STABILIZATION OF EXPANSIVE SOILS USING MARBLE POWDER AND GLASS POWDER (MP-GP) COMPOSITE

FINAL YEAR PROJECT 2018

By

M. Qasim Ali Khan (243380)

Danyal Hasnat (266615)

Abdul Ahad (247435)

Ali Ahmed (263546)

Supervised by

Dr. Zain Maqsood

Co-Supervised by

Dr. Badee AlShameri

Department of Geotechnical Engineering,

NUST Institute of Civil Engineering, School of Civil and Environmental Engineering National University of Sciences and Technology Islamabad ,Pakistan.

2022.

This is to clarify that the Final Year Project titled

STABILIZATION OF EXPANSIVE SOILS USING MARBLE POWDER & GLASS POWDER (MP-GP) COMPOSITE

Submitted by

Muhammad Qasim Ali Khan(GL)   243380

Danyal Hasnat   266615

Abdul Ahad   247435

Ali Ahmed   263546

Has been accepted towards the requirements for the undergraduate degree in Civil Engineering

____

Supervisor

Dr. Zain Maqsood (Assistant Professor Geotech, NICE-NUST)

____

Department of Geotechnical Engineering,

NUST Institute of Civil Engineering, School of Civil and Environmental Engineering National University of Sciences and Technology Islamabad ,Pakistan.

2022.

Declaration

I certify that this Final Year Project titled " Stabilization of Expansive Soils using Marble Powder & Glass Powder (MP-GP) Composite" is my own work. The work is unique and has never been evaluated before. The material that has been used from other sources has been properly referred.

Signature of Student:______________________

M. Qasim Ali Khan

(Group Leader)

ACKNOWLEDGEMENT

We are grateful to Allah the Almighty for making us all capable of carrying this research and making our parents and teachers proud.

We are all thankful to our parents and teachers for their help and assistance in this project throughout the project. We would love to appreciate the efforts of our supervisor Dr. Zain Maqsood (Assistant Professor, Geotechnical Engineering, NICE-NUST) for his constant help and support and making sure that we are on the right track following the right procedure.

We are also thankful to the Head of Geotechnical Engineering Department (NICE) Dr. Badee AlShameri for providing us all the help required in our testing phase, provision of labs, cooperation between departments. Finally, we would like to acknowledge the efforts of the Lab Staff, the Lab Engineers, and our co-student fellows for being a constant support from day 1.

ABSTRACT

Expansive Soils are the type of soils which changes their volumes when encounter water. This change in volume makes them a problematic soil for engineers. Soil Stabilization is the technique used to tackle such problematic soils by enhancing their engineering properties.

This research focuses on three main goals, where the first one is evaluating the engineering properties of expansive soils. The other goal is to find alternatives that can be used in place of cement for soil stabilization and the third goal is to utilize the waste materials in soil stabilization to give a solution that is environment friendly. In this research, waste marble powder and waste glass powder were used for soil stabilization.

The research had three main objectives. First one is to perform testing on Nandipur Soil and classify it based on the results of that testing. Second Objective was optimization of marble powder and stabilizing the soil using marble powder. Third and last objective was addition of glass powder to previously marble stabilized soil to enhance its strength.

The tests performed in this research were Sieve Analysis, Hydrometer Analysis, Atterberg Limits Test, Shrinkage Limit Test, Standard Proctor Test, UCS Test. These tests were first performed on Local Nandipur soil then on soil with 5%, 7.5% and 10% marble powder and 1.25% and 2.5% glass powder.

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER:1

INTRODUCTION

1.1 GENERAL:

A mixture of organic matter, minerals, gases, liquids, and organisms that together support life is termed as soil . Earth's body of soil is called the pedosphere. Pedosphere has four important functions given below: (Voroney, et al. 2007)

- As a medium for the growth of plants.
- As a source of water storage, its supply and its purification.
- As a modifying the atmosphere of Earth.
- As a habitat for all living organisms.

In the last point, it is mentioned that it is used for the habitat for organisms(Taylor, et al. 1972). For habitats of humans, we need construction. And for construction, we need to study the properties of the land orground where any building is about to construct. So, the properties of Soil are very important and plays a very important role in construction as the whole design depends on them. It is not necessary that every time we study the properties of soil, we get good results. Sometimes, the soil is problematic. These problems mayinclude the expansion of soil, high plasticity, less cohesion, less bearing strength etc. To cater these problems, different techniques are used to improve theproperties of soil known as Soil Stabilization.(Fang, et al. 1991)

1.2 CLASSIFICATION OF SOILS:

On the bases of size, soil can be classified into 2 types depending on their sizes i.e., Fine Grains Soil and Coarse Grain Soil . Fine Grain Soils are those in which less than 50% of particles have diameter greater than 0.075mm and in case of coarse grain soils, the percentage of particles having diameter more than 0.075mm. (ASTM International. ASTM International. 1996-2009.)

Generally, the civil engineers encounter 3 types of soil

- **SAND** is a pale-yellow brown loose granular substance that results from erosion of rocks. A big portion of deserts, beaches and seabed are formed by sand. It has maximum particles ranging in size from 0.0625mm to 2mm. They let the water drain easily. (ASTM International. ASTM International. 1996-2009.)
- **SILT** is a fine sand, clay, or other material carried deposited as a sediment. It has maximum particles ranging in size from 0.0625 to 0.004mm. They may or may not let the water to drain out.(ASTM International. ASTM International. 1996-2009.)
- **CLAY** is a sticky and stiff fine grained soil particles that has the ability to get molded in to different shapes once it is wet and can be made into bricks, pottery and ceramics when dried and baked. It has maximum particles having diameter less than 0.004mm. They don’t let the water to drain out.(ASTM International. ASTM International. 1996- 2009.)

1.3 NEED FOR RESEARCH

Form all the three types of soils, clays are the most problematic ones. And clay is the soil civil engineers mostly find on their construction sites. The problems with clays include their expansive nature (shrinkage-swelling properties), their plasticity, no drainage, freezing and thawing (Ural, N.(2018).*Importance of Clay in Geotechnical Engineering*). Sometimes, it is not feasible to construct any sort of building on the untreated soil present on site. So, we need specific treatment of the soil to get feasible results. This is done by a process called soil stabilization as mentioned earlier.

Soil stabilization mostly includes reinforcing the soil with some additives. These additives may include some admixtures or any composite. We can also stabilize the soil by providing some reinforcement, but the selection of the additive is very important. We cannot choose any additive for any type of soil. We have to perform various tests on the sample to determine whether the material is suitable or not. Other than the cost and availability of the material, material must show reliable results on testing. If the material fails to do so, we can use that for the soil improvement.

1.4 RESEARCH OBJECTIVES:

Following were the research objectives of our study.

- First objective of our study was to classify our local Soil according to its particle size and the Atterberg limits. Determining its Optimum Moisture Content, Maximum Dry Density, Unconfined Shear Strength, and Shrinkage Limit.
- Second objective was to Optimize the Marble Powder Content in the Soil using UCS.
- Third objective was addition of Glass Powder to enhance the engineering properties of our Soil.

1.5 SCOPE OF RESEARCH :

A comparative analysis was made between the result obtained from testing on original soil sample and Stabilized Soil sample. All the experiments are conducted in NUST Institute of Civil Engineering(NICE) Geotechnical Lab. These experiments are Sieve Analysis, Hydrometer Analysis, Atterberg Limits test, Shrinkage Limit Test, Standard Proctor Test, Unconfined Shear Strength Test. The results obtained from these experiments will help in determination of percentages of marble powder and glass powder for soil stabilization purposes on site.

1.6 SIGNIFICANE OF STUDY

There are three main goals of the research:

- To improve the engineering properties of the soil so that it may become feasible for construction purposes.
- To minimize the use of cement for soil stabilization. For this purpose, we need to find different alternatives that gives the same result as that of cement but are economical.
- To provide an environment friendly solution by using the material that is harming the environment if left open in the environment.

Glass powder is injurious if left in environment or disposed in water. Similarly marble powder has its own effects on environment if left untreated in environment so using them will give an environment friendly solution. Also, glass has 68% silica and marble has 52% CaO which shows it can be a replacement of cement in soil stabilization and since both of them are waste materials, they are very economical.

CHAPTER:2

LITERATURE REVIEW

2.1 GENERAL:

As discussed earlier, there are three common types of soils i.e Sand, Silt and Clay. From civil Engineering point of view, clays are the problematic ones. One of the biggest problems for a civil engineer before the start of construction is presence of clay in the subgrade. This is known as clayey Soils as they possess high ratio of clay content that leads to many problems especially when the water content is raised due to leaking of sewerage lines, rains, floods, etc. The problems might include high compressibility, swelling and low shear strength. Due to these problems, a civil engineer may face threat to construction, so he must devise ways to cater these problems. Engineers must use different Soil stabilization techniques. One of the most common soil stabilization techniques is addition of additives which may include cement, lime, rice husk, fly ash etc. One can use a single additive or mixture of two different additives to get desirable results. In that case, the mixture is called a composite.

2.2 SOIL PROPERTIES:

As we have studied in last chapter, there are many types of soils. So, the first step to start testing on any soil is always soil classification. As the classification of soil usually determines that how are we going to perform other testing. Once the soil is classified, its behavior can be determined. So, Classification of soil is very important. The classification of soil usually depends on its 2 main characteristics:

- Particle Size Distribution
- Index Properties

The index properties of soil are that helps us indicating the nature of that soil. These properties include Liquid Limit, Plastic Limit and Plasticity Index.

Liquid Limit is the percentage of moisture in which a hardened clay changes into liquid state. Whereas Plastic Limit is defined as the hardened state of soil sample at which we can roll it into a 3mm thread such that it doesn't break according to ASTM D4318. Plasticity Index is calculated to determine the plasticity of our soil sample. This is the difference between LL and PL.

PI = LL-PI

All LL, PL and PI are always measured in percentages.

2.2.1 CLAY:

Clays, as mentioned earlier are those which has some plasticity and don't allow water to pass through them. Most of their particles have diameter less than 0.004 mm. Now, since they can be given different shapes after addition of moisture, this is an indication that clays do have plasticity. But this plasticity depends on the plasticity index which is a property of its LL and PL. The detailed classification of clays based on their Plasticity are given in following table

Table 2.1: PI Classification (Sowers, 1979)

PI	Classification
0-3	Non-plastic
3-15	Slightly plastic
15-30	Medium plastic
>30	Highly plastic

This was classification of clays based on their plasticity index. However, we can classify clays based on their undrained shear strengths. British standard (C.P. 8004:1986) classifies clays based on their Undrained Shear Strength and Consistency. There are many classifications, but we are specifically mentioning this classification as this is most widely used in Geotechnical Engineering. In this, the soil is classified in different groups depending on data collected from field inspection. These groups are detailed in the following table:

Table 2.2: Classification of Clay (After B.S.C.P.8004: 1986)

consistency		Undrained shear strength (kPa)
Widely used	Field indication	
Very stiff or hard	Brittle or very tough	Greater than 150
Stiff	Cannot be molded in the finger	100 – 150
Firm to stiff	----------	75 – 100
Firm	Can be molded in the finger by strong pressure	50 – 75
Soft to firm	----------	40 – 50
Soft	Easily molded in the finger	20 – 40
Very soft	Exudes between the fingers when squeezed in the fist	Less than 20

Similarly, we can also classify clays based on their Unconfined Compressive strengths. This also classifies the clay in soft, firm, stiff , very stiff, and hard categories depending on the UCS. The classification of clays based on their UCS is given in following table:

Table 2.3: Classification of Clays based on UCS

Soil Properties	Unconfined Compression Strength (kg/cm^2)
Very soft	< 0.25
Soft	0.25 – 0.50
Firm	0.5 – 1
Stiff	1 – 2
Very stiff	2 – 4
Hard	> 4

2.3 SOIL STABILIZATION:

2.3.1 INTRODUCTION:

Soil Stabilization is a technique used to stabilize the engineering properties of the soil. These engineering properties include its plasticity, strength, shrinkage and swelling potential, workability, durability, etc. Basically, stabilization is of 2 types. Either we stabilize the soil by changing its conditions i.e., compaction or dewatering or we stabilize it by addition of some additive to enhance its engineering properties.(Fang, et al. 1991)

This research is focused on stabilization of expansive soils using glass powder or marble powder composite so in this literature we will focus more on them.

2.3.2 EXPANSIVE SOILS:

Expansive Soils are the soils that expands when water is added to them and shrinks when water is removed. This shrink-swell property makes them a problematic soil. To explain the phenomenon of expansion we need to get in the details of their structures.

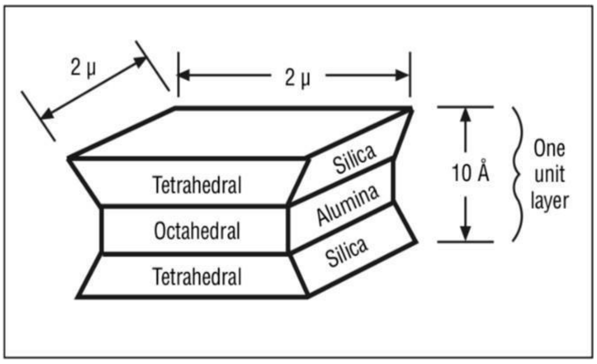

Figure 2.1: Montmorillonite Structure taken after (agushoe.wordpress)

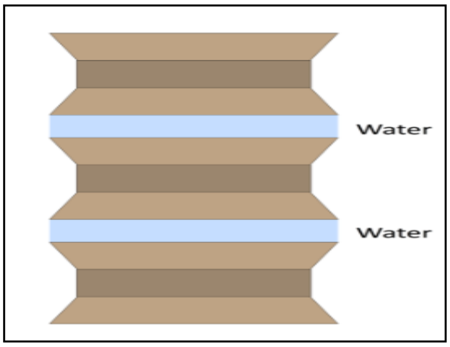

Figure 2.2: Montmorillonite Structure taken after (ceramicartsnetwork.org).

In expansive soils, presence of bentonite or montmorillonite layers are the reason of expansion. In single layer of montmorillonite, the layer has 2 tetrahedral layers of silica and one octahedral layer of alumina in middle. The height of 1 layer is 10A and size of side of square unit is 2 microns. When water molecules come in the layers, the weak Wander Val Forces break, and the water molecule enters the gap between the two layers. This causes the soil expansion.

The following picture shows the presence of expansive soils in Pakistan.

