Geomechanics and Engineering, *Vol. 12, No. 3 (2017) 523-539*
DOI: https://doi.org/10.12989/gae.2017.12.3.523

Experimental and modelling study of clay stabilized with bottom ash-eco sand slurry pile

Sathyapriya Subramanian [*1], P.D. Arumairaj [1] and T. Subramani [2]

[1] *Department of Civil Engineering, Government College of Technology, Coimbatore, India*
[2] *Department of Mining Engineering, Anna University, Chennai, India*

(*Received April 24, 2016, Revised November 16, 2016, Accepted November 19, 2016*)

Abstract. Clay soils are typical for their swelling properties upon absorption of water during rains and development of cracks during summer time owing to the profile desorption of water through the inter-connected soil pores by water vapour diffusion leading to evaporation. This type of unstable soil phenomenon by and large poses a serious threat to the strength and stability of structures when rest on such type of soils. Even as lime and cement are extensively used for stabilization of clay soils it has become imperative to find relatively cheaper alternative materials to bring out the desired properties within the clay soil domain. In the present era of catastrophic environmental degradation as a side effect to modernized manufacturing processes, industrialization and urbanization the creative idea would be treating the waste products in a beneficial way for reuse and recycling. Bottom ash and ecosand are construed as a waste product from cement industry. An optimal combination of bottom ash-eco sand can be thought of as a viable alternative to stabilize the clay soils by means of an effective dispersion dynamics associated with the inter connected network of pore spaces. A CATIA model was created and imported to ANSYS Fluent to study the dispersion dynamics. Ion migration from the bottom ash-ecosand pile was facilitated through natural formation of cracks in clay soil subjected to atmospheric conditions. Treated samples collected at different curing days from inner and outer zones at different depths were tested for, plasticity index, Unconfined Compressive Strength (UCS), free swell index, water content, Cation Exchange Capacity (CEC), pH and ion concentration to show the effectiveness of the method in improving the clay soil.

Keywords: stabilization; bottom ash-ecosand; ANSYS fluent; plasticity index; UCS

1. Introduction

The arena of building construction depends for the overall structural strength and stability on a meticulously chosen foundation which in turn depends for its anchorage on a flawless soil or rocky stratum as the cushion that imparts a uniform settlement with a safe bearing capacity. This basic premise gets a shake when the cushioning soil properties are adverse even if the overlying foundation is strong. Universally clay soils are known for their typical impulse of swelling upon water absorption during rains and shrinkage coupled with cracking during water desorption to meet the evaporation needs in summer, which evoke a response in the form of unequal settlement leading to cracks on the building for an eventual collapse. Considering the gravity of situation in India, lot of efforts have been taken hitherto in tackling the maladies of undependable clays

*Corresponding author, Assistant Professor, E-mail: sathyapriya@gct.ac.in

http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

impregnating them with possible stabilizing additives, beginning with the traditional stabilizers viz., lime and cement for improvisation.

In the present era of extensive urbanization and intensive industrialization the generation of wastes as by-products from manufacturing processes or from point and non-point source domestic or industrial sewage disposal over land or into water bodies is inevitable. It is quite indispensable from the stand point of environmental protection that such waste materials should be transformed into usable products in the construction industry after proper treatments as partial or full replacements of the conventional materials (Canakci *et al*. 2015) without detrimental to the strength and stability criteria. In this context, a creative idea is struck for the reuse and recycling of two major transformable waste by-products viz., Bottom ash and Ecosand from cement industry, in an optimal conjunctive mixing and improvising the clay soil structure to avert swelling or shrinkage or cracks in a dependable way.

Bottom ash is nearly a sand sized coarse angular material with a porous surface texture. It comprises mainly silica, alumina, iron and small amounts of calcium and magnesium (Kumar *et al*. 2014). The size of the bottom ash ranges from 0.075 mm to 10 mm and the specific gravity of dry bottom ash lies around 2.00 to 2.60 (Kim *et al*. 2006). Ecosand a by product of cement industry consists of Silica (62%) and Calcium Carbonate (23%).

Bottom ash finds its application as a filler material, road base or sub-base and also as fine aggregate in asphalt paving mixtures (Muhardi *et al*. 2010). The research studies carried out hitherto relate to use of bottom ash as a filler material, partial replacement in cement and concrete, synthesis of geo-polymers, manufacture of bricks and construction of highway embankments (Usmen 1997, Canpolat *et al*. 2004, Kim *et al*. 2005, Gines *et al*. 2009, Pan *et al*. 2008, Rifai *et al*. 2009, Naganathan *et al*. 2012, Ramadoss and Sundararajan 2014). The quantum of research on use of bottom ash as an additive to soil stabilization is very limited (Güllü 2014)

Ecosand has been used as a replacement material for fine aggregates in concrete (Chinnaraju *et al*. 2013, Varghese *et al*. 2014). However, there are no reports on using Ecosand as a filler material in stabilizing clay soils against swelling and shrinkage. An investigation on Microwave Characterization of Ecosand for Electromagnetic Interference (EMI) shielded construction has been reported (Naveena *et al*. 2015).

The shrinkage cracks due to soil desiccation are advantageously utilized for effective dispersion of stabilizing materials through the crack lines and interconnected pores. Effective increase in the strength and stiffness of clay is brought about by the chemical alteration of clay and with long term cementing reactions (Rogers and Glendinning 1997) in tandem with alternate wetting and drying. Rao and Thyagaraj (2003) reported the efficacy of lime slurry application to soil deposits with artificially induced shrinkage cracks. Barker *et al*. (2006) outlined the physico-chemical changes due to the ion migration brought about by combination of three drivers viz., chemical, electrical and hydraulic gradients. Many researchers have used the technique of lime pile for groundwater control, stabilization of foundations, liquefaction mitigation, contaminant routing, reinforcement of soft clay and stability of slopes (Nelson and Miller 1992, Shen *et al*. 2003, Tonoz *et al*. 2003, Chand and Subbarao 2007, Larsson *et al*. 2009, Abiodun and Nalbantoglu 2014)

Realizing the significance of environmental protection against the unscrupulous dumping of wastes in all forms either through point source delivery into streams or non-point source dumping into water bodies and soils, it has become the need of the hour to explore the feasibilities of treating them for reuse and recycling in a beneficial way. Construction arena offers the greatest scopes for using these treated waste material by means of partial material substitution or complete replacement of the conventional building materials without detrimental to the strength and stability.

