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Studies on the Enhancement of Soil Stabilization Using Electro-Kinetic Process

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Abstract— To study the effect of Geo-synthetics material for varying orientation and number of layers in the dewatering process of soft clay subjected to electric field, for varying Initial Moisture Content, spacing of electrode and voltage across the terminals. Using electro kinetic cell experiments were conducted by varying voltage of 40 and 60 V, IMC of 65% and 75% and electrode spacing of 20 to 40 cm. It is concluded that the number of Geotextiles increases, the time taken to attain steady state considerably decreases. Regarding the orientation, for vertical orientation is only marginal increase in rate of dewatering but for horizontal orientation the enhancement in dewatering rate is appreciable.In another attempt is made to enhance the soil-lime stabilization by Electro-kinetic process, with and without electrical field it is found that thepH variation is negligible initially and appreciable variations were seen at 24hrs and 48hrs when voltage is not applied. When voltage is applied the pH increases in cathodic region and decrease in anodic region and also dewatering take place from anode to cathod. Hence the strength increases due to calcium accumulation and dewatering process. The same influence is observed for increasing spacing (20cm and 30cm) and voltage (20V and 40V).Thus it may be summarized that Electro- Kinetic process of dewatering for horizontally placed geotextiles are effective and also soil-chemical reaction can be substantially enhanced using the same

Index Terms—Electro Kinetic, Geotextile, Dewatering, Lime Stabilization, Shear Strength, Problematic Soils, pH Variation, Fly ash

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1 INTRODUCTION

In today's scenario due to increasing awareness of new technologies, the field of geotechnical engineering has achieved many milestones with brilliant ideas and advancements. The ground improvement is one of the disciplines which have attained lots of interest and improvements. The performance and stability of structure depends on the properties of surrounding soil mass. Construction without soil improvement is usually impractical due to anticipated long-term settlement, low shear strength and high compressibility. So, to ensure the safety of structures, several ground improvement techniques are adopted. Selection of a method for improving the soil must of course is made with the thorough knowledge of the subsurface. It should also take into account the type of structure being planned, its tolerance to settlements, the time schedule, availability of equipment and materials, magnitude and cost etc.

NasimMosavat et al (2012) made an attempt to improve the engineering characteristics of low permeable problematic soils by using electro kinetic treatment technique. They concluded that the electro kinetic (ek) soil treatment induces several changes in the pore fluid chemistry, diffuse double layer (DDL), soil fabric and the hydraulic conductivity.

Stalin et al (2011) made an attempt to study the influence of initial moisture content (IMC), voltage and spacing of electrodes on the effectiveness of electro-osmotic stabilization of soft clays. Using electro-kinetic cell, experiments were conducted for a varying voltage, IMC and electrode spacing. It was found that as the IMC and voltage increase the volume of water collected at cathode also increases at any time interval. Increase of voltage not only enhanced the process of dewatering but very much also the propagation of cracks especially at lower IMC. Decrease of the spacing of electrodes reduces the dewatering process and also early attainment of strength. The flow of current was uniform at higher IMC irrespective of voltage and spacing.

2 EXPERIMENTAL PROGRAM

2.1 Natural Soil

The soil sample was collected from Kishkinta, Chennai. The soil was made to dry at room temperature and soil lumps were powdered and sieved through 425 micron sieve before the same is used for laboratory tests. The soil has 78% clay and 17% silt. The Liquid and plastic limits are 70% and 34% respectively and the soil is classified as 'CH' type.

2.2 Geo Textiles

The Geotextile adopted is a non-woven type. Non-woven geotextiles are made from high resistance staple fiber polypropylene with needle punching. They have high chemical resistance & do not absorb water. Needle punched non-woven geotextiles have far superior flow rates with less tendency to clog than heat bonded non-woven geotextiles & therefore are ideal for drainage, stabilization, and separation and erosion control. The hydraulic properties of Geotextile are shown in Table 2.1

2.3 Electro Kinetic Cell

To Study the electro kinetic phenomena in soils, an electro kinetic cell was designed and fabricated.

