0.59973	-0.355
12	3.4641	0.37	0.015	18.802	18.787	0.59973	0.00128	0.59845	-0.37
16	4	0.39	0.02	18.787	18.767	0.59845	0.0017	0.59675	-0.39
30	5.47723	0.42	0.03	18.767	18.737	0.59675	0.00255	0.5942	-0.42
60	7.74597	0.46	0.04	18.737	18.697	0.5942	0.0034	0.59079	-0.46
90	9.48683	0.49	0.03	18.697	18.667	0.59079	0.00255	0.58824	-0.49
120	10.9545	0.5	0.01	18.667	18.657	0.58824	0.00085	0.58739	-0.5
1230	35.0714	0.56	0.06	18.657	18.597	0.58739	0.0051	0.58228	-0.56

Table 56: Settlement observation of BCS + 15% CS at 400kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	18.447	18.447	0.58228	0	0.58228	0
0.5	0.70711	0.23	0.23	18.447	18.217	0.58228	0.01973	0.56256	-0.23
1	1	0.25	0.02	18.217	18.197	0.56256	0.00172	0.56084	-0.25
2	1.41421	0.29	0.02	18.177	18.157	0.55912	0.00172	0.55741	-0.29
3	1.73205	0.31	0.02	18.157	18.137	0.55741	0.00172	0.55569	-0.31
4	2	0.33	0.02	18.137	18.117	0.55569	0.00172	0.55398	-0.33
5	2.23607	0.34	0.01	18.117	18.107	0.55398	0.00086	0.55312	-0.34
10	3.16228	0.38	0.01	18.077	18.067	0.55055	0.00086	0.54969	-0.38
12	3.4641	0.4	0.02	18.067	18.047	0.54969	0.00172	0.54797	-0.4
16	4	0.41	0.01	18.047	18.037	0.54797	0.00086	0.54712	-0.41
30	5.47723	0.45	0.04	18.037	17.997	0.54712	0.00343	0.54369	-0.45
100	10	0.55	0.1	17.997	17.897	0.54369	0.00858	0.53511	-0.55
160	12.6491	0.59	0.04	17.897	17.857	0.53511	0.00343	0.53168	-0.59
220	14.8324	0.62	0.03	17.857	17.827	0.53168	0.00257	0.5291	-0.62
221	14.8661	1.62	1	17.827	16.827	0.5291	0.08577	0.44333	-1.62
222	14.8997	2.62	1	16.827	15.827	0.44333	0.08577	0.35755	-2.62
223	14.9332	3.62	1	15.827	14.827	0.35755	0.08577	0.27178	-3.62
224	14.9666	4.62	1	14.827	13.827	0.27178	0.08577	0.18601	-4.62

Table 57: Change in void ratio of BCS + 15% CS

load	Change in height from initial (mm)	Deformation (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
5	0	0	20	20	0.4598	0	0.4598	0
5	-3.3	-3.3	20	23.3	0.4598	-0.2409	0.70067	3.3
25	-2.95	0.35	23.3	22.95	0.70067	0.02555	0.6718	2.95
50	-2.85	0.1	22.95	22.85	0.6718	0.00728	0.66359	2.85
100	-2.45	0.4	22.85	22.45	0.66359	0.02912	0.62993	2.45
200	-1.89	0.56	22.45	21.89	0.62993	0.04066	0.58228	1.89
400	2.73	4.62	21.89	17.27	0.58228	0.33395	0.18601	-2.73

ANNEXURE 6.3

Table 58: Swelling observation of BCS + 15% CS + Geotextile (at H/2)