This paper focuses on the technical feasibilities of using a combination of bottom ash-ecosand pile on clay columns in improvising the physico-chemical as well as engineering properties of surrounding soil which includes the plasticity index values, shear strength, free swell index, water content, pH, CEC, Calcium, Silica and Aluminium ion concentrations. The crux of this presentation is to discuss the study results pertaining to the extent of improvisation that can be achieved in clay soils upon the ion migration and dispersion dynamics of bottom-ash and ecosand mix.

2. Materials

Different clay dominating zones in and around Coimbatore were identified by typical clay soils that are vulnerable for undesired swelling, shrinkage and cracking were culled out. The textural composition and physical properties of the representative soil samples taken from Thudiyalur zone of Coimbatore are furnished in Table 1. These values also fortify our selection criteria for this particular soil warranting improvisation with impregnation of external materials towards balancing the dynamic equilibrium of the soil base to become amenable for construction arena. The materials for impregnation and improvisation of the basic clay material selected were bottom ash and

Table 1 Textural composition and physical properties of the representative soil sample

S. No.	Properties	Values
1.	Natural moisture content	13.5%
2.	Specific gravity	2.69
3.	% of gravel	1.7%
	% of sand	27.6%
	% of silt	23.4%
	% of clay	47.3%
4.	Free swell index	52.0%
5.	Liquid limit (w_L)	48.0%
	Plastic limit (w_P)	21.0%
	Shrinkage limit (w_S)	13.0%
	Plasticity index (*Ip*)	27.0%
6.	Soil classification	CI
7.	Optimum moisture content	26.5%
	Maximum dry density (g/cc)	1.48
8.	Unconfined compressive strength (kN/m^2) at optimum moisture content	190
9.	pH	8.18
10.	Cation exchange capacity (meq/100g)	64.43
11.	Silica (meq/100g)	767.97
	Aluminium (meq/100g)	170.2
	Calcium (meq/100g)	9.39

ecosand that are abundantly available as by products of the nearby cement factory at Madhukkarai. Ecosand is a sort of sandy by product realised and recovered out of the major process of segregating lime dominated dolomitic limestone towards cement production. Even as ecosand is characterised by its predominating presence of silica and alumina, traces of $CaC0_3$ indicate the presence of lime in insignificant quantities that can become significant as cementitious resource in integrating the other two ingredients towards improvisation and normalisation of the basic clay material. Due to the abundance of these two wasted materials and the consequent problem of their safe disposal without detrimental to the environment, it was envisaged to transform them to beneficial recovery materials to improve upon the basic clay material under study.

The crux of the investigation lies on the null hypothesis that at a particular optimal combination only these two recycled materials can be reused as the potential additives to clay making it favourable for construction activities. As for the raw bottom ash is concerned mixing this with ecosand for improvisation purposes may not yield the desirable levels of material substitution since bottom ash is itself a highly heterogeneous material dump. Hence for the meticulous usage, bottom ash is subjected to pulverization in a ball mill till we can get a desirable particle size of 425 microns. Kim and Do (2012) has showed that smaller particle size of bottom ash increases the strength from the pozzolanic reaction due to larger specific surface area. To help actuate the

Table 2 Physical properties of Bottom ash and Ecosand

Properties	Bottom ash	Eco sand
% Gravel	7.8	0
% Sand	89.6	90.1
% Silt & Clay	2.6	9.9
Fineness modulus	3.72	0.97
Specific gravity	2.32	2.63
pH value	5.5	8.81
Permeability	5.76×10^{-5} cm/sec	3.20×10^{-3} cm/sec

Table 3 Chemical composition of Bottom ash and Ecosand

Compound	Bottom ash (%)	Ecosand (%)
SiO_2	58.11	62.7
Al_2O_3	21.01	3
Ca O	7.64	-
$CaCO_3$	-	23.5
Fe_2O_3	10.01	1
Mg O	1.34	0.8
Mn_2O_3	-	0.04
K_2O	0.89	2.46
Na_2O	0.65	4.3
Ti_2O_5	0.35	-
BaO	-	2.2

pozzolanic reactions towards forming CAH and CSH gel as binding agent portable water has been used as in the conventional way to form slurry. Table 2 depicts the physical properties of bottom ash and ecosand that are mutually exclusive. Table 3 furnishes the chemical composition of bottom ash and ecosand that are mutually exclusive.

3. Methodology

The essential prerequisite of such improvisation study warrants a near perfect simulation of the natural environment of clay leading to its adverse properties of swelling or shrinkage or crack formation attributed to the different phases of moisture absorption, retention and desorption. The crux of the simulation is to investigate the response in clay soil mechanics to the impulses of the dispersion dynamics associated with the proliferation of the improvisation additives within the intergranular network of interconnected soil pores.

3.1 Preparation of clay soil sample

As regards the real time stratification of a clay soil environment, it is a complicated multidirectional flux of variation in the physico-chemical properties of the clay soil matrix getting subjected to spatial (lateral and depth wise) and temporal variations in tandem with the soil moisture status resulting in swelling or shrinkage or cracking properties. This kind of naturally unconfined variation poses hassles in real time analysis with respect to the highly undependable variation due to the prevailing heterogeneity. Hence it becomes imperative to create a simulation standard bringing in all these variations to occur in a confined controlled homogenous clay soil stratification base. Later on to get into real time situation appropriate correction factors are to be developed in accordance with the space and time besides the dynamics and mechanics. As a stepping stone in this relatively new approach of clay improvisation a homogenous comparison base has been developed and test verified for ideal conditions only without applying any correction factors.

The soil sample was air dried and pulverised and placed in a galvanised iron tank of 500 mm diameter and 500 mm long at water content equal to 2% wet of optimum and compacted with its corresponding dry density of 1.36 g/cc simulating the field conditions. The soil was placed inside the tank using static compaction in layers (see Fig. 1). A hole of diameter 100 mm was made at the centre and allowed to dry under natural sunlight to facilitate the development of shrinkage cracks. Extensive shrinkage cracks developed throughout the soil specimen within a period of two months has resulted in decrease of water content from 28.5% to 10.5% and increases in dry density to 1.89 g/cc. The clay sample with extensive formation of shrinkage cracks is shown in Fig. 2.

