Evaluation of Engineering Properties of Clay Soil Using Geopolymer

A. Sai Prasanth, Student, Department of Civil Engineering, Dhanekula institute of Engineering & Technology, Ganguru, Vijayawada-521139.

K.V.S.G.S Pradeep, Student, Department of Civil Engineering, Dhanekula institute of Engineering& Technology, Ganguru, Vijayawada-521139.

T. Sai Pranav Keerthan, Student, Department of Civil Engineering, Dhanekula institute of Engineering& Technology, Ganguru, Vijayawada-521139.

V. V. Ramana Reddy, Student, Department of Civil Engineering, Dhanekula institute of Engineering & Technology, Ganguru, Vijayawada-521139.

T. Kishore Kumar, Assistant. Professor, Department of Civil Engineering, Dhanekula institute of Engineering& Technology, Ganguru, Vijayawada-521139

Abstract: *Stabilization is the broad sense for the various methods employed and modifying the properties of a soil to improve its engineering performance and used for various engineering works. In today's scenario soil stabilization is the good practiced process for increasing the stability of soil and to reduce the construction cost. The main properties required for the stabilization are strength, volume stability, durability and permeability. In India, nearly 20% of the land is covered with clay soil. It is considered as problematic soil due to volume changes with variation in moisture content. When it comes in contact with water it shows immense swelling whereas it shrinks with the decrease in water content and develops cracks on drying. In order to solve the problem a geopolymer is used.*

Index Terms **-** Clay Soil, Atterberg's Limits, Compaction, UCS

INTRODUCTION

The Highly compressible clay is a problematic soil because of their nature to show volumetric variations with variable moisture content. When these soils come in contact with water, they expand immensely but when the water content is decreased it shows shrinkage and development of cracks. The soil exerts nominal pressure in dry state but on increase in water content the soil swells and exerts high swelling pressure on structure, this type of soil creating a big challenge to the civil engineers especially in big infrastructure constructions like road pavements, high infrastructural buildings. In India nearly 23% of land is covered with black cotton soil and it is available at the depth of 3.7m. Clay soils are characterized by low bearing capacity and high compressibility. This soil experience very large settlement when loaded. There are two methods to stabilize the soil mechanical method and chemical method. Stabilization of clay soils using conventional chemical binders though popular, introduces harmful gases which pollute the environment. Black cotton soil has various problems like less stability, less shear strength and large expansion and shrinkage in volume with changing seasons. These demerits obstruct constructions like big infrastructure, road pavements etc., on the soil. In order to avoid these problems, there are various materials which are used as an admixture to the soil and to improve the engineering properties of soil. The materials selected must have be ensured for the quality and compaction requirements. If the natural soil is weak it needs some improvement to act as a foundation. It is therefore, needed to add the natural soil by stabilization with improved strength and compressibility characteristics. In India, the problems have its own importance due to the fact that climatic changes are frequent especially the water content and temperature and need for improvement of soil. The scenario is further worsened by the rapid urbanization which demands the construction of infrastructures over such weak soil.

1.DEFINITION

Soil stabilization in its general meaning considers every physical and chemical method employed to make a soil suitable for its required engineering purpose. In its specific meaning in foundation engineering, soil stabilization is a process to improve the soil strength by using additives in order to use as foundation to the building to bear heavy load.

1.2 GEOPOLYMER STABILIZATION

Geopolymers are new materials for fire- and heat resistant coatings and adhesives, medicinal applications, high-temperature ceramics, new binders for fire-resistant fiber composites, toxic and radioactive waste encapsulation and new cements for concrete. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in other types of engineering process technologies. Geopolymers are part of polymer science, chemistry and technology that forms one of the major areas of materials science. Polymers are either organic materialize. carbon-based, or inorganic polymer, for example silicon-based. In general, Geopolymer is a mixture of chemicals and waste hence in this work the Sodium Silicate and Sodium Hydroxide which are well known as Alkaline Earth Materials having good characteristics in improvement of geotechnical properties are mixed with flash is added to the soil to enhance its properties. The present stabilization of soil is for building foundations, the soaked UCS values show considerable improvement for Geopolymer mixes. Although usually effective, cost, stability, availability, constructability and environmental issues are some of the factors that inhabit use of mechanical and chemical stabilization technologies.

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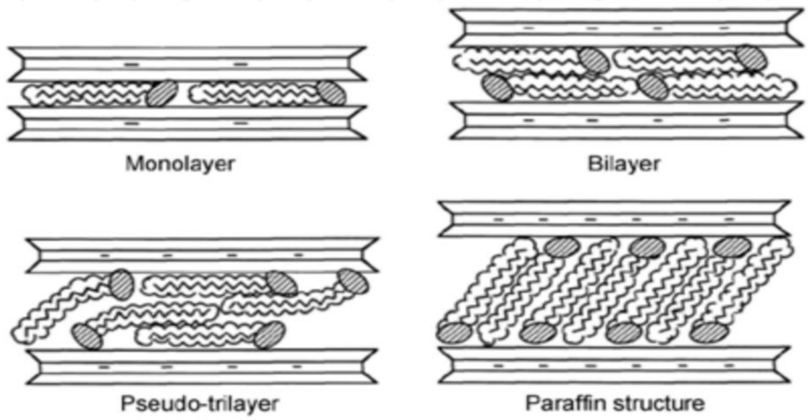
The feasibility of using geopolymer as the next-generation soil stabilizer has been confirmed by this experimental study. Stabilization with metakaolin based geopolymer.

