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A Laboratory Study on the Stabilized Expansive Soil with Partial Replacement of Fly Ash and Palm Oil Fuel Ash

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Abstract. Expansive soil always creates higher problems for lightly loaded structures than the moderate to heavy loaded structures by changing its volume along with the seasonal moisture variation and unequal settlement. As a result, damage to foundation systems, structural elements and architectural features defeat the purpose for which the structures are built. Geotechnical researchers are searching for various options to mitigate the adverse nature of the expansive soil. In the present study, an attempt is made to investigate the feasibility of mixing the fly ash and palm oil fuel ash, to the expansive soil to reduce its plasticity characteristics to stabilize the expansive soil. Test results show that stabilizing with fly ash and Palm oil fuel ash enhance the properties and the strength of the expansive soil as compared to untreated expansive soil.

Keywords: Expansive Soil, Fly ash, Palm Oil Fuel Ash, Stabilization.

1 Introduction

The expansive soils undergo volume changes with the variation of moisture content in the soil mass. The construction of civil engineering projects in these types of soil deposits is very difficult. Swelling and shrinking of soil with seasonal moisture variation has always created higher problems for light loaded structures than moderate loaded structures by changing its volume along with unequal settlement may damage foundation systems, structural elements and architectural features results in loss of its function for which the structures are erected. The losses due to extensive damage to the highways running over the expansive sub-grades are estimated to be billions of dollars all over the world [1].

Geotechnical researchers are searching for various options to mitigate the adverse nature of the expansive soil. Volume change characteristics of the expansive soil can be controlled by reducing its plasticity characteristics or by a physical cementing mechanism. Therefore, soil stabilization techniques may be necessary to ensure the better stability of soil so that it can successfully sustain the load from the superstructure especially in case of soil, which is highly active. Many efforts are being made by the researchers to minimize the effect of the expansive soils on the structures constructed with or within it. Every method has its own limitations. Katti and Katti [2] recommended the use of Mechanically Stabilized Mix (MSM) cushion below the footing with CNS material. This process increases the cost of the foundation. However, studies conducted by Subba Rao [3] on the Black cotton soil stabilized with the CNS cushion become ineffective after the first swell-shrink cycle.

This has led to the use of a stabilized fly ash cushion by the researchers, because lime reacts with silica in fly ash to produce cementitious products. Thus, it serves the same purpose as a CNS material. This may also solve the problem of fly ash disposal. The efficacy of lime [4] and cement [5] stabilized fly ash cushions, in arresting heave has been established. Cement-stabilized fly ash cushion have yielded satisfactory results in arresting heave [6]. Rao et al [7] observed that the reduction in the heave of the expansive soil stabilized with the lime and fly ash.

The chemical composition of palm oil fuel ash indicates presence of high amount of silica, which may be useful to stabilize the expansive soils. Muhammad et al [8] reported that the behavior of the silty soil improved by stabilizing it with the palm oil fuel ash. Juhaizad et al [9] reported that the strength of the peat soil can be improved by the addition of cement and palm oil fuel ash.

Attempts to study about such unpredictable behavior through research on how to bring these problems under control form the backdrop for this project work. Therefore, a number of laboratory experiments were conducted to ascertain host of soil engineering properties of a naturally available expansive soil before and after stabilization. Pre-and post-stabilized results are compared to arrive at a conclusion that can thwart expansive soil problems.

In the present work, an experimental study is conducted to determine the properties of soil, the compaction, Unconfined Compression Test and California Bearing Ratio (CBR) on expansive soil as well as on the stabilized expansive soil, mixed with different percentages of fly ash and Palm oil fuel ash with a view to determine the optimum percentage. Test results show that stabilizing with fly ash and palm oil fuel ash enhance the properties and the strength of the expansive soil as compared to untreated expansive soil.

2 Experimental Program

2.1 Materials used

Soil. The soil used was a typical black cotton soil collected from ‘Mummidivaram’ near Amalapuram, in East Godavari District, Andhra Pradesh State, India. The properties of soil are presented in the table1. All the tests carried on the soil are as per IS specifications.

Table 1. Properties of Expansive Soil.

