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SOIL STABILIZATION USING LOCAL FLY ASH

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Abstract. Vidarbha region of Maharashtra, India is known for its rich diversity of crops and good black cotton soil. Nearly 52 million hectares of land area in India are covered with expansive soil mainly black cotton soil. In light of property of expansive soils it serves as problem to resolve for engineers. For construction purposes soil stabilization is significant, as it is widely utilized in road pavement constructions and in foundations; this is because such a stabilization regime improves geotechnical properties of the soil. In present study, fly ash obtained from local thermal plant is used for stabilization of local black cotton soil. With 10% incremental increase in proportion of fly ash, expansive soils is stabilized and found that incremental increase in fly ash results in decrease in plasticity index and swelling ratio of mix. The peak value of maximum dry density and unconfined compressive strength was observed at 30% fly ash content in BC soil.

Keywords: BC soil, fly ash, soil stabilization, plasticity index, swelling ratio, maximum dry density, UCS.

1. INTRODUCTION

Increased urbanisation and industrialization raises the demand for power, which leads to an increase in the number of thermal power plants using coal to generate electricity. Fly ash is the mineral residue that remains after coal has been burned. Fly ash is employed in this study to minimise expansiveness and increase the bearing capacity value of black cotton soil, allowing it to be used instead of laying as a fine waste product from thermal power plants.

2. GENERATION AND DISPOSAL OF FLY ASH

The use of coal to generate steam in thermal power plants is a prevalent practice. Thermal power plants began using pulverized coal mass instead of the aforementioned content to reduce energy production from coal mass. During this process, the pulverized coal is initially added to the combustion chamber, where it is burned efficiently. As a result, the ash produced is referred to as fly ash, and it contains molten minerals. The sphere shape of the fly ash particle is created when coal ash is mixed with flue gases and steam around this molten mass. Following that, the economizer is used to recover heat from steam and fly ash gases. Consequently, the temperature of the fly ash shows a sharp decrease in value. If the temperature drop is unintentional, the fly ash material's structure will be amorphous. The fly ash, on the other hand, becomes more crystalline in character if the temperature drop during the cooling process is modest. This discusses how the economizer is implemented and how it enhances the reactivity process. Finally, a mechanical dust collector known as an Electro Static Precipitator separates fly ashes from flue gases (ESP). The remainder of the flue gases was released in the atmosphere through chimney. The efficiency of electro static precipitator is nearly 90%-98%, for the separation of finer and lighter fly ash particles. The number of fields available in an ESP is related to the fineness of the fly ash particles collected. Fly ash content have specific surface area nearly 2800 cm^2/gm which was collected from the 1st hopper, collection from the last hopper shows a bigger about 8200 cm^2/gm specific area. When pulverised coal is scorched, it produces ash, which is collected as fly ash. Fly ash recovered are 80% of coal ashes that are extracted from flue gases, while the remaining 20% is collected at the bottom of the furnace as they are coarser in size and is called as bottom ash. The bottom ash is taken either from a water-filled hopper or in dry form.

3. CHARACTERIZATION OF FLY ASH

When it comes to fly ash, two key challenges arise: its safe disposal and use. Because industrial waste has complex features and is dangerous, it is critical to dispose of it in a safe and effective manner to avoid disrupting the natural system. If these industrial wastes are not pre-treated before being disposed of or stored, contamination will result. Fly ash particles are typically spherical in shape, which makes it easier for them to blend and flow together to form a suitable mixture. The content of fly ash created includes both amorphous and crystalline minerals. The content varies depending on the type of coal used in the burning process, but it is mostly non-plastic silt. Fly ash has a lot of promise for trash liners, and can also be utilized as a hurdle causing material when combined with particular minerals for example lime and bentonite. The amount of fly ash produced greatly outnumbers its current use.

