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Sustainability Considerations of Clayey Soil Stabilization Techniques with OPC and Flyash

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Abstract

One of the most crucial elements in civil engineering is soil, mainly clayey soil made of tiny particles. Furthermore, it causes serious harm to any structure's foundation and payment. Therefore, the phrase stabilization is utilized to lessen this issue in the foundation. We stated that it must be stabilized before building anything on top of dirt. Therefore, the primary emphasis of this research study is on soil stabilization with fly ash and ordinary Portland cement (OPC). The strength and geotechnical characteristics of the soil sample were assessed in this study by treating it with OPC and fly ash in different percentages ranging from 0% to 12%

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at regular intervals of 3% mixed with the soil sample. Tests including the California Bearing Ratio (CBR), standard proctor compaction, unconfined compressive strength (UCS), and Atterberg Limits (plastic and liquid limit, plasticity index) were performed. The findings show that adding OPC and fly ash lowers plastic and liquid limitations. Maximum strength was achieved at 12% at OPC and fly ash after increasing the UCS and CBR. Furthermore, fly ash might stabilize the clayey soil and lessen the issue.

Keywords: Fly Ash, Unconfined Compressive Strength, California bearing ratio, Standard proctor Compaction, Clayey Soil, and Atterberg Limits.

Introduction

Thus, "naturally occurring loose, un-cemented, and unconsolidated mineral particles having properties of organic and in organic and be formed by different particles clay, sand, silt, etc. [1]" is one definition of soil that may be approached in various ways. The British soil classification system allows soil to be categorized into many groupings, as shown in Table 1 below.

Table 1: Soil Classification

Very Coarse soils	Boulders		> 200 mm
	Cobbles		60 - 200 mm
Coarse Soils	Gravel (G)	Coarse	20 - 60 mm
		Medium	6 - 20 mm
		Fine	2 - 6 mm
	Sand (S)	Coarse	0.6 - 2.0 mm
		Medium	0.2 - 0.6 mm
		Fine	0.06 - 0.2 mm
Fine Soil	Silt (M)	Coarse	0.02 - .06 mm
		Medium	0.006 - 0.02 mm
		Fine	0.002 - 0.006 mm

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	Clay (C)	<0.002mm

It was seen from the above table that clay soil is regarded as having a fine texture. Although clayey soils behave similarly, their appearance might vary depending on the location. The term "clay" often refers to clay soil that is cohesive and pliable, with most of its grain being made up of clay minerals [2]. The engineering behavior of clayey soil is complicated by the presence of water in fine-grained soils. However, particle size and shape impact the engineering behavior of Clay and granular soil [3–4].

Clays with unfavorable engineering characteristics, clay has poor shear strength, decreasing even more when wet or subjected to physical stress [5–6]. Clay may be flexible and compressible when damp and shrinks when it dries. Cohesive soils are prone to sliding under continuous pressure because they might creep with time, mainly when the shear force is close to its shear strength. There were significant lateral pressures created. Their robust modulus values are often low. Clays are often inferior materials [7-9]. The enhancement of soil engineering qualities on the site is known as soil stabilization. For lightly laden structures, swelling soil usually causes issues since it consolidates under stress and changes volumetrically with seasonal moisture variations.

Consequently, the superstructures often prevent excessive settlement and differential motions, which can damage structural components, architectural features, and foundation systems [10–11]. Despite attempts to ameliorate swelling soil, volumetric changes can occur due to inadequate technology, causing billions of dollars' worth of damage annually. This is the reason the current effort has been undertaken. The goal is to determine whether adding additives may increase bearing capacity value and decrease expansiveness. Various soil

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stabilization techniques, including mechanical and chemical stabilization, were employed to get the necessary engineering soil qualities. Local approaches should be used to stabilize the soil with minimal costs and accessible money because most of these methods were expensive and difficult for slow-developing countries to implement [12].

The soil was frequently found to be soft or weak on construction sites due to its low plasticity, low shear strength, and excessive swelling characteristics. Depending on the nature of the project, the expansion option in design is to remove the soft and weak soil and replace it if the project site-bearing strata were determined to be weak or soft. Lightweight aggregates, crushed rocks, and other materials are substituted with granular materials. Further techniques to enhance the ground conditions include using stone columns, grouting, wick drains, and chemical admixtures like lime or cement [13]. Using chemical additives was one of the most efficient and cost-effective strategies. By using various outdated and modern techniques and processes, many types of other waste products have also been used to improve the soil's qualities and reduce the costs associated with treating loose and weak soil [14–18]. Fly ash is the waste product that thermal plants generate. It requires hectares of land for disposal and poses several health and environmental risks [19]. To stabilize expansively, the usage of Clay's fly ash proved successful. Tests like the California Bearing Ratio values and unconfined compressive strength (UCS) were used to determine the strength characteristics of fly ash-stabilized clays. Depending on the kind of soil, fly ash percentage ranges from 15 to 30% to enhance the soil's engineering qualities [20]. Fly ash is either dumped dry or combined with water and released as slurry into areas known as ash ponds. The amount of fly ash produced increased daily and continues to do so. Only three

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nations, China, India, the United States (USA), and Poland, produced 270 million tons of fly ash annually [21].

Stabilization of the soil increased its engineering qualities, including strength, volume, stability, and durability. The strength of stabilized black cotton soil is improved by adding a fraction of fine, coarse fly ash, and the moisture-density connection is comparatively well-defined [22–23]. This study primarily focuses on the engineering characteristics for stabilizing soil with fly ash injection. The dirt in that specific area Because Bannu City is causing issues for construction, mainly cracks in building walls and road settlements, it is necessary to examine the problem from the ground up and suggest using fly ash in clayey soil (if appropriate based on lab test results) to resolve it.

The following are the objectives of the study.

- Bannu City soil identification and Characterization.
- To check the suitability of Ordinary Portland Cement (OPC) and Fly Ash as a soil stabilizing agent in the improvement of compaction of clayey soil.
- To determine the effects of Ordinary Portland Cement and Fly ash on engineering properties of clayey soil (Mechanical strength – CBR)

The main issue is dealing with weak and poor subgrade soil. These circumstances mostly pertain to or occur in geotechnical engineering or during building roads or highways.

Finding strategies for soil improvement to meet the demands is challenging since fewer locations are available for construction development. In civil engineering, soil composed of clay minerals and other mineral components with some cohesiveness and flexibility is called clay soil. Removing soft soil first is the most popular and typical method for stabilizing weak and soft subgrade soil. Crushed rock or gravel that is sturdy and sound must be utilized as a substitute for soft or

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loose soil. Since the precise quantity needed to replace the materials was somewhat large, other researchers devised alternative solutions to the problem. To satisfy the requirements of specific engineering projects, bearing capacity enhancement is not just the goal of soil stabilization; it also includes improving and enhancing the shear strength, filtration, drainage system, permeability, and soil resistance to weathering action and traffic utilization. A lower void ratio results from proper compaction, and soil stabilizes through mechanical and physical mechanisms.

Research Methodology and Material

This study's research methodology mainly relies on laboratory tests and procedures to achieve the necessary goals. Three soil samples were taken from three trail pits on the UET Bannu campus, situated on the significant Bannu-D-I-Khan road, two kilometers from Bannu City. All samples utilized in this investigation were remolded in the lab using standard protocols. For this clayey soil, fly ash and regular Portland cement were thought to be stabilizing agents. Nine samples were prepared for testing.

S_N (Pure Soil Sample), S_{O3} (Soil mix with 03 % OPC), S_{O6} (Soil mix with 06 % OPC), S_{O9} (Soil mix with 09 % OPC), S_{O12} (Soil mix with 12 % OPC), S_{F3} (Soil mix with 03 % Fly Ash), S_{F6} (Soil mix with 06 % Fly Ash), S_{F9} (Soil mix with 09 % Fly Ash), S_{F12} (Soil mix with 12 % Fly Ash)

Various studies investigated the possibility of employing fly ash and OPC as stabilizing agents in soil to enhance its qualities. The following tests are carried out: sieve analysis, standard Proctor test, and unconfined compression test, California bearing ratio test, liquid limit, plastic limit, plasticity index, and natural moisture content. Table 1 lists the standard protocols used for the tests above.