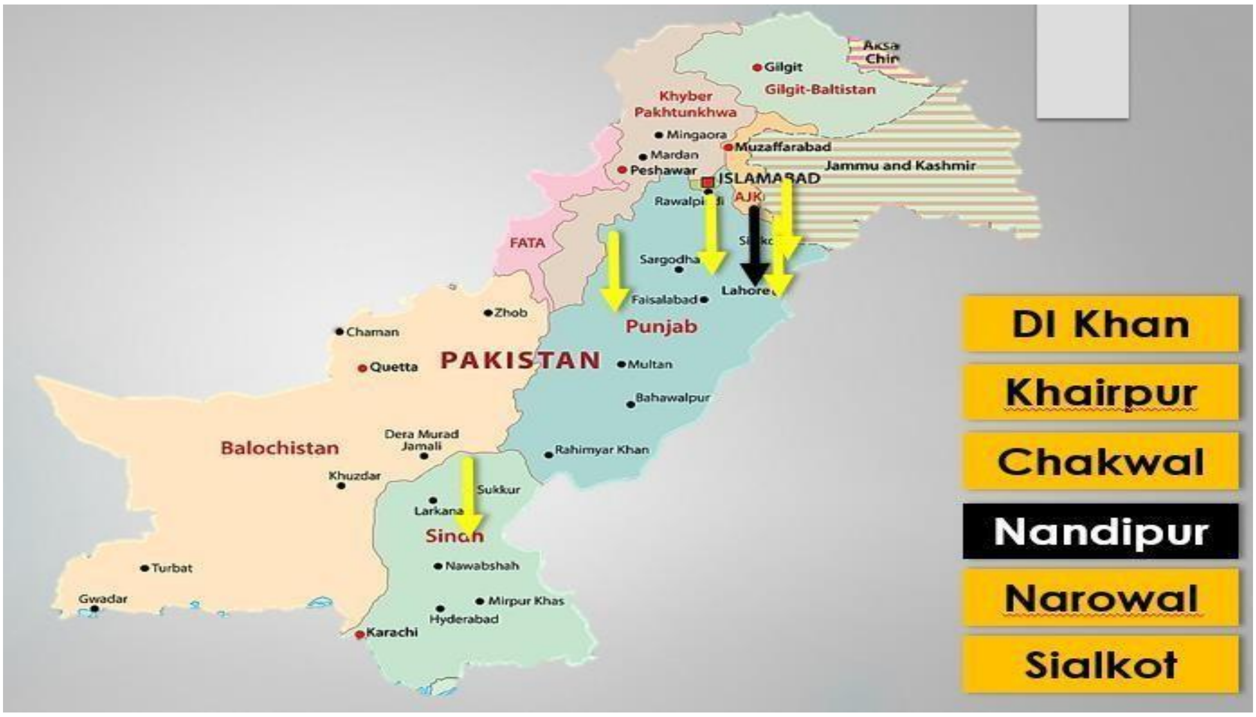

Figure 2.3: Expansive Soils in Pakistan

To stabilize these expansive soils, we need to add some admixture like cement that acts as a binder between the layers of montmorillonite and stops the penetration of water in between the layers. Since we used Glass Powder and Marble Powder, we will be explaining their use for soil stabilization in detail.

2.3.3 MARBLE POWDER:

Marble is a metamorphic rock formed by recrystallization of carbonate minerals majorly calcites. Generally, metamorphosed limestone is considered as marble but when used in stonemasonry, it is considered unmetamorphosed limestone. (Kharrufa, et al. 2013).

Once Marble is crushed in powdered form, it can be used for soil stabilization purpose. Marble has a large proportion of Calcium Oxide in it that gives marble some binding properties. One of the properties of marble for which it is famous is its absorption of water which is less than 1% so this indicates that it can easily be used to decrease the liquid limit of a soil sample. Similarly, since it is not a plastic material i.e., it can't be given different shapes which is an indicator that it will decrease the plasticity index of the soil.(A. Minhas, et al. 2016)

So, we can say that Marble Powder can be used to stabilize the Atterberg Limits of the soil. Since marble has binding properties, we can say that it will have effect on the strength of soil as well. However, marble powder has some of the disadvantages. There is no clear evidence of use of marble powder to increase the UCS of soil.

2.3.4 GLASS POWDER:

Glass is a transparent, non-crystalline solid that usually exists in amorphous state, often formed by quenching of the molten form. Mostly, they are manufactured but volcanic glasses are naturally occurring. (Zallen. & Richard.(2008) The physics of amorphous solids)

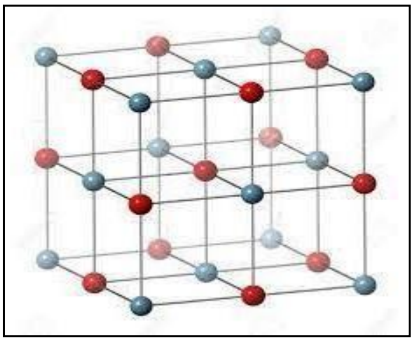

Figure 2.4: Glass Structure taken after Zhang, et al. 2013.

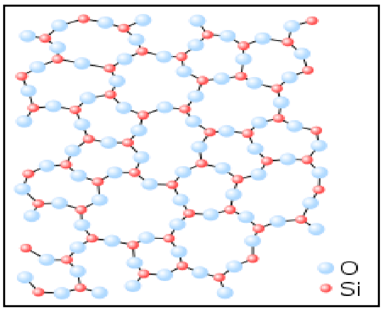

Figure 2.5: Glass Structure taken after Giehl, et al. 2019.

When glass is crushed in powdered form, it can be used for soil stabilization. Usually, glass consists of 70% silica. Mostly glass powder is used for soil stabilization as a filler material. Fine glass particles fill the voids between the soil layers and thus it increases the UCS of soil. Major effect of glass powder is on the stabilization of UCS of soil. In one study ,Addition of 15% glass powder increased the UCS by 80% (RA. Blayi, et al. 2020). Similarly in other researches,the main impact of GP was on UCS.

CHAPTER:3

METHODOLOGY

3.1 GENERAL:

The subsequent discussed research has been proceeded in three following stages:

- Stage I: Properties of untreated soil
- Stage II: Optimization of MPGP (marble powder, and glass powder) content
- Stage III: Properties of treated soil

3.2 PHASE I: PROPERTIES OF NATURAL (UNTREATED) SOIL

In this phase, tests have been carried out on Nandipur soil to determine its properties like natural gradation, Atterberg properties, Shrinkage limit, maximum dry density (MDD), optimum moisture content (OMC), unconfined compressive strength (UCS). The tests that were carried out are named below:

- Shrinkage Limit Test
- Atterberg Limit Test
- X-Ray Fluorescence (XRF) Test
- Sieve Analysis
- Hydrometer Analysis
- Unconfined Shear Strength (UCS) Test

3.2.1 SAMPLE COLLECTION:

The soil was extracted from site near ***Nandipur Power Plant Gujranwala***. The depth taken to avoid any form of impurities was taken to be ***20 feet***. The soil was High Plastic Clay.

3.2.2 ATTERBERG LIMIT TEST:

Atterberg Limit Test was carried out in correspondence to ASTM standard D4318-10. The Casagrande Test was conducted to determine the Liquid Limit and Plastic limit test was used to determine the Plastic Limit. Liquid limit (LL), plastic limit (PL), plasticity index (PI), of soil was calculated. 250 grams of #40 sieve passing was used to carry out the test. The oven dried sample was moisturized such that it meets on 25 to 35 blows when cut in Casagrande apparatus.

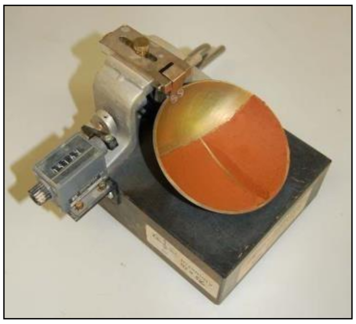

Figure 3.1: Casagrande Apparatus taken after Andrade, et al. 2011

The remaining sample is more moisturized by addition of water to a limit that now it meets on 15 to 25 blows and sample is taken. The remaining is again moisturized such that now it meets on 10 to 20 blows and sample is taken. Sample are oven dried and LL is determined. For PL, a 3mm stick is used. Soil threads are made to 3 mm thickness and when they start breaking on size of stick, they are collected. Then they are oven dried and PL is determined. Its purpose was to classify the soil.

3.2.3 STANDARD PROCTOR TEST:

Standard Proctor Test was carried out in accordance with ASTM standard D698-07. Moisture content, dry density and their relation is studied to observe optimum moisture content (OMC), and maximum dry density (MDD). Its purpose was to determine compaction characteristics of soil.

Figure 3.2: Proctor Apparatus taken after Timely Engineering Soil Tests, 2010

The test uses a proctor mould and a rammer. The compaction in mould is carried out in 3 layers where in each layer the soil is compacted by 25 blows of the rammer. The rammer used for SPT weighs around 5.5 lbs and has dropping height of 2.5 ft.

3.2.4 SIEVE ANALYSIS:

Sieve Analysis was performed according to ASTM standard D422-07. Soil sample weighing 400 grams was pulverized to get the soil in its natural gradation. The pulverized soil is then passed through sieve set. The sieve set had sieves of #4, #16, #32, #40, #100, #200. The retain on all the sieves are then weighted and the cumulative pass percentage is determined. The purpose of sieve analysis is to determine grain size distribution (GSD) of a soil in its natural gradation.

Figure 3.3: Set of Sieves taken after theconstructor.org

3.2.5 HYDROMETER ANALYSIS:

Hydrometer analysis was performed on passing of sieve #200 in correspondence to ASTM standard D7928-16. 40 grams of pass of #200 is taken and a solution is prepared by mixing it with sodium hexametaphosphate. The solution is then added to a 1000ml mark cylinder filled with water. Then hydrometer is placed, and readings are taken at different intervals. The purpose of this test was to obtain the percentage of silty and clayey particles.

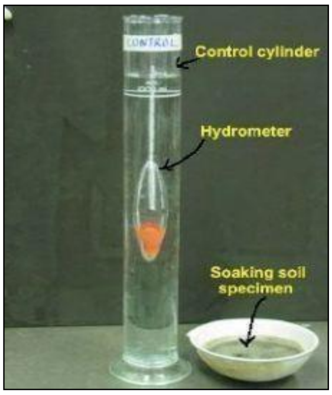

Figure 3.4: Hydrometer Apparatus taken after GSJ volume 7, Sept 2019

3.2.6 UNCONFINED COMPRESSION TEST:

UCS of untreated soil was tested in accordance with ASTM standard D2166-13. Calculation of strength was carried out of two soil samples with 95 percent of OMC and MDD. Mold 14cm high, and 8cm diameter was used to form soil specimen. Soil sample was compacted completely within the mold, and care was taken not to over compact the soil sample.

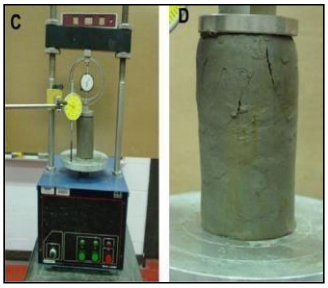

Figure 3.5: UCS Testing Apparatus taken after GSJ volume 7, Sept 2019

Then sample was taken to UCS machine where load is applied, and graph is made. Once, the sample breaks we get the maximum stress take and then the average of maximum stresses of two samples were recorded. This test was performed to examine soil's strength in unconfined conditions.

3.2.7 X-RAY FLUORESCENCE TEST(XRF):

X- Ray Fluorescence Test is a non-destructive test used to determine the presence of different elements present in the sample. In this test, primary X-Rays are emitted from the source which strikes the particles of our sample. These primary X-Rays excites the particles of our sample. The excited sample then emits secondary X-Rays which are received at the source end. These secondary X-Rays tells the percentages of different elements present in the sample. The standards used for this test were ASTM D7220.

3.2.8 SHRINKAGE LIMIT TEST:

Shrinkage Limit was determined using the shrinkage limit test in accordance with the ASTM D 427. 40 grams of oven dried soil (passing of #40) is taken. Water is added to make a paste of the soil. This paste is then filled in small containers. These containers are first lubricated. The paste is filled in 3 layers and with every layer, the container is tapped to remove air bubbles. Then it is air dried for 8 hrs and oven dried for 24 hrs. Then we determine the shrinkage limit of soil by change in volume. This test is done to check the shrinkage limit of the soil.

3.3 PHASE II: OPTIMIZATION OF MPGP CONTENT

In this phase, soil samples were prepared and tested by adding 5, 7.5, and 10 percent of MP (marble powder) content with respect to soil sample's mass. After obtaining optimum MP content graphically, that optimum MP content is added in correspondence to 1.25 and 2.5 percent of GP (glass powder) content with respect to marble treated soil sample's mass. This was done to enhance the engineering properties of our marble treated soil.

3.3.1 COMPACTION CHARACTERISTICS:

Step 1: Samples were prepared by mixing 5, 7.5, 10 percent of MP. Standard Proctor Test was carried out in correspondence to ASTM standard D698-07, to plot relation between moisture content and dry-density.

Step 2: Samples prepared by mixing optimum MP, and 1.25 and 2.5 percent of GP. Standard Proctor Test was carried out in correspondence to ASTM standard D698-07, to plot relation between moisture content and dry-density.

Note: Each sample was formed by compacting it in 3 layers. This was done by 25 blows of 5.5lb hammer on each layer.

3.3.2 UNCONFINED COMPRESSIVE STRENGTH CHARACTERISTICS:

UCS of treated soil was calculated using ASTM standard D2166-13. Two samples of soil specimen were made at 95 percent of OMC, and MDD. And thus, recording their average value. UCS samples were prepared at optimum MP, and 1.25 and 2.5 percent of GP with soil.

Note: The percentage giving the highest strength is taken to be an optimum percentage for that additive.

3.4 PHASE III: PROPERTIES OF TREATED SOIL

The properties of treated soil with optimum MP-GP were Atterberg Limits, swellpotential, and the effect of additives on the strength of untreated soil.

Note: All tests are performed on CH soil type.

3.4.1 ATTERBERG LIMITS:

Atterberg Limit Test was carried out in correspondence to ASTM standard D4318-10. Liquid limit (LL), plastic limit (PL), plasticity index (PI), of both CH and CL type soil was calculated. 250 grams of #40 sieve passing was used to carry out the test. Its purpose was to classify the soil.

3.4.2 SHRINKAGE LIMIT TEST:

Shrinkage Limit was determined using the shrinkage limit test in accordance with the ASTM D 427. 40 grams of oven dried treated soil (passing of #40) is taken. Water is added to make a paste of the soil. This paste is then filled in small containers. These containers are first lubricated. The paste is filled in 3 layers and with every layer, the container is tapped to remove air bubbles. Then it is air dried for 8 hrs and oven dried for 24 hrs. Then we determine the shrinkage limit of soil by change in volume. This test is done to check the increase in shrinkage limit of the treated soil.

3.4.3 COMPACTION CHARACTERISTICS:

Standard Proctor Test was carried out in accordance with ASTM standard D698-07. Moisture content, dry density and their relation is studied to observe optimum moisture content (OMC), and maximum dry density (MDD) of this

treated soil sample. Its purpose was to determine compaction characteristics of MPGP treated soil.

3.4.4 UNCONFINED COMPRESSIVE STRENGTH:

UCS of treated soil was tested in accordance with ASTM standard D2166-13. Calculation of strength was carried out of two soil samples with 95 percent of OMC and MDD. Mold 14cm high, and 7cm diameter was used to form soil specimen. Soil sample was compacted completely within the mold, and care was taken not to over compact the soil sample, and then the average max. stress of two samples was recorded. This test was performed to examine soil's strength assuming there was no pore pressure development in field.