SI No.	Property	Value
1	Differential Free Swell (%)	120
2	Specific Gravity	2.62
3	Grain Size Analysis Gravel (%)	0
	Sand (%)	8
	Silt (%)	27
	Clay	65
4	Liquid Limit (%)	79.3
5	Plastic Limit (%)	30.4
6	Plasticity Index	48.9
7	Compaction	
	Optimum Moisture Content (%)	29.1
	Maximum Dry Density (g/cc)	1.43
8	Unsoaked CBR (%)	3.1
9	Soaked CBR (%)	1.3
10	Unconfined Compressive Strength (kN/m^2) at MDD & OMC	81

Fly ash. Fly ash was collected from the Rajahmundry International Paper Mill, Rajahmundry. The chemical composition of the fly ash is given in the table 2.

Table 2. Chemical Composition of Fly ash. (Courtesy: RIPM, Rajahmundry)

Name of the Chemical	Symbol	Range by Percentage of Weight
Silica	SiO_2	61 to 64.29
Alumina	Al_2O_4	21.6 to 27.04
Ferric Oxide	Fe_2O_3	3.09 to 3.86
Titanium Dioxide	TiO_2	1.25 to 1.69
Manganese Oxide	MnO	Upto 0.05
Calcium Oxide	CaO	1.02 to 3.39
Magnesium Oxide	MgO	0.5 to 1.58
Phosphorous	P	0.02 to 0.14
Sulphur Trioxide	SO_3	Upto 0.07
Potassium Oxide	K_2O	0.08 to 1.83
Sodium Oxide	Na_2O	0.26 to 0.48
Loss on ignition		0.20 to 0.85

Palm oil fuel ash. Palm oil fuel ash used for this study was collected from local Oil Industries, Samalkot, Mandal, East Godavari district of Andhra Pradesh. The chemical composition of palm oil fuel ash is given in the table 3.

Table 3. Chemical Composition of Palm Oil Fuel Ash.

Name of the Chemical	Symbol	Range by Percentage of Weight
Silica	SiO_2	55.7 to 66.91
Alumina	Al_2O_4	0.9 to 6.44
Ferric Oxide	Fe_2O_3	2.0 to 5.72
Calcium Oxide	CaO	5.56 to 12.5
Magnesium Oxide	MgO	3.13 to 5.10
	P_2O_2	0 to 3.72
Sulphur Trioxide	SO_3	0.33 to 1.90
Potassium Oxide	K_2O	5.2 to 11.9
Sodium Oxide	Na_2O	0.9 to 1.0
Loss on ignition		

2.2 Sample preparation

The soil was initially air dried, pulverized and then was sieved through a 4.75 mm sieve, prior to the testing. The samples were prepared by mixing the required quantity of pulverized soil with the predetermined fly ash in dry condition and followed by the addition of required amount of water to make a consistent mix by thorough mixing.

2.3 Laboratory experimentation

In the laboratory, the following experiments were conducted on expansive soil with different percentages of fly ash and palm oil fuel ash for various mixes. Differential free swell index (DFSI), liquid limit, plastic limit, compaction, CBR and unconfined compressive tests were conducted with a view to determine the optimum combination of fly ash and palm oil fuel ash in expansive soil.

2.4 Methodology

The experimental work is done in three stages. In the first stage laboratory tests are conducted on the clay soil, fly ash and palm oil fuel ash separately to estimate the individual behaviour of the above materials.

In the second stage, fly ash is blended with expansive soil in different proportions varying from 10% to 25% by weight of dry soil, in increments of 5 %. The maximum dry density and optimum moisture content of the corresponding soil and each combination are determined and unconfined compressive strength (UCS) and CBR tests are performed at their respective MDD and OMC. The optimum dosage of fly ash is determined based on the CBR and UCS results.

In the third phase, the optimum percentage of fly ash and palm oil fuel ash with 2.0 %, 4.0 %, 6.0% and 8.0 % were blended with Expansive Soil with a view to determine optimum percentage of fly ash and palm oil fuel ash respectively to calculate the improvement in the geotechnical properties like compaction, CBR and unconfined compressive strength tests.

3 Results and Discussion

With a view to determine the optimum combination of fly ash and Palm Oil Fuel Ash (POFA) as a replacement in expansive soil, free swell index, plasticity, shear strength and CBR tests were conducted on fly ash and POFA expansive soil mix.