3.2 Installation of waste slurry pile

The optimum dosage of bottom ash and eco sand was obtained based on the maximum UCS value. The bottom ash and eco sand were mixed at 10% and 25% respectively (optimum dosages).This mix was converted into slurry with the addition of 70% water by volume. The slurry thus prepared was poured and allowed to permeate through the interconnected voids. The prepared waste slurry easily permeated into the developed shrinkage cracks in the surrounding clay sample as shown in Fig. 3.The desiccated soil, absorbed water from the slurry increasing the water content from 10.5% to 40%.This results in reduction in dry density to 1.21 g/cc in accordance with the

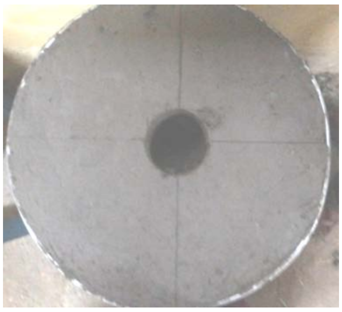


Fig. 1 Clay sample statically compacted inside the mould

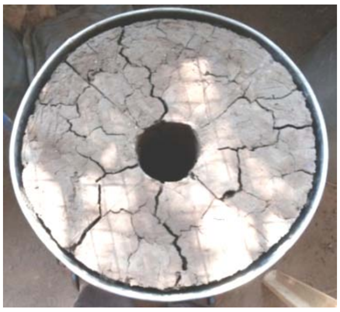


Fig. 2 Formation of shrinkage cracks

Fig. 3 Waste slurry permeating into shrinkage cracks

relation $\gamma b = \gamma d(1 + w)$, where $\gamma b, \gamma d, w$ refers to bulk density of soil, dry density of soil and water content.

The tank was covered with wet gunny bag and left for curing at room temperature. To study the effect of changes in the physico-chemical and engineering properties, the sample was demarcated within the circle of 1 d and 2 d where d represents the diameter of the central hole. Test samples were taken at depths of 15 cm, 30 cm and 45 cm. Replicate testing was done to confirm accuracy of the results.

3.3 Experimental tests and analysis

In order to investigate impulse of bottom ash-eco sand slurry impregnation in modelling the response on the integrated and improvised behaviour of the clay soil to become suitable in the construction arena without detrimental to the strength and stability of the structure in tandem with environmental protection. (in as much as treated and stabilized waste materials are used as a part of materials substitution), the standard procedures with modifications need to be outlined.

Treated samples were tested for changes in properties such as acid soluble ion concentration (silica, aluminium ions), calcium ion concentration, liquid limit, plastic limit, free swell index, pH, cation exchange capacity, unconfined compression strength. Liquid limit and Plastic Limit test, free swell index and pH were conducted as per IS: 2720 (Part5) –1985, IS: 2720 (Part 40) –1977 and IS 2720 (Part 26): 1987 respectively. The Unconfined Compression strength test (UCS) was conducted as per IS 2720 (Part 10): 1991 on treated undisturbed samples. The exchangeable silica, aluminium and calcium ion concentration were analysed using an Atomic Adsorption Spectrophotometer (AAS). AAS can be used to determine over 70 different elements in solution or directly in solid samples

3.3.1 Preliminary modelling on best fitting Bottom ash-Ecosand slurry in the dispersion dynamics (Spatial and temporal)

Computer Aided Three Dimensional Interactive Application (CATIA V5R20) has been used along with ANSYS Fluent to study the dispersion dynamics. Since the impulse response modelling relies on the spatial and temporal variations in accordance with the dispersion dynamics governed by laminar flow of the slurry through the soil pores which is mathematically depicted by the Darcy's law related to the flow nets of seepage. The dispersion pattern should also conform to the orthogonal grid of potential lines and flow lines of the seeping slurry from the centralized injection

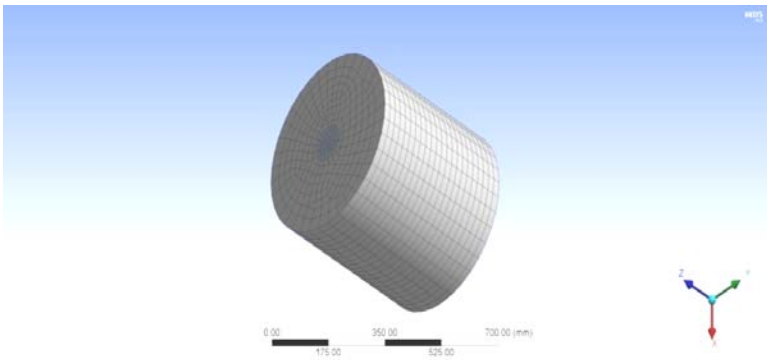


Fig. 4 Mesh generation of the model

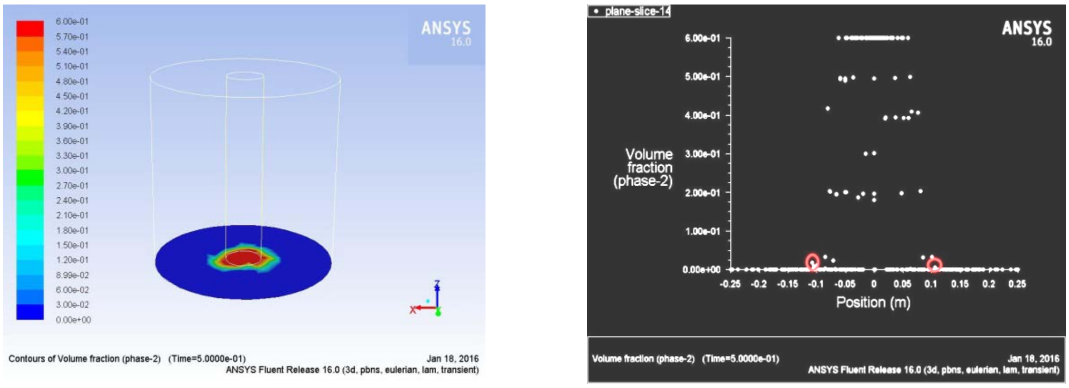


Fig. 5 Dispersion of slurry at the bottom plane section

pit. For any given aerial extent of the adverse clay columns, it is equally important to decide upon the grid spacings of injection pits facilitating proper intersection of the dispersion spheres towards achieving the desired degree of uniformity in transforming the basic clay soil mechanics in compatibility with the structural strength and stability requirements. To facilitate the two dimensional and three dimensional dispersion, 10 cm diameter slurry pits were aligned on grid squares of size 1 m × 1 m assuming that the radii of influence of the slurry dispersion around individual pits will sufficiently intersect with each other for improving upon the uniformity.