The shrinkage of the soil was reduced after the stabilization with metakaolin based geopolymer.

The formation of geopolymer gel in the stabilized soil was confirmed by examining the SEM–EDX and XRD results.



Formation of Geopolymers in Soil layers

Composition of Admixture:

$NaOH + Na_2SiO_3$ + Flyash = Flyash based Geopolymer

In simple words, Geopolymer is combination of chemicals and industrial waste which is used as admixture in the soil to improve its strength and other properties.

The materials used in the present research work are fly ash and alkaline activator solution.

The fly ash used is very fine residues obtained from Dr. Narala Tata Rao Thermal Power Station, Vijayawada. It has a CaO percentage of less than 10% and classified as Class F

fly ash.

Flyash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by Electrostatic precipitator. Depending upon the source and composition of the coal being burned, the components of flyash may vary.

The alkaline activator solution composed by sodium silicate (SS) and sodium hydroxide (SH) was used to synthesize geopolymer. The SH is prepared dissolving sodium hydroxide flakes in water until the desired concentration is reached. The sodium silicate was originally in solution form, with a specific gravity of 1.5, a sodium oxide (Na_2O) content of 13.0% and a SiO_2/Na_2O ratio of 2.0. The SH flakes have a specific gravity of 2.13 at 20ºC (99 wt%).

MATERIALS

2.1 HIGHLYCOMPRESIBLECLAY

Highly compressible clay is an expensive clay with the potential for shrinkage or swelling under moisture change. They usually exhibit high shrinkage characteristics with surface cracks, opening during the dry seasons which are more than 50 mm or wider and several mm deep. These cracks close during the wet season and an uneven soil surface is produced by irregular swelling. Such soils are especially troublesome as foundation to buildings.

Highly compressible clay is a very hard when dry, but lose it strength completely when in wet condition. This type of soil is useful for farmers but problematic for civil engineers these soils are deficient in nitrogen, phosphoric acid and organic matter but rich calcium, potash and magnesium. Civil engineering structures experience large scale damage due to change in properties of soil. Intermediate compressible clay always pose challenge to Geotechnical engineers.

These soils are deficient in nitrogen, phosphoric acid and organic matter but rich calcium, potash and magnesium. The clay soil was collected from site which is near to your college. The soil sample was collected at a depth of 1 to 2m from the ground level.

2.2 FLYASH BASED GEOPOLYMER

Geopolymer is definitely an advanced material for effective soil stabilization. It can be used as binding agents in natural soil. Polymer soil stabilization refers to the addition of***polymers*** to improve the physical properties of soils, most often for ***geotechnical engineering***, construction, or agricultural projects. Even at very small concentrations within soils, various polymers have been shown to increase ***water retention***and reduce erosion, increase soil *shear strength*, and support soil structure. A wide range of polymers have been used to address problems ranging from the prevention of***desertification*** to the reinforcement of***roadbeds***. Coatings of adsorbed polymers on***clays*** can increase their steric stabilization by preventing clay particles from approaching each other as closely. Alternatively, polymer molecule that bond with multiple clay particles promote ***flocculation***.

3. EXIPERIMENTAL PROGRAM

3.1 SPECIFIC GRAVITY

$$G = (M_2-M_1)/ [(M_2-M_1) - (M_3-M_4)]$$

Where M_1=Mass of Empty bottle

M_2=Mass of bottle and dry soil

M_3=Mass of bottle, soil and water

M_4=Mass of bottle filled with water

3.3 COMPACTION TEST

Weight of empty mould = $W_m$gm

Volume of mould = V_m cc

Wet density, $\gamma_m = \frac{(w - w_m)}{v_m} g/cc$

Let the moisture content be = w %

Then dry density, $\gamma_d = \frac{\gamma_m}{\left(1 + \frac{w}{100}\right)} = \frac{(w - w_m)}{v_m\left(1 + \frac{w}{100}\right)} g/cc$

3.4 UNCONFINED COMPRESSION TEST

P= axial load at failure, A= corrected area = $\frac{A_0}{1 - \varepsilon}$, where A_0 is the initial area of the specimen, ε = axial strain = change in length/original length. The undrained shear strength (s) of the soil is equal to the one half of the unconfined compressive strength,

$$s = \frac{q_u}{2}$$

Void ratio, $e = \frac{G\rho_w}{\rho_d} - 1$ Degree of saturation, $S = \frac{wG}{e} \times 100$

3.5 DIFFERENTIAL FREE SWELL

$$\text{DFS} = \frac{\text{Settled soil volume in water} - \text{Settled soil volume in kerosene}}{\text{Settled soil volume in Kerosene}} \text{ X } 100$$

