ENHANCING THE PROPERTIES OF SOIL BY STABLIZATION TECHNIQUE USING BASALT FIBER

MAJOR PROJECT 2 REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

SUBMITTED BY
RAHUL CHAUDHARY

UNDER THE SUPERVISION

OF

Prof. ASHOK KUMAR GUPTA

CIVIL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

NEW DELHI – 110042

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DELHI TECHNOLOGICAL UNIVERSITY, NEWDELHI

CANDIDATE'S DECLARATION

I **,RAHUL CHAUDHARY,** belonging to Master of Technology, Geotechnical Engineering, Delhi Technological University hereby certify that the work being presented in the minorentitled **"**ENHANCING THE PROPERTIES OF SOIL BY STABLIZATION TECHNIQUE USING BASALT FIBER" in partial fulfillment for the award of degree of Master of Technology in the Geotechnical Engineering and submitted in the Department of Civil Engineering of Delhi Technological University, Delhi is an authentic record of my own work carried out under the supervision of Prof. Ashok Kumar Gupta, Department of CivilEngineering, Delhi Technological University, Delhi, India.

The matter presented in this thesis has not been submitted by us for the award of any other degree in this or any other institution.

DATE: 30 JULY 2021

RAHUL CHAUDHARY

(2K19/GTE/21)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Supervisor

Prof. Ashok Kumar Gupta

Date: 30 JULY 2021

CERTIFICATE

CIVIL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, New Delhi -110042

I hereby certify that the Project Dissertation titled **"**ENHANCING THE PROPERTIES OF SOIL BY STABILIZATION TECHNIQUE USING BASALT FIBER"**,** belonging to Master of Technology, Geotechnical engineering, Civil Engineering Department, Delhi Technological University, New Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: New Delhi **Prof. A.K. Gupta**

Date: 30 JULY 2021

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RAHUL CHAUDHARY (2K19/GTE/21)

ABSTRACT

Soil stabilization is the process of the alteration of the geotechnical properties to satisfy the engineering requirements. Numerous kinds of stabilizers were used as soil additives to improve its engineering properties. A number of stabilizers, such as lime, cement and fly ash, depend on their chemical reactions with the soil elements in the presence of water.

Other additives, such as basalt fiber, plastic waste, wood chippers, rubber tyres pieces, sugarcane rusk ash, plant roots, depend on their physical effects to improve soil properties. In addition, it can be combined both of chemical and physical stabilization. In recent times, with the increase in the demand for infrastructure, raw materials and fuel, soil stabilization has started to take a new shape. With the availability of better research, materials and equipment, it is emerging as a popular and cost-effective method for soil improvement.

This study provides details of advantages and disadvantages of using basalt fiber as soil stabilizer. The organic soils are unsuitable for construction works due to its low shear strength, high swelling potential and poor bearing capacity. These types of soils can be treated by stabilization and compaction methods. In this research, study on effective use of stabilization using basalt fiber in varying proportions and the main objective of this study is to increase the geotechnical properties of soil.

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Chapter 1

INTRODUCTION

1.1 Soil Stabilization

- Soil stabilization is the technique of enhancing the properties, the stability or the bearing capacity of the soil by the utility of controlled compaction, proportioning and by inserting the suitable admixtures, fibers or the stabilizers.

- Soil stabilization is the process of enhancing or altering the properties of soil with different methods, chemical or mechanical methods used to produce an improved soil material, as desired for the engineering use.

- Stabilization of soil is essentially changing the chemical properties of soft soil by addition of fibers, stabilizers or binders either in dry or wet condition for developing or increasing the stiffness and strength of the originally weak soil.

- Soil stabilization can also be called as the reinforcement of soil, which is widely being acquired or taken for improving several physical and mechanical properties of soil.

1.2. Methods used for stabilization:

❖ **Chemical stabilization**

In this method of soil stabilization, the stabilization of soil takes place due to the chemical reactions between the stabilizers used and the minerals present in soil.

Through soil stabilization, unblocked soil materials gets stabilized by cementitious materials like lime, fly ash, cement, bitumen etc.

After stabilization, the soil which get stabilized have higher strength, higher permeability and lower compressibility than the original weak soil.

This method of soil stabilizing is one of the economical techniques of enhancing the engineering behavior of weak soils.

- **Mechanical stabilization**

This technique of soil stabilization is a physical process which changes the physical nature, gradation of the nearby soil particles either by compaction or induced vibrations or densification by applying the mechanical energy with the help mechanical equipment's such as rollers, rammers, vibration techniques and sometimes blasting also.

- **Using the Stabilizing Agents**

This technique of stabilization of soil is done by the help of various stabilizing agents, fibers etc.

These stabilizing materials comes in contact of soil and water they get reacted with it and forms cementitious composite materials.

Various binding materials that are used for stabilization of soil are lime, fly ash, bagasse ash, rice husk ash, copper slag, cement, cement kiln dust, Surkhi, basalt fiber, jute fiber, nylon fiber, coconut shell, geopolymers, plastic wastes etc.

1.3. Various Stabilizing materials:

- **Lime-**

  It was first used in stabilization as stabilizing material of soil in modern construction practices in 1924 on short stretches of highway strengthened by adding hydrated lime.

Lime gives an economical way of stabilization of soil. It gives modification to the properties of soil and enhances the strength which is due to the cation exchange capacity rather than cementing effect.

Fig. 1 Lime Powder

- **Rice Husk Ash-**

When the DE husking process of paddy taken place, the shell produces at that time, that shell is called the Rice Husk.

