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REVIEW ON SOIL STABILIZATION TECHNIQUES

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ABSTRACT

Low rise buildings are particularly vulnerable to ground movements sourced from swelling and shrinking of the expansive clay soils. Geotechnical engineers have long recognized that swelling of expansive clays caused by moisture variation may result in considerable damage to the overlying structures, and engineers should take them into the consideration. This paper highlights the performance of fly ash and limestone for soil stabilization by means of swell potential and strength. Atterberg limits, Standard Proctor Compaction and Unconfined Compressive Strength(UCS) tests were carried out on stabilized soil samples, after a curing a period of 7 days. The use of two waste by-products, limestone and fly ash, may provide an inexpensive and advantageous construction process. This paper gives a comprehensive report on stabilization techniques for clayey soils.

KEYWORDS: Soil Stabilization, Swell and Shrinkage, Atterberg Limits, Proctor Compaction, UCS

INTRODUCTION

Clay is a material with low strength and markedly affected by water but it can be relatively strong in dry condition. If water is added to clay, it will behave as plastic or flow like liquid. Because of its low permeability, dissipation of excess pore pressure is slow. These soils cause distress and damage to structures founded on them as they show volumetric changes in response to changes in their moisture content. These phenomenon create a lot of problem at construction sites, so the improvement of soil is needed. Both, Lime and fly ash provide an economic and powerful means of chemical improvement, as demonstrated by the dramatic transformation that is evident in their mixing with clay.

The addition of lime to soils to improve their use for construction purposes has a very long history. For instance, McDowell (1959) mentioned that stabilized earth roads were used in ancient Mesopotamia and Egypt, and that the Greeks and Romans used soil-lime mixtures. The clay minerals have a high adsorptive capacity for water which leads to the problem of swelling. mechanism of swelling is complex and is influenced by a number of factors such as the type and amount of clay minerals present in the soil, the specific surface area of the clay, structure of the soil and the valency of the exchangeable caution.

When lime and fly ash are added into a soil, this results in a rapid hydration process and a simultaneous caution exchange that flocculates the soil into larger lumps. The cementation of these lumps by pozzolanic reaction produces new pozzolanic reaction products, calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) that are responsible for improved durability, reduced permeability, increased strength and a material that is resistant to cracking.

REVIEW OF LITERATURE

G. S. Xeidakis et al [1996] made an attempt to stabilize the swelling clay mineral structure by the addition of $Mg(OH)_2$. This will turn the swelling minerals, like montmorillonite, into non swelling ones, e.g. chloride. Similarly various factors affecting the precipitation-adsorption of Mg-hydroxide by clays, was investigated and the conditions giving the best results were established.

Some of the factors that were examined were the sequence and the duration of the reagents addition, the base that was used as the precipitant (NH_2OH and NaOH), the preparation of the precipitate. Fast titration of the base and drying at 105 degrees to complete dryness also gave satisfactory results. Test results concluded that the most important factors influencing the development of the hydroxyl-Mg-inter layers and the stabilization of the montmorillonite lattice were the base used as a precipitant, the preparation of the precipitate, in or out, of the clay suspension, the drying temperature and the rate of titration.

The best conditions for the laboratory preparation of the hydroxy-Mg-interlayers, as revealed in the study were a dilute (about 1-2%) and well dispersed clay suspension, pH between 10 and 12; some 12 meq Mg^{2+} as Mg-salt (e.g. $MgCl_2$) per gram of clay, added before the base and followed by the drop wise titration of 1-2 N NaOH solution into the clay suspension, to give a molar ratio OH/Mg of about 1.5; vigorous agitation of the suspension during titration of the reagents; centrifugation and decantation of the supernatant liquid and drying the product at about 250 degrees.

The process of the $Mg(OH)_2$ adsorption by clays is quite similar with that of Ca(OH)2 widely used for soil stabilization. Thus the results obtained here could be applied to decipher the mechanism of $Ca(OH)_2$ adsorption by soil days. Both these hydroxides could be employed, either alone or in combination, for soil stabilization in a non-acidic environment.