Table 3.5.1 Differentials Free Swell

S. No.	Degree of expansion	DFS
1	Low	< 20%
2	Moderate	20 - 35%
3	High	35 – 50%
4	Very High	>50%

4. RESULTS &DISCUSSIONS

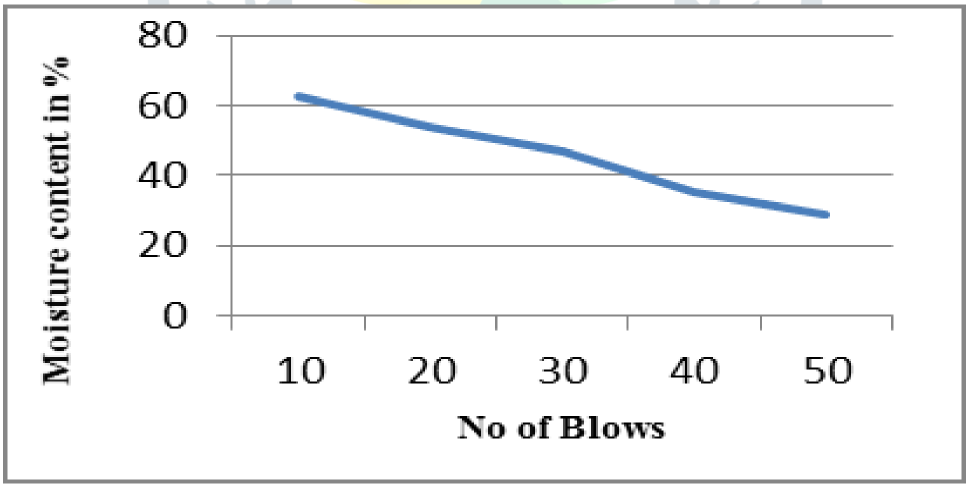
4.1 LABORATORY TEST RESULTS

To find the optimum percentage Geopolymer with Highly Compressible Clay and to find the unconfined compressive strength of clay with fly ash based geopolymer various tests were conducted by using different proportions of clay, fly ash, NaOH & Na_2SiO_3.

4.2 LIQUID LIMIT TEST RESULTS

Table: Liquid Limit Values of Untreated Clay

Sample No .	1	2	3
Mass of empty can	156.00	156.00	156.00
Mass of can +wet soil in gms .	206.00	221.56	216.48
Mass of can +dry soil in gms .	167.87	172.12	178.32
Mass of soil solids	25.13	27.46	23.32
Mass of pore water	15.86	15.99	12.83
Water content (%)	55.5	31.78	28
No .of blows	19	32	44

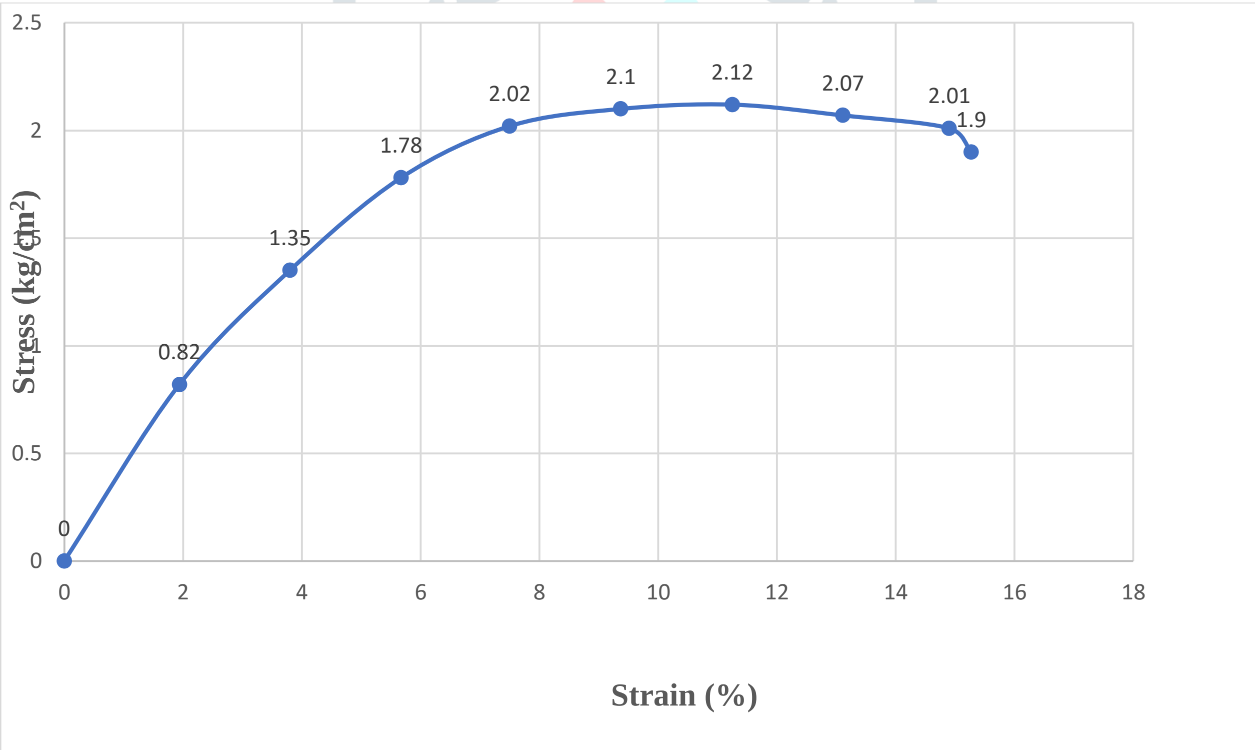


4.2Liquid limit graph for untreated clay

4.3 Table: UCS Values for Untreated Clay

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	9.5	1.94	0.82
3	16	3.8	1.35
4	21.5	5.67	1.78
5	24.8	7.5	2.02
6	26.3	9.37	2.1
7	27.1	11.25	2.12
8	27.1	13.11	2.07
9	26.9	14.9	2.01
10	25.7	15.27	1.9