For the disposing of the rice husk, it burns and the residue which lefts after burning is called as Rice Husk Ash.

Fig. 2 Rice Husk Ash

- **Bagasse Ash-**

When the bagasse of sugar cane is burns in the sugar industry, the residue which lefts after burning is called as the Bagasse Ash.

The byproduct obtained from the sugar and ethanol industry is the Bagasse Ash.

Fig. 3 Bagasse Ash

- **Plastic Waste:**

This material is very easily and cheaply available material anywhere.
Plastic can also be used in the stabilization of soil. Plastic is not easily disposable so it can be used as fibers by cutting it into small pieces and is then mixed with soil so as to stabilize it.
Waste can be a bottle, from industries, electronic items, polyethene’s etc.

Fig. 4 Plastic Waste

- **Copper Slag:**

During the process of smelting in the copper industries, the waste product which is obtained in large quantity is referred as Copper slag.

It can be used as a effective stabilizing agent when mixed with the soil, improves the properties of problematic soils.

Fig. 5 Copper slag

- **Fly Ash:**

The byproduct obtained by the power generation with the help of coal, in various power generation units is referred as Fly ash.

It can be used for cement manufacturing unit, brick manufacturing, and also for the stabilization of soil.

It helps to enhance the strength and also be used in bases and subgrades.

Fig. 6 Fly Ash

- **Basalt Fiber:**

The basalt fiber is a material which is made up of extremely fine fibers of basalt, which contains different minerals like plagioclase, pyroxene, and olivine.

It is a byproduct which is manufactured by the melting of the crushed and washed basalt rock at about 1500 ° C.

The basic purpose of producing the basalt fiber as it is a naturally occurring material which is obtained by the basalt rock.

It is a non- metallic fiber which shows very high performance. It does not contain any other admixture in its production which makes it cost affective. It is environment friendly also.

Fig. 7 Basalt Fiber

- **Jute Fiber:**

  This fiber is obtained from the plants. Jute is a lignocellulosic fiber that is partially a textile fiber and partially wood.

  Jute fiber is also referred as the suitable fiber of geosynthetics.
  It is a good water absorber material.

Fig. 8 Jute Fiber

1.4. Materials Used:

- **Soil:** When the small pieces of broken rock and decaying plants (called organic matter) combines together, the mixture formed is termed soil.

  Soil can be of two types transported soil and residue soil.

  When the weathered soil deposits that are transported from one place to another place by transportation with natural agents like water, wind, ice, glaciers etc. is known as transported soil.

  When the weathered soil particles, after broken the get deposited on their parent rock mass, the soil is known as Residual soil.

The soil used here was taken from **Shahabad village nearby DTU**.

Fig. 9 Soil

- **Basalt Fiber:**

  The basalt fiber is a material which is made up of extremely fine fibers of basalt, which contains different minerals like plagioclase, pyroxene, and olivine.

  It is a byproduct which is manufactured by the melting of the crushed and washed basalt rock at about 1500 ° C.

  The basic purpose of producing the basalt fiber as it is naturally occurring material which is obtained from the basalt rock.

It is non- metallic fiber which shows very high performance and owes a very good property. It is environment friendly also. The basalt fiber is bought from **India mart**.

The fiber used here have following properties:

Table-1: Fiber Properties

Physical & Chemical Properties	**Value of Basalt Fiber**
Type of Fiber	Single
Avg. Diameter of Fiber	15 micro meters
Avg. Length of Fiber	13 mm
Tensile strength of fiber	4 GPa
Elastic modulus of fiber	95 GPa
Color	Golden Brown
Density	2.6 g/cm^3
Specific Gravity	2.7
Cost	400 Rs/ kg

Fig. 10 & 11 Basalt Fiber used in Lab

Chapter 2

Literature Review

2.1. Sanjay K. Shukla1 *, Nagaratnam Sivakugan2, Braja M. Das3, July 2009, "Fundamental concepts of soil reinforcement — an overview":

This paper tells us about the study of reinforced materials, which can be used in soil stabilization techniques, in various orientations as systematically reinforced soil and randomly distributed fiber etc.

Conclusion: After going through this research paper, it can be concluded that the different reinforced materials in soil is very effective for the stabilization and improvement of various soil properties using the fibers in different orientation in soil.

2.2. Nahla Salim1, * Kawther Al-Soudany1, and Nora Jajjawi1,2018 "Geotechnical properties of reinforced clayey soil using nylons carry's bags by products" :

It is not easily possible to make structure on the soft soil, to fulfill this the stabilization of soil is needed. The previous technique such as compaction and changing the soil was very costly.

In this paper, we get to know about the Nylon carry bag which can also be used as a good stabilizing agent in soft soil, it is used in different proportions in soil to improve the properties of soil.

Conclusion: After going through the research paper, it can be concluded that the nylon carry bag byproduct can be used as the reinforced fiber and easily used in the weak soil to improve the properties of soil. This study gives various results on improvement of soil properties such liquid limit, plastic limit, specific gravity, plasticity index etc.

2.3. Humphrey Danso, 21-23 June 2017, "Properties of Coconut, Oil Palm and Bagasse Fibers: As Potential Building Materials":

The use of naturally occurring fibers as reinforced materials is increasing in the research work and field work. This is because of the ability of these fibers in various aspects, increasing strength, reducing environmental issues, and making cost effective.

These fibers are as bagasse ash, rice husk ash, groundnut shell ash, basalt fiber, nylon fiber, plastic waste, chemicals etc.

