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EFFECT OF DESICCATION ON THE GEOTECHNICAL PROPERTIES OF LIME-FLY ASH STABILIZED COLLAPSIBLE RESIDUAL SAND

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ABSTRACT

Berea Red Sands underlying most of the Kwazulu Natal midlands and coastal plain is a very recent unconsolidated, weakly cemented red to brown, collapsible sands. The effect of wetting and drying cycles on the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) of compacted and cured samples of stabilized Berea Sands was investigated. Different sample mix were prepared with 4% and 8% Lime and 0%, 6% 12% and 18% Fly Ash, and tested after 4, 8 and 12 cycles of wetting and drying. Changes in mass of the stabilized sands were measured to facilitate the interpretation of changes in strength properties. The results showed reduction in UCS and CBR with increase in the number of wetting and drying cycles that is dependent on the amount of Lime and Fly Ash and the ratio of Lime to Fly Ash. For given amount of Fly Ash, samples stabilized with 8% Lime are more durable than samples stabilized with 4% Lime. For samples stabilized with 8% Lime, increase in Fly Ash quantities results in an increase in durability for up to 18% Fly Ash used in this research. The process of wetting and drying results in general reduction in the mass of the test samples, and the percentage reduction in mass decreases with increase in quantities of Fly Ash. In the long term, defined by 12 cycles of wetting and drying, only the 8% lime and 18% fly ash material have adequate CBR under the operative drainage conditions to sustain the stresses applied by traffic loadings.

Keyword: collapsible sand, fly ash, durability, unconfined compression strength, california bearing ratio.

INTRODUCTION

The weathering of rock and soil deposits in tropical and semi arid environments result in formation of highly variable macro structure and strength properties. In some cases, the soil particle matrix is collapsible, necessitating the treatment of such materials before use as subgrade and other road layer to ensure the retainment of macro structural integrity with minimal degradation under the combined effect of extreme climatic and axle loading over the designed service period. Berea Red Sand that underlies most of the West Coast of South Africa from Kwazulu Natal coastline to Morgan Bay in East London is a weakly cemented reddish coastal plain weathering product of the Sandstone and Calcarenite that underlie most of the Indian Ocean coast line of South Africa. It has been associated with the failure of roads and buildings as well as land slide and slope instability problems associated with the inherently unstable seaward dipping (Jennings and Knight 1975), because its physical and engineering properties vary significantly both laterally and vertically (Maud, 1968 and Brink 1984 and Mcknight 1999).

Efforts to stabilized Berea Sand with Cement, Lime and Hydrocarbons are not well reported, but Maud (1968) noted significant improvement in the CBR of Lime stabilized Berea Sand, while Paige Green and Garryts (1998) reported excellent performance by base courses designed with foamed bitumen mixed with Berea sand and cement for low traffic volume roads. Bennets *et al*., (2002) evaluated the average field strength and cost of base courses of Berea Sands stabilized with Lime, Bitumen seals and Cement stabilized sands. They reported relatively low maintenance cost and acceptable design strength for Lime stabilized Berea Sand pavement. In general, while reports on the effect of the stabilization of Berea Sand with Lime, Cement, Lime - Fly Ash and Cement - Fly Ash are not well reported, extensive literature on the positive effect of Lime stabilization on the strength of soils abound (Ola, 1977, Al Khalaf and Yousif 1984, Rahman, 1986, Hossain *et al*., 2007, Ali *et al*., 1992).

The benefits of Industrial by-products like GGBS, Fly Ash, and Silica Fume in soil stabilization have been fairly well reported in studies documented by Sezer *et al*., 2006, Kolias *et al*., 2005, Basha *et al*., 2005).

Findings from significant number of research studies on the durability of Lime and Fly Ash stabilized clayey soils (Shihata *et al*., 2001 and Ali *et al*., 1992) suggest that the wetting and drying cycles can result in either strength improvement or deterioration depending on the soil type, fine content, mineralogy, percentage of additive and test method. Because of the inherent mineralogical and structural variability of residual tropical soils, laboratory study would be required to establish their stability in relation to Lime - Fly Ash stabilization.