3.1 Fly Ash Categorization

After pulverisation, the ash collected from ESP as flue gas is known as fly ash. In comparison to bottom ash and pond ash, the finest of particles is fly ash. The fly ash mostly consists of non-combustible particulate debris, mostly silt-sized particles, with some unburned carbon. On the basis of lime reactivity, fly ash has been categorized into 4 main categories such as 1) Pozzolanic fly ash, 2) Non-pozzolanic fly ash, 3) Cementitious fly ash and 4) Cementitious & Pozzzolonic fly ash. On the basis of fly ash's chemical it has been categorized into 2 categories, as given 1) Class C fly ash and 2) Class F fly ash. The chemical composition of Class C and Class F fly ashes is shown in the table below:

"Table 1 Chemical requirement of class C and class F fly ashes" (data source: ASTM C618-94a)

Particulars		**Fly ash**	
		Class F	**Class C**
$SiO_2+Al_2O_3+Fe_2O_3$	% maximum	70.0	50.0
SO_2	% maximum	5.0	5.0
MC	% maximum	3.0	3.0
LOI	% maximum	6.0	6.0

3.2 BC Soil & Fly Ash Reaction

Even while fly ash has little cementitious value on its own, it interacts chemically and produces cementitious chemicals when it comes into touch with moisture and these compounds contribute enhancing compressibility properties of soil. Fly ash of class C and class F both are pozzolans ie containing siliceous and aluminous elements. Fly ash can so form a variety of cations Ca2+, Fe3+, Al3+ (divalent, trivalent and so on) etc. under ionised circumstances, which can promote flocculation of scattered particles of clay. Thus theoretically expansive soil can be effectively stabilised through cationic exchange with fly ash.

3.3 Geotechnical Characterization of fly ash

Fly ash was procured from the Local Thermal Power Plant in Wardha, Maharashtra, for the purposes of this study. It was screened using a 2 mm filter to remove organic materials and foreign substances. It is now possible to utilise the samples after they have been dried in the oven for around 24 hours. A series of tests were done to study the effect of fly ash as a stabilising agent in BC soils from 0% to 50% in the multiples of 10% by weight of the total quantity. During the execution of the following studies, the Indian Standard codes referred were IS 2720part7_1980 IS 2720part10_1991, IS 2720part16_1987 IS 2720part40_1977 and IS 2720part5_1985 for SPT, UCS, CBR, free swelling index and LL &PL respectively.

4. CHARACTERIZATION OF LOCAL BLACK COTTON SOIL

The clay mineral is the main component that reveals the swelling properties of any non expansive soil. From the various forms of clay minerals montmorillonite has the most swelling potential. Under alkaline conditions, primary clay minerals form in-situ or breakdown of blast rocks might be considered as the source of such soil expansive soil. Such soils can also occur as a result of weathering in alkaline environments with sufficient magnesium, ferric or ferrous oxides. Montmorillonite is more likely to form when there is a lot of alumina and silica available.

4.1 The expansive nature of the soil

Swelling of soil is basically divided into two types ie elastic rebound and elastoplastic rebound due to a reduction in compressive force in the compressed soil mass. The ingestion of water causes water-sensitive clays to expand. Clay minerals with a predominantly expanding lattice are present in swelling clays, which display the later form of swelling. One of the most distinguishing qualities of clayey soil is that it has little cohesiveness and it strength when it is moist, but hardens when dry. However, none of them swell as a result of soaking. At saturation, the ultimate bearing capacity decreases, resulting in substantial differential settling. As a result, clayey soils have foundation issues. If the soil moisture content is smaller than the equilibrium moisture content, the soil has a high swelling capacity. Swelling can occur as a result of high swelling pressure caused by upheaving of the soil or structure. Although other theories exist, the process of swelling remains unknown. There hasn't been any progress on the mechanism. One of the most widely accepted causes of soil swelling is soil that has a significant amount of clay or colloid, with Montmorillonite as the main mineral. The pressure exerted while expansion of expansive soil when comes in contact with water is called as Swell Pressure. Estimating pressure due to swelling will almost certainly become a critical issue when structure designed on such soils or constructing core part of a earthen dam or building embankment of road or construction of canals in such soils.

4.2 Swelling-related factors

The most influential component is the moulding water or the initial moisture content in the case of a re-moulded sample. According to Holts and Gibbs' observations, "the behaviour of re-moulded clays is similar to that of undisturbed clays." The initial water content of a sample and its water affinity as well as swelling pressure, will be critical component in calculating its water affinity and swell pressure for a given dry density. A clay's w_n (minimum moisture content) required for swelling to commence below a sub-grade which is pre-paved is calculated as follows:

if $_1$ is liquid limit then w_n (%) = $0.2w_1$ + g

The elements that influence a soil's swelling are mostly determined by the soil's environmental conditions. When a soil particle is near to the surface, swelling is greater; however, if the soil element is below the surface, swelling is insignificant due to overburden pressure neutralises the growth of swelling pressure of the dry soil. Factors commonly liable for it are thickness and shape of the sample, surface location of the soil sample, change in volume, nature of pore fluid, stress history, time & temperature etc.