3.5 MATERIAL

3.5.1 SOIL SAMPLE:

The soil sample was taken from Nandipur region near Gujranwala, Pakistan. Geographical Coordinates of Nandipur are 32°15'20"North and 74°15'55" East. The soil is very famous for its un-stabilized characteristics and researchers from all over the world have been testing on this soil for quite a few years.

3.5.2 GLASS POWDER:

The Glass Powder was obtained from glass industry in Lahore. It was basically the powdered glass formed during the cutting of glass in industry and is being washed with water. The water containing the glass powder is then disposed in a tank where the glass powder settles in the bottom form a glass pulp. This is then taken, oven dried and crushed to get fine glass powder. Glass dust or Glass powder has been used for soil stabilization for quite a lot of years. Glass is usually added as a filler material in soil.

3.5.3 MARBLE POWDER:

Marble Powder was obtained from Bagheecha Marble Rawalpindi. Marble Powder was obtained directly from the factory, so it was easy to use. Marble Powder was just oven dried and then added to soil. Marble also is very common and is used in soil for stabilization purpose for quite a lot of time. Addition of marble is very common because of its initial increase in soils strength and binding capacity.

CHAPTER:4

RESULTS

4.1 GENERAL:

As discussed earlier, testing has been carried out in following three phases i.e.

- Stage I: Properties of untreated soil
- Stage II: Optimization of MP-GP (marble powder, and glass powder) content
- Stage III: Properties of treated soil

The results of tests conducted in these phases on virgin materials are as follows:

4.2 PHASE I: PROPERTIES OF NATURAL (UNTREATED) SOIL

Tests that were carried out in this phase are as follows:

- Sieve Analysis
- Hydrometer Analysis
- Atterberg Limit Test
- Shrinkage Limit Test
- Unconfined Shear Strength Test
- X-Ray Fluorescence (XRF) Test

4.2.1 SIEVE AND HYDROMETER ANALYSIS:

Sieve and Hydrometer Analysis were performed on pulverized soil to determine grain size distribution.

Results of sieve analysis are shown below in Table 1, and Figure 1.

Table 5.1: Sieve Analysis on Untreated Soil

Sieve Number	Diameter (mm)	Soil Retained (g)	Accumulative Retain (gm)	% Mass Retain	% Passing
#4	4.75	0	0	0	100
#10	2	0	0	0	100
#16	1.18	0	0	0	100
#100	0.15	1	1	0.2724	99.7276
#200	0.075	0.13	1.13	0.3078	99.6922
Pan		366	367.13		

Table 5.2: Hydrometer Analysis on Untreated Soil

Input Parameters		
Viscosity of water at 25 C temperature	0.00000922	g s/cm2
Specific gravity of soil	2.65	
Weight of dry soil	40	g
Zero Correction	5	g
Miniscous Correction	1	

Time (s)	Ra	T	Tc=-4.85+0.25T	Rc=Ra-Zc+Tc	% finer = (Rcxa)/Ws	Rcorrected for miniscous	L=16.3-0.164Ra	K	D (mm)	Actual % finer wrt to fines
									0.075	99.6922
1	43	23.8	1.1	39.1	97.75	44	9.084	0.012947	0.039	97.449
2	41	23.8	1.1	37.1	92.75	42	9.412	0.012947	0.0281	92.465
4	39	23.8	1.1	35.1	87.75	40	9.74	0.012947	0.0202	87.48
8	36	23.9	1.125	32.125	80.3125	37	10.232	0.012947	0.0146	80.065
15	34	23.9	1.125	30.125	75.3125	35	10.56	0.012947	0.0109	75.081
30	32	24	1.15	28.15	70.375	33	10.888	0.012947	0.0078	70.158
60	31	24	1.15	27.15	67.875	32	11.052	0.012947	0.0056	67.666
120	29	24.5	1.275	25.275	63.1875	30	11.38	0.012947	0.004	62.993
240	27	24.9	1.375	23.375	58.4375	28	11.708	0.012947	0.0029	58.258
1440	23	23.8	1.1	19.1	47.75	24	12.364	0.012947	0.0012	47.603

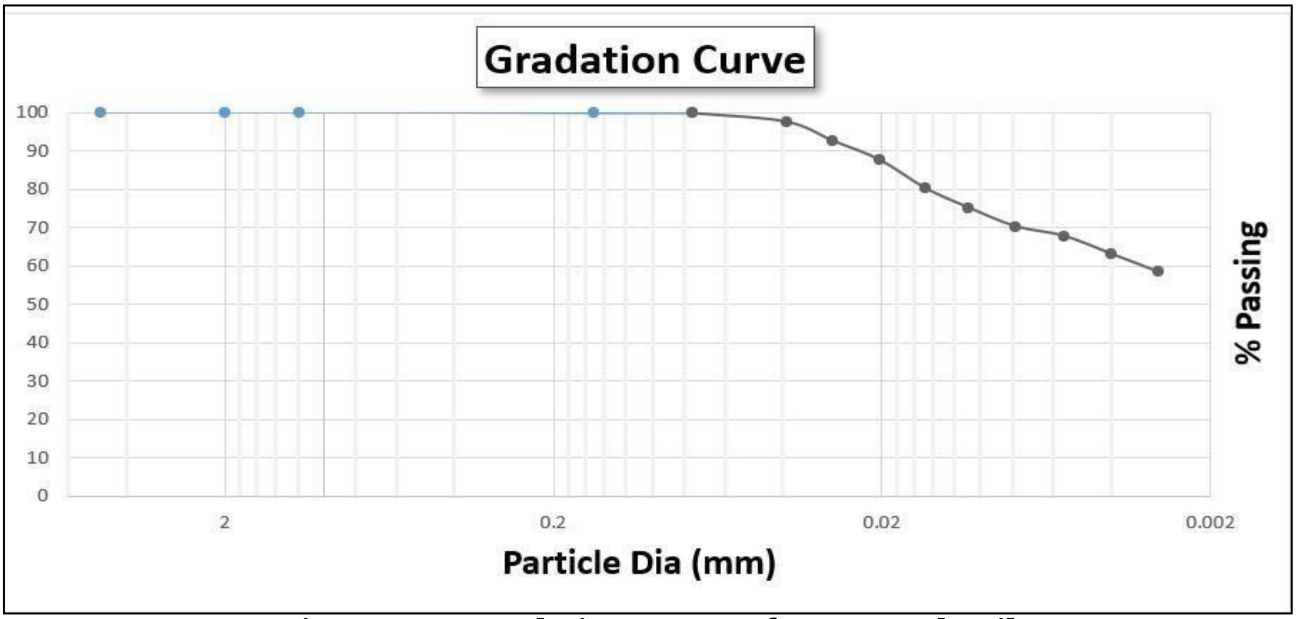

Figure 5.1: Gradation Curve of Untreated Soil

4.2.2 ATTERBERG LIMIT TEST:

Atterberg Limit Test was carried out on Untreated soil to determine its Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). Its results are shown below in several tables and figures.

Table 5.3: First Trial of Atterberg on untreated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		34	24	14	25	
Mass of Container (gm)	W1	11.2	11.9	13		32.25
Mass of wet soil + container (gm)	W2	28.7	30.6	35.01		40.57
Mass of Dry soil + container (gm)	W3	23.09	24.44	27.23		38.91
Mass of Dry soil (gm)	W4 = W3-W1	11.89	12.54	14.23		6.66
Weight of Water (gm)	W5 = W2-W2	5.61	6.16	7.78		1.66
Moisture Content (%)	MC=W5/W4	47.18	49.12	54.67	**50**	**24.92**

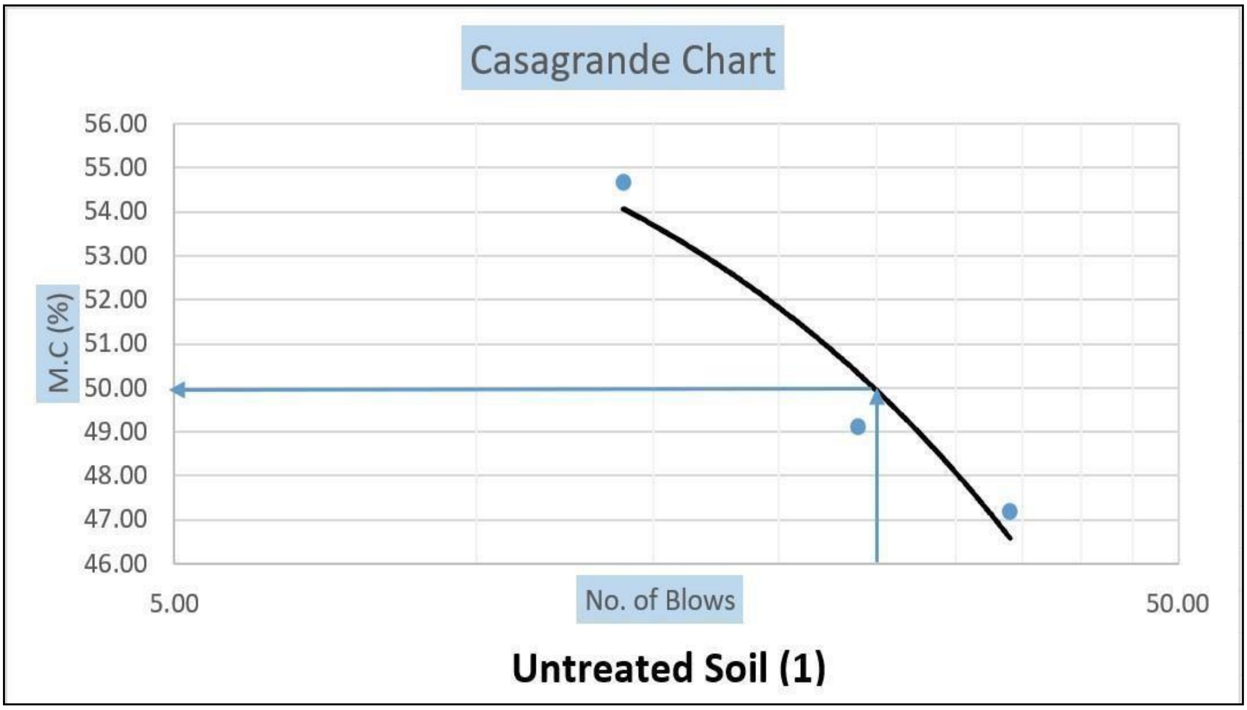

Figure 5.2: First Trial of Atterberg on untreated soil

Table 5.4: Second Trial of Atterberg on untreated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		32.00	26.00	17.00	25	
Mass of Container (gm)	W1	11.2	11.7	12.8		28.2
Mass of wet soil + container (gm)	W2	25	34.6	38		41.5
Mass of Dry soil + container (gm)	W3	22.6	25.7	28.5		38.79
Mass of Dry soil (gm)	W4 = W3-W1	11.40	14.00	15.70		10.59
Weight of Water (gm)	W5 = W2-W2	2.40	8.90	9.50		2.71
Moisture Content (%)	MC=W5/W4	21.05	63.57	60.51	**49**	**25.59**

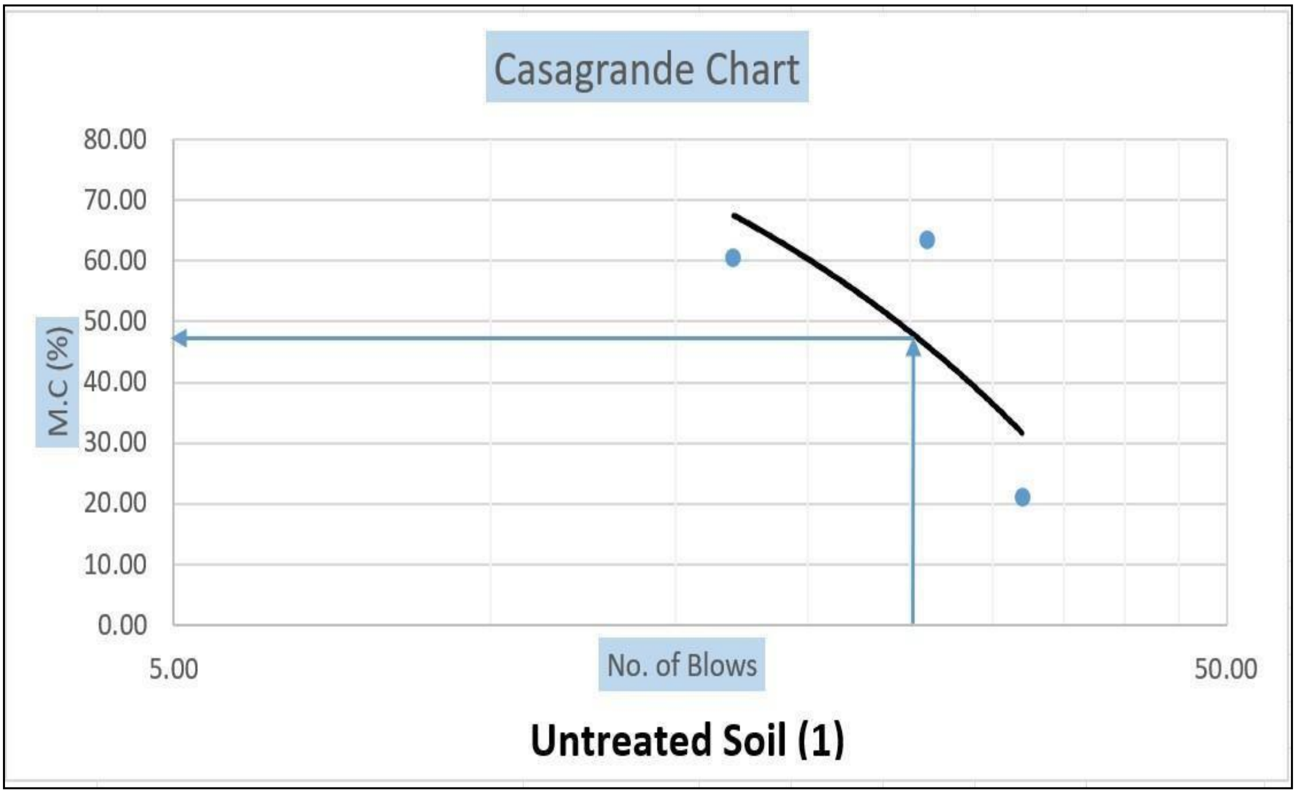

Figure 5.3: Second Trial of Atterberg on untreated soil

Table 5.5: Third Trial of Atterberg on untreated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		34.00	24.00	15.00	25	
Mass of Container (gm)	W1	11	11.3	12.8		29.2
Mass of wet soil + container (gm)	W2	27	33.7	39		47.65
Mass of Dry soil + container (gm)	W3	22.6	24.8	28.5		43.93
Mass of Dry soil (gm)	W4 = W3-W1	11.60	13.50	15.70		14.73
Weight of Water (gm)	W5 = W2-W2	4.40	8.90	10.50		3.72
Moisture Content (%)	MC=W5/W4	37.93	65.93	66.88	**55**	**25.25**

