EVALUATION OF STABILIZATION POTENTIAL OF PLASTIC WASTE IN EXPANSIVE SOIL

By

19-Civil-025 Name: Waleed Ahmed Tanoli

19-Civil-033 Name: Qazi Waseeq ur Rehman

19-Civil-018 Name: Muhammad Ali Abbasi

Project Supervisor

(Lecturer Engr. Hassan Danish)

Project Co-Supervisor

(Lecturer Engr. Muhammad Irfan)

CIVIL ENGINEERING DEPARTMENT
HITEC UNIVERSITY, TAXILA

July, 2023

EVALUATION OF STABILIZATION POTENTIAL OF PLASTIC WASTE IN EXPANSIVE SOIL

FINAL YEAR PROJECT REPORT

SESSION 2019

THESIS IS SUBMITTED TO THE FACULTY OF THE DEPARTMENT OF CIVIL ENGINEERING, HITEC UNIVERSITY, TAXILA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR'S OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

EVALUATION OF STABILIZATION POTENTIAL OF PLASTIC WASTE IN EXPANSIVE SOIL

Submitted by

19-Civil-025 Name: Waleed Ahmed Tanoli
19-Civil-033 Name: Qazi Waseeq ur Rehman
19-Civil-018 Name: Muhammad Ali Abbasi

Project Co-Supervisor

Lecturer Engr. Muhammad Irfan

Project Supervisor

Lecturer Engr. Hassan Danish

Head of Department

Dr. Sabahat Hassan

DEDICATED

TO

HOLY PROPHET (P.B.U.H)

MINERAT OF KNOWLEDGE

AND

MY LOVING PARENTS, MY TEACHERS & INSTITUTE

WHO GAVE ME A LOT OF INSPIRATION,

COURAGE &

SUPPORTED MORALLY &

FINANCIALLY FOR MY STUDIES

ACKNOWLEDGEMENTS

I am grateful to Almighty ALLAH, the Most Merciful and the Most Beneficial, who made it possible for me to finish this research project. Many greetings to the Holy Prophet (P.B.U. H), the fountain of wisdom who has led humanity in all facets of existence. My supervisor, Lecturer Engr. Hassan Danish, my co-supervisor, Lecturer Engr. Muhammad Irfan, and Engr. Hamza Munir consistently and effectively communicated a spirit of hard effort to complete the project. I would like to express my sincere gratitude to them. The completion of this project would not have been possible without his assistance and direction.

My parents are my inspiration and motivation, and I will always be grateful to them for their understanding, unending patience, and support when I needed it the most. My parents have my honest and heartfelt thanks. This whole endeavor has been enjoyable and fulfilling.

Abstract

From a geotechnical point of view, problematic soils are soils having a tendency of expanding or shrinking after getting in contact with water. Clays often experience volumetric changes when they come into contact with water. Due to their impaired qualities, such as poor shear strength, low bearing capacity, high shrink-swell potential, and high compressibility, these soils are a very frequent cause of most foundation failures. It is impossible to avoid using these soils for future construction given the expanding requirement for infrastructural development. To achieve structural requirements, the engineering features of these soils must be modified chemically or mechanically. This study is done on purpose to check the effect of fine crushed plastic waste (Polyethylene Terephthalate) on the properties of problematic soil. Specific Gravity, Atterberg Limits, M.D.D, Shear strength, CBR value, and the coefficient of compression, swell, and consolidation, etc. were determined first on untreated soil and then after treating the soil with plastic waste. It was observed that the specific gravity of the soil decreased as the plastic content increased, and the M.D.D of treated soil also decreased. There was an increase in the value of shear strength. CBR value was also increased and it was observed that with the addition of plastic, the process of settlement was slow as compared to untreated soil in which the rate of settlement was high under small loads. The results specify that the addition of plastic waste in the soil can offer a practical and affordable way of handling clays.

Keywords:

Problematic Soils, Fine Crushed Plastic waste, Polyethylene Terephthalate, M.D.D, Shear Strength, CBR value, Coefficient of compression, swell, and consolidation

Table of Contents

List of Tables

List of figures

Nomenclature

Abbreviation	Nomenclature
ASTM	American Standard of Testing Material
AASHTO	American Association of State Highway and Transportation
USCS	Unconfined Soil Classification system
CEC	Cation Exchange Capacity
PET	Polyethylene Terephthalate
M.D.D	Maximum Dry Density
O.M.C	Optimum moisture content
L.L	Liquid limit
P.L	Plastic Limit
P. I	Plasticity Index

CBR	California Bearing Ratio
C	Cohesion
Φ	Angle of Internal Friction
CL	Clayey Soil
CL-ML	Between Clayey soil and silty soil
Cc	Coefficient of compression
Cs	Coefficient of swell
Cv	Coefficient of Consolidation
S. S	Shear Strength

CHAPTER 1: Introduction

1.1 STUDY BACKGROUND

Expansive soils are the soils that tend to go through critical volume change with the addition or removal of water content. The clayey soil plays a significant role among different soils having an exceptional way of behaving because of its broad nature. This variety capability of soil lies on the expansive clayey minerals present in the soil. Montmorillonite, brendelite, vermiculite, nontronite, chlorite, bentonite, and smectite are common clayey minerals. These sorts of soils can easily absorb the water content and expand because of weak inter-particle bonding and fine particles. Due to the high CEC of montmorillonite and vermiculite soils in which these minerals are present they, change their behavior in the presence of moisture. Swelling and shrinkage occur and the behavior of the soil changes drastically.

Figure 1: Expansive Soil of Nandipur Pakistan with ground cracks

Expansive soils bring about the cracking and breaking of asphalts, structures, canals, irrigation system frameworks, and sewer lines. Expansion of soil additionally brings in pressure on the vertical essence of the foundation, retaining walls, and basement which results in the lateral movement of soil. This enlarging or shrinkage of soil results in a decrease in the strength or capacity of the soil. Under small loads expansive soils settles and when the heavy load is applied the settlement increases and it is more than allowable value. As the demand for land is truly developing and avoiding these soils for foundation improvement couldn't be imaginable in not so distant future. It is well known that the Problematic soils are typically present in the areas where the amount of rainfall is very less. Expansive Soils are notable for their downgraded properties like high shrink and swell, high compressibility, low shear strength and low bearing capacity, and so on. Expansive soils are not appropriate for Engineering development projects. Therefore, different stabilization methods have been created to improve these soils which incorporate the Mechanical and Chemical properties. As Mechanical methods incorporate compaction, pre-wetting, overcharge loading, and so on while the Chemical methods incorporate the addition of some chemical admixture to the soil which improves the strength of soil by directly responding with soil. These responses can be chemical or pozzolanic. The most common chemical substances used to stabilize soils incorporate lime, cement, gypsum, fly ash, and so on. But some of them are expansive as well as not environmental friendly. Like soil stabilization with cement is more expansive as it is an expansive material and the production of cement is also hazardous for the environment. As plastic is non-biodegradable substance and it will take centuries to decompose the plastic. So using plastic waste as a stabilizing agent will be more economical and beneficial.

As Expansive soils can be exposed easily in the field as they show deep cracks of polygonal patterns especially when there is dry season. This swelling and shrinkage behavior of these soils becomes a serious hazard for the structure lying on these soils majorly affects the strength of foundations by uplift because when the expansive soil swells it causes uplift of foundation which may cause cracks to differential movements which results to failure of the structure and also effects the bearing capacity of soil.

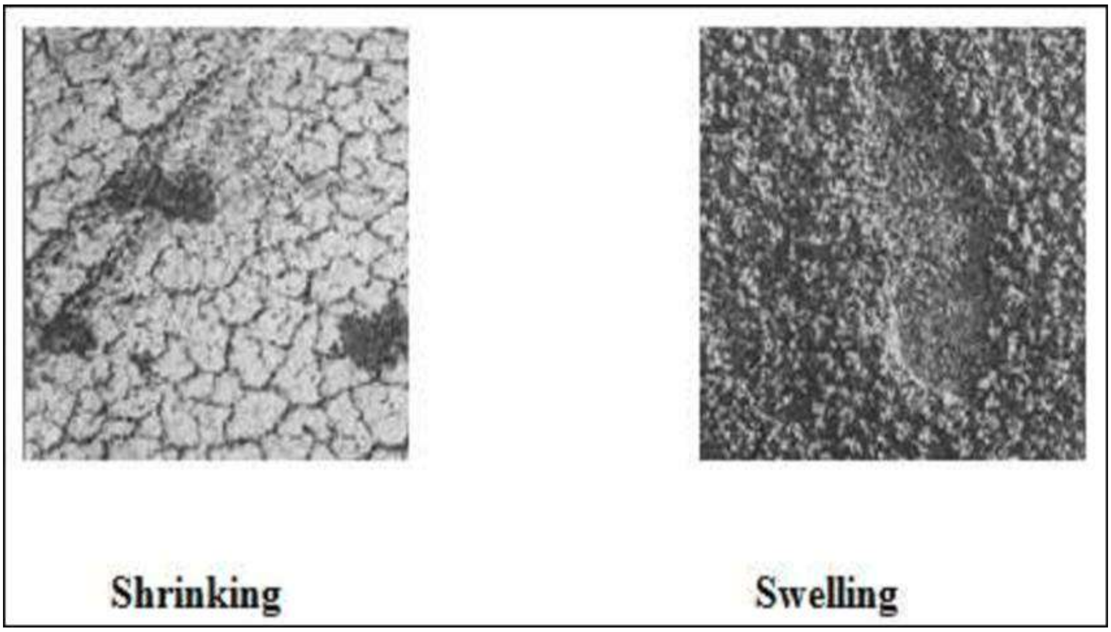

Figure 2: Shrinkage and swelling in soil

In this study we have used the plastic bottles waste, polyethylene terephthalate (PET) in the form of powder. As we know that the plastic waste is one of the major issue which is faced by the whole World main issue which had been faced is the decomposition of plastic waste as plastic is non-biodegradable and it does not decompose. So it's sustainable to use the waste or non-useable product into the usable purpose of stabilization of soil. In this way the plastic can be decreased and can be used in the positive way as a stabilizing agent.

Stabilization of soil using polyethylene terephthalate (PET) waste involves incorporating patchy or granulated polyethylene terephthalate (PET) particles into the soil. The polyethylene terephthalate (PET) particles act as a reinforcing agent, improving the strength, durability, and load-bearing capacity of the soil. The interlocking nature of the polyethylene terephthalate (PET) particles helps in reducing soil settlement, improving compaction characteristics, and increasing resistance to erosion.

1.2 NEED OF RESEARCH:

Soil stabilization gives a practical and technically feasible solution for some Engineering problems related to expansive soils. However, there is always an uncertainty related to the subsurface circumstances. So, a technique reasonable for one case probably won't be appropriate for the other. A large portion of the arrangements in geotechnical engineering are site-specific, in this manner, a recommended treatment for a specific site may not be relevant in an alternate area. It is subsequently suggested that detailed field and laboratory investigations be done before recommending a particular stabilization strategy.

Scientists have been dealing with attempting different chemical substance admixtures and evaluating their impact on the engineering properties like permeability, compressibility, particle size gradation, durability, and consistency limits of soil.

Till now many materials (chemical and natural) are used as stabilizing agents to stabilize the soil. Plastic is also used as stabilizing agent in different forms but no one till now has used plastic pellets as a stabilizing agent, so this study will help to fill the gap plastic is a waste material and a Non-Bio degradable substance so, we can use plastic in form of balls or pellets to stabilize the soil. Using plastic is an economical as well as Environmentally friendly solution to enhance the properties of soil.

1.3 RESEARCH OBJECTIVES:

The main goal of this study is to evaluate the suitability of waste plastic as a soil stabilizer. To evaluate the optimum content of polyethylene terephthalate (PET) waste powder. The primary focus of this study will be on how plastic waste can improve the properties of soil given below:

- Soil plasticity
- Maximum dry density
- Shear Strength of soil
- Reduce Settlement in expansive soils
- CBR value
- Swelling and shrinkage

1.4 SCOPE AND METHODOLOGY:

The main goal of our research was to enhance the physical and mechanical properties of soil by using plastic waste. As discussed earlier utilizing plastic waste as a stabilizing agent is the best economical way to improve soil properties. In this research different tests were performed on the soil of Nandipur to check its behavior when it contacts with water. Then testing was done on the treated soil in which soil was replaced with different percentages of plastic. Then comparison of the results of different experiments on both soils was done to find out whether the properties are enhanced or not.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Problematic soils

Expansive or Problematic soils, sometimes called shrink-swell soils, are a kind of soil that experience substantial volume fluctuations in reaction to changes in moisture levels. Clay minerals having a high swelling potential, such as smectite or montmorillonite, are frequently found in these soils. Expansive soils absorb water, expand, and put pressure on nearby or adjacent buildings. In contrast, they contract during dry spells, which may result in ground settlement and structural harm. The expansive character of these soils is a significant difficulty for infrastructure development and construction as it may lead to broken foundations, warped buildings, and uneven pavements. To lessen the negative impacts of expansive soils and ensure the long-term viability of the project, effective soil stabilization procedures, such as moisture management, suitable drainage systems, and the use of chemical additives, are required for surroundings that are stable and long-lasting.

