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Effect of Fly Ash on an Expansive Soil for Flexible Pavement Design

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Abstract*— Fly ash is the waste material, which is obtained after burning coal in Thermal Power Plants. It can be used as a stabilizer for soil due to its pozzolonic effect or an inherent self hardening property under favorable conditions of moisture and compaction. This project aim is to study the effect of fly ash on an expansive soil for flexible pavement design and to reduce the quantity of lime in lime fly ash by the effective use of Fly ash itself. Some percentage of Fly ash without any additives was utilized so as to reduce the cost of construction and this is a good method for disposal of it. Initially the index properties of the soil were studied by conducting liquid limit, plastic limit, shrinkage limit, grain size analysis and specific gravity tests. CBR, OMC and swell index tests confirmed that the soil had taken was clay which is highly expansive in nature. Unconfined compressive strength and soaked CBR tests were conducted for various proportions of Fly ash and optimum contents were obtained and found that soil strength improved. If the locally available soil is good in nature pavement construction becomes easier and cheaper. But If the soil is weak in nature instead of going for an alternative, which costs higher the available soil can be modified by adding this type of stabilizer which involves low cost.

Index Terms: **Flexible Pavement, CBR, Plasticity Index, Pavement Layers, Stabilization, Expansive Soil.**

I. INTRODUCTION

Transportation is vital for the economic development of any region. With over 75% of the population of the country living in the villages, the development in urban centers alone does not indicate the overall development of the country. Only with the improvements in the transportation facilities in rural areas, there could be faster development of the rural centers. With improved facilities for education, health care and other social needs in the villages, the urge for the migration to urban centers decreases, thus helping in balanced development of the country as a whole. Roads serve as feeder lines for railways, waterways and airways and invariably promote the development of their classes of transport. In developing countries like India the biggest handicap to provide a complete network of road system is the limited finances available to build roads by conventional methods. Therefore there is a need to resort to one of the suitable methods of low cost road construction.

The construction cost of roads can be considerably decreased by selecting local materials including local soil for the construction of the lower layers of the pavement such as the sub base course. If the stability of the local soil is not adequate for supporting wheel loads, the properties are improved by soil stabilization techniques. Thus the principle of soil stabilized road construction involves the effective utilization of local soils and other suitable stabilizing agent. Low cost roads should utilize the material found in the vicinity of the roads. Different methods are available to obtain low cost roads. In developing countries like India soil stabilization methods using locally available materials have scope in reducing the initial construction of pavement. Generally, the granular materials such as natural sand, moorum ,gravel, laterite , kankar or other naturally occurring or artifial soft aggregate like slag, cinder, broken brick aggregates and low grade iron ores are most commonly used .Apart from these, industrial wastes such as Fly ash, lignin, and molasses can be used which contribute only transportation cost

Fly ash disposal & utilization shall continue to be an important area of national concern due to India's dependence on thermal power generation for its energy supply. The scenario with respect to Fly ash management has undergone considerable improvement over the past few years .Due to increasing environmental concern and growing magnitude of the problem it has become imperative to manage it. More importantly because it has tremendous potential to be utilized.

II. SOIL STABILIZATION

It may result the following changes like increases the strength (ie) reducing the sensitivity of strength to environmental changes, reduces frost susceptibility, changes in the properties like density or swelling and retains the desired minimum strength by water proofing. The basic principles of soil stabilization are evaluating the properties of given soil, deciding the method of supplementing the lacking property by the effective and economical method of stabilization, designing the stabilized soil mix for intended stability and durability values & considering the construction procedure by adequately compacting the stabilized layers.

Table 1 Choice of Stabilizer

Purpose	Soil type	Recommended stabilization methods
Sub grade stabilization	Course granular	SA, SC, C
	Fine granular	SA, SC,C
	Clay of low PI	C,SC,CMS,LMS,SL
	Clay of high PI	SL,LMS
Base course stabilization	Fine granular	SC,SA,LF
	Clay of low PI	SC,SL

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The choice of stabilization depends upon economic consideration, utility of stabilized construction, possibility of future improvement under stage construction and speed of construction. Before choosing a particular method of stabilization it is necessary to carry out both field and laboratory investigation e.g. collection of soil sample, field identification of soil and other types of materials in the vicinity, mode of haulage, physical, chemical and engineering laboratory test and soil classification tests. These results help in arriving at an economically feasible method of soil stabilization.