Time	sq. root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	swelling (mm)
0	0	0	0	20	20	0.5649	0	0.5649	0
1	1	0.14	0.068	20.072	20.14	0.570534	0.005321	0.575854	0.14
2	1.414214	0.268	0.128	20.14	20.268	0.575854	0.010015	0.58587	0.268
3	1.732051	0.388	0.12	20.268	20.388	0.58587	0.009389	0.595259	0.388
4	2	0.48	0.092	20.388	20.48	0.595259	0.007199	0.602458	0.48
5	2.236068	0.536	0.056	20.48	20.536	0.602458	0.004382	0.606839	0.536
10	3.162278	0.634	0.008	20.626	20.634	0.613881	0.000626	0.614507	0.634
12	3.464102	0.646	0.012	20.634	20.646	0.614507	0.000939	0.615446	0.646
16	4	0.654	0.008	20.646	20.654	0.615446	0.000626	0.616072	0.654
25	5	0.68	0.026	20.654	20.68	0.616072	0.002034	0.618107	0.68
30	5.477226	0.688	0.008	20.68	20.688	0.618107	0.000626	0.618733	0.688
60	7.745967	0.716	0.028	20.688	20.716	0.618733	0.002191	0.620923	0.716
120	10.95445	0.74	0.024	20.716	20.74	0.620923	0.001878	0.622801	0.74
240	15.49193	0.754	0.014	20.74	20.754	0.622801	0.001095	0.623897	0.754
1080	32.86335	0.824	0.07	20.754	20.824	0.623897	0.005477	0.629374	0.824

Table 59: Settlement observation of BCS + 15% CS + Geotextile (at H/2) at 25kN load

Time	sqr root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.619	20.619	0.6293	0	0.6293	0
1	1	0.18	0.18	20.619	20.439	0.6293	0.01422	0.61508	-0.18
2	1.41421	0.19	0.01	20.439	20.429	0.61508	0.00079	0.61429	-0.19
3	1.73205	0.2	0.01	20.429	20.419	0.61429	0.00079	0.6135	-0.2
4	2	0.21	0.01	20.419	20.409	0.6135	0.00079	0.61271	-0.21
6	2.44949	0.22	0.01	20.409	20.399	0.61271	0.00079	0.61192	-0.22
12	3.4641	0.24	0.01	20.389	20.379	0.61113	0.00079	0.61034	-0.24
20	4.47214	0.25	0.01	20.379	20.369	0.61034	0.00079	0.60955	-0.25
35	5.91608	0.27	0.02	20.369	20.349	0.60955	0.00158	0.60796	-0.27
930	30.4959	0.3	0.03	20.349	20.319	0.60796	0.00237	0.60559	-0.3
1640	40.4969	0.31	0.01	20.319	20.309	0.60559	0.00079	0.6048	-0.31

Table 60: Settlement observation of BCS + 15% CS + Geotextile (at H/2) at 50kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.377	20.377	0.6048	0	0.6048	0
1	1	0.05	0.02	20.347	20.327	0.60244	0.00158	0.60086	-0.05
2	1.41421	0.07	0.02	20.327	20.307	0.60086	0.00158	0.59929	-0.07
3	1.73205	0.08	0.01	20.307	20.297	0.59929	0.00079	0.5985	-0.08
4	2	0.09	0.01	20.297	20.287	0.5985	0.00079	0.59771	-0.09
5	2.23607	0.095	0.005	20.287	20.282	0.59771	0.00039	0.59732	-0.095
15	3.87298	0.118	0.008	20.267	20.259	0.59614	0.00063	0.59551	-0.118
30	5.47723	0.128	0.01	20.259	20.249	0.59551	0.00079	0.59472	-0.128
60	7.74597	0.137	0.009	20.249	20.24	0.59472	0.00071	0.59401	-0.137
120	10.9545	0.14	0.003	20.24	20.237	0.59401	0.00024	0.59377	-0.14
240	15.4919	0.15	0.01	20.237	20.227	0.59377	0.00079	0.59299	-0.15
900	30	0.17	0.02	20.227	20.207	0.59299	0.00158	0.59141	-0.17
1560	39.4968	0.2	0.03	20.207	20.177	0.59141	0.00236	0.58905	-0.2