In South Africa, power station Fly Ash is disposed off by either dry dumping or by hydraulic deposition into ash dams (Fourie and Blight 1999). Series of geotechnical and chemical tests on Fly Ash collected from some of the stations revealed the presence of significant amounts of free lime, quartz, alumina and iron oxide, indicating high likelihood of pozzolanic hardening of the ashes (Fourie *et al*., 1997, Fourie *et al*., 1998). The availability of Fly Ash provided the impetus for the study of the effect of Fly Ash on the durability of Lime stabilized collapsible residual sands in typical tropical environments of high rainfall intensity and scorching sunshine. The main objective of this investigation is to evaluate the durability of compacted Lime and Fly Ash stabilized Berea Sands. It is intended to use Fly Ash as a replacement for fines and also to take advantage of the pozzolanic property.

MATERIALS AND METHODS

Mineralogy and physical properties of the test materials

The Berea Sand used in this research was collected from construction site within the Pinetown Campus of Howard College. The major physical properties are shown in Table-1. The particle size distribution is plotted in conjunction with the range given by Brink (1980) in Figure-1. The samples plot at the lower zone of the band. Brink (1980) noted that the moderately weathered sand containing significant amount of fines plots in the upper region while the most recent formations with limited fine plot in the lower region and is uniformly graded sand. Details of the major constituent minerals determined by X - Ray diffraction method shown in Table-2 indicate the presence of hematite in the 0.25mm fractions. The major minerals are quartz and kaolin. The percentage constitution of the major active compounds are $Si0_2$ = 62.68 %; Al_2O_3 = 19.48%; Fe_2O_3 = 13.56%; CaO = 0.83%.

Table-1. The physical properties of Berea sands.

Particle gradation	Atterberg limit	Specific gravity	Asstho compaction
Gravel = 0 Sand = 75 Silt = 8 Clay = 18	LL = 15 PL = 3 SL = 3%	D $_{2.0}$ = 2.67 D $_{0.075}$= 2.69 D $_{0.425}$= 2.71	MDD = 18.02 Mg/m^3 OMC = 10.2%

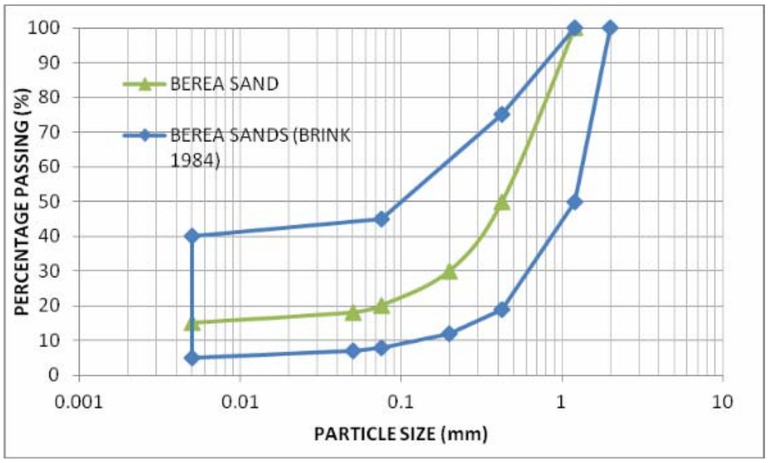

Figure-1. Particle size curve of Berea sands.

Table-2. Mineral constitution of Berea sands.

0.075mm Berea sand			**0.150mm Berea sand**		
Angle (˚2ϴ)	**Relative intensity** (%)	**Clay type**	**Angle** (˚2ϴ)	**Relative intensity** (%)	**Clay type**
5.255	2.6	Kaoline	14.3	1.3	Kaolin
14.315	3.2	Kaoline	21.6	0.3	Kaolin
27.71	1.6	Kaoline	23.3	1.3	Kaolin
23.105	5.5	Kaoline	24.27	14.8	Quartz
24.245	23.6	Quartz	27.72	3.2	Hematite
29.205	1.8	Kaoline	29.115	0.6	Kaolin
31.015	100	Quartz	31.040	100	Quartz

Hydrated Lime is produced by adding to quicklime sufficient moisture to satisfy its affinity for water under hydration conditions. It is less dangerous to handle than quicklime although they are both caustic and produce heat upon contact with water. The percentage constitution of the major active compounds in the commercially available hydrated lime used for this study are SiO_2 = 2.23%; Al_2O_3 = 0.19%; Fe_2O_3 = 0.27; CaO = 93.87.