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Table 1: Standard Testing Procedures

S. No.	Test	ASTM
1	Grain size analysis	D422
2	Atterberg Limit	D4318
3	Specific gravity	D854
4	Moisture Content	D2216
5	Proctor Test	D1557
6	California Bearing Ratio (CBR)	D1883

Fly Ash

Class F and Class C are the primary categories into which fly ash may be divided. Because Class F fly ash comprises particles coated in particular molten glass, it can boost resistance to alkali-aggregate reactions and sulfates while lowering the chance of concrete expansion [24]. Because Class C fly ash has more extensive calcium oxide content, it strengthens structural concrete more effectively [25]. The fly ash in this study was acquired from "MiZ Builders," a business in Karachi, and transported to the study site for analysis.

Ordinary Portland Cement (OPC)

The cement used in this research study was of high quality, and the brand name is "Lakki Cement."

Results and Discussion

Sieve and Hydrometer Analysis

The Total Sample is 500 mg. The sieve and Hydrometer Analysis of Soil Type S_N is given in the tables and figure below.

Table 2: Sieve Analysis of Soil Type S_n

Sieve No.	Sieve Size, mm	Retained (gm)	Cumulative % retained	% Finer/ Passing
4	4.75	0	0	100

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8	3.28	0	0	100
10	2	1.96	1.96	100
20	0.841	2.02	3.98	99
40	0.42	5.9	9.88	98
60	0.25	7.42	17.3	97
80	0.177	6.52	23.82	95
100	0.149	7.38	31.2	94
200	0.074	20.8	52	89.6

Table 3: Hydrometer Analysis of Soil Type S_n

Description of soil	Brown Clay	Location	UET Campus Bannu
Gs = 2.5	a = 1.04	Zero Correction	F_z = +7
Dry weight of soil Ws	50 g	Temp Correction	F_T = +2.15
Meniscus Correction	F_m = 1	Temperature	28^{0}C

Time (min)	Hydrometer Reading (R)	R_{cp}	Percent Finer	R_{CL}	L (cm)	A	L/t	D (mm) $A(L/t)^{1/2}$
0.25	48	43.15	89.75	49	7.9	0.013	31.60	0.0731
0.5	48	43.15	89.75	49	8.3	0.013	16.60	0.0530
1	47	42.15	87.67	48	8.4	0.013	8.40	0.0377
2	46	41.15	85.59	47	8.6	0.013	4.30	0.0270

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4	45	40.15	83.51	46	8.8	0.013	2.20	0.0193
8	44	39.15	81.43	45	8.9	0.013	1.11	0.0137
15	43	38.15	79.35	44	9.1	0.013	0.61	0.0101
30	42	37.15	77.27	43	9.2	0.013	0.31	0.0072
60	40	35.15	73.11	41	9.6	0.013	0.16	0.0052
120	37	32.15	66.87	38	10.1	0.013	0.08	0.0038
240	33	28.15	58.55	34	10.7	0.013	0.04	0.0027
480	30	25.15	52.31	31	11.2	0.013	0.02	0.0020
1440	28	23.15	48.15	29	11.5	0.013	0.01	0.0012
2880	25	20.15	41.91	26	12	0.013	0.00	0.0008

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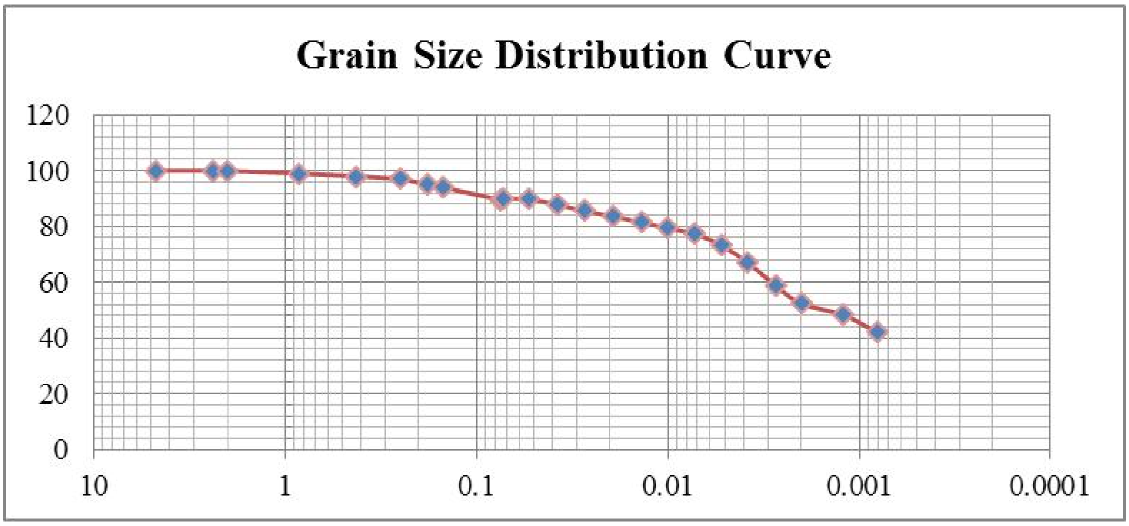

Figure 1: Gradation curve for soil type S_N

The gradation curve of the soil sample is shown in Fig 6.The soil sample is inorganic and classified as inorganic Clay with low to medium plasticity (CL) according to the unified soil classification system (USCS).

Standard Proctor Compaction Test of Soil S_N

The standard proctor compaction test of the soil is given in the table and Fig as below.

Table 4: Standard Proctor Test for Soil Type S_N

S. No.	Soil type	MDD (kg/m^3)	OMC (%)
1	S_N	1728	18
2	S_{O3}	1722	18.75
3	S_{O6}	1725	15.75
4	S_{O9}	1766	18.2
5	S_{O12}	1733	18
6	S_{F3}	1760	18.5
7	S_{F6}	1723	17
8	S_{F9}	1734	15.7
9	S_{F12}	1734	15.5

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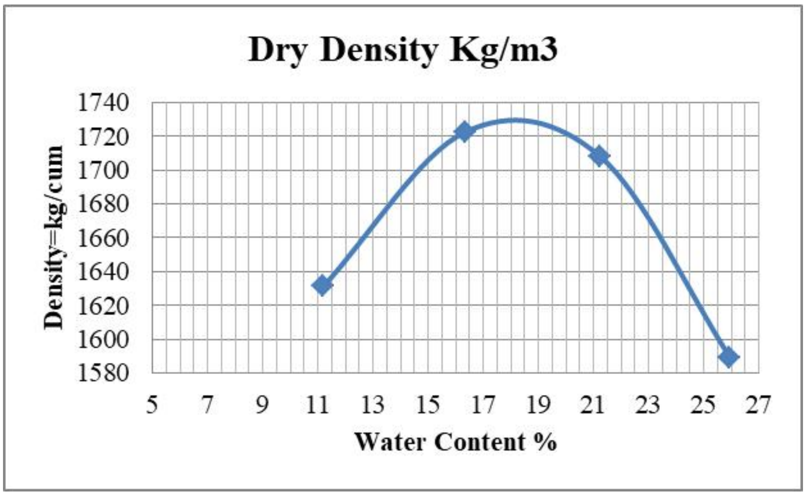

