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Laboratory studies on the efficacy of Palm Oil Fuel Ash and Phosphogypsum for improving the properties of Expansive soil as subgrade for Flexible pavements

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Abstract— Expansive soils are found in many parts of the world and in India they extend to twenty percentage of the area. Expansive soils experience significant volume changes associated with changes in water content. Any type of construction work on Expansive soils with high swelling and shrinkage behaviour will cause damage to the structures. The changes in volume of the soil are due to the minerals present in Expansive soils. This study aims to reduce the swelling behaviour of the soil and increase the strength of the soil with stabilisation technique using different admixtures and chemicals. In the present study palm oil fuel ash and phosphogypsum were used to improve the soil characteristics. The soil for the present study was collected from Thoorpulanka village, Allavaram mandal, East Godavari district, Andhra Pradesh, India. The changes in the soil properties due to addition of Palm Oil Fuel Ash and Phosphogypsum in different percentage combinations were studied through laboratory investigations.

Keywords—Expansive soils, Palm Oil Fuel Ash, Phosphogypsum, OMC, MDD, CBR

I. INTRODUCTION

For any type of structure the foundation has to be strong enough to with stand the loads. The load bearing capacity depends on the type of soil and its properties. The soils with low bearing capacity are generally avoided to minimize the structural damage. But in places where only problematic soils are available, they have to be treated for preventing the damages to structure. In case of flexible pavements subgrade soil plays a major role in the load bearing and durability characteristics of the pavement. The most encountered problem in pavements with Expansive soil are longitudinal cracks and shrinkage. This is mainly due to the swelling and shrinkage behavior of the minerals present in the bed soil. In such cases the soil beneath the pavement should be stabilized before laying the pavement to improve the strength and durability of the pavement. So the subgrade soil of pavement plays a crucial role in design of pavement. Many types of admixtures can use in the stabilization of the soils. The aim is to choose the materials in such a way that they should be economical and accessible. Many researches have proven that adding different pozzolanic materials and chemicals improves the soil properties. Using of waste by products in improving the soil strength is considered both economical and ecofriendly. The effect of quarry dust on the black cotton soils is studied (Aditya Chasoria et.al 2016). Strength improvement of Expansive soil on addition of fly ash and Phosphogypsum (Divya Krishnan et.al 2014). Lime and Phosphogypsum (A.Ravi Teja et.al 2015) ferric chloride and rive husk ash (Dr.D.Koteswara Rao et.al 2012). In the present study Palm Oil Fuel Ash and Phosphogypsum were used. The admixtures were added in different percentages and were tested as per Indian standard soil testing codes (IS 2720-3(1980)), (IS 2720-4(1985)), (IS 2720-5(1985)) (IS 2720-8(1983)), (IS 2720-10(1991)), (IS 2720-16(1987)), (IS 2720-20(1992)), (IS 2720). IRC-37(2012) used as the standard reference.

II. OBJECTIVES OF THE STUDY

- To study the properties of Untreated Expansive soil
- To study the effect of Palm Oil Fuel Ash on improving the properties of Untreated Expansive soil.
- To study the effect of Phosphogypsum on Palm Oil Fuel Ash treated Expansive soil.
- To study the load carrying capacity of treated Expansive soil as Subgrade for flexible pavements under cyclic pressures.

III. MATERIALS USED

A.Expansive Soil:

The soil used in this study was Expansive soil. Differential free swell was conducted on the soil to check the swelling of the soil. The soil was collected at a depth of 0.5m from the ground level near Thoorpulanka village, Allavaram Mandal, East Godavari District ,A.p, India. Index properties and engineering properties of the soil were determined as per Indian Standard soil testing codes. Differential free swell ,Specific Gravity, Consistency limits, grain size analysis and Optimum moisture content, Maximum dry density, California Bearing Ratio, Unconfined compressive strength were determined.