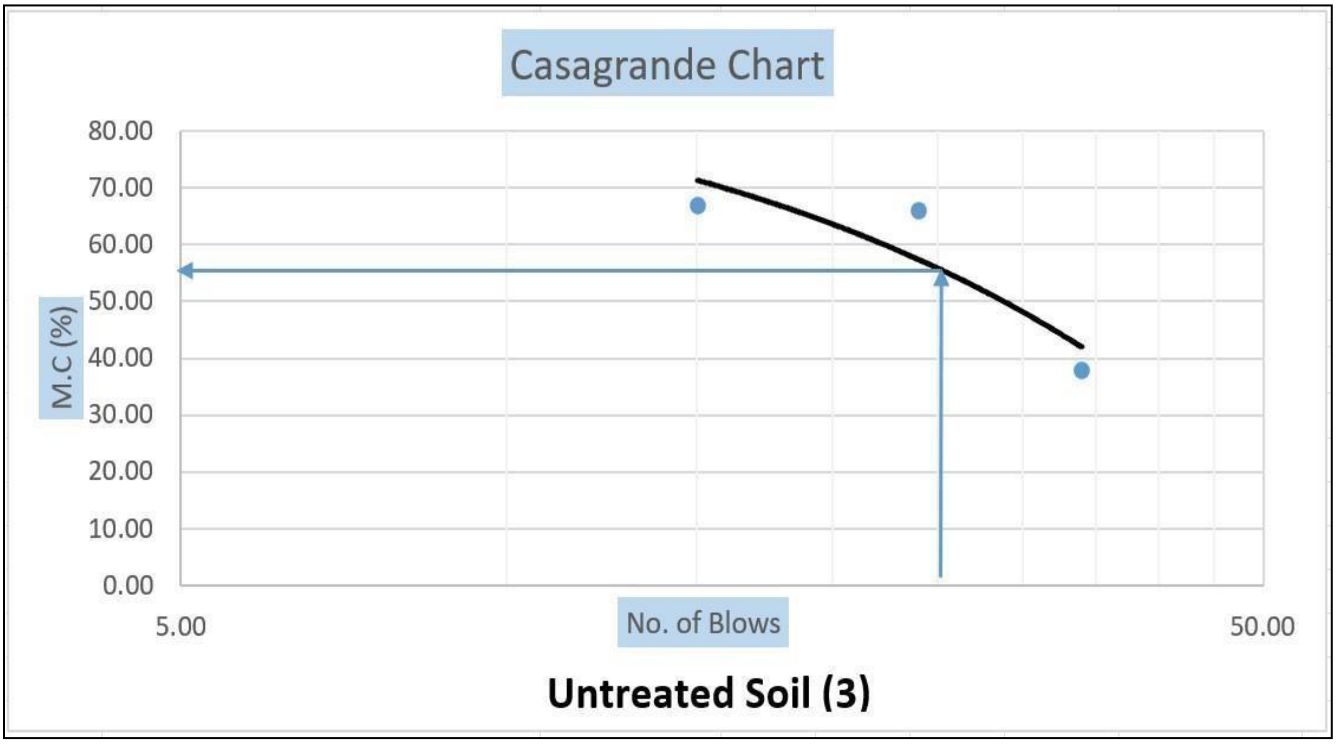

Figure 5.4: Third Trial of Atterberg on Untreated soil

From the above attached data, mean Atterberg Limits come out to be,

i. **Liquid Limit = 51.33 %**

ii. **Plastic Limit = 25.34 %**

iii. **Plasticity Index = 25.99 %**

4.2.3 SHRINKAGE LIMIT TEST:

Shrinkage Limit Test was performed to determine the cohesiveness of our experimental i.e., Nandipur Soil. Its results are shown below in Table 6.

Table 5.6: Three trials for Shrinkage Limit Test

Soil	can wt.	WS+can	DS+can	MC	K	SL	SR
Sample 1	11.62	44.02	32.45	55.5449	41.8415	13.70	1.91
Sample 2	10.58	43.97	32.87	49.7981	37.7032	12.09	1.98
Sample 3	11.52	44.31	32.15	58.9433	46.9743	11.97	2.08

pan wt.	Hg+pan	Hg	den of Hg	Vf	Hg+can	Hg	Vi
327.84	475.45	147.61	13.5458	10.8971	277.29	265.67	19.6127
327.84	480.71	152.87	13.5458	11.2854	277.29	266.71	19.6894
327.84	462.34	134.5	13.5458	9.92924	277.29	265.77	19.62

Where,
WS = wet soil   DS = dry soil   MC = moisture content
Hg = mercury's displaced weight   den of Hg = density of mercury
Vf = volume of dry soil Vi = volume of wet soil   K = (Vi - Vf)/DS)x 100
SL = MC – ((Vi - Vf)/DS)x 100   SR = DS/(density of water x Vf)

From the above attached data, mean Shrinkage Limit comes out to be,

Shrinkage Limit = 12.59 %

4.2.4 STANDARD PROCTOR TEST:

Standard Proctor Test was performed on untreated soil to determine its maximum dry density (MDD) and moisture content at this density i.e., optimum moisture content (OMC). Its results are shown in figures and tables below.

Table 5.7: First Trial of Standard Proctor Test

Density	Trial Number				
Trial Number	1	2	3	4	5
Mass of mould + compacted soil	3242.0	3295.0	3368.0	3284.0	3194.0
Mass of mould (M 2) g	1457.0	1457.0	1457.0	1457.0	1457.0
Volume of Mould (Cubic Cm)	944.0	944.0	944.0	944.0	944.0
Mass of compacted soil (g) M3	1785.0	1838.0	1911.0	1827.0	1737.0
Wet Density (gm/Cc) ɣwet	1.89	1.95	2.02	1.94	1.84
Dry density (ɣdry)	1.89	1.95	2.02	1.94	1.84
Moisture Content					
Water content = W = WW	17.1	18.5	21.3	23.8	25.7

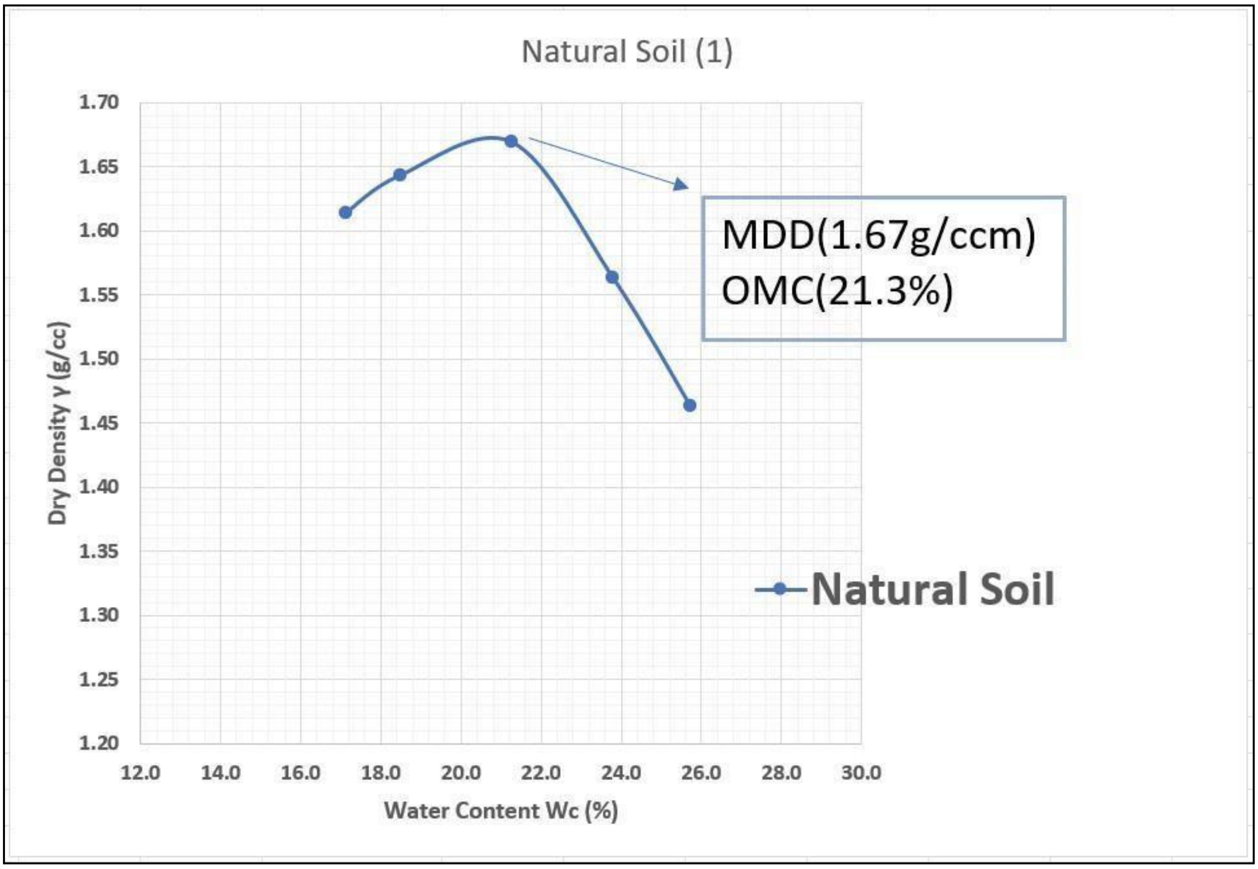

Figure 5.5 : First Trial of Standard Proctor Test

Table 5.8 : Second Trial of Standard Proctor Test

Density	**Trial Number**				
Trial Number	1	2	3	4	5
Mass of mould + compacted soil	3160.0	3240.0	3340.0	3284.0	3194.0
Mass of mould (M 2) g	1457.0	1457.0	1457.0	1457.0	1457.0
Volume of Mould (Cubic Cm)	944.0	944.0	944.0	944.0	944.0
Mass of compacted soil (g) M3	1703.0	1783.0	1883.0	1827.0	1737.0
Wet Density (gm/Cc) ɣwet	1.80	1.89	1.99	1.94	1.84
Dry density (ɣdry)	1.80	1.89	1.99	1.94	1.84
Moisture Content					
Water content = W = WW	16.1	18.3	20.9	23.5	25.7

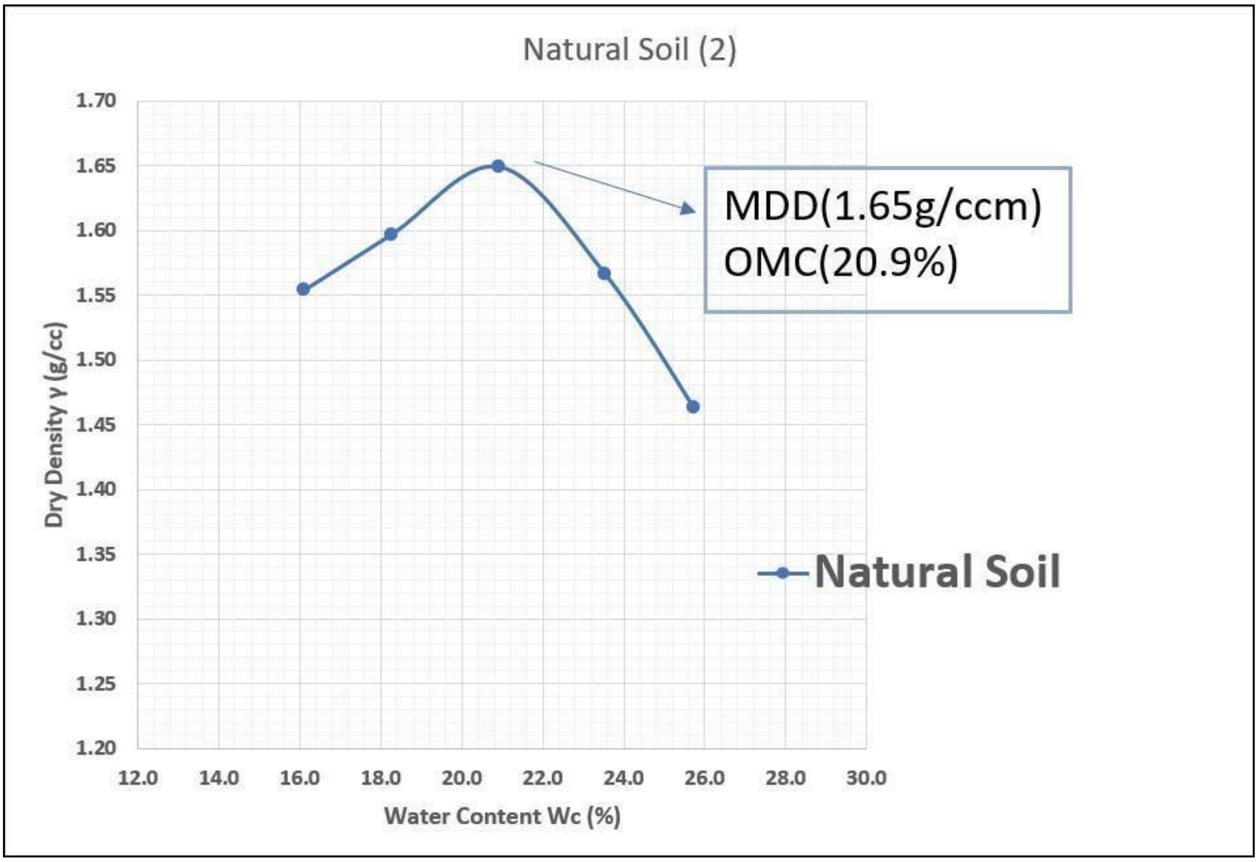

Figure 5.6 : Second Trial of Standard Proctor Test

From the above attached data, mean OMC and MDD comes out to be,

i. **Maximum Dry Density = 1.66 g/ccm**

ii. **Optimum Moisture Content = 21.1 %**

4.2.5 UNCONFINED COMPRESSION TEST:

UCS was performed to determine the maximum stress taken by sample at OMC, and MDD. Its results are shown below.

.