Figure 02: Moisture Content vs. MDD for Soil Type S_N

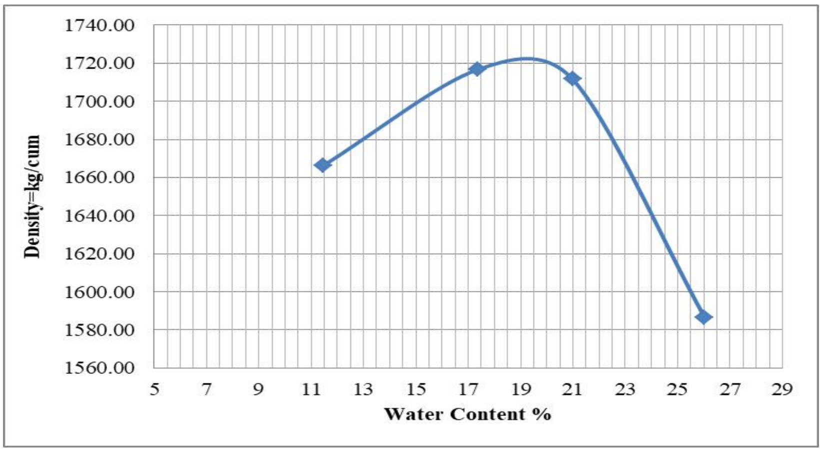

Figure 03: Moisture Content vs. MDD for Soil Type S_{O3}

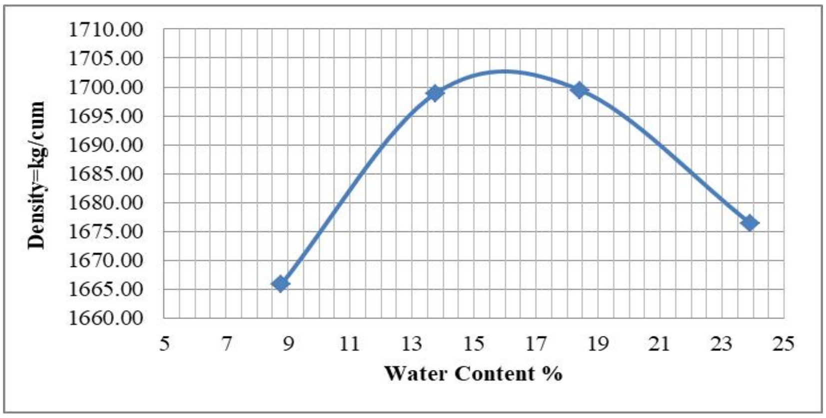

Figure 04: Moisture Content vs. MDD for Soil Type S_{O6}

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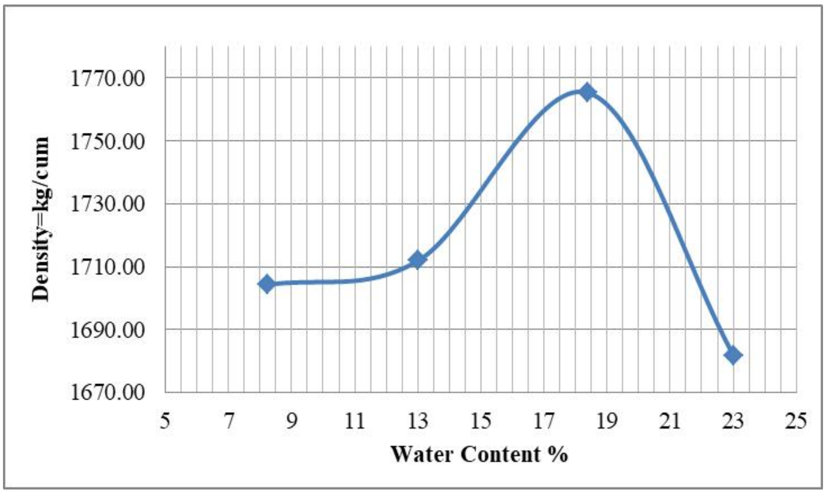

Figure 05: Moisture Content vs. MDD for Soil Type S_{O9}

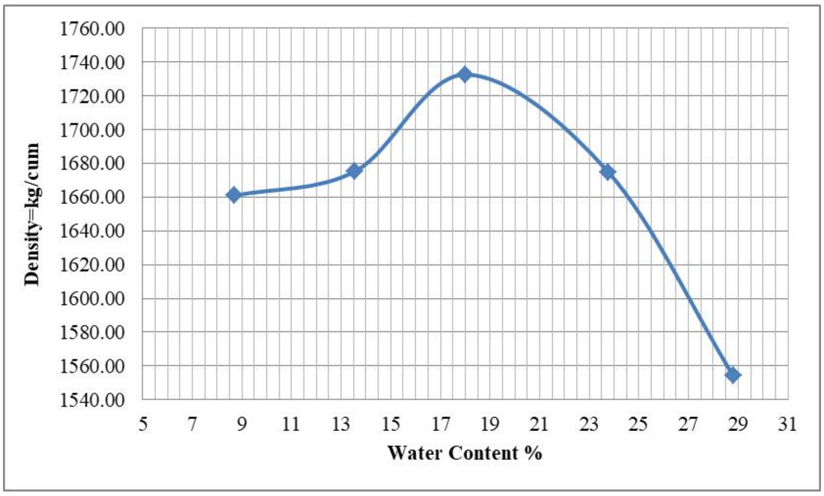

Figure 06: Moisture Content vs. MDD for Soil Type S_{O12}

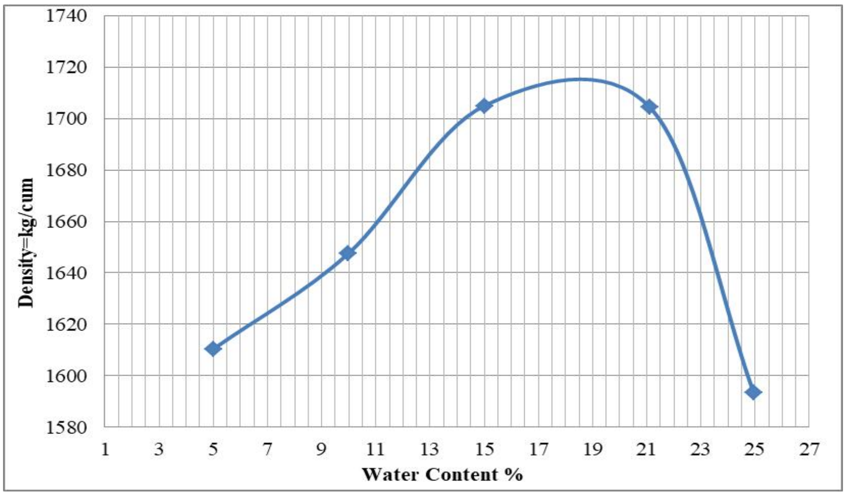

Figure 07: Moisture Content vs. MDD for Soil Type S_{F3}

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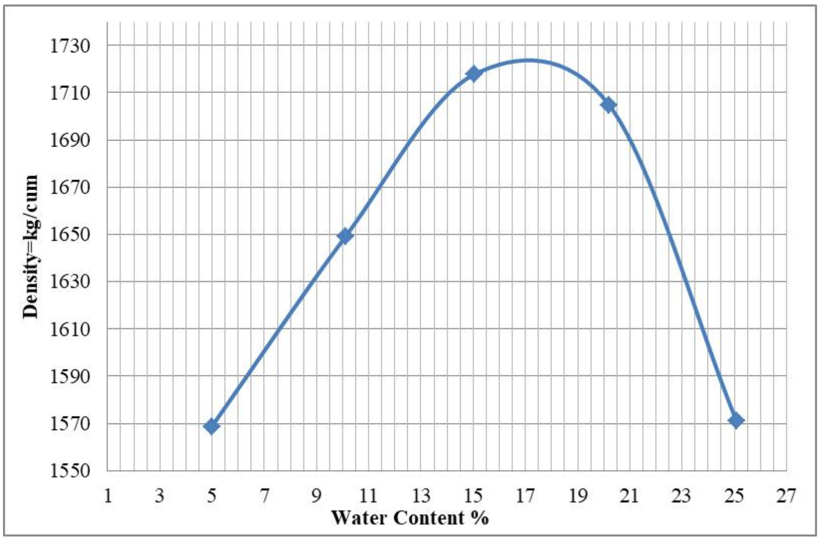