4.3 Geotechnical Characterization of local black cotton soil

The expansive black cotton soil was obtained as part of this inquiry from the college site in Sawangi, Wardha, Maharashtra. Sacks were used to transport the black cotton dirt to the laboratory. To assess the natural moisture content of soil, a little sample was extracted then sieved through a sieve of size 4.75 mm then first weighed and before weighing again it was air dried. The following table shows geotechnical characteristics of the obtained soil:

Table 2 Geotechnical characteristics of BC soil

Sr. No.	Properties	Code referred	Value
1	Sp. Gravity	IS 2720 Part 3_1980	2.48
2	Moisture Content	IS 2720 Part 2_1973	7.30%
3	Liquid Limit	IS 2720 Part 5_1985	68%
4	Plastic Limit	IS 2720 Part 5_1985	37.18%
5	Shrinkage Limit	IS 2720 Part 6_1972	17.40%
6	Max. Dry Density (MDD)	IS 2720 Part 7_1980	1.51gm/cc
7	Opt. Moisture Content (OMC)	IS 2720 Part 7_1980	22.68%
8	Free Swell Index	IS 2720 Part 40_1977	102%

5. GEOTECHNICAL CHARACTERIZATION OF BC SOIL–FLY ASH MIX

To assess the effectiveness of fly ash as a stabilising agent in BC soils, various tests were carried out in which the amount of fly ash in the BC soil was adjusted from 10% till 50% (at 10% increment) by weight of the total quantity taken. During the execution of the following studies following IS codes were referred:

1. For LL & PL IS 2720 Part 5_1985
2. For SPT IS 2720 Part 7_1980
3. For UCS IS 2720 Part 10_1991
4. For FSI(free swell index) IS 2720 Part 40_1977

5.1 SPT-Standard Proctor Test

SPT for BC soil and FA mix was conducted as per IS code 2720 Part 7 for 0%, 10%, 20%, 30%, 40% and 50% incremental rise in percentage of FA in the mix.

Table 3 SPT for plain BC soil without fly ash ie 0% FA

Vol. of Mould (m^3)	Wt. of soil in mould(kg)	Moist unit wt. (g/cm^3)	Moisture content (%)	Dry unit wt. (g/cm^3)
$99.981*10^{-5}$	1.57	1.57	17.78	1.33
$99.981*10^{-5}$	1.75	1.75	19.55	1.46
$99. 981*10^{-5}$	1.88	1.88	23.90	**1.51**
$99. 981*10^{-5}$	1.88	1.88	24.88	1.51
$99. 981*10^{-5}$	1.83	1.83	27.93	1.43

Table 4 SPT for BC soil and 10% FA

Vol. of Mould (m^3)	**Wt. of soil in mould(kg)**	**Moist unit wt. (g/cm^3)**	**Moisture content (%)**	**Dry unit wt. (g/cm^3)**
99. 981*10^{-5}	1.61	1.61	15.2	1.40
99. 981*10^{-5}	1.78	1.78	19.11	1.49
99. 981*10^{-5}	1.85	1.85	22.15	**1.51**
99. 981*10^{-5}	1.81	1.81	27.97	1.42
99. 981*10^{-5}	1.78	1.78	32.72	1.34

Table 5 SPT for BC soil and 20% FA

Vol. of Mould (m^3)	**Wt. of soil in mould(kg)**	**Moist unit wt. (g/cm^3)**	**Moisture content (%)**	**Dry unit wt. (g/cm^3)**
99. 981*10^{-5}	1.65	1.65	19.63	1.38
99. 981*10^{-5}	1.75	1.75	20.98	1.44
99. 981*10^{-5}	1.89	1.89	22.59	**1.54**
99. 981*10^{-5}	1.9	1.9	25.24	1.51
99. 981*10^{-5}	1.85	1.85	29.16	1.43

