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Stabilization of local expansive soil with fly ash and cement

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Abstract— ***Infrastructure projects such as highways, railways, water reservoirs, reclamation etc. requires earth material in very large quantity. In urban areas, borrow earth is not easily available which has to be hauled from a long distance. Quite often, large areas are covered with highly plastic and expansive soil, which is not suitable for such purpose of such expansive soil after stabilization with additives such as sand, silt, lime, fly ash and cement etc. we can improve the properties of soil. As fly ash is freely available, for projects in the vicinity of a Thermal Power Plants, it can be used for stabilization of expansive soils for various uses. The properties of expansive soil with fly ash in varying percentages can be used. The laboratory tests will be carried out and one of the major difficulties in field application will be solved by thorough mixing of the two materials (expansive soil, fly ash and cement) in required proportion to form a homogeneous mass.***

I. INTRODUCTION

Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil. Mechanical stabilization. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required or a borrow area. The blended material is then spread and compacted to required densities by conventional means. Additive stabilization. Additive stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. The selection of type and determination of the percentage of additive to be used is dependent upon the soil classification and the degree of improvement in soil quality desired. Generally, smaller amounts of additives are required when it is simply desired to modify soil properties such as gradation, workability, and plasticity. When it is desired to improve the strength and durability significantly, larger quantities of additive are used. After the additive has been mixed with the soil, spreading and compaction are achieved by conventional means.

A. BLACK COTTON SOIL

Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are characterized by high shrinkage and swelling properties. This Black cotton soils occurs mostly in the central and western parts and covers approximately 20% of the total area of India. Because of its high swelling and shrinkage characteristics, the Black cotton soils (BC soils) has been a challenge to the highway engineers. The Black cotton soil is very hard when dry, but loses its strength completely when in wet condition. It is observed that on drying, the black cotton soil develops cracks of varying depth. As a result of wetting and drying process, vertical movement takes place in the soil mass. All these movements lead to failure of pavement, in the form of settlement, heavy depression, cracking and unevenness. This article covers highway construction in Black cotton soils (BC soils) and also describes a case history of highway construction in Black cotton soils.

B. FLY ASH: AN OVERVIEW

Fly ash or precipitator ash or pulverized fuel ash, an artificial pozzolana is the residue from combustion of pulverised coal, collected by mechanical or electrostatic separators from the fuel gases of power plants, where powdered coal is used as a fuel. Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. Fly ash is classify into two category, Class F fly ash and Class C Fly ash. The main difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolinic in nature, and contains less than 20% lime (CaO). And Class C fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, will harden and gain strength over time. Generally it contains more than 20% lime (CaO).

Nowadays fly ash is fully utilised in the field of embankment, pavement construction, production of pozzolonic cement, reclamation of low lying areas , filling of abandoned mines, road sub base, manufacture of bricks, aggregate for light weight concrete, hollow block, cellular concrete and admixture of cement. Large scale utilisation of fly ash in construction industry as a replacement to the conventional materials will solve two problems i.e. elimination of solid waste problem and provision of needed construction material.

Indian scenario: About 120 coals based thermal power stations in India are producing about 112 million tonne fly ash per year. With the increasing demand of power and coal being the major source of energy, more and more thermal power stations are expected to be commissioned/ augment their capacities in near future.

Indian coal has high ash content (35%-45%) and low calorific value (3500 kcal/kg – 4000 kcal/kg) as a result of which huge quantity of fly ash is generated. Out of total power generated of India, about 70% is produced by thermal

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power plants (TPPs). The Majority of thermal power plants 84% are run by coal; rest on gas (13%) and oil (3%). Thermal power plants uses 260 million tonnes (MT) of coal which is about 65% of annual coal produced in India. The quality of fly ash which depends on coal, coal particle fineness, percentage of ash in coal, combustion technique used, air/fuel ratio, burners used, and type of boiler. The fly ash generation and utilization in various countries (Alam et al. 2011) and in India (Chatterjee 2010) are given in Table 1.1 and Table 1.2 respectively.