Figure 08: Moisture Content vs. MDD for Soil Type S_{F6}

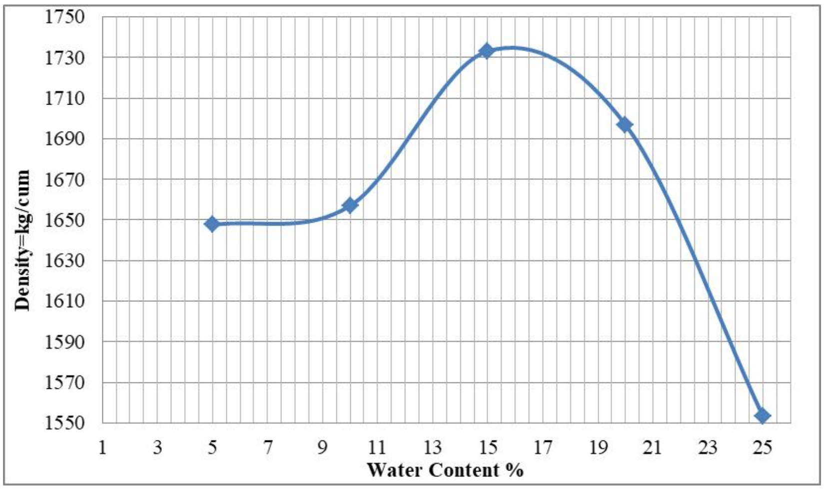

Figure 09: Moisture Content vs. MDD for Soil Type S_{F9}

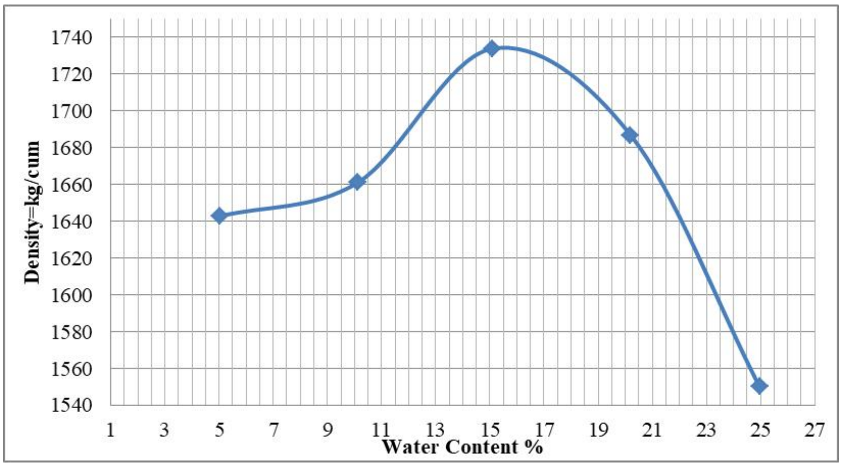

Figure 10: Moisture Content vs. MDD for Soil Type S_{F12}

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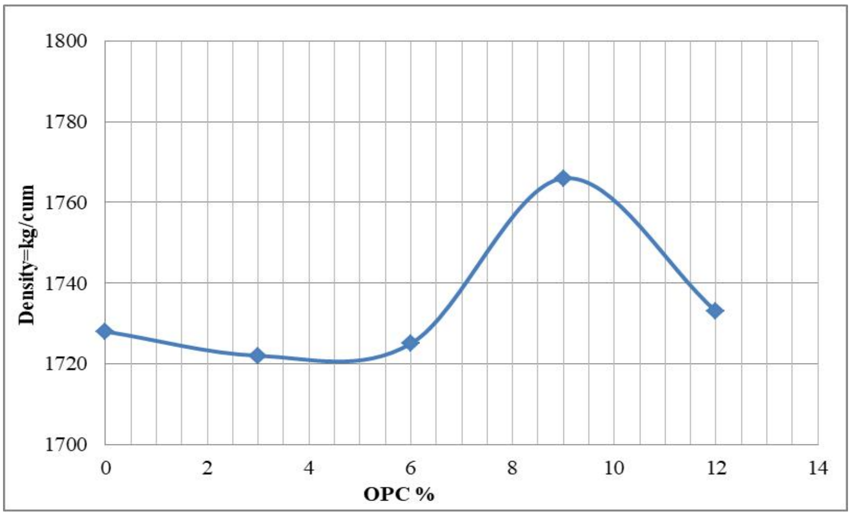

Figure 11: Graph between MDD and OPC %

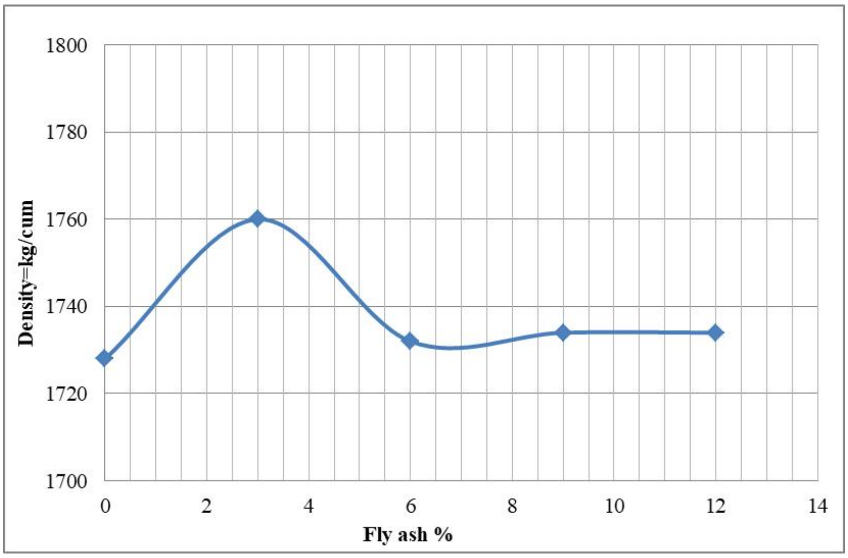

Figure 12: Graph between MDD and Fly ash %

Liquid Limit (LL) Test

Figures below show liquid limit test results for some soil samples (S_N, S_{O6}, S_{O12}, S_{F3}, and S_{F9}).

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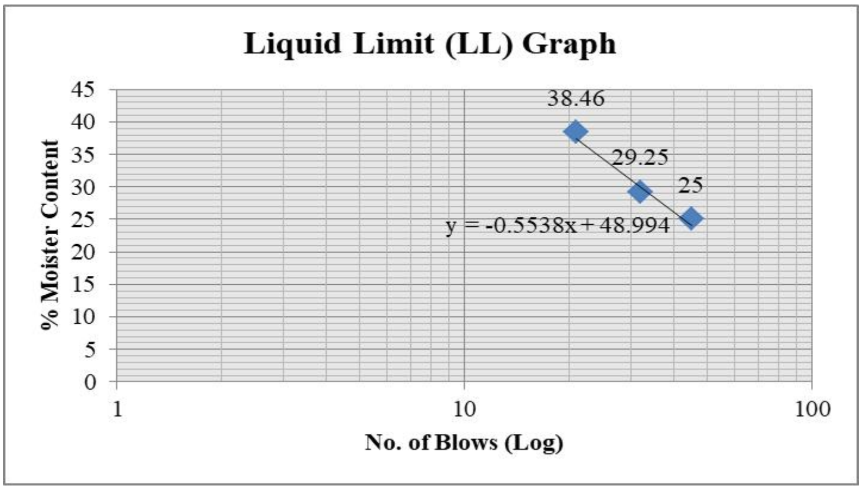