Table 6 SPT for BC soil and 30% FA

Vol. of Mould (m^3)	**Wt. of soil in mould(kg)**	**Moist unit wt. (g/cm^3)**	**Moisture content (%)**	**Dry unit wt. (g/cm^3)**
99. 981*10^{-5}	1.66	1.66	15.14	1.44
99. 981*10^{-5}	1.78	1.78	18.98	1.49
99. 981*10^{-5}	1.88	1.88	21.29	**1.55**
99. 981*10^{-5}	1.89	1.89	24.73	1.52
99. 981*10^{-5}	1.84	1.84	28.15	1.47

Table 7 SPT for BC soil and 40% FA

Vol. of Mould (m^3)	**Wt. of soil in mould(kg)**	**Moist unit wt. (g/cm^3)**	**Moisture content (%)**	**Dry unit wt. (g/cm^3)**
99. 981*10^{-5}	1.61	1.61	16.24	1.39
99. 981*10^{-5}	1.73	1.73	18.54	1.46
99. 981*10^{-5}	1.84	1.84	23.59	**1.49**
99. 981*10^{-5}	1.86	1.86	26.44	1.47
99. 981*10^{-5}	1.82	1.82	31.83	1.38

Table 8 SPT for BC soil and 50% FA

Vol. of Mould (m^3)	**Wt. of soil in mould(kg)**	**Moist unit wt. (g/cm^3)**	**Moisture content (%)**	**Dry unit wt. (g/cm^3)**
99. 981*10^{-5}	1.56	1.56	14.14	1.37
99. 981*10^{-5}	1.64	1.64	17.26	1.40
99. 981*10^{-5}	1.76	1.76	21.37	**1.45**
99. 981*10^{-5}	1.81	1.81	25.79	1.44
99. 981*10^{-5}	1.79	1.79	31.23	1.36

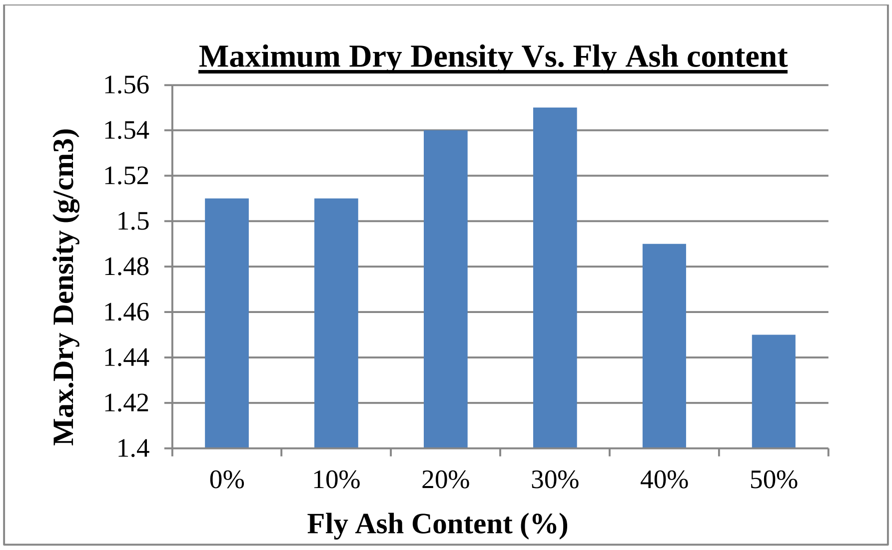

Figure 1 Relation between Maximum dry density and % of fly ash content in BC soil

5.2 Unconfined Compressive Strength (UCS) test for BC soil& FA mix

UCS test for black cotton soil and fly ash mix was conducted as per IS 2720 (Part 10) for 0%, 10%, 20%, 30%, 40%, 50% incremental rise in percentage of FA in the mix.

Table 9 Unconfined Compression Strength test for plain BC soil without FA ie 0% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0.00	11.34	0	0	0
2	10	0.1	0.13	11.35	7	1.51	0.133
3	25	0.25	0.33	11.38	9.5	1.62	0.142
4	50	0.5	0.5	11.41	13	1.8	0.158
5	100	1	1.2	11.49	37	5.3	0.461
6	150	1.5	1.8	11.56	68	9.9	0.856
7	200	2	2.5	11.64	102	14.5	1.246
8	250	2.5	3.2	11.72	112	15.9	1.357
9	300	3	3.8	11.80	132	18.7	1.585
10	350	3.5	4.5	11.88	150	21.5	1.810
11	400	4	5.2	11.96	160	22.5	1.881
12	450	4.5	5.8	12.05	165	23.6	1.959
13	500	5	6.5	12.13	169	24	1.979
14	550	5.5	7.2	12.22	170	24.2	1.980
15	600	6	7.8	12.31	170	24.2	1.966
16	650	6.5	8.5	12.40	170	24.1	1.944
17	700	7	9.1	12.49	170	24.1	1.930
18	750	7.5	9.7	12.58	168	23.9	1.900
19	800	8	10.4	12.67	167	23.8	1.878
20	850	8.5	11.2	12.76	167	23.5	1.842
	900	9	11.6	12.86	165	23.3	1.812
	950	9.5	12.2	12.95	163	23	1.776