Table 1

Geotechnical properties of untreated Expansive soil

S.No	Property	Value
1	Specific Gravity	2.25
2	Differential Free Swell (%)	120
3	Grain Size Distribution	
	Gravel (%)	0
	Sand (%)	0
	Silt (%)	18
	Clay(%)	82
4	Liquid Limit (%)	86
5	Plastic Limit (%)	36.5
6	Plasticity Index (%)	49.5
7	Soil Classification	CH
8	Optimum Moisture Content (%)	25.42
9	Maximum Dry Density (g/cc)	1.41
10	Soaked CBR (%)	1.24
11	Cohesion (kN/m²)	97.1
12	Angle of Internal Friction Ø (^{0})	2.00

B. Palm Oil Fuel Ash (POFA):

Palm oil fuel ash (POFA) is a by-product obtained during the burning of waste materials such as palm kernel shell, palm oil fiber, and palm oil husk. POFA is rich in SiO_2, therefore, is a good pozzolanic material for this study POFA was obtained from ruchi soya industries, Samalkot. In this study palm oil fuel ash is used as an admixture with varying percentages of 5%, 7.5%, 10%, 12.5%. The chemical composition of Palm Oil Fuel Ash is given in Table 2.

Table 2

Chemical composition of palm oil fuel ash

Chemical Constituent	Percentage (%)
Silicon Dioxide(SiO_2)	53.8
Aluminium oxide(Al_2O_3)	5.67
Ferric Oxide(Fe_2O_3)	4.55
Calcium Oxide(CaO)	4.25
Potassium Oxide(K_2O)	4.48
Loss on Ignition(LOI)	10.5

(Courtesy: Ruchi Soya Industries, Samalkot , East Godavari(Dt),A.P, India.)

C. Phosphogypsum (PG):

Phosphogypsum is a by-product of Phosphate fertiliser industries that is obtained from the production of Phosphate rock and Phosphoric Acid. Phosphogypsum for this study is obtained from Nagarjuna Fertilisers. Phosphogypsum was added in percentages of 2%, 4%, 6%, 8% to the Palm oil stabilised Expansive soil. The chemical Composition of Phosphogypsum is given in Table 2.

Table 3

Chemical composition of Phosphogypsum

Chemical Composition	Percentage(%)
Calcium Oxide(CaO)	31.20
Silicon dioxide(SiO_2)	3.92
Sulphur TriOxide(SO_3)	42.3
Phophorous Pentoxide (P_2O_5)	3.6
Magnesium Oxide MgO)	0.49
Phosphate Floride	18.49

(Courtesy: Nagarjuna Fertilisers,Samalkot , East Godavari(Dt),A.P, India)

Fig 1: Expansive Soil

Fig 2: Palm Oil Fuel Ash

Fig 3: Phosphogypsum

IV TESTING & RESULTS

I. Methods of Testing:

The geotechnical properties of the untreated Expansive soil were determined as per IS codes of practise for soils. The tests conducted on the soil were differential free swell, Specific Gravity, Liquid Limit, Plastic Limit , Modified proctor compaction test, California Bearing Ratio ,Tri axial test. The results were tabulated in Table 1. Based on obtained results the admixtures were selected. The admixtures used in this were Palm oil Fuel Ash and Phosphogypsum. The properties of Palm Oil Fuel Ash and Phosphogypsum were noted in Table 2 & Table 3 respectively. The soil was mixed with different percentages of 5%, 7.5%, 10%, 12.5% Palm oil Fuel Ash as a soil replacement. For each percentage of Palm Oil Fuel ash and soil Mixture OMC&MDD and CBR tests were conducted . The results were studied . Phosphogysum was used as a chemical admixture in this study. The chemical was used as an additive in this study. Phosphogypsum was added to the optimum percentage of Palm Oil Fuel Ash and Soil mixture in percentages of 2%, 4%, 6% and 8%. OMC%, MDD, CBR tests were conducted on Expansive Soil treated with Palm Oil Fuel Ash and Phosphogysum Mixtures.

A. Liquid limit:

The liquid limit test was conducted on the untreated Expansive soil, treated Expansive soil with an optimum of 10% of POFA ,and also on the Expansive soil stabilised with POFA with an optimum of 6% PG by using Casagrande's liquid limit apparatus , as per specifications given in IS: 2720 part 4 (1970).

B. Plastic limit:

Similarly the Plastic limit test was conducted on Untreated Expansive soil, treated Expansive soil with an optimum of 10% of POFA ,and also on the Expansive soil stabilised with POFA with an optimum of 6% PG as per the specifications given in IS: 2720 part 4 (1970).

C. Differential Free Swell:

Differential Free Swell (DFS) is used for the determining the extent of expansiveness of the soil. To determine the free swell index of a soil, 20g of oven dry soil passing through 425µ size sieve is taken. 10g of soil sample is taken into a l00cc capacity graduated cylinder containing water, and another 10g of soil sample is taken into a l00cc capacity graduated cylinder containing kerosene oil.