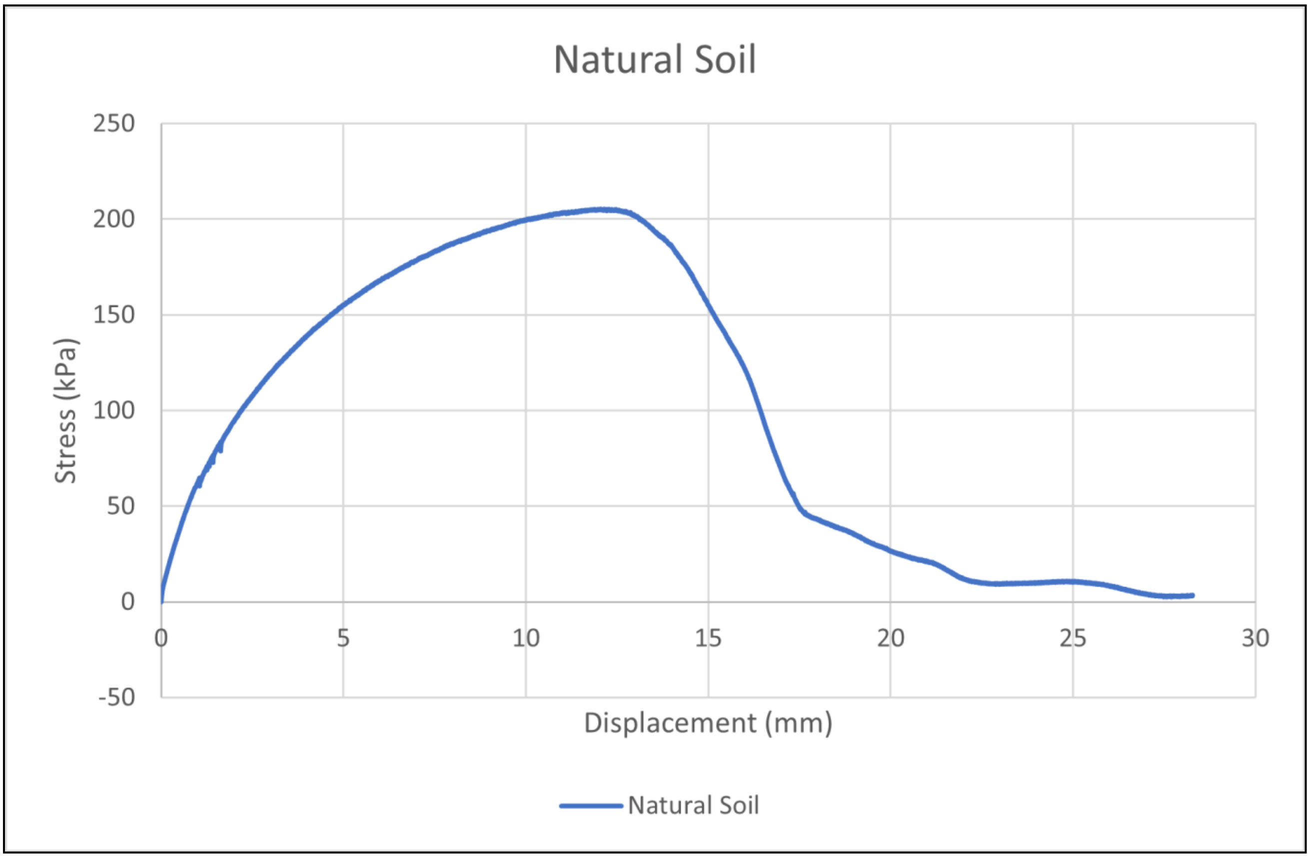

Figure 5.7 : UCS at untreated soil

According to above attached graph,

i. **Max Axial Stress = 205.40 kPa** at

ii. **displacement = 12.04 mm**

4.2.6 X-RAY FLUORESCENCE (XRF) TEST:

XRF was performed on the virgin materials, i.e., soil, marble powder, and glass powder to determine their minerology. Its results are as follows,

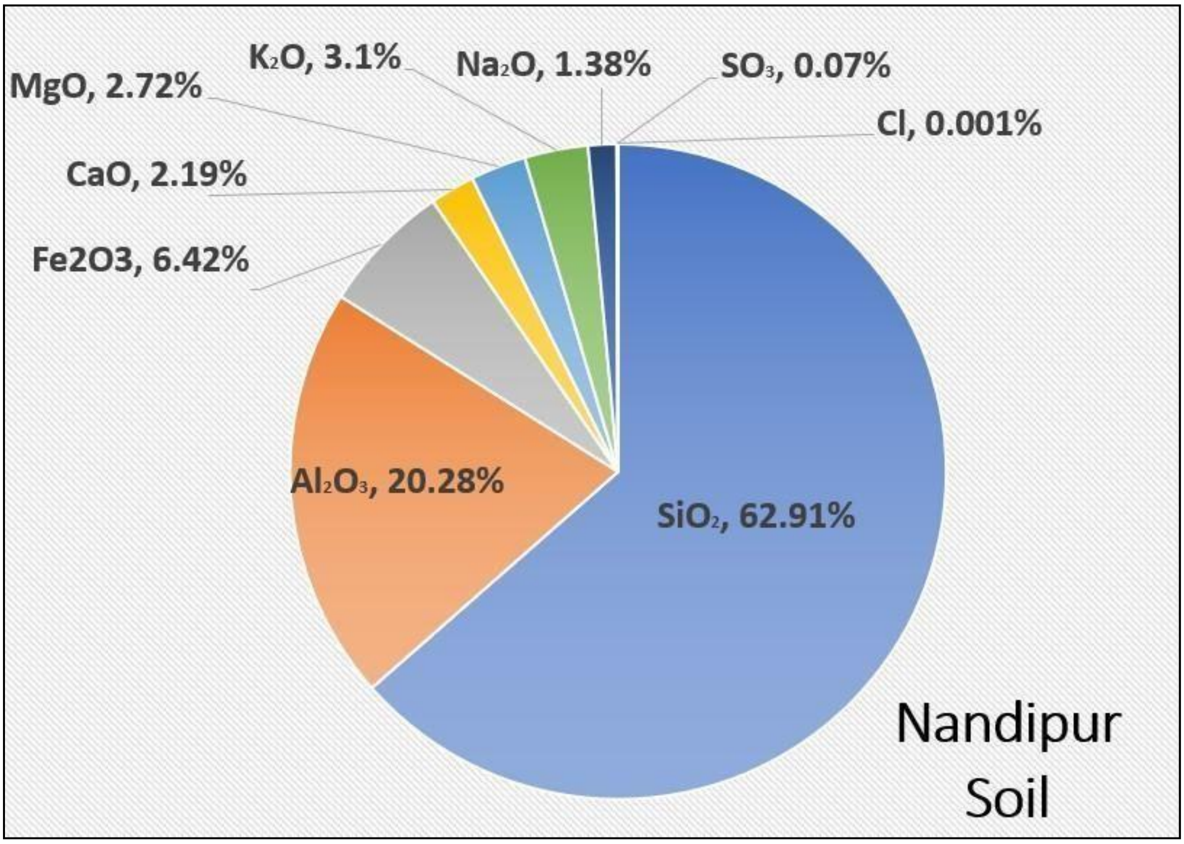

Figure 5.8 : XRF of soil

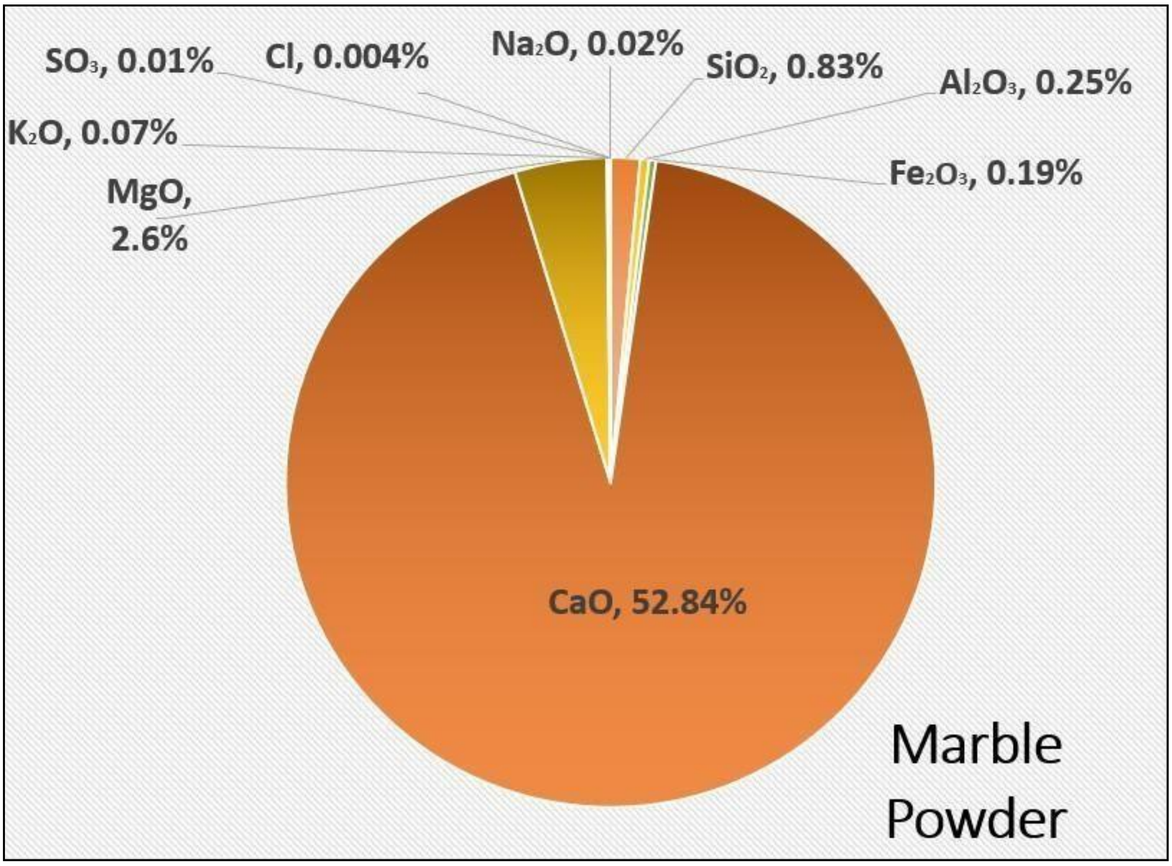

Figure 5.9 : XRF of waste Marble powder (MP)

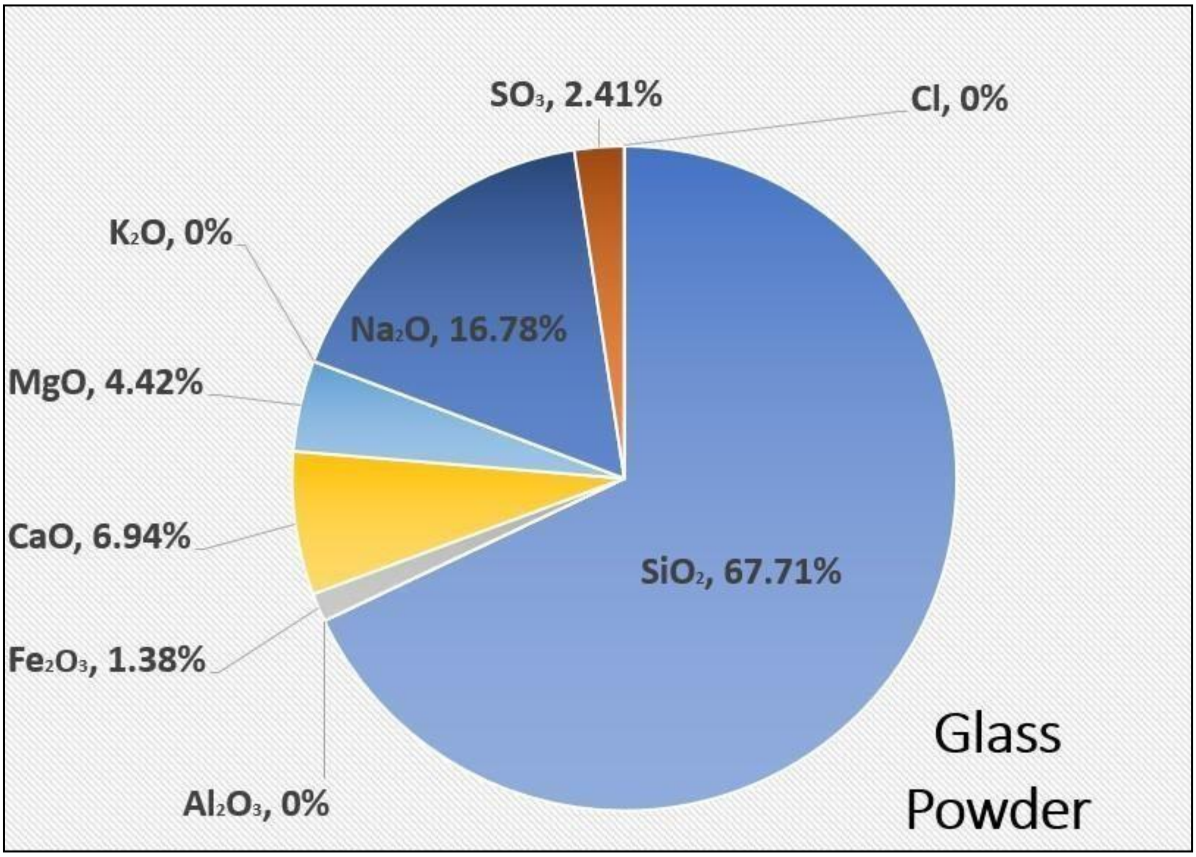

Figure 5.10 : XRF of waste Glass powder (GP)

4.3 OPTIMIZATION OF MARBLE AND GLASS POWDER CONTENT

4.3.1 CONTENT

First Marble powder was optimized with UCS, and then strength properties were studied with increments of Glass powder.

4.3.2 COMPACTION CHARACTERISTICS:

Step 1: MDD and OMC were determined of sample with 5%, 7.5%, and 10% Marble Powder. Its results are shown in below in figure 11.

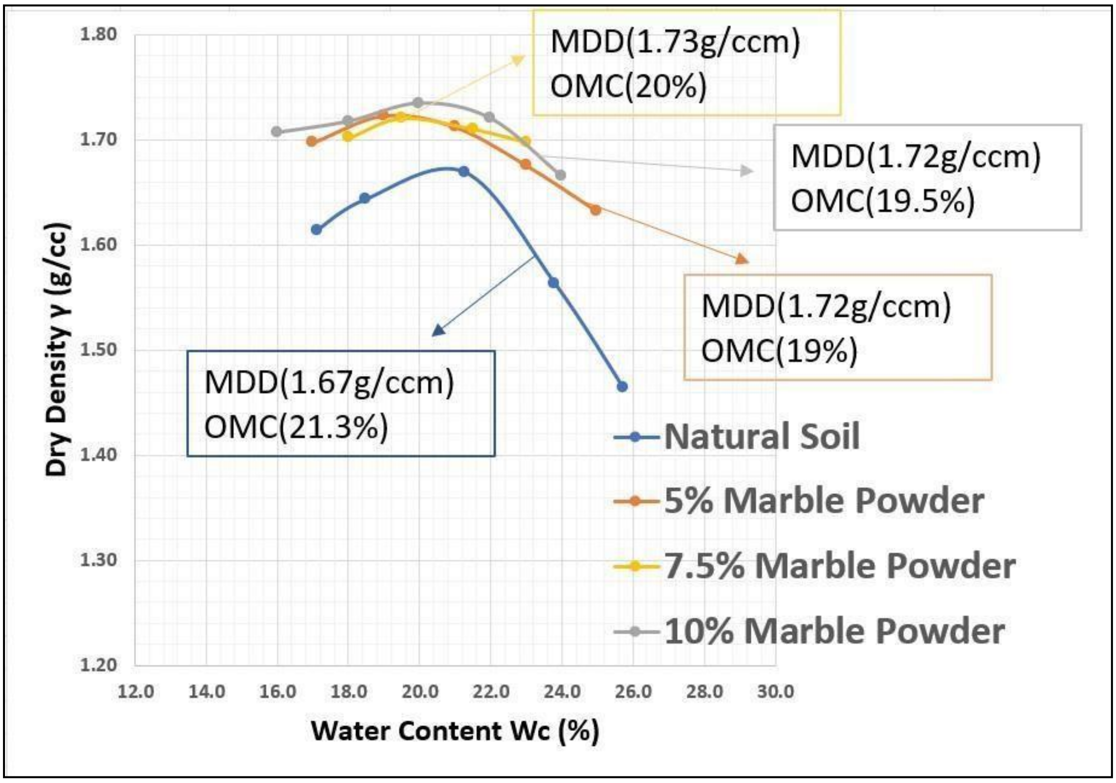

Figure 5.11: Standard Proctor Tests with MP increments

Step 2 : MDD and OMC were determined of sample with 1.25%, and 2.5% Glass Powder. Its results are shown in below in figure 12.