Computer Aided Design modelling for the dispersion study is done with CATIA V5R20 software as shown in Fig. 4. The model is discretized using eight node hexahedron and six node linear wedge elements with number of nodes as 8147 and the number of elements as 6926. The mesh file is imported to ANSYS Fluent and the model is setup. Continuity equation, X – momentum equation, Y – momentum equation, z – momentum equation, Eulerian Multiphase equation were solved to simulate the flow of slurry. Solution got converged at 1068 iterations for flow at 0.5 s. The average diameter of soil particles in the bed is taken as 0.01 mm.The viscous resistance co-efficient and inertial resistance co-efficient is calculated as 1.485×10^{12} and 3465×10^{5}.Viscosity of material in the pile assuming it to be a slurry is calculated to be 2.625×10^{-3} Ns/m^2. Taking the bottom section, midplane section and top plane, the rates of dispersion were appreciable in the bottom zone followed by middle zone and top zone. (see Figs. 5, 6 and 7).

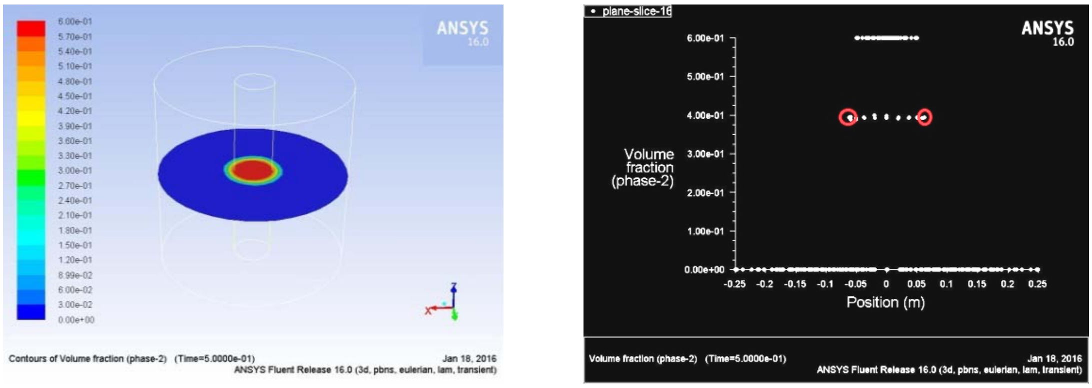


Fig. 6 Dispersion of slurry at the mid plane section

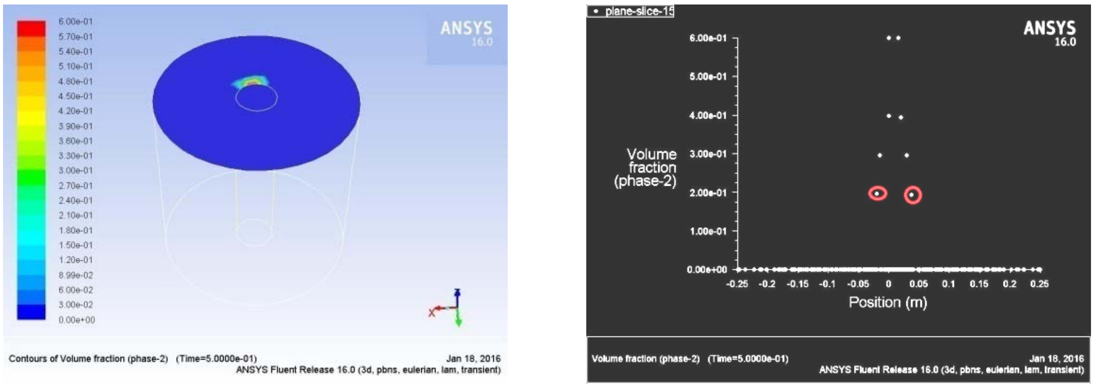


Fig. 7 Dispersion of slurry at the top plane section

3.3.2 Dynamics of bottom ash-ecosand slurry

The subsurface dispersion domain as for the ideal nature of the interconnected pores in the horizontal, vertical and radial direction are concerned, depends on the basic assumptions that the hydraulic conductivity of the soil for the potable water used and the combined permeability of the soil for the dissolved combination of bottom ash-ecosand at specific proportions with potable quality of water. The combined solute permeability depends on the admixture components of bottom ash and ecosand independently as well as interdependently after mixing. In solution the quality of portable water is also vulnerable to get affected culminating into acidic or alkaline in nature as can be exhibited by the pH values. The possible reason is that to some extent the bottom ash and ecosand may behave independently before mixing, interdependently after mixing and intradependently after dissolved in portable water. This complex phenomenon is bound to play a crucial role in determining the extent and rate of dynamic dispersion of the solute. The dispersion resistance can be defined as the ratio of unaffected hydraulic conductivity of soil medium to the influential permeability of the soil medium to facilitate the solute movement. Darcy’s law is employed to determine the hydraulic conductivity or permeability of the soil medium through the ideally interconnected soil pores at uniform rates in all the directions o movement. However the actual permeability of the soil medium gets modified due to the solute concentration that may enhance the flow velocities in the downward vertical direction compared to horizontal and radial directions due to gravitational influence and self weight factors. The theoretical subsurface flow velocity of portable water with uniform hydraulic conductivities in the vertical, radial and horizontal direction can be reckoned by using the Darcy's law $v = ki$ where $k = k_v = k_r = k_h$ the unaffected uniform hydraulic conductivity for portable water, i is the hydraulic gradient, considering the interconnected pore system as pipe lines. In case of dissolving bottom ash and ecosand in water the resultant hydraulic conductivities will not be the same due to the internal resistance caused by the solutes in solution. In such cases $k > k_v > k_h > k_r$. Hence to study the extent and rate of the dispersion dynamics correction factors need to be applied for the solute transport in all the directions compared to the uniform original hydraulic conductivity for potable water.

4. Results and discussions

Any improvisation attempted on an undesirable clay soil should manifest a reduction in the plasticity index, free swell index and water content and an increase in shear strength. Depicting the effects of dispersion dynamics associated with ion migration from bottom ash – ecosand slurry pile with respect to the depth and lateral extent of the soil column confined within the physical tank model. In the present case the gross diameter of the clay soil column was kept as 50 cm taking the first 10 cm as the core pit stuffed with the improvising ingredients namely bottom ash –ecosand. The proximity zone is kept from 10-20 cm and the outer zone is kept from 20-30 cm for the entire 50 cm depth of the soil column as shown in Fig. 8.