2.1.2 Plastic a Non-biodegradable substance:

As polyethylene terephthalate PET bottles are not environmentally friendly and not beneficial to the environment as they are non-biodegradable and every year millions of these bottles are wasted in fact these bottles can be recycled and beneficially used.

2.2 Soil Stabilizing:

Basically, stabilization of soil is the process that enhances the properties of soil like bearing capacity, shear strength, etc. As the most important part of the structure is its Foundation because if the foundation fails the whole structure will automatically fail so the foundation of the structure should be as much strong to bear the whole load of any building or structure applying to it. So, we can use plastic waste as a soil stabilizer and increases the strength of soil plastic waste is one of the major issues facing the whole world as it is not environmentally friendly and causes environmental pollution because plastic is non-biodegradable. This study shows that by adding the waste plastic strips increases the soil's cosmic radiation price. To increase the soil cosmic radiation the fabric and also plastic can be used for the purpose of soil stabilizer but only enough amount of plastic waste should be present. Because there is a lack of high-quality soil suitable for a number of constructions, using plastic as a soil stabilizer is, therefore, a cost-effective and profitable construction.[1]

2.3 Utilizing Plastic Strips in Soil:

In many studies, polyethylene terephthalate (PET) and polypropylene fibers are used for the purpose of Soil Improvement. To the insufficiency of research using the overview of synthetic or plastic strips which can be taken through waste materials, we can reuse the plastic waste (strips) which are highly prospective to improve the characteristics or properties of Soil. This research proves the result of the addition of polyethylene terephthalate strips from plastic bottle waste having different lengths and percentages of clayey soil and sandy soils. The following two tests are performed which are the Unconfined Compression test and Direct Shear test was performed on two soils at two different compaction degrees which are 95% and 100%.

The following results which were achieved in this study shows that the addition of plastic waste (recycled bottles) with soil enhances the geotechnical properties of soil as recycled bottles are not environmentally friendly we can reuse them in the form of strips and resulting in enhancement in the properties of soil. The maximum strengths by unconfined compression test on sandy soil as length = 20mm; 1.5% and that of clayey soil as length = 30mm; 1.5%. By the addition of polyethylene terephthalate strips we can see that it enhances the sandy soil in a better way by the increase of 66.4% compaction degree CD =100% and compaction degree CD = 95% in cohesive obstruct. In common by reusing polyethylene terephthalate PET bottles it's social and environmentally friendly and beneficial for the environment and also by reusing this waste, we can improve the geotechnical properties of soil.[2]

2.4 Utilizing Plastic Flakes in Soil:

This study proposed the mechanical behavior of clayey soil which is mixed with different percentages of PET crushed powder at 10%, 20%, and 30% while with PET flakes at 3% and 5%. These types of materials can be used to enhance the geotechnical properties of clay. The results of the standard compaction test on the clayey soil tells that the addition of Polyethylene terephthalate involves directly the values of moisture present in the clay as well as in the dry weight of the clay by reducing both of them. This is due to the less value of the dry mass of finely crushed polyethylene terephthalate decreases the dry mass of the mixture when mixed with the soil. As for the polyethylene terephthalate flakes the water content increased while dry mass slightly decreased. The top results of load capacity and improvement in parameters are observed by mixing C70P30 and C95F05. The percentage of Polyethylene terephthalate PET fine crushed can fill the voids in a better way by enhancing the bonding between the soil and PET improving the friction angle and cohesion.[3]

2.5 Plastic Strips as a Reinforcement in Soil:

Plastic strips are also used as reinforcement material in soil because of their size as compared to soil. In this case, lime was used as stabilizing agent with the combination of plastic reinforcement. The lime replacement was constant while plastic replacement varied. Results show that there was a slight decrease in the value of the liquid limit and plastic limit which reduced the value of the plasticity index.

As the plastic content increased in soil its M.D.D decreased this was because of the light unit weight of plastic strips as compared to soil. When the lime was added alone in soil the O.M.C of the soil increased due to the high-water absorption of lime. The unconfined compressive strength increased with rise in the quantity of plastic waste. A slight increase in the CBR value was also observed with an increase in the quantity of plastic waste. [4]

This study proves the effect of using polyethylene terephthalate PET bottle waste strips on the compressibility parameters and soil strength. The results show that this soil was classified as the A-6 category according to the American Association of State Highway and Transportation official AASHTO which proves the poor geotechnical properties of the soil. However, the study shows how the waste polyethylene terephthalate PET bottle strips by performing the durability tests reinforce the soil parameters and enhances the long life of the geotechnical structures.[5]

As plastic waste is one of the most important challenges which is faced by the whole World and its usage in our daily life is also important. Plastic waste is increasing day by day and its disposal methods cause environmental pollution like the burning of plastic. One of the Eco-friendly and effective processes of plastic waste is to utilize the plastic waste in civil engineering construction as plastic is almost free of cost. By adding the plastic waste in the soil also enhance the parameters of the soil and enhances the foundation lying on that soil and overall construction. As the optimum results were found in the addition of (0-5%) aspect ratio. After review of the study, we concluded that the polyethylene terephthalate PET fibers are environmentally friendly and cheap which enhances the properties and strength of soil. The following properties of soil are improved increase in shear strength, reduction of consolidation settlement, decreases in the cracks present in the soil, and decrease in the reduction of swelling of soil when we use plastic fibers as the stabilizer of the soil. When the plastic strips are added at the percentage of (0-5%) in the soil shows the best results.[6]

The properties of soil such as shear strength, bearing capacity, etc. can be improved by adding different types of admixtures as the soil stabilizers such as lime, cement, fly ash, plastic, etc. As plastic waste is such a challenge that is faced by the whole world for dispose of as it is a Non-Biodegradable as creates environmental pollution which is harmful so it’s a better way to use non-useful waste plastic in a useful way to use it as a soil stabilizer agent. like plastic bottles and polythene bags. This problem of plastic waste disposal is increasing day by day so in this study we will use the waste plastic bottles for the purpose of soil stabilizer by enhancing its physical properties. Different tests were performed using the plastic waste on clayey soil samples and checking the effects on the sample by adding different percentages of plastic waste at 5%, 10%, 15%, 20%, and 25% and results are obtained. The sample used for the tests are clayey soil samples and the stabilizer used is waste plastic strips. The values of cohesion and unconfined compression strength had been increased by 20% to 70% by adding the waste plastic strips to the soil. The value of dry density of the given soil sample increased by 5% to 20% when waste plastic strips are added to the soil. The optimum moisture content OMC of the given soil sample has decreased by 8% to 20% from the natural soil sample.[7]

As soil is the most important aspect in the civil engineering projects because the soil is used in the construction of buildings, road rail tracks, highways, etc., and is responsible for the sustainability of these structures because when the soil fails the structures lying on the soil will automatically fail. In this research, the soil is stabilized using waste plastic bottles to improve the engineering properties of subgrade construction. For subgrade construction waste plastic bottles are used to reduce the landfill and using the waste plastic bottles in reinforcing the soil structure. In this research, the soil is stabilized by using lime and plastic fibers which are taken from the waste materials. It is well known that these waste materials are increasing the problems of the entire World day by day and as a result the Environment is polluted so in this study the waste material is used in a positive sense. In this study, the amount of non-usable waste products such as water bottles, polythene bags, food packaging, etc. can be decreased by using this type of waste as a soil stabilizer. For making the structure economical the optimum proportion of lime is 5% in the clayey soil at this percentage of lime the results obtained are the best. The compressive strength increases at the percentage of 0.8% of polypropylene fibers PPF while the percentage increases to 23.08% which was achieved. At 0.8% plastic waste there is an increase in CBR of about 17.06% which is obtained from the results.[8]

In the Engineering world, improvements have changed the lifestyle of humans to a lot extent. Day by day inventions are introduced for human comfort but in the same way, they are making risks to the health of humans in the same way one of the major issues is plastic which is taking place in the whole world and results in environmental pollution. By viewing from a geotechnical point of view these wastes of plastic can be utilized positively and used in soil stabilization in the form of plastic strips. Different tests are performed like standard proctor, and unconfined compression test, to check the effect of plastic waste strips on the silty clay. The positive aspects include in this research are the usage of waste products, economics, and use of natural resources i-e silty clay. This research is basically to check the performance of plastic fibers as a stabilizer, the study shows that if the waste plastic fibers are properly mixed with the silty soil sample at different percentages acts as a great soil stabilization technique. The addition of 0.5% of plastic waste reduced the OMC of the soil and increased the maximum dry density. On the same percentage unconfined compressive strength of the soil increased. At 1% value of MDD and UCC decreased. So, the optimum feed of plastic waste was 0.5%.[9]

It can be observed from the results and discussions that the addition of plastic waste had a positive impact on soil properties as the CBR value of the soil is increased when the plastic waste is added in it. The plastic strip additions increased the soil resistance against penetration load. As in pavement, the total load is carried out by the subgrade so the plastic strips can be added to the soil to enhance CBR value and it will reduce the phenomenon of rutting or settlement.[10]

In this study, polypropylene fibers were utilized to check the impact of these fibers on the properties of soil. These fibers were added with different percentages. There was a notable decrease in the value of the liquid limit and plastic limit as well. Due to the decrease in the Liquid limit and plastic limit shrinkage limit of the soil decreased which means that after the addition of polypropylene fibers soil was more suitable for foundation as the swell index of the soil is reduce.[11]

Polypropylene strips were added to the soil to check the behavior of the soil. The result showed that the inclusion of plastic fibers increased the unconfined compressive strength of the soil. The strength of the soil decreased as interlock bond b/w strips and soil was not good. The CBR value of the soil increased with the inclusion of plastic waste. So, it can be used as a stabilizing agent in the case of pavements, and if there is a need for filling on the embankment the loss in strength causes less load on backfilling.[12]

The combination of waste that can be produced by crushing plastic bottles and polypropylene fibers can be used to reinforce the soil. This study aimed to enhance soil properties by using polypropylene fibers and polyethylene strips. It was observed that an increase in the length of the strips resulted in higher strength. The value of CBR and MR increases with an increase in the content of strips. The optimum value of strips for CBR, MR, and USCS was between 1 to 2%.[13]

The utilization of plastic fiber as a stabilizing material reduced the value of the liquid limit and plastic limit which overall decreased the swell potential of the soil. The Maximum dry density of plastic is also reduced as plastic is lighter than soil. With the addition of 4% of fibers,[1] there was a significant increase in CBR value up to 200%. The specific gravity of the soil also reduced when the plastic content in the soil increased. [14]

2.6 Clayey Soils:

Clay is a word that refers to both mineralogy and soil particle size. It is a substance with particles that are less than 0.002 mm in size. It is defined as a substance with a net negative charge, flexibility, cohesiveness, and weather resistance in terms of mineralogy. Clayey soils are created when rocks undergo chemical weathering. Kaolinite, illites, montmorillonites, vermiculites, etc. are some of the most popular clay minerals.[15]

2.7 Clay Structure:

Clay is a composition of materials like montmorillonites and illites. Montmorillonites have a greater tendency to cation exchange. The high cation exchange capacity of montmorillonites present in the soil will try to expand the soil and affect the volume change which will lead to swelling and shrinkage in the soil. Illites are also present in clayey soils and they have similar surface area to montmorillonites.[16]

2.8 Cation Exchange Capacity:

The quantity of exchangeable cations in clay minerals that can be replaced by cations with more replacement power than the absorbed cation is known as the cation exchange capacity of the soil. In table 2.1 the capacity of different minerals present in clayey soils can be checked. It can be observed theat vermiculite and montmorillonite have the higher and surface area. Due to presence of these two minerals in clay the occurring of swelling and shrinkage phenomenon is very high. [17]

Table 1: CEC of different minerals[17]

Clay Minerals	CEC (me/100 g)	Surface Area (m2/g)
Vermiculite	100 - 150	600 - 800
Montmorillonite	80 - 120	600 - 800
Illite	10 - 40	65 - 100
Chlorite	10 - 40	25 - 40
Kaolinite	3 - 15	7 - 30

Chapter 3

3 Problem Statement, Materials, and Methodology:

3.1 General

This research initiates the intent of plastic waste use to modify the properties of problematic soils. The soil of Nandipur, Gujranwala was used for this research. All the tests are performed according to American Society of Testing Materials ASTM standards.