Conclusion: After going through the research paper, the study tells that these naturally occurring fibers have various good properties and can be used in various soil stabilizing works, these fibers as reinforcement, increases the properties of soil and make project cost effective.

2.4. Mr. Vishal Ghutke, Ms. Pranita Bhandari, Mr. Vikash Agrawal,2018" Stabilization of soil by using rice husk ash":

Black cotton soils are clays of high plasticity, which are having high shrinkage and very low bearing capacity. This study is in black cotton soil and the rice husk ash which is used as a reinforced material in the soil, and stabilization is taking place. The rice husk ash is mixed with soil in different proportions and tests are performed on it.

Conclusion: From the research paper it can be concluded easily that the rice husk ash is very beneficial in soil stabilization and it improves various properties of soil.

2.5. T. Murali Krishna Sd. Shekun Beedi, 3 June ,2015 "Soil Stabilization by Groundnut Shell Ash and Waste Fiber Material":

This paper gives the study of the utility of groundnut shell ash and waste polypropylene fiber in the geotechnical engineering for the stabilization of soil. Various tests were performed on unreinforced and reinforced soil to study the effect.

Conclusion: From the paper, it can be concluded that groundnut shell ash and polypropylene fiber both are very preferable as reinforced material in soil, and improves various soil properties and make cost effective.

2.6. Sanjeev Singh1, Umesh Dhiman2, Rubel Sharma3, May -2017 "Soil Stabilization using Scrap Rubber Tyre":

The disposal of rubber waste is very challenging job nowadays, so the study tells us about the suitable use of rubber waste, i.e., the stabilization of soil using rubber waste as reinforced material so as to improve the property of soil and to make it cost effective and also environmental efficient.

Conclusion: The conclusion made after study the research paper that rubber increases the UCS strength and improves the soil properties and reduces the cost.

2.7. Gobinath R1, MaheshV2, G. Shyamala3 and Adla Rajesh4, 2020 "Strength and Settlement studies on basalt fiber reinforced marginal soil":

In this research paper, it is made an attempt to study or to analyze the load vs. settlement characteristics of soil and the reinforced soil. Dial gauges are used to take the precise reading and the curve is then made.

Conclusion: After studying the research work, it can be concluded that the characteristics of soil increases by using the basalt as a fiber in reinforcement, the strength and settlement of the soil also get increase.

2.8. Krishan Pareek1, Dr. Purnachandra Saha2*, 1-3 Feb, 2019 "Basalt Fiber and Its Composites: An Overview":

In this research paper, it is made an attempt to study about the various physical, mechanical or chemical properties of basalt fiber & its applications.

Conclusion: After studying the research work, it can be concluded that the basalt fiber has very high alkali resistance, high thermal resistance, high compressive strength, shows good flexural strength.

2.9. PRAGYAN BHATTARAI 1, A. V. A BHARAT KUMAR 2, K. SANTOSH3, T. C. MANIKANTA4 & K. TEJESWINI, Jun 2013 "ENGINEERING BEHAVIOR OF SOIL REINFORCED WITH PLASTIC STRIPS":

In this paper, the different types of plastic waste are taken such as shopping bags, plastic bottles, electronic item waste etc. were used as reinforcement for stabilization of soil. The plastic waste is cut into pieces and mixed with the soil and various test were performed on it.

Conclusion: The plastic waste is not disposable easily, but it can be used as a reinforced material. From the paper, it can be easily said that the plastic waste has a very effective use in the soil stabilization in various aspects easily available, provides good strength, cost effective, so plastic waste is overall a good stabilizing material.

2.10. H. P. Singh1 , M. Bagra2, 8, August 2013 "IMPROVEMENT IN CBR VALUE OF SOIL REINFORCED WITH JUTE FIBER":

In this research paper, the study of reinforced and unreinforced soil samples prepared at its maximum dry density to its optimum moisture content in the CBR mould to carry out the CBR test. The soil sample was reinforced with jute fiber.

Conclusion: After going through the research paper, it can be concluded that using jute as a reinforced fiber in the soil, the CBR value of soil get increased than the unreinforced soil.

2.11. 1Adla Prathyusha, 2Mudigonda Harish Kumar,2020 "Experimental Study on the Suitability of Basalt Fiber Reinforced Red Soil for Highway Construction":

In this research paper, it is made a try to study of locally available red soil at Telangana for construction of highway, the soil samples prepared at its maximum dry density to its optimum moisture content in the CBR mould to carry out the CBR test. The soil sample was reinforced with basalt fiber.

Conclusion: After going through the research paper, it can be concluded that using basalt as a reinforced fiber in the soil, the CBR value of soil get increased than the unreinforced soil and the strength of the soil gets improved for highway construction.

Chapter 3

EXPERIMENTAL ANALYSIS

3.1. Assessing Soil Properties

The soil used in the study is taken from **Shahabad village nearby DTU**. Different tests will pe performed on the soil to find out the condition and physical properties of soil chosen. The unit weight of the sample will be determined. Specific Gravity will be determined. The Liquid limit, plastic limit will be determined. Sieve analysis will also be carried out to classifythe soil sample. Proctor compaction test will be done to determine the optimum moisture content and maximum dry density of the sample.

3.1.1. Specific Gravity

The specific gravity test was carried out as per the **IS: 2720(Part III)- 1980.**

Table-2: Determination of Specific Gravity of soil.