Table 61: Settlement observation of BCS + 15% CS + Geotextile (at H/2) at 100kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.767	19.767	0.58905	0	0.58905	0
1	1	0.2	0.2	19.767	19.567	0.58905	0.01608	0.57297	-0.2
2	1.41421	0.22	0.02	19.567	19.547	0.57297	0.00161	0.57136	-0.22
3	1.73205	0.24	0.02	19.547	19.527	0.57136	0.00161	0.56976	-0.24
4	2	0.25	0.01	19.527	19.517	0.56976	0.0008	0.56895	-0.25
5	2.23607	0.26	0.01	19.517	19.507	0.56895	0.0008	0.56815	-0.26
6	2.44949	0.27	0.01	19.507	19.497	0.56815	0.0008	0.56734	-0.27
10	3.16228	0.3	0.005	19.472	19.467	0.56534	0.0004	0.56493	-0.3
12	3.4641	0.31	0.01	19.467	19.457	0.56493	0.0008	0.56413	-0.31
16	4	0.315	0.005	19.457	19.452	0.56413	0.0004	0.56373	-0.315
30	5.47723	0.32	0.005	19.452	19.447	0.56373	0.0004	0.56333	-0.32
60	7.74597	0.34	0.02	19.447	19.427	0.56333	0.00161	0.56172	-0.34
120	10.9545	0.36	0.02	19.427	19.407	0.56172	0.00161	0.56011	-0.36
1580	39.7492	0.4	0.04	19.407	19.367	0.56011	0.00322	0.55689	-0.4

Table 62: Settlement observation of BCS + 15% CS + Geotextile (at H/2) at 200kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.157	19.157	0.55689	0	0.55689	0
0.5	0.70711	0.23	0.23	19.157	18.927	0.55689	0.01869	0.5382	-0.23
1	1	0.255	0.025	18.927	18.902	0.5382	0.00203	0.53617	-0.255
2	1.41421	0.275	0.02	18.902	18.882	0.53617	0.00163	0.53455	-0.275
3	1.73205	0.29	0.015	18.882	18.867	0.53455	0.00122	0.53333	-0.29
4	2	0.3	0.01	18.867	18.857	0.53333	0.00081	0.53251	-0.3
5	2.23607	0.31	0.01	18.857	18.847	0.53251	0.00081	0.5317	-0.31
6	2.44949	0.32	0.01	18.847	18.837	0.5317	0.00081	0.53089	-0.32
10	3.16228	0.36	0.01	18.807	18.797	0.52845	0.00081	0.52764	-0.36
12	3.4641	0.38	0.02	18.797	18.777	0.52764	0.00163	0.52601	-0.38
16	4	0.4	0.02	18.777	18.757	0.52601	0.00163	0.52439	-0.4
30	5.47723	0.44	0.04	18.757	18.717	0.52439	0.00325	0.52114	-0.44
60	7.74597	0.47	0.03	18.717	18.687	0.52114	0.00244	0.5187	-0.47
90	9.48683	0.495	0.025	18.687	18.662	0.5187	0.00203	0.51667	-0.495
120	10.9545	0.5	0.005	18.662	18.657	0.51667	0.00041	0.51626	-0.5
1230	35.0714	0.56	0.06	18.657	18.597	0.51626	0.00488	0.51138	-0.56

Table 63: Settlement observation of BCS + 15% CS + Geotextile (at H/2) at 400kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	18.447	18.447	0.51138	0	0.51138	0
0.5	0.70711	0.14	0.14	18.447	18.307	0.51138	0.01147	0.49991	-0.14
1	1	0.25	0.11	18.307	18.197	0.49991	0.00901	0.4909	-0.25
1.5	1.22474	0.27	0.02	18.197	18.177	0.4909	0.00164	0.48926	-0.27
2	1.41421	0.29	0.02	18.177	18.157	0.48926	0.00164	0.48762	-0.29
3	1.73205	0.31	0.02	18.157	18.137	0.48762	0.00164	0.48598	-0.31
4	2	0.33	0.02	18.137	18.117	0.48598	0.00164	0.48435	-0.33
5	2.23607	0.34	0.01	18.117	18.107	0.48435	0.00082	0.48353	-0.34
6	2.44949	0.35	0.01	18.107	18.097	0.48353	0.00082	0.48271	-0.35
10	3.16228	0.37	0.005	18.082	18.077	0.48148	0.00041	0.48107	-0.37
12	3.4641	0.38	0.01	18.077	18.067	0.48107	0.00082	0.48025	-0.38
16	4	0.4	0.02	18.067	18.047	0.48025	0.00164	0.47861	-0.4