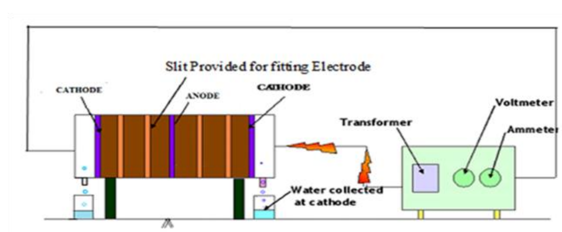

Fig 1. Schematic representation of Electro Kinetic Cell

The cell includes the components like rectangular box open at top, electrodes, voltmeter, ammeter, AC to DC transformer and multimeter. Fig 3.1 shows the schematic representation of the fabricated cell. The dimensions of box are 500 x 150 x 150 mm which made up of acrylic material with one-sided open. The soil sample of varying initial moisture content will be placed in the tube up to a height of 10cm by hand remolding. At the cathode end, provision is given at bottom of box to collect the drained water during the process of passage of current across the soil sample. The voltmeter is provided to measure the voltage applied. The voltage can be varied as 40 and 60V required. For the reason of accuracy, both digital as well as analog voltmeters were used in the study. The ammeter is used to measure the amount of current passing through the soil sample. The ammeter is capable of measuring current from 1A to 10A. For the reason of accuracy, both digital as well as analog ammeters were used in the

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study. The selection of electrodes is made such that it is simple, strong as well and inexpensive. This is because some electrode material may act as a very good conductor of electricity, for instance, graphite even through is non-corrosive but is very brittle and some other material like stainless steel may be efficient but costly. Hence, the cathodic electrode is made up of copper with perforations to facilitate removal of water and the anodic electrode is made up of zinc. The transformer converts the incoming AC current to DC current. The transformer, voltmeter and ammeter are fitted together in a small box so that the apparatus is compact.

3 Results and Discussions

3.1 Studies on the Enhancement of Dewatering in Electro Kinetic Cell

The Standard proctor tests were conducted on the class 'F' Fly ash with 0, 5,10,15,20,25,30,35 and 50 percentage addition of class C fly ashes. The maximum dry density and optimum moisture content of Class 'F' fly ash alone are 11.25 kN/m3 and 29.5% for class 'C' fly ash.

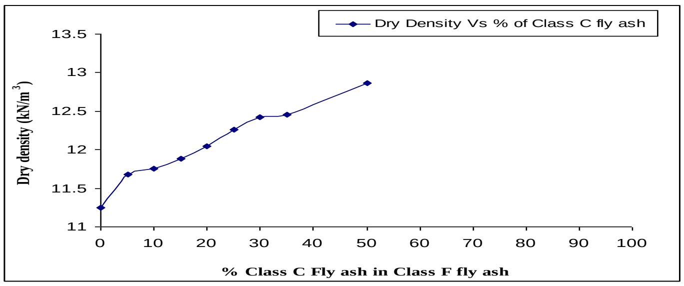

Fig 2(a) Maximum Dry Density Vs Percentage of Class 'C' in fly ash

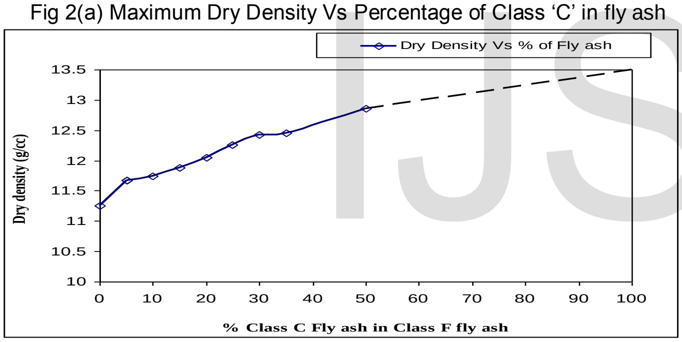

Fig 2(b) Maximum Dry Density Vs Percentage of 'F' fly ash

Table 2 Variation of Maximum Dry Density of Class 'F' Fly Ash and Class 'C' Fly Ash Mixes

Class 'C' + Class 'F' Fly ash	Maximum Dry Density (kN/m3)	Optimum Moisture Content (%)
Class 'C' Fly ash alone	13.50	-
Class 'F' Fly ash alone	11.25	-
F 95% + C5%	11.68	28.28
F90% + C10%	11.75	29.16
F85% + C15%	11.88	29.03
F80% + C20%	12.05	27.98
F75% + C25%	12.26	28.51
F70% + C30%	12.52	27.80
F65% + C35%	12.46	28.04
F50% + C50%	12.62	27.80