Fly Ash is a waste product that accounts for approximately three fourths of the residue obtained from burning pulverized coal in electrical power stations for the generation of electricity. It is a pozollanic material, consisting of non - crystalline silicate and aluminates particles and rounded magnetic iron oxide (Fe_3O_4) grains, materials which when mixed with other chemicals like Cement or Lime containing calcium and in the presence of water can enhance cementation. The percentage constitution of the major active compounds are SiO_2 = 83.0 %; Al_2O_3 = 8.0 %; Fe_2O_3 = 2.65; CaO = 0.18.

Sample preparation

Batches of Berea Sand were thoroughly mixed with the required amount of Lime, Fly Ash and water. The mix combinations are 4% and 8% Lime stabilizer and 0%, 6%, 12% and 18% Fly Ash additive. The samples are left to equilibrate for 24 hours prior to compaction. The Maximum Dry Density and Optimum Water Content for each mix is determined according to the standard AASTHO compaction method TMH1 1996.

Compacted specimens are cured for 7 days at a relative humidity of 95 to 100 per cent and temperature of 22^0C to 25^0C in a curing room. Samples were cured prior to compression testing and while the curing times adopted were 7 days, a limited number of samples were also cured for 28 days, all by the use of permeable hessian bags to cover the samples and water sprinkled constantly on the cover over the seven day period (TMH1, 1996).

After 7 days the specimens are removed from the curing room. Specimens were completely immersed in distilled water for 12hrs hours and then dried at 40˚C for 36 hours. This completes one cycle of drying and wetting. The selected numbers of cycles are 4, 8 and 12 cycles of wetting and drying. After the designated cycles of drying and wetting, the mass of the specimens are measured before testing for Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR).

For the UCS two sets of samples were cured for 7days and 28 days before being subjected to cycles of wetting and drying. CBR tests were conducted on sands stabilized with combinations of 4% and 8% Lime and 12% and 18% Fly Ash. The samples were compacted at the respective OMC to 95% of the associated Modified AASTHO MDD, soaked for seven days and then subjected to cycles of drying and wetting.

For the implementation of low - cost road projects in developing countries, CBR of naturally occurring materials is the most common design parameter. It remains a simple and direct parameter for the design of roads and can also the correlated with other more complex mechanical pavement parameters. In conjunction with the UCS and other basic physical properties, it has formed the basis of the Catalogue method of Design specified in the TRH 4.

The CBR values were determined on two set of samples, the first is 4% lime and 6% and 12% fly ash soil mix and the second is 8% lime and 6% and 12% fly ash soil mixes. The soil mixes were compacted to 95% mod AASTHO MDD and OMC and tested after curing for 7 days. The tests were conducted on each compacted sample after soaking for 7days. The CBR tests were conducted in accordance with TMH1(1996).

Table-3. Test programme.

MIX	Wetting and drying cycles					
	After 7 days curing			After 28 days curing		
4% Lime 0% Fly ash	UCS	UCS	UCS	UCS	UCS	UCS
4% Lime 6% Fly ash	UCS	UCS	UCS	UCS	UCS	UCS
4% Lime 12% Fly ash	UCS CBR	UCS CBR	UCS CBR	UCS	UCS	UCS
4% Lime 18% Fly ash	UCS CBR	UCS CBR	UCS CBR	UCS	UCS	UCS
8% Lime 0% Fly ash	UCS	UCS	UCS	UCS	UCS	UCS
8% Lime 6% Fly ash	UCS	UCS	UCS	UCS	UCS	UCS
8% Lime 12% Fly ash	UCS CBR	UCS CBR	UCS CBR	UCS	UCS	UCS
8% Lime 18% Fly ash	UCS CBR	UCS CBR	UCS CBR	UCS	UCS	UCS

RESULTS AND DISCUSSIONS

MDD and OMC of stabilized soils

The MDD of Berea Sand is 18.08 Mg/m^3 and the OMC is 10.2%. The initial series of test were conducted to determine the ASSTHO MDD and OMC of Berea Sands that were stabilized with 4% Lime and 8% Lime, as well as the effect of addition of Fly Ash on these values. The results are presented in Figure-2(a) and Figure-2(b); show that for the same comp active effort, the addition of Lime alone decreases the MDD and increase the OMC. The marginal change in density and moisture content is associated with limited amount of silica and alumina in the clay required to cause flocculation and coagulation. Further decrease in density and increase in moisture content was indicated by samples stabilized with increasing amount of Fly ash.