III. EXPERIMENTAL TESTS AND RESULTS

A Materials Used

1. Soil – Clay
2. Fly ash
3. Lime

B Tests on soil

To study the characteristics and classification of soil the following tests were conducted

1. Grain size Analysis test(wet sieve & dry sieve analysis)
2. Specific Gravity test
3. Liquid Limit test
4. Plastic Limit test
5. Unconfined compressive strength test
6. Swell index test

C Tests on Fly ash

To study the characteristics of fly ash sieve analysis and specific gravity tests were conducted

D Tests on Clay-Fly Ash Proportion

Fly ash for this project was obtained from Tuticorin, in Tamil nadu thermal power plant. It was class F fly ash. It was obtained by burning anthracite and bituminous coal. It was used as it was. The following tests on clay with different proportions of fly ash such as 5%, 10%,15% and so on

1. Liquid limit test
2. Plastic limit test
3. Proctor's compaction test
4. California bearing ratio test
5. Unconfined compressive strength test
6. Swell index test

Liquid Limit and plastic limit tests were conducted for clay and fly ash up to 25%.These two tests were conducted in two stages

(i) Immediately after mixing (ii) 24 hours after mixing

CBR test had conducted in the following stages Un soaked condition- Immediate & After one day Soaked condition - After four days soaking In addition CBR test for 5%Fly ash content after 3 days and 7 days curing.

Table 2 Soil-Particle Size Distribution

Particles	Distribution (%)
Gravel	1
Sand	9
Silt	44
Clay	46

Table 3: Clay Properties

Liquid limit(LL) %	60
Plastic limit(PL)%	22
Plasticity Index(PI)	38
Specific Gravity	2.38
Optimum moisture content(OMC) %	16.00
Dry density at OMC g/cc	1.66
CBR Value(un soaked)	10.36
Unconfined compressive strength N/mm^2	38.87
Swell index %	40.00
BIS classification	CH-(clay of high compressibility)

E Fly Ash Properties

Table 4 Grain size distribution

Sieve Size(microns)	% of finer
300	99.5
150	79.3
75	41.5

Specific Gravity of fly ash =2.1

Table 5 Show the Results Immediately After Mixing

Properties	5 % Fly ash	10 % Fly ash	15 % Fly ash	20 % Fly ash	25 % Fly ash
Liquid limit(LL) %	56.80	56.00	55.00	52.00	50.50
Plastic limit(PL)%	21.70	30.79	37.36	21.00	20.00
Plasticity Index(PI)	35.10	25.21	17.64	31.00	30.50
Optimum moisture content(OMC) %	21.40	16.00	20.00	20.00	-
Dry density at OMC g/cc	1.57	1.64	1.57	1.54	-
CBR Value	3.89	16.79	12.52	11.35	-
Unconfined compressive strength N/mm^2	16.15	47.80	19.20	18.20	-
Swell index %	30.00	18.18	8.33	12	12.00

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Table 6 Show The Results After One Day Mixing

Particular	5 % Fly ash	10 % Fly ash	15 % Fly ash	20 % Fly ash	25 % Fly ash
Liquid limit(LL) %	57.90	57.20	55.00	51.80	50.00
Plastic limit(PL)%	24.70	26.00	28.00	20.90	20.40
Plasticity Index(PI)	33.20	31.20	27.00	30.90	29.60
CBR Value	11.31	26.57	16.79	14.13	-

Table 7 Test on soaked Sample

After 4 days soaking

Particular	Clay	5 % Fly ash	10 % Fly ash	15 % Fly ash	20 % Fly ash
CBR Value %	3.14	4.49	4.67	5.15	4.51

F Effect of Curing

Table 8 Shows CBR Value at One Day, 3 Days, 7 Days Curing

Particular	1 Day curing	3 Days curing	7 Days curing
CBR Value %	11.31	15.47	20.65