S.NO.	**Representation**	**Trial 1**	**Trial 2**	**Trial 3**
1.	Weight of Pycnometer(w_1)	44.5	44.5	44.5
2.	Weight of Pycnometer + soil (w_2)	70.5	68.5	69.5
3.	Weight of Pycnometer + soil +water (w_3)	116	115	116
4.	Weight of Pycnometer + water (w_4)	101.5	101.5	101.5
5.	Specific Gravity(G)	2.26	2.28	2.38

Specific gravity of soil is found by the given formula

$$G = (w_2 - w_1) / (w_2 - w_1) + (w_4 - w_3)$$

Specific Gravity of soil, **G = 2.30.**

3.1.2. Liquid Limit of Soil

The liquid limit test was carried as per **IS:2720(Part V) – 1970.**

Table-3: Determination of Liquid Limit of soil

S. No.	Weight of soil (g)	Water added(ml)	Water content (%) (W)	No. of blows
1	100	54	54	46
2	100	56	56	43
3	100	59	59	38
4	100	61	61	33
5	100	63	63	22
6	100	65	65	19

From the below shown curve,

Liquid Limit (L.L.) = water content corresponding to **25 no.** of blows, shown in the curve below

= **62.803%.**

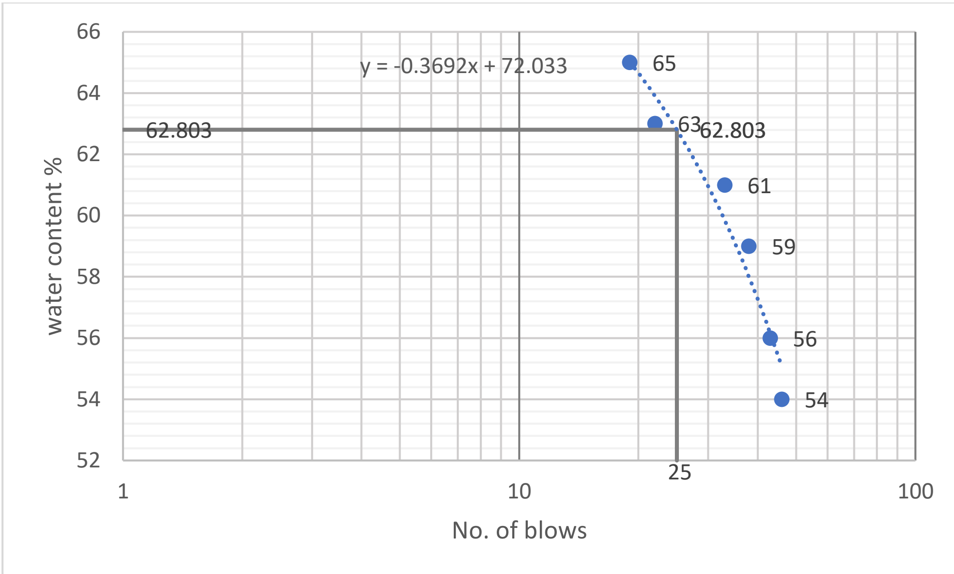

Fig. 12 Liquid limit of soil in log scale.

3.1.3. Plastic Limit of Soil

The plastic limit test was performed as per **IS:2720 (PART -V) – 1970.**

Weight of pan (W_1) = 13 g

Weight of pan + weight of wet soil (W_2) = 23 g

Weight of pan + weight of dry soil (W_3) = 21 g

Plastic Limit (P.L.) = $(W_2-W_3)/(W_3-W_1) \times 100$

Plastic limit of soil = **25%**

Plasticity Index of soil (Ip) = L.L – P.L = 62.803-25

= **37.8%.**

From the A- Line equation and chart, the soil is classified as **Clay of Intermediate compressibility.**

I_P = 0.73 (L.L - 20), A – Line equation.

3.1.4. Shrinkage limit of soil

The Shrinkage limit test was performed as per the **IS:2720 Method of test of soil Part VII – (1972).**

Weight of shrinkage dish, W_1= 28 g

Weight of shrinkage dish+ wet pat, W_2 = 63 g

Weight of wet soil, $W_{wet} = W_2 - W_1$ = 63-28 = 35 g

Weight of shrinkage dish + dry pat, W_3 = 48 g

Weight of dry pat, $W_d = (W_3 - W_1)$ =20 g

Weight of mercury filled in shrinkage dish, W_1 = 338.5 g

Volume of Shrinkage dish ,V = W_1 / 13.6 = 338.5/ 13.6 = 24.88 cm3

Weight of mercury displaced by dry pat, W_2 = 144 g

Volume of mercury displaced ,$V_d = W_2/13.6$ =144/13.6 = 10.58 cm3

Shrinkage Limit (W_s) = $\{(W_{wet}-W_d)-(V-V_d)\gamma_w\}/ W_d \times 100$

= 3.5%

3.1.5. Free Swell Index of Soil

The free swell index test is performed as per IS:2720 (Part 40) 1977.

Table 4: Free Swell Index Values

Determination of values	**Trial 1**	**Trial 2**
Mass of dry soil passing 425 μ sieve (g)	12	12
Volume of soil in water after 24 hrs swell (V_d) in Cm^3	14	15
Volume of soil in kerosene after 24 hrs (V_k) in Cm^3	10	10

Free swell index value = $\{(V_d - V_k)/ V_k\} \times 100$

So average **free swell index value is 45%**

Table-5: Free Swell Index properties

Free Swell Value	**Level of expansiveness**
0- 20	Low
20 – 35	Moderate
35 – 50	High
>50	Very High

So, the soil is **high expansive soil** and its free **swell index value is 45%**

3.1.6. Compaction test for soil by standard proctor method

The compaction test i.e. the standard proctor test is performed as per IS code.