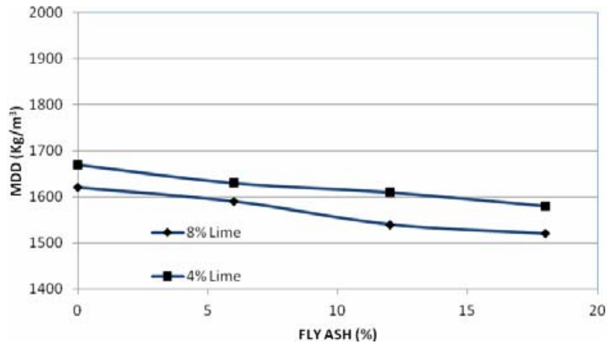

Figure-2(a). MDD of lime - fly ash stabilized Berea sands.

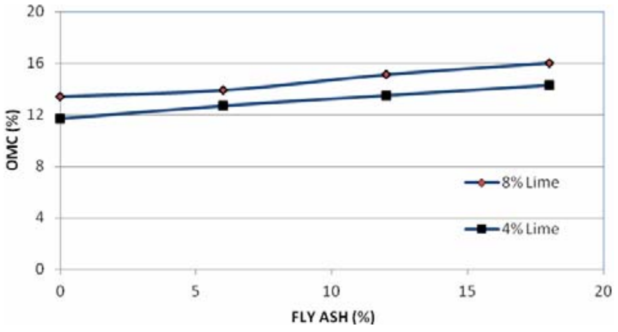

Figure-2(b). OMC of lime - fly ash stabilized Berea sands.

The increase in optimum moisture content is due to water absorption by Fly Ash and the increase in amount of held water associated with lime induced coagulation and flocculation of clay particles water held within the flocculent soil structure resulting from lime interaction (Ali *et al*., 1992). The significant decrease in maximum dry density of due to fly ash additives is indicative of increased resistance offered by the flocculants soil structure to the comp active effort. Fly-ash particles contain significant electric charge that causes particle - particle repulsion and bulking of mix material which is detrimental to compaction. The presence of Fly ash in excess of the amount required for reaction with Lime lead to reduction in dry density associated with the reduced specific gravity of the fly ash (Ali *et al*., 1992).

The effect of curing and wetting and drying on UCS

The UCS test remains the standard and most common strength test used for the evaluation of the strength of materials utilized in the construction of simple and low cost structures i.e., small dams, levees, stabilized earth retaining walls and artificial embankments.

The result of samples cured for seven days before being subjected to cycles of wetting and drying are shown in Figure-3 for the 4% Lime mix and in Figure-4 for the 8% lime mix.

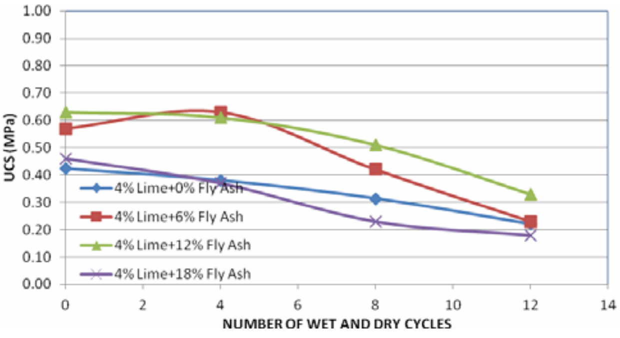

Figure-3. UCS of 4% lime and flyash stabilized Berea sands.