Table 9 CBR Test on Lime Fly ash

FLY ASH	CBR VALUE %		
	2 % Lime	3 % Lime	4 % Lime
5 %	6.25	21.60	47.30

IV. DISCUSSION ON RESULTS

Addition of fly ash with the soil decreases the liquid limit and plasticity index of the soil Table 6 .From Table 5 and 7 it is clearly understood that maximum CBR value is obtained for 15% of Fly ash content and swell index is less for 15% Fly ash content. So 15% fly ash content is taken as optimum. Table 8 shows for designing the other structural elements above the compacted sub grade of FA stabilized soil, the CBR values of other Fly ash contents are insufficient for our requirements. Hence to increase the strength of the soil LFA stabilization is considered for the design of sub base.

V. PAVEMENT DESIGN

The surface of the road should be stable and non yielding, to allow the heavy wheel loads of road traffic to move with least possible rolling resistance. At high moisture content, the soil becomes weaker and soft and starts yielding under heavy wheel loads, thus increasing the tractive resistance. A pavement consisting of a few layers of pavement materials is constructed over a prepared soil sub grade to serve as a carriage way.

The pavement carries the wheel loads and transfer the load stresses through a wider area on the soil sub grade below. A pavement layer is considered more effective or superior, if it is able to distribute the wheel load stress through a larger area per unit depth of the layer. One of the objectives of a well designed and constructed pavement is therefore to keep this elastic deformation of the pavement within the permissible limits, so that the pavement can sustain a large number of repeated load applications during the design life.

Depending upon the mode of supporting and distributing loads pavements are classified as flexible pavement, Rigid pavement and semi rigid pavement. The difference between the flexible & rigid pavement is the manner in which they distribute the load over the sub grade. The design of flexible pavement based the principle that a load of any magnitude by carrying it deep enough into the ground through successive layers of granular material, the intensity of a load diminishes as the load is transmitted downwards from the surface by virtue of spreading over an increasingly large area. Consequently, there could be grading in the quality of material used, the materials with a high degree of strength being used at or near the surface. Thus, the strength of the sub grade primarily influences the thickness design of the flexible pavement.

A California Bearing Ratio Method

This is an empirical based on arbitrary soil strength tests. The CBR value of the soil gives an idea about the quality of the sub grade material compared to that of an excellent base material. In India, the CBR method of design is adopted for traffic classified according to the number of heavy vehicles. The Indian Road Congress has recommended the use of design curves evolved by the road research laboratory U.K. These curves give the total thickness of pavement in terms of volume of traffic carried by the roads. In order to design by CBR method, first the soaked CBR value of the soil sub grade is evaluated. Then the appropriate design curve is chosen by taking the design wheel load by taking the design wheel load by taking the anticipated traffic into consideration. Thus the total thickness of flexible pavement needed to cover the sub grade of the known CBR value is obtained. With the CBR values the pavement has been designed by referring the chart provided by the Indian Road Congress.

B Design of Structural Elements

From the table it is found that by adding Fly ash with our soil the CBR value increases only up to 5.15(i.e. up to 64% or 1.64 times the CBR value of the soil). As per IRC's standard chart the depth of construction for the clayey soil we have taken is 43 cm. The CBR value for 15% of Fly ash content is 5.15 and the depth of construction for 5.15 CBR is 32 cm. Over the existing sub grade we have to design the structural elements to a depth of 43cm. We have provided Fly ash (15%) stabilized sub grade of thickness 11cm over the

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existing soil. The CBR values obtained for other percentages of Fly ash are not higher than Fly ash of 15%. We are in a position to provide LFA stabilized sub base because the CBR value of the structural elements should increase in ascending order while designing.

While designing the sub base, we have taken LFA stabilization in which 3% of lime & 5% of Fly ash added to the soil. We limited the FA content to 5% to reduce transportation cost of FA. More over we wanted a CBR value greater than 17 for designing the layers above the sub base. We are satisfied with the CBR of clay adding 3% lime. So we have provided LFA stabilized soil with 3% of lime and 5 % of Fly ash.