Figure 13: Moisture Content (%) Vs. Number of Blows for Soil Type S_N

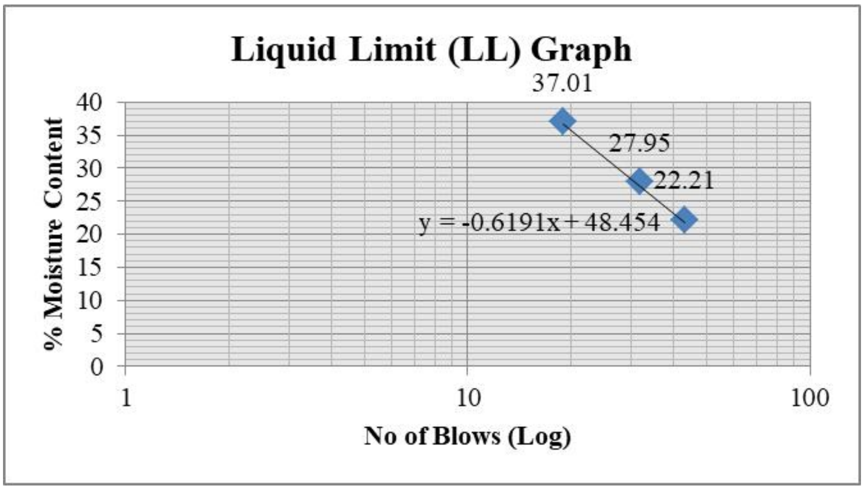

Figure 14: Moisture Content (%) Vs. Number of Blows for Soil Type S_{O3}

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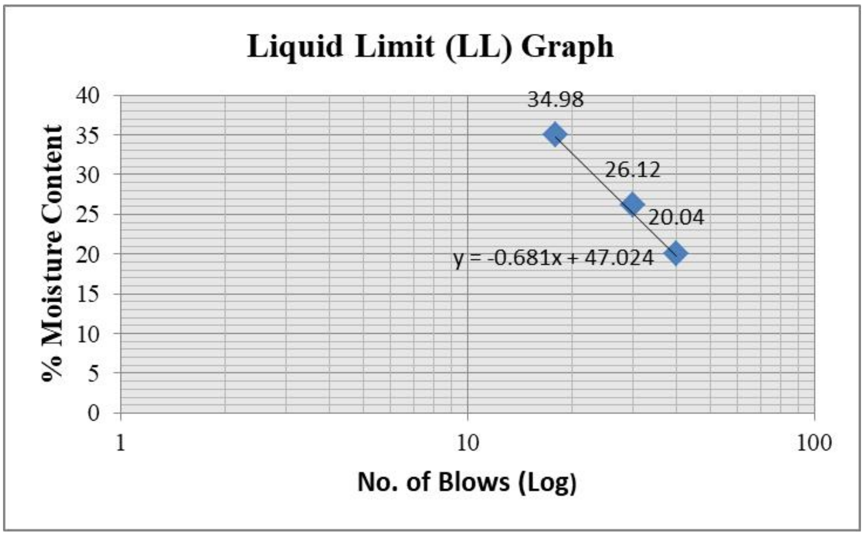

Figure 15: Moisture Content (%) Vs. Number of Blows for Soil Type S_{O6}

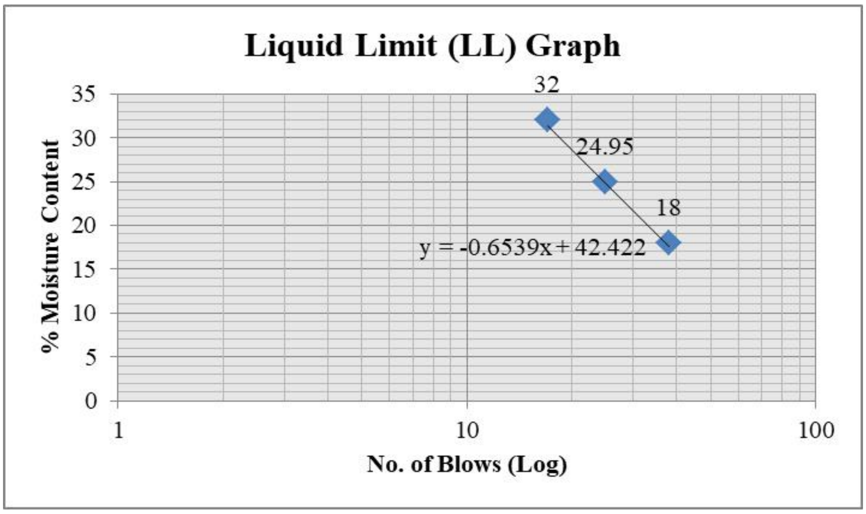

Figure 16: Moisture Content (%) Vs. Number of Blows for Soil Type S_{O9}

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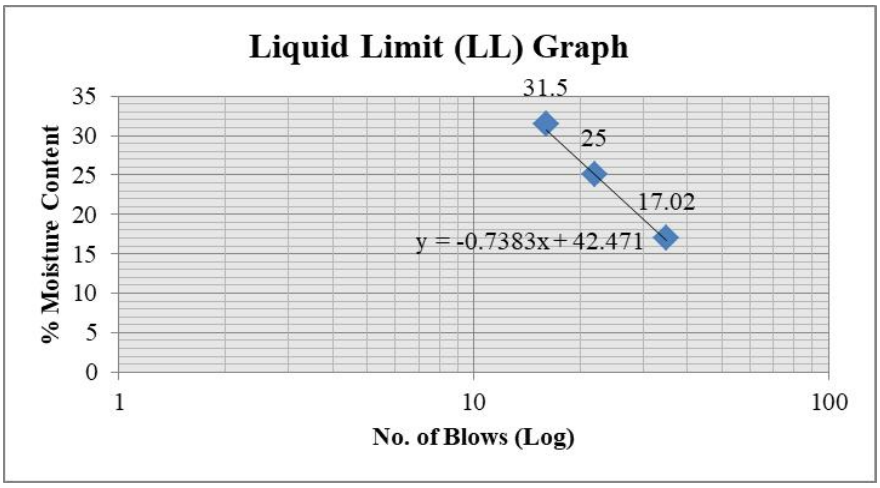

Figure 17: Moisture Content (%) Vs. Number of Blows for Soil Type S_{O12}

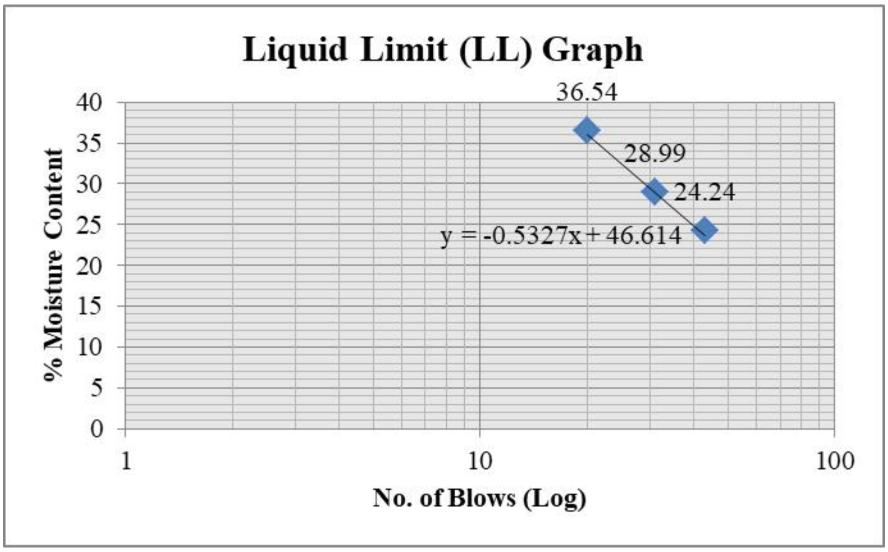

Figure 18: Moisture Content (%) Vs. Number of Blows for Soil Type S_{F3}

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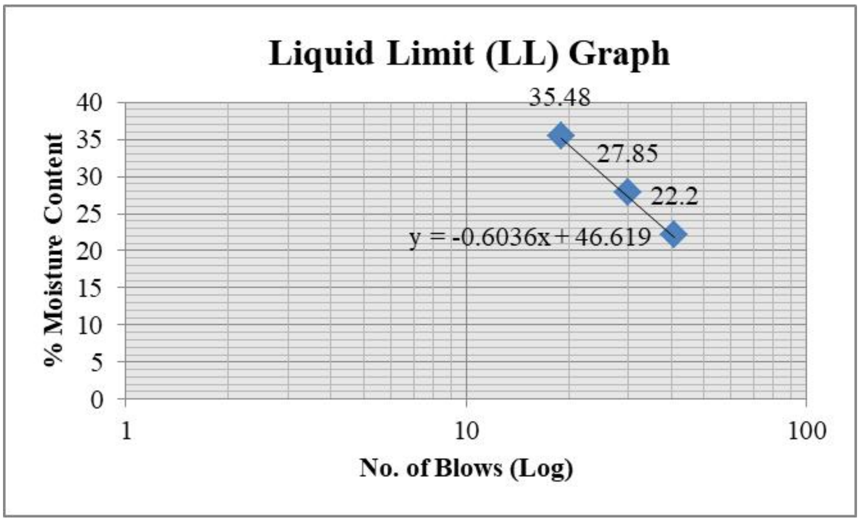