4.1 Modelling Plasticity Index (*PI*)

The fluctuations in plasticity index in both the inner and outer zones with respect to curing period for samples taken at top, middle and bottom level are illustrated in Figs. 9(a), (b) and (c). The variations in the values of Liquid limit and plastic limit for different curing periods for samples taken at top, middle and bottom level are illustrated in Figs. 10(a), (b) and (c).

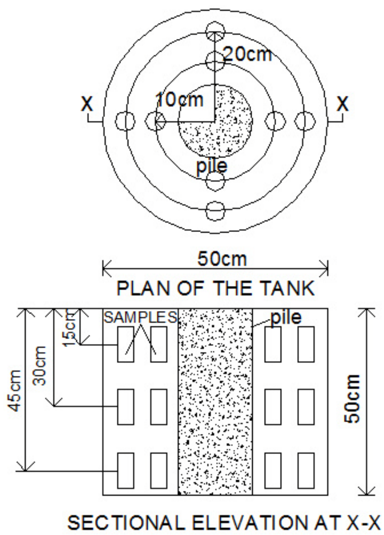
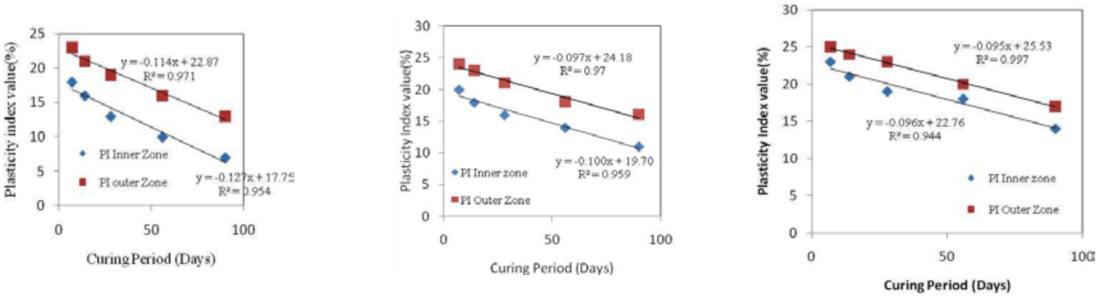
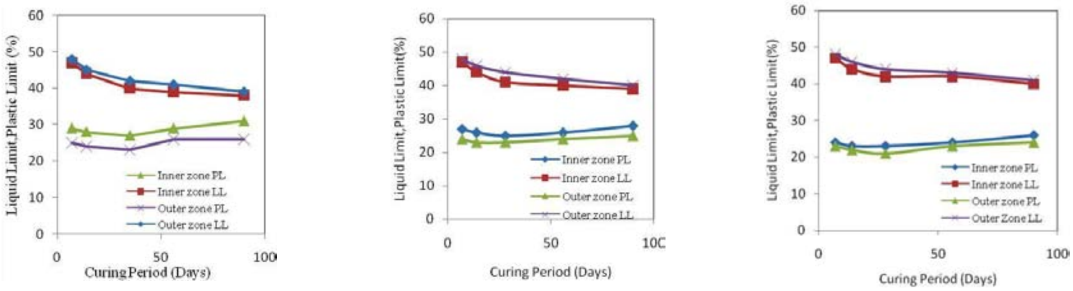


Fig. 8 Plan and Elevation of the model tank showing the sampling points



(a) For samples taken from top level (b) For samples taken from bottom level (c) For samples taken from middle level

Fig. 9 Fluctuations in plasticity index (PI) values at a radial distance of 10 cm (Inner) and 20 cm (Outer) with different curing periods



(a) For samples taken from top level (b) For samples taken from bottom level (c) For samples taken from middle level

Fig. 10 Variation of Liquid limit (LL), Plastic limit (PL) in inner and outer zone with different curing periods

The plasticity index reckoned as the difference between the liquid limit and the plastic limit is an indicator of the efficacy of the dispersion dynamics with respect to curing period. The modelling was tried for three different depths namely top 15 cm, middle 15-30 cm and bottom 30-45 cm with the radial dispersion across two vertical cylindrical interfaces around the core zone as the 10-20 cm proximity zone and 20-30 cm outer zone. In the modelling process the rate of reduction in the Plasticity index as an integrated effect of the liquid limit and plastic limit with respect to curing period was attempted. Also the independent rates of reduction or fluctuations in the liquid limit and plastic limit were also tried. As per the methodology outlined for regression modelling linear best fitting regression equation as part of the model components were arrived at. The improvisation parameters were taken as the dependent variable y upon the independent variable namely the curing period x in days. If y is a function of x then for a simple linear regression model based on the principle of least squares which is the basis for any statistical or mathematical curve fitting can be obtained by evaluating the slope gradient of the curve m and the ordinate intercept c for the linear regression equation $y = mx + c$. The correlation coefficient R^2 can also be computed for assessing the dependability of the variables within the domain of variables.

In the case of top proximity zone the initialised plasticity index after 7 days was predicted as 17.75 compared to a relatively higher value of 19.7 for the bottom zone followed by 22.76 for the middle zone. It is an indication that the top zone has experienced a relatively good dispersion of the stuffed materials [Bottom ash-Ecosand slurry] resulting in highly reduced value of plasticity index compared to middle and bottom zones. Possibility due to the gravitational influence and the self weight factors during and after dispersion, the bottom layer indicates a relatively better performance compared to middle layer with a plasticity index value of 19.7 slightly on a higher side to the top layers. It is interpreted that in the top proximity layer the initialized PI value is lower than that in the bottom layer due to better lateral dispersion through the cracks and the interconnected pores .When the stuffed materials descend down due to gravity through the vertical holes .the lateral dispersion in the middle zone is slightly hampered due to the relative absence of the cracks and the gravity dominating over the lateral dispersion. The middle layer has registered a relatively higher value of plasticity index at 22.76 due to the domination of gravity in the vertical dispersion and hampering a lateral dispersion due to the absence of prominent cracks compared to the top layer. In the bottom zone though the gravity dominates over the lateral dispersion due to the bottom sealing and interception of the stuffed materials an upward pressure builds up and is getting resisted by the self weight and gravitational forces resulting in an accelerated lateral dispersion as shown by the reduced plasticity index value of 19.7 compared to 22.76 of the middle layer. Hence it is concluded that as far as the proximity zone is concerned the performance of dispersion in the reduction of PI thereby improving upon the engineering properties and resulting in shrinkage/swelling reductions are appreciable in all the layers. However when compared between the layers .the top proximity zone has registered the lowest PI at 17.75 followed by the bottom layers at 19.7 followed by the middle layers at 22.76, that is the top proximity zone has revealed a relatively better performance followed by the bottom layer compared to middle layer as far as the initialization of PI after 7 days in concerned.