C Fly Ash Stabilized Pavement Design

Light Traffic

CBR value of soil = 3.14%
From IRC chart (curve C)
Depth of construction for CBR value of 3.14% = 43cm
CBR value for the soil + 15 % Fly ash = 5.15%
Depth of construction for CBR value of 5.15% = 32 cm
Depth of construction for the sub grade = 43-32 = 11cm
CBR value for soil + 5 % Fly ash+ 3% lime = 21.6%
Depth of construction for CBR value of 21.6% = 15cm
Depth of construction of sub base =32-15 = 17cm
Depth of surfacing = 5 cm
Depth of base = 10cm
Total designed depth = 43cm

Table 10 Layers of Pavement

Layers	Depth
Carpeting	2 cm
Surface course	5 cm
Base granular CBR> 80%	10cm
Subbase(5% FA +3% L) CBR= 21.6%	17cm
Stabilized subgrade(15% FA) CBR=5.15%	11cm

Medium Traffic

CBR value of soil =3.14 %

From IRC chart (curve D)

Depth of construction for CBR value of 3.14 %= 48cm

CBR value for the soil + 15%Fly ash = 5.15%

Depth of construction for CBR value of 5.15% = 36cm

Depth of construction for the sub grade= 48-36= 12cm

CBR value for soil + 5% Fly ash + 3 % lime = 21.6%

Depth of construction for CBR value of 21.6% = 17cm

Depth of construction of sub base=36-17 = 19cm

Depth of surfacing = 7cm

Depth of base = 10cm

Total designed depth = 48cm

Table 11 Layers of Pavement for medium traffic

Layers	Depth
Carpeting	2 cm
Surface course	7 cm
Base granular CBR> 80%	10cm
Subbase(5% FA +3% L) CBR= 21.6%	19cm
Stabilized subgrade(15% FA) CBR=5.15%	12cm

Heavy Traffic

CBR value of soil = 3.14 %

From IRC chart (curve E)

Depth of construction for CBR value of 3.14 %= 54 cm

CBR value for the soil + 15%Fly ash = 5.15%

Depth of construction for CBR value of 5.15% = 42 cm

Depth of construction for the subgrade=54-42 = 12cm

CBR value for soil + 5% Fly ash + 3 % lime = 21.6%

Depth of construction for CBR value of 21.6% = 18cm

Depth of construction of subbase=42-18 = 24cm

Depth of surfacing = 8cm

Depth of base = 10cm

Total designed depth = 54cm

Table 12 Layers of Pavement for Heavy traffic

Layers	Depth
Carpeting	2 cm
Surface course	8 cm
Base granular CBR> 80%	10cm
Subbase(5% FA +3% L) CBR= 21.6%	24cm
Stabilized subgrade(15% FA) CBR=5.15%	12cm

VI CONSTRUCTION METHODS IN SOIL STABILIZATION

The three principal methods of construction are

1. Mix- in-place
2. Travelling plant
3. Stationary plant

A Preparation of the Sub-grade

The site is leveled to the required formation and cleared of stumps, boulders and debris for a depth of about 12m in. In preparation of the sub grade, the top soil is normally

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removed, although in some instances top soils have been stabilized.

B Pulverization of the soil

This comprises scarifying to the required depth of treatment and pulverizing the scarified soil until a fine silt is produced suitable for mixing in the stabilizer. Suitable plant for cutting up to the required depth is a plough or robust tiller with a positive depth control. Rippers and cultivators when used on their own, tend to leave ruts in the sub grade. The plough should always be used to turn the soil towards the centre of the road; this leaves a vertical face of soil at the shoulders and prevents processing being carried outside the limits of the road. Rotary tillers are used for pulverization, but disc harrows may be a useful addition with some soils. When pulverization is completed about 80% or more of the soil, exclusive of stones, should pass a 3/16 in B.S. sieve. The loose surface is then shaped with a grader to give an even distribution of loose soil along the length and width of the road.

C Mixing

At this stage mixing is begin with rotary tillers or special soil mixers. Dry mixing is usually done in two or three passes of the machines. It is normally followed by wet mixing, when a mixing takes place concurrently with the application of water. This is continued until the mixture has a uniform color; this criterion has to be used as there is no rapid means for assessing the uniformity of mixing. Even in the climatic conditions experienced in this country, the amounts of water required to be added to the soil are sometimes quite considerable and efficient and even distribution is essential. To avoid interruptions two water distributors should be used one spraying while the other is being filled. These are followed by the mixing machines and processing is continued until sufficient water has been sprayed and the mixtures is uniformly damp, an operation which should not last longer than 3 hours.

