MODIFICATION OF SOIL PROPERTIES USING BACILLUS SPHAERICUS

A dissertation submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology

in

Geotechnical Engineering

by

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(Formerly Delhi College of Engineering) July 2015

Delhi Technological University, Delhi

CERTIFICATE

This is to certify that Major Project-II entitled **— "Modification of Soil Properties using Bacillus Sphaericus"** is bonafide record of work carried out by Tanuj Kumar (Rollno.2K13/GTE/22) under the guidance and supervision, during session 2015 in partial fulfilment of the degree of Master of Technology (Geotechnical Engineering) from Delhi Technological University New Delhi.

The work in this Major Project- II has not submitted for the award of any other degree to the best of my knowledge.

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**Modification of Soil Properties using Bacillus Sphaericus**" in the partial fulfilment of the requirements for the award of the degree of "Master of Technology " in Geotechnical Engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of our own work carried out from December 2014 to July 2015 under the supervision of Prof. A.Trivedi, Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: July 2015

Tanuj kumar
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ABSTRACT

Generally construction is not done on soil having very low strength but with time we need to construct on soil having very low strength. Bio cementation is very interesting phenomena in which properties of soil are improved which are very beneficial for construction on soil. Properties improved are strength of soil, permeability, water tightness, resistance to washout. Bacteria introduced in soil causes the bonding in between particles of soil by calcite precipitate. Voids present in soil also decreases due to calcite precipitation which lead to the phenomena called bio clogging in soil. We found out increase in strength of soil due to bio cementation of soil. There are various types of soil improvement method but MICP has advantage that it doesn't cause any type harmful effect on soil and surrounding environment. Microorganisms play a very indispensable role in geotechnical engineering in future.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER-1
INTRODUCTION

Biocementation is the process of increase in strength of soil due to bonding of soil particles by bacteria using some chemicals. Similarly bioclogging is the decrease in permeability of soil by bacteria using chemicals. Strength of soil can be improved by various ingredient but they require cost which effect the economy of construction project. But in case of microbially induced calcite precipitate we require bacteria and few chemicals. These bacteria are also not harmful to human and animals, so they can be used without any threat anywhere. With time we require to build multi-storey building which requires high bearing capacity of soil and bearing capacity of soil can be increased by microbially induced calcite precipitate technique. Some microorganisms play a very indispensable role in the geotechnical engineering. Both geotechnical and the biotechnology come together with same aim to improve the various properties of soil like strength, permeability, resistance to washing, stiffness of soil. But proper handling of microorganisms is required in this process and recent research shows that Bio enzymes also play a important role in the soil stabilisation. Bio enzymes are the organic chemical liquid stabilisers and they are generally used for stabilisation of soil subgrade by improving soil properties. Bio enzymes are natural, non-toxic, non-corrosive, and non-flammable and these are fermented from vegetable extracts. Terrazyme modify soil properties by increasing the load resistant of soil but it is useful for cohesive soil. Microbiologically induced calcium carbonate precipitate is a bio-geochemical process which causes the calcium carbonate precipitate in soil and leads to the bonding in soil. Urea hydrolysis is the process which causes the calcite carbonate precipitate in between soil particles. Microbially-induced calcite precipitate (MICP) is a new sustainable soil improvement technique. Bio-activity is used for the calcite precipitate formation which forms coating and bonds between soil particles and finally it leads to improvement in engineering properties of soil. (MICP) is a “green construction” because it has no negative effects on soil, health and environment which is very beneficial from minimal generation of pollution point of view. All chemical grouts have negative effect on soil because they are toxic and hazardous but these urease producing bacteria found in nature in abundant quantity in soil and they hydrolysis urea continuously which has no negative effect on soil. MICP combine microbiology, geochemistry and geotechnical engineering to give a new method of soil stabilization which utilises biological

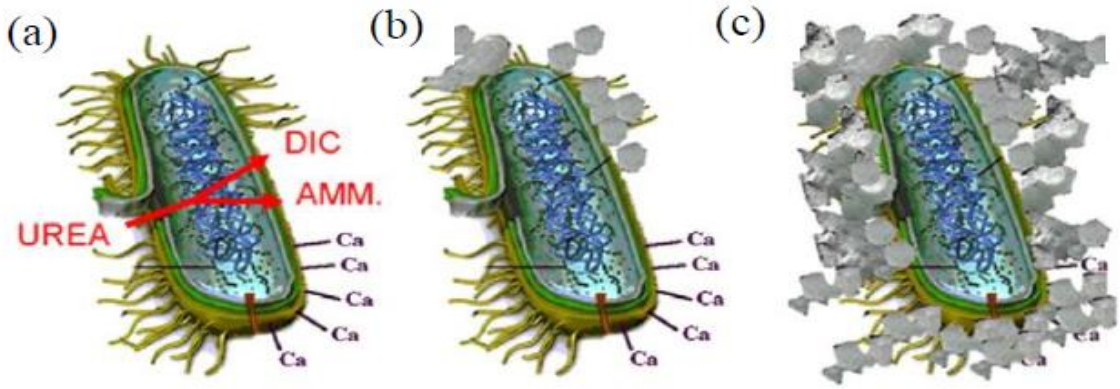
process. A new soil improvement technique that utilizes a biological process, which is termed technically as Microbial-Induced Calcite Precipitation (MICP), has emerged recently. MICP has been enabled through interdisciplinary researches at the confluence of microbiology, geochemistry, and geotechnical engineering, to find natural treatments for soil improvement. MICP process can be intensified by introducing large amount of bacteria which causes urea hydrolysis and cementation reagent in soil. Generally, MICP can be achieved by urea hydrolysis, aerobic oxidation, denitrification, sulphate reduction, etc., but research found that maximum urea hydrolysis possess maximum calcite conversion. In urea hydrolysis, urea ($CO(NH_2)_2$) is decomposed by urease enzyme which is produced by urease positive bacteria(Bacillus Sphaericus in our case) and the corresponding chemical reaction involves 1 mole of urea decomposes into 2 moles of ammonium.

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH^{4+} + CO_3^{2-}$$

Release of ammonium (NH^{4+}) increases pH, and eventually creates an ideal condition for calcite precipitation and we supply calcium chloride externally which is a source of calcium ion for the calcium precipitation.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

This formation of calcium chloride is responsible for the improvement in soil properties.



Source: http://labmet.ugent.be/user/willem-de-muynck

Figure 1.1 Formation of calcite precipitate during MICP, (a) attraction of calcium ion towards cell wall, (b) Formation of calcite precipitation near the cell wall, (c) Increase in calcite content around the bacteria.

Calcium Ions supplies externally have positive charge and these are attracted by negatively charged cell walls of microbes. Urea breaks to give ammonium ion and carbonate ion, this

presence of carbonate ion causes the formation of calcium precipitate on cell walls of microorganism. Finally whole cell wall is engulfed by the calcium precipitate and this condition leads to no supply of nutrients and bacteria finally died. Calcium chloride is a gelatinous like substance which act as binder between soil particles. Nutrients are the energy source of bacteria and so we provide nutrients 3g/litre (in form of nutrient broth) in treatment solution for the growth of bacteria. We use Bacillus *Sphaericus* for urea hydrolysis in our case which is able to catalyse urea hydrolysis reaction. Higher concentration of bacteria in soil sample increases the calcite precipitate in the soil and the bacterial concentration has direct relationship with calcite precipitation, provided sufficient cementing reagent is provided. Microbial activity and growth rate is less sensitive in 20 to 30^0 temperature and if we provide equimolar rate of reactant then it is beneficial for the calcite formation.

1.1 OBJECTIVE

Our main aim is to find out the effect of particular microorganism on the strength of soil and growth of bacteria in soil. When bacteria act on a soil some of the engineering properties of soil are changed and we will check whether they get improved or not, because if they get improved it is very beneficial for the geotechnical engineering. Firstly we will check whether strength will improve or not and after that will also check whether other parameter change or not. Apart from that we will also see the change in the structure of soil.

1.2 SCOPE OF STUDY

Bio cementation has huge scope of study and in future a lot of research in this field is going to be done. Still a lot of research is taking place in this field. We know some bacteria which help bonding of soil particles and there must be many more such type of bacteria existing in nature which are going to be find out. Bacteria which are needed to be finding out are must be such that they can act in all type of temperature and pressure, So that they can be used on soil in all places where climate is very extreme. Bacteria must be such that it will take only small amount of time to act on the soil, so that time of whole project can be decreases and it will finally help financially. Bacteria has a big impact on soil and the extent of impact depends on the types of bacteria, amount of bacteria required in soil, favourable temperature required for bacteria, bacterial cell concentration, fixation and distribution of bacteria in cell, availability of food of bacteria which is nutrient broth, pH of soil which is need be between

7.5-8.0, reactant concentration. In future we need to find out such types of bacteria which require less handling and give maximum output by improving the properties of soil. Microorganism requires for bio cementation and bio clogging can be produced commercially and can be used at required place before construction. Search of those bacteria is required which take very less time for bio cementation and bio clogging of soil. Bacteria should be such that which can't cause any type of harm to human, animals and surrounding environment so that life remain uninfected due to the bacteria. Bacteria should be such that their growth can't be effect by other microorganism present in soil already. Also we need to find out the type of soil this bio cementation is beneficial.

Basically we want to state that this field has huge scope of work in future which requires biotechnology help to find out the various type of microorganism. Finally these microorganism help geotechnical engineers by improving the properties of soil. Already a lot research is done but still a lot of research is going to be done. Further the extent of bio cementation and bio clogging by the bacteria is needed to be finding out. So we can say that with time a lot of improvement is going to be done.

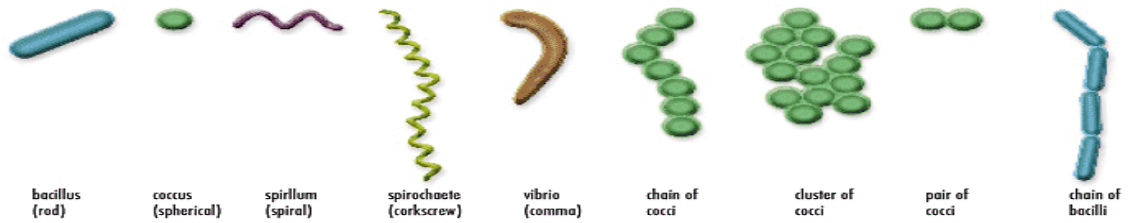
1.3 VARIOUS TYPES OF BACTERIA

Bacteria are single celled microbes and their cell structure is simpler than other microorganism because there is no nucleus and other membrane bound structures. Their control centre is contained in single loop of structure. In 1676 Anton van Leeuwenhoek first observed the bacteria through microscope and called them "animalcules". Later German naturalist Christian Gottfried Ehrenberg called it bacteria meaning "little stick".

1.3.1 Types of Bacteria on basis of Shape

Bacteria are classified in five groups according to their shape:-

- Spherical(cocci)
- Rod(bacilli)
- Spiral(spirilla)
- Comma(vibrios)
- Corkscrew(spirochaetes)



Source: http://www.microbiologyonline.org.uk/themed/sgm/img/slideshows/3.1.2_bacteria_1.png

Figure 1.2 Types and shapes of various Bacteria

1.3.2 Habitats of Bacteria

Bacteria found on every habitat of earth like soil, rock, oceans, snow and also in extreme condition where no animals can survive. Few bacteria live in or on plants and animals including humans. Large number of bacteria found on inner lining of digestive system. Bacteria play a very important role in the recycling of nutrients. Some bacteria causes food spoilage and crop damage but on the other hand they play a very important role in fermentation. Few bacteria are which causes disease in plants and animals.

1.3.3 Reproduction in Bacteria

Bacteria reproduce by binary fission in which parent bacteria is divided into two daughter cells. DNA of bacteria is divided into two identical replicates and then cell elongates and divided into two daughter cells. In favourable condition and at appropriate temperature bacteria divide every 20 minutes and in 7 hours it become 2097152 and after one more hours bacteria will rise to 16777216. This is the reason we quickly get ill when bacteria comes in contact of our body.

1.3.4 Survival Mechanism

Bacteria form spores which are dormant structure and are highly resistant to hostile physical and chemical conditions such as heat, UV radiation and disinfectants.

1.4 UREASE POSITIVE BACTERIA

That bacterium which causes urea hydrolysis is called urease positive bacteria. Urease is an

enzyme which causes catalyses hydrolysis of urea to form ammonia and carbonate. Urease activity increases the pH because it forms ammonia which is a basic molecule. Other examples of urease positive bacteria are Proteus mirabilis, ureaplasma urealyticum, helicobacter jejuni, staphylococcus epidermitis, etc.

1.5 BACILLUS SPHAERICUS

Bacillus Sphaericus is aerobic bacteria used as a larvicide to control mosquito. They are rod shaped bacteria and produce a protein which is toxic to only larvae of mosquito. Benefit of using these bacteria is that it is not harmful to pets, birds, fish, worm, humans and environment. It is found widely in soil substrata and produced commercially by fermentation.

Scientific classification:-

Kingdom :- Bacteria

Phylum :- Furmicutes

Class :- Bacilli

Order :- Bacillales

Family :- Bacillaceae

Genus :- Bacillus

Species :- Bacillus *Sphaericus*

CHAPTER-2
LITERATURE REVIEW

Martinez et al. [2013] deals with MICP and effect of various parameters on calcite precipitation. According to this paper shear wave velocity give idea of amount of calcite precipitation, if shear wave velocity increases then amount of calcite precipitation increases and shear wave velocity change from 140m/s to 600m/s. Various parameters are monitored and controlled on half meter long column on which tests are done to give the accurate results of all parameters.