After 7 days of the initialized PI values, the rate of reduction in PI /day was observed to be very high in the first layer at the rate of 0.127/day compared to almost a reduced rate of around 0..096/day in the middle layer and 0.1/day in the bottom layer. Hence it is deduced that in the initialization period of 7 days itself the top layer could stabilize a better performance compared to bottom and middle layers and also with a higher rate of reduction in the PI values after 7 days upto 90 days compared to both middle and bottom layers. Hence in respect of spatial and temporal rates of dispersion of bottom ash-ecosand slurry, the overall performance is appreciable in the top layer followed by bottom layer compared to middle layer.

The performance as far as the dispersion dynamics is concerned with the outer zone it depends on the performance of the proximity zone in supplying the stuffed materials as inputs for dispersion, the statistical model prediction equation for the outer zone also corroborate this hypothesis by way of regression co-efficients obtained for top, middle and bottom layers in succession to the proximity zone. In the top outer zone the initialized PI after 7 days is registered as around 23 compared to 17.75 of the proximity layer that is when radial distance increases the performance decreases with respect to dispersion resulting in a relative decrease in the engineering properties. Same is the case repeated with the middle and bottom layers. The regression co-efficients for initialization range from 22 to 25 and the rate of reduction range from 0.095 to 0.114/day indicating that the overall performance is almost same in all the layers of the outer zone without much influence of dispersion felt. Hence it is expected that the difference gets narrowed down within the proximity zone to the core and the difference gets widened in the outer zone.

The reduction in the plasticity index values occur due to a number of factors. The relative abundance of silica, aluminium and calcium ion concentrations replace cations of lower valence such as sodium and potassium ions commonly found in the clay lattice. Such replacement would decrease the thickness of absorbed water layer as valence increase reduces the concentration and potential between interacting plates, thereby decreases interplate repulsion (Mitchell 1993).

4.2 Modelling Shear Strength (*UCS*)

The behaviour between shear strength and curing period for the outer and inner zones is illustrated in Figs. 11 and 12. A very common and pliable method of evaluating the strength of treated soil is the unconfined compressive strength (UCS) test (Fattah *et al*. 2015, Calik and Sadoglu 2014). The shear strength parameter is taken as the dependent variable y upon the independent variable namely the curing period *x* in days. A simple linear regression model obtained for assessing the efficacy of dispersion dynamics showed that in the proximity zone, the initialised shear strength after 7 days was predicted as 84.86, 59.83 and 45.69 in the top, bottom and middle zone respectively. For any given instantaneous curing period, the dispersion of the improvising ingredients rapidly penetrate through the proximity zone whereas when the radial distance increase outside the proximity zone, the dispersion rate is apparently slow. Hence for any given time instance of curing the shear strength for the outer zone always lies below that for the inner zone.

After 7 days of the initialized shear strength values, the rate of increment in shear strength /day was observed to be very high in the first layer at the rate of 3.414/day compared to almost a

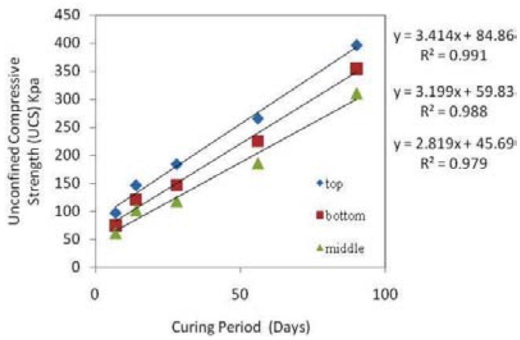


Fig. 11 Correlation between shear strength and curing period for the Inner zone at varying depths (top, middle, bottom)

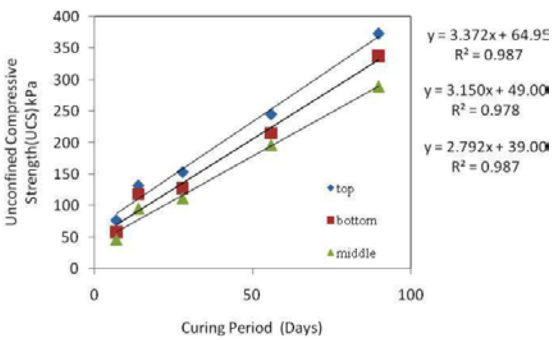
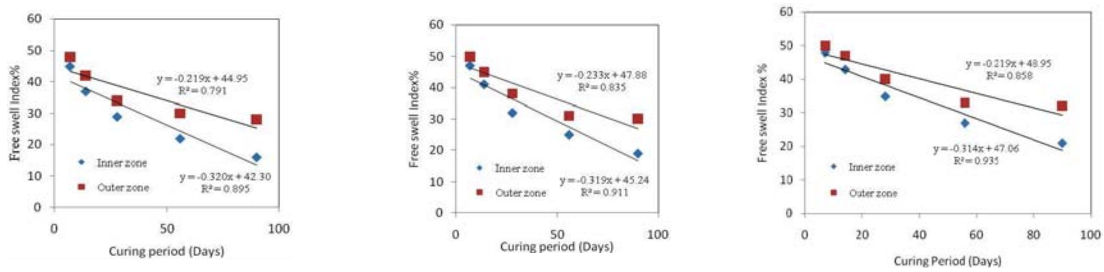


Fig. 12 Correlation between shear strength and curing period for the Outer zone at varying depths (top, middle, bottom)



(a) For samples taken from top level

(b) For samples taken from bottom level

(c) For samples taken from middle level

Fig. 13 Variation of free swell index with different curing periods in the inner and outer zones

reduced rate of around 2.819/day in the middle layer and 3.199/day in the bottom layer. Hence in respect of spatial and temporal rates of dispersion of bottom ash-ecosand slurry the overall performance is appreciable in the top layer followed by bottom layer compared to middle layer. In the top outer zone the initialized shear strength value after 7 days is noted as around 65 compared to 85 of the proximity layer indicating once again when radial distance increases the performance decreases with respect to dispersion resulting in a relative decrease in the shear strength value. Same is the case repeated with the middle and bottom layers. Both in the inner and outer zone, unconfined compressive strength (UCS) is highest at the top level. This may be due to high dispersion of ions from the waste slurry through shrinkage cracks resulting in the formation of cementitious products which improves the strength.