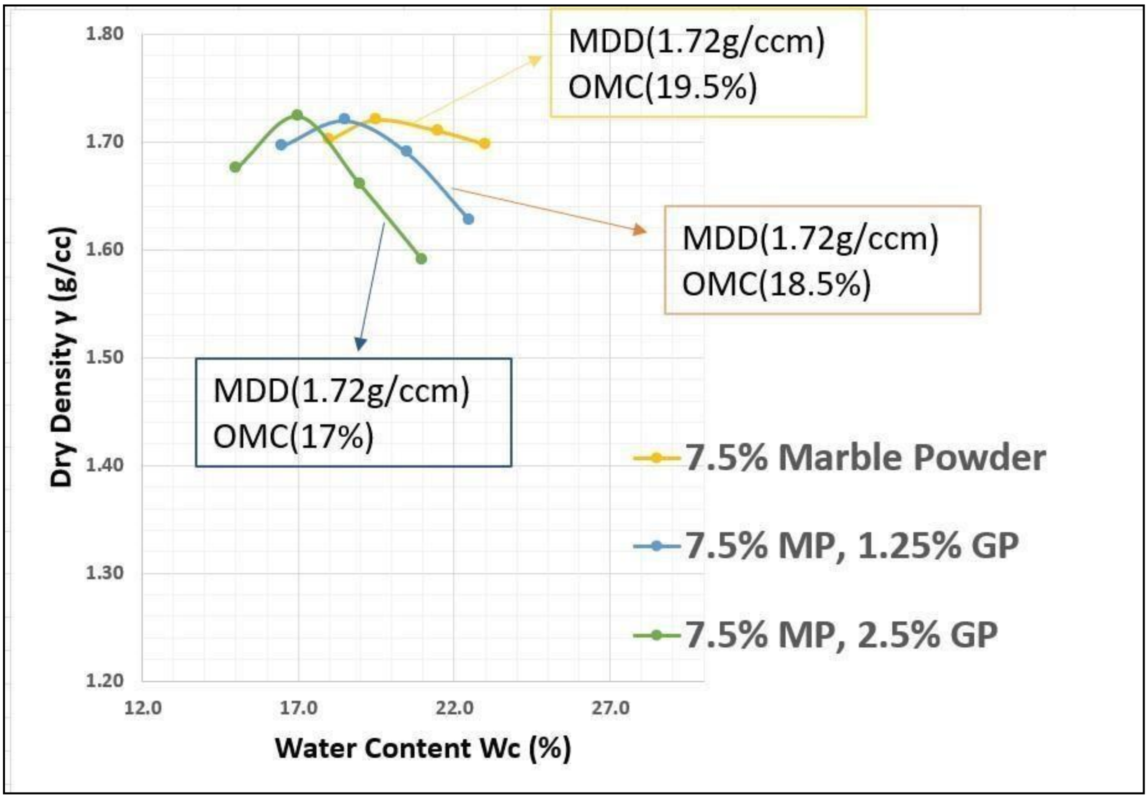

Figure 5.12: Standard Proctor Tests with GP increments

4.3.3 UNCONFINED COMPRESSIVE STRENGTH CHARACTERISTICS:

Step 1: UCS of virgin soil with 5%, 7.5%, and 10% MP composite were found. Its results are shown below.

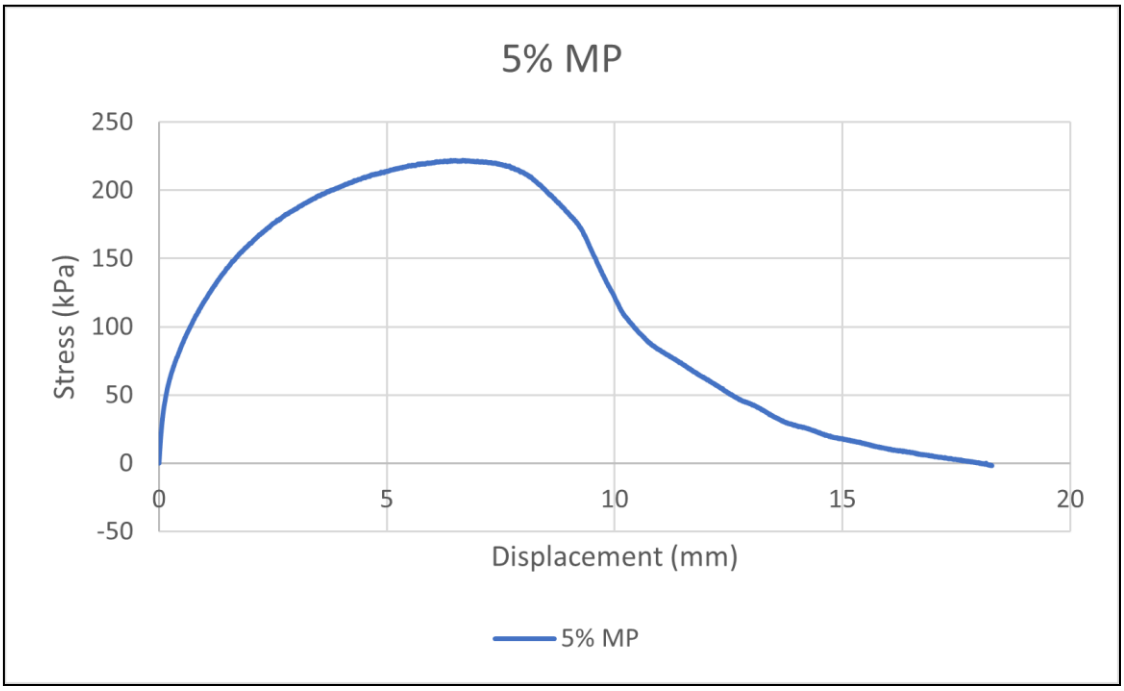

Figure 5.13: UCS at soil with 5% Marble Powder

According to above attached graph,

i. **Max Axial Stress = 222.12 kPa** at

ii. **Displacement = 6.41 mm**

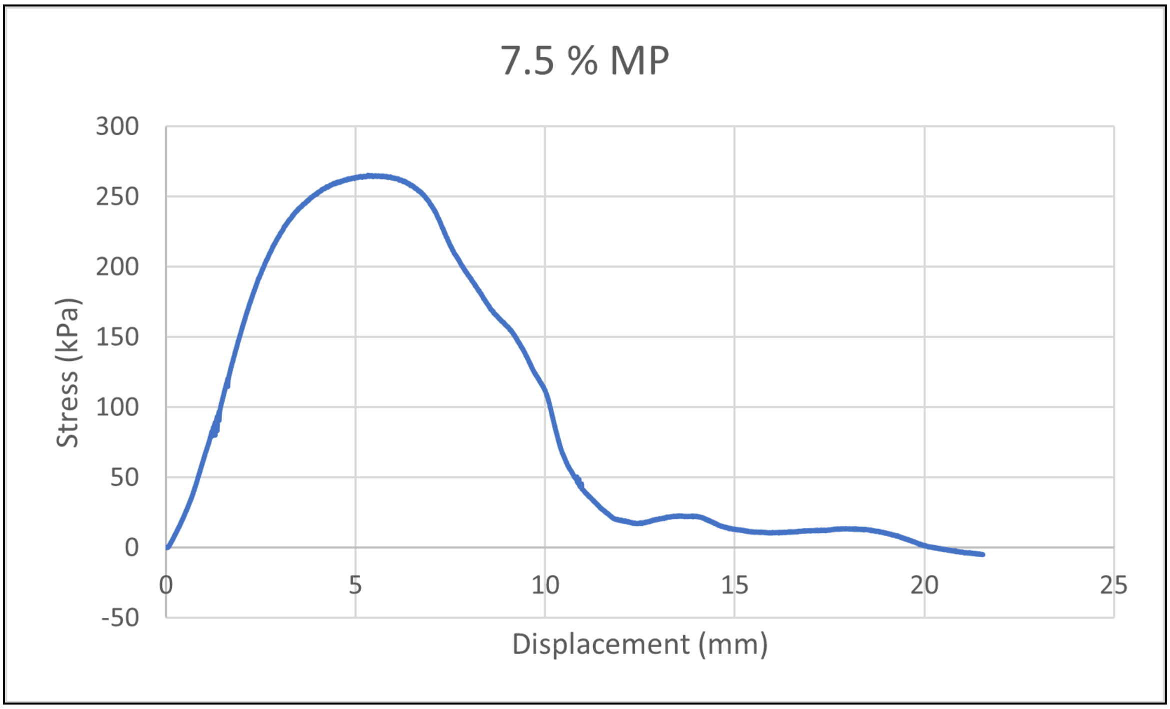

Figure 5.13: UCS at soil with 7.5% Marble Powder

According to above attached graph,

i. **Max Axial Stress = 265.54 kPa** at
ii. **Displacement =5.33mm**

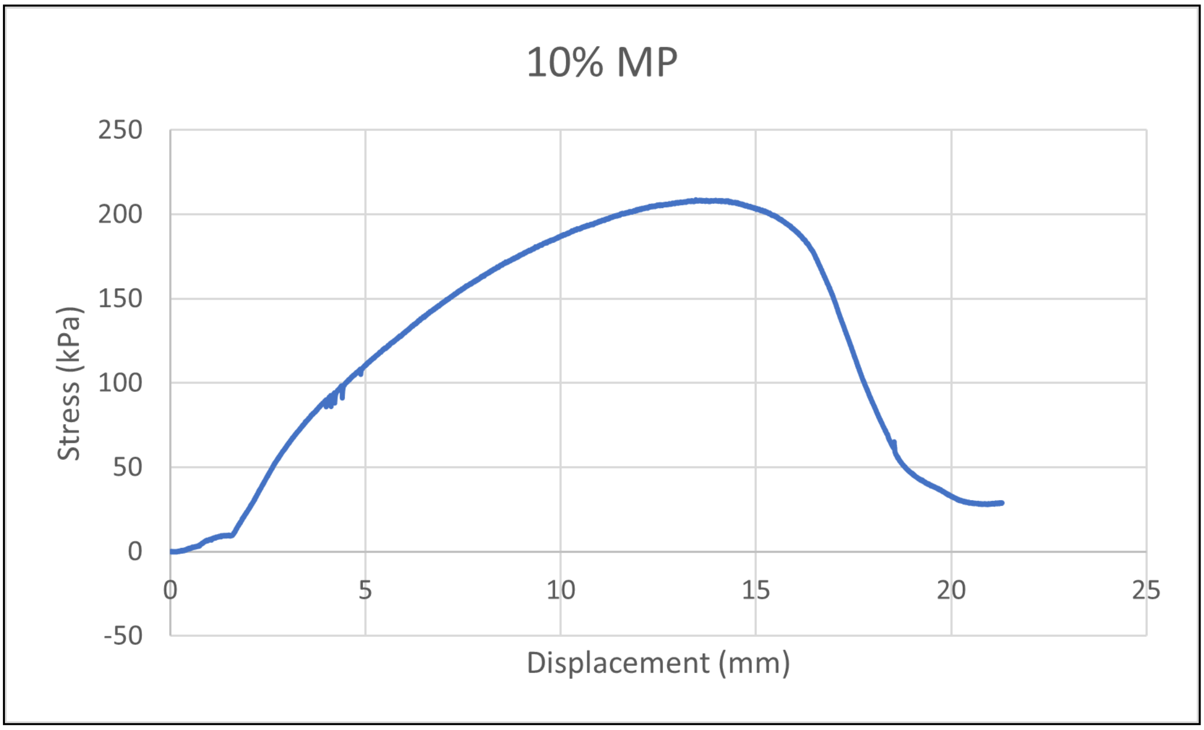

Figure 5.14: UCS at soil with 10% Marble Powder

According to above attached graph,

i. **Max. Axial Stress = 208.8 kPa** at

ii. **Displacement = 13.46 mm**

Step 2: UCS of soil + 7.5% MP with 1.25%, and 2.5% GP composite were found. Its results are shown below.