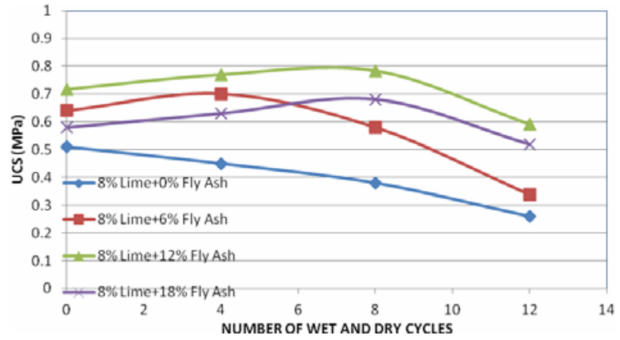

Figure-4. UCS of 8% lime and flyash stabilized Berea sands.

The effects of Fly Ash additive on the durability of samples subjected to 4, 8 and 12 cycles are strongly depicted. The general trend is increment in strength development with the addition of Fly Ash until an optimum value of 12% is reached, above which the strength begins to drop. The unconfined compressive strength results show that improvement in strength in the Lime stabilized soil can be enhanced by adding Fly ash.

From Figures 4 and 5 it can be seen that lime stabilization alone enhances the strength characteristics of the soil. The gain in strength due to the pozzolanic reaction between amorphous silica and or alumina from the soil and lime to form various types of cementing agents. The introduction of Fly ash results in additional amounts of amorphous silica being available for reaction with lime resulting in a further increase in strength. The drop in strength after the optimum is reached is due to the addition of Fly ash of relative lower specific gravity, in excess of the amount needed for the reaction with the available lime (Ali *et al*., 1992). Both the 4% Lime and 8% Lime mixes show that the strength continues to increase until the 12 cycles of wetting and drying, above which a decrement in strength for subsequent cycles occurs. However the number of cycles at which the peak is reached is dependent of the percentage lime in the mix. For the mixes containing 4% lime the peak is reached at the 8 cycles, however for the 8% lime mix the peak strength was developed after only 4 cycles, This may be due to the development of a significant percentage of maximum strength during the curing stage due to the availability of sufficient quantity of lime for the completion of the pozzollanic reaction.

The result of samples cured for 28 days before being subjected to cycles of wetting and drying are shown in Figure-5 and Figure-6 for the 4% lime mix and 8% lime mix respectively. Similar to the samples cured for 7days, for the number of soak dry cycles used, the peak strength was developed by the mix with 12 percent fly ash.

However unlike the soil mixes cured for 7days, the strength of soil mixes cured for 28 days decreases with increase in the number of cycles. The rate of deterioration in strength is dependent on the percentage of lime. The 8% lime mixes with 12% lime additive is the most durable at it has the least rate of cycle induced decay in strength.

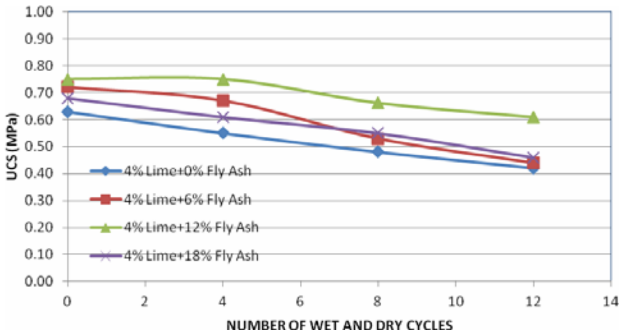

Figure-5. UCS of 4% lime and flyash stabilized Berea sands.

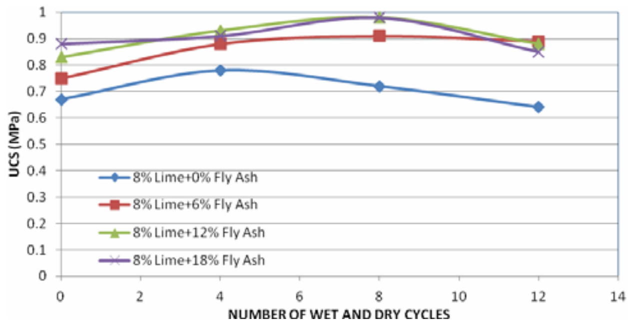

Figure-6. UCS of 8% lime and flyash stabilized Berea sands.

Residual mass and moisture absorbion upon wetting and drying

After each cycle of wetting and drying the samples are weighed. Due to the absorption of water and simultaneous loss of materials, the effective mass of the samples at the end of each cycle changes in relation to specimen constitution, curing programme and number of wetting and dry cycles. Table 2 shows the mass of the samples after different cycles of wetting and drying.