Table 10 Unconfined Compression Strength test for mix of BC soil + 10% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0	11.34	0	0.00	0.00
2	50	0.5	0.6	11.41	10	1.40	0.12
3	100	1	1.3	11.49	24	3.40	0.30
4	150	1.5	1.9	11.56	49	6.90	0.60
5	200	2	2.6	11.64	67	9.50	0.82
6	250	2.5	3.3	11.72	90	12.80	1.09
7	300	3	3.9	11.80	101	14.40	1.22
8	350	3.5	4.6	11.88	119	16.90	1.42
9	400	4	5.3	11.97	126	17.90	1.50
10	450	4.5	5.9	12.05	137	19.50	1.62
11	500	5	6.6	12.13	144	20.50	1.69
12	550	5.5	7.2	12.22	146	20.80	1.70
13	600	6	7.9	12.31	169	24.10	1.96
14	650	6.5	8.5	12.40	168	23.90	1.93
15	700	7	9.2	12.49	168	23.90	1.91
16	750	7.5	9.8	12.58	167	23.80	1.89
17	800	8	10.5	12.67	165	23.5	1.85
18	850	8.5	11.2	12.76	165	23.5	1.84

Table 11 Unconfined Compression Strength test for mix of BC soil + 20% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0	11.34	0	0	0.00
2	50	0.5	0.6	11.41	6	0.8	0.07
3	100	1	1.3	11.49	24	3.4	0.30
4	150	1.5	1.9	11.56	48	6.8	0.59
5	200	2	2.6	11.64	71	10.1	0.87
6	250	2.5	3.3	11.72	93	13.2	1.13
7	300	3	3.9	11.80	107	15.2	1.29
8	350	3.5	4.6	11.88	128	18.2	1.53
9	400	4	5.3	11.97	141	20.1	1.68
10	450	4.5	5.9	12.05	147	20.9	1.73
11	500	5	6.6	12.13	150	21.3	1.76
12	550	5.5	7.2	12.22	151	21.5	1.76
13	600	6	7.9	12.31	151	21.5	1.75
14	650	6.5	8.5	12.40	150	21.3	1.72
15	700	7	9.2	12.49	149	21.2	1.70
16	750	7.5	9.8	12.58	148	21.1	1.68

Table 12 Unconfined Compression Strength test for mix of BC soil + 30% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0	11.34	0	0	0.00
2	50	0.5	0.6	11.41	11	1.5	0.13
3	100	1	1.3	11.49	35	4.9	0.43
4	150	1.5	1.9	11.56	71	10.1	0.87
5	200	2	2.6	11.64	98	13.9	1.19
6	250	2.5	3.3	11.72	109	15.5	1.32
7	300	3	3.9	11.80	132	18.8	1.59
8	350	3.5	4.6	11.88	153	21.8	1.83
9	400	4	5.3	11.97	164	23.3	1.95
10	450	4.5	5.9	12.05	170	24.2	2.01
11	500	5	6.6	12.13	173	24.6	2.03
12	550	5.5	7.2	12.22	177	25.2	2.06
13	600	6	7.9	12.31	177	25.2	2.05
14	650	6.5	8.5	12.40	178	25.3	2.04
15	700	7	9.2	12.49	176	25	2.00
16	750	7.5	9.8	12.58	175	24.9	1.98
17	800	8	10.5	12.67	175	24.9	1.97
18	850	8.5	11.2	12.76	174	24.8	1.94
19	900	9	11.8	12.86	173	24.6	1.91