3.1 Effect of stabilization on differential free swell index

From the figure 1, we can observe the free swell index is decreasing with the increase in fly ash replaced in the expansive soil. The differential free swell index is decreasing from 120 to 108, 95, 86 and 78 respectively, for 5, 10, 15, 20 and 25% fly ash replaced in the expansive soil. Figures 2 show the variation of free swell index of 20 % fly ash, as a replacement in the expansive clay and mixed with different percentages of Palm Oil fuel ash. The percentage of palm oil fuel ash varied from 0 to 8 % with an increment 2 %. The DFS value decreased from 86 to 41 with the addition of palm oil fuel ash by 8%. It can be observed that further reduction in the free swell index with the increase in percentage of palm oil fuel ash in the fly ash expansive soil mix. This phenomenon clearly gives an idea of the improvement of the weak expansive clay when partly replaced with a non-plastic waste, i.e. fly ash and agro waste material, i.e., POFA.

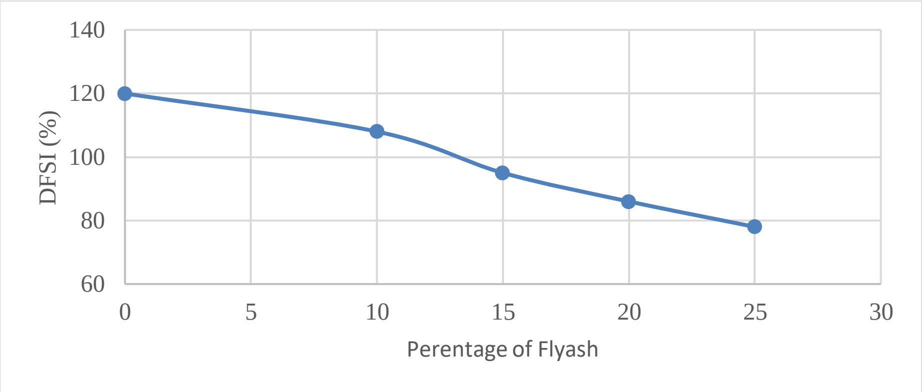

Fig.1. Variation of Differential Free Swell of Stabilized Expansive Soil with the Percentage of Replacement of Fly Ash

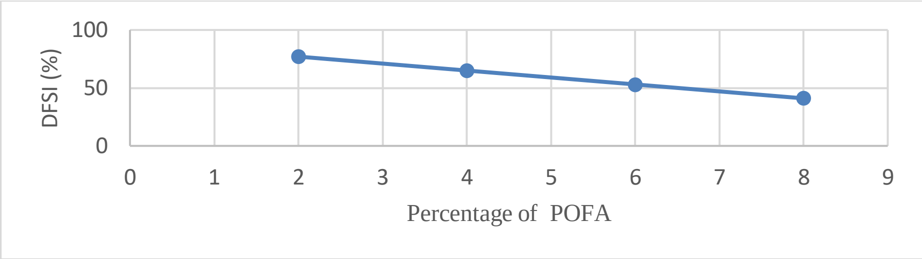

Fig.2. Variation of Differential Free Swell with the Palm Oil fuel ash of stabilized expansive soil with the 20% fly ash as replacement

3.2 Effect of stabilization on the Atterberg's limits

The variation of liquid limit and plastic limit of the stabilized soil mix with the percentage of replacement of fly ash in expansive soil is presented in Fig.3. With the increase in percentage of replacing fly ash in the stabilized soil mix from 0 to 25%, the liquid limit decreased from 79.3 to 64.2 and the plastic limit increased from 30.4 to 39.7. This phenomenon may be resulted due to the some portion of plastic soil replaced with a non-plastic waste material. The effect of palm oil fuel ash as a replacement in expansive soil was presented in Fig. 4. The liquid limit further reduced from 68.5 to 54.1 and the plastic limit increases from 38.2 to 42, with for the stabilised expansive clay with 8 % the palm oil fuel ash and 20% fly ash as a replacement in the expansive soil.

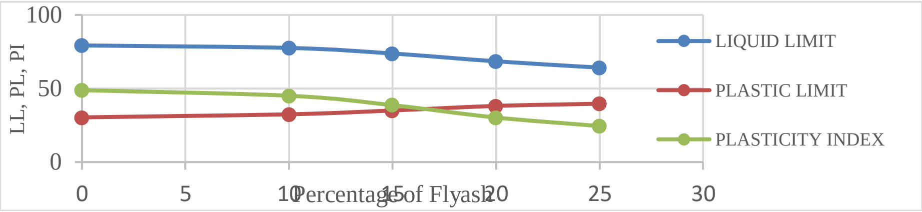

Fig.3. Variation of Liquid Limit, Plastic Limit and Plasticity Index with the Percentage of Replacement of Fly Ash