Figure 19: Moisture Content (%) Vs. Number of Blows for Soil Type S_{F6}

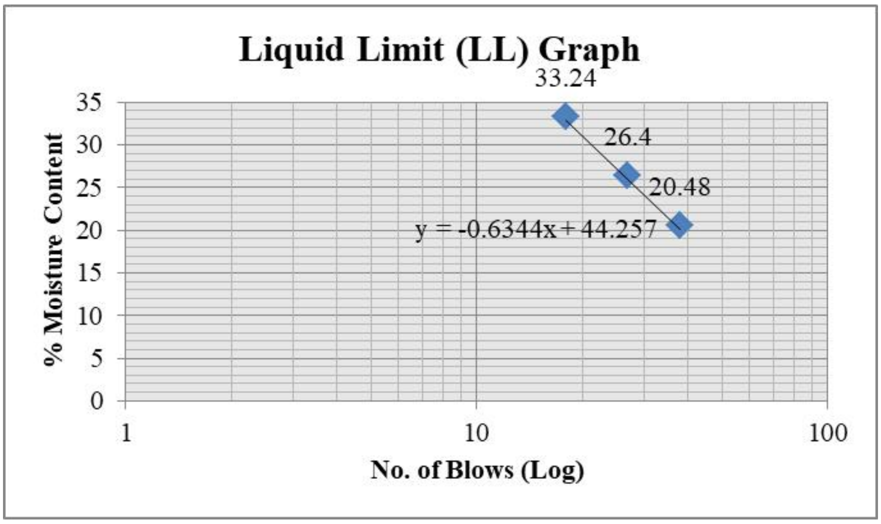

Figure 20: Moisture Content (%) Vs. Number of Blows for Soil Type S_{F9}

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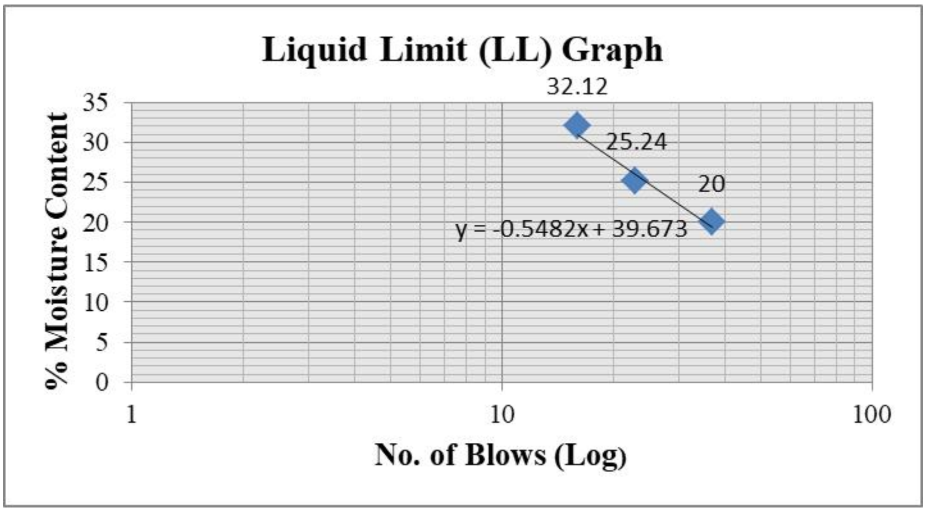

Figure 21: Moisture Content (%) Vs. Number of Blows for Soil Type S_{F12}

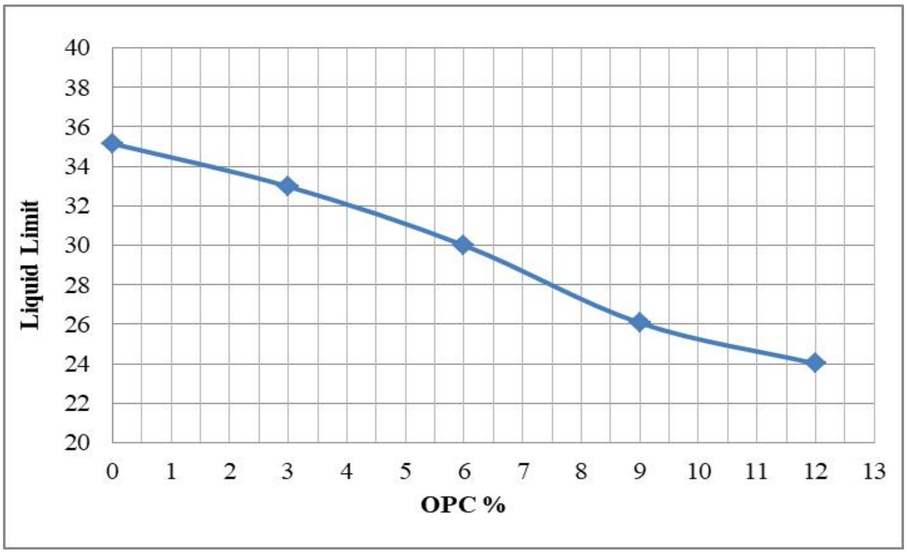

Figure 22: Graph between Liquid Limit and Percentage of OPC

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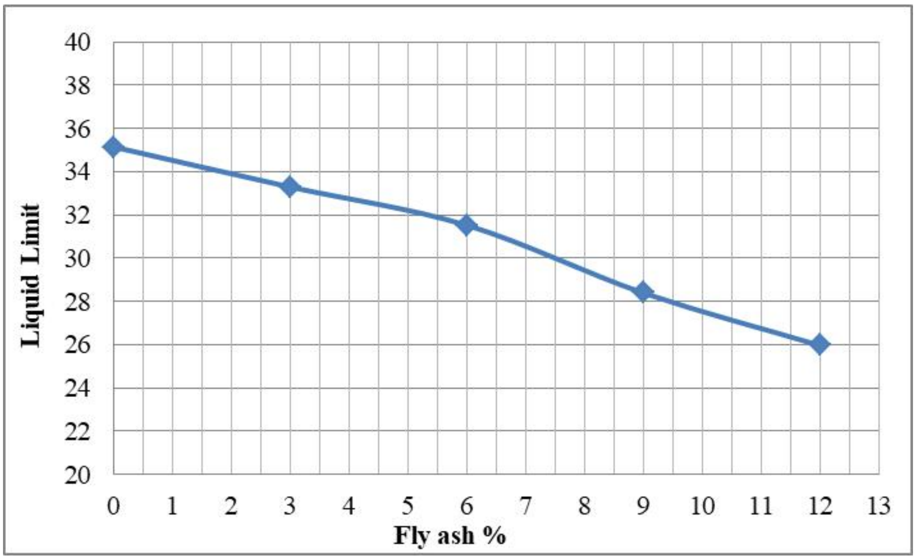

Figure 23: Graph between Liquid Limit and Percentage of Fly ash

Discussion: The Percentage of variation of liquid limit to the admixture (OPC and Fly ash) is given in Figures. As the percentage of admixture (OPC and Fly ash) increases, the liquid limit decreases.

Plastic Limit (PL) Test

The plastic limit test results of some soil samples (S_N, S_{O3}, S_{O9}, S_{F6}, and S_{F12}) are shown in the table below.