Differential Free Swell (%) = V_d-V_k/V_k *100

Where, V_d = volume of soil sample in the graduated cylinder containing distilled water.

V_k = volume of soil sample in the graduated cylinder containing kerosene.

Kerosene is a non polar liquid, So it does not cause any swelling in the soil. The test was conducted as per IS 2720: part 40(1977) .

D. Modified Proctor compaction Test:

Modified proctor compaction test was conducted on the Expansive soil to establish a relation between water content and dry density. The optimum Moisture Content was used to carry out CBR test. The test was conducted as per the procedure of IS 2720: part 8(1983).

E. Specific Gravity:

Specific gravity of a soil is the ratio of the mass of unit volume of soil to the mass of the same volume of distilled water 20g of oven dried soil sample is used to determine the specific gravity. The specific gravity test was conducted using density bottle method as per IS:2720 Part 3 (1980).

F. California Bearing Ratio Test:

The California bearing ratio test was conducted on the Expansive soil using POFA with varying percentages of 5%, 7.5%, 10%, 12.5%. CBR value increased up to 10 % addition of Palm Oil Fuel Ash, but on further addition of POFA CBR value of soil decreased. The maximum value of CBR i.e., 4.03% was obtained after 10 % addition of POFA. After the addition of 6% PG to soil with 10% POFA, the CBR value was increased from 4.03% to 8.42%.

II. Results:

The Expansive soil was mixed with 5%, 7.5%, 10% &12.5% of POFA . In the first three trials the maximum dry density of the soil mixture increased continuously. On further addition of 12.5% POFA the maximum dry density of the soil was decreased indicating that the optimum strength of the soil has reached.