Mitchell et al. [2005] This paper deals with the effect of microorganisms on soil. In last 300 years a lot of research is done on mechanical properties of soil but effect of bio-activity remains unexplored. So in this paper we will see bio cementation of soil and improvement of different engineering properties of soil. Microorganism play a very important role in formation of fine grained soil and it will also change various properties of soil. This paper use the microbial concept and its potential for the advancing the state of knowledge and practice in geotechnical engineering. Microorganism also accelerates the various geochemical reactions by high order of magnitude, promote both weathering and aging. So extensive research is need for the effect of biomass and biochemical reaction on soil and it has huge scope in future.

Ivanov et al. [2008] Microbial geotechnology is a new branch which deals with application of microbial technology on geotechnical material used in the construction. Aim of this application is to improve the mechanical properties of soil. Bio cementation is the generation of particle binding material through the biological processes. Another similar term called bio clogging is used for the generation of pore filling material which finally decrease the size of voids and also decreases the permeability of soil. The most suitable bacteria for the bio cementation are facultative anaerobic and micro-aerophilic bacteria. Apart from those anaerobic fermenting bacteria, anaerobic respiring bacteria and obligate aerobic bacteria may also be used for bio cementation of soil and improve geotechnical properties of soil. Microbial geotechnology is still in laboratory stage because it will require coordination of microbiology, ecology, biochemistry and geotechnical engineering.

Ivanov et al. [2009] Talk about various method available has its own advantages and

drawbacks based on methodology like accessibility to site, economy, effectiveness, environment impact. So there is a need of exploration of suitable method of soil improvement because suitable land for the construction is scare. This paper uses microbial biological processes for the improvement of initially loose and collapsible sand. MICP is achieved using the microorganism bacillus *pasteurii*, aerobic bacteria generally found in natural soil deposits. Microbes are introduced in liquid medium in soil and properly mixed to get the desired results and finally various tests are done to find the improvement of various engineering properties of soil.

Dejong et al. [2006] Bio cementation of soil depends upon the consolidation of soil particles due bio-activity of microorganism in soil. Bacteria used is ureolytic bacteria(bacillus *pasteurii*) which causes the calcite precipitation in soil to provide bonding between different soil particles. Bonding of particle is done in presence of urea and calcium ions. Calcite precipitate is a gelatinous mix which is the ultimate substance which causes final bonding between soil particles. Energy dispersive X-ray and electron microscope reveal the bonding of soil particles.

Montoya et al. [2013] Microorganism can also be used in coastal sands to improve the various engineering properties of soil. After bio cementation soil becomes more resistant to the damage from storm on soil like coastal infrastructure, highways, buildings, pipelines and other utilities. Finally bacteria together with urea and calcium flood in soil and then various tests are done to get the desired results. Unconfined compressive test is done to check the improvement in strength of soil.

Salwa et al. [2013] Biocementation of soil depends on consolidation of soil using by using pure urease positive bacteria under complete sterilised condition during the cellular growth. Urealytic bacteria are used for biocementation of soil under non-sterilised condition, then consolidation in presence of urea and calcium ions takes place. After that various tests are performed to check the ability of bacteria on bonding of soil particles.

Rahim shahrokhi et al. [2014] Microbially-induced calcite precipitation is relatively a new technique in which calcite deposition can be achieved by reagent like urea, calcium and urealytic bacteria. Loose sand is investigated and change in strength is found by UCS and finally SEM images are used to find the calcite precipitation.

Chunxiang et al. [2010] tells about how incompact sands can be consolidated by using microbes which produce carbonate in an environment favourable to precipitation.

Technology used is environment friendly and even allow water to penetrate inside soil unlike silicate cement which destroy ecosystem of the earth. Most favourable bacteria for this work is chosen and they are purified to get the efficient benefit for soil. Effectiveness of bacteria can be tested by compressive strength test and porosity. Finally XRD analysis shows the calcite formation between the soil particles.

Khun et al. [2012] talk about use of MICP on sand and residual soil (which is sandy soil). Finally it is found that effect of calcite precipitation is more on sand in comparison to residual soil. MICP improves the strength of soil and on the other hand it will reduce hydraulic conductivity. Calcite content increases to 1.889% in treated residual soil but in case of sand it will increases to 60.102%.

Soon et al. [2012] deals with the biochemical process that presents naturally in soil and calcite precipitation is uplifted by increasing the concentration of urease positive bacteria. It also talk about the factors on which calcite precipitation depends like nutrients, bacteria type, bacteria concentration, temperature, reagent concentration, pH, injection method. Various laboratory tests prove that bacteria improves the shear strength and permeability of bacterially treated soil.

Gomez et al. [2014] tells about the bio-mediated cementation process(MICP) which improves the geotechnical properties of soil through calcite precipitation between soil particles. Three plots are selected and they are treated with different concentrations of nutrients and at the end it is found that most improved soil received the minimum urea and calcite precipitation. Dynamic cone penetration and calcite content measurement tests prove that stiffness of soil increased at depth of 28cm.

Paassen et al. [2009] deals with process of biogrouting in which bacteria is used to induce calcite precipitate in subsurface in order to increase strength and stiffness. Biogrouting is done on large scale and unconfined compressive strength test is done to check the feasility of biogrouting. Geophysical test is also done, they confirm the results shown by the unconfined compressive test. Stiffness increase quantified as a function of injecting volume of grouting agents.

Wangjie at al. [2010] deals with soil solidification with the help of microrganisms due to calcite precipitate in between soil particles. Finally it is found that compressive strength of soil is increased after 7 days of treatment. Various tests like SEM and XRD prove the benefit of microorganism in soil

Table 2.1 Literature review of various Research Work

S. no.	Author	Journal	Soil type	Bacteria	Scale of study	Test conducted	Results
1.	Martinez etal. (2013)	ASCE	Ottawa sand	Sporoscarcina *Pasteurii*	Lab study	Shear Wave velocity test, Hydraulic Conductivity	With increase in shear wave velocity, there is increase in calcite content, Hydraulic conductivity decreases with increases in shear velocity
2.	Ivanov etal. (2008)	Springer	Sand	Bacillus *pasteurii*	Lab study	X-ray, Triaxial, Shear wave velocity test	Increase in strength of soil due calcite content
3	Qabany etal. (2012)	ASCE	Sand	Sporoscarcina *Pasteurii*	Lab study	SEM, Spectrophotometer	Calcite precipitate seen on surface of soil particles
4.	Montoya etal. (2013)	ICSM-GE	Ottawa sand	Sporoscarcina *Pasteurii*	Lab study	UCS	Increase in compressive strength of soil
5.	Dejong etal.	ASCE	Sand	Bacillus *Pasteurii*	Lab study	SEM, X-ray, Triaxial	Same behaviour as shown by gypsum treated soil
6.	Gomez etal. (2014)	ICE	Sand	Sporoscarcina Pasteurii	Lab study	DCP	Increase resistant to erosion
7.	Passen etal.	ASCE	Granular soil	Bacillus *Pasteurii*	Field study	UCS, Shear wave velocity test	Increase in UCS value with in crease in calcite level
8.	Qabany	ASCE	Sand	Sporoscarcina *Pasteurii*	Lab study	SEM and Photospectrometer	Calcium precipitate seen on the surface of soil particles

CHAPTER-3
METHODOLOGY

In experiment work we use following steps to do our work to get the final results:-

- Sterilization
- Preparation of bacteria
- Preparation of sample
- MICP

3.1 STERILIZATION: - It is the processes of properly making the various instrument used infection free. Various instrument used are beaker, micropippte, etc. In sterilization every instrument is washed with ethanol and put in ultraviolet rays for 10 mins. Hands should be washed with ethanol during sterilization. This is the one of the very important technique in biotechnology, without it all work becomes useless.

3.2 PREPARATION OF BACTERIA: - First of all 2 litre beaker is taken and washed properly and 13 gram nutrient broth is taken and mixed in 1 litre of distilled water because this much amount of food is required for bacteria for growth. Nutrient broth is a food of bacteria and its composition for 1 litre is-

- Peptic digest of animal tissue 5.0g/l
- Sodium chloride 5.0g/l
- Beef extract/yeast extract 3.0g/l

It will also require a proper pH at 25 degree Celsius of 7.4-7.6. It should be autoclave at15 pascal(lbs) (121^0C) for 15 minutes.

Here we will make only100 ml of nutrient broth so various ingredients require is also become one-tenth of 1 litre of sample. So composition becomes:-

- Peptic digest of animal tissue 0.5g/l
- Sodium chloride 0.5g/l
- Yeast extract 0.3g/l

Other things remain same like temperature and the pressure. Then we add bacteria into it and it will grow in 24 hours to reach in log phase. It should be used in log phase because their activity is highest in this phase. After log phase they come to stationary and endogenous phase in which growth of bacteria is very less in comparison to log phase.

3.3 PREPARATION OF SOIL SAMPLE: - Then soil is taken and sieved through the 425 micron sieve. We sieve out 1 kilogram soil and we add bacteria and cementing solution according to optimum moisture content of soil which is in our case is 17.2%. So, for 1 kilogram we add 172 ml of total ingredient in which 100ml bacteria and 72 ml cementing agent is added. Cementing agent consists of predefined proportion of nutrient broth, urea, ammonium chloride, sodium bicarbonate, calcium chloride diluted hydrochloric acid. After mixing all these properly we make sample for our various tests and finally tests are performed after 6 hours, 3days and 7 days mixing of bacteria and cementing agent and also in between cementing agent is mixed.

3.4 MICP (Microbial induced calcite precipitation):- In this method, Calcite Precipitates will be induced with help of an aerobic urease producing bacteria, i.e. Bacillus *Sphaericus*. The soil will be directly mixed with the prepared solutions of nutrient broth and Bacillus *Sphaericus*. Concentration of Bacillus *Sphaericus* will be 1×10^8 cfu/ml.

Concentration of Nutrient Broth that will be added will be 3 gm /litre. Nutrient Broth is needed to be added to soil because it is necessary for survival of Bacteria in soil. Concentration of Nutrient Broth is selected based on earlier studies done and 3 gm /litre were found to be most viable amount.

Composition of chemicals used in bacterial reagent and cementation reagent per litre (Dejong *et al.*, 2006; Qabany *et al*., 2011; Stocks-Fischer *et al*., 1999; Stoner *et al*., 2005)

• Nutrient broth 3g/l

• Urea (NH2-CO-NH2) 20g/l

• Ammonium chloride (NH4Cl) 10 g/l

• Sodium bi-carbonate (NaHCO3) 2.12 g/l

For Bacterial reagent 100ml per kg of soil

• $1*10^8$ cells/ml Bacillus *Sphaericus*

• 2 ml Calcium Chloride solution (140g/l)

For Cementation reagent 72ml per kg of soil

• 1.44 ml Calcium Chloride solution (140g/l)

Bacteria and cementation reagents are mixed as per OMC of soil. After addition of Bacteria, soil will be compacted to Maximum Dry Density and to this cementation reagent will be added.

The soil will be placed in a mould and cementation reagent will be supplied from relatively higher level.

The cementation reagent for the MICP treatment will consist of urea and calcium chloride. The urea and calcium chloride serve as important ingredients for promoting calcite precipitation. Concentration of cementation reagent will be 1 M. This concentration is selected based on study performed by Lee M.L. et al. [2012] on similar type of soil.

The cementation reagent will be added from separate container and will be added from top and cementation reagent will be flowed into the soil. Effect of calcite precipitation will be studied on compressive strength, shear parameters and CBR value of soil.

Amount of cementation reagent will be varied, which in turn will vary the amount of calcite precipitated. The soil specimen will be taken out of mould and will be tested for compressive strength, shear parameters and CBR Values.

CHAPTER-4
RESULTS AND DISCUSSION

4.1 SOIL PROPERTIES

The tests on soil sample taken from Delhi technological university is performed and various basic properties are found out like grain size, optimum water content, maximum dry density, liquid limit, plastic limit, plastic index, specific gravity, etc.

Table 4.1 Basic Properties Test Results

Area	DTU Campus, Delhi
Depth	0.5m
Grain Size Analysis	
Gravel	3.54%
Sand	80.2%
Fines(silt + clay)	16.26%
Index Properties	
Liquid limit %	24.20%
Plastic limit%	20.64%
Plasticity Index%	3.56%
Specific Gravity	2.579
Engineering Properties	
Optimum Moisture Content(OMC)	17.274%
Maximum Dry Density(MDD)	1.7275 g/cm^3

4.1.1 SIEVE ANALYSIS

Sieve analysis is done to know about the various sizes of particles present in soil. After doing sieve analysis on both virgin and bacterial treated soil we find that there is not much change on the particles of soil.