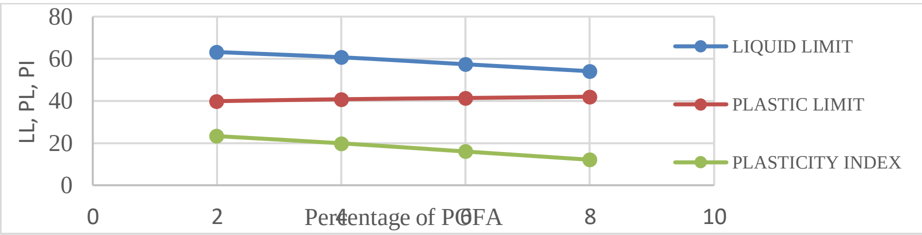

Fig.4. Variation of Liquid Limit, Plastic Limit and Plasticity Index with the Percentage of Palm Oil fuel ash of Stabilized Expansive Soil with the 20% Fly Ash as Replacement

3.3 Effect of stabilization on compaction properties

The variation in maximum dry density and optimum moisture content with the partial replacement in expansive soil with the fly ash are presented in the Fig. 5. The maximum dry density is obtained as 1.47 g/cc at 20% partial replacement of fly ash in expansive soil. The corresponding OMC is 25.60% as shown in Fig. 5. The maximum dry density of the stabilized expansive soil further increases from 1.49 to 1.56 and the corresponding optimum moisture content decreases from 23.80 to 21.20 for further replacement with the palm oil fuel ash as shown in Fig. 6 for 20% replaced the fly ash in the expansive soil.

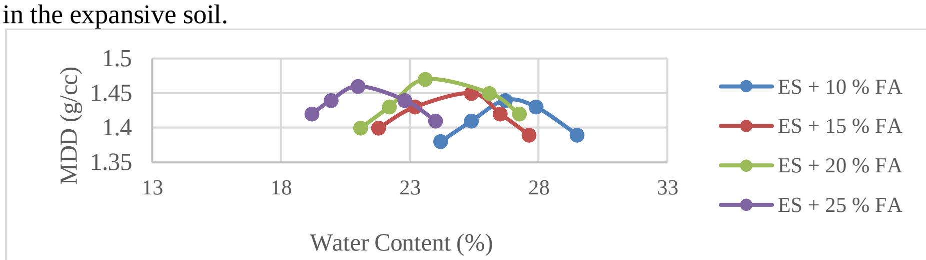

Fig.5. Variation of Dry Density and Moisture Content with the Percentage of replacement of Fly ash

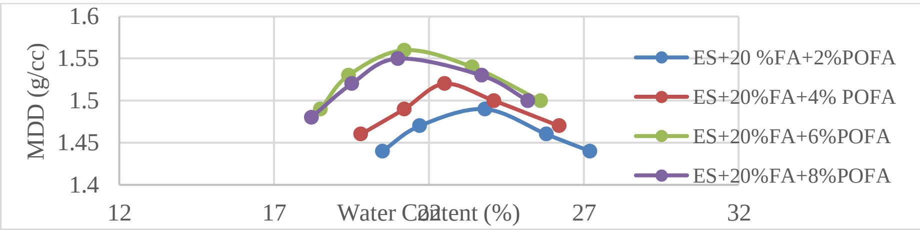

Fig.6. Variation of Dry Density and Moisture Content with the Percentage of Palm Oil fuel ash of stabilized expansive soil with the 20% fly ash as replacement

3.4 Effect of stabilization on CBR

The variation of CBR value with the partial replacement of fly ash in the expansive soil is presented in the figure 7. It can be observed that the maximum soaked CBR values are obtained for the 20% of fly ash replaced in the expansive soil. The soaked CBR values are increased from 1.30 to 4.20 for a 20% replaced fly ash in the expansive soil. Further replacement of fly ash results in decreasing the CBR value. This trend may be because of more non-plastic material results in reduction of binding property of the soil. The Fig. 8 shows the variation of further improvement in CBR values with the further replacement of expansive soil with palm oil fuel ash. The soaked CBR values are further increases from 4.70 to 6.80 for an optimum combination of 20 % fly ash and 6% palm oil fuel as replaced in the expansive soil.