30	5.47723	0.42	0.02	18.047	18.027	0.47861	0.00164	0.47697	-0.42
100	10	0.46	0.04	18.027	17.987	0.47697	0.00328	0.47369	-0.46
160	12.6491	0.47	0.01	17.987	17.977	0.47369	0.00082	0.47288	-0.47
220	14.8324	0.49	0.02	17.977	17.957	0.47288	0.00164	0.47124	-0.49
480	21.9089	0.5	0.01	17.957	17.947	0.47124	0.00082	0.47042	-0.5
720	26.8328	0.52	0.02	17.947	17.927	0.47042	0.00164	0.46878	-0.52
1400	37.4166	0.55	0.03	17.927	17.897	0.46878	0.00246	0.46632	-0.55

Table 64: Change in void ratio of BCS + 15% CS + Geotextile (at H/2)

load	Change in height from initial (mm)	Deformation (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
5	0	0	20	20	0.5649	0	0.5649	0
5	0.824	0.824	20	19.176	0.5649	0.06447	0.62937	-0.824
25	1.134	0.31	19.176	18.866	0.62937	0.02634	0.6048	-1.134
50	1.334	0.2	18.866	18.666	0.6048	0.01701	0.58905	-1.334
100	1.734	0.4	18.666	18.266	0.58905	0.03405	0.55689	-1.734
200	2.294	0.56	18.266	17.706	0.55689	0.04773	0.51338	-2.294
400	2.854	0.56	17.706	17.146	0.51338	0.04786	0.4655	-2.854

ANNEXURE 6.4

Table 65: Swelling observation of BCS + 15% CS + Geotextile at (2H/5)

Time	sq. root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	swelling (mm)
0	0	0	0	20	20	0.4647	0	0.4647	0
1	1	0.025	0.025	20	20.025	0.4647	0.00183	0.46653	0.025
2	1.41421	0.04	0.015	20.025	20.04	0.46653	0.0011	0.46763	0.04
3	1.73205	0.05	0.01	20.04	20.05	0.46763	0.00073	0.46836	0.05
4	2	0.06	0.01	20.05	20.06	0.46836	0.00073	0.46909	0.06
5	2.23607	0.07	0.01	20.06	20.07	0.46909	0.00073	0.46983	0.07
6	2.44949	0.08	0.01	20.07	20.08	0.46983	0.00073	0.47056	0.08
10	3.16228	0.16	0.01	20.15	20.16	0.47569	0.00073	0.47642	0.16
12	3.4641	0.18	0.02	20.16	20.18	0.47642	0.00146	0.47788	0.18
18	4.24264	0.26	0.08	20.18	20.26	0.47788	0.00586	0.48374	0.26
30	5.47723	0.38	0.12	20.26	20.38	0.48374	0.00879	0.49253	0.38

60	7.74597	0.59	0.21	20.38	20.59	0.49253	0.01538	0.50791	0.59
120	10.9545	0.88	0.29	20.59	20.88	0.50791	0.02124	0.52915	0.88
240	15.4919	1.32	0.44	20.88	21.32	0.52915	0.03222	0.56137	1.32
480	21.9089	1.89	0.57	21.32	21.89	0.56137	0.04174	0.60311	1.89
990	31.4643	2.1	0.21	21.89	22.1	0.60311	0.01538	0.61849	2.1
1400	37.4166	2.17	0.07	22.1	22.17	0.61849	0.00513	0.62362	2.17
1680	40.9878	2.22	0.05	22.17	22.22	0.62362	0.00366	0.62728	2.22

Table 66: Settlement observation of BCS + 15% CS + Geotextile at (2H/5) at 25kN load