Table 13 Unconfined Compression Strength test for mix of BC soil + 40% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0	11.34	0	0	0.00
2	50	0.5	0.6	11.41	8	1.1	0.10
3	100	1	1.3	11.49	21	3	0.26
4	150	1.5	1.9	11.56	46	6.5	0.56
5	200	2	2.6	11.64	71	10.1	0.87
6	250	2.5	3.3	11.72	92	13.1	1.12
7	300	3	3.9	11.80	114	16.2	1.37
8	350	3.5	4.6	11.88	132	18.8	1.58
9	400	4	5.3	11.97	140	19.9	1.66
10	450	4.5	5.9	12.05	144	20.5	1.70
11	500	5	6.6	12.13	145	20.6	1.70
12	550	5.5	7.2	12.22	145	20.6	1.69
13	600	6	7.9	12.31	145	20.6	1.67
14	650	6.5	8.5	12.40	144	20.5	1.65
15	700	7	9.2	12.49	143	20.3	1.63

Table 14 Unconfined Compression Strength test for mix of BC soil + 50% FA

Sr. No.	DG reading	Deformation (mm)	Strain (%)	Co. Area (cm^2)	LDGR reading	Load (kg)	Comp. Strength (kg/cm^2)
1	0	0	0	11.34	0	0	0.00
2	50	0.5	0.6	11.41	12	1.7	0.15
3	100	1	1.3	11.49	36	5.1	0.44
4	150	1.5	1.9	11.56	69	9.8	0.85
5	200	2	2.6	11.64	92	13.11	1.13
6	250	2.5	3.3	11.72	104	14.8	1.26
7	300	3	3.9	11.80	124	17.6	1.49
8	350	3.5	4.6	11.88	130	18.5	1.56
9	400	4	5.2	11.97	139	19.8	1.65
10	450	4.5	5.9	12.05	141	20.1	1.67
11	500	5	6.5	12.13	142	20.2	1.66
12	550	5.5	7.2	12.22	142	20.2	1.65
13	600	6	7.9	12.31	140	19.9	1.62
14	650	6.5	8.5	12.40	140	19.9	1.61
15	700	7	9.2	12.49	139	19.8	1.59
16	750	7.5	9.8	12.58	138	19.6	1.56

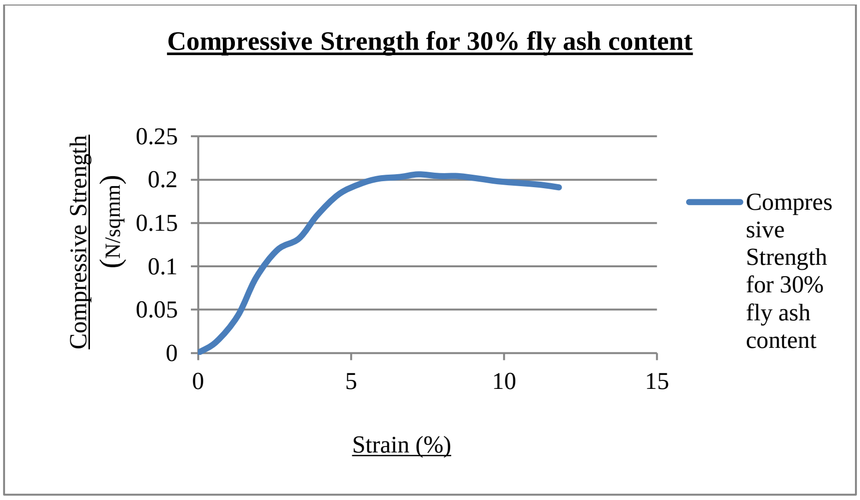

Figure 2 UCS test readings in BC soil with 30% fly ash

5.2 Free swell ratio and plasticity index of BC soil and FA mixture

Plasticity Index test and free swell index test conducted as per IS 2720 (Part 5) and (Part 40) respectively.