3.1.1 Problem Statement and Objectives

From a geotechnical point of view problematic soil is soil that has the potential to shrink, expand when it comes in contact with moisture. When it comes in contact with moisture properties of the soil changes immediately and no one can predict the behavior of the soil. It can go under excessive settlement under small loads and under very low stresses the failure may occur due to the settlement in soil. Nandipur region is famous for containing this expansive soil in different areas located near Nandipur. The main objective of this research was to stabilize the soil by using fine crushed plastic waste. As can be seen in different research, plastic waste was utilized to enhance the properties of soil. Some other materials can be used as stabilizing agents like cement, lime, etc but cement and lime are not environment friendly and they are expensive too. So this study aims to have an economical and environmentally friendly solution to enhance the properties of soil.

3.2 Materials

Detailed information on materials (Soil and Plastic) is given in this part. Finely crushed plastic was used in this research as a stabilizing agent. The material was brought from a **“Small crushing plant near Master Upvc pipe Marble Factory” Westridge Rawalpindi.**

3.2.1 Plastic:

Finely crushed polyethylene terephthalate was bought from a small plastic crushing plant which is located near “Marble upvc pipe factory near Westridge

Rawalpindi". The plastic was in powder form and added to the soil to check the behavior of the soil after the addition of crushed plastic.

3.2.2 Soil:

Soil from Nandipur Gujranwala Pakistan is used in this research. Samples were collected from the village of Gagewali located near Nandipur Gujranwala. Figure 3.1 show the location where samples were collected.

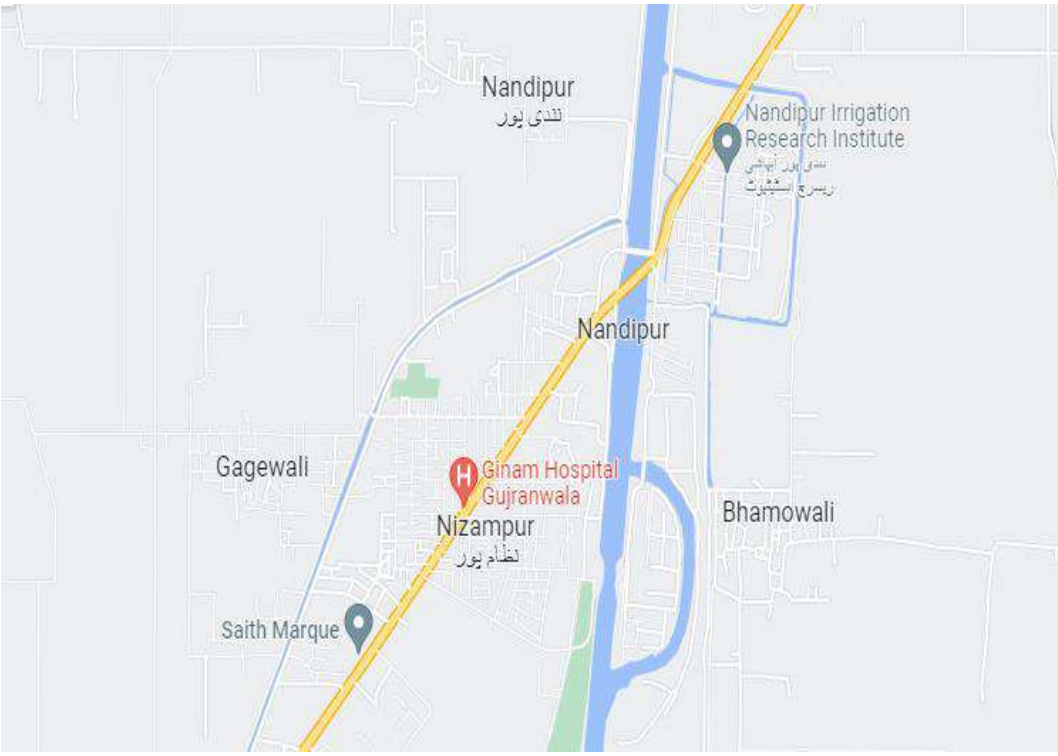

Figure 3 Satellite View of Sample Collection Point Village Gagewali Near Nandipur

3.3 METHODOLOGY:

This research is completed in three phases.

- Testing on untreated soil
- Testing on treated soil
- Finding the optimum feed of plastic waste

3.3.1 Phase I

3.3.2 Properties of Untreated Soil:

The first step of our research was to determine the natural soil properties(untreated) in which no admixture was added. Tests was performed on natural soil to find the properties of the soil.

3.3.3 Sample Collection:

The sample of soil was collected from the village of Gagewali which is located near Nandipur Gujranwala Pakistan. This region is famous for having expansive and clayey soils and these soils are exported for making cricket pitches all over Pakistan. The Soil was collected from a site of a building and a 3ft depth from N.S.L so that there are no chances of organic matter in the soil. The location of the soil is given in Figure 3.1.

3.4 Tests and their standards:

Table 2 Tests and their standards

Tests	Standard
Particle size distribution	ASTM D422
Specific gravity test	ASTM D792
Atter Berg's Limit test	ASTM D4318
Standard Proctor Test	ASTM D698

Direct Shear Test	ASTM D3080
CBR Test	ASTM D1883
Consolidation Test	ASTM D2435

3.5 Testing on untreated soil

3.5.1 Particle Size Distribution

This test is used for classifying the soil. Sieve analysis on a given sample of soil was done and the values were noted. Then mass retained on every sieve and mass passing through every sieve was calculated. Then the percentage of sand and coarse soil was determined and then soil classification was done accordingly.

3.5.2 Specific Gravity Test:

This test was performed according to ASTM D792. In this test specific gravity of the soil was found out by using pycnometer apparatus and its value was calculated accordingly.

3.5.3 Atterberg's Limit Test:

The Atterberg's limit test was performed according to the ASTM D4318 to find out the liquid limit and plastic limit of the soil. Soil passing from the #40 sieve was used in this test. This test is performed for the classification of soil. To find out the liquid limit of soil the Casagrande apparatus was used while to find out the plastic limit of soil glass plates are used.

3.5.4 Standard Proctor Test:

This test was performed according to ASTM D698 to find the OMC of soil under given compaction. Soil is filled in three layers with 25 blows on each layer. This test is performed to figure out the soil's MDD. As optimal moisture content is that which is attained when the soil is squeezed at a reasonably high humidity level and nearly all the air is pulled out. The MDD may be calculated by producing a graph with the dry density and moisture content as the abscissa and ordinate, respectively.

Figure 4 Sample preparation for Standard proctor Test

Figure 5 Cutting off extra soil from the mold with cutting edge

3.5.5 Direct Shear Test:

This test was performed according to the ASTM D3080 to find out the shear strength of soil against the normal load. The sampler has a 6 inches diameter with 2 inches height with one filter paper and porous stone below the soil sample while one porous stone and filter paper above the soil sample in the assembly. Through the use of a Direct Shear Test, the internal friction angle (ϕ) and the cohesion (c) of a planar soil sample has been identified. Results have been derived from the normal Stress against Shear Stress curve after it has been drawn.

Figure 6 Sample preparation

Sample of untreated soil

Figure 7 Sample of treated soil

Samples after performing under different loads

3.5.6 CBR Test (California bearing ratio):

CBR test was performed according to ASTM D1883 to find out the strength of soil subgrades and base course. CBR samples were prepared in apparatus having mold whose internal diameter is 6 inches while its height is 7 inches. The surcharge weight was 5kg while a 2” spacer disk was used. It was performed on unsoaked samples. CBR measures the difference between the force per unit area required to penetrate a soil mass at a rate of 1.25 mm/min using a circular plunger with a standard diameter of 50 mm and the force required to achieve the same in a standard material. The ratio is typically determined for penetrations of 2.5 and 5 mm. When it consistently outperforms the ratio at 2.5 mm, the 5 mm ratio is used

Figure 8 CBR sample after test

CBR test apparatus during testing

3.5.7 Consolidation Test:

A consolidation test was performed according to ASTM D2435 to determine the rate and magnitude of settlement in soils. The apparatus we used to perform the consolidation test is a saturated cylindrical soil specimen. Oedometer apparatus was used to perform the consolidation test with a sample having 6 inches diameter and height of 2”. Values were observed at different time intervals after the application of load. After every 24 hours load was first increased and after 5 days load was removed to check the value of consolidation on the unloading condition.

Figure 9 Consolidation Test   Oedometer Apparatus

Chapter 4

4 Results and Calculations:

4.1 General:

This research is done to check the adequacy of plastic waste as an additive in the soil to stabilize the expansive soil.

4.2 Phase I Results of Untreated/Natural Soil:

4.2.1 Specific Gravity Test:

The specific gravity of natural soil was calculated according to standard ASTM D792. The specific gravity of soil was 2.78 which is in the range of clayey soil according to ASTM D792.

4.2.2 Particle Size Distribution:

The Unified Soil Classification System (USCS) and the AASHTO classification system both depend on the particle size distribution of soil samples. Insights into the engineering features of soils can be gained by classifying soils into various groups depending on the ranges of their particle sizes. For this purpose, soil sample was taken in sieves for the results of this test.

Results	Particle size distribution
% age of gravel	5.2
% age of sand	93.82
% age of fines	0.98
D60=	0.975585
D30=	0.509208
D10=	0.238381
Cu= D60/D10	4.092539
Cc=	1.114946

Table 3 Results from particle size distribution

4.2.3 Atterberg Limits Test:

ASTM D4318 was followed to perform the Atterberg limits test. Casagrande apparatus was used to determine the liquid limit of the soil and the plastic limit was determined by making tiny threads of 1/8" size according to standard.

The liquid limit of the soil was 46.17% while the plastic limit of the soil was 28.94% and the plasticity index was 17.06%.

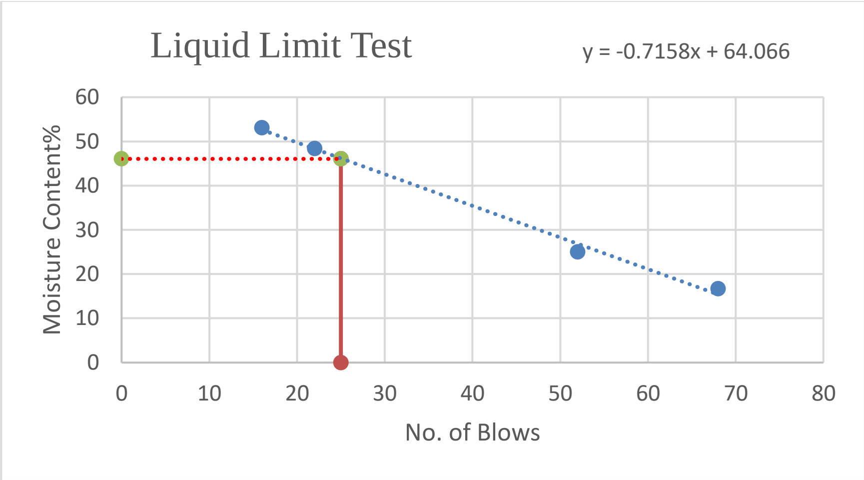

Figure 10 Graph for Liquid Limits

Untreated Soil	
USCS System	**AASHTO System**
• **Group Name= CL** • **Group Name= Sandy lean clay**	• **Group Symbol=Clayey Soils** • **Group Name= A-7-6**

Table 4 Soil classification according to both systems

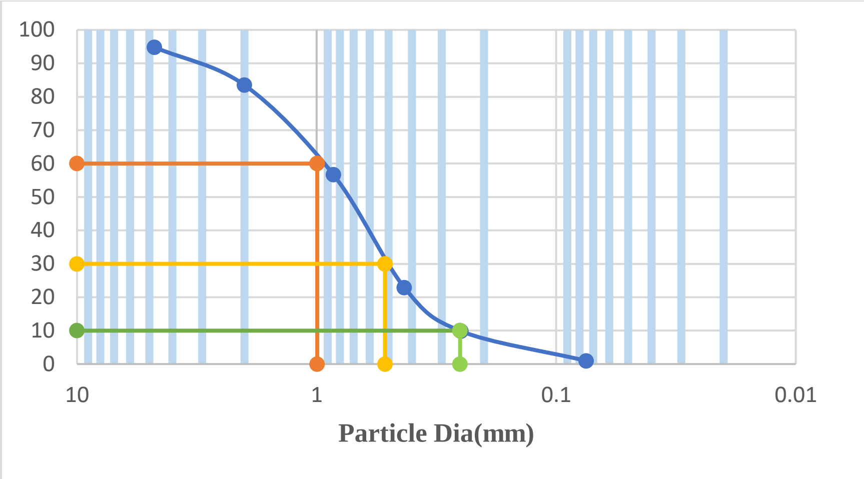

Figure 11 Particle size curve for untreated soil

4.2.4 Standard Proctor Test:

To find out the O.M.C of the soil standard proctor test was done. ASTM D698 was followed to perform the test. M.D.D was found to be 2042.91 kg/m3 or 2.042 g/cm3 and the O.M.C was 14.5%.