4.3 Modelling free swell index

The initialized free swell index in the proximity zone range from 42 to 47 and rate of reduction is around 0.32/day. The regression co-efficients obtained for outer zone range around 45 to 49 and rate of reduction is around 0.22/day. The continuous reduction in free swell values owes to the reduction in diffuse double layer at the initial stages of curing and hydration products formed due to the pozzolanic reaction, at the later period of curing. Figs. 13(a)-(c) shows the variation of free swell index with different curing periods in the two zones.

4.4 Water content

The variations of water content with depth for the stabilized soil at different curing periods are shown in Figs. 14(a)-(b). It can be seen that at the top level, there is a gradual reduction in the water content with increase in curing period owing to more migration of ions and subsequent pozzolanic reaction due to increase in shrinkage cracks at the top level. A reduction in water content at the bottom level may be attributed to the consolidation and the pozzolanic reaction between additives and clay.

4.5 Cation exchange capacity

The cation exchange capacity of the clay is varying and is synonymous with the variations in the pH value. Table 4 shows pH values of treated soil at two radial distance and varying depths with different curing periods. Table 5 shows the Cation Exchange Capacity (CEC) values for soil samples taken at two radial distance and varying depths of 15 cm, 30 cm and 45 cm with different

(a) In the inner zone (b) In the outer zone

Fig. 14 Variations of water content with depths for the stabilized soil at different curing periods

Table 4 pHs of treated soil at two radial distance and varying depths with different curing periods

Radial distance (cm)	Depth (cm)	Curing days				
		7	14	28	56	90
10	15	8.92	8.72	9.08	8.89	9.18
	30	8.82	8.67	8.9	8.75	8.81
	45	8.88	8.68	8.95	8.82	9.05
20	15	8.8	8.65	9	8.85	9.03
	30	8.7	8.55	8.84	8.73	8.78
	45	8.76	8.6	8.89	8.8	9

Table 5 CEC values of treated soil at two radial distance and varying depths with different curing periods

Radial distance (cm)	Depth (cm)	Curing days (Values of CEC in meq/100g)				
		7	14	28	56	90
10	15	70.72	70.3	75.76	74.8	78.6
	30	68.45	69.3	71.7	70.2	73.1
	45	69.6	70.8	73.9	71.6	74.5
20	15	69.14	69.3	72.3	73.2	74.3
	30	68.32	69.15	69.8	69.5	70.2
	45	69.03	68.7	70.4	70.0	72.3

curing days. There is an increase in the diffuse double layer as the CEC increases along with pH indicating higher charge deficit at the surface of the clay lattice attracting more ions.

4.6 Concentration of silica, aluminium and calcium ions

A remarkable feature observed is the concentration of aluminium ions in the outer zone. It is relatively high which indicates the dispersion of free aluminium ions in solution away from the Bottom ash-Ecosand pile. Figs. 15-16 show the changes in the concentration of acid soluble ions at two radial distances for samples taken at top level. The aluminium in solution is capable of migrating away under the influence of hydraulic, chemical and electrical gradient than the OH^- ion

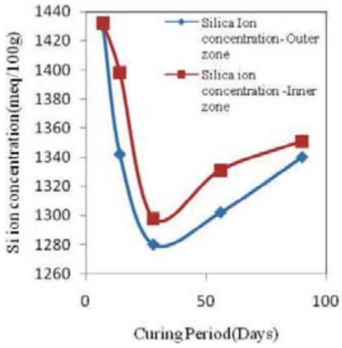


Fig. 15 Concentration of silica ions at two radial distances of 10 cm, 20 cm for samples taken at top level

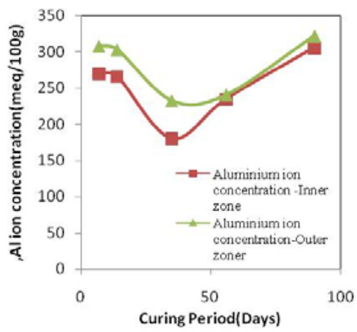


Fig. 16 Concentration of Aluminium ions at two radial distances of 10 cm, 20 cm for samples taken at top level

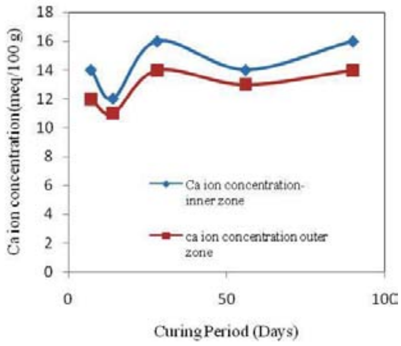


Fig. 17 Concentration of Calcium ions at two radial distances of 10 cm, 20 cm for samples taken at top level

migration (Barker *et al*. 2006).

Fig. 17 shows the concentration of calcium ions at two radial distances with reference to different curing periods. During early days of curing, the concentration of calcium ions increases due to migration of calcium ions from the pile. There is a decrease in the concentration of ions from 7-28 days with marked increase from 28-90 days. The concentration levels in the outer zone are lower than the inner zone. It is noted that the calcium ion concentration is more or less uniformly distributed throughout the entire soil mass. The silica and aluminium concentration levels increases during early days of curing (upto 7 days) followed by a decrement in concentration upto 28 days. Beyond 28 days there is a continuous increase in their concentrations due to replenishment of silica and alumina from the pile.

5. Conclusions

Computer Aided Three Dimensional Interactive Application(CATIA V5R20) and ANSYS Fluent has been used in tracking the dispersion sphere in accordance with the subsurface solute transport dynamics. The nature and extent of the solute dispersion through the network of interconnected clay soil pores and the dispersion rates at the top, middle and bottom plane sections were reckoned from the experimental results. The results were compared in parallel rails with the software results assuming that the physical model is devoid of shrinkage cracks. However in practice, the dispersion dynamics is apparently enhanced in improvising the clay properties effectively during dry season. Besides the modelling component namely Plasticity Index, UCS and Free Swell Index, the other prominent indicators such as water content, pH, CEC and ion concentrations do corroborate that the top and bottom proximity zones perform better in dispersion compared to the middle proximity zone. However the outer zone performance that is beyond 10 cm,in all the three layers is not appreciable in bringing about the desired level of engineering properties or reductions in swelling properties as the radial distance from the core stuff increases beyond the proximity zone. Eventhough variations in the rate of reduction/increase have been observed after the initialization period of 7 days to 90 days linear regression models do not take into account the ups and downs of variation till the end of 90 days curing period. If it is to be done so accounting for the instantaneous variations too, then a curvilinear modelling needs to be tried out.