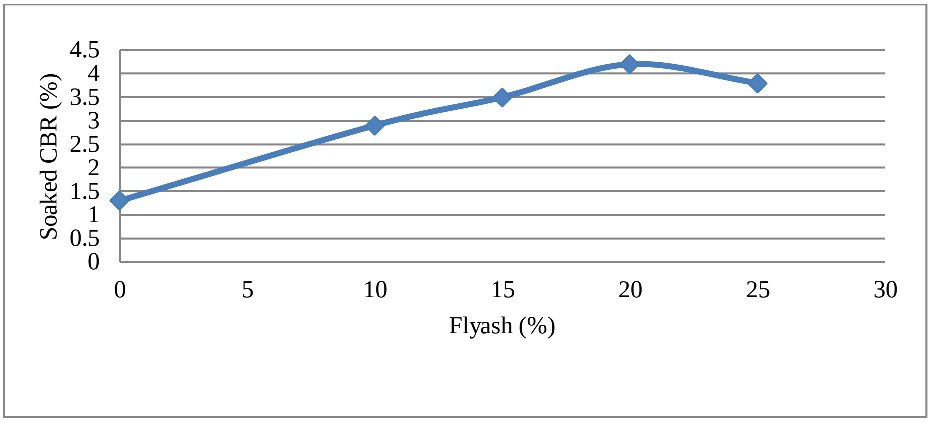

Fig.7. Variation of Soaked CBR with the Percentage of Replacement of Fly Ash

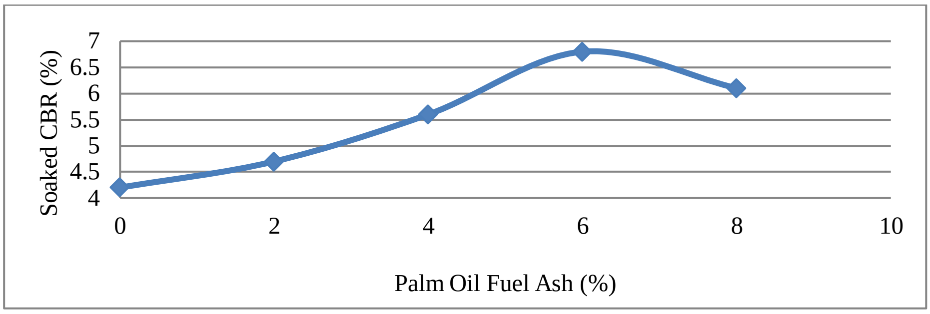

Fig.8. Variation of Soaked CBR with the Percentage of Palm Oil Fuel Ash of Stabilized Expansive Soil with the 20% Fly Ash as Replacement

3.5 Effect of stabilization on Unconfined compressive strength

Figure 9 shows the variation of unconfined strength with the partial replacement of fly ash in the expansive soil. The specimen is prepared at maximum dry density and optimum moisture content. The unconfined compressive strength is increased from 81 kPa to 133 kPa with the partial replacement of fly ash from 0 to 20%. A decrease in unconfined strength is observed in 25% partial replaced fly ash in the expansive soil. The effect on unconfined compressive strength, for the stabilized mix with optimum fly ash and palm oil fuel ash is shown in Fig. 10. It was observed that the increasing POFA, the unconfined compressive strength is increased from 158 kPa to 225 kPa.

Penetration resistance and the strength of the soil improved may be due to the development of bonding between the plastic and non plastic soil particles at optimum combination. Hence, it can be summarized from the results of the experimental study, ascertain the objective of improving the weak expansive clay by using fly ash and an agro waste, Palm Oil Fuel Ash (POFA), thereby giving a twofold advantage of improving weak expansive clay with a sustainable solution by reusing the waste materials effectively.

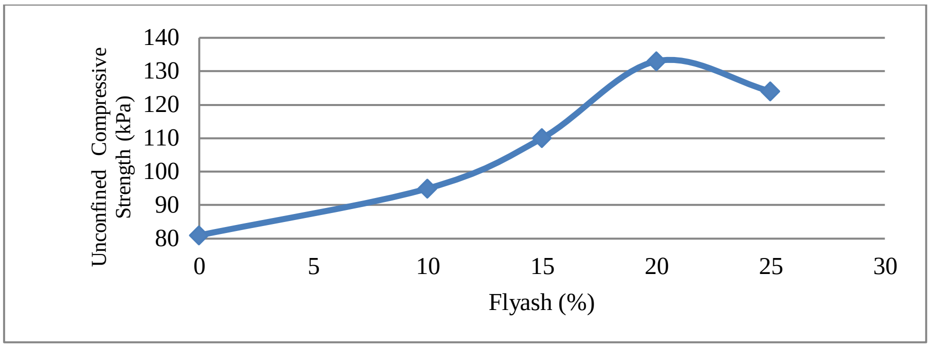

Fig.9. Variation of Unconfined Compressive Strength with the Percentage of Replacement of Fly Ash