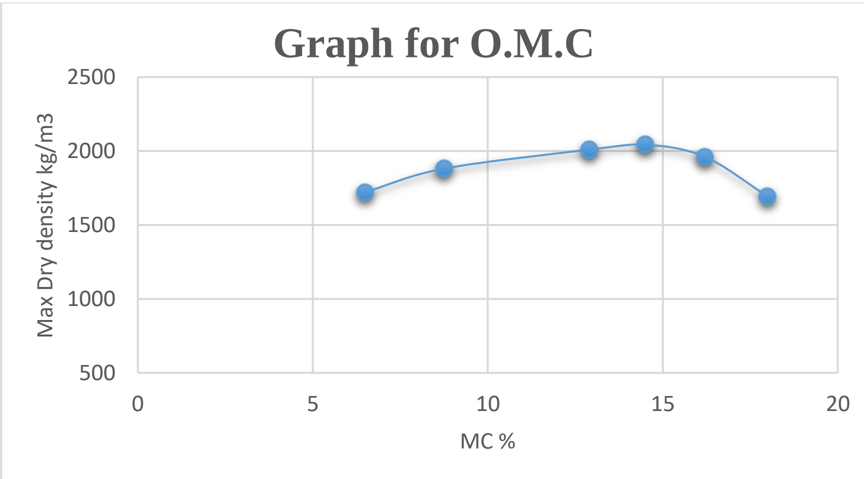

Figure 12 Relation b/w Density and O.M.C

4.2.5 Direct Shear Test:

A direct shear test was done to find out the shear strength of the soil. ASTM D3080 was followed. The shear strength of the soil depends on C and ϕ. The value of C was 16.256 and ϕ was 13.15˚. Shear strength is found by using the S. S= C+σtan(ϕ). The value of shear strength was 27.875 KPa.

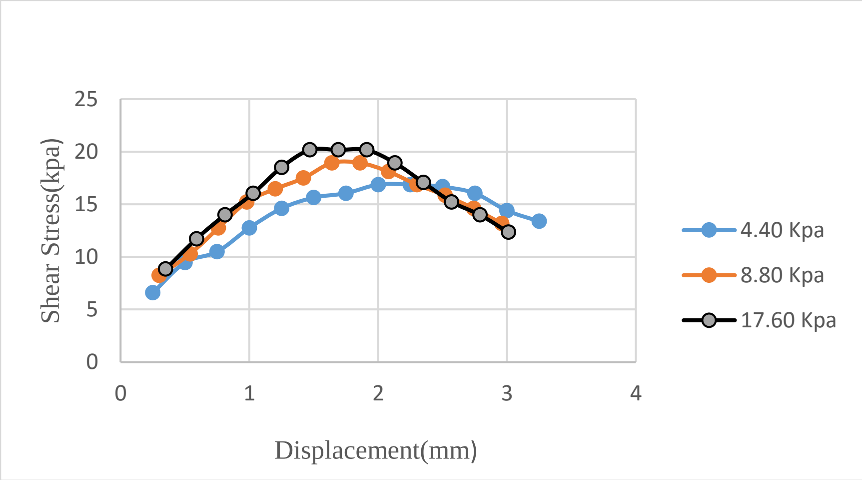

Figure 13 Stress Strain Graph b/w Shear strength and Displacement

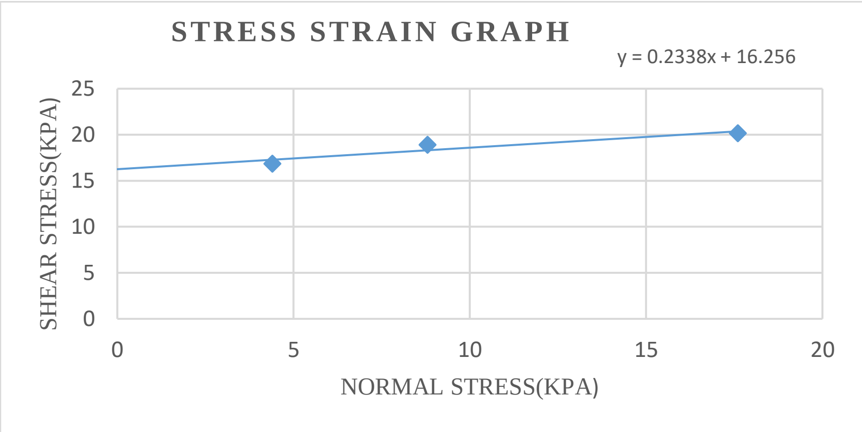

Figure 14 Graph b/w Normal Stress and Shear stress

4.2.6 California Bearing Ratio (CBR) test:

CBR test was performed according to ASTM D188. It was done on an unsoaked sample. The CBR value for soil was found out 9.83%.

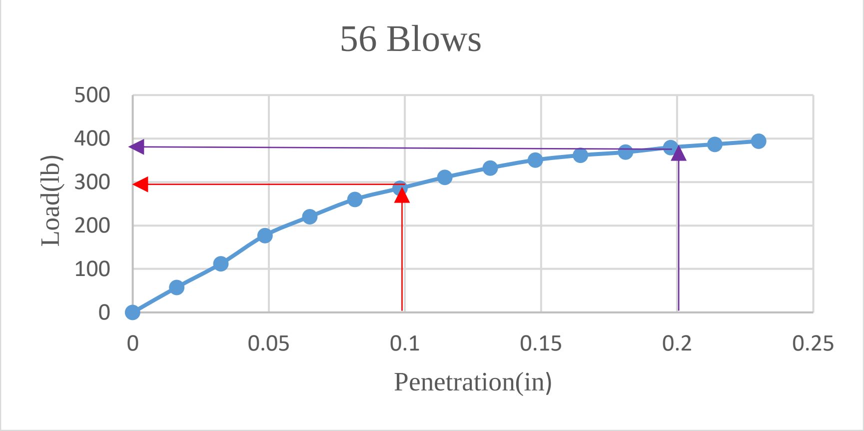

Figure 15 Graph for CBR value (Untreated Soil)

4.2.7 Consolidation Test:

The consolidation test is done by using oedometer apparatus. It is done according to standard ASTM D2435. It was done to find out the rate of consolidation in soil and other important parameters like Cc, Cs, Cv, void ratio, and pre-consolidation pressure as well. The value of Cc was 0.2616, the value of Cs was 0.078592 value of Cv was 0.21774 cm2/min and the pre-consolidation pressure was about 7.75 KPa. All the above values were determined by using the Taylor Method of Curves.

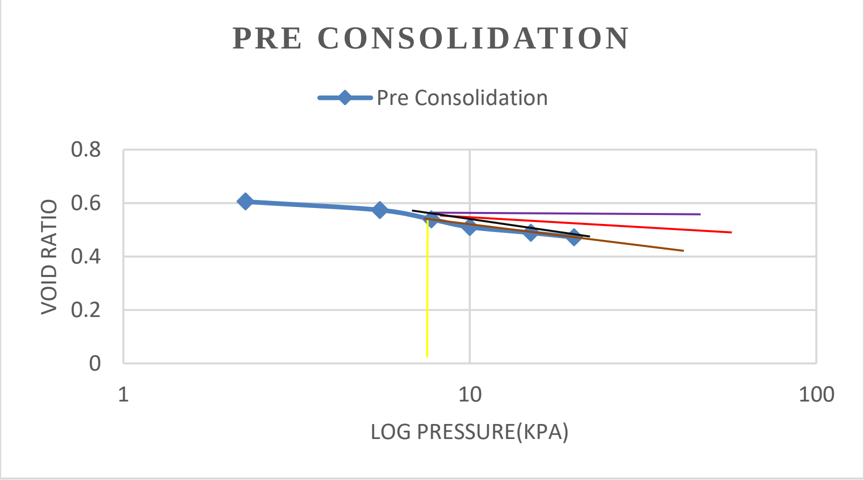

Figure 16 Graph for Pre-Consolidation Pressure

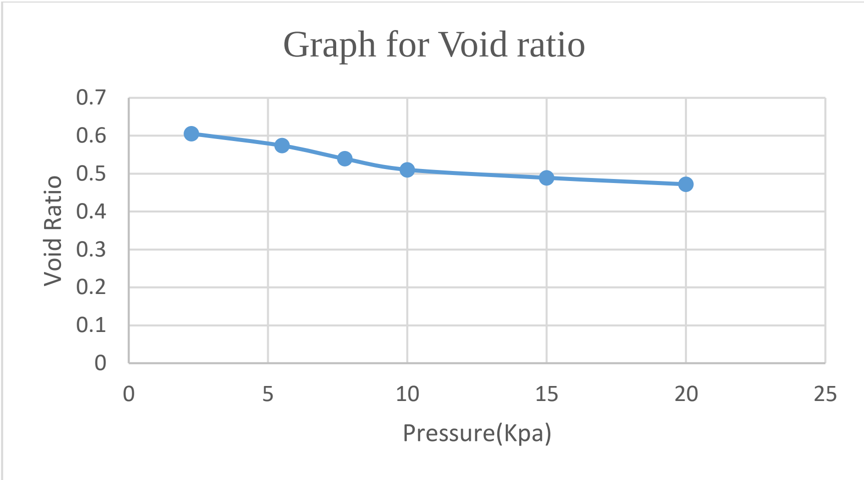

Figure 17 Relation b/w Void Ratio and load

Sr. no.	Properties of Untreated Soil	Results
1)	Specific Gravity	2.78
2)	L.L (%)	46.84
3)	P.L (%)	28.94
4)	P. I (%)	17.06
5)	M.D. D (g/cm^3)	2.042
6)	O.M.C (%)	14.5
7)	C(KPa)	16.526
8)	Φ °	13.15°
9)	Shear Strength (KPa)	27.875
10)	CBR Value (%)	9.83
11)	Cc	0.26164
12)	Cs	0.07859
13)	Cv (cm^2/min)	0.21774

Table 5 Results of untreated soil

4.3 Phase II Results of Treated Soil:

4.3.1 Standard Proctor Test:

After testing on untreated soil was completed standard proctor test was performed introducing plastic waste as an additive. Different percentages of plastic were added to find an optimum feed of an additive. The test was performed by replacing 3%,6%,9%,12%, and 15% of soil with plastic respectively. It had been noticed that the M.D.D of soil decreased by 1.357 g/cm^3 while the addition of plastic increased the O.M.C of the treated soil which was 16.67%.

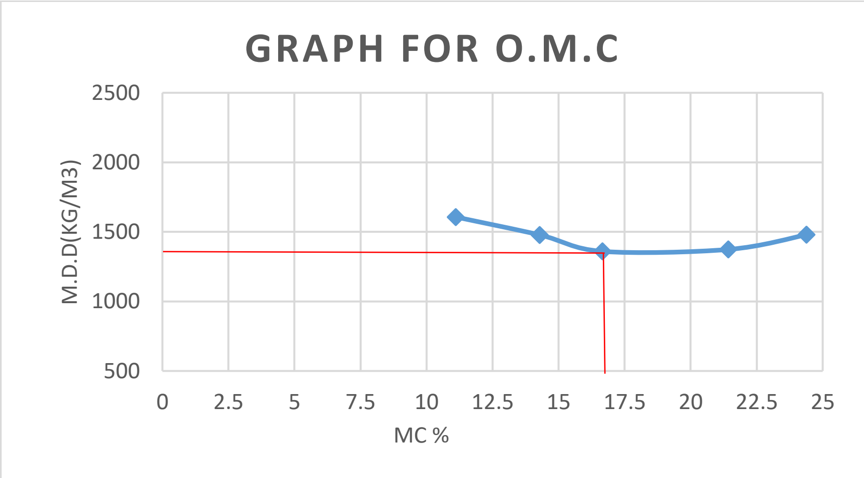

Figure 18 Graph for O.M.C for Treated Soil

4.3.2 Specific Gravity Test:

After that specific gravity test was performed by replacing 9% of the soil as it was the optimum feed of plastic. The specific gravity of soil decreased and it was about 2.62 which was in between the range of Sandy soil given by ASTM.