Diameter of mould = 10 cm

Height of mould = 13 cm

Weight of mould = 2136 g

Volume of mould = 1021 cm^3

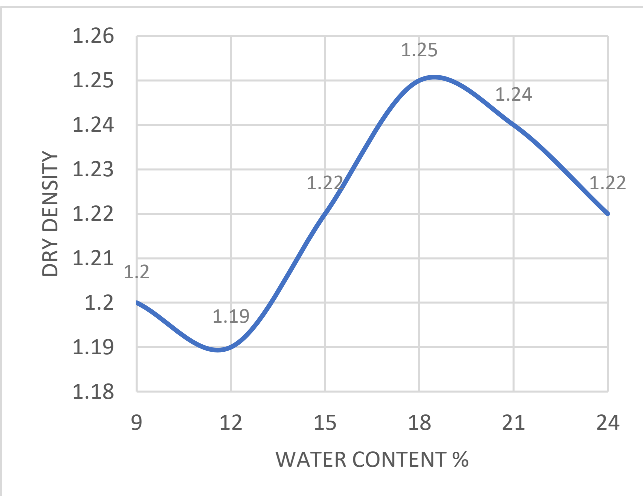

Fig. 13 MDD & OMC

As from the above compaction curve,

Optimum moisture content = 18%

Maximum dry density =1.25 g/cm³

3.1.7. Different Soil properties before reinforcement are accumulated below.

Table- 6: Properties of Soil

S.No.	Interpretation	Outcome values
1.	Color	Brown
2.	**Atterberg's Limit**	
i.	Liquid Limit	62.803%
ii.	Plastic Limit	25%
iii.	Free swell index	45%
iv.	Plasticity index	37.8%
3.	Specific Gravity	2.30
4.	**Characteristics of Compaction**	
i.	Optimum Moisture Content	18%
ii.	Maximum dry density	1.25 g/cm^3
5.	UCS	179 kPa
6.	USS	89.5 kPa
7.	**Grain Size Analysis**	
i.	Gravel	0.2%
ii.	Sand	9.3%
iii.	Clay & Silt	90.5%
8.	Soil Classification	Clay of intermediate compressibility

The particle size distribution curve is shown below:

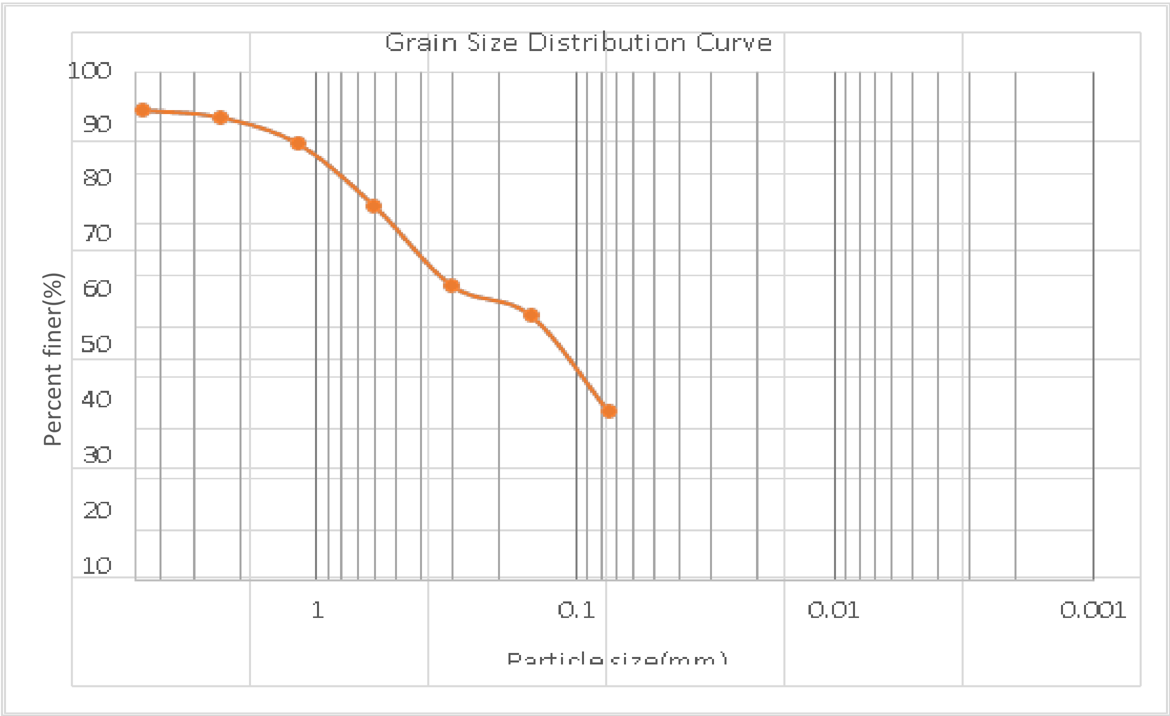

Fig. 14 Particle size distribution curve

Chapter 4

RESULTS

4.1. Changes seen in properties of soil after reinforcing the fiber in different percentages.

4.1.1. Effect of adding fiber on Atterberg's Limits

Table-7: Atterberg's Limit

S.no.	% Of Basalt fiber	Liquid Limit	Plastic Limit	Plasticity Index
1.	0	62.803	25	37.8
2.	3	62	26	36
3.	6	61	26.5	34.5
4.	9	60	27	33
5.	12	62.5	27.5	35
6.	15	63.5	26.5	37

Liquid Limit:

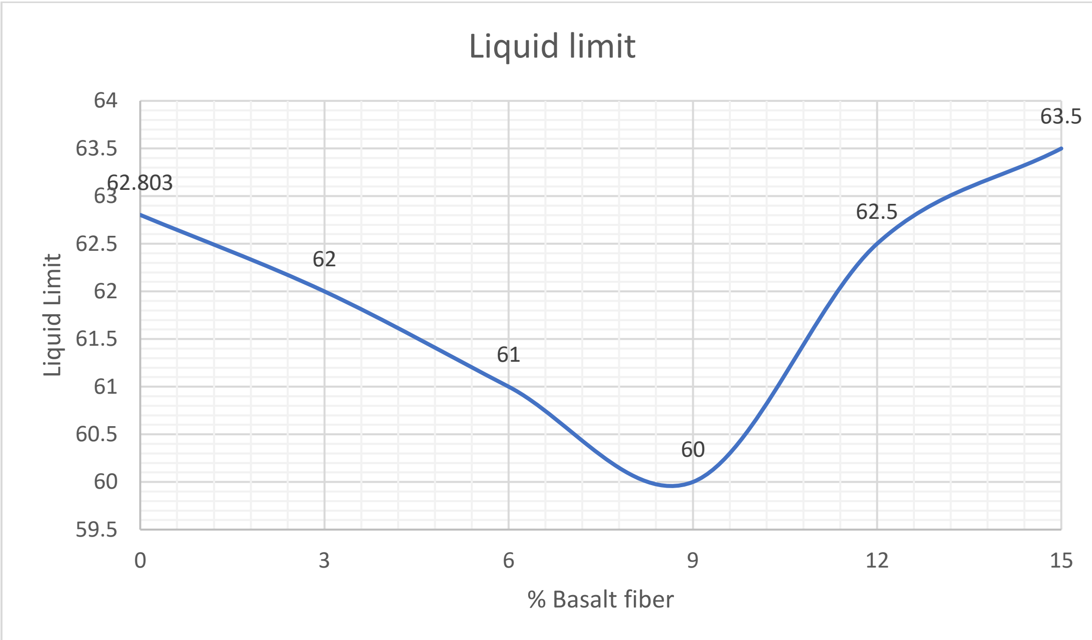

Fig. 15 Liquid Limit after reinforcement

Plastic Limit:

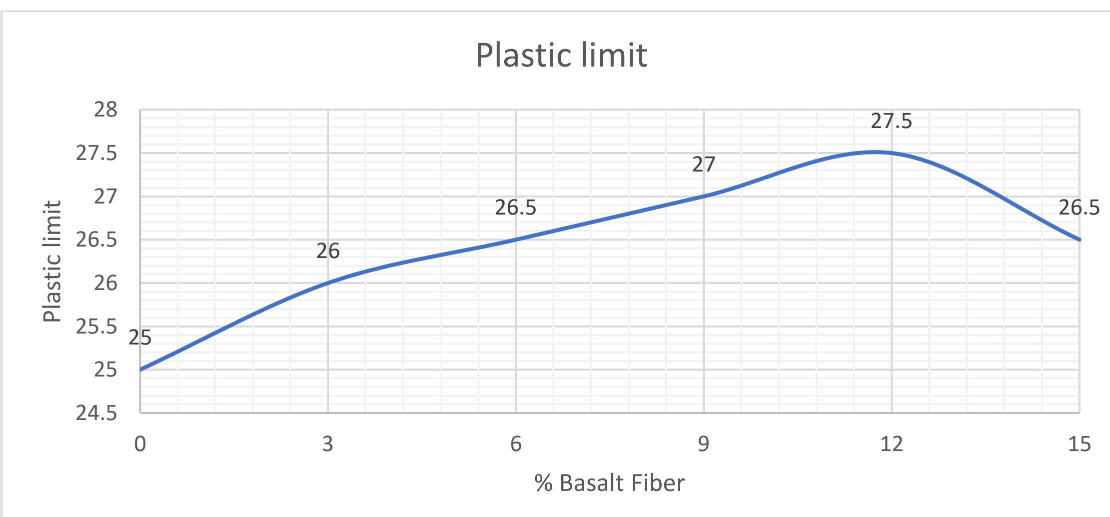

Fig. 16 Plastic limit after reinforcement

Plasticity Index:

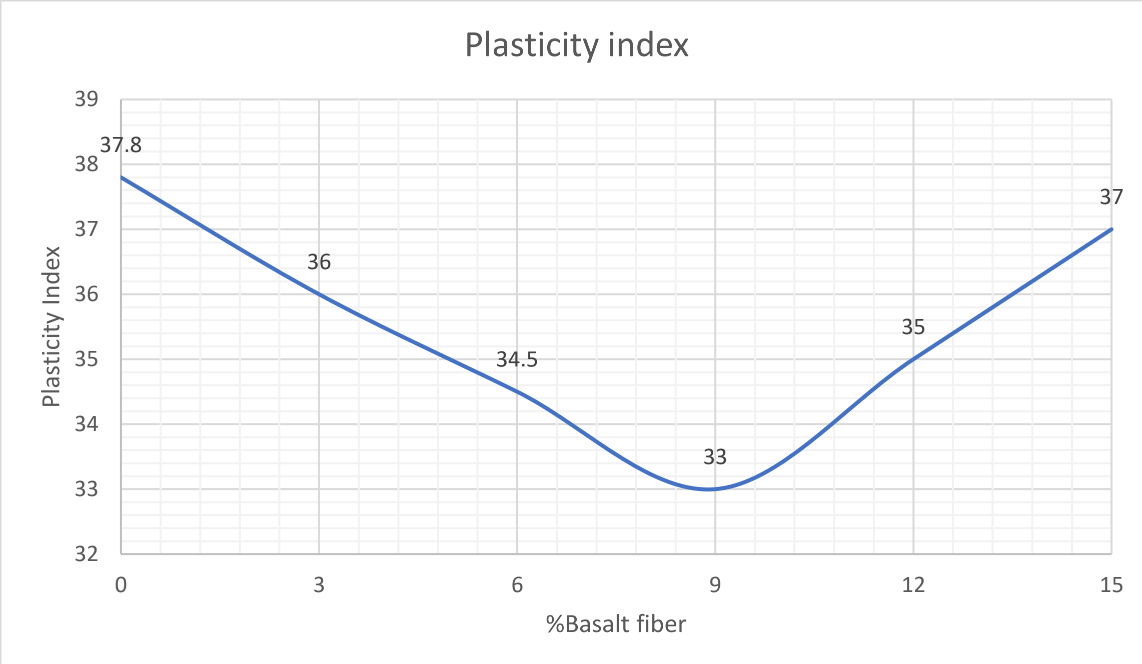

Fig. 17 Plasticity index after reinforcement

- From the above table & curves, we can see that the Liquid Limit of soil gets decreased after the addition of reinforcement (basalt fiber) in soil in different percentages. (i.e., 0%, 3%,6%, 9%, 12%, 15%).
- It can also be said that the plastic limit of soil gets increased after the addition of reinforcement (basalt fiber) in soil in different percentages. (i.e., 0%, 3%, 6%, 9%. 12%, 15%).
- It is directly seen that the plasticity index of soil also gets reduced after the addition of reinforcement (basalt fiber) in soil in different percentages (i.e., 0%, 3%, 6%, 9%, 12%, 15%).
- The above all changes in Liquid Limit, Plastic Limit & Plasticity Index is due to the basalt fiber content added in it, as the fiber has the tendency or property of absorbing the water or moisture from the soil, so that the Liquid Limit gets decreased, the Plastic Limit gets enhanced & the plasticity index gets reduced also and make the soil stabilized.

4.1.2. Effect of adding fiber on the compaction characteristics of soil

Standard Proctor test was performed in study and the results of this test is mentioned above.

Table no.8: Compaction Characteristics after reinforcement

% Basalt Fiber	OMC (%)	MDD (g/cm^3)
0	18	1.25
3	18.4	1.24
6	18.9	1.22
9	19	1.20
12	19.5	1.20
15	19.5	1.20

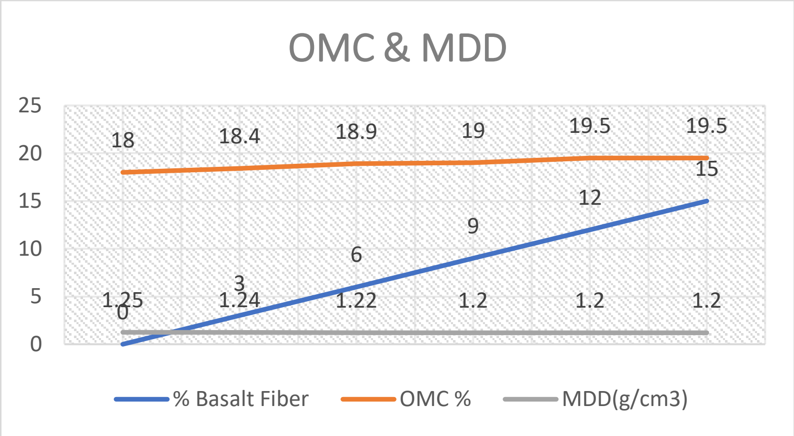

Fig. 18 showing variations on OMC and MDD.

- We can observe directly from the curve and the table that, the fiber type used i.e., basalt fiber may not remarkably affect the OMC, but this increase in OMC is due to the moisture absorption property of fiber.
- From the above curve it can be observe that there is a very slight decrease in the MDD of reinforced soil on increasing the % of fiber.

4.1.3. Effect of adding fiber on the strength characteristics of soil

Initial length of specimen, L_o= 7.6 cm

Final length of specimen, L_f = 7.2 cm

Initial diameter of specimen, D_o = 3.8 cm

Final diameter of specimen, D_f = 4.0 cm

Initial weight of specimen, W_o = 150 g

Final weight of specimen, W_f = 149 g

Initial Area of specimen, $A_o = (\pi/4) \times D_o^2$

$= (\pi/4) \times 3.8^2 = 11.335\ cm^2$

Axial strain (ε) $= \Delta L/L = (7.6-7.2)/7.6 = 0.05263$

Average cross-sectional area = $A_o/(1-\varepsilon) = 11.335/(1-0.05263) = 11.965\ cm^2$

The UCS and USS of soil before adding any % of basalt fiber = **179 kPa & 89.5 kPa.**

The soil and the small fiber pieces were mixed gently and the cylindrical specimen were made and totally 6 samples were made and the UCS and USS test value was calculated as per the **IS:2720 (PART X)-1970**.