UCS Value for Untreated Clay (q_u) = 2.3 kg/cm^2 (or) 22.56 N/cm^2
Shear Strength (q_u/2) = 11.28 N/cm^2

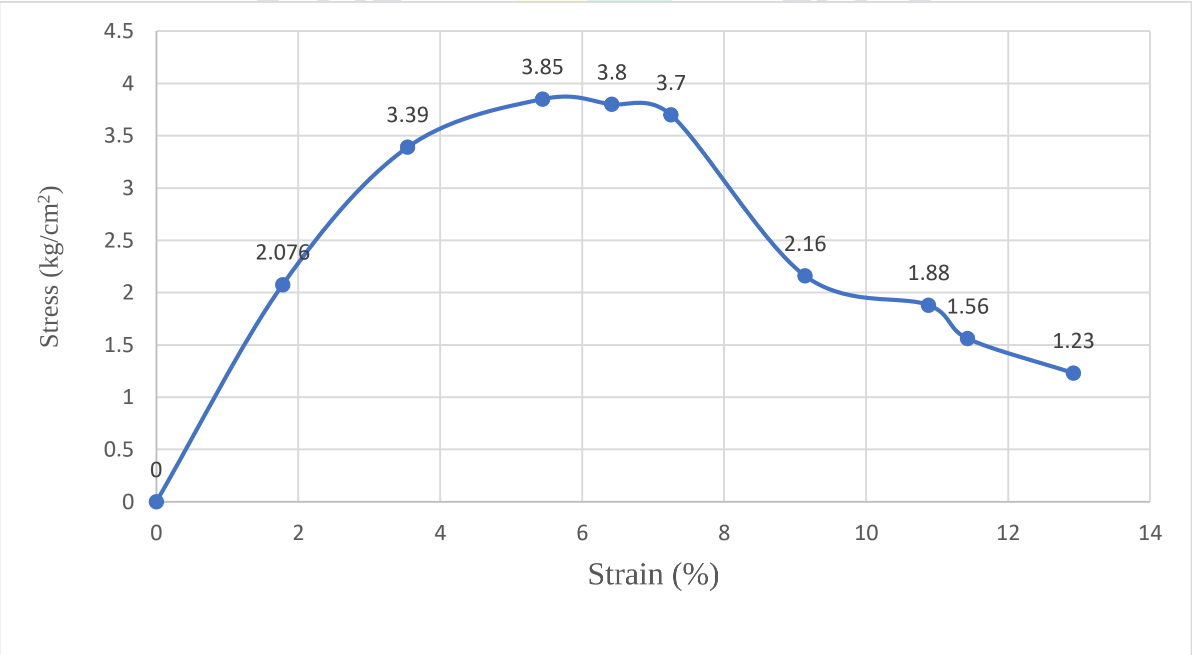


Graph:4.3 UCS graph for Untreated Clay

4.3.1 Table: UCS Values for Treated Clay with 5% Fly ash based Geopolymer at 7days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	24	1.78	2.076
3	40	3.54	3.39
4	46.2	5.44	3.85
5	46.2	6.417	3.8
6	46	7.25	3.7
7	27	9.14	2.16
8	24	10.88	1.88
9	20	11.43	1.56
10	16	12.92	1.23

UCS Value for Treated Clay with 5% Fly ash based Geopolymer at 7 days
(q_u) = 3.9 kg/cm^2 (or) 38.26 N/cm^2
Shear Strength (q_u/2) = 19.13 N/cm^2

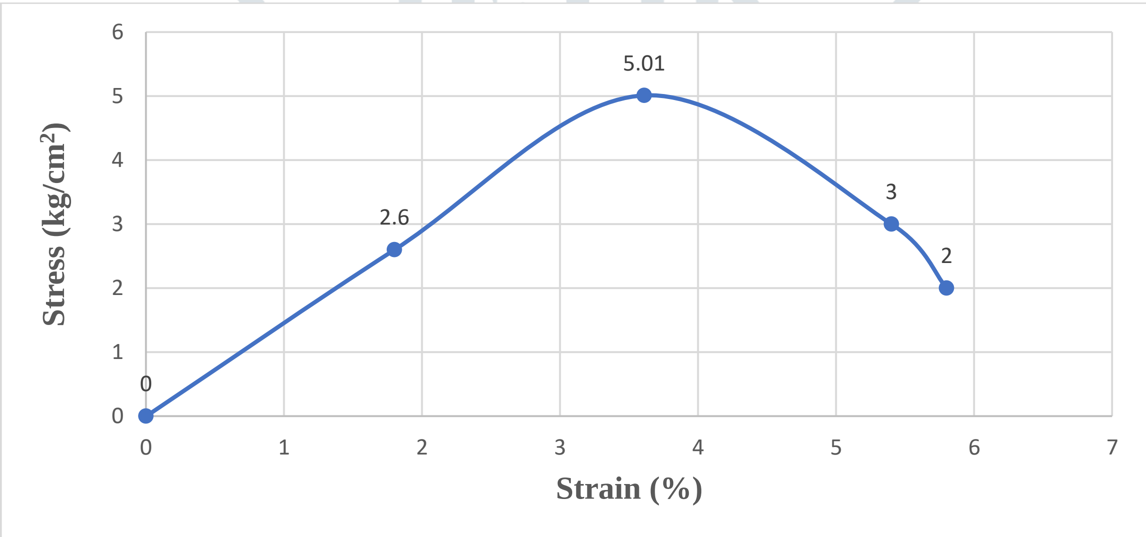


4.3.1 Graph: UCS graph for Treated Clay with 5% admixture at 7 days

4.3.2 Table: UCS Values for Treated Clay with 10% Fly ash based Geopolymer at 7days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	30	1.8	2.6
3	59	3.61	5.01
4	36	5.4	3
5	24	5.8	2