D Grading

It should be done at the following stages of the work

- In the preparation of the sub grade
- When pulverization is complete
- Continuously during mixing. This is to keep the levels as near correct as possible in order to reduce the time taken in the final grading of the loose material.
- When mixing is complete, this should be done as rapidly as possible before evaporation losses cause a need for further wet mixing
- Final shaping of the compacted road. This should be avoided altogether if possible, since any grading removes stabilized material. The rollers should leave the road shaped adequately, but if further grading is necessary, then care should be taken to see that the depth of the treated layer is not reduced by an excessive amount

E Compaction

When mixing is complete and the soil graded to the required section, compaction is begun. Particular care must be taken in the final stage of compaction. However in order to avoid overstressing the processed soil by the use of a roller that is too heavy, or by rolling for too long. This might reduce the strength by cracking.

F Curing

Many stabilizing agents require a period of curing after mixing, before they become fully effective. The surface should be kept wet by frequent applications of a light spray of water. A bituminous priming coat has also been used as a curing agent by applying it soon after compaction.

G Surfacing

Before a surfacing is applied, the stabilized soil should be sprayed with a bituminous priming coat, having a viscosity of about 5 to 20 sec, at 30o C. The priming coat, which provides a key for the surfacing , should be a bitumen if the surfacing contains a bitumen binder, while a latter contains a tar binder the priming coat should also be a tar.

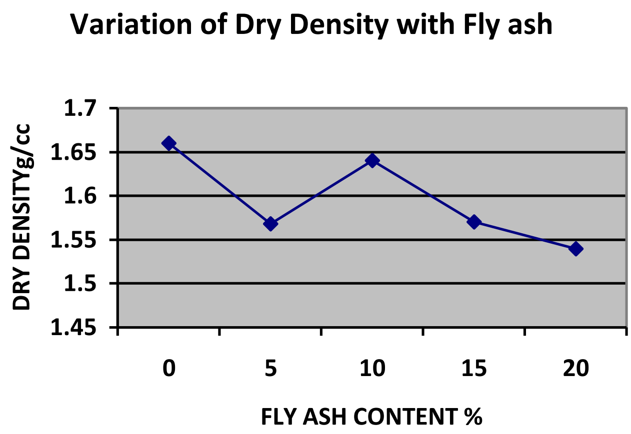

Figure 1. Variation of Dry Density with Fly ash

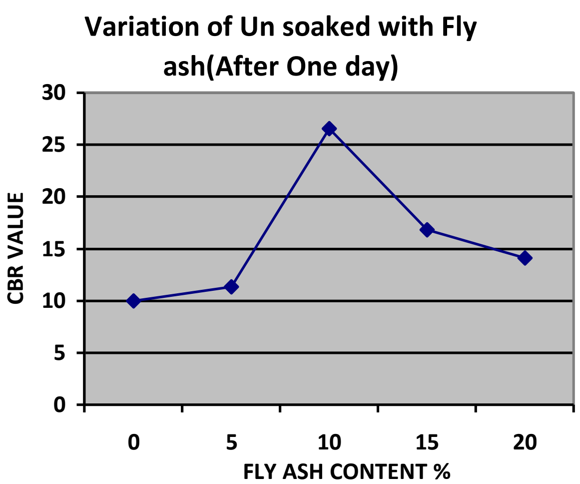

Figure 2 Variation of Unsoaked with fly ash

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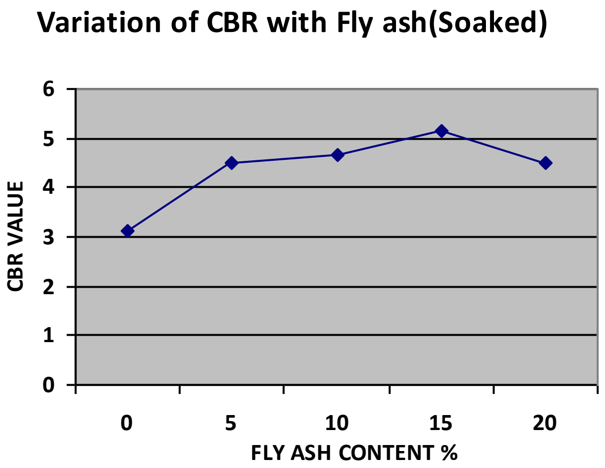