As seen from table 2, the γd (max) values of fly ash 'F' increased from 11.25 kN/m3 to a maximum value of 12.62 kN/ m3 corresponding to F 50% + C 50%. It is expected that the γd (max) values of class 'F' fly ash would further increase with the percentage of class 'C' fly ash as shown in Fig. (1a &1b) because, the γd (max) of 'C' fly ash alone is 13.5 kN/ m3 and whereas for 'F' fly ash the same is 11.25 kN/m^3. The OMC values of fly ash mixes are ranging from 27.8% to 29.16%.compared to F 95%+C5% to F50% to C50% optimum moisture content value is increased 28.28% to decreased 27.80%.Sridharan and Prakash (2007) showed that γd (max) of Indian fly ashes are ranging between 8.9 kN/m^3 to 13.8 kN/m^3. Corresponding to specific gravity values of 1.66 to 2.55. The specific gravity of class 'F' and class 'C' fly ash are 1.92 and 2.57 respectively. It is obvious that when more amounts of higher specific gravity particles of class 'C' fly ash is replaced by class 'F' fly ash particle, the γd (max) values keep increasing. Unlike variation of γd (max) of the fly ash mix, there is no proper trend noticed in the changes of OMC of class 'F' + class 'C' fly ash mixes. Interestingly, the OMC of the mixes at any percentage between 0 to 50% of class 'C' are well below the OMC of either of the fly ash constituents (Fig 3(a) & 3(b)).

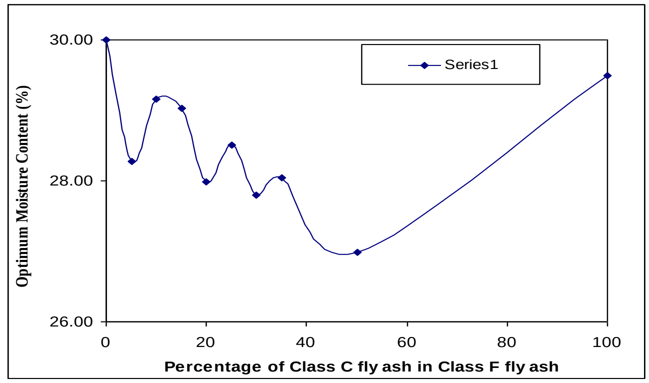

Fig 3(a) Optimum Moisture content Vs Percentage of Class 'C' in Fly ash

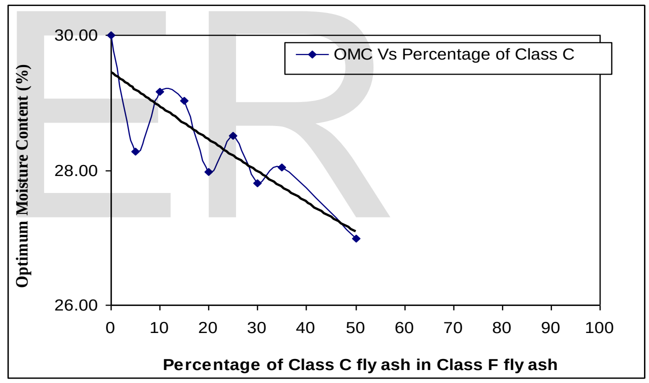

Fig 3(b) Optimum Moisture content Vs Percentage of Class 'F' in fly ash

It is indicating that the fly ash mixture behavior is better than the individual constituents. However, if the OMC of 100% fly ash 'C' is not considered, then a general decreasing trend is noticed as in Fig 4.3b. Sridhar an and Prakash (2007) stated that the OMC of Indian fly ashes are ranging between 17.9 to 62.3% irrespective of whether class 'C' or class 'F' fly ashes.