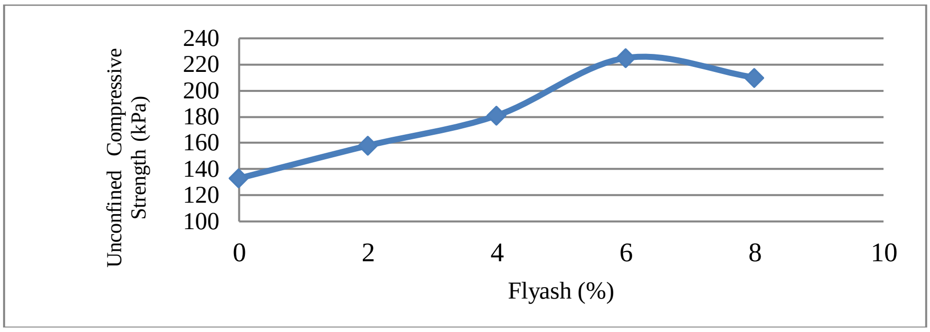

Fig.10. Variation of Unconfined Compressive Strength with the Percentage of Palm Oil Fuel ash of Stabilized Expansive Soil with the 20% Fly Ash as Replacement

4 Conclusions

The following conclusions may be drawn based on the experimental results.

1. The differential free swell is reduced by 28.3% with the 20 % fly ash as a replacement in the expansive Clay. It can be further reduced by 27.5%, a total of 55.8% reduction with the addition of 6% Palm Oil Fuel Ash.
2. The replacement of fly ash by 20 % in the expansive soil had reduced the virgin Plasticity Index of the expansive clay by about 38 % and on further addition of palm oil fuel as by 6 % it had further reduced by about 29.2 %. This is due to the replacement of plastic soil with a non-plastic waste material.
3. The soaked CBR values have increased by about 223 % and 423 %, respectively, with 20% fly ash as a replacement and with further addition of palm oil fuel ash by 6 %.

4. The unconfined compressive strength is increased by about 64.2 %, with 20 % of fly ash replaced in expansive soil. The unconfined compressive strength is increased by about 177 % with the further addition of 6% palm oil fuel.
5. The present study concluded that problematic expansive clay was improved with a sustainable solution by reusing the waste materials giving a dual advantage.

References

1. Jones, D.E. and Holtz, W.G.: Expansive Soils - the Hidden Disaster Civil Engineering, Vol. 43, No. 8 (1973).
2. Katti, A.R and Katti, R.K.:, Procedure for design and construction of shallow foundations in expansive clayey soils with CNS and MSM technology. Seminar on partially saturated soils and expansive soils, IGC, Kakinada, PP 5 – 14 (1996).
3. Subba Rao,K.S.: Swell-shrink behavior of expansive soils-Geotechnical challenges. IGS Annual lecture, Calcutta (1999).
4. Nanda Kishore, Y.: A study on minimizing swell of expansive clay bed with lime-stabilized fly ash cushion. A thesis submitted to Jawaharlal Nehru Technological University, Kakinada (2003).
5. Prasad, S.: A study on minimizing swell of expansive clay bed with cement-stabilized fly ash cushion. A thesis submitted to Jawaharlal Nehru Technological University, Kakinada (2002).
6. Sreerama Rao,A., Seelam Prasad, Madhuri Manmadha and Dayakar Babu , R.: Use of cement-stabilized fly ash cushion in minimizing swell of expansive clays. Geotechnical Engineering for Infrastructural Development, IGC 2003, Roorkee, pp 455-458 (2003)
7. Sreerama Rao, A., Dayakar Babu, R., and Gopal Krishna Reddy, G.: (2004), Efficacy of Lime Stabilized Fly Ash Cushion in Arresting Heave of Expansive Clay Bed, IGC 2004 Warangal (2004)
8. Muhammad, S. A., Muhammad, H. O., Mohd, F. A., Chow, S.H. and Damanhuri, J.: Performance of POFA with Lime as Stabilising Agent for Soil Improvement. Esteem, Vol. 5, No.1, 2009.
9. Juhaizad, A., Abdul, S., Abdul, R., Mohd, Ridzuan, M. A. and Khif, F. A. R.: Peat Soil Treatment using POFA. IEEE colloquium on Humanities, Science and Engineering research Dec 5-6, Penang. (2011)