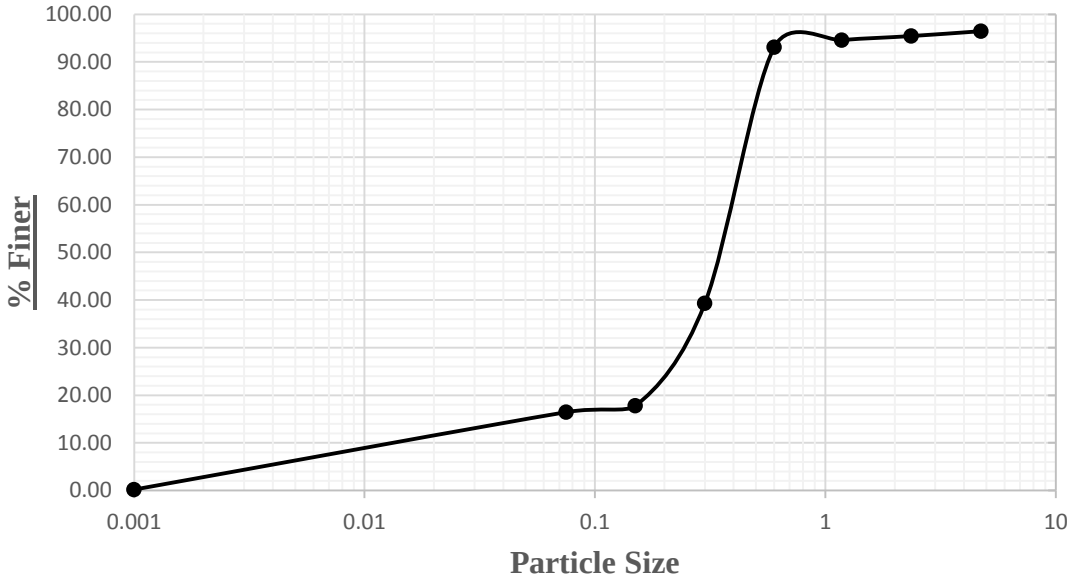


Figure 4.1: grain size analysis

Table 4.2 Grain Size Analysis Values

S. no.	Sieve Size (mm)	Mass of Soil retained (gm.)	Percentage on each Sieve Retained Mass of soil/Wt. *100	Cumulative % retained	% Finer, 100-cumulative retained
1	4.75	35.42	3.54	3.54	96.46
2	2.36	10.24	1.02	4.57	95.43
3	1.18	8.42	0.84	5.41	94.59
4	0.6	15.2	1.52	6.93	93.07
5	0.3	537.75	53.78	60.70	39.30
6	0.15	214.98	21.50	82.20	17.80
7	0.075	13.45	1.35	83.55	16.45
8	0.001	162.58	16.26	99.80	0.20

4.1.2 LIQIUD LIMIT

Liquid limit tell us about the water content at which soil starts flowing and at this point shear strength of soil becomes zero. The liquid limit for given soil sample is 24.20 percent.

Table 4.3 Liquid Limit Determination

No. of blows	Water content
14	60.26
19	39.42
24	27.12
30	18.10

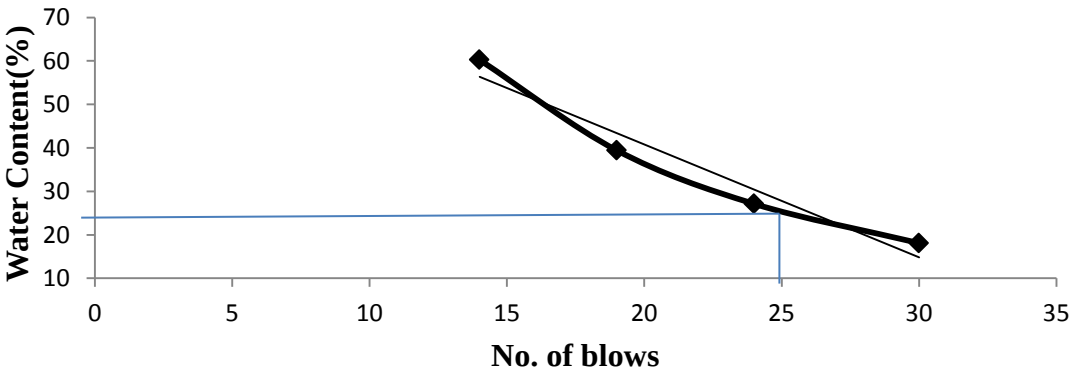


Figure 4.2 liquid limit

4.1.3 PLASTIC LIMIT

Weight of empty pan = 13.84 gm

Weight of pan + weight of soil =29.56 gm

Weight of pan + dried sample = 26.87 gm

The plastic limit of the adopted sample is 20.64 percent

4.1.4 STANDARD PROCTOR'S TESTS

Standard procter test is done to know about the optical moisture content of soil. It is that value at which we get the maximum dry density of soil. Bacteria is added according to the optical moisture content of soil which we get in this test.

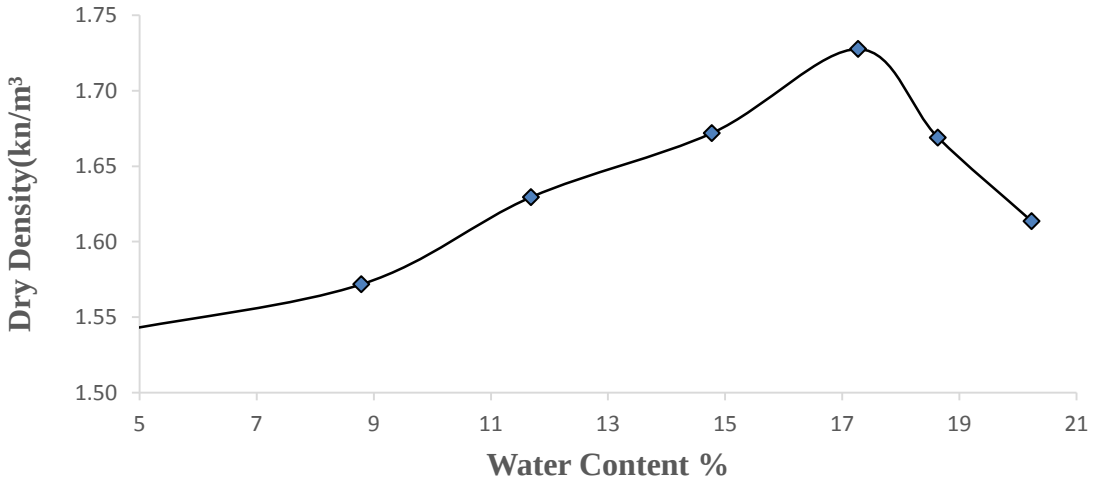


Figure4.3 Proctor Compaction

4.1.5 UNCONFINED COMPRESSIVE STRENGTH TEST (UCS)

This test is type of Tri-axial test in which no confining pressure is applied, therefore this test is used to determine undrained unconfined compressive strenght of soil. This test cannot be performed with cohesion less soils because such soils are not able to stand freely without any confinement.

Length of sample = 7.6 cm

Diameter of sample = 3.8 cm

Area of sample = 11.341 cm^2

UCS value of virgin soil is 19.01 KN/sq.m

Table no.4.4 For Virgin Soil

ΔL, mm	Dial gauge reading	Load, P, kg	Ɛ = ΔL/L	A = A_0/1-Ɛ	σ = P/A kg/sq.cm	σ kN/sq.m
0	0	0	0	0	0	0
0.5	0.2	0.658512	0.006579	11.41626	0.057682	5.656636
1	0.3	0.987768	0.013158	11.49236	0.08595	8.428763
1.5	0.4	1.317023	0.019737	11.56949	0.113836	11.16343
2	0.5	1.646279	0.026316	11.64767	0.14134	13.86063
2.5	0.6	1.975535	0.032895	11.7269	0.168462	16.52037
3	0.63	2.074312	0.039474	11.80722	0.175682	17.22839
3.5	0.66	2.173089	0.046053	11.88865	0.182787	17.92517
4	0.68	2.23894	0.052632	11.97121	0.187027	18.34099
4.5	0.69	2.271865	0.059211	12.05493	0.188459	18.48147
5	0.7	2.304791	0.065789	12.13982	0.189854	18.6182
5.5	0.71	2.337717	0.072368	12.22592	0.19121	18.75119
6	0.72	2.370642	0.078947	12.31325	0.192528	18.88043
6.5	0.73	2.403568	0.085526	12.40183	0.193807	19.00592
7	0.72	2.370642	0.092105	12.4917	0.189777	18.61071
7.5	0.71	2.337717	0.098684	12.58288	0.185785	18.21924
8	0.71	2.337717	0.105263	12.6754	0.184429	18.08625
8.5		0	0.111842	12.76929	0	0
9		0	0.118421	0	0	0

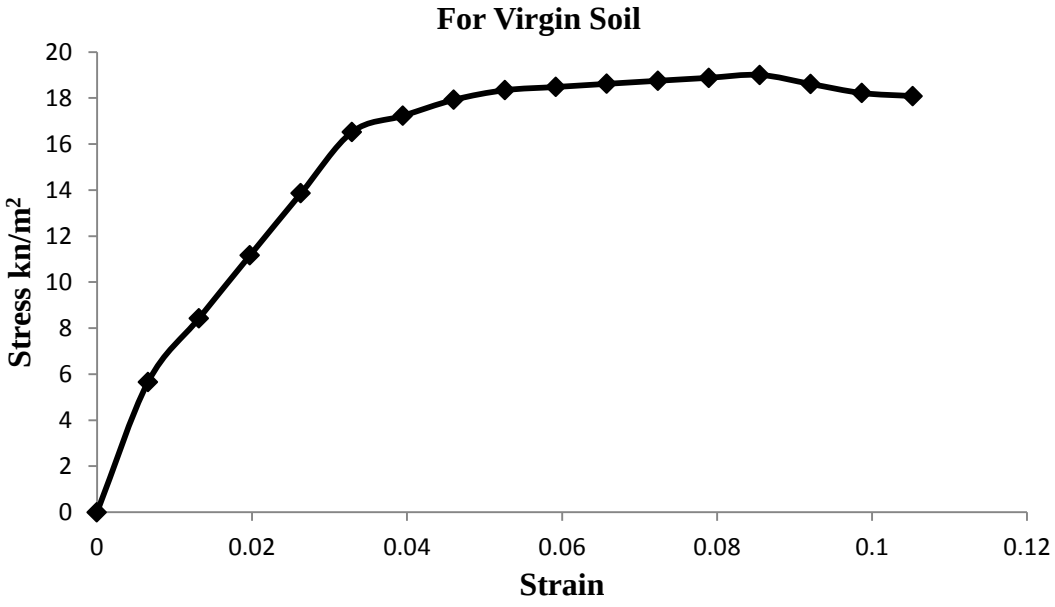


Figure 4.4 for virgin soil

UCS value for soil treated with MICP after 8 hours is 30.16KN/sq.m

Table 4.5 For 8 hour Treated Soil

ΔL, mm	Dial gauge reading	Load, P, kg	Ɛ = ΔL/L	A = A_0/1-Ɛ	σ = P/A	Column1
0	0	0	0	0	0	0
0.5	0.2	0.658512	0.006579	11.41626	0.057682	5.656636
1	0.4	1.317023	0.013158	11.49236	0.1146	11.23835
1.5	0.5	1.646279	0.019737	11.56949	0.142295	13.95428
2	0.6	1.975535	0.026316	11.64767	0.169608	16.63276
2.5	0.7	2.304791	0.032895	11.7269	0.196539	19.27377
3	0.8	2.634047	0.039474	11.80722	0.223088	21.87732
3.5	0.85	2.798675	0.046053	11.88865	0.235407	23.08544
4	0.9	2.963303	0.052632	11.97121	0.247536	24.27484
4.5	1	3.292559	0.059211	12.05493	0.27313	26.78473
5	1.05	3.457187	0.065789	12.13982	0.284781	27.9273
5.5	1.1	3.621814	0.072368	12.22592	0.296241	29.05114
6	1.15	3.786442	0.078947	12.31325	0.30751	30.15624
6.5	1.1	3.621814	0.085526	12.40183	0.292039	28.63906
7	1.05	3.457187	0.092105	12.4917	0.276759	27.14062
7.5	1	3.292559	0.098684	12.58288	0.26167	25.6609