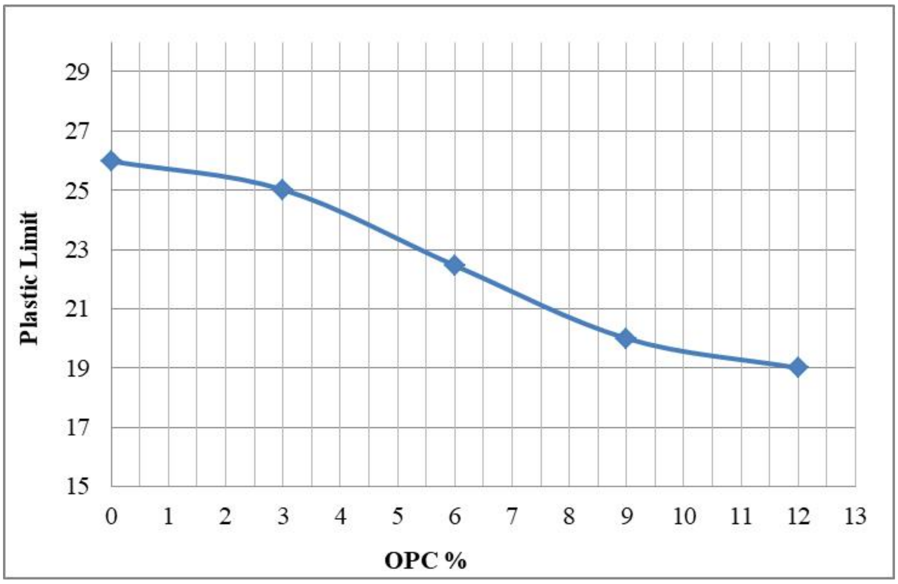

Figure 24: Graph between Plastic Limit and Percentage of OPC

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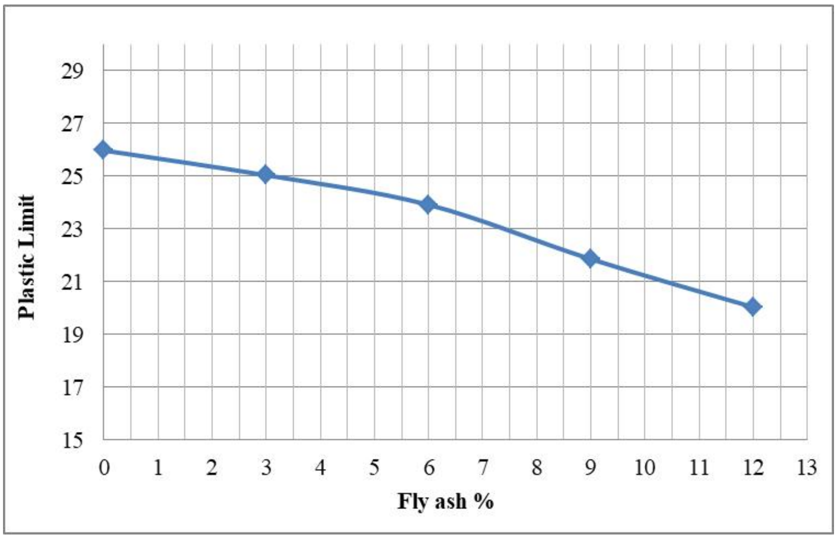

Figure 25: Graph between Plastic Limit and Percentage of Fly ash

Discussion: The Percentage of variation of Plastic limit to the admixture (OPC and Fly ash) is given in Fig 19and 20. The plastic limit decreases as the percentage of admixture (OPC and Fly ash) increases.

Plasticity Index (PI)

The plasticity index (PI) values are as follows:

Table 5: Plasticity Index for 0, 03, 06, 09 & 12% OPC

S. No	Percentage of OPC	Liquid Limit	Plastic Limit	Plasticity Index
1	0	35.15	25.98	9.17
2	3	32.98	25.02	7.96
3	6	30.00	22.46	7.54
4	9	26.07	20.00	6.07
5	12	24.01	19.00	5.01

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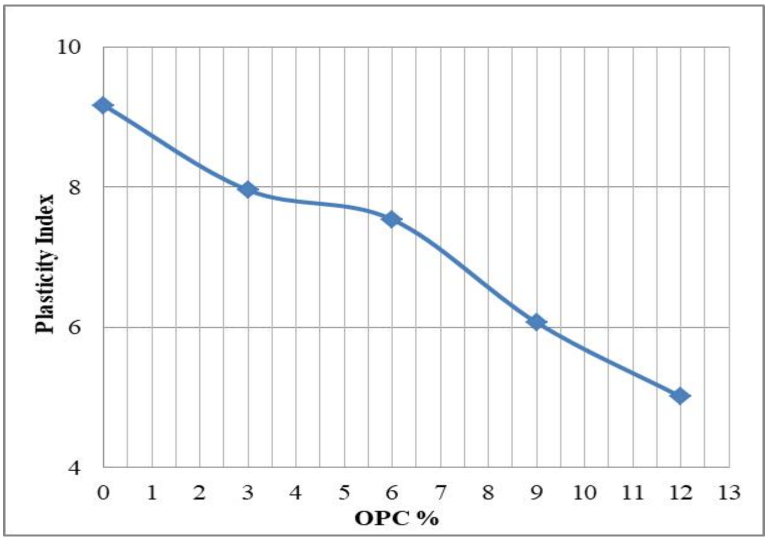

Figure 26: Plot of plasticity index vs. percentage of OPC

Table 6: Plasticity Index for 0, 03, 06, 09 & 12% Fly ash

S. NO	Percentage of Fly Ash	Liquid Limit	Plastic Limit	Plasticity Index
1	0	35.15	25.98	9.17
2	3	33.30	25.04	8.26
3	6	31.53	23.92	7.61
4	9	28.40	21.86	6.54
5	12	25.97	20.04	5.93

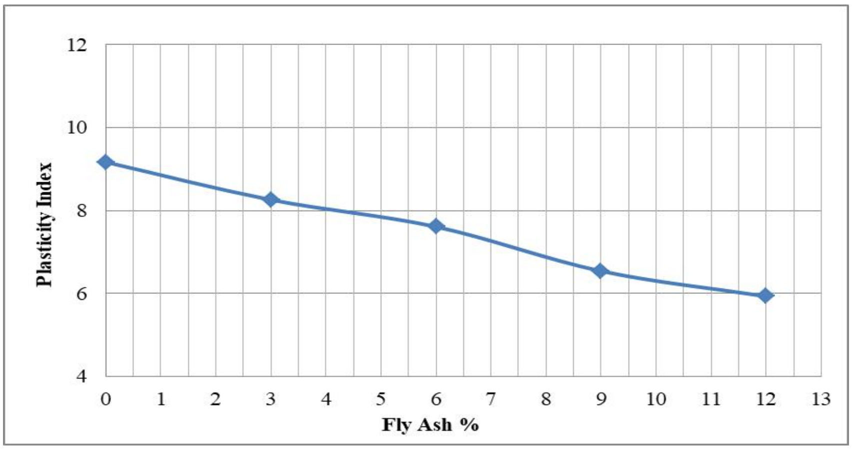

Figure 27: Plot of plasticity index vs. percentage of fly ash

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Specific Gravity

The graphs of specific gravity versus OPC and fly ash test results are found in the following figures.