UCS Value for Treated Clay with 10% Fly ash based Geopolymer at 7 days
(q_u) = 5.1 kg/cm^2 (or) 50.03 N/cm^2
Shear Strength (q_u/2) = 25.02 N/cm^2

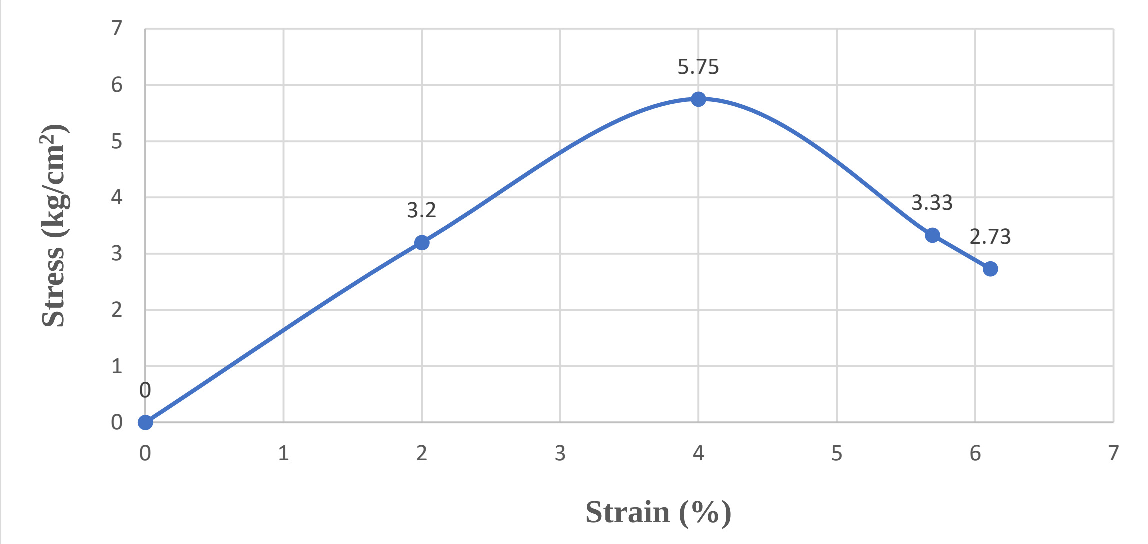


4.3.2 Graph: UCS graph for Treated Clay with 10% admixture at 7 days

4.3.3 Table: UCS Values for Treated Clay with 15% Fly ash based Geopolymer at 7days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	37	2	3.2
3	68	4	5.75
4	40	5.69	3.33
5	33	6.11	2.73

UCS Value for Treated Clay with 15% Fly ash based Geopolymer at 7 days
(q_u) = 5.8 kg/cm^2 (or) 56.9 N/cm^2
Shear Strength (q_u/2) = 28.45 N/cm^2

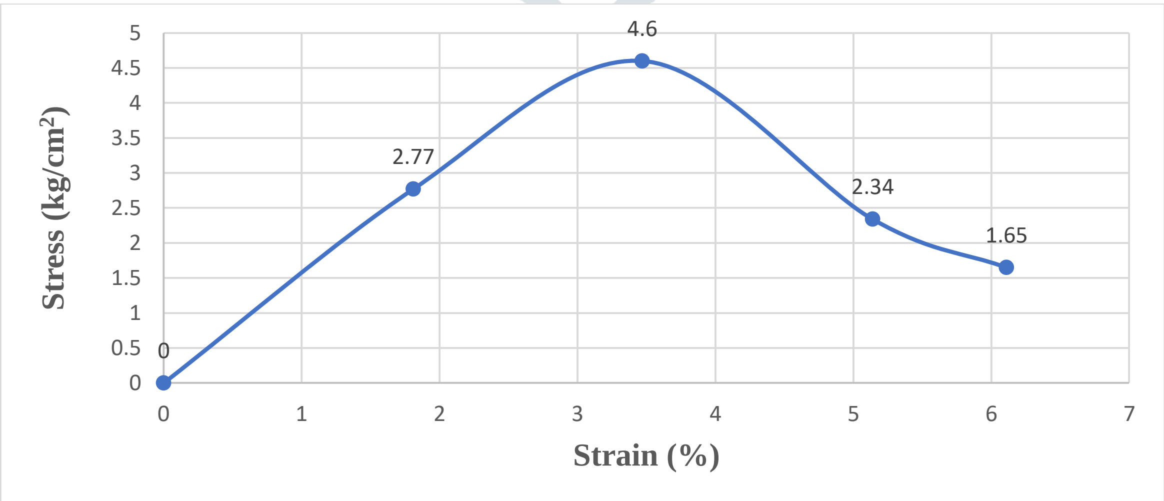


4.3.3 Graph: UCS graph for Treated Clay with 15% admixture at 7 days

4.3.4 Table: UCS Values for Treated Clay with 5% Fly ash based Geopolymer at 14days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	32	1.81	2.77
3	54	3.47	4.6
4	28	5.14	2.34
5	20	6.11	1.65