References

Abiodun, A.A. and Nalbantoğlu, Z. (2014), “Lime pile techniques for the improvement of clay soils”, *Can. Geotech. J.*, **52**(6), 760-768.

Barker, J.E., Rogers, C.D. and Boardman, D.I. (2006), “Physio-chemical changes in clay caused by ion migration from lime piles”, *J. Mater. Civil Eng.*, **18**(2), 182-189.

Canakci, H., Aziz, A. and Celik, F. (2015), “Soil stabilization of clay with lignin, rice husk powder and ash”, *Geomech. Eng., Int. J.*, **8**(1), 67-79.

Canpolat, F., Yilmaz, K., Köse, M.M., Sümer, M. and Yurdusev, M.A. (2004), “Use of zeolite, coal bottom ash and fly ash as replacement materials in cement production”, *Cem. Concr. Res.* **34**(5), 731-735.

Calik, U. and Sadoglu, E. (2014), “Engineering properties of expansive clayey soil stabilized with lime and perlite”, *Geomech. Eng., Int. J.*, **6**(4), 403-418.

Chand, S.K. and Subbarao, C. (2007), “In-place stabilization of pond ash deposits by hydrated lime columns”, *J. Geotech. Geoenviron. Eng.*, **133**(12), 1609-1616.

Chinnaraju, K., Ramkumar, V.R., Lineesh, K., Nithya, S. and Sathish, V. (2013), “Study on concrete using steel slag as coarse aggregate replacement and ecosand as fine aggregate replacement”, *IJREAT Int. J. Res. Eng. Adv. Technol.*, **1**(3), 1-6.

Fattah, M.Y., Al-saidi, A.A. and Jaber, M.M. (2015), “Improvement of bearing capacity of footing on soft clay grouted with lime-silica fume mix”, *Geomech. Eng., Int. J.*, **8**(1), 113-132.

Gines, O., Chimenos, J.M., Vizcarro, A., Formosa, J. and Rosell, J.R. (2009), “Combined use of MSWI bottom ash and fly ash as aggregate in concrete formulation: Environmental and mechanical considerations”, *J. Hazard. Mater.*, **169**(1), 643-650.

Güllü, H. (2014), “Factorial experimental approach for effective dosage rate of stabilizer: application for fine-grained soil treated with bottom ash”, *Soils Found.*, **54**(3), 462-477.

Kim, Y.T. and Do, T.H. (2012), “Effect of bottom ash particle size on strength development in composite geomaterial”, *Eng. Geol.*, **139**, 85-91.

Kim, B., Prezzi, M. and Salgado, R. (2005), “Geotechnical properties of fly and bottom ash mixtures for use in highway embankments”, *J. Geotech. Geoenviron. Eng.*, **131**(7), 914-924.

Kim, B., Yoon, S., Balunaini, U. and Salgado, R. (2006), “Determination of ash mixture properties and construction of test embankment—part A”, *Joint Transp. Res. Program*, Final Report; Purdue University, West Lafayette, IN, USA.

Kumar, D., Kumar, N. and Gupta, A. (2014), “Geotechnical properties of fly ash and bottom ash”, *Int. J. Sci. Res.* (*IJSR*), **3**(9), 1487-1494.

Larsson, S., Rothhamel, M. and Jacks, G. (2009), “A laboratory study on strength loss in kaolin surrounding lime–cement columns”, *Appl. Clay Sci.*, **44**(1-2), 116-126.

Mitchell, J.K. (1993), *Fundamentals of Soil Behavior*, (2nd Ed.), John Wiley and sons, New York, NY, USA.

Muhardi, A., Kassim, K.A., Makhtar, A.M., Lee, F.W. and Yap, S.L. (2010), “Engineering characteristics of Tanjung Bin coal ash”, *Electro. J. Geotech. Eng.*, **15**, 1117-1129.

Naganathan, S., Subramanian, N. and Mustapha, K.N. (2012), “Development of brick using thermal power plant bottom ash and fly ash”, *Asian J. Civil Eng.* (*Building and Housing*), **13**(1), 275-287.

Nelson, J.D. and Miller, J.D. (1992), *Expansive Soils*: *Problems and Practice in Foundation and Pavement Engineering*, John Wiley and Sons Inc., New York, NY, USA.

Naveenaa, S., Sruthi, S. and Sabarish Narayanan, B. (2015), “Microwave characterization of ecosand for electromagnetic interference (EMI) shielded construction”, *Appl. Mech. Mater.*, **813**, 263-266.

Pan, J.R., Huang, C., Kuo, J.J. and Lin, S.H. (2008), “Recycling MSWI bottom and fly ash as raw materials for portland cement”, *Waste Manag.*, **28**(7), 1113-1118.

Ramadoss, P. and Sundararajan, T. (2014), “Utilization of lignite-based bottom ash as partial replacement of fine aggregate in masonry mortar”, *Arab. J. Sci. Eng.*, **39**(2), 737-745.

Rao, S.M. and Thyagaraj, T. (2003), “Lime slurry stabilization of an expansive soil”, *Proceedings of the Institution of Civil Engineer- Geotechnical Engineering*, **156**(3), 139-146.

Rifai, A., Yasufuku, N. and Tsuji, K. (2009), “Characterization and effective utilization of coal ash as soil stabilization on road application”, In: *Ground Improvement Technologies and Case Histories*, Research Publishing Services, Singapore.

Rogers, C.D.F. and Glendinning, S. (1997), “Improvement of clay soils in situ using lime piles in the UK”, *Eng. Geol.*, **47**(3), 243-257.

Shen, S.L., Miura, N. and Koga, H. (2003), “Interaction mechanism between deep mixing column and surrounding clay during installation”, *Can. Geotech. J.*, **40**(2), 293-307.

Tonoz, M., Gokceoglu, C. and Ulusay, R. (2003), “A laboratory scale experimental investigation on the performance of lime columns in expansive Ankara (Turkey) clay”, *Bull. Eng. Geol. Environ.*, **62**(2), 91-106.

Usmen, M.A. (1977), “A critical review of the applicability of conventional test methods and materials specifications to the use of coal associated wastes in pavement construction”, Ph.D. Dissertation; West Virginia University, Morgantown, WV, USA.

Varghese, S., Govind, A.K. and Manjummekudy, E.M. (2014), “Comparative study on the effect of concrete using eco sand, weathered crystalline rock sand and gbs as fine aggregate replacement”, *Int. J. Eng. Res. Technol.*, **3**(10) ,1030-1035.

CC