1. OMC and MDD variation of Expansive soil treated with different percentages of Palm Oil Fuel Ash:

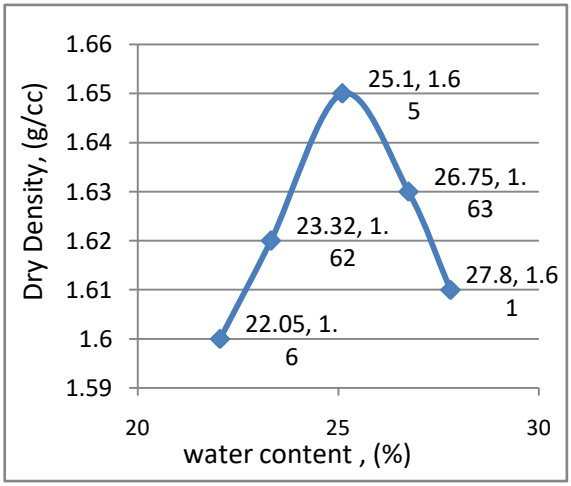

Fig 4: OMC&MDD of ES treated with 5% POFA

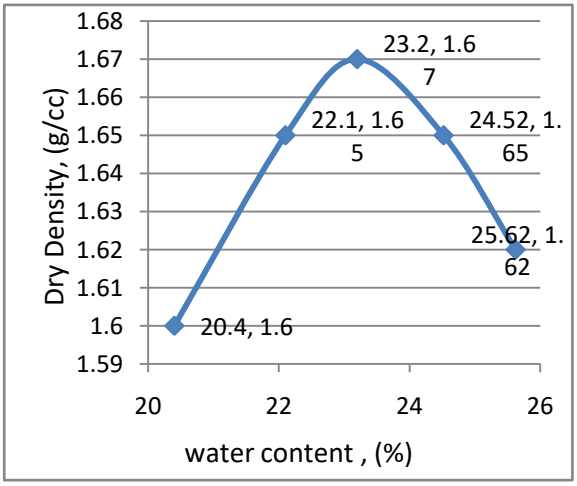

Fig 5: OMC&MDD of ES treated with 7.5% POFA

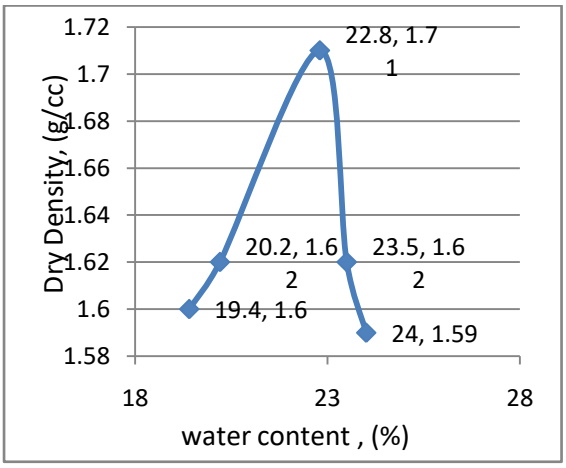

Fig 6: OMC&MDD of ES treated with 10% POFA

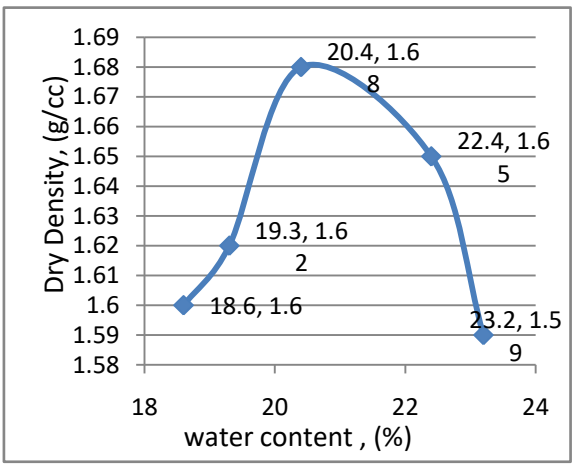

Fig 7: OMC&MDD of ES treated with 12.5% POFA

Table 4
OMC & MDD values of Expansive soil treated with Palm Oil Fuel Ash

Expansive Soil treated with different percentages of Palm Oil Fuel Ash	Maximum Dry Density (g/cc)	Optimum Moisture content(%)
Soil	1.41	25.42
Soil+ 5% POFA	1.65	25.1
Soil + 7.5% POFA	1.67	23.2
Soil + 10% POFA	**1.71**	**22.8**
Soil + 12.5% POFA	1.68	20.4

2. CBR variation of Expansive soil treated with different percentages of Palm Oil Fuel Ash:

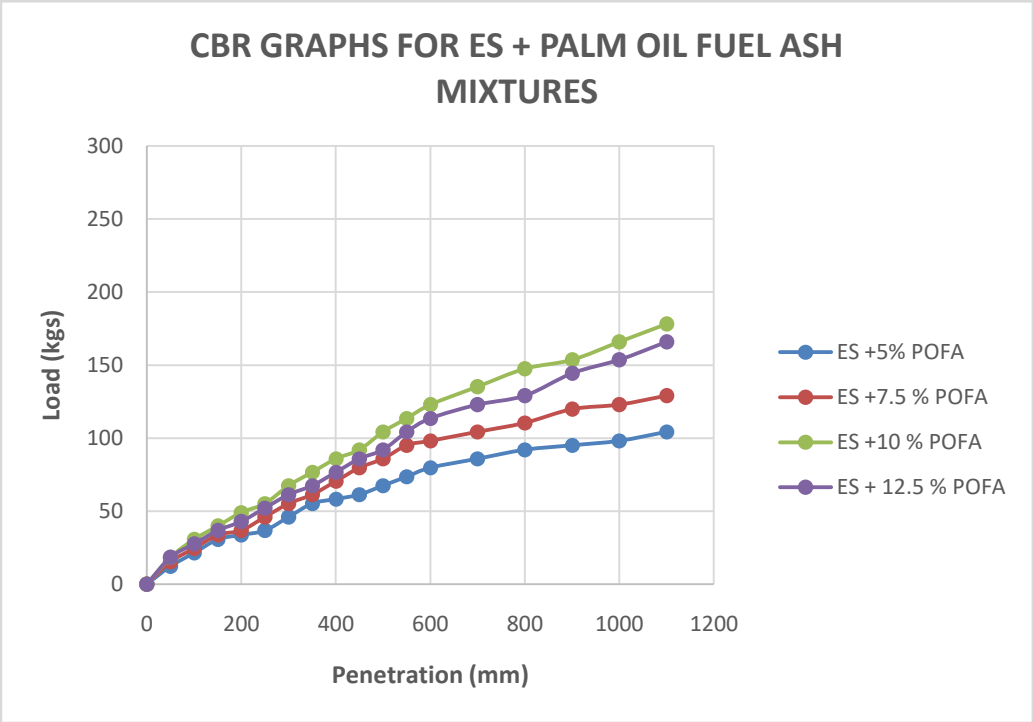

Fig 8: CBR variation of Expansive Soil treated with different percentages of Palm Oil Fuel Ash

Table 5

CBR values of Expansive soil treated with different percentages of Palm Oil Fuel Ash

Expansive Soil Treated with Different percentages of Palm Oil Fuel Ash	Soaked CBR (%)
Soil	1.84
Soil+ 5% POFA	2.69
Soil + 7.5% POFA	3.36
Soil + 10% POFA	**4.03**
Soil + 12.5% POFA	3.81

DISCUSSION-1

1. From the laboratory test results, it was observed that the CBR value of the soil has been increased to 4.03% on addition of 10% Palm Oil Fuel Ash as an optimum.