UCS Value for Treated Clay with 5% Fly ash based Geopolymer at 14 days
(q_u) = 4.65 kg/cm^2 (or) 45.62 N/cm^2
Shear Strength (q_u/2) = 22.81 N/cm^2

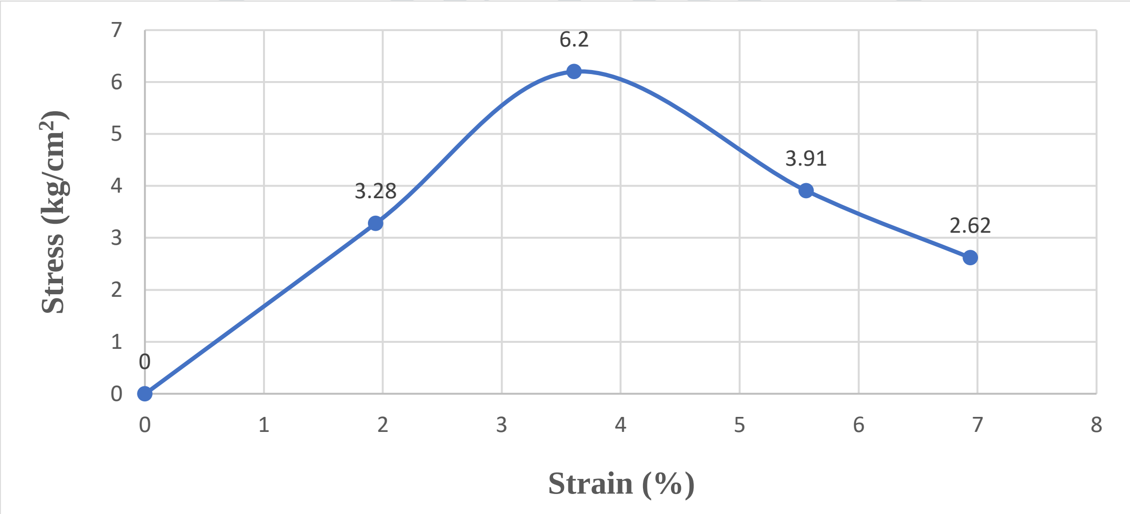


4.3.4 Graph: UCS graph for Treated Clay with 5% admixture at 14 days

4.3.5 Table: UCS Values for Treated Clay with 10% Fly ash based Geopolymer at 14days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	38	1.94	3.28
3	73	3.61	6.2
4	47	5.56	3.91
5	32	6.94	2.62

UCS Value for Treated Clay with 10% Fly ash based Geopolymer at 14 days
(q_u) = 6.25 kg/cm^2 (or) 61.31 N/cm^2
Shear Strength ($q_u/2$) = 30.655 N/cm^2

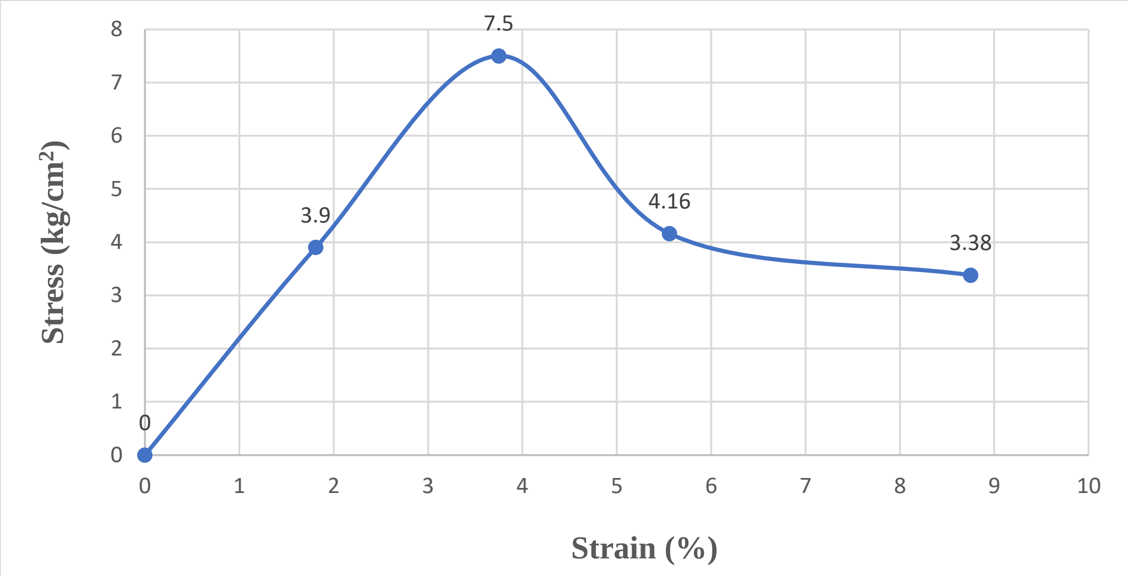


4.3.5 Graph: UCS graph for Treated Clay with 10% admixture at 14 days

4.3.6 Table: UCS Values for Treated Clay with 15% Fly ash based Geopolymer at 14days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	45	1.81	3.9
3	89	3.75	7.5
4	50	5.56	4.16
5	42	8.75	3.38