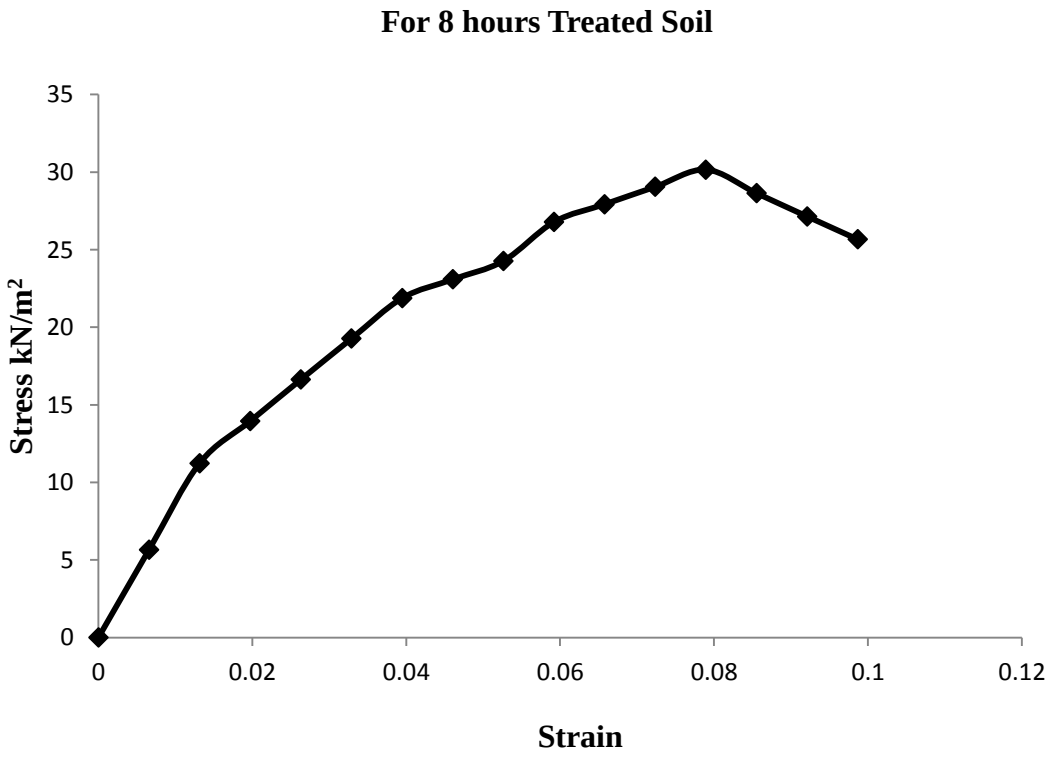


Figure 4.5 for 8 hours treated soil

UCS value for soil treated with MICP after 3 days is 75.50KN/sq.m

Table 4.6 For 3 days Treated Soil

ΔL, mm	Dial gauge reading	Load, P, kg	Ɛ = ΔL/L	A = A_0/1-Ɛ	σ = P/A	Column1
0	0	0	0	0	0	0
0.5	0.5	1.646279	0.006579	11.41626	0.144205	14.14159
1	0.7	2.304791	0.013158	11.49236	0.20055	19.66711
1.5	1	3.292559	0.019737	11.56949	0.28459	27.90857
2	1.5	4.938838	0.026316	11.64767	0.424019	41.5819
2.5	1.8	5.926606	0.032895	11.7269	0.505385	49.56112
3	2	6.585117	0.039474	11.80722	0.557719	54.6933
3.5	2.1	6.914373	0.046053	11.88865	0.581594	57.03463
4	2.2	7.243629	0.052632	11.97121	0.605087	59.33849
4.5	2.3	7.572885	0.059211	12.05493	0.628198	61.60489
5	2.4	7.902141	0.065789	12.13982	0.650927	63.83383
5.5	2.5	8.231397	0.072368	12.22592	0.673274	66.02531
6	2.8	9.219164	0.078947	12.31325	0.748719	73.42389
6.5	2.9	9.54842	0.085526	12.40183	0.76992	75.50298
7	2.8	9.219164	0.092105	12.4917	0.738023	72.37498
7.5	2.6	8.560652	0.098684	12.58288	0.680341	66.71834
8	2.5	8.231397	0.105263	12.6754	0.649399	63.68398
8.5	2.4	7.902141	0.111842	12.76929	0.618839	60.68709

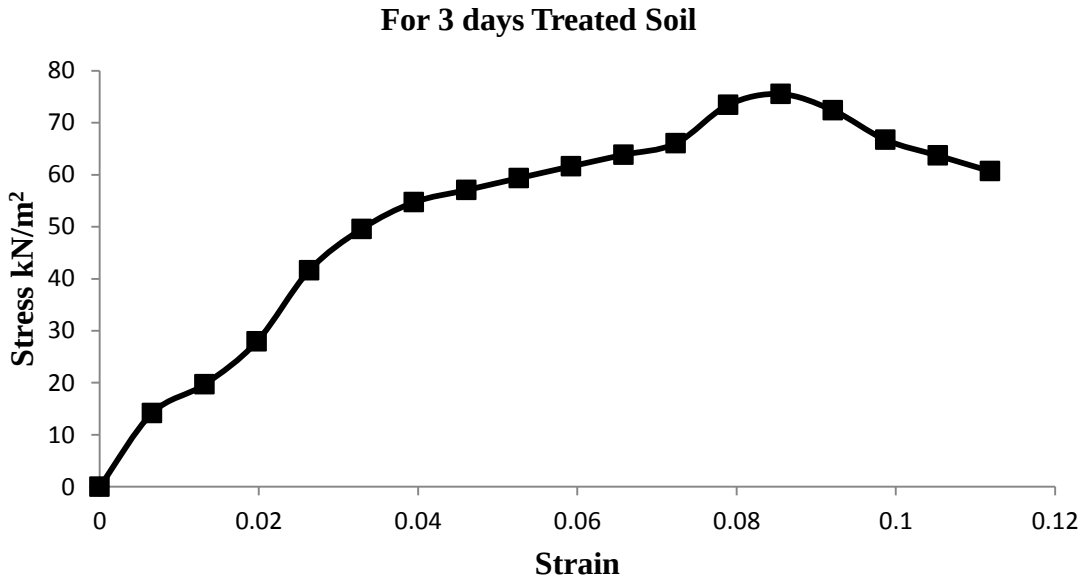


Figure 4.6 for 3 days treated soil

UCS value for soil treated with MICP after 7 days is 89.79KN/sq.m

Table 4.7 For 7 days Treated Soil

ΔL, mm	Dial gauge reading	Load, P, kg	Ɛ = ΔL/L	A = A_0/1-Ɛ	σ = P/A	Column1
0	0	0	0	0	0	0
0.5	0.7	2.304791	0.006579	11.41626	0.201887	19.79823
1	1.2	3.95107	0.013158	11.49236	0.3438	33.71505
1.5	2	6.585117	0.019737	11.56949	0.569179	55.81714
2	2.5	8.231397	0.026316	11.64767	0.706699	69.30316
2.5	2.6	8.560652	0.032895	11.7269	0.730001	71.58829
3	2.7	8.889908	0.039474	11.80722	0.752921	73.83596
3.5	2.8	9.219164	0.046053	11.88865	0.775459	76.04617
4	3	9.877676	0.052632	11.97121	0.825119	80.91612
4.5	3.1	10.20693	0.059211	12.05493	0.846702	83.03268
5	3.3	10.86544	0.065789	12.13982	0.895025	87.77152
5.5	3.4	11.1947	0.072368	12.22592	0.915653	89.79442
6	3.2	10.53619	0.078947	12.31325	0.855679	83.91302
6.5	3.1	10.20693	0.085526	12.40183	0.823018	80.71009
7	3	9.877676	0.092105	12.4917	0.790739	77.54462
7.5	3	9.877676	0.098684	12.58288	0.785009	76.9827
8	2.9	9.54842	0.105263	12.6754	0.753303	73.87342
8.5	2.8	9.219164	0.111842	12.76929	0.721979	70.80161

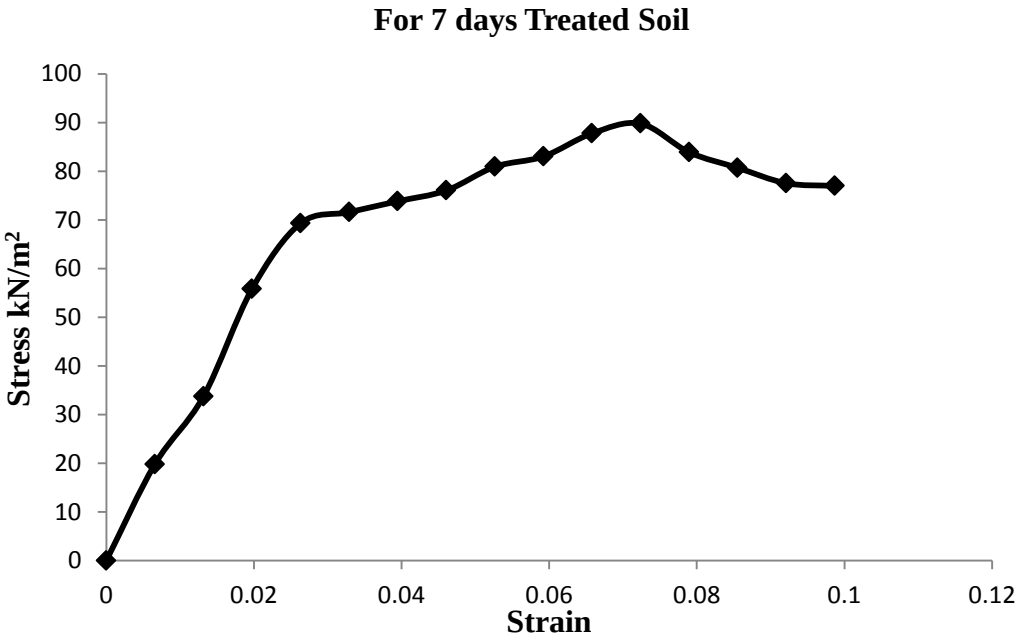


Figure 4.7 for 7 days treated soil

Combined graph

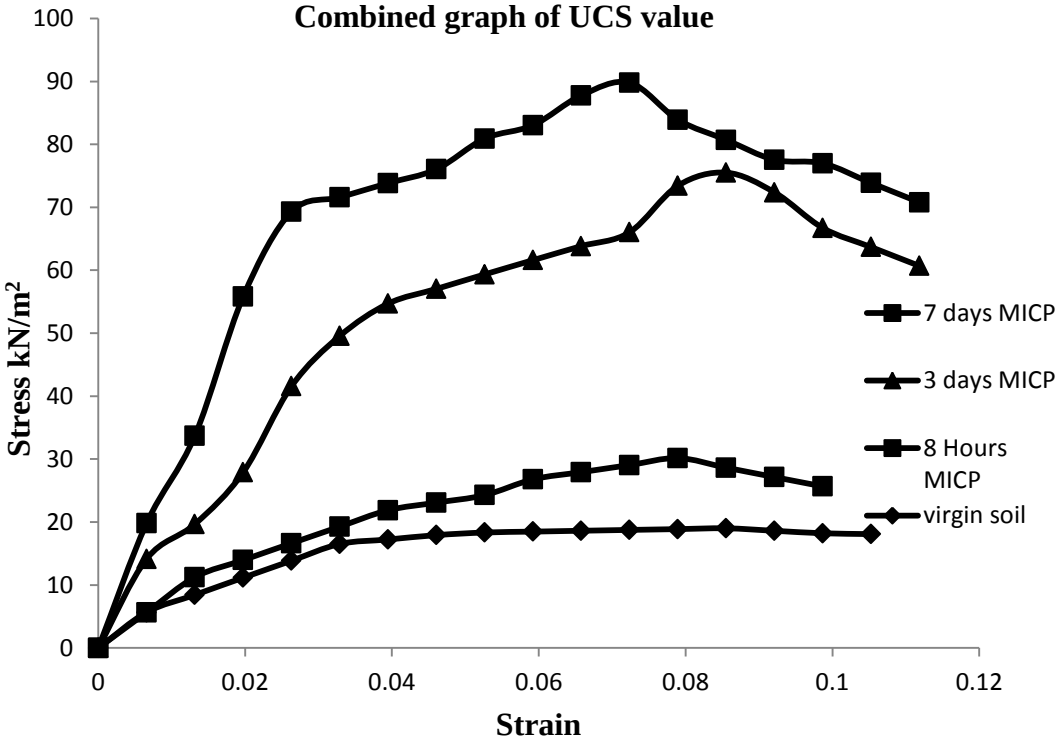


Figure 4.8 combined graph of all UCS tests

4.1.6 CALIFORNIA BEARING RATIO (CBR)

CBR value is the percentage of force per unit area required to penetrate a soil mass with circular plunger of 50mm diameter at the rate of 1.25mm/min to that required for corresponding penetration in a standard material. CBR test is used for the evaluation of strength and this test is generally used for road pavement and it is very significant for the geotechnical engineering. For virgin soil the CBR value is low but after calcite precipitation CBR value increases because more resistant occur against the penetration of soil due to biocementation of soil.