Time	sqr root time	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.619	20.619	0.62728	0	0.62728	0
1	1	0.24	0.24	20.619	20.379	0.62728	0.018941	0.608339	-0.24
2	1.414214	0.28	0.04	20.379	20.339	0.608339	0.003157	0.605182	-0.28
3	1.732051	0.3	0.02	20.339	20.319	0.605182	0.001578	0.603604	-0.3
4	2	0.31	0.01	20.319	20.309	0.603604	0.000789	0.602814	-0.31
6	2.44949	0.32	0.01	20.309	20.299	0.602814	0.000789	0.602025	-0.32
12	3.464102	0.34	0.01	20.289	20.279	0.601236	0.000789	0.600447	-0.34
16	4	0.35	0.01	20.279	20.269	0.600447	0.000789	0.599658	-0.35
30	5.477226	0.37	0.02	20.269	20.249	0.599658	0.001578	0.598079	-0.37
60	7.745967	0.41	0.04	20.249	20.209	0.598079	0.003157	0.594922	-0.41
120	10.95445	0.43	0.02	20.209	20.189	0.594922	0.001578	0.593344	-0.43
240	15.49193	0.47	0.04	20.189	20.149	0.593344	0.003157	0.590187	-0.47
500	22.36068	0.5	0.03	20.149	20.119	0.590187	0.002368	0.587819	-0.5
1680	40.9878	0.52	0.02	20.119	20.099	0.587819	0.001578	0.586241	-0.52

Table 67: Settlement observation of BCS + 15% CS + Geotextile at (2H/5) at 50kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	20.377	20.377	0.58624	0	0.58624	0
0.5	0.70711	0.03	0.03	20.377	20.347	0.58624	0.00234	0.58391	-0.03
1	1	0.05	0.02	20.347	20.327	0.58391	0.00156	0.58235	-0.05
2	1.41421	0.06	0.01	20.327	20.317	0.58235	0.00078	0.58157	-0.06
6	2.44949	0.07	0.01	20.317	20.307	0.58157	0.00078	0.58079	-0.07
25	5	0.09	0.02	20.307	20.287	0.58079	0.00156	0.57923	-0.09
60	7.74597	0.095	0.005	20.287	20.282	0.57923	0.00039	0.57885	-0.095

120	10.9545	0.1	0.005	20.282	20.277	0.57885	0.00039	0.57846	-0.1
240	15.4919	0.11	0.01	20.277	20.267	0.57846	0.00078	0.57768	-0.11
1560	39.4968	0.12	0.01	20.267	20.257	0.57768	0.00078	0.5769	-0.12

Table 68: Settlement observation of BCS + 15% CS + Geotextile at (2H/5) at 100kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.767	19.767	0.5769	0	0.5769	0
1	1	0.07	0.07	19.767	19.697	0.5769	0.00558	0.57132	-0.07
2	1.41421	0.11	0.04	19.697	19.657	0.57132	0.00319	0.56812	-0.11
3	1.73205	0.14	0.03	19.657	19.627	0.56812	0.00239	0.56573	-0.14
4	2	0.16	0.02	19.627	19.607	0.56573	0.0016	0.56414	-0.16
6	2.44949	0.17	0.01	19.607	19.597	0.56414	0.0008	0.56334	-0.17
10	3.16228	0.18	0.01	19.597	19.587	0.56334	0.0008	0.56254	-0.18
20	4.47214	0.2	0.02	19.587	19.567	0.56254	0.0016	0.56094	-0.2
30	5.47723	0.22	0.02	19.567	19.547	0.56094	0.0016	0.55935	-0.22
60	7.74597	0.232	0.012	19.547	19.535	0.55935	0.00096	0.55839	-0.232
120	10.9545	0.24	0.008	19.535	19.527	0.55839	0.00064	0.55775	-0.24
240	15.4919	0.243	0.003	19.527	19.524	0.55775	0.00024	0.55751	-0.243
480	21.9089	0.258	0.015	19.524	19.509	0.55751	0.0012	0.55632	-0.258
1440	37.9473	0.267	0.009	19.509	19.5	0.55632	0.00072	0.5556	-0.267