3.2 Unconfined Compressive Strength Test

It is not preferable for soil with dominant silt and sand sized particles; because the UCC specimen may not be stable enough even to test due to lack of cohesion component. The UCC test of both class 'F' and class 'C' fly ash could not be carried out without curing condition because of its unstable nature. However,both class 'C' and class 'F' fly ash were stable with minimum of one day curing and hence UCC strength values are reported for class 'F' with one day curing and class 'F' with one day and 7 day curing. While one day cured class 'F' fly ash alone showed ultimate failure and strength of 38.68 kPa, for the same period class 'C' resulted in ultimate strength of 5869.32 kPa which is 150 times higher than the later. Table (3) shows the variation of UCC Strength of class 'F' with class 'C' fly ash mixes at different percentage of 5,10,15,20,25,30,35 and 50%. These differences in the strength of class 'F' and class 'C' fly ash are mainly due to higher amount of pozzolanic content (CaO > 10%) present in class 'C' fly ash and for class 'F' fly ash because of its poor cementing components (CaO <5%). For class 'C' fly ash alone, the 7 days cured sample yielded strength of 6668.86 kPa which is only 14% higher than the one day cured sample. Gray and Lin (1972) has showed that the UCC strength variation between 300 to 400 kPa for British fly ashes corresponding to one day curing

TABLE 3 VARIATION OF UCC STRENGTH OF CLASS 'F' + CLASS 'C' FLY ASH MIXES FOR DIFFERENT CURING PERIODS

Type of Fly ash		UCC strength, kPa				
		Curing Period in days				
Class F	Class C	1	3	7	14	28
100	0	38.68	--	--	--	--
95	5	230.23	238.87	238.27	241.76	261.33
90	10	601.9	631.40	664.15	687.40	707.00
85	15	690.4	759.61	788.24	780.24	811.74
80	20	833.7	1030.75	1061.49	1158.15	1486.74
75	25	1566.7	1263.36	1559.05	2053.10	1718.99
70	30	2100.7	2296.48	2397.63	2489.26	2616.29
65	35	2125.52	2360.55	2548.70	2631.80	2808.50
50	50	3908.57	4071.53	4619.41	4708.11	4850.77
0	100	5839.32	--	6668.56	--	--

From table 3, The UCC strength increases slowly with curing period with maximum increase of 13.5 % corresponding to 28 days curing and hardly 3.70% was the enhanced strength value for 3 day and 7 day curing. Compared to class F 95+ C 5% mix combinations, the enhancement of UCC strength corresponding to F50% C50% fly ash is varying between 15.9 times to the maximum of 19.38 times higher .In the case of F90%+C10% fly ash the strength increased from 601.93 kPa to 707 kPa, with a percentage increase of 17.45%. For F85%+C15% fly ash combination also the percentage increases to a maximum of 17.5% with respect to 28 days of curing. However, corresponding to F80%+C20% the gain of strength is 78.32% with respect to 28 days curing that is from one day curing strength value of 833.75 it has gone to 1486.74 kPa. However for 25, 30, 35 and 50 % of 'C' fly ash in class 'F' fly ash, the percentage increase is ranging between 9.70 % to the maximum of 32.13.

3.3 MODULUS OF ELASTICITY

From table 4 shows the variation of modulus of elasticity of class F with class C mixes for different curing period with different percentages. From test result it was observed that the modulus of elasticity increase from 14.2 to 21.36 kPa with respect to curing periods. Curing period increases modulus of elasticity is decreases corresponding to the mixer combinations.

TABLE 4 CBR TEST RESULTS FOR THE CLASS 'F' FLY ASH, CLASS 'C' FLY ASH AND THE VARIOUS COMBINATIONS OF CLASS 'C' IN CLASS 'F' FLY ASH (MODULUS OF ELASTICITY CURING PERIOD IN DAYS)

Type of Fly ash		Modulus of Elasticity (10^3 kPa)				
		Curing Period in days				
Class F	Class C	1	3	7	14	28
95	5	21.36	19	16.6	13.1	14.2
90	10	18.5	20.31	-	-	39.56
85	15	43.75	41.57	46.76	44.4	42.63
80	20	25.75	61.11	63.15	64.76	82.5
75	25	94.44	62.5	77.319	110	96.21
70	30	110	88.89	92.85	108	98.3
65	35	122.2	96.15	120.8	105	104.3
50	50	192.3	213	190.3	235.714	178.57

3.4 CBR TEST

Design of flexible pavement is carried out commonly by CBR values of sub grade even though there are other empirical, semi-empirical and theoretical methods available (Justo & Khanna, 2001). The CBR tests were conducted on class 'F' fly ash with varying percentage of class 'C' fly ash both in soaked and unsoaked condition where in the samples were prepared corresponding to maximum dry density and OMC of the respective mixes. The CBR values were calculated corresponding 2.5 mm and 5 mm penetration and the same is reported in table 5.