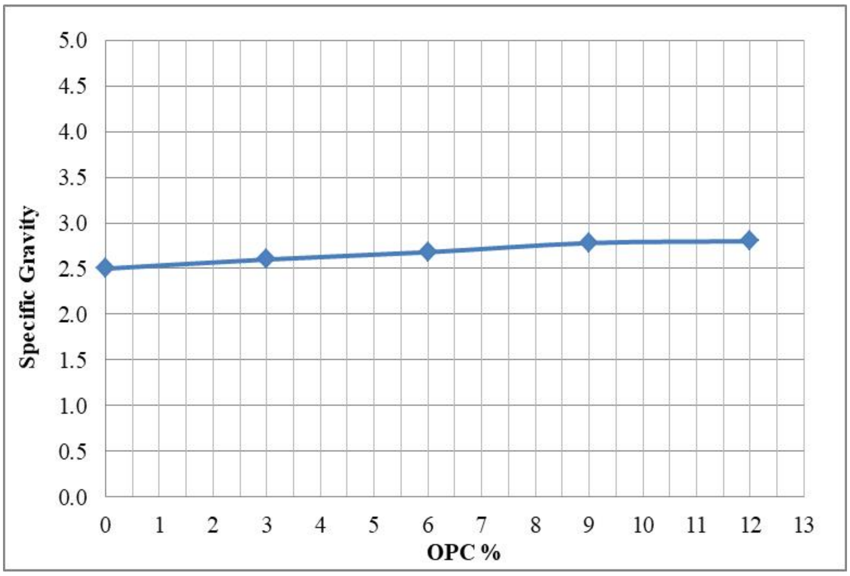

Figure 28: Plot of specific gravity vs. percentage of OPC

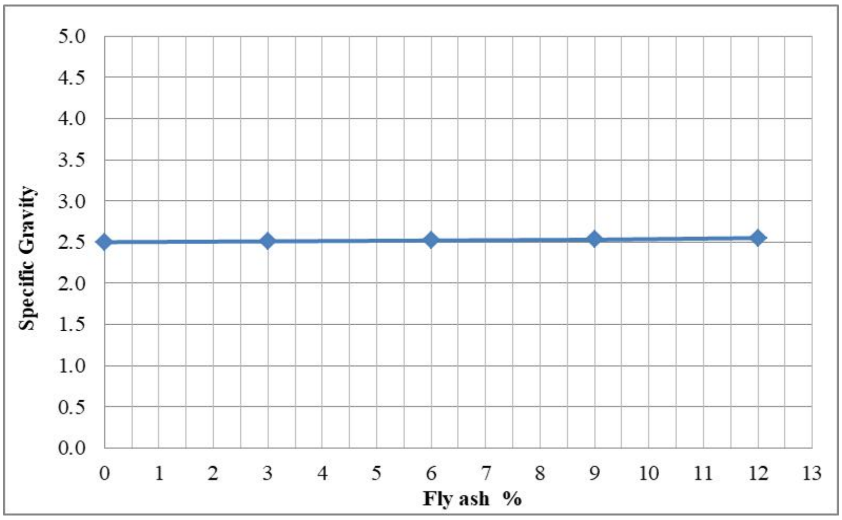

Figure 29: Plot of specific gravity vs. percentage of Fly ash

UCC and CBR

The table below shows the comparative test results of the unconfined compression test (UCC) and California Bearing Ratio (CBR) for all types of soils.

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Table 7: Comparative Test Results of UCC and CBR Tests Performed

Soil Type	qu (UCC)	% Increase	CBR	% Increase
S_N	0.41	0.00	9.70	0.00
S_{O3}	0.55	34.15	11.78	21.44
S_{O6}	0.74	80.49	13.16	35.67
S_{O9}	1.01	146.34	14.55	50.00
S_{O12}	1.12	173.17	15.93	64.23
S_{F3}	0.43	4.88	10.39	7.11
S_{F6}	0.48	17.07	11.09	14.33
S_{F9}	0.56	36.59	11.43	17.84
S_{F12}	0.68	65.85	12.47	28.56

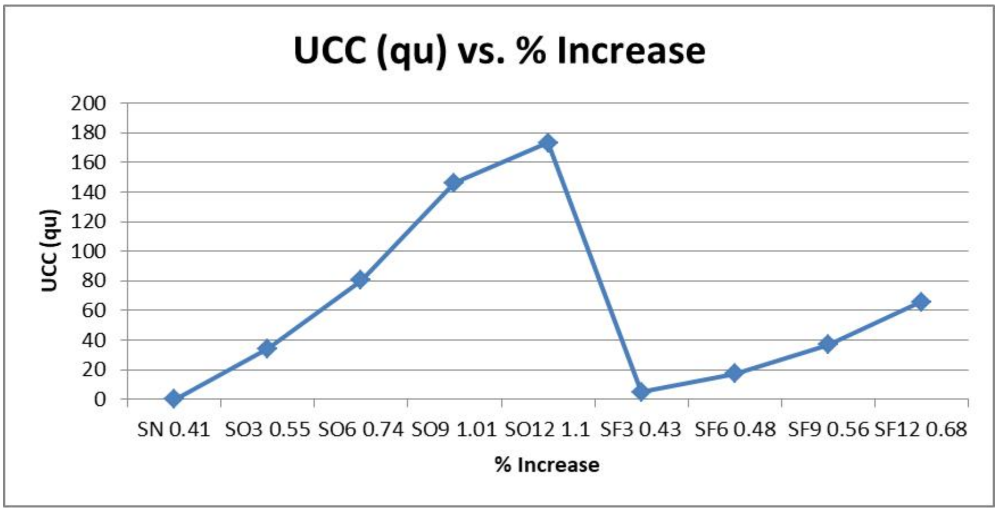

Figure 30: UCC vs. percent increase

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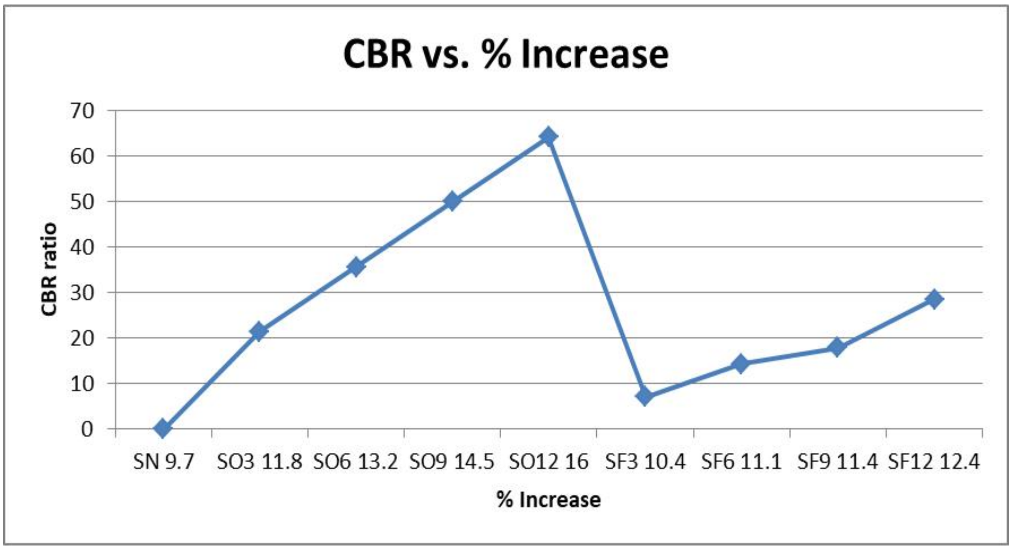

Figure 31: CBR rato vs. percent increase

Conclusions and Recommendations

- Adding OPC and Fly ash up to 12% decreases the liquid limit. The corresponding values are 24.01 % for a 12% addition of OPC and 25.97 % for a 12% addition of Fly ash.
- The corresponding values are 19.00 % with the addition of 12% OPC and 20.40 % with the addition of 12% fly ash. The liquid limit decreases with the addition of OPC and Fly ash up to 12%.
- In the soil sample, the MDD up to 9 % with the addition of OPC first decreases and then up to 12% with the addition of ordinary Portland cement increase. With the addition of Fly ash, first MDD increases at 03% addition, then decreases at 06% addition, and then decreases up to 12% addition.
- The Unconfined Compressive strength and specific gravity for both Fly ash and ordinary Portland cement additions rise to 12%.
- The specific gravity and Unconfined Compressive strength values are 2.80 at 12% ordinary Portland cement addition and 1.12 Kg/cm^2 at 12% ordinary Portland cement addition.

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- The specific gravity and Unconfined Compressive strength values are 2.55 at 12% Fly Ash addition and 0.68 Kg/cm^2 with 12% ordinary Portland cement addition.
- The addition of ordinary Portland cement
- and Fly Ash increased California Bearing Ratio values up to 12%
- The CBR values are 15.93 % with the addition of 12% ordinary Portland cement and 12.47 % with the addition of 12% Fly ash, respectively.
- The above results clearly showed that the engineering behavior of clayey soil changes with the addition of ordinary Portland cement and Fly ash and increases strength parameters at an optimum dose of 12%.
- It is recommended that up to 12% of the OPC and fly ash be used for soil stabilization.

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