2. As per IRC:37-2012 the required subgrade CBR value for the design of Flexible pavements is 8%.

3. Hence an attempt was made to use Phosphogypsum as a chemical to further improve the strength of Expansive soil treated with Palm Oil Fuel Ash.

3. OMC & MDD values of the Expansive soil stabilised with POFA & various percentages of Phosphogypsum:

The POFA Stabilised soil was treated with different percentages of phosphogypsum to further increase the strength of the soil . Phosphogysum was added in percentages of 2%, 4%,6%,8% to the POFA stabilised Soil.

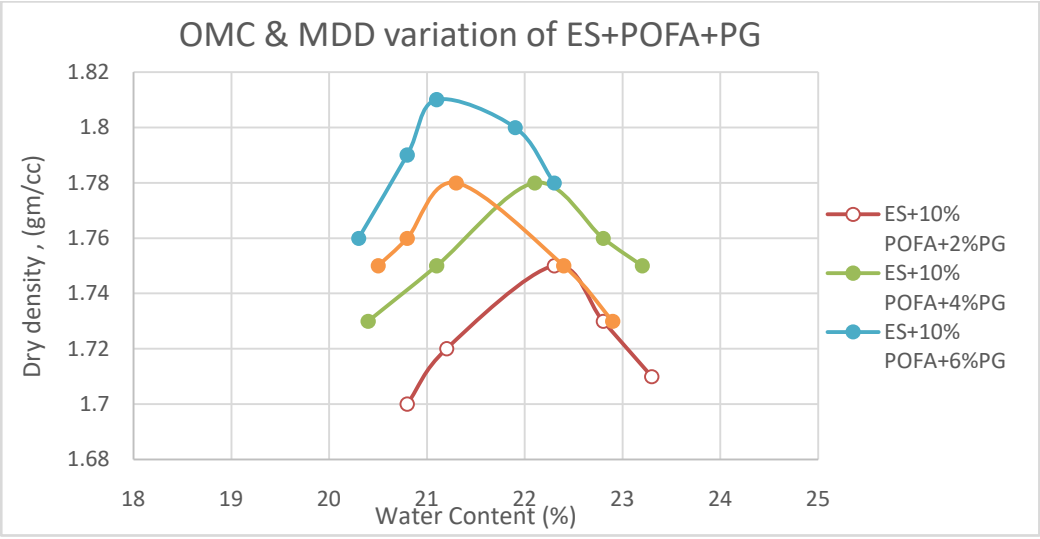

Fig 9: OMC&MDD variation of Expansive soil stabilised with POFA & various percentages of Phosphogypsum

Table 6

OMC & MDD values of Expansive soil stabilised with POFA and varying percentages of Phosphogypsum

Expansive soil Stabilised with POFA and Phosphogypsum	Maximum Dry Density (g/cc)	Optimum moisture content (%)
ES+10%POFA+2%PG	1.75	22.3
ES+10%POFA+4%PG	1.78	22.1
ES+10%POFA+6%PG	1.81	21.1
ES+10%POFA+8%PG	1.78	21.3

