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Construction of a Road in the Black Cotton Soil using Fly Ash

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Abstract

This paper deals with the technique to stabilize the black cotton soil for the construction of road by using fly ash. Construction of road in a black cotton soil is a challenging task in the civil engineering field. Excessive heaves associated with swelling of expansive soil can cause considerable distress to lightweight civil engineering structures. When the B.C. soil comes in contact with the moisture, it shows considerable volumetric changes. Due to this type of phenomenon, many problems associated regarding maintenance and economic life of the highway and roadway. An attempt is made here to find out solution by using fly ash, which is a by-product of thermal power station. Fly ash becomes a main concern of worry because of its disposal problems and hazardous nature. Use of fly ash in an expansive soil gives economical and ecological solution for stabilization of sub grade of road embankment. So it is a case of "Churning waste into wealth and turning ash into cash". Experimental works have been carried out in a laboratory, which shows that fly ash improves various engineering properties of the expansive soil like liquid limit, plastic limit, plasticity index, swelling pressure, swelling index, shear strength etc. Investigation says that fly ash is a good stabilizing agent for the construction of road in the black cotton soil.

Keywords: Black Cotton Soil, Blending Method, Fly Ash, Sand Drain Method, Strip Method

1. Introduction

The B.C. soil is expansive in nature and posses high swelling and shrinkage properties. The B.C. soil is hard so long as it is dry but loses its stability almost completely when it becomes wet. When again it becomes dry it shows lots of cracks on its surface. Expansive soil undergoes extensive volumetric change when subjected to fluctuating moisture. Considerable damage has taken place over the years to canals, roads, buildings and other existing structure, constructed on or with the use of black cotton soil. The present thrust is on the construction of road on the expansive soil. The typical behavior of this soil under different climatic condition has made construction of road over them, due to considerable volumetric change of this soil. Due to shrinkage properties of this soil, top surface settled excessively and shows failure. The pavements constructed in black cotton soil areas are found to suffer from early failure. In flexible pavements with heavy traffic excessive unevenness, ruts, waves and corrugations are formed almost after every monsoon season, resulting in heavy cost of maintenance demand every year. An attempt is here made to eliminate such problems by adopting proper soil stabilization technique. The term soil stabilization is used to indicate any treatment or process on soil to improve its strength or bearing power by reducing its susceptibility to the adverse influences of water and traffic. Soil stabilization of black cotton soil is to be done with fly ash in this case. Fly ash is a hazardous by-product of thermal power station. Disposal of fly ash becomes the main concern for many countries because of its bulk production. However wastes are not completely worthless. Fly ash is having good cementing and pozzolanic properties. Use of fly ash in road construction on the black cotton soil is an excellent technique of killing two birds with one stone meaningful utilization of industrial waste and stabilizing this high expansive black cotton soil.

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2. Properties of the Materials

2.1 Properties of the Black Cotton Soil

The black cotton soil is one of the major soil groups in India, which covers around 25% of total land area. The B.C. soil is highly clayey and grayish to blackish in colour[1]. The black cotton soil is mainly originated from weathering of igneous rocks and basaltic rocks. The black colour of the black cotton soil is due to presence of titanium oxide. The black cotton soil is found to contain montmorillonite clay mineral that has high expansive characteristics. The black cotton soil in this experimental work was brought from the Porbandar district of the Saurastra region. Some part of the western costal area of the Gujarat state is covers with pockets of the black cotton soil. The black cotton soil is having the following index properties as mentioned in Table 1[2].

Table 1. Geotechnical properties of the soil

Sr. No	Geotechnical properties	
1	Specific Gravity	2.65
2	Particle Size:	
	Gravel Content	0 %
	Coarse Sand	0 %
	Medium Sand	1 %
	Fine Sand	0 %
	Silt and Clay	99 %
3	Atterberg's Limits:	
	Liquid Limit	65 %
	Plastic Limit	40 %
.	Plasticity Index	25 %
4	Optimum Moisture Content	24 %
5	Maximum Dry Density	13.24 KN/m3
6	Free Swell Index	65 %
7	Soil Classification	CH

2.2 Properties of the Fly Ash

Fly ash is a finely divided residue that results from the combustion of the pulverize coal and is transported from the combustion chamber by exhausted gases[3,4]. Fly ash is typically finer than cement and lime. Fly ash consists of silt size particles, which are generally spherical, typically resting in a size between 10 to 100 micron. Fly ash used in this work is Class-F fly ash. This fly ash was brought from the thermal power plant of Torrent Power, Ahmedabad. Standard composition of Class-F fly ash is as listed in below Table 2.