As illustrated in Table-4, the mixes with 4% Lime that were cured for 7days experienced the most amount of mass reduction. There is a general trend of increased specimen stability with increase in curing periods. The samples cured for 28 days experienced the least reduction in mass. There is also a general trend of decreased specimen stability with increase in the number of cycles. There is a weak correlation between the curing period and the mobilized compressive strength. The samples that were cured for 28 days exhibited higher compressive strength and experienced minimum reduction in mass during the wetting and drying cycles. The improved sample stability experienced by the specimens with high percentage of fly ash is also associated with the changes in the water absorption potentials of the mixes. The samples mix with 18 % Fly ash show the least amount of water absorption. This trend is followed by both the 4% and the 8% mixes. It was observed that the moisture absorption at 6% Fly ash content is less than that at 0% Fly ash content but the strength at 6% Fly ash content is higher than that at 0% Fly ash content and thus strength increases with decreasing moisture absorption. However the trend is not linear as it was also observed that some samoles with increased fly ash content also absorbed more water that samples withot fly ash. This is reflected by in Figure-3 and Figure-4 where the unconfined compressive strength results show that the strength increases up until 12% Fly Ash content, after which the strength drops. However for those mixes containing 4% lime the correlation between strength and mass loass is weak for samples cured for 7 days.

Table-4. The Effect of wetting and drying cycles on the average percentage change in sample mass.

Average percentage in mass (%)				
No. of cycles	**7days cured**		**28 days cured**	
	4 % Lime	**8 % Lime**	**4 % Lime**	**8 % Lime**
4	2.3	2.4	1.5	1.4
8	2.8	2.3	1.8	1.7
12	4.3	2.9	1.8	1.9

The effect of curing and cyclic moisture on CBR

The CBR number is used to rate the performance of soils primarily for use as bases and sub grades beneath airfields and road pavement, It is a measure of shearing resistance of a soil that is laterally confined, under controlled moisture and density conditions, and because the CBR test is relatively simple and cheap and can be run on standard loading frames, it is widely used for low cost road projects (TRRL, 1988).

The result of series of CBR tests shown in Figures 7 to 10 reflects a trend of decreasing CBR with increase in piston penetration, and increasing CBR with increase in piston penetration. The significant drop in piston penetration exhibited by samples mixed with 4% lime and 12% Fly Ash is a reflection of non uniform bulk density resulting from the cycles of wetting and drying. Also the CBR increases from 4 cycles to 8 cycles and then drop at 12 cycles. The average CBR of the 8% Lime mixes are higher than the CBR of the 4% Lime mixes. This trend is exhibited by all the samples irrespective of Lime and Fly ash content. The trend suggests that the strength development due to the pozzolanic reaction between amorphous silica and / or alumina from the soil and lime to form various types of cementing agents is dependent on the quantity of fly ash used up in the reaction. For the 8% lime mixes, 12% fly ash provides sufficient additional silica for the reaction, while the amount of fly ash required for optimum reaction in the 4% lime mix is less than 12%. The excess fly ash simply contributed to the drop in strength.

It can also be deduced from Figures 7 to 10, that the lower percentage of fly ash i.e. 12% produced stronger and more durable samples than 18% fly ash irrespective of the quantity of lime in the mix. The drop in strength of the mixes containing higher amount of fly ash is also significant. In the long term, defined by 12 cycles of wetting and drying, the difference in strength between the two 4% lime mixes is also significant. For the 4% lime and 12% fly ash mixes, four cycles of wetting and drying induced similar effect as curing i.e., increased strength development.

The results shown in Figures 7 to 10 indicate that the strength of mixes at 12 cycles of wetting and drying are very low and, can only be used in the subgrade layer of the pavement. Only the 8% lime and 18% fly ash material have adequate shear strength under the operative drainage conditions to sustain the stresses applied by traffic loadings (TRH4 1996).