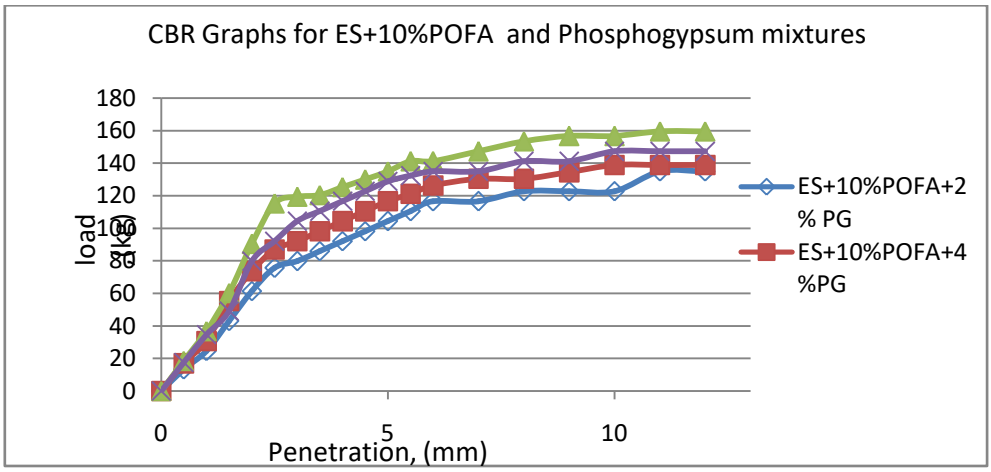

Fig 10: CBR variation of Expansive soil stabilised with POFA & treated with different percentages of Phosphogypsum

Table 7

CBR values of Expansive soil stabilised with POFA & treated with different percentages of Phosphogypsum

Expansive soil stabilised with POFA &Phosphogypsum	CBR (%)
ES+10%POFA+2%PG	5.52
ES+10%POFA+4%PG	6.34
ES+10%POFA+6%PG	8.42
ES+10%POFA+8%PG	6.72

DISCUSSIONS-2

1. From the above laborotary test results, it is observed that the CBR value of the soil increased to 8.42% , when the soil was treated with an optimum percentage of 10% Palm Oil Fuel Ash and 6% Phosphogypsum.
2. The obtained CBR value satisfies the design criteria for subgrade of Flexible pavements as per IRC:37-2012.
3. Hence the Optimum percentages of Palm Oil Fuel Ash and Phosphogypsum were used to determine the index properties liquid limit, plastic limit, Differential Free Swell, Cohesion and Angle of internal friction. The results were tabulated in Table 8.

Table 8

Geotechnical Properties of Untreated and Treated Expansive Soil

S.No	Property	Untreated Expansive Soil	Expansive soil treated with 10% of POFA	Expansive soil treated with 10% POFA and 6% PG
1	Differential Free Swell (%)	120	75	42
2	Liquid Limit (%)	80	60	45
3	Plastic Limit (%)	30.5	35.6	37.4
4	Plasticity Index (%)	49.5	24.4	7.6
5	Soil Classification	CH	CH	CI
6	Optimum Moisture Content (%)	25.42	22.8	21.1
7	Maximum Dry Density (g/cc)	1.41	1.71	1.81
8	Soaked CBR (%)	1.24	4.03	8.42
9	Cohesion (kN/m²)	97.1	76.2	64.5
10	Angle of Internal Friction Ø (^{0})	2.0	7.24	10

V.CONCLUSIONS

1. On addition of 10% of Palm Oil Fuel Ash the maximum dry density of the soil increased 21.3% and Optimum moisture content decreased by 10.3% when compared to the untreated Expansive soil.
2. Further CBR value of soil increased by 119% on addition of 10% Palm Oil Fuel Ash when compared to the untreated Expansive soil.
3. Also the index properties of the soil were improved considerably. The Liquid limit of POFA stabilised Soil reduced by 25% and Plastic limit increased by 16.7% when compared to the untreated Expansive soil.
4. Differential Free Swell of POFA stabilised Soil reduced by 35% when compared to the untreated Expansive soil.
5. At an addition of 6% of Phosphogysum to the POFA stabilised soil the properties of MDD & CBR increased, further addition of Phosphogypsum reduced the MDD & CBR values.
6. Therefore 6% of Phosphogypsum was taken as optimum chemical admixture percentage.
7. The POFA & PG stabilised soil properties were improved as, MDD value increased by 5.84% ,OMC reduced by 17% and CBR value increased by 357.6% when compared to the untreated Expansive soil.
8. The index properties of the POFA &PG stabilised soil improved as, Liquid limit reduced by 43.75% ,Plastic limit increased by 22.62% ,Differential free swell reduced by 56.67% when compared to the untreated Expansive soil.
9. Based on the above observations the optimum percentages of admixture and chemical at which the soil strength optimised was observed as , optimum Palm Oil Fuel Ash percentage was 10% and optimum Phosphogypsum was 6%.
10. According to IRC-37:2012 subgrade CBR value required for flexible pavements design is 8%. So the soil stabilised with 10% POFA, 6% PG gives a CBR value of 8.42% satisfies the design criteria of Subgrade for Flexible pavements.

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