UCS Value for Treated Clay with 15% Fly ash based Geopolymer at 14 days
(q_u) = 7.5 kg/cm^2 (or) 73.58 N/cm^2
Shear Strength ($q_u/2$) = 36.79 N/cm^2

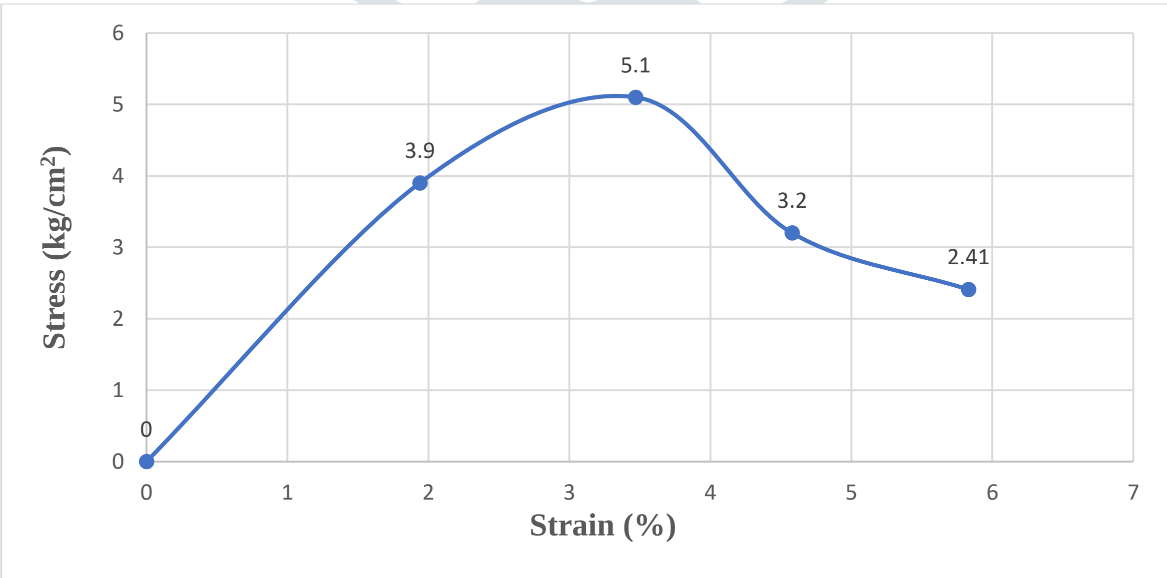


4.3.6 Graph: UCS graph for Treated Clay with 15% admixture at 14 days

4.3.7 Table: UCS Values for Treated Clay with 5% Fly ash based Geopolymer at 28days.

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	45	1.94	3.9
3	60	3.47	5.1
4	38	4.58	3.2
5	29	5.83	2.41

UCS Value for Treated Clay with 5% Fly ash based Geopolymer at 28 days.
(q_u) = 5.2 kg/cm^2 (or) 51.01 N/cm^2
Shear Strength (q_u/2) = 25.505 N/cm^2

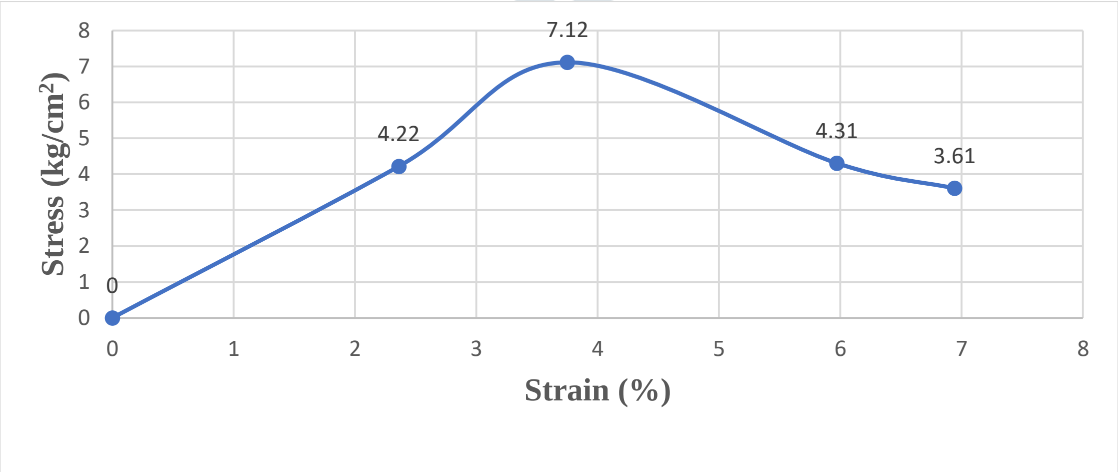


4.3.7 Graph: UCS graph for Treated Clay with 5% admixture at 28 days.

4.3.8 Table: UCS Values for Treated Clay with 10% Fly ash based Geopolymer at 28days.

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	49	2.36	4.22
3	84	3.75	7.12
4	52	5.97	4.31
5	44	6.94	3.61

UCS Value for Treated Clay with 10% Fly ash based Geopolymer at 28 days
(q_u) = 7.15 kg/cm^2 (or) 70.14 N/cm^2
Shear Strength ($q_u/2$) = 35.07 N/cm^2