Fly ash generation and utilization in different countries Report FAUP (2004-05)

Sr. No	Country	Annual ash production, MT	Ash utilization %
1	India	112	38
2	China	100	45
3	USA	75	65
4	Germany	40	85
5	UK	15	50
6	Australia	10	85
7	Canada	6	75
8	France	3	85
9	Denmark	2	100
10	Italy	2	100
11	Netherland	2	100

Fly Ash Generation and Utilization in India (Report-CPCB2007)

Year	Generation MT	Utilization MT	Utilization (%)
1993-94	40.0	1.2	3.0
2004-05	112.0	42.0	38.0
2006-07	130.0	60.0	46.0
2011-12	170.0	170.0	100% utilization mandated
2031-32	600.0	----	Not yet planned

C.CEMENT:

STABILIZATION WITH PORTLAND CEMENT:

Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass with increased strength and durability. The amount of cement used will depend upon whether the soil is to be modified or stabilized. Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450 °C in a kiln, in a process known as calcination, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC).Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

CHEMICAL COMPOSITION OF PORTLAND CEMENT

Typical chemical composition of ordinary Portland cement (Ref.Dirk India Ltd)

SR.NO.	COMPOUND	COMOPOSITION AS %
1	C_3S	48-52 %
2	C_2S	22-26 %
3	C_3A	6-10 %
4	C_4AF	13-16 %
5	Free-lime	1-2 %

II. EXPERIMENTAL WORK

A. Specific Gravity

The specific gravity of the various materials were determined according to IS: 2720(part-III, section -1) 1980. The specific gravity of the Black cotton soil and fly ash were found to be 2.00, and 2.10 respectively.

B. Grain Size Distribution Curve

To determine the actual grain size distribution for black cotton soil dry sieve analysis was carried out. Wet sieve analysis was carried out to determine the actual grain size distribution of Fly ash as per IS: 2720(part-IV). Fly ash was passed through standard set of IS test sieves and percentage by weight retained on each sieve was found out after 24 hours of oven drying.

The results indicate that the Co-efficient of uniformity (Cu) and co-efficient of curvature (Cc) obtained from the gradation curve of black soil are 10.5 and 3.42 respectively indicating it as a nearly the uniformly graded material.

The results indicate that fly ash contains 90% of material finer than 75 micron. Thus we can say that fly ash is fine grained material. Co-efficient of uniformity (Cu) and co-efficient of curvature (Cc) obtained from the gradation curve of FA are 10 and 6.4 respectively indicating it as well graded material.

Table. Grain Size Analysis for materials :

Sieve Analysis	Black Cotton Soil
Coefficient of uniformity (Cu)	10.5
Coefficient of curvature (Cc)	3.42

C. Atterberg Limit

Atterberg limit tests were carried out as per IS: 2720 (part-V) 1985. Black Cotton Soil was found to be plastic in nature. But Fly Ash was found to be non plastic in nature. The plasticity index (%) of black cotton soil was 39.7.%.

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This property is beneficial for use in sub base layer of road pavements and the category of black cotton soil is MH or OH.

D. Free Swell Index

Phenomenon of swelling was not observed in Fly ash. The free swell index of Black cotton soil material was found to be 52%. The degree of expansiveness of black cotton soil is very high.

E. Compaction Characteristics

Modified Proctor test (heavy compaction) was conducted by varying the proportions of water for each of the mixes. The compaction curves showing change in dry density of mix with moisture content obtained from the test are plotted in figure 4.2. Optimum moisture content (OMC) and Maximum dry density (MDD) were determined as per IS: 2720 (part VIII) 1983.