A. M. O. Mohamed et al [1998] found that lime or cement stabilization of marly soils was used as convenient and expedient means for the development of foundation base courses and inexpensive wearing courses for transport purposes. The failure of many of these natural and stabilized marly soils to perform their functions had been reported. Mechanical factors generally used to explain the causes for the foundation failures had not been satisfactorily accepted. This study used thermodynamic modelling and X-ray diffraction analysis to explain the general basic causes for deterioration of the support capability of these types of soils. The presence of palygorskite in marlysoils provides it with some very unique features in its natural state, and particularly when it is stabilized with lime or cement. Formation of an expansive mineral, ettringite, as a transformation product of palygorskite increases the swelling potential of the stabilized soils. The various interactions, reactions and factors contributing to the stability and instability of marly soils, and lime stabilized marly soils were discussed.

Zalihe Nalbantog˘ lu et al [2003] studied that fly ash treatment can effectively reduce the swell potential of highly plastic clays and prevent the swell beneath the smaller foundation pressures studied in a soil in Cyprus. The geology and climatic condition in Cyprus produce a wide distribution of expansive soils.

These soils presented problems in construction and possess a variety of undesirable characteristics such as low strength, high plasticity, difficult compaction and high swell potential. Laboratory test results on these soils indicated that fly ash is effective in ameliorating the texture and plasticity of the fly ash treated soils by reducing the amount of clay size particles, plasticity index and the swell potential. Caution exchange is one of the important reactions responsible for the improvement in the soil characteristics. In the study, caution exchange capacity (CEC) values have been used to indicate the changes in the mineralogy of the fly ash treated soils and the reduction in the plasticity and water absorption potential have been explained.

J. Prabakar et al [2004] describes the behavioral aspect of soils mixed with fly ash to improve the load bearing capacity of soil. As construction of any infrastructure over a weak or a soft soil is highly typical on the geo-technical grounds as the soil undergoes differential settlements, poor shear strength and high compressibility, improvement of load bearing capacity of soil has been improved by adopting various techniques like soil stabilization, adoption of reinforcement etc. Three different types of soil have been considered using different percentage of fly ash ranging from 9 to 46% by weight of soil. The study also benefits the effective use of fly ash and thus cost effective method for improving the soil properties. It covers the characterization of soil, fly ash, compaction behavior, settlement, California bearing ratio, shear strength parameters (C and f) and swelling characteristics, etc. Experiments were conducted in a laboratory and results were found that addition of fly ash reduces the dry density of the soil due to the low specific gravity and unit weight of the soil. The reduction in dry density can be in the order of 15–20%.

The void ratios and porosity varied by the increasing amount of fly ash in soils. By adding fly ash up to 46%, the void ratios of soils can be increased by 25%. The shear strength of fly ash mixed soil is improved due to the addition of fly ash. The shear strength increased nonlinearly with the increase in fly ash content in soil.The maximum value of cohesion was obtained as 0.39 kg/cm^2 in case of loamy soils and 0.66 kg/cm^2 the case of clayey soil. The increase in the fly ash increased the value of cohesion and this variation is linear to fly ash content. Also further results have concluded that the swelling behavior can be effectively controlled by the addition of fly ash and that fly ash can be used in soil to get improved in shear strength, cohesion and thus improved bearing capacity.

S. Kolias, V. Kasselouri-Rigopoulou, A. Karahalios et al [2004] studied the effectiveness of using high calcium fly ash and cement in stabilizing fine-grained clayey soils (CL,CH). Strength tests in uniaxial compression, indirect (splitting) tension and flexure were carried out on samples to which various percentages of fly ash and cement had been added. Modulus of elasticity was determined at 90 days with different types of load application and 90-day soaked CBR values were also reported. Pavement structures incorporating sub grades improved by in-situ stabilization with fly ash and cement were analyzed for construction traffic and for operating traffic. These pavements were compared with conventional flexible pavements without improved sub grades and the results clearly show the technical benefits of stabilizing clayey soils with fly ash and cement. In addition TG–SDTA and XRD tests were carried out on certain samples in order to study the hydraulic compounds, which were formed.

Amer Ali-Rawas et al [2005] studied the effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. The effect of lime, cement and their proportionate combinations