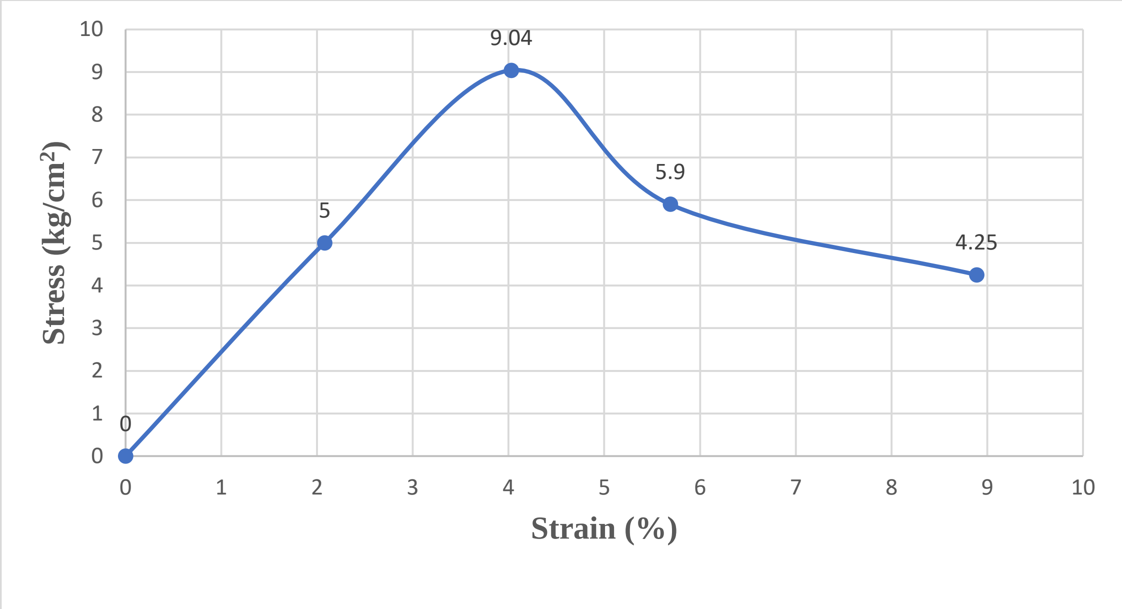


4.3.8 Graph: UCS graph for Treated Clay with 10% admixture at 28 days

4.3.9 Table: UCS Values for Treated Clay with 15% Fly ash based Geopolymer at 28days

S. No	Load (kg)	Strain (%)	Stress (kg/cm^2)
1	0	0	0
2	58	2.08	5
3	107	4.03	9.04
4	71	5.69	5.9
5	53	8.89	4.25

UCS Value for Treated Clay with 15% Fly ash based Geopolymer at 28 days
(q_u) = 9.15 kg/cm^2 (or) 89.76 N/cm^2
Shear Strength ($q_u/2$) = 44.88 N/cm^2



4.3.9 Graph: UCS graph for Treated Clay with 15% admixture at 28 days

5.SUMMARY& CONCLUSIONS

In order to improve the engineering behavior of soils, several improvement techniques are available in geotechnical engineering practice. The fact that the selection of any one of these methods for any problem can be made only after a comparison with other techniques proves that the method is well suited for a particular system. In fine-grained soils Mechanical stabilization methods are well suited to improve their engineering behavior and to make them less sensitive to environmental factors.

Various tests were carried out in the laboratory for finding the properties of the intermediate compressible clay treated with additive fly ash based Geopolymer. The relative performance of stabilizer with the percentage variations were investigated to find the optimum percentage of additives in laboratory.

5.1 CONCLUSIONS

By experimental data it can be concluded that the selected soil is classified as clay with Intermediate compressibility (CI).

By experimental data it can be concluded that the selected soil is classified as clay with Highly Compressible (CH).

The addition of **5%**Flyash based Geopolymer at **7** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **38.26 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **19.13 N/cm^2**

The addition of **10%**Flyash based Geopolymer at **7** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **50.03 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **25.02 N/cm^2**

The addition of **15%**Flyash based Geopolymer at **7** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **56.9 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **28.45 N/cm^2**

The addition of **5%**Flyash based Geopolymer at **14** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **45.62 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **22.81 N/cm^2**

The addition of **10%**Flyash based Geopolymer at **14** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **61.31 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **30.655 N/cm^2**

The addition of **15%**Flyash based Geopolymer at **14** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **73.58 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **36.79 N/cm^2**

The addition of **5%**Flyash based Geopolymer at **28** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **51.01 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **25.5 N/cm^2**

The addition of **10%**Flyash based Geopolymer at **28** days to the clay is improving its Unconfined Compressive Strength value up to **22.56 N/cm^2** to **70.14 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **35.07 N/cm^2**

The addition of **15%**Flyash based Geopolymer at **28** days to the clay is improving its Unconfined Compressive Strength value up **to 22.56 N/cm^2** to **89.76 N/cm^2**. Shear Strength Value from **11.28 N/cm^2**to **44.88 N/cm^2**

Finally, it is concluded that the Compressive Strength and Shear Strength of Clay Soil was improved with addition of various percentages of Flyash based Geopolymer.

5.2 FURTHER SCOPE OF STUDY

The work can be extended further by adding different admixtures with their optimal dosage.

Cost analysis for a project can be done and may be compared.

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