Table 2. Geotechnical properties of the soil

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
SF0	65.00	30.30	34.70
SF8	58.35	24.70	34.65
SF10	54.80	23.10	31.70
SF12	52.00	21.80	30.20
SF14	50.00	21.30	28.70
SF20	47.50	20.10	27.40
SF30	43.00	19.80	23.20
SF40	41.00	17.80	24.00

3. Prepare Experimental Investigations

The purpose of the experimental work is to find out effects of fly ash on various engineering properties of the black cotton soil, on which the road is going to be constructed. In this experimental work, soil is mixed with the different proportion of fly ash. Various mixes were prepared and tested for liquid limit, plastic limit, plasticity index, swelling pressure and swelling index[5].

3.1 Mix Proportions

Soil is mixed with 8, 10, 12, 14, 20, 30 and 40% of fly ash by dry unit weight of the soil, e.g., 8% of fly ash +92% of soil. Various mixed was classified as following ways.

Table 3. Classification of various soil-fly ash mixtures

% of the soil	% of the fly ash	Symbol
100	0	SF0
92	8	SF8
90	10	SF10
88	12	SF12
86	14	SF14
80	20	SF20
70	30	SF30
60	40	SF40

3.2 Effects of Fly Ash on Various Soil Properties

Effects of various proportions of fly ash on swelling index, swell pressure and CBR value are as shown here in Table 4.

Table 4. Effects of fly ash on swelling index and swell pressure

Sample	Swelling Index (%)	Swelling Pressure (Kg/Cm^2)	C.B.R.
SF0	65.00	0.685	3.95
SF8	40.90	0.520	5.50
SF10	36.36	Not Tested	5.90
SF12	32.83	0.430	6.20
SF14	30.43	0.398	6.30
SF20	27.36	Not Tested	6.20
SF30	20.26	0.325	6.00
SF40	22.23	Not Tested	5.95

4. Analysis and Discussion of Test Results

Effects on Atterburg's Limit: the results mentioned in Table 4 indicate that liquid limit, plastic limit, and plasticity index decrease considerably as we increase the fly ash content. Constant decrease in liquid limit, plastic limit and plasticity index is observed up to 30% fly ash addition. Addition of 30% of fly ash causes reduction in liquid limit up to 34% as compare to initial value[6,7]. Same type of reduction can be seen in plastic limit and plasticity index. Plastic limit is decreased up to 24% by adding 10% fly ash while addition of 40% fly ash can reduce plastic limit up to 42% as compare to initial value. Plasticity index also decrease as increase in fly ash content. Addition of 10% fly ash cause reduction of 9% as compare to initial value and 30% addition give reduction in plasticity index up to 34%.

Effects on swelling properties: as result mention in Table 5 clearly indicating the decrement of swelling properties of the soil. Swelling pressure and swelling index is decrease considerably as there is an increase in fly ash content. Swelling index was 65% but it was reduced up to 20.26% by adding 30% fly ash, which shows reduction of 70% than initial value. Swell pressure is also reduced up to 53% when we add 30% fly ash[8].

Effects on California Bearing Ratio: the effect of fly ash addition to black cotton soil in different percentages on CBR at the respective maximum proctor's dry densities are tested and the results are as said in following sentence. It is to be found that addition of fly ash content increase the CBR value. Initially the black cotton soil having a very poor around 4.95, which can be improved up to 6.30 by adding 14% fly ash and up to 6.00 by adding 30% fly ash[9]. The increase in strength in terms of CBR may be due to two factors, viz., the change in gradation and plasticity and pozzolanic reaction between the soil and fly ash.

Fly ash reduces the potential of black cotton soil to undergo volumetric expansion by a physical cementing mechanism. Fly ash control shrink swell by cementing the soil grain together, much like a Portland cement bonds aggregate together to make a concrete[10]. By bonding the soil grain together, soil particles movements are restricted. Fly ash provides adequately array of divalent and trivalent cat ions (Ca^{+2}, Al^{+3}, Fe^{+3}, etc.) under ionized conditions that can promote fluctuation of dispersed clay particles. Thus black cotton soil can be potentially stabilized by cat ions exchange using fly ash.

5. Construction Methodology

5.1 Blending Method

In this method sub grade is strengthen by blending of expansive soil and fly ash. At the time of addition of fly ash, the soil should be reasonably in pulverized state.

Whereas light texture soils are generally friable, and therefore easy to pulverize, this is not so in the case of the black cotton soil, which is soft and sticky when wet but very hard when dry[11]. Degree of pulverization should be aimed like given in a following table in the field.