Table no. 9: strength characteristics after reinforcement

% Basalt Fiber	**UCS (Unconfined compressive strength) kPa**	**USS (Undrained shear strength) kPa**
0	179	89.5
3	180.5	90.25
6	183	91.5
9	187	93.5
12	203	101.5
15	205	102.5

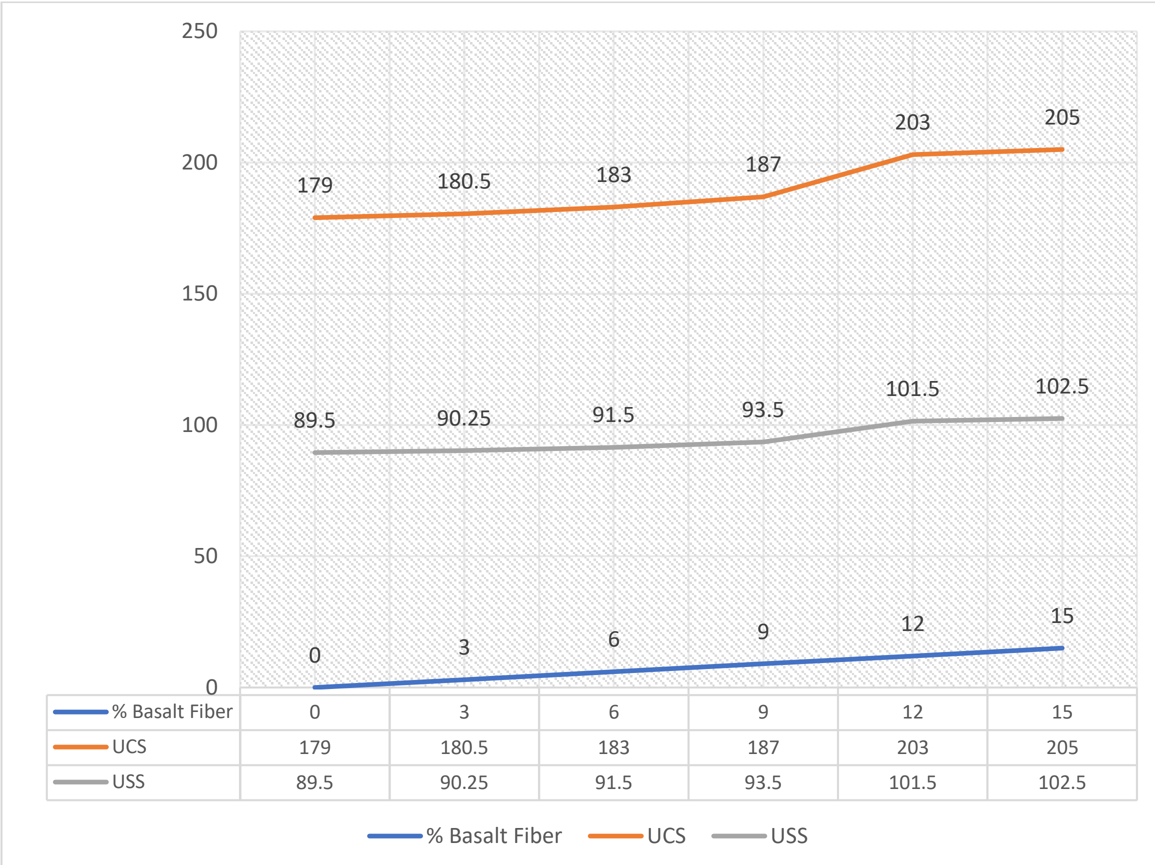

Fig. 19 Strength characteristics

- From the above table & curve, it can be observed that the strength characteristics i.e., both UCS & USS gets enhanced by adding the basalt fiber in the soil and make the soil stabilized and useful to carry loads.
- This increase in the strength because of adding the basalt fiber in soil as the basalt fiber have a very high compressive strength, have good resistance against chemicals. It can be break into fine and also can be turn into very fine particle fibers.

Chapter-5

Conclusion

From the above study, it can be concluded that the usage of basalt fiber as a reinforced material is very beneficial for the stabilization of the soil, for enhancing the various properties of soil.

The basalt fiber is environment friendly material, easily available, has very sound properties itself. It has very high resistance against chemicals. It owes brilliant compressive strength. About 1 kg of basalt fiber as reinforced material is equal to 9 kg of steel as reinforced material.

From the above study, the properties get improved in such a way are as follows:

- We can see that the Liquid Limit of soil gets decreased after the addition of reinforcement (basalt fiber) in soil in different percentages. (i.e., 0%, 3%, 6%, 9%, 12%, 15%).
- The plastic limit of soil gets increased after the addition of reinforcement (basalt fiber) in soil in different percentages. (i.e., 0%, 3%, 6%, 9%. 12%, 15%).
- The plasticity index of soil also gets reduced after the addition of reinforcement (basalt fiber) in soil in different percentages (i.e., 0%, 3%, 6%, 9%, 12%, 15%).
- The above all changes in Liquid Limit, Plastic Limit & Plasticity Index is due to the basalt fiber content added in it, as the fiber has the tendency or property of absorbing the water or moisture from the soil, so that the Liquid Limit gets decreased, the Plastic Limit gets enhanced & the plasticity index gets reduced also and make the soil stabilized.
- We can observe directly from the curve and the table that, the fiber type used i.e., basalt fiber may not remarkably affect the OMC, but this increase in OMC is due to the moisture absorption property of fiber.
- From the above curve it can be observe that there is a very slight decrease in the MDD of reinforced soil on increasing the % of fiber.

- It can be observed that the strength characteristics i.e., both USS & UCS gets enhanced by adding the basalt fiber in the soil and make the soil stabilized and useful to carry loads.

- This increase in the strength because of adding the basalt fiber in soil as the basalt fiber have a very high compressive strength, have good resistance against chemicals. It can be break into fine and also can be turn into very fine particle fibers.

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