The optimum moisture content is observed to be increase with addition of Fly ash. Whereas dry density is found to be highest with the addition of 10% Fly ash. The size of particles of black cotton soil is higher as compared to that of Fly ash. With increase in Fly ash content, the fineness or specific surface area increases which increases the water holding capacity thus, resulting in increase in OMC. Fly ash particles fill the voids between the black cotton soil particles resulting in a densely compacted mix, thus giving higher MDD as compared to that of 100% black cotton soil mix. For fly ash content more than 10%, the mix remains dense but as the specific gravity of fly ash is very less as compared to that of black cotton soil, the MDD of the mix decreases beyond 10% fly ash content.

From the compaction tests done on the various mixes the following values were obtained for OMC and MDD which are given below in Table 4.

Table. Values of OMC and MDD for various Mixes

Type of Mix	OMC (%)	MDD (kN/m^3)
100 BC	17.10	14.7
90BC+10FA+1C	17.40	14.81
80BC+20FA+2C	17.85	14.85
70BC+30FA+3C	18.05	14.92
60BC+40FA+4C	18.15	14.98
50BC+50FA+5C	18.30	15.2
100FA	19.23	14.40

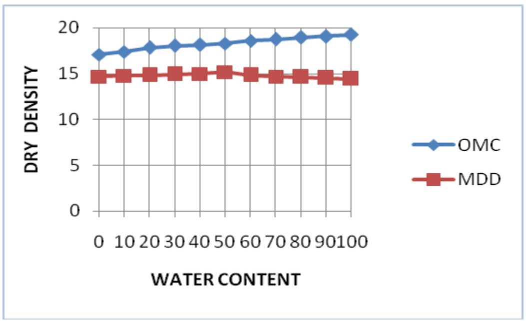

Fig. Variation of OMC and MDD with Fly ash & Cement

F. Unconfined Compressive Strength Test Results

For determination of compressive strength of various mixes total 99 samples were tested to determine the effect of fly ash content and also the effect of curing period. The samples were first cured in humidity chamber at 30 degree temperature and 85% relative humidity for a period of 0, 7, 28 days. The raw materials used are black cotton soil and fly ash.

The unconfined compression strength of average of 3 samples of all the mixes are given in Table.

The compressive strength of these cured samples were then determined using a compression testing machine at strain rate of 0.6mm/ min.

Table. Unconfined Compression Strength

Curing Period (days)	Soaked CBR values (%)						
	100 FA	50 FA + 5BC+ 5C	40 FA + 60BC +4C	30 FA + 70BC +3C	20 FA + 80BC+ 2C	10 FA + 90BC+ 1C	100 BC
0	12	4.5	4.2	3.8	3.6	3.6	3.0
7	18	7.2	5.64	5.70	4.90	4.10	3.0
14	22	11	9.77	8.10	8.0	6.30	3.0

Effect of Fly ash content on strength

Fig 1to fig 2 shows graphs of variation of UCS value with fly ash content for 0, 7, 28 days curing period. From fig 1 .for 0 days curing period the samples were prepared and tested immediately. As they were in a more compacted form the mix showed higher UCS values compared to other fly ash content. More ever, no pozzolonic reaction took place as it requires sometime for the reaction.

From fig 1 it can be observed that with the increase in curing period from 0 day to 7, 28 days the UCS value of the mix 90 FA+ 10 BC +1C was more as compared to other mixes. This is because of curing period there was enough time for pozzolonic reactions to take place. Hence binding of material resulted in more UCS values