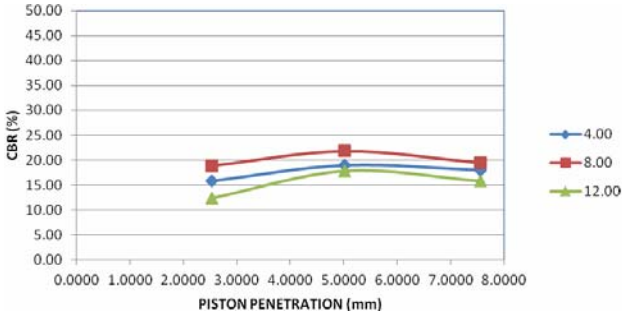

Figure-7. CBR of 4% lime and 12% flyash stabilized Berea sands.

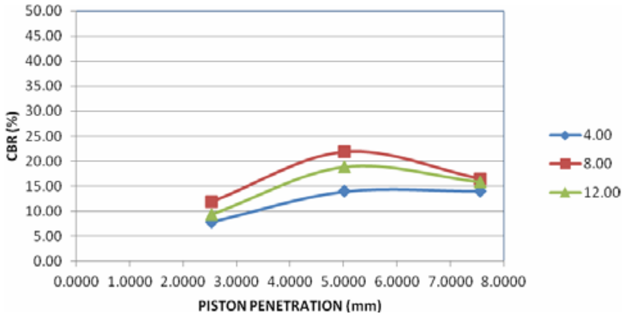

Figure-8. CBR of 4% lime and 18% flyash stabilized Berea sands.

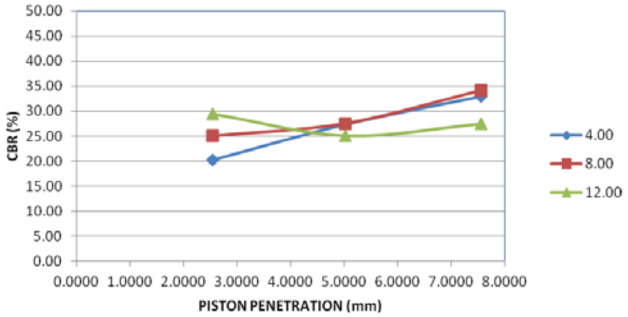

Figure-9. CBR of 8% lime and 12 % flyash stabilized Berea sands.

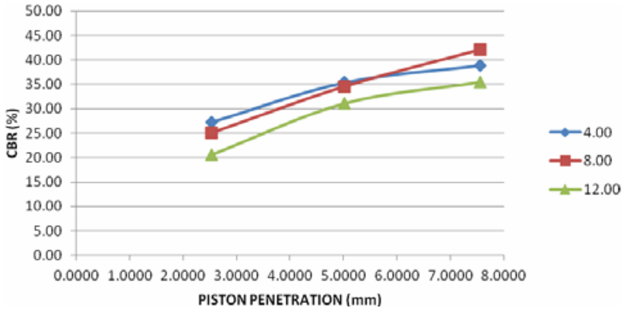

Figure-10. CBR of 8% lime and 18% flyash stabilized Berea sands.

CONCLUSIONS

- The addition of Fly Ash increases the optimum moisture content and decreases the maximum dry density. These changes are associated with the increased coagulation of the fines in the presence of the Fly ash and the lower specific gravity of the Fly ash displacing the sand particles;
- The cycles of wetting and drying results in increase in UCS after few cycles (four cycles) and decrease in UCS with increase in the number of wetting and drying cycles;
- Wetting and drying induced reduction in strength decreases with increase in Fly Ash, to a maximum UCS associated with 12% Fly Ash for 4% Lime stabilized soil. For Fly Ash content greater than 12%, increased cycle of wetting and drying result in

significant decrease in UCS associated with Fly Ash quantities that were not utilized in the pozzolanic reaction;

- Cycles of wetting and drying results in loss of mass of test samples, the percentage decrease in mass decreases with increase in Fly Ash;
- The CBR of the stabilized mix increases with increase in the quantities of Lime and Fly Ash and decreases with increasing cycles of wetting and drying;
- The significant drop in piston penetration exhibited by samples mixed with 4% lime and 12% Fly Ash is a reflection of non uniform bulk density resulting from the cycles of wetting and drying; and
- In the long term, defined by 12 cycles of wetting and drying, only the 8% lime and 18% fly ash material have adequate shear strength under the operative drainage conditions to sustain the stresses applied by traffic loadings.

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