CBR value for unsoaked soil sample without bacterial treatment is 7.02

Table 4.8 CBR value for Unsoaked Sample without Bacteria

Penetration	dial gauge reading	actual reading	load, kg	CBR value
0	0	0	0	
0.5	2.1	10.5	41.223	
1	2.85	14.25	55.9455	
1.5	3.45	17.25	67.7235	
2	4.2	21	82.446	
2.5	4.9	24.5	96.187	7.02
3	5.15	25.75	101.0945	
3.5	5.9	29.5	115.817	
4	6.2	31	121.706	
4.5	6.85	34.25	134.4655	
5	7.2	36	141.336	6.87
5.5	7.85	39.25	154.0955	
6	8.2	41	160.966	

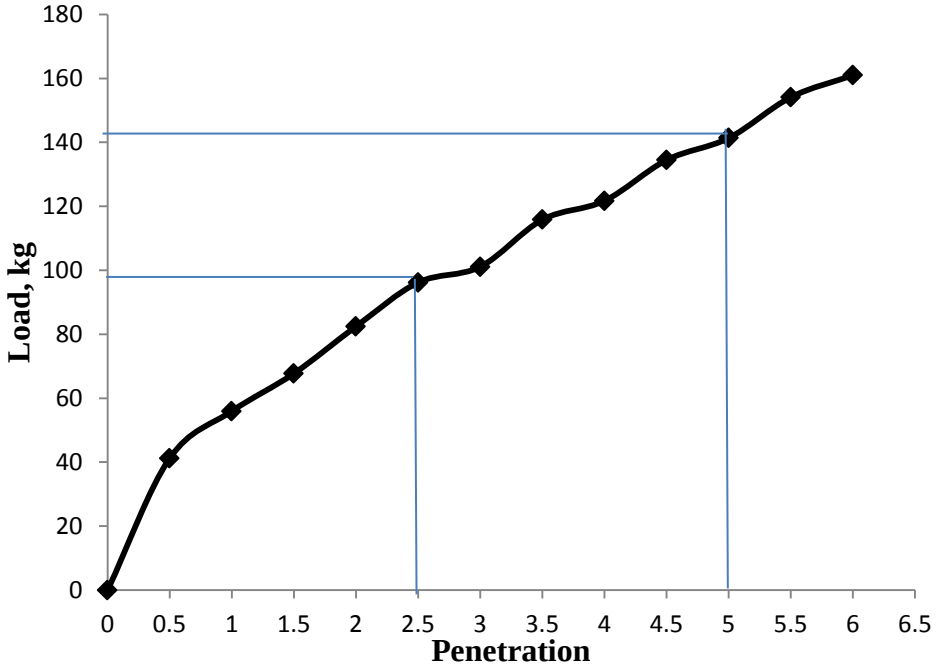


Figure 4.9 For CBR value for Unsoaked Sample without Bacteria

CBR value for unsoaked soil sample with bacterial treatment is 11.61

Table 4.9 CBR value for Unsoaked Sample with Bacteria

Penetration	Dial gauge reading	Actual reading	Load, kg	CBR value
0	0	0	0	
0.5	2.6	13	51.038	
1	4.8	24	94.224	
1.5	6.4	32	125.632	
2	7.2	36	141.336	
2.5	8.1	40.5	159.003	11.60
3	8.95	44.75	175.6885	
3.5	9.7	48.5	190.411	
4	10.45	52.25	205.1335	
4.5	11.6	58	227.708	
5	12.1	60.5	237.523	11.55
5.5	13.1	65.5	257.153	
6	13.6	68	266.968	

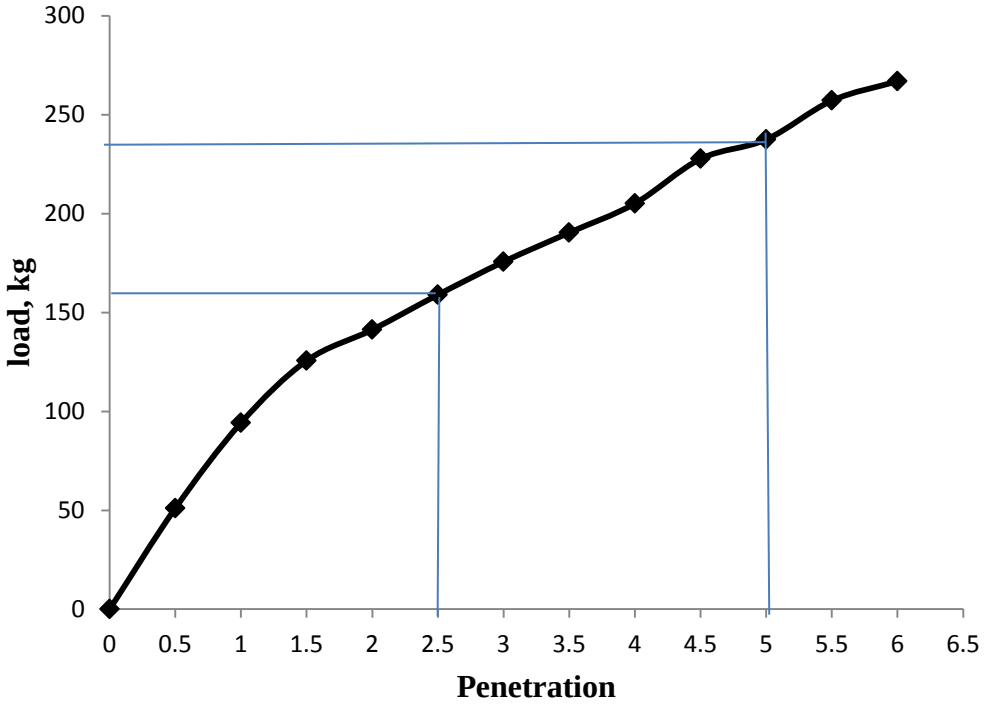


Figure 4.10 For CBR value for unsoaked sample with bacteria

CBR value for 3 days soaked soil sample without bacterial treatment is 3.29

Table 4.10 CBR value for 3 days Soaked Sample without Bacteria

Penetration	Dial gauge reading	Actual reading	Load, kg	CBR value
0	0	0	0	
0.5	0.8	4	15.704	
1	1.2	6	23.556	
1.5	1.6	8	31.408	
2	2	10	39.26	
2.5	2.3	11.5	45.149	3.29
3	2.45	12.25	48.0935	
3.5	2.6	13	51.038	
4	2.7	13.5	53.001	
4.5	2.85	14.25	55.9455	
5	3.2	16	62.816	3.05
5.5	3.45	17.25	67.7235	
6	3.7	18.5	72.631	

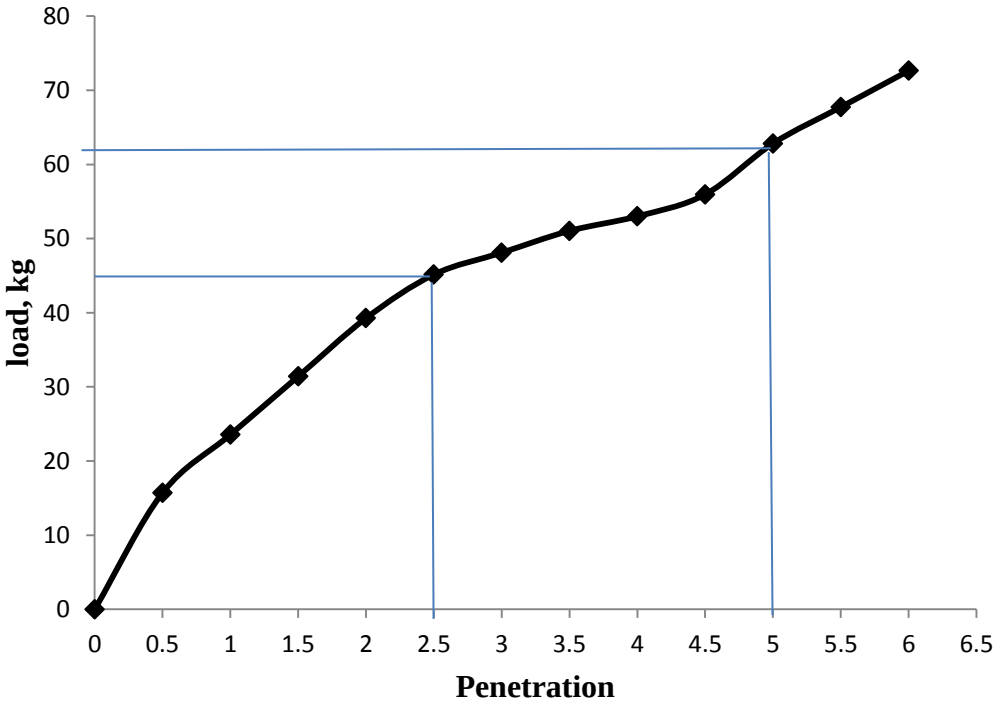


Figure 4.11 for CBR value for 3 days soaked sample without bacteria

CBR value for 3 days Soaked Soil sample with Bacterial treatment is 5.15

Table 4.11 CBR value for 3 days Soaked Sample with Bacteria

Penetration	Dial gauge reading	Actual reading	Load, kg	CBR value
0	0	0	0	
0.5	1.1	5.5	21.593	
1	1.7	8.5	33.371	
1.5	2.2	11	43.186	
2	2.9	14.5	56.927	
2.5	3.6	18	70.668	5.15
3	4.2	21	82.446	
3.5	4.4	22	86.372	
4	4.6	23	90.298	
4.5	4.8	24	94.224	
5	5	25	98.15	4.77
5.5	5.3	26.5	104.039	
6	5.5	27.5	107.965	

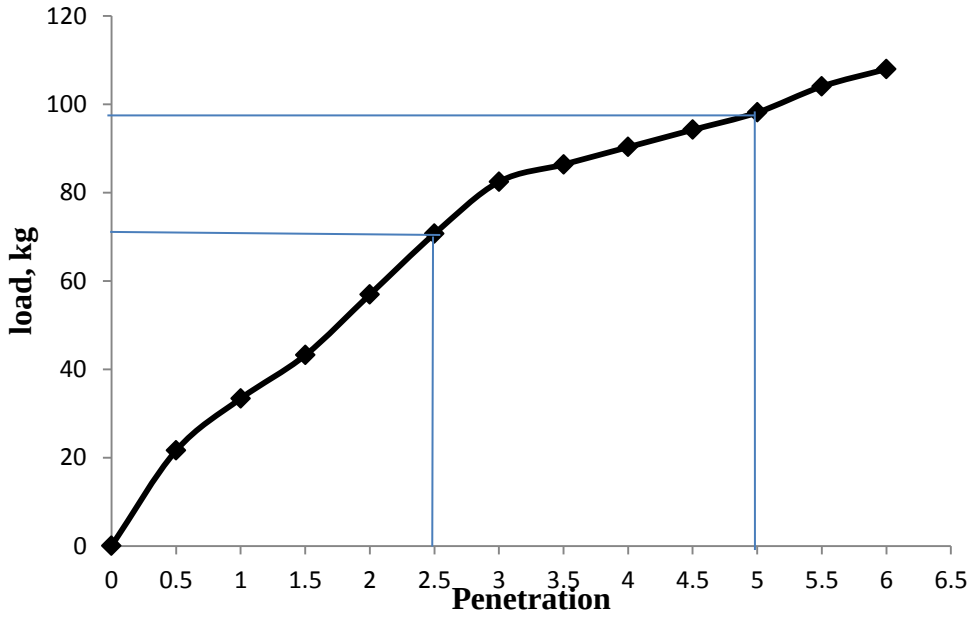


Figure 4.12 for CBR value for 3 days soaked sample with bacteria

CBR value for 7 days soaked soil sample without bacterial treatment is 1.86

Table 4.12 CBR value for 7 days Soaked Sample without Bacteria

Penetration	Dial gauge reading	Actual reading	Load, kg	CBR value
0	0	0	0	
0.5	0.15	0.75	2.9445	
1	0.3	1.5	5.889	
1.5	0.7	3.5	13.741	
2	1.1	5.5	21.593	
2.5	1.3	6.5	25.519	1.86270073
3	1.4	7	27.482	
3.5	1.5	7.5	29.445	
4	1.6	8	31.408	
4.5	1.65	8.25	32.3895	
5	1.8	9	35.334	1.71941606
5.5	1.85	9.25	36.3155	
6	1.9	9.5	37.297	

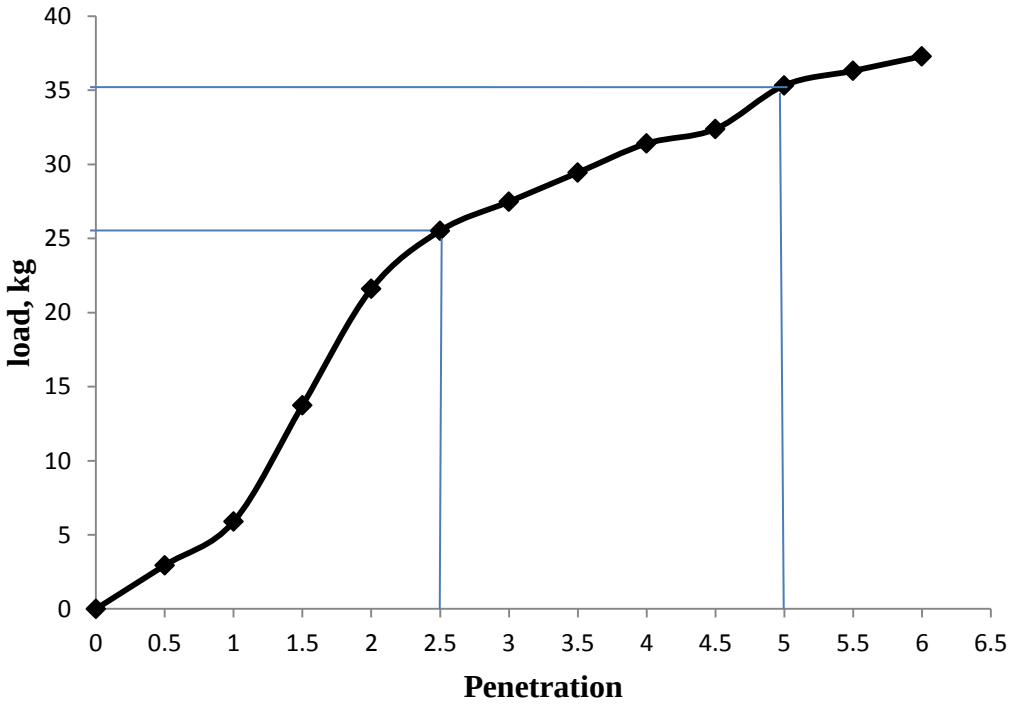


Figure 4.13 for CBR value for 7 days soaked sample without bacteria

CBR value for 7 days soaked soil sample with bacterial treatment is 2.08

Table 4.13 CBR value for 7 days soaked sample with bacteria

Penetration	Dial gauge reading	Actual reading	Load, kg	CBR value
0	0	0	0	
0.5	0.4	2	7.852	
1	0.6	3	11.778	
1.5	0.95	4.75	18.6485	
2	1.2	6	23.556	
2.5	1.45	7.25	28.4635	2.07762774
3	1.6	8	31.408	
3.5	1.75	8.75	34.3525	
4	1.85	9.25	36.3155	
4.5	2	10	39.26	
5	2.1	10.5	41.223	2.0059854
5.5	2.15	10.75	42.2045	
6	2.2	11	43.186	