Figure 3 Variation of CBR with Fly ash soaked

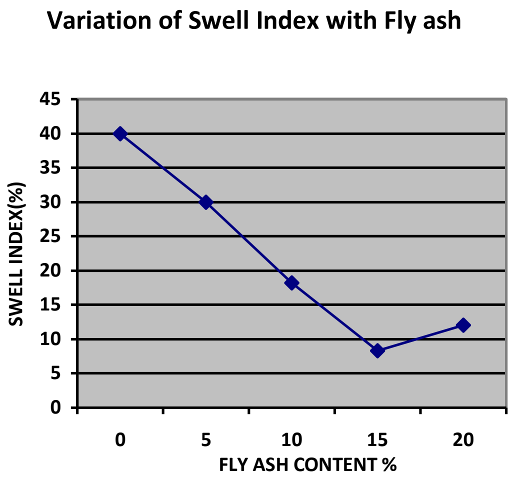

Figure 4 Variation of Swell Index with Fly ash

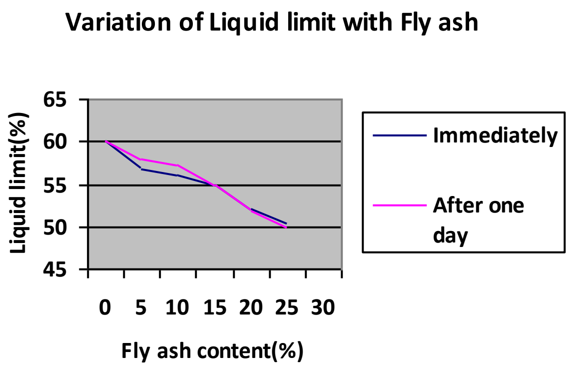

Figure 5 Variation of Liquid limit with Fly ash

VII. CONCLUSION

The characteristics and strength of a highly expansive soil can be improved by fly ash stabilization. From the results, the following conclusions are warranted.

- Liquid Limit and Plasticity index are decreased with percentage Fly ash added.
- The California Bearing Ratio can be increased 1.64 times approximately to the initial strength of the soil.
- Swelling is reduced by adding Fly ash.
- Even though the Fly ash stabilized soil cannot be provided for the sub base, by providing it in the compacted sub grade itself reduces the cost of construction to a greater extent compared to LFAS & LS.
- An amount of Rs.1.7 lakhs to Rs.2 Lakhs/km can be definitely saved compared to LFA stabilization.
- Also the cost on construction can be saved from Rs. 2.85 lakhs to Rs 5.30 lakhs/km when compared with lime stabilization.
- As the disposal of Fly ash is a big problem in thermal industries, Fly ash stabilization is one of the best methods for the effective and economical disposal of Fly ash.
- The main aim of our project is to use Fly ash effectively to bring down the cost of construction of the roads and achieved the goal of research.

Nomenclature

LFAS Lime and Fly ash stabilization
LS Lime Stabilization
C Compaction
CMS Cement modified soil
SA Soil Asphalt
SL Soil Lime
SC Soil Cement

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Traffic	**Lime stabilized Pavement**		**Lime-Flyash Stabilized Pavement**		**Fly ash stabilized Sub-grade**		**Savings(per load) Rs**	
	Quantity of lime (kg)	**Cost of Lime (Rs)**	**Quantity of lime (kg)**	**Cost of Lime (Rs)**	**Quantity of lime (kg)**	**Cost of Lime (Rs)**	**Compared to LS pavement Design**	**Compared to LFA pavement Design**
Light	3830	14360	2900	10880	1554	5830	8530	5050
Medium	4328	16230	3260	12230	1772	6650	9580	5580
Heavy	6519	24440	3890	14590	2290	8590	15850	6000

Table 13 Comparative Cost Schedule (Per Load)