Table 5. Percentage soil passing

Sieve designation	% By wt. of soil passing the sieve after pulverization
25 mm	100
4.75 mm	50

The best method of pulverization is by using power roller rather than using manual labor. After pulverization of soil, blending of soil and fly ash is to be done. This can be done by In-place mixing method. The soil sub grade may be treated with a small portion of fly ash up to the desire depth of 0.8 to 1.00 meter. A layer of compacted soil fly ash (30 % fly ash) is to be used to construct the sub grade[12].

Some factors are to be kept in our mind to while adding fly ash in the soil. Three factors, delay time, moisture content and fly ash addition ratio are governing factors for the compressive strength and durability of the sub grade in a black cotton soil. When there will not availability of good earth material for sub base and base then we must go for same black cotton soil and it should be also stabilized in a same manner by using this fly ash.

5.2 Strip Method

The procedure to be adopted for construction of road in this method is similar to construction of embankments using normal soil. The original ground should be leveled, scarified and sprinkled with water and then compacted by rolling so as to achieve 97% of the modified proctor density. Fly ash and cover soil should be spread in layers of uniform thickness over the entire width of the embankment, by mechanical means. The cover soil and fly ash should be laid simultaneously to ensure confinement of fly ash. The most efficient lift thicknesses are a function of roller weight and vibratory energy. Medium weight rollers with dead weight in range of 6 to 10 tons, provide satisfactory compaction for loose lift thickness of about 25 centimeter. For better compaction heavier vibratory rollers are required. Two passes without vibration followed by 6 to 10 passes with vibration would be generally sufficient to compact individual layer. Moisture content of the fill material should be checked at the site of placement prior to commencement of compaction. Moisture content of fly ash laid for compaction should vary from OMC to OMC +2%. Moisture content of cover soil should be maintained at its OMC. Where water is required to be added to the fill material, it should be sprinkled uniformly without flooding. At moisture contents higher than the appropriate range, fly ash will liquefy and would be difficult to confine and compact. At lower moisture content ash may require an excessive amount of energy to compact.

5.3 Sand Drain Method

This method is also known as Sand blanket method. When ground water is encountered in close proximity to the propose embankment, a blanket drainage material should be provided.

In this method, a drain of some diameter (d) is to be provided and depth of sand drain is 2.5 times diameter is to be provided below the pavement thickness. This will also provide a working platform for the construction of fly ash fill.

6. Compatibility of Fly Ash as a Stabilizing Agent

6.1 Advantages of Fly Ash

- Fly ash reduces swelling properties of the soil, which gives stability to the embankment during the wet season. Hence the road in such type of expansive soil gets more service life. There will not be any problems like settlement and failure of pavement.
- Fly ash is used as a fill material, which eliminates needs for expensive borrow materials.
- It expedites the construction process by improving excessive wet or unstable sub grade.
- It improves the sub grade condition, which ultimately results in the reduction of thickness of pavement. Thus, the economical benefits can be directly achieved by such type of depth reduction.
- Low specific gravity of fly ash results in a low base pressure.
- Fly ash is a good drying agent, which is effectively utilized to reduce the soil moisture content in the field.
- Fly ash can be spread and compacted by using conventional construction equipment.
- The pozzolanic hardening of fly ash imparts additional strength and very less settlement.
- On one hand fly ash proves to be an effective admixture for improving the soil quality, on other hand in this type of utilization affords means of disposing of industrial by product without adversely affecting environment.

6.2 Limitation of Fly Ash Usages

- Fly ashes are not available in bags in certified quality packs, which is the main limitation in their ready utilization.
- Erosion of fly ash is the main concern when using as a fill material. Due to its fine-grained non-cohesive nature, fly ash is easily suspected to erosion.
- Transportation of fly ash should be careful enough hence pollution can be avoided due to spreading of fine particles in air on route of transportation.
- The sulphate content of fly ash some time causes concern about possibilities of sulphate attack on adjacent concrete structure.

7. Conclusion

- Addition of fly ash reduces liquid limit, plastic limit, plasticity index and swelling characteristics of the soil. Hence fly ash improves most of the engineering properties of the black cotton soil as expansive soil tends to become non expansive in nature.
- Fly ash improves the CBR value of the black cotton soil. This improved value of CBR gives reduction in thickness of pavement which ultimately results in a cost saving.

- Fly ash is a hazardous industrial waste, which can be effectively utilized in road construction.
- Moving from the laboratory to field construction site, there would be some variation introduced as results of relatively uncontrolled construction practices as compare to carefully controlled laboratory condition

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