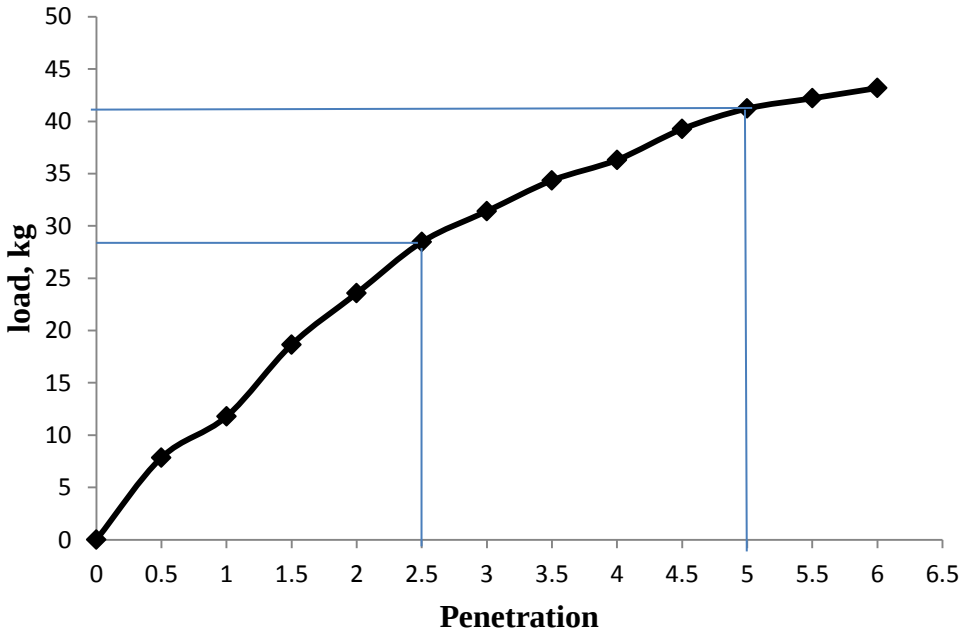


Figure 4.14 for CBR value for 7 days soaked sample with bacteria

4.1.7 TRIAXIAL TEST

Tri-axial test is used to find the mechanical properties of soil and it will give us shear parameters of soil. Stress is applied along the one axis of the sample not on its perpendicular direction, in perpendicular direction stress is applied by the fluid which is water. Finally we will make mohr circle in graph between shear stress and normal stress. We will make three more circle using three different cell pressure and finally a line tangential to all three circles give us the value of shear parameter.

Length of sample = 7.6 cm

Diameter of sample = 3.8 cm

Area of sample = 11.341 cm^2

Angle of friction of virgin soil=25.8º and cohesion was 9.33KN/m^2

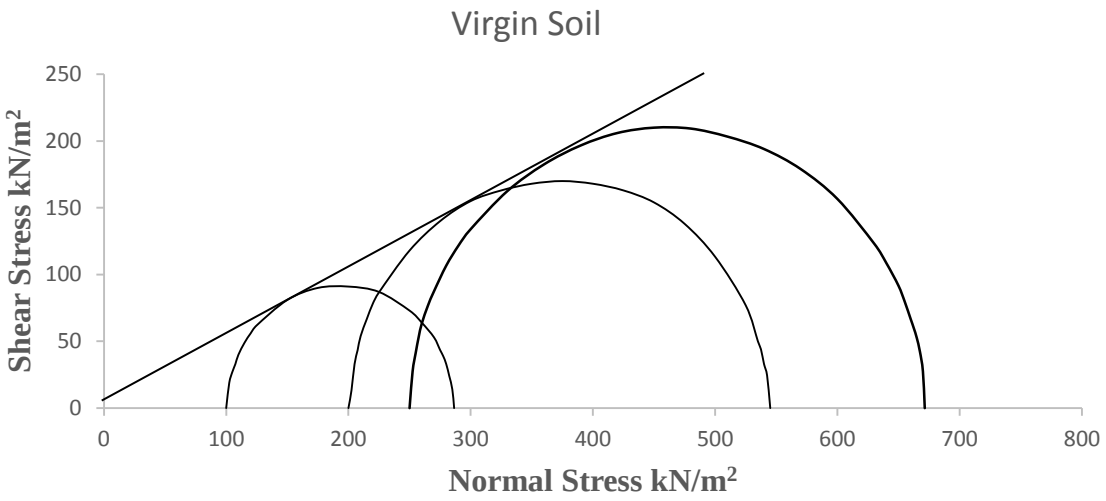


Figure 4.15 Mohr circle of virgin soil

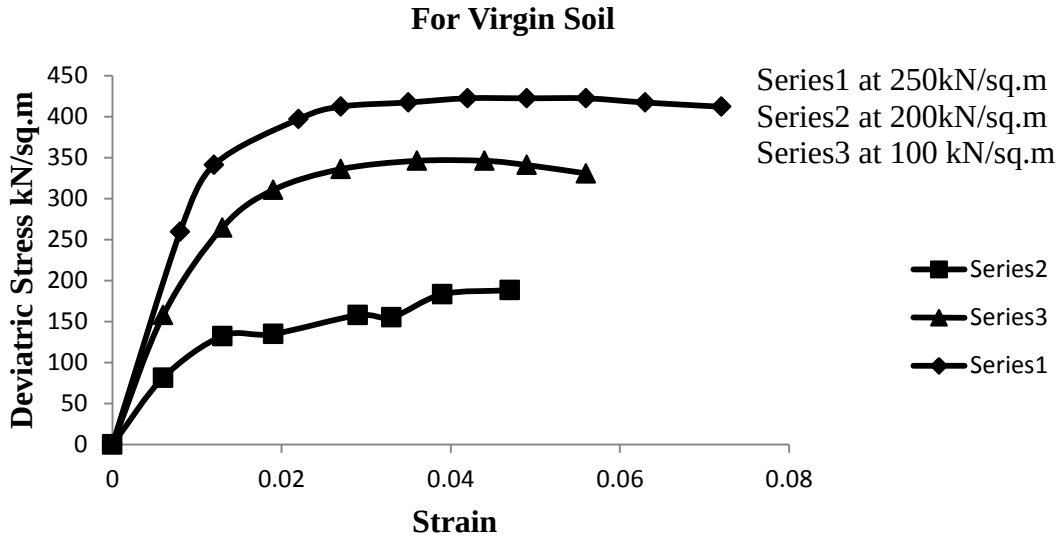


Fig 4.16 stress v/s strain curve for virgin soil

Table 4.14 At 100kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	100.00	200
75.3	0.7	95	0.009211	1144.66	82.99	182.99	282.9942
74.6	1.4	155	0.018421	1155.40	134.15	234.15	334.1528
73.9	2.1	160	0.027632	1166.34	137.18	237.18	337.1809
73.2	2.8	185	0.036842	1177.50	157.11	257.11	357.113
72.5	3.5	185	0.046053	1188.87	155.61	255.61	355.6106
71.8	4.2	220	0.055263	1200.46	183.26	283.26	383.2637
71.1	4.9	230	0.064474	1212.27	189.73	289.73	389.726

Table 7.15 At 200kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	200.00	400.00
75.3	0.7	180	0.009211	1144.66	157.25	357.25	557.25
74.6	1.4	305	0.018421	1155.40	263.98	463.98	663.98
73.9	2.1	360	0.027632	1166.34	308.66	508.66	708.66
73.2	2.8	395	0.036842	1177.50	335.46	535.46	735.46
72.5	3.5	410	0.046053	1188.87	344.87	544.87	744.87
71.8	4.2	415	0.055263	1200.46	345.70	545.70	745.70
71.1	4.9	415	0.064474	1212.27	342.33	542.33	742.33
70.4	5.6	405	0.073684	1224.33	330.79	530.79	730.79

Table 7.16 At 250kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	250.00	500.00
75.3	0.7	300	0.009211	1144.66	262.09	512.09	762.09
74.6	1.4	395	0.018421	1155.40	341.87	591.87	841.87
73.9	2.1	465	0.027632	1166.34	398.68	648.68	898.68
73.2	2.8	485	0.036842	1177.50	411.89	661.89	911.89
72.5	3.5	495	0.046053	1188.87	416.36	666.36	916.36
71.8	4.2	505	0.055263	1200.46	420.67	670.67	920.67
71.1	4.9	510	0.064474	1212.27	420.70	670.70	920.70
70.4	5.6	520	0.073684	1224.33	424.72	674.72	924.72
69.7	6.3	515	0.082895	1236.62	416.46	666.46	916.46
68.8	7.2	515	0.094737	1252.80	411.08	661.08	911.08

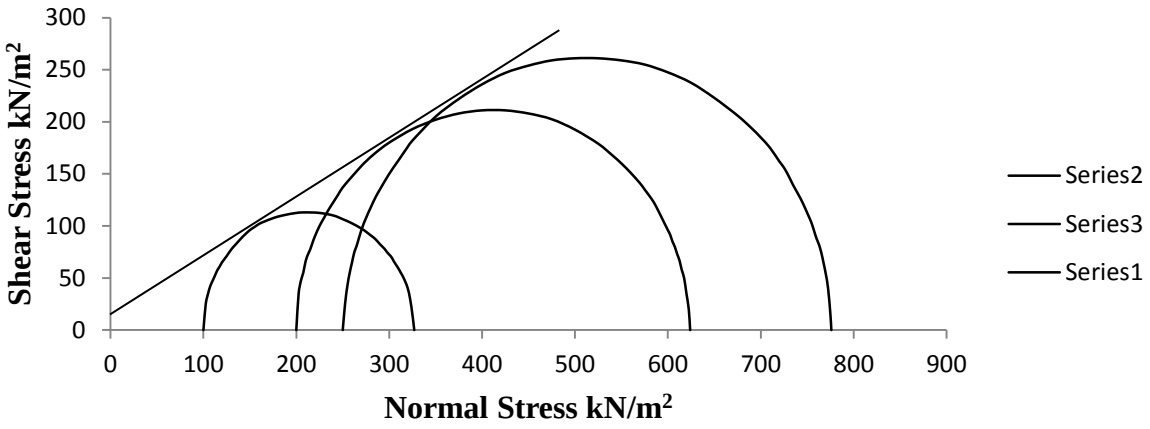


Figure 4.17 Mohr circle of 8 hour treated soil

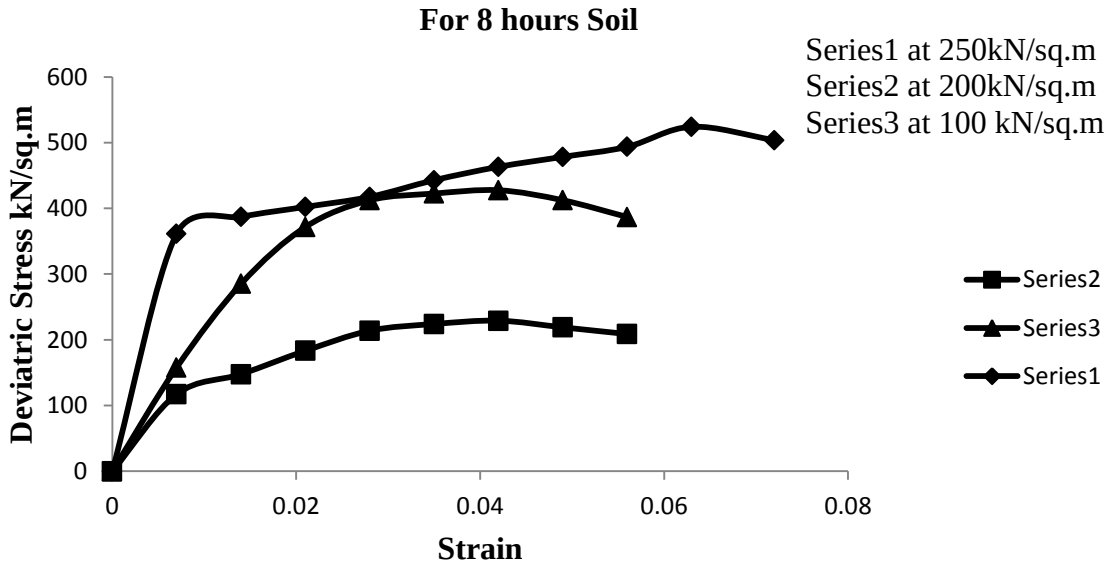


Figure no. 4.18 stress v/s strain curve for 8 hours treated soil

Table 7.17 At 100kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	100.00	200
75.3	0.7	135	0.009211	1144.66	117.94	217.94	317.9392
74.6	1.4	170	0.018421	1155.40	147.14	247.14	347.1354
73.9	2.1	215	0.027632	1166.34	184.34	284.34	384.3369
73.2	2.8	250	0.036842	1177.50	212.31	312.31	412.3149
72.5	3.5	265	0.046053	1188.87	222.90	322.90	422.9016
71.8	4.2	275	0.055263	1200.46	229.08	329.08	429.0796
71.1	4.9	265	0.064474	1212.27	218.60	318.60	418.5973
70.4	5.6	255	0.073684	1224.33	208.28	308.28	408.2774