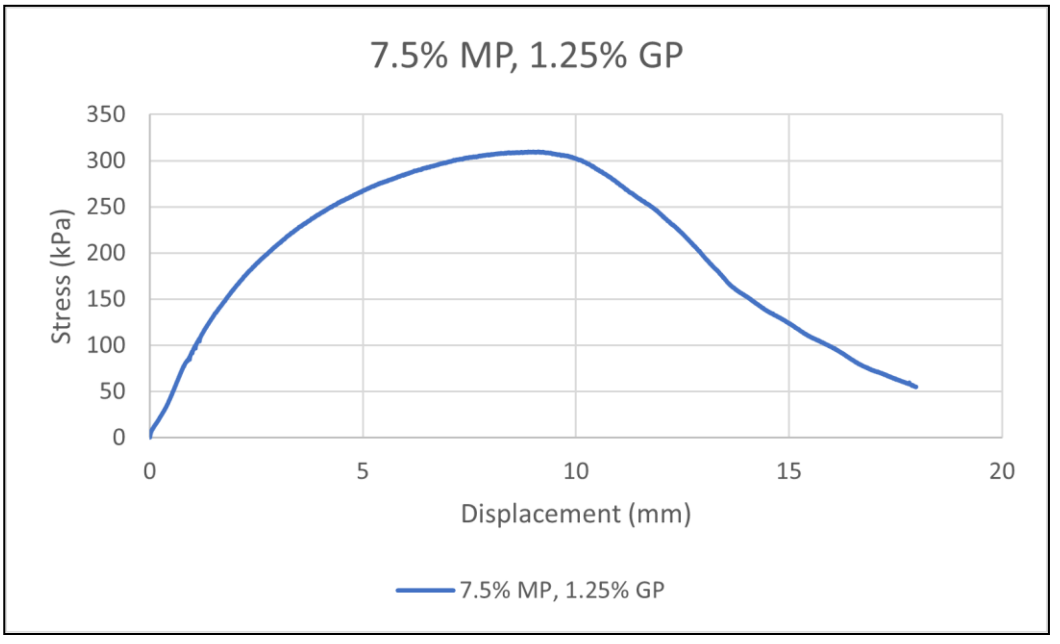

Figure 5.15: UCS at soil with 7.5% MP with 1.25% Glass Powder

According to above attached graph,

i. **Max Axial Stress = 309.80 kPa** at

ii. **Displacement = 9.01 mm**

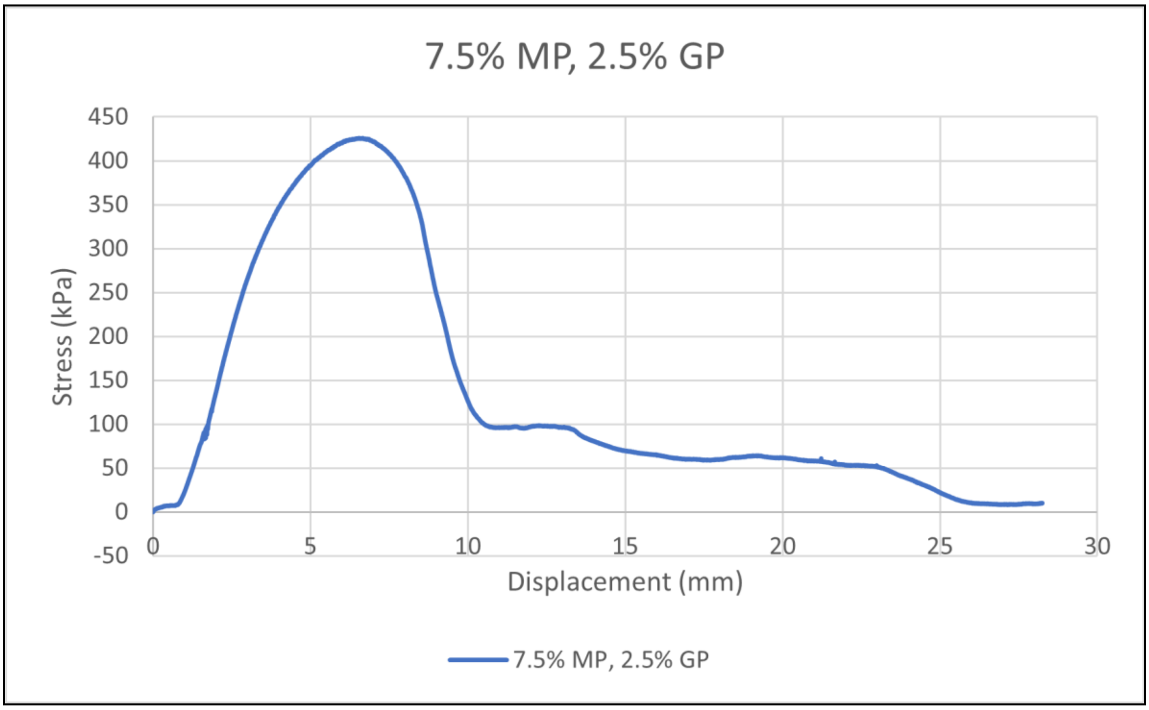

Figure 5.15: UCS at soil with 7.5% MP with 2.5% Glass Powder

According to above attached graph,

i. **Max Axial Stress = 425.90 kPa** at
ii. **Displacement = 6.54 mm**

4.4 PHASE III: PROPERTIES OF TREATED SOIL:

As according to UCS results, virgin soil is optimized on 7.5% marble powder, and 2.5% glass powder. Therefore, this becomes our treated soil on which further testing is performed to determine its properties.

4.4.1 ATTERBERG LIMITS:

Atterberg Limit Test was carried out on treated soil to determine its Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). Its results are shown below in several tables and figures.

Table 5.9: First Trial of Atterberg on treated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		32.00	24.00	12.00	25	
Mass of Container (gm)	W1	12.5	10.85	11.65		11.06
Mass of wet soil + container (gm)	W2	25.45	26.88	24.71		23.42
Mass of Dry soil + container (gm)	W3	21.82	22.08	20.55		20.71
Mass of Dry soil (gm)	W4 = W3-W1	9.32	11.23	8.90		9.65
Weight of Water (gm)	W5 = W2-W2	3.63	4.80	4.16		2.71
Moisture Content (%)	MC=W5/W4	38.95	42.74	46.74	**42**	**28.08**

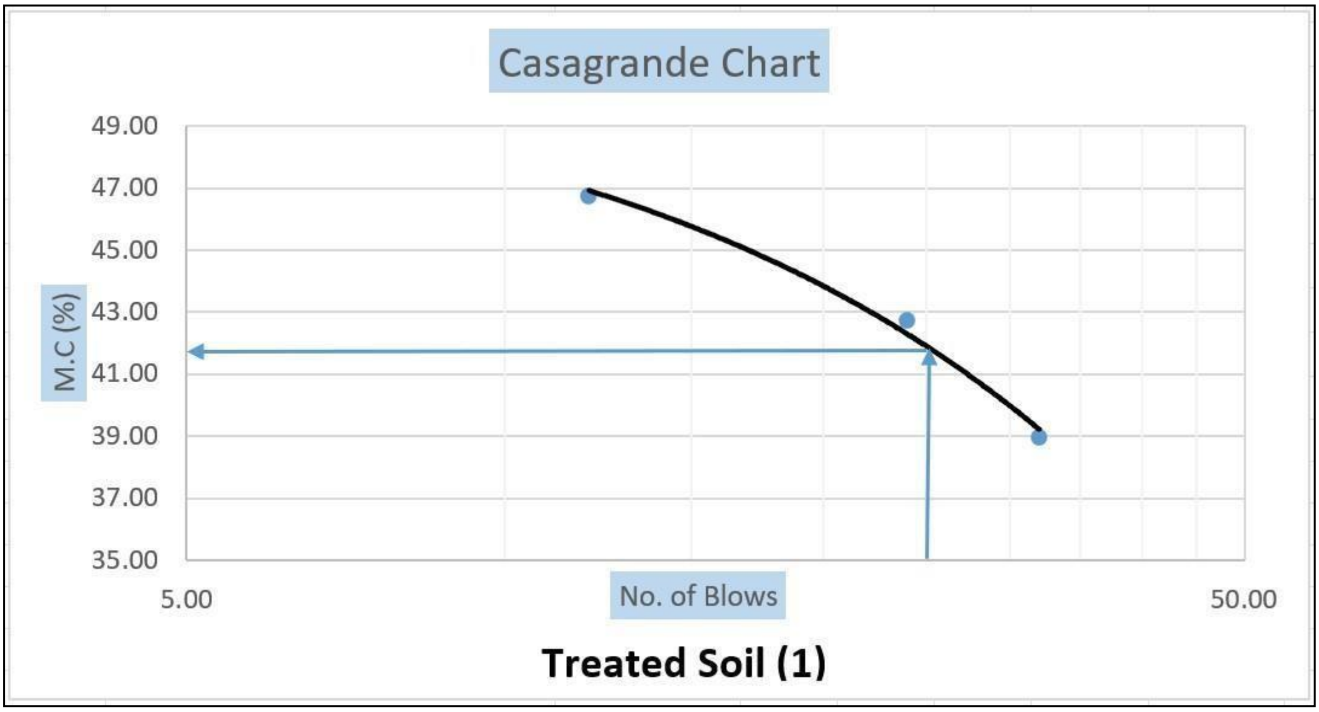

Figure 5.16: First Trial of Atterberg on treated soil

Table 5.10: Second Trial of Atterberg on treated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		34.00	22.00	15.00	25	
Mass of Container (gm)	W1	10.5	11.8	12.2		31.75
Mass of wet soil + container (gm)	W2	28.5	29.7	33.6		41.2
Mass of Dry soil + container (gm)	W3	24.6	24.3	26		39.21
Mass of Dry soil (gm)	W4 = W3-W1	14.10	12.50	13.80		7.46
Weight of Water (gm)	W5 = W2-W2	3.90	5.40	7.60		1.99
Moisture Content (%)	MC=W5/W4	27.66	43.20	55.07	**40**	**26.68**

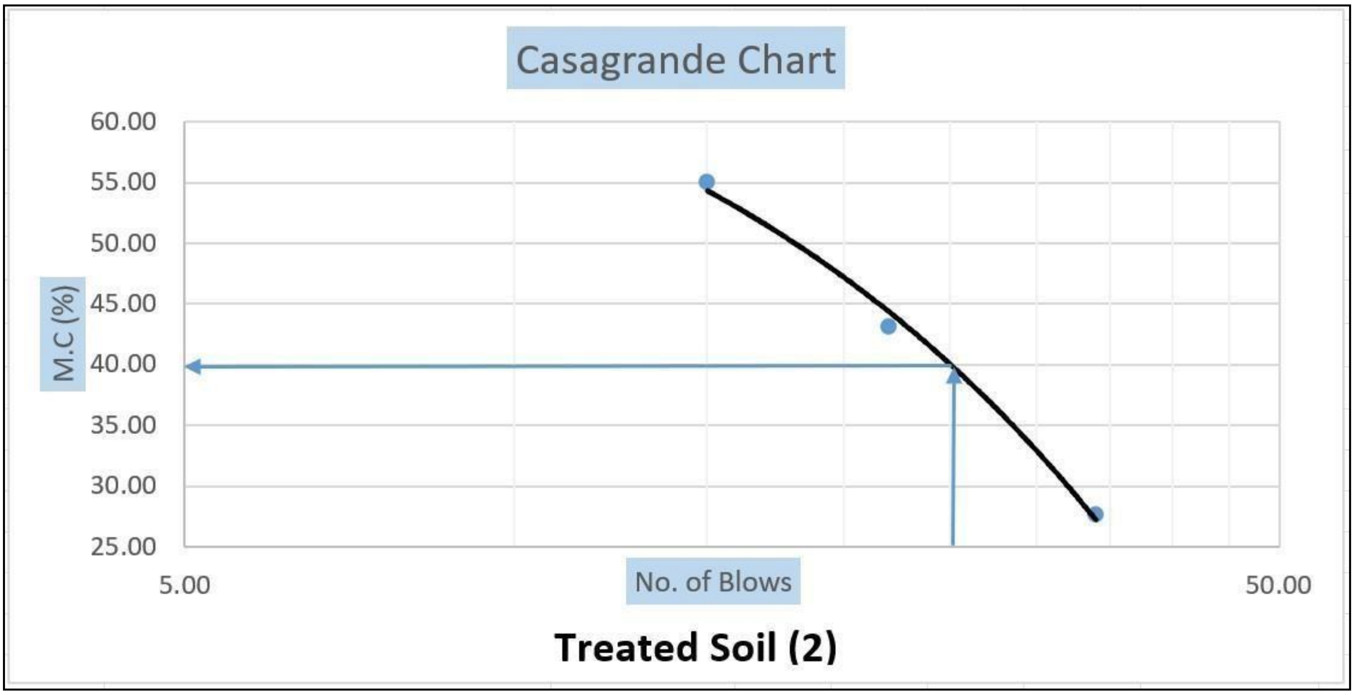

Figure 5.18: Second Trial of Atterberg on treated soil

Table 5.11: Third Trial of Atterberg on treated soil

		Trial-1	Trial-2	Trial-3	LL	PL
No. of Blows		34.00	21.00	13.00	25	
Mass of Container (gm)	W1	11.2	11.9	13		28.2
Mass of wet soil + container (gm)	W2	26.5	31.2	34.67		43.27
Mass of Dry soil + container (gm)	W3	22.48	25.11	26.42		40.01
Mass of Dry soil (gm)	W4 = W3-W1	11.28	13.21	13.42		11.81
Weight of Water (gm)	W5 = W2-W2	4.02	6.09	8.25		3.26
Moisture Content (%)	MC=W5/W4	35.64	46.10	61.48	**43**	**27.60**

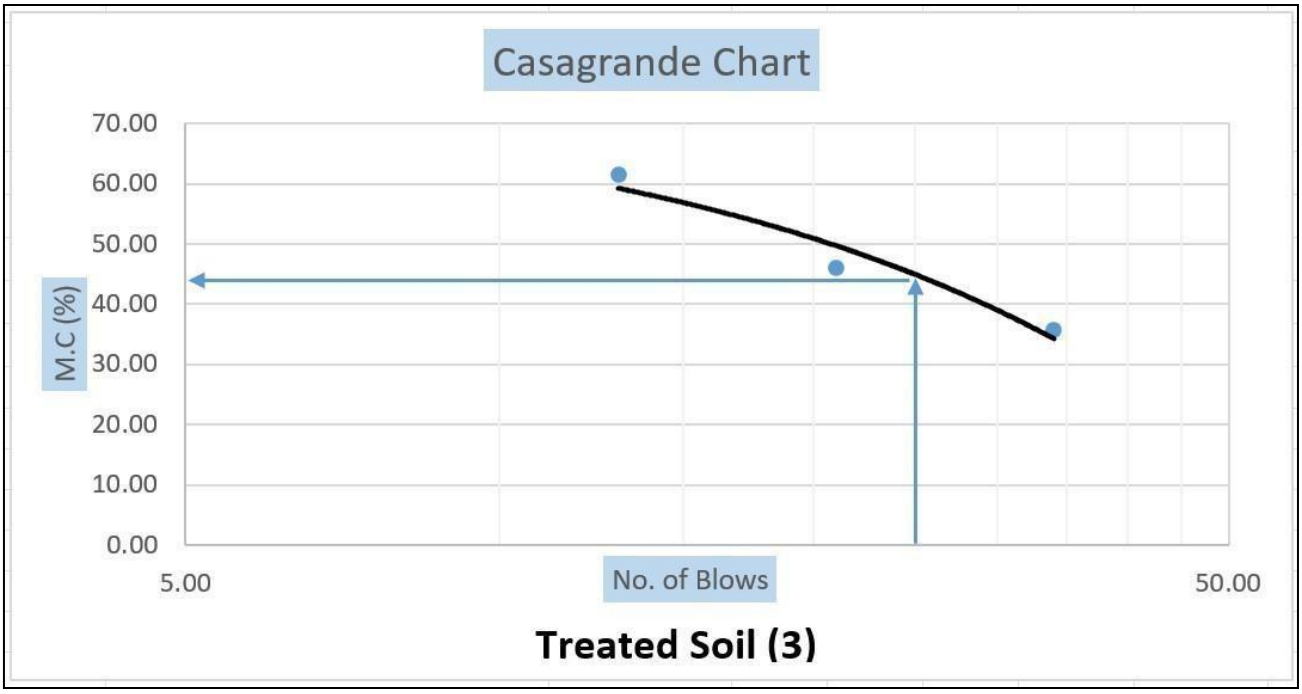

Figure 5.19: Third Trial of Atterberg on treated soil

From the above attached data, mean Atterberg Limits come out to be,

i. **Liquid Limit = 41.67 %**
ii. **Plastic Limit = 27.45 %**
iii. **Plasticity Index = 14.22 %**

4.4.2 SHRINKAGE LIMIT TEST:

Shrinkage Limit Test was performed to determine the cohesiveness of our treated soil. Its results are shown below in Table 11.