Table 15 Free swell ratio and plasticity index variation with fly ash content in BC soil

Mixture	Liquid limit	Plastic limit	Plasticity index	Free swell ratio
Only soil	65.44	34.90	30.54	2.10
Soil + 10% fly ash	62.12	33.62	28.50	1.90
Soil + 20% fly ash	58.28	32.21	26.07	1.78
Soil + 30% fly ash	56.51	31.42	25.09	1.70
Soil + 40% fly ash	51.24	27.86	23.38	1.63
Soil + 50% fly ash	49.11	25.90	23.21	1.52

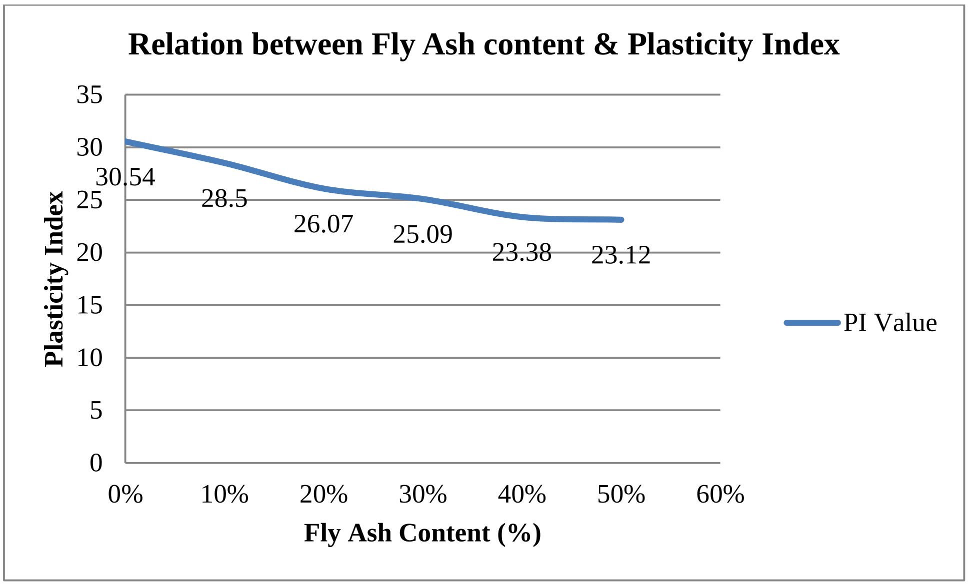

Figure 3 Plasticity index variation with fly ash content in BC soil

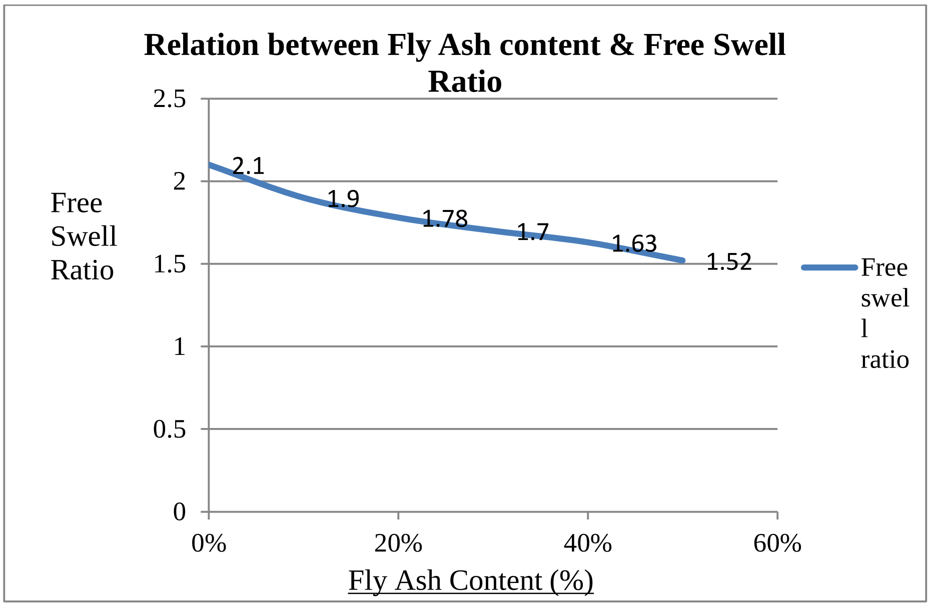

Figure 4 Free swell ratio variation with fly ash content in BC soil

6. Result and Discussions

BC soil is mixed with fly ash at 10% incremental increase and it is done upto 50% by weight to study its consequence on the BC soil. It was found that highest value of MDD was observed at 30% addition of fly ash by weight. We also found that the UCS was maximum when 30% of fly ash by weight was added in the BC soil. The plasticity index and free swell ratio values were also computed which continuously decreases with the increase of fly ash content.

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