Table 69: Settlement observation of BCS + 15% CS + Geotextile at (2H/5) at 200kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	19.157	19.157	0.5556	0	0.5556	0
1	1	0.05	0.05	19.157	19.107	0.5556	0.00406	0.55154	-0.05
2	1.41421	0.08	0.03	19.107	19.077	0.55154	0.00244	0.5491	-0.08
3	1.73205	0.11	0.03	19.077	19.047	0.5491	0.00244	0.54667	-0.11
4	2	0.13	0.02	19.047	19.027	0.54667	0.00162	0.54504	-0.13
10	3.16228	0.19	0.015	18.982	18.967	0.54139	0.00122	0.54017	-0.19
16	4	0.21	0.02	18.967	18.947	0.54017	0.00162	0.53855	-0.21
30	5.47723	0.225	0.015	18.947	18.932	0.53855	0.00122	0.53733	-0.225
60	7.74597	0.24	0.015	18.932	18.917	0.53733	0.00122	0.53611	-0.24
120	10.9545	0.27	0.03	18.917	18.887	0.53611	0.00244	0.53368	-0.27

240	15.4919	0.295	0.025	18.887	18.862	0.53368	0.00203	0.53165	-0.295
1440	37.9473	0.34	0.045	18.862	18.817	0.53165	0.00365	0.52799	-0.34
1680	40.9878	0.345	0.005	18.817	18.812	0.52799	0.00041	0.52759	-0.345

Table 70: Settlement observation of BCS + 15% CS + Geotextile at (2H/5) at 400kN load

Time	sqrt(t)	Change in height from initial (mm)	Deformation, (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
0	0	0	0	18.447	18.447	0.52759	0	0.52759	0
1	1	0.21	0.21	18.447	18.237	0.52759	0.01739	0.5102	-0.21
2	1.41421	0.28	0.07	18.237	18.167	0.5102	0.0058	0.5044	-0.28
3	1.73205	0.3	0.02	18.167	18.147	0.5044	0.00166	0.50275	-0.3
4	2	0.32	0.02	18.147	18.127	0.50275	0.00166	0.50109	-0.32
10	3.16228	0.345	0.005	18.107	18.102	0.49943	0.00041	0.49902	-0.345
14	3.74166	0.35	0.005	18.102	18.097	0.49902	0.00041	0.49861	-0.35
30	5.47723	0.36	0.01	18.097	18.087	0.49861	0.00083	0.49778	-0.36
60	7.74597	0.37	0.01	18.087	18.077	0.49778	0.00083	0.49695	-0.37
120	10.9545	0.37	-1E-16	18.077	18.077	0.49695	-9E-18	0.49695	-0.37
240	15.4919	0.38	0.01	18.077	18.067	0.49695	0.00083	0.49612	-0.38
480	21.9089	0.4	0.02	18.067	18.047	0.49612	0.00166	0.49447	-0.4
1440	37.9473	0.42	0.02	18.047	18.027	0.49447	0.00166	0.49281	-0.42
1620	40.2492	0.425	0.005	18.027	18.022	0.49281	0.00041	0.4924	-0.425
2830	53.1977	0.43	0.005	18.022	18.017	0.4924	0.00041	0.49198	-0.43

Table 71: Change in void ratio of BCS + 15% CS + Geotextile (at 2H/5)

load	Change in height from initial (mm)	Deformation (mm)	Initial ht. (mm)	Final ht. (mm)	initial void ratio	change in void ratio	final void ratio	settlement (mm)
5	0	0	20	20	0.4598	0	0.4647	0
5	2.22	2.22	20	17.78	0.4647	0.16258	0.62728	-2.22
25	1.7	-0.52	17.78	18.3	0.62728	-0.0476	0.58624	-1.7
50	0.4	-1.3	18.3	19.6	0.58624	-0.1127	0.5769	-0.4
100	-0.19	-0.59	19.6	20.19	0.5769	-0.0475	0.5556	0.19
200	-0.037	0.153	20.19	20.037	0.5556	0.01179	0.52759	0.037
400	-0.083	-0.046	20.037	20.083	0.52759	-0.0035	0.49189	0.083

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