4.3.3 Atterberg Limits test:

Atterberg limits test was performed according to the ASTM D4318. Different percentages of additives were added. The Casagrande apparatus was used to perform the liquid Limit test. It was determined that the L.L. of the soil decreased to 26.84%. to check the plasticity of the soil the plastic limit test was performed by making threads of 1/8" and its value was 24.40% and the Plasticity index was 4.28%.

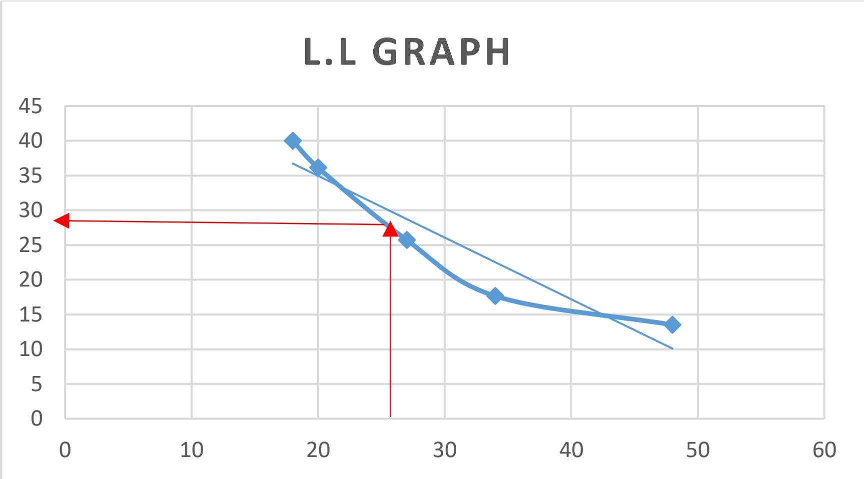

Figure 19 Graph for L.L for Treated Soil

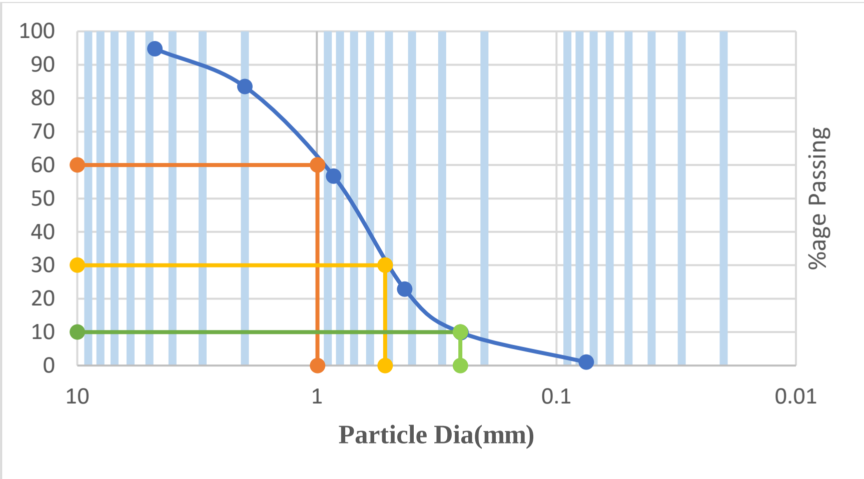

Figure 20 Particle size distribution curve for treated soil

USCS System	**AASHTO System**
• **Group Name= CL-ML** • **Group Name= Sandy silty clay with gravel**	• **Group Symbol= Silty or clayey gravel with sand** • **Group Name= A-7-6**

Table 6 Soil classification for treated soil

4.3.4 X-rays Diffraction:

X-ray diffraction was done on plastic waste-treated soil. It can be observed in figure 4.11 (b) shows different percentages of minerals.

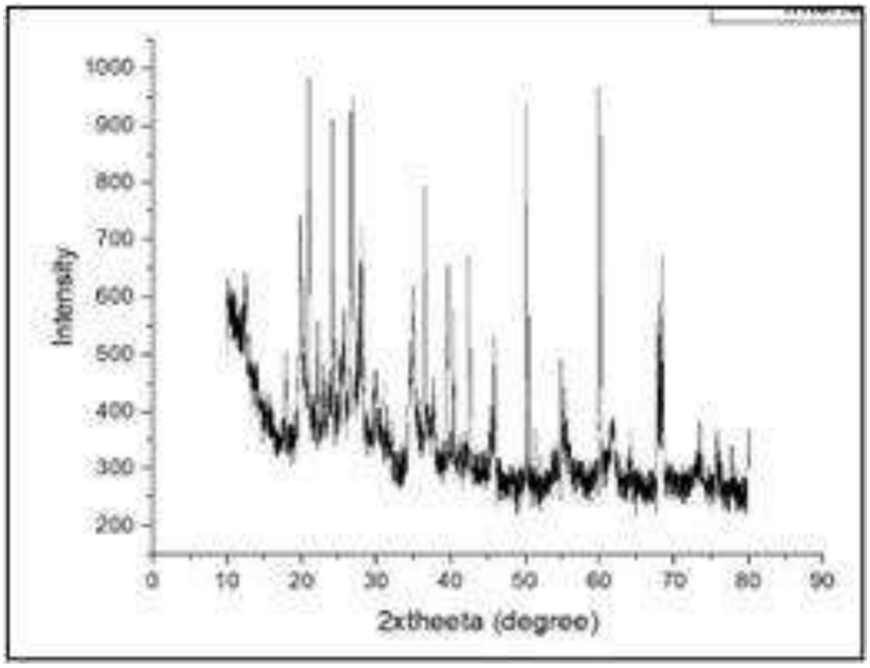

Figure 21 2 Theeta Graph For illite and montmorillonite

Formula	Matched phase	Quant.(%)
O2 Si	Silicon oxide $-alpha Quartz low	58.5
C	Carbon Graphite 2H	31.6
O2 Si	Quartz	6.4
Al0.5 Li0.5 O...	(Li Al (Si O4))0.5	2.2
H2	Hydrogen	1.3

Figure 22 Chemical Composition of Minerals in soil

4.3.5 Direct Shear Test:

This test was performed to check the effect of plastic on the shear strength of the soil. It was observed that the values of parameters like C and ϕ on which shear strength depends, the soil's shear strength rose as a result of higher shear strength dependencies. At 9% replacement of soil maximum value of shear strength was achieved which was 45.56 KPa.

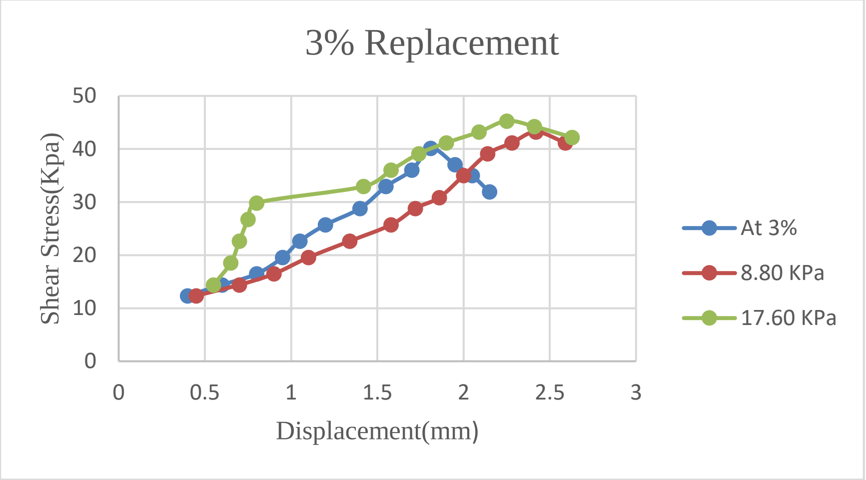

Figure 23 Stress-strain graph for 3% replacement

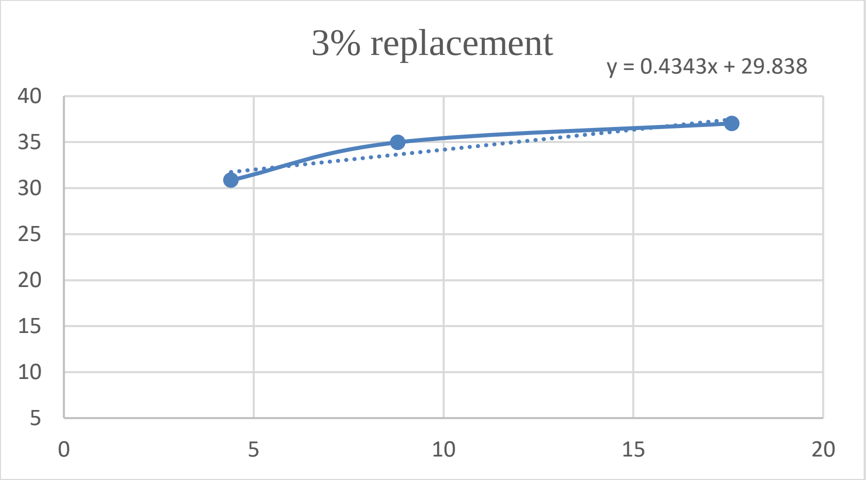

Figure 24 Graph b/w normal stress to Shear Stress at 3% replacement (For Treated Soil)