TABLE 5 CBR TEST RESULTS FOR THE CLASS 'F' FLY ASH, CLASS 'C' FLY ASH AND THE VARIOUS COMBINATIONS OF CLASS 'C' IN CLASS 'F' FLY ASH(BOTH SOAKED AND UN SOAKED CONDITION)

Fly ash mixes	Un soaked CBR (%)		Soaked CBR (%)	
	2.5 mm	5 mm	2.5 mm	5 mm
Class 'F' fly ash	0.44	0.61	0.23	0.29
Class 'C' fly ash	1.45	1.90	Hardened	
C5% + F95%	0.84	1.12	0.60	0.80
C10% + F90%	0.36	0.42	0.74	0.97
C15% + F85%	1.52	2.49	3.70	4.43
C20% + F80%	1.56	2.04	3.85	4.87
C25% + F75%	1.67	2.73	4.15	4.22
C35% + F 65%	2.67	3.22	Hardened	

Unsoaked CBR values of fly ash alone and fly ash mixes are seen from table 5. The unsoaked CBR of class 'F' and class 'C' fly ash alone are 0.44% and 1.45%, for 2.5 mm penetration and 0.61% and 1.90% for 5 mm penetration respectively without any curing periods. The CBR value of fly ash 'F' increased from 0.44% to 2.67 % for F65%+C35% combination at 2.5 mm penetration. There is an approximate 5 times increaseof CBR value is noticed for F65%+C35 % fly ash mix for 5mm penetration compared to fly ash 'F' alone. That is the CBR value increased from 0.6% to 3.22%. These variations only imply that clay 'F' is becoming a suitable material as sub-base/subgrade on addition of fly ash 'C'. The unsoaked CBR results are for only immediate effect and it is expected that curing period would lead to further enhancement of CBR strength. Similarly the soaked CBR also increases with percentage of 'C' fly ash in fly ash 'F' but the increasing trend is on a higher side. From a soaked CBR value of 0.29 % (for fly ash alone), it has raised to 4.22% at F65% and C35% combination of mix, which is 14.5 times higher when compared to fly ash 'F' alone. The soaked CBR test could not be conducted for F65+C35% mix, because by the time when test was conducted after soaking period 3 days, the sample became very hard. It is known that the wet curing generally enhances the pozzolanic reaction because of which the fly ash specimen became so hard. (Sridharan and Prakash, 2007).

4. CONCLUSIONS

In order to improve the class 'F' fly ash by another type of class 'C' fly ash, experiments such as compaction, UCC strength and SEM analysis were conducted on varying percentage of class 'C' fly ash in 'F' fly ash and from the analysis of test results, the following conclusions may be drawn.

1. While the maximum dry density keeps constantly increasing with percentage of fly ash 'C' in fly ash 'F', the optimum moisture content variation did not show trend. The enhanced γd max of class 'F' on the addition of class 'C' fly ash is mainly due to the better packing of coarse sized 'F' fly ash with finer 'C' fly ash in addition to the pozzolanic reaction and replacement of high specific gravity class 'C' fly ash. (G of 'F' fly ash = 1.92 and 'G' of 'C' fly ash = 2.57)
2. The UCC strength of class 'F' fly ash increases with 'C' fly ash content to many folds that is 15 to 19 times higher than that of class 'F' fly ash alone. For instance, while F 95% + C 95% fly ash mix has ultimate failure strength of 300 kPa, the same is 3500 kPa for F 50% + C 50% fly ash mixtures. On the other side, the UCC strength increases moderately with curing periods at any percentage combination of class 'F' on class 'C' fly ashes. More than the curing period, it is % of class 'C' in class 'F' seemed to dominate on the strength variations. This is attributed to the fact that more the availability of pozzolanic

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material ‘CaO’ content in class ‘F’ with increasing percentage class ‘C’ fly ash. (The ‘CaO’ content of class ‘F’ fly ash is hardly less than 5% and whereas for class ‘C’ fly ash CaO component is > 15%).

Thus it can be concluded that solid waste fly ash ‘C’ itself can be used to stabilize fly ash ‘F’ instead of using some other stabilizers, which paves the way for large scale solid waste fly ash utilization for various geotechnical engineering applications.

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