Table 7.18 At 200kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	200.00	400.00
75.3	0.7	180	0.009211	1144.66	157.25	357.25	557.25
74.6	1.4	330	0.018421	1155.40	285.62	485.62	685.62
73.9	2.1	435	0.027632	1166.34	372.96	572.96	772.96
73.2	2.8	485	0.036842	1177.50	411.89	611.89	811.89
72.5	3.5	505	0.046053	1188.87	424.77	624.77	824.77
71.8	4.2	515	0.055263	1200.46	429.00	629.00	829.00
71.1	4.9	500	0.064474	1212.27	412.45	612.45	812.45
70.4	5.6	475	0.073684	1224.33	387.97	587.97	787.97

Table 7.19 At 250kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	250.00	500.00
75.3	0.7	415	0.009211	1144.66	362.55	612.55	862.55
74.6	1.4	450	0.018421	1155.40	389.48	639.48	889.48
73.9	2.1	470	0.027632	1166.34	402.97	652.97	902.97
73.2	2.8	490	0.036842	1177.50	416.14	666.14	916.14
72.5	3.5	525	0.046053	1188.87	441.60	691.60	941.60
71.8	4.2	555	0.055263	1200.46	462.32	712.32	962.32
71.1	4.9	580	0.064474	1212.27	478.44	728.44	978.44
70.4	5.6	605	0.073684	1224.33	494.15	744.15	994.15
69.7	6.3	650	0.082895	1236.62	525.62	775.62	1025.62
68.8	7.2	630	0.094737	1252.80	502.87	752.87	1002.87

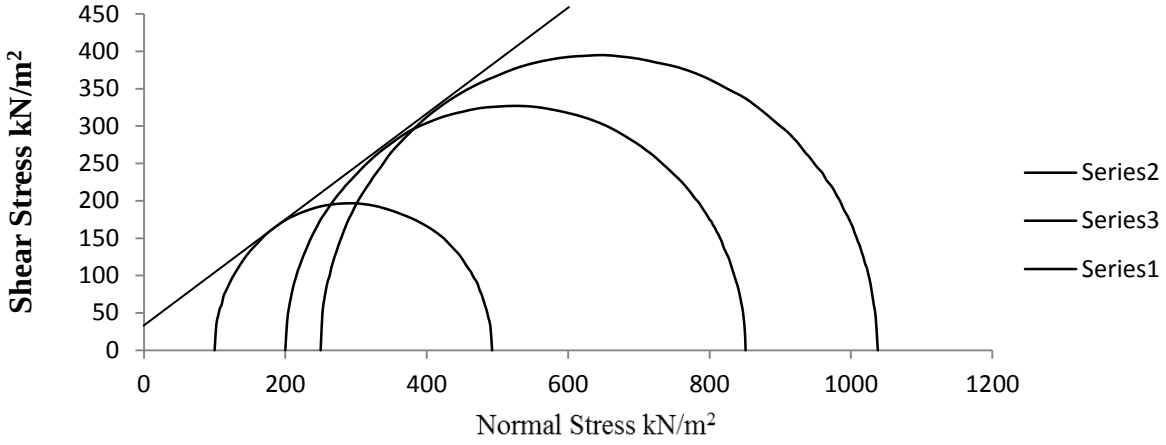


Figure 4.19 Mohr circle of 3 days treated soil

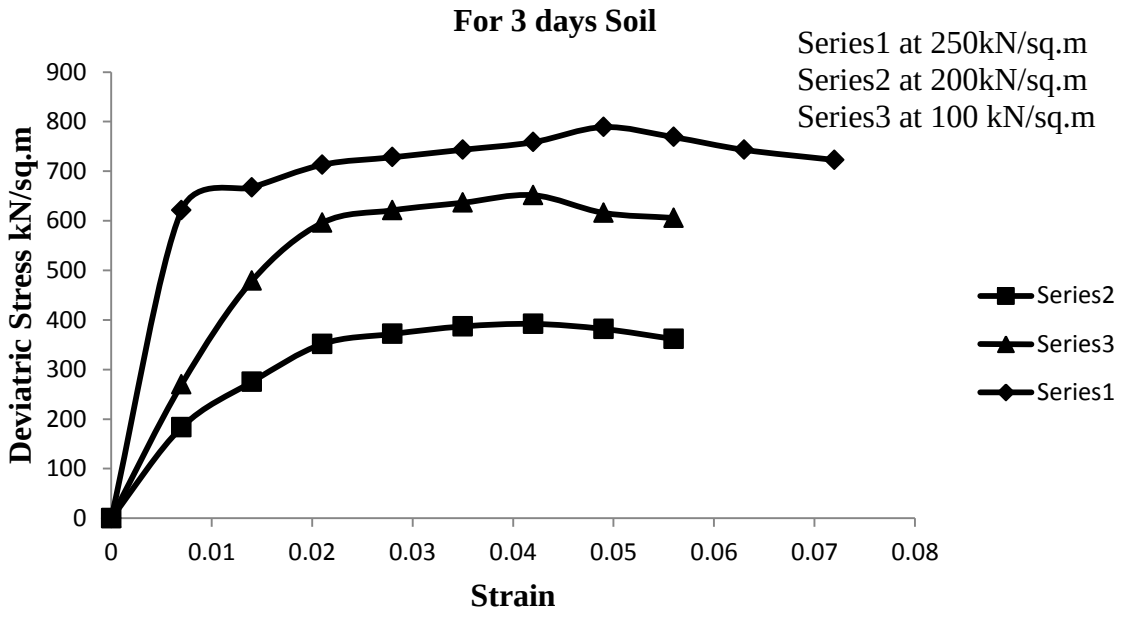


Figure no. 4.20 stress v/s strain curve for 3 days treated soil

Table 7.20 At 100kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	100.00	200
75.3	0.7	210	0.009211	1144.66	183.46	283.46	383.4609
74.6	1.4	320	0.018421	1155.40	276.96	376.96	476.9607
73.9	2.1	410	0.027632	1166.34	351.53	451.53	551.5261
73.2	2.8	440	0.036842	1177.50	373.67	473.67	573.6742
72.5	3.5	460	0.046053	1188.87	386.92	486.92	586.9236
71.8	4.2	470	0.055263	1200.46	391.52	491.52	591.5179
71.1	4.9	465	0.064474	1212.27	383.58	483.58	583.5764
70.4	5.6	440	0.073684	1224.33	359.38	459.38	559.3806

Table 7.21 At 200kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	200.00	400.00
75.3	0.7	310	0.009211	1144.66	270.82	470.82	670.82
74.6	1.4	555	0.018421	1155.40	480.35	680.35	880.35
73.9	2.1	695	0.027632	1166.34	595.88	795.88	995.88
73.2	2.8	730	0.036842	1177.50	619.96	819.96	1019.96
72.5	3.5	755	0.046053	1188.87	635.06	835.06	1035.06
71.8	4.2	780	0.055263	1200.46	649.75	849.75	1049.75
71.1	4.9	745	0.064474	1212.27	614.55	814.55	1014.55
70.4	5.6	740	0.073684	1224.33	604.41	804.41	1004.41

Table 7.22 At 250kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	250.00	500.00
75.3	0.7	710	0.009211	1144.66	620.27	870.27	1120.27
74.6	1.4	770	0.018421	1155.40	666.44	916.44	1166.44
73.9	2.1	830	0.027632	1166.34	711.63	961.63	1211.63
73.2	2.8	855	0.036842	1177.50	726.12	976.12	1226.12
72.5	3.5	885	0.046053	1188.87	744.41	994.41	1244.41
71.8	4.2	910	0.055263	1200.46	758.05	1008.05	1258.05
71.1	4.9	955	0.064474	1212.27	787.78	1037.78	1287.78
70.4	5.6	940	0.073684	1224.33	767.77	1017.77	1267.77
69.7	6.3	920	0.082895	1236.62	743.96	993.96	1243.96
68.8	7.2	905	0.094737	1252.80	722.38	972.38	1222.38

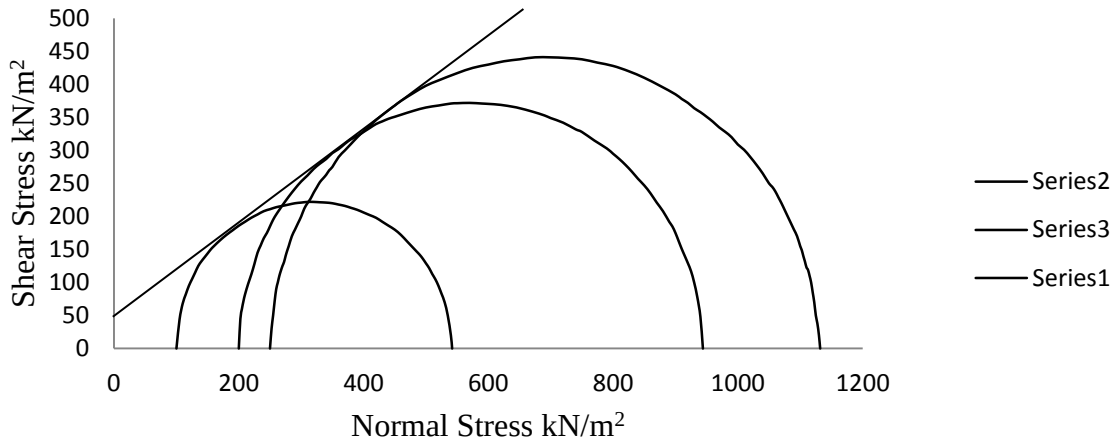


Figure 4.21 Mohr circle of 7 days treated soil

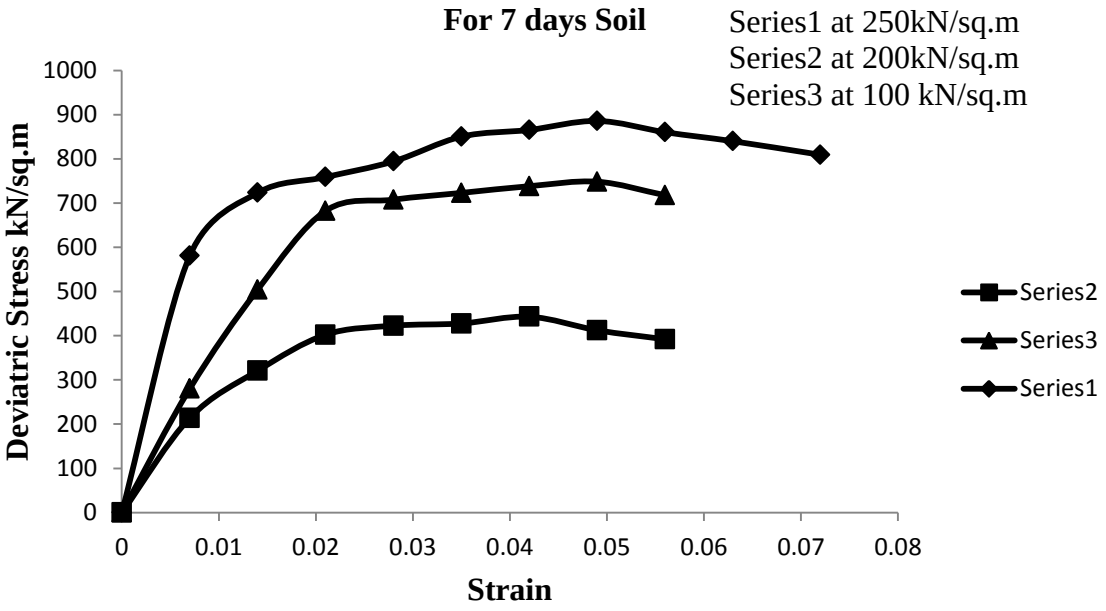


Figure no. 4.22 stress v/s Strain curve for 7 days treated soil

Table 7.23 At 100kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	100.00	200
75.3	0.7	245	0.009211	1144.66	214.04	314.04	414.0378
74.6	1.4	370	0.018421	1155.40	320.24	420.24	520.2358
73.9	2.1	470	0.027632	1166.34	402.97	502.97	602.969
73.2	2.8	495	0.036842	1177.50	420.38	520.38	620.3835
72.5	3.5	510	0.046053	1188.87	428.98	528.98	628.9805
71.8	4.2	530	0.055263	1200.46	441.50	541.50	641.4989
71.1	4.9	500	0.064474	1212.27	412.45	512.45	612.4477
70.4	5.6	480	0.073684	1224.33	392.05	492.05	592.0516

Table 7.24 At 200kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	200.00	400.00
75.3	0.7	320	0.009211	1144.66	279.56	479.56	679.56
74.6	1.4	580	0.018421	1155.40	501.99	701.99	901.99
73.9	2.1	795	0.027632	1166.34	681.62	881.62	1081.62
73.2	2.8	835	0.036842	1177.50	709.13	909.13	1109.13
72.5	3.5	860	0.046053	1188.87	723.38	923.38	1123.38
71.8	4.2	885	0.055263	1200.46	737.22	937.22	1137.22
71.1	4.9	905	0.064474	1212.27	746.53	946.53	1146.53
70.4	5.6	890	0.073684	1224.33	726.93	926.93	1126.93