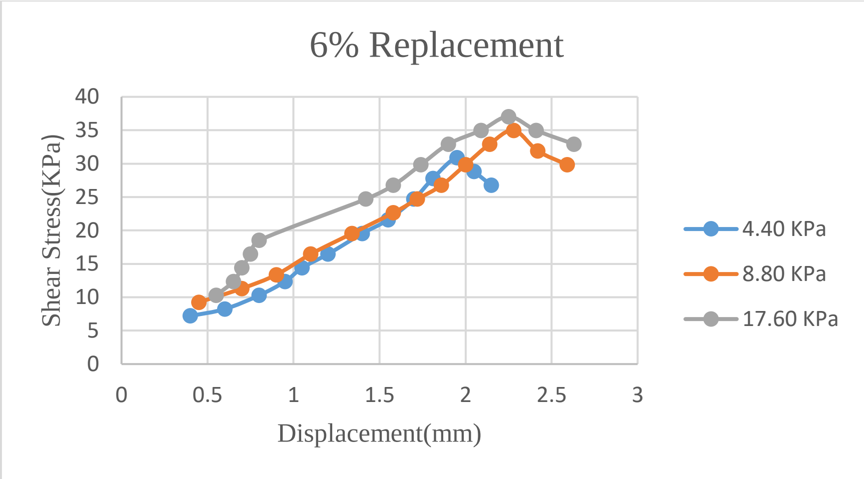

Figure 25 Stress-strain graph for 6% replacement

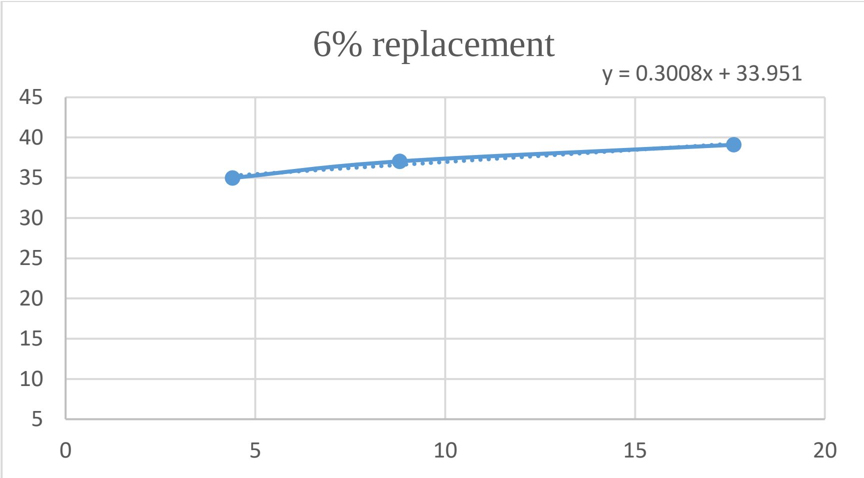

Figure 26Graph b/w normal stress to Shear Stress at 6% replacement

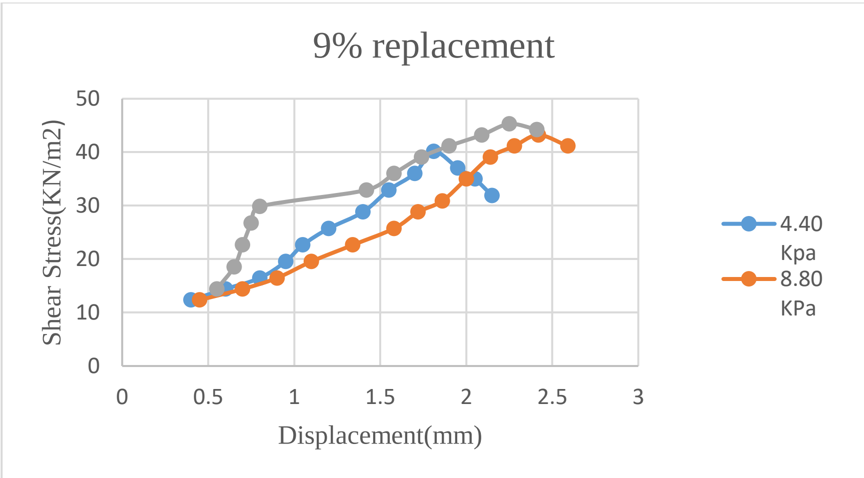

Figure 27 Stress-Strain Graph for 9% Plastic Replacement

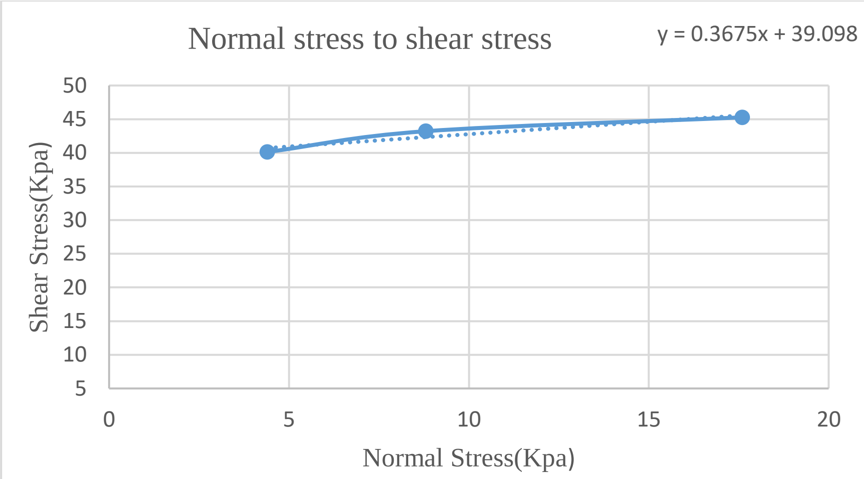

Figure 28 Graph b/w normal stress to Shear Stress at 9% replacement

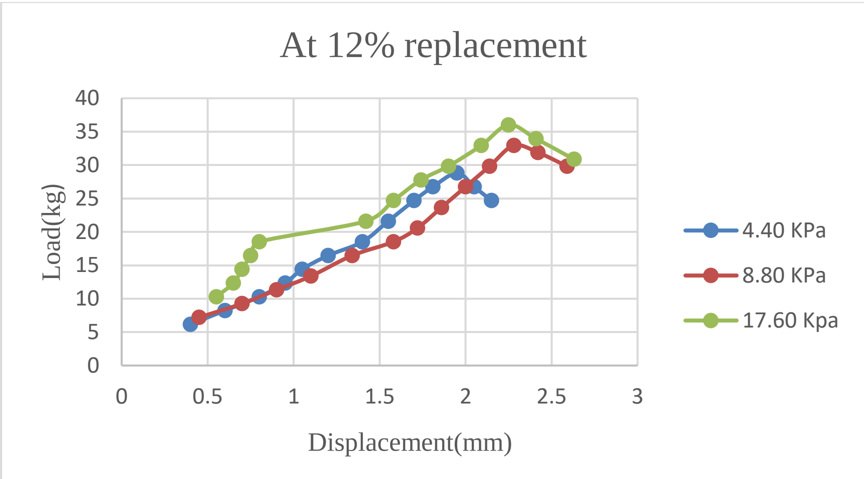

Figure 29 Stress-Strain Graph for 12% Plastic Replacement

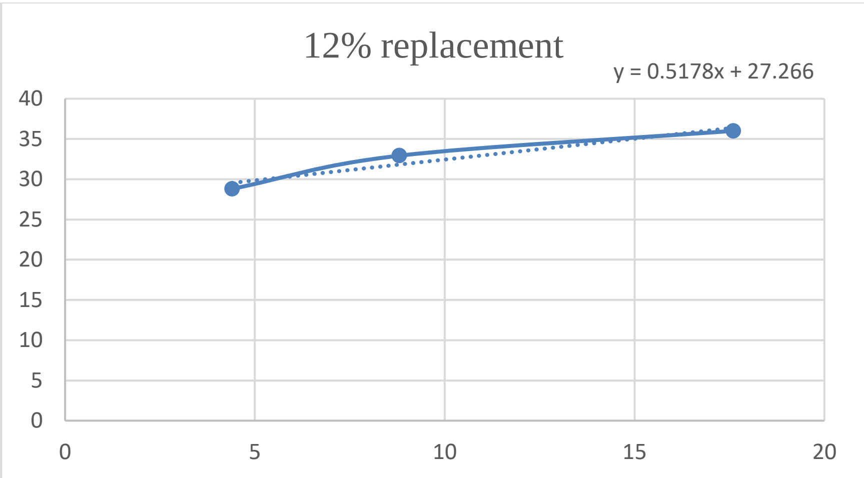

Figure 30 Graph b/w normal stress to Shear Stress at 12% replacement

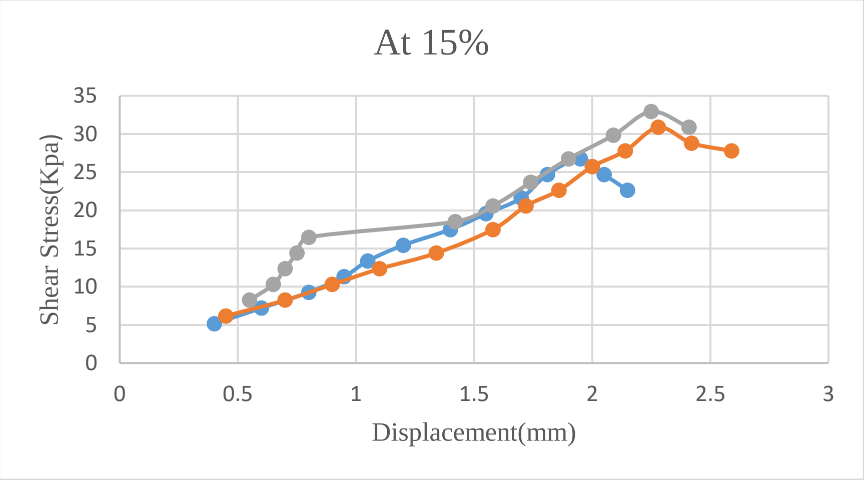

Figure 31 Stress-Strain Graph for 15% Plastic Replacement

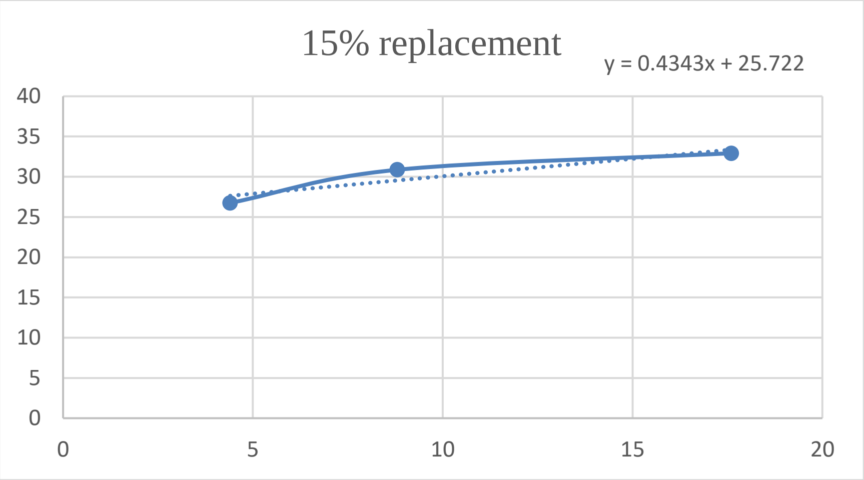

Figure 32 Graph b/w normal stress to Shear Stress at 15% replacement

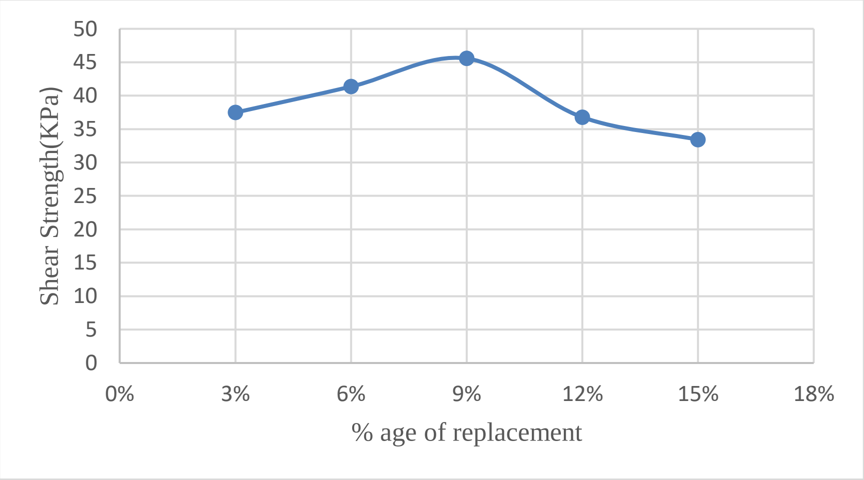

Figure 33 Graph b/w Shear strength values and % age of replacement

4.3.6 California Bearing Ratio (CBR) Test:

California bearing ratio test was performed according to ASTM D1883. It was observed that the CBR value on the 9% replacement of soil increased to 20.33%.