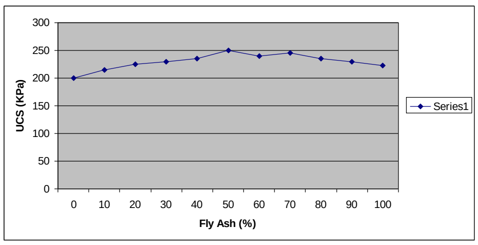

Fig 1. Unconfined Compression Strength for 0 days curing period

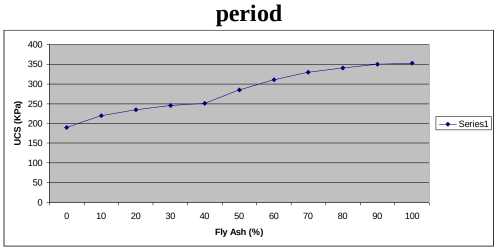

Fig 2. Unconfined Compression Strength for 7 days curing period

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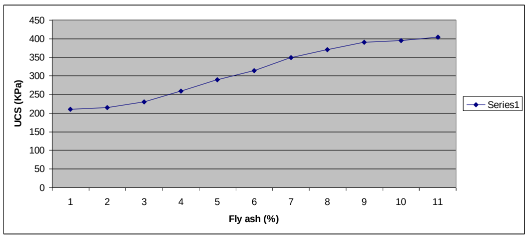

Fig 3. Unconfined Compression Strength for 28 days curing period

G. California Bearing Ratio Test

Test was carried out to find the effect of addition of fly ash & cement in black cotton soil. Samples were prepared for two optimum mixes i.e. 40FA+60BC+4C and 50FA+50BC+5C. The samples were first cured in humidity chamber at 30 degree temperature and 85% relative humidity for a period of 0, 7, 14 days and then soaked in water for 4 days prior to testing.

Variation of CBR values with Curing Period

It was found out that the CBR values of both the mixes increased with the increase in curing period. From the load penetration curves after applying the corrections the CBR value of black cotton soil was found to be 3. The tests were then conducted on the two optimum mixes i.e. 40F+60B+4C and 50F+50B+5C. The samples were first cured in humidity chamber at 30 degree temperature and 85% relative humidity for a period of 0, 7, 14, days and then soaked in water for 4 days prior to testing. The CBR values of the mixes at different curing period are given in Table.

Table . CBR values of the various mixes

Fly Ash %	0 DAYS (kPa)	7 DAYS (kPa)	28 DAYS (kPa)
0	200	190	210
10	215	220	215
20	225	235	230
30	230	245	260
40	235	251	290
50	250	285	315
100	223	353	405

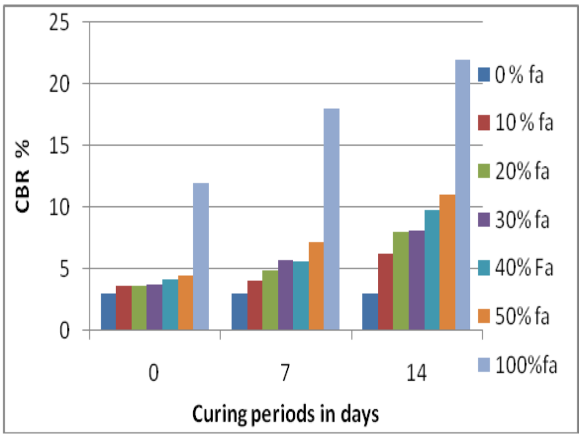

Fig. Variation of CBR values with Curing Period

III. CONCLUSION

The following are the conclusions from the laboratory tests done:-

- Black cotton soil is a blackish material having specific gravity of 2.45 and fly ash having specific gravity 2.1.
- Fly ash was found to be non plastic in nature and black cotton soil is highly plastic having PI 39.7 and belongs to MH or OH category.
- It is observed that in the black cotton soil and fly ash mix, with the increase in fly ash content there is an increase in MDD with the corresponding decrease in OMC.
- It is observed that the Unconfined Compression Strength value for the black cotton soil- fly ash mix after 7 and 28 days of curing increases with increase in fly ash content.
- The CBR value of black cotton soil is 3. The CBR values for the mixes increased with the increase in curing period.
- The CBR value increases with fly ash content hence by using fly ash content it improves geotechnical properties of black cotton soil which will be helpful for civil engineering projects.

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