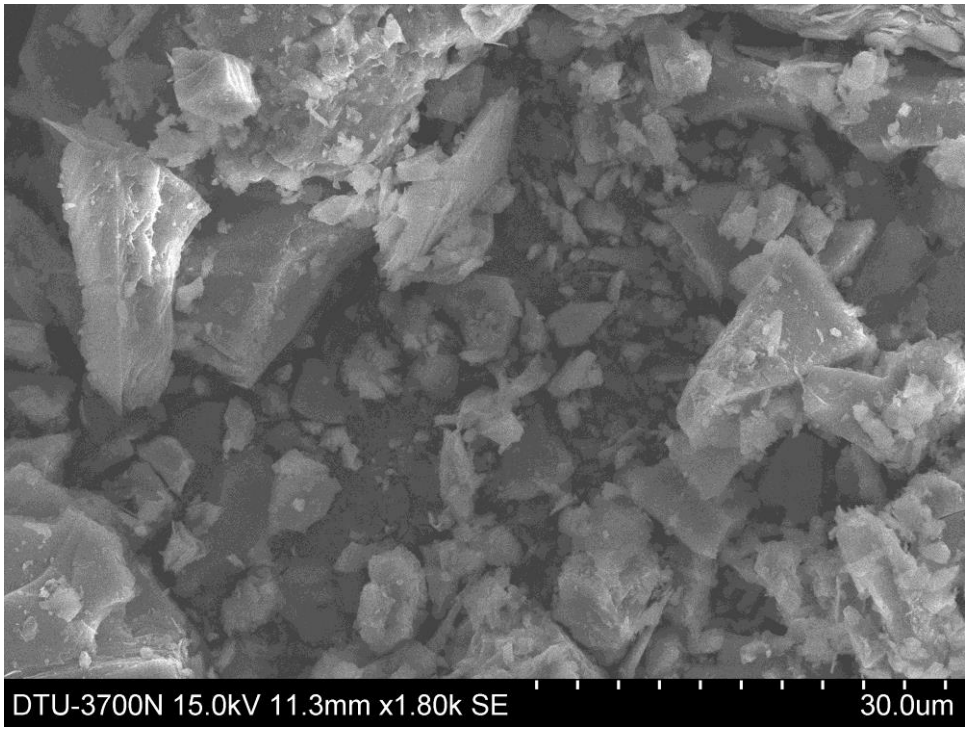
Table 7.25 At 250kN/sq.m Cell Pressure

L (mm)	**ΔL, mm**	**Load, P, kg**	**Ɛ = ΔL/L**	**A = A_0/1-Ɛ** (sq.mm)	**σ = P/A** (kN/sq.m)	Sig1 (kN/sq.m)	Sig1 + Sig3 (kN/sq.m)
76	0	0	0	1134.11	0	250.00	500.00
75.3	0.7	665	0.009211	1144.66	580.96	830.96	1080.96
74.6	1.4	835	0.018421	1155.40	722.69	972.69	1222.69
73.9	2.1	885	0.027632	1166.34	758.78	1008.78	1258.78
73.2	2.8	935	0.036842	1177.50	794.06	1044.06	1294.06
72.5	3.5	1010	0.046053	1188.87	849.55	1099.55	1349.55
71.8	4.2	1040	0.055263	1200.46	866.34	1116.34	1366.34
71.1	4.9	1075	0.064474	1212.27	886.76	1136.76	1386.76
70.4	5.6	1055	0.073684	1224.33	861.70	1111.70	1361.70
69.7	6.3	1040	0.082895	1236.62	841.00	1091.00	1341.00
68.8	7.2	1015	0.094737	1252.80	810.18	1060.18	1310.18

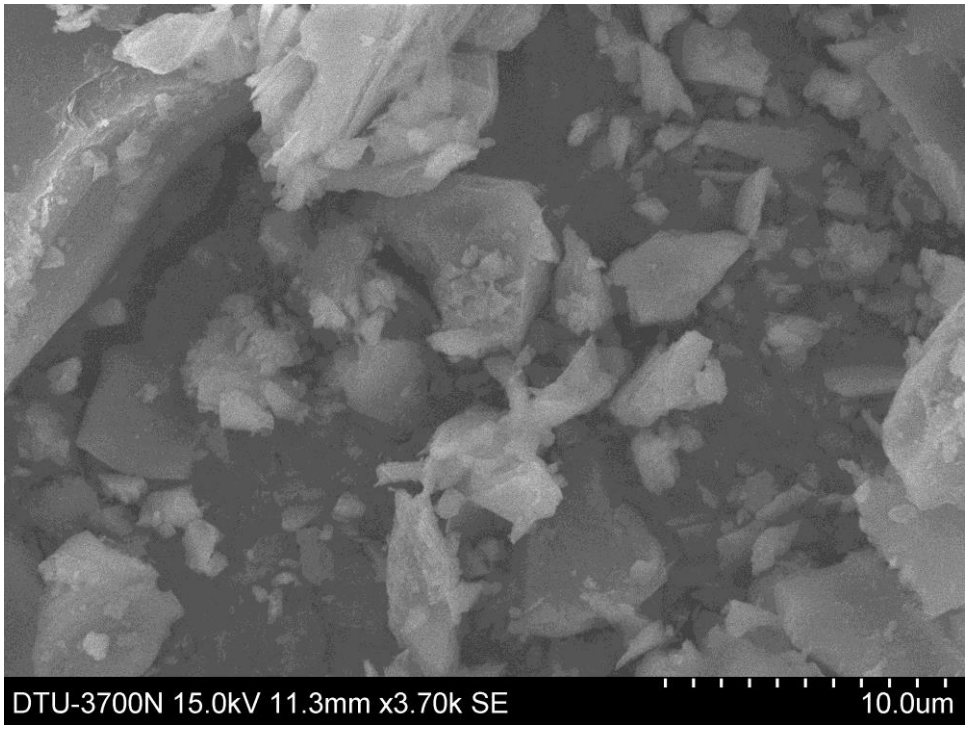
Table 4.26 Shear Parameter of Soil after Triaxial Test

S.No.	DTU soil	Angle of friction (^{o})	Cohesion KN/m^2
1.	Virgin soil	25.8	9.33
2.	Bacterial treated soil at 0 days	29	14
3.	Bacterial treated soil at 3 days	34	35
4.	Bacterial treated soil at 7 days	36	40

4.1.8 SEM IMAGE

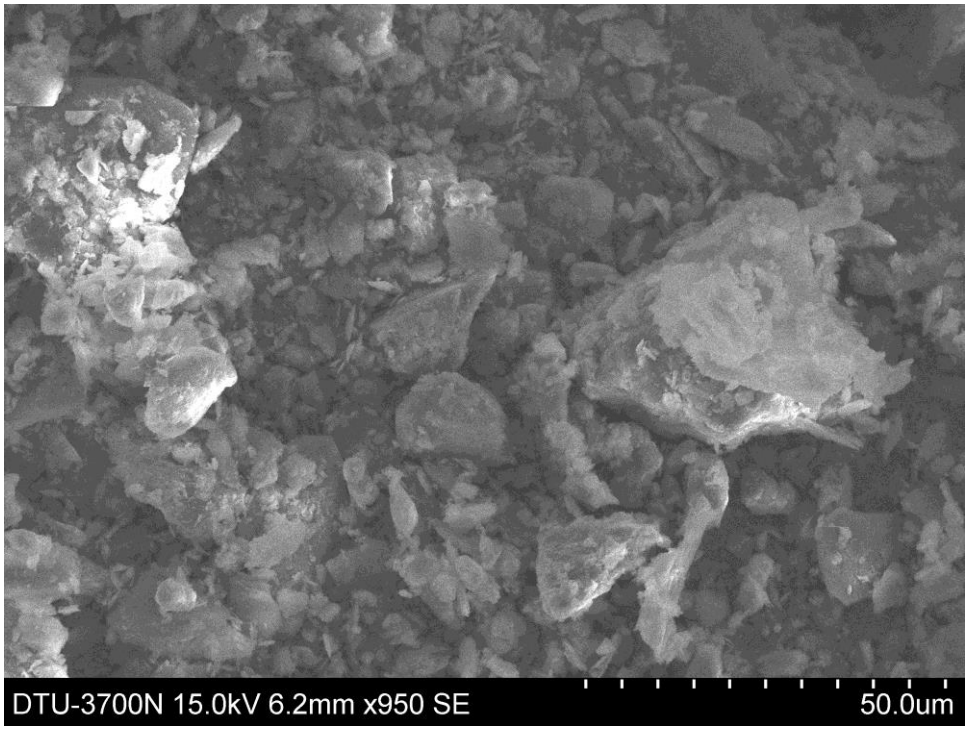


(a)

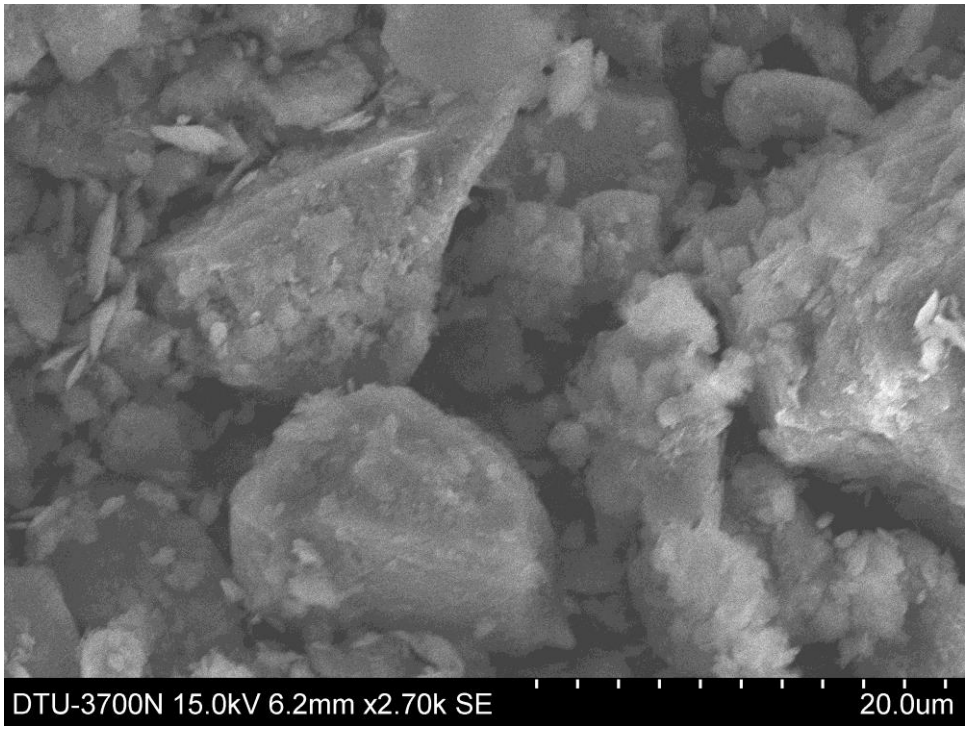


(b)

Figure 4.23 SEM images of virgin soil



(a)



(b)

Figure 4.24 SEM images of bacterial treated soil

CHAPTER-5
CONCLUSION

Various types of tests like UCS, CBR, Triaxial are done and we found out the following Points from that:-

- Soil is classified as Silty Sand i.e SM after analysing the Liquid limit and Plasticity Index.
- Triaxial tests done on soil gives us fine results in form of increase in Shear Parameter like Cohesion value and also increase in frictional angle.
- Cohesion value increases from 9.33KN/m^2 to 14 KN/m^2 in 8 hours means it values increases about 50%, then 14 KN/m^2 to 35KN/m^2 in 3 days that means it increases about 150%, after that it will become 35 KN/m^2 to 40 kN/m^2 after 7 days means it increases around 15%. So, we get the conclusion that maximum increase in Cohesion Takes place between 0 to 3 days. After 3 days there is not much increase in Cohesion value because bacteria are not in active phase.
- Unconfineed Compressive Strength also show significant increase after bacterial treatment. We saw in 8 hours UCS value increases from 19.01KN/m^2 to 30.16 KN/m^2 means there was around 30% increase in UCS value and also after 3 days UCS value increases from 30.16 KN/m^2 to 75.50 KN/m^2 that its value increase around 150%, this is possible due very high activity of bacteria during first 2 days.
- CBR Tests which are conducted also show beneficial results both in case of unsoaked and soaked. Unsoaked CBR value of Virgin soil is 7.125 but after bacterial treatment unsoaked CBR value becomes 11.745. Similar results we got in case of soaked CBR tests also, CBR value after 3 days soaking increases from 3.29 to 5.16 which caused due to cementation of soil particles and in same way CBR value after 7days soaking increases marginally that shows that bacteria also have some effect after 3 days.
- Finally we conclude that presence of cementation caused by calcite precipitation was verified by images of MICP treated soil from Scanning Electron Microscope. Unconfined compressive strength of soil increases due to the action of urease positive bacteria and

there is big increase in strength of soil in 3 days. After three days strength will became more than three times and after seven days strength will becomes more than four times.

- Calcite precipitation over the soil grains are verified by presence of roughness in images of Scanning Electron Microscopic images. Two images of SEM at different magnification clearly shows presence of bonding material between soil particles and that particular material is also responsible for decrease in permeability of soil.
- Finally we conclude Bacillus *Sphaericus* caused a significant improvement in mechanical properties of soil.

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