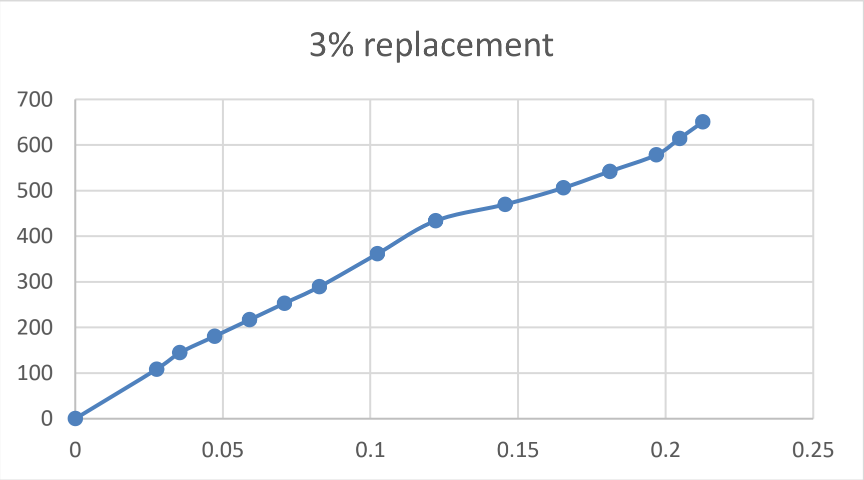

Figure 34 Graph of CBR value at 3% replacement

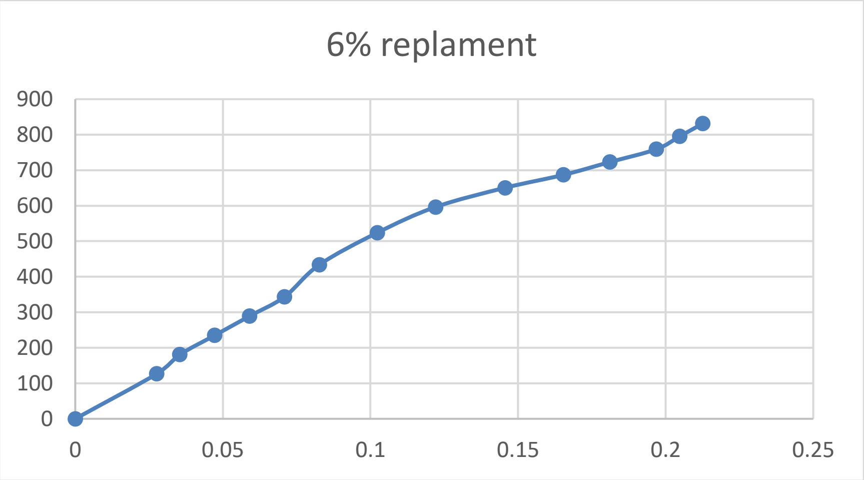

Figure 35 Graph of CBR value at 6% replacement

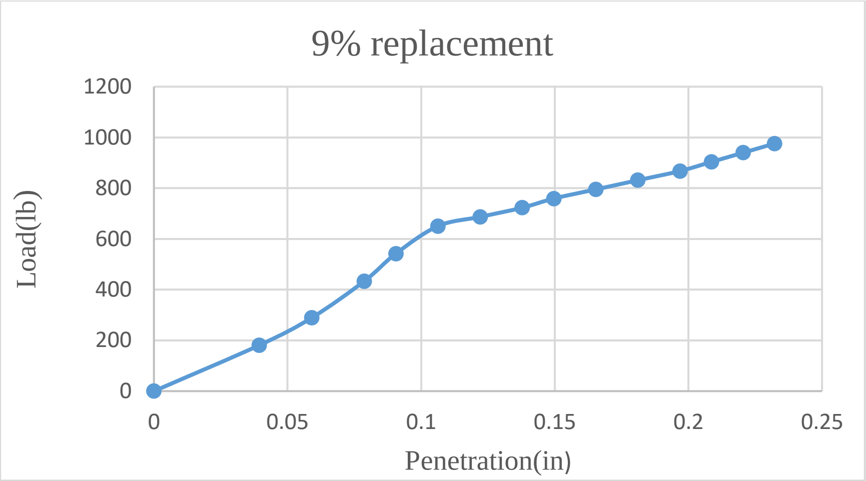

Figure 36 Graph of CBR value at 9% replacement

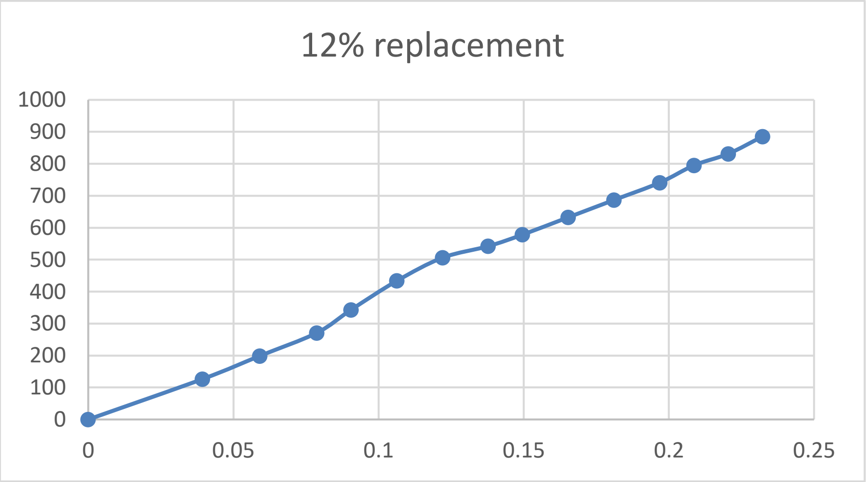

Figure 37Graph of CBR value at 12% replacement

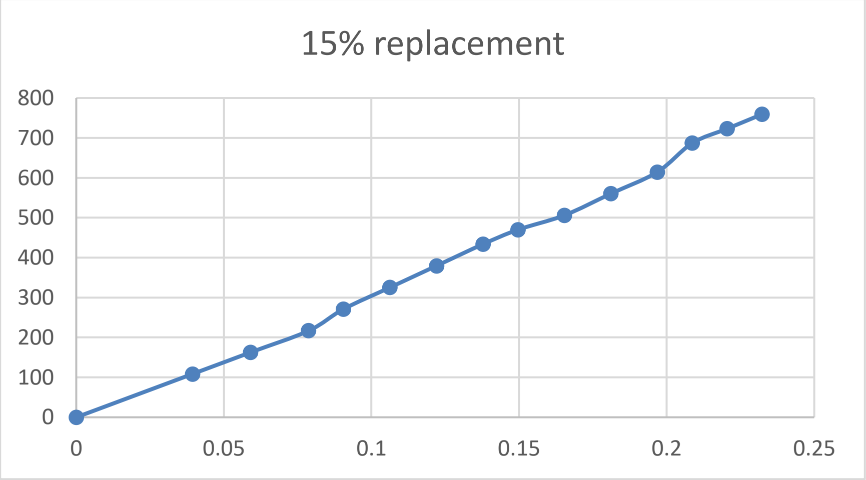

Figure 38 Graph of CBR value at 12% replacement

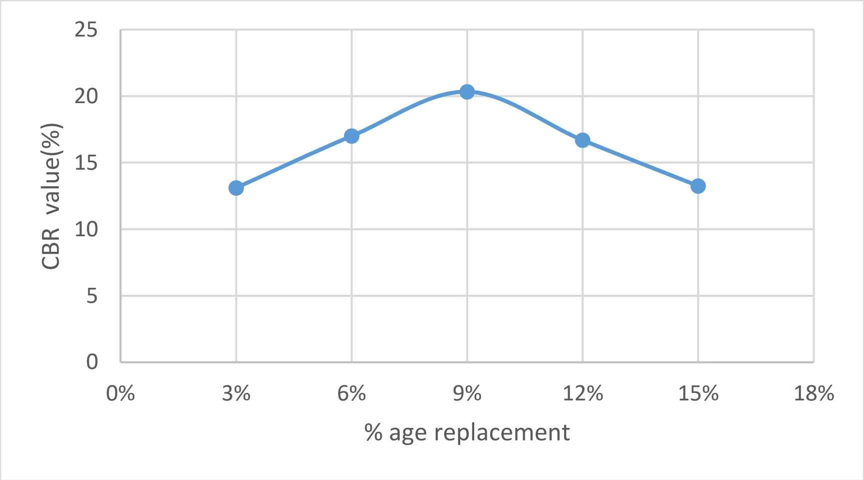

Figure 39 Graph of CBR value at different %ages

4.3.7 Consolidation Test:

At the last consolidation, a test was performed. It was observed that the value of Cc, Cs, and Cv decreased as the quantity of plastic waste increased in the soil. The value of Cc was 0.2026, Cs was 0.0354 and the value of Cv reduced to 0.01964 cm2/min.

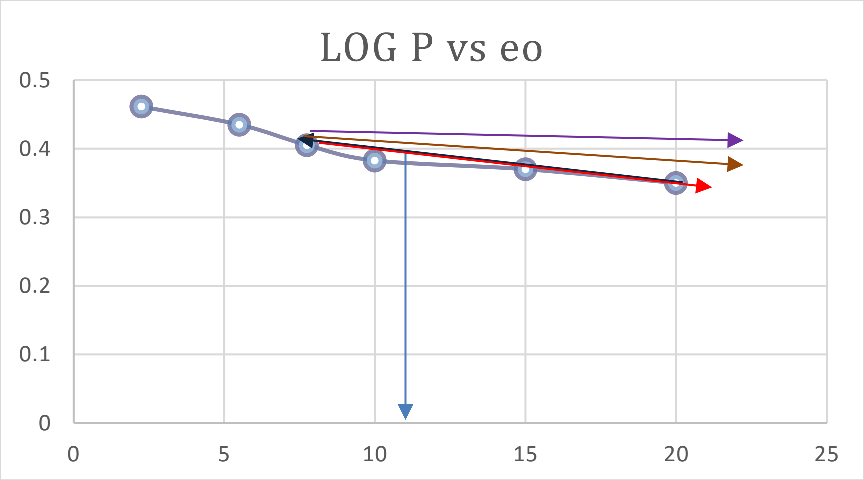

Figure 40 Graph for pre-Consolidated pressure (Treated Soil)

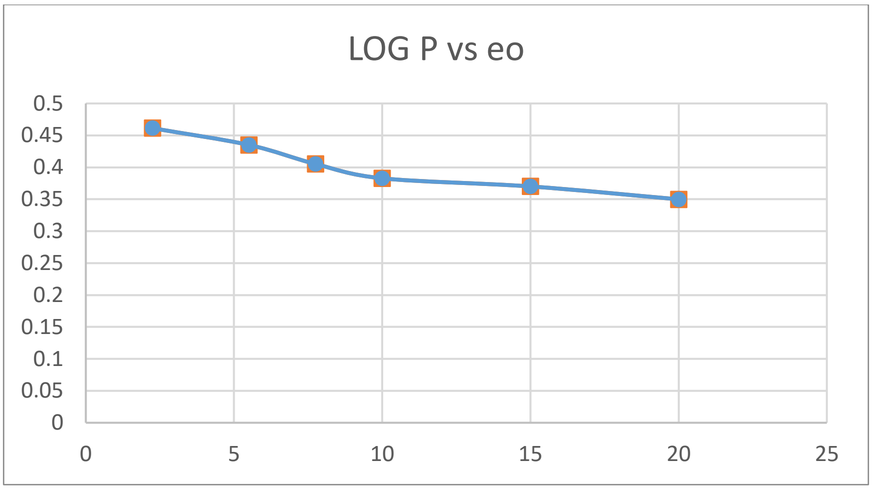

Figure 41 Relation b/w Void Ratio and Load

Sr. no.	Properties of treated Soil	
1)	S. G	2.62
2)	L.L (%)	26.84
3)	P.L (%)	24.40
4)	P. I (%)	4.28
5)	M.D. D (g/cm3)	1.359
6)	O.M.C (%)	16.67
7)	C(KPa)	39.08
8)	Φ°	20.17
9)	Shear Strength (KPa)	45.56
10)	CBR Value (%)	20.33
11)	Cc	0.20256
12)	Cs	0.03546
13)	Cv (cm2/min)	0.019667

Table 7 is the summary of the results of treated soil

Chapter 5

5 Analysis of Results:

5.1.1 General:

In this portion comparison of treated and untreated soil is done and analysis of results is done by comparing the results of untreated and treated soil.

5.1.2 Particle Size Distribution:

The outcomes of the particle size distribution are shown in Figure 4.2. For the classification of soil under the USCS and AASHTO systems, it is crucial. It is simple to see how the particle size distribution is distributed across the soil sample when the results of the soil sieve analysis are plotted on a semi-log graph with the sieve size or particle diameter as the abscissa, a logarithmic axis, and the% passing as the ordinate. Using this curve, D10 and D60 are determined. The diameter of the soil that 10% of the soil particles are below is designated as D10. The relationship between these two variables determines the uniformity coefficient (Cu), a measure of the range of particle sizes.

5.1.3 Specific Gravity:

From the above calculations, we can conclude that when the soil was treated with plastic the specific gravity of the soil decreased from 2.78 to 2.62.