Table 5.12: Three trials for Shrinkage Limit Test

Soil	can wt.	WS+can	DS+can	MC
Sample 1	11.54	45.2	32.85	57.954
Sample 2	11.42	46.51	31.91	71.2543
Sample 3	11.31	43.91	33.12	49.4727

K	SL	SR
35.2038	22.75	1.64
47.3457	23.91	1.89
27.9046	21.57	1.51

pan wt. Gg	Hg+pan	Hg	den of Hg	Vf
327.84	504.21	176.37	13.5458	13.0202
327.84	474.54	146.7	13.5458	10.8299
327.84	523.62	195.78	13.5458	14.4531

Hg+can	Hg	Vi
289.53	277.99	20.5222
289.53	278.11	20.531
289.53	278.22	20.5391

Where,
WS = wet soil DS = dry soil MC = moisture content
Hg = mercury's displaced weight den of Hg = density of mercury
Vf = volume of dry soil Vi = volume of wet soil K = (Vi - Vf)/DS)x 100
SL = MC – ((Vi - Vf)/DS)x 100 SR = DS/(density of water x Vf)

From the above attached data, mean Shrinkage Limit comes out to be,

Shrinkage Limit = 22.74 %

4.4.3 STANDARD PROCTOR TEST:

Standard Proctor Test was performed on treated soil to determine its maximum dry density (MDD) and moisture content at this density i.e., optimum moisture content (OMC). Its results are shown in figure 20, and table 11.

Table 5.13: Standard Proctor Test of Treated Soil

Density	**Trial No**			
Trail Number	1	2	3	4
Mass of mould + compacted soil M 1(g)	3253.0	3338.0	3299.0	3251.0
Mass of mould (M 2) g	1434.0	1434.0	1434.0	1434.0
Volume of Mould (Cubic Cm)	944.0	944.0	944.0	944.0
Mass of compacted soil (g) M3	1819.0	1904.0	1865.0	1817.0
Wet Density (gm/Cc) ɣwet	1.93	2.02	1.98	1.92
Dry density (ɣdry)	1.93	2.02	1.98	1.92
Moisture Content				
Water content = W = WW	15.0	17.0	19.0	21.0

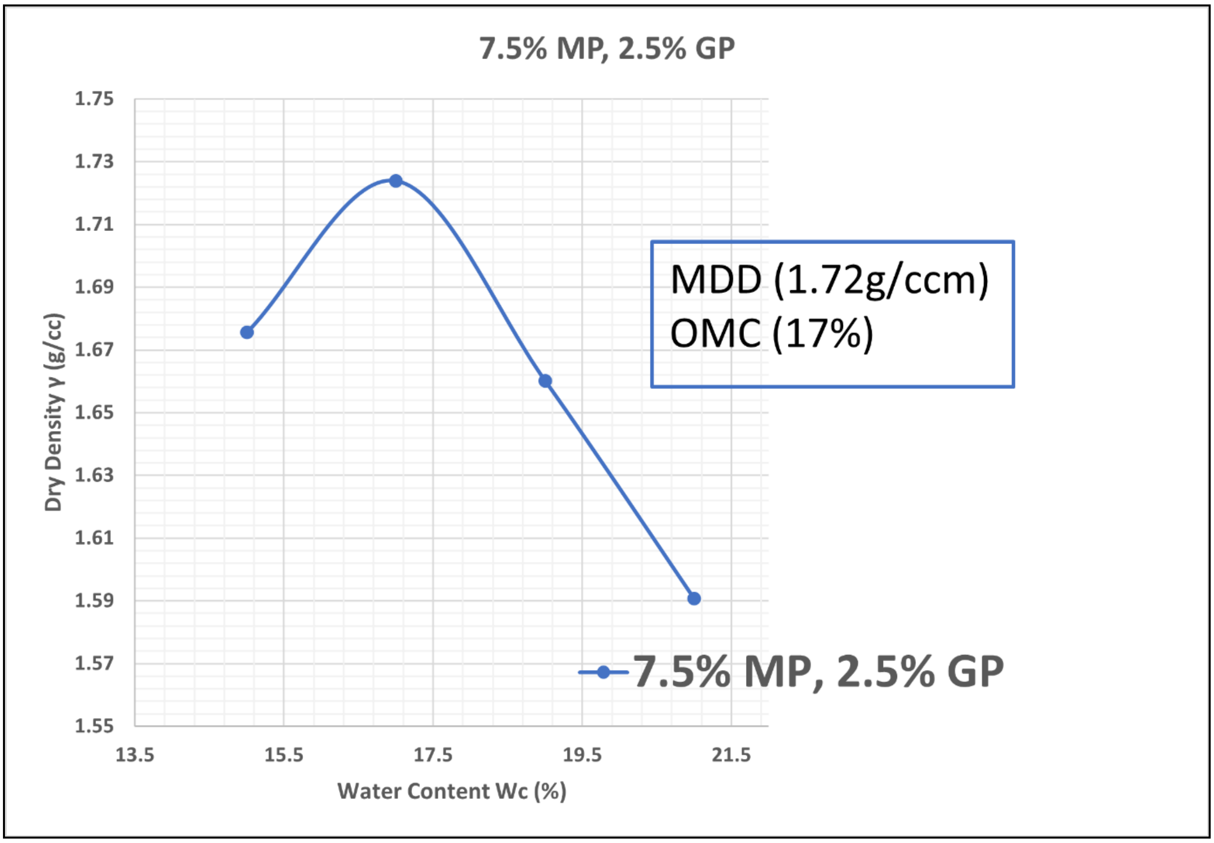

Figure 5.20: Standard Proctor Test of Treated Soil

4.4.4 UNCONFINED COMPRESSION TEST:

UCS was performed to determine the maximum stress taken by treated soil at OMC, and MDD. Its results are shown below.

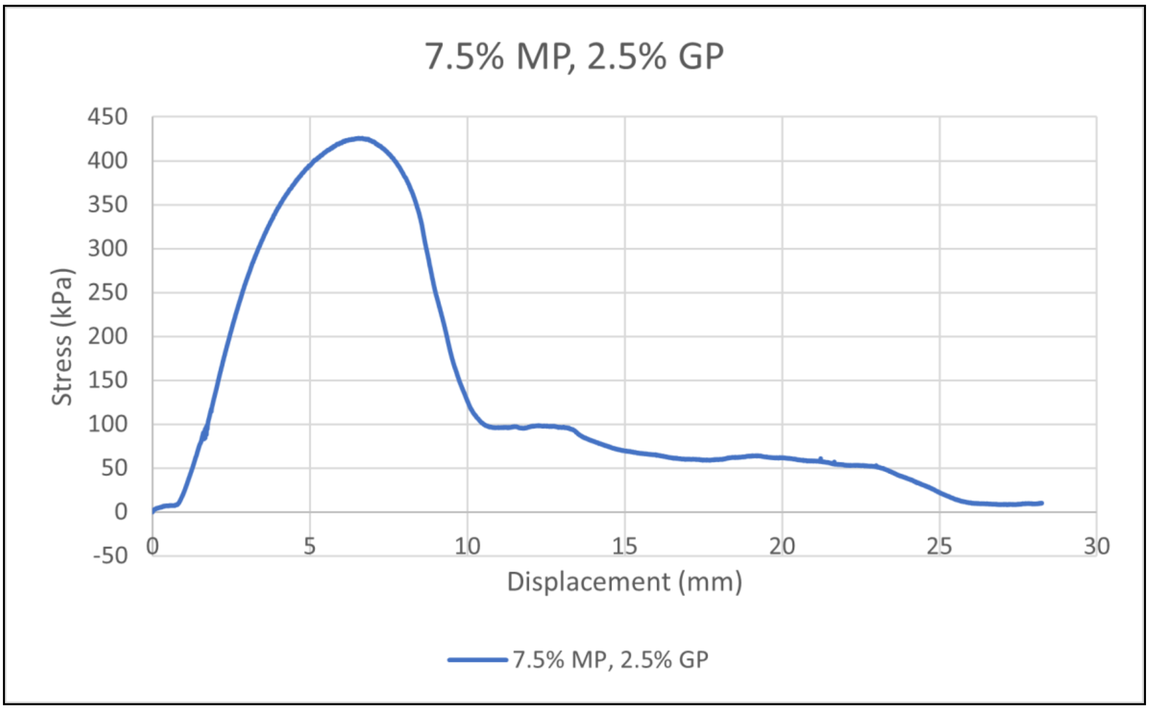

Figure 5.15: UCS at soil with 7.5% MP with 2.5% Glass Powder

According to above attached graph,

i. **Max Axial Stress = 425.90 kPa**

at

ii. **Displacement = 6.54 mm**

4.4.5 SUMMARY OF RESULTS

Also, we compared the properties of soil, with the addition of optimized Marble Content, and addition of Glass Content. It is shown below in Table 12.

Table 5.14: Comparative Analysis after completion of 1st and 2nd phases

Sr No.	Property	Untreated Soil	7.5% MP (Step one)	7.5% MP & 2.5% GP (Step two)	Percentage Difference
1	Liquid Limit	50	-	42	-16%
2	Plastic Limit	29.52	-	26.78	-9.30%
3	Plasticity Index	20.48	-	15.22	-25%
4	Shrinkage Limit	13.70%	-	24.22%	46%
5	Unconfined Shear Strength	205.4	265.6	425.9	107%
6	Maximum Dry Density	1.69	1.72	1.72	1.70%
7	Optimum Moisture Content	21.30%	19.50%	17.14%	-18.31%

CHAPTER:5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION:

The purpose of this chapter is to conclude the results that were being obtained after the testing on untreated soil as well as treated soil. The research is not only about testing on the soil and discussing the results but also giving recommendations for future study. So, this chapter will give recommendations for future work as well.

5.2 CONCLUSIONS:

From the results of sieve analysis and hydrometer analysis, we can say that our soil has 98.3% of fines content which classifies it as clays. The Liquid Limit of our untreated soil was 50% and Plasticity Index was 21% which classifies it as High Plastic Clay according to the British System (BS-1377-2;1990).

MDD of untreated soil came out to be 1.67 g/ccm and OMC came out to be 21.3%. The shrinkage limit of our untreated soil came out to be 13.71%. The unconfined shear strength of untreated soil was 205 kPa.

It was noticed that Marble Powder was optimized at 7.5% giving UCS of 264 kPa. OMC and MDD of marble optimized soil were 20% and 1.73g/ccm and by the adding of 2.5% of Glass Powder, LL of soil became 42% while PI decreased to 15.2% which indicated that it was no longer a High Plastic Clay. The MDD increased to 1.72 g/ccm and OMC decreased to 17.41%.

The Unconfined Shear Strength of soil increased to 425 kPa which makes this increase of 107%. The shrinkage limit of soil also increased to 24.22% making it a less expansive clay.

So, we stabilized our untreated clay by replacement of 10% soil with Cementous material which contained 7.5% MP and 2.5% GP.

5.3 LIMITATIONS:

Following are the limitations in the research:

1. The samples were tested in unconfined conditions.
2. No study on the effect of permeability.
3. Consolidation properties of soil weren't discussed in this research.

5.4 RECOMMENDATIONS:

Knowing these limitations , following can be the recommendations for future studies:

1. Behavior of MPGP treated Soils in Triaxial Conditions.
2. Research on permeability characteristics of MPGP treated soils.
3. Research on consolidation properties of MPGP treated soils.

REFERENCES

- 1994. Soil and rock. Philadelphia: ASTM. ASTM D 427
- 2007. Standard test method for unconfined compressive strength of cohesive soil. Weat Conshohocken, PA: ASTM International. ASTM D2166-13
- 2007. Standard test methods for laboratory compaction characteristics of soil using standard effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))¹. Philadelphia, Pa.: ASTM International. ASTM D698-07
- 2010. Standard test methods for liquid limit, plastic limit, and plasticity index of soils. West Conshohocken, PA: ASTM International. ASTM D4318-10
- Belouadah, Messaouda, Zine El Abidine Rahmouni, and Nadia Tebbal. "Influence of the addition of glass powder and marble powder on the physical and mechanical behavior of composite cement." Procedia Computer Science 158 (2019)
- Beverwijk, A., 1967. Particle size analysis of soils by means of the hydrometer method. Sedimentary Geology, 1, pp.403-406. ASTM D7928-16
- bigthink.com/starts-with-a-bang/complex-systems-nobel
- Casagrande apparatus for measuring the liquid limit (Timely Engineering Soil Tests, 2010)
- Classification of Soils for Engineering Purposes: Annual Book of ASTM Standards C, D 2487-83, vol. 04, American Society for Testing and Materials, 1985, pp. 395-408
- Fang, Hsai, ed. 2.nd ed. New York, NY: VanNostrand Reinhold, 1991.
- GSJ; Volume 7, Issue 9, September 2019
  ISSN 2320-9186
- Ibrahim, Hawkar Hashim, Yousif Ismael Mawlood, and Younis M. Alshkane. "Using waste glass powder for stabilizing high-plasticity clay in Erbil city-Iraq." International Journal of Geotechnical Engineering 15.4 (2021)
- Importance of Clay in Geotechnical Engineering, Navile Ural
- Javed, Syed Aaqib, and Sudipta Chakraborty. "Effects of waste glass powder on subgrade soil improvement." World Scientific News 144 (2020)
- Kearey, Philip (2001). Dictionary of Geology, Penguin Group, London and New York, p. 163. ISBN 978-0-14-051494-0
- Minhas, Adarsh, and Veena Uma Devi. "Soil stabilization of alluvial soil by using marble powder." Int. J. Civ. Eng. Technol 7.5 (2016)
- Muthukkumaran, Kasinathan, and S. Sentamil Selvan. "Stabilization of montmorillonite-rich bentonite clay using neem leaves ash." International Journal of Geosynthetics and Ground Engineering 6.2 (2020)

- n.d. Standard test method for particle-size analysis of soils. ASTM D422-07
- Rathee, Ajeet, et al. "Soil stabilization using powdered glass." Int Res J Eng Technol 5.5 (2018)
- Shukla, Rajesh P., et al. "Effect of marble dust and glass fiber on expansive soil." Inżynieria Mineralna (2020)
- Singh, Parte Shyam, and R. K. Yadav. "Effect of marble dust on index properties of black cotton soil." Int J Engg Res Sci Tech 3 (2014)
- Taylor, Sterling A.; Ashcroft, Gaylen L. (1972)
- Voroney, R. Paul; Heck, Richard J. (2007)
- Zallen, R. (1983). The Physics of Amorphous Solids. New York: John Wiley. pp. 1-32. ISBN 978 0-471-01968-8
- Zumrawi, Magdi ME, and Eman AE Abdalla. "Stabilization of expansive soil using marble waste powder." Conference Proceedings Civil Engineering 2018. 2018