5.1.4 Atterberg Limits test:

The value of the liquid limit decreased from 46.84% to 28.84%. The physical properties of soils are improved by using different percentages of fine crushed plastic waste as it reduced the value of liquid limits more while slightly decreasing the value of plastic limits from 28.94% to 24.40% which resulted in the reduction of the plasticity index. As plastic waste is coarser than clayey soil fine particles replaced the soil’s fine particles which resulted in the overall conversion of soil from clayey soil to sandy soil. In Figure 4.2 particle size distribution is done on untreated soil which will help in classifying soil. Table 4.1 shows the classification of soil according to the USCS and AASHTO classification systems for untreated soil. Figure 4.10 shows the particle size distribution of treated soil and Table 4.3 shows the classification of soil according to USCS and AASHTO classification system. The reduction in LL and PL is due to the transformation of soil from a finer to a coarser state. Based on the test results, it is evident that the values of liquid limit (LL) and plasticity index (PI) decrease for the treated soil, indicating a decrease in the soil's swelling potential

5.1.5 Standard Proctor Test:

The inclusion of plastic waste resulted in a decrease in the maximum dry density (MDD) of the soil. The MDD for the untreated soil was measured at 2.042 g/cm³, whereas the treated soil exhibited a reduced MDD of 1.359 g/cm³. However, there was a slight increase in the optimum moisture content (OMC) of the treated soil. This increase can be attributed to plastic waste enhancing the soil's water absorption capacity. The results of the MDD and OMC for the native soil can be observed in Figure 4.3 while Figure 4.8 displays the outcomes for the MDD and OMC of the treated soil. It can be seen in Fig. 4.8 that with an increase in plastic content the M.D.D of soil decreased up to some extent but after 9% replacement the M.D.D started to increase again.

5.1.6 X-rays Diffraction Results:

In figure 4.11(a) two peaks of illite minerals can be observed in b/w 20-22° and 30-32°. In case of montmorillonite the angle at which the layer of spacing of the material causes X-rays diffraction is 8-10° the recognizable peak at this location correlates to the mineral's layer spacing. Presence of Quartz and Silica SiO_2 increases overall hardness and strength of the soil. Soil mostly contains moisture in form of hydrogen which can be also seen with other minerals like carbon graphite etc. Carbon graphite has the ability to reduce the cohesiveness of the soil carbon graphite may be harmful for the soil strength and its stability. At 26° the peak shows the presence of carbon graphite in soil.

5.1.7 Direct Shear Test:

The introduction of plastic in soil exhibited a positive influence on its shear strength. The initial shear strength value of the untreated soil, as determined through testing, was found to be 27.845 KPa. However, when the soil was treated with finely crushed plastic, it experienced reinforcement. The shear strength initially increased with the addition of plastic, reaching a peak value at a replacement percentage of 9%. At this point, the interlocking bond between the soil and plastic was strengthened, allowing the soil to bear higher loads under shear stress. However, as the replacement percentage exceeded 9% and reached 12% and 15%, the shear strength of the soil began to decline. This behavior can be attributed to a transition in the soil's mechanical response from brittle to ductile. Overall, the incorporation of plastic enhanced the shear strength of the soil up to a certain replacement percentage, after which diminishing returns were observed. This trend can be observed in Figure 4.12(j).

5.1.8 CBR Test:

The addition of plastic to the soil increased soil resistance against penetration, leading to an overall improvement in the California Bearing Ratio (CBR) value. The CBR value exhibited a rising trend with plastic addition, reaching its maximum at a 9% replacement ratio. At this point, the soil demonstrated the highest resistance. However, at replacement percentages of 12% and 15%, the CBR values decreased, as shown in Figure 4.10(f). The utilization of plastic waste has the potential to enhance soil properties and mitigate issues such as pavement cracks caused by poor subgrade conditions and subgrade rutting. The addition of plastic increased the frictional resistance and ductility of the soil, as plastic acted as a reinforcement material. Consequently, it can be employed for slope stabilization, as well as in embankment applications.

5.1.9 Consolidation Test:

Based on the aforementioned results, it can be inferred that the addition of plastic waste led to a decrease in the values of the compression index (Cc), swelling index (Cs), and consolidation index (Cv). This observation was based on the tests conducted at a 9% replacement ratio, as depicted in Figures 4.14(a) and 4.14(b). The decrease in Cc, Cs, and Cv values indicates that the soil particles exhibited reduced uniformity due to the addition of plastic waste. The presence of plastic particles resulted in a higher void ratio, contributing to a lower value of Cv. This decrease in Cv signifies increased resistance against settlement and consolidation, as the plastic particles occupied a significant portion of the voids in the soil. As Cc, Cs, and Cv have a direct relation with consolidation and settlement of soil. From the above results, it can be observed that the addition of plastic reduced the value of these three parameters which led to a decrease in the overall settlement of soil against normal loads.

Sr. No	Tests performed	Results of Untreated soil		Results of treated	Comparison of results
1)	Specific Gravity test	2.78		2.62	Decreased. The addition of plastic made the
2)	Atterberg's limits test	L.L= 46.84% P. L= 28.94% P. I=17.06		L.L= 46.84% P. L= 28.94%	Decreased. Soil converts from "CL" to "CL-ML".
3)	Standard Proctor Test	M.D. D=2.042g/cm^3 O.M.C= 14.5 %		M.D.D = 1.359 g/cm^3 O.M.C=	M.D.D of treated soil decreased while its O.M.C
4)	Direct Shear Test	C= 16.526 Φ = 13.15° S.S =27.875KPa		C= 39.08 Φ = 20.17	Shear strength increased and max. value was obtained on 9% replacement.
5)	CBR Test	CBR value= 9.83%		CBR Value= 20.33 %	Resistance against penetration
6)	Consolidation Test	Cc= 0.2616 Cs= 0.0785 Cv= 0.2177		Cc= 0.20256 Cs= 0.03546	The value of Cc, Cs, and Cv decreased.

Table 8 Comparison of Results of Untreated and treated soil

CHAPTER 6

6 Budgeting and Costing:

In this chapter, the total cost spent during this research is discussed in detail.

6.1 Soil:

One bag of soil containing 30kg of soil costs about 5000 Rs. A total of two bags were bought during this research due to the wastage of soil during tests. Total soil costs 10,000 Rs during this research.

6.2 Plastic:

As plastic is taken from a small shop near Westridge Rawalpindi. It costs around 300Rs/kg and total 3kg plastic was bought for this research. Adding the rent the total cost was 1500 Rs.

6.3 Fuel:

Transporting the material costs about 1500 Rs fuel for one trip from HITEC University Taxila to Chongi no. 26 bus stop. The material was transported in two trips having one bag of soil in each trip. The total cost of fuel was 3000 Rs.

The whole project costs around about 14,500 Rs including all the expenses like soil, plastic, fuel, which were submitted during the research.

CHAPTER 7

7 Recommendations:

- The terrazyme can also be tested in combination with other stabilizing agents, such as lime, rice husk, fly ash, etc.
- Terrazyme is a non-toxic liquid enzyme that can be used with different additives to extract better results.
- This study can also be extended further by testing alternate wetting and drying methods (Soaked and Unsoaked Conditions).
- Field performance should be done to validate the effectiveness of plastic waste as Real-world conditions may introduce additional factors that can influence the effectiveness of plastic waste treatment on expansive soil.

CHAPTER 8

8 Conclusions:

This research has included the effect of plastic waste and its efficiency as a stabilizing agent. Plastic waste was added in different percentages to find the optimum feed of plastic waste. From the above results, we can conclude that the optimum feed of plastic waste was 9%. Based on experimental data following conclusions can be drawn

- Using recycled plastic fibers to improve soft soil causes a reduction in the specific gravity as the proportion of additive material increases
- Atterberg limits test was performed on both treated and untreated soil. There was a significant decrease in the value of liquid limit and plasticity index while there was a slight decrease in plastic limit. The improvement in liquid limit was significant when soil is treated with plastic and the soil is converted from CL to CL-ML.
- The specific gravity of soil decreased as the plastic content increased in soil. The test was performed on 9% replacement and the value decreased from 2.78 to 2.62.
- The maximum dry density of the soil decreased and at 9% replacement of plastic, the maximum decrease in the value of M.D.D was observed. While there was a slight increase in the value of O.M.C of the soil.
- The addition of plastic had a good impact on the shear strength of soil up to some extent but after 9 % values start decreasing. The maximum increase in the shear strength was observed at 9%. The total increase in shear strength at 9% was 38.81% and after that, it started decreasing.
- From the results, we can conclude that resistance to penetration increased with an increase in the plastic content. The highest CBR value was also observed at 9% replacement of soil replacement with plastic.

At 9% CBR value was increased by 51.64% which was the highest among other replacements.

- The value of Cc, Cs, and Cv decreased when the soil was replaced by 9% with plastic waste. A decrease in the value of Cc, Cv, and Cs indicates that the rate of settlement, coefficient of curvature, and coefficient of swell reduced which overall decreased the rate of settlement. From the results, it can be concluded that the value of settlement under load is less than the allowable value.
- As soil showed best results on 9% replacement of soil with plastic content. So it can be concluded that optimum content of plastic replacement was 9%.

References:

[1] W. A. Rather and S. A. Bhat, "Use of Plastic as Soil Stabilizer," *International Journal of Research in Engineering and Science (IJRES, 9 (1), 81–88,* 2021.

[2] T. W. Castilho, R. A. Rodrigues, and P. C. Lodi, "Use of recycled polyethylene terephthalate strips in soil improvement," *Geotechnical and Geological Engineering,* vol. 39, no. 8, pp. 5943-5955, 2021.

[3] N. d. S. L. Louzada, J. A. C. Malko, and M. D. T. Casagrande, "Behavior of clayey soil reinforced with polyethylene terephthalate," *Journal of Materials in Civil Engineering,* vol. 31, no. 10, p. 04019218, 2019.

[4] S. Amena and D. Chakeri, "A study on the effects of plastic waste strips and lime on strength characteristics of expansive soil," *Advances in Civil Engineering,* vol. 2022, 2022.

[5] J. Niyomukiza, A. Bitekateko, J. Nsemerirwe, B. Kawiso, and M. Kiwanuka, "Investigating the effect of PET plastic bottle strips on the strength and compressibility properties of clayey soil," in *IOP Conference Series: Earth and Environmental Science*, 2021, vol. 894, no. 1: IOP Publishing, p. 012021.

[6] A. Iravanian and A. Haider, "Soil Stabilization Using Waste Plastic Bottles Fibers: A Review Paper," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 614, no. 1: IOP Publishing, p. 012082.

[7] P. Chakravarthy, S. Banupriya, and T. Ilango, "Soil stabilization using raw plastic bottle," in *AIP Conference Proceedings*, 2020, vol. 2283, no. 1: AIP Publishing.

[8] M. Chauhan, S. Kalra, and H. Singh, "Stabilization of clayey soil using lime and plastic fiber in sub grades," *Int. J. Innov. Technol. Explor. Eng,* vol. 8, pp. 2118-2123, 2019.

[9] J. Kalliyath, J. Joy, J. Paul, and A. M. Vadakkel, "Soil stabilization using plastic fibers," *International Journal of Science Technology & Engineering,* vol. 2, no. 12, pp. 484-487, 2016.

[10] R. K. Mai, P. Sarathkumar, V. Dinesh, and N. Sathish, "PET as soil stabilization material," *International Journal of ChemTech Research,* vol. 10, no. 11, pp. 127-130, 2017.

[11] S. Tiwari and N. Tiwari, "Soil stabilization using waste fiber materials," *International Journal of Innovative Technology and Research,* vol. 4, no. 3, pp. 2927-2930, 2016.

[12] R. B. Kassa, T. Workie, A. Abdela, M. Fekade, M. Saleh, and Y. Dejene, "Soil stabilization using waste plastic materials," *Open Journal of Civil Engineering,* vol. 10, no. 1, pp. 55-68, 2020.

[13] H. J. A. Hassan, J. Rasul, and M. Samin, "Effects of plastic waste materials on geotechnical properties of clayey soil," *Transportation Infrastructure Geotechnology,* vol. 8, no. 3, pp. 390-413, 2021.

[14] N. M. Salim, K. Y. AL-Soudany, and A. A. Ahmed, "The impact of using recycled plastic fibres on the geotechnical properties of soft Iraqi soils," in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 433, no. 1: IOP Publishing, p. 012017.

[15] A. Usman, M. H. Sutanto, M. Napiah, S. E. Zoorob, N. S. A. Yaro, and M. I. Khan, "Comparison of performance properties and prediction of regular and gamma-irradiated granular waste polyethylene terephthalate modified asphalt mixtures," *Polymers,* vol. 13, no. 16, p. 2610, 2021.

[16] M. E. Sumner and W. P. Miller, "Cation exchange capacity and exchange coefficients," *Methods of soil analysis: Part 3 Chemical methods,* vol. 5, pp. 1201-1229, 1996.

[17] T. J. Katsube *et al.*, "Prediction and validation of soil electromagnetic characteristics for application in landmine detection," in *Detection and Remediation Technologies for Mines and Minelike Targets VIII*, 2003, vol. 5089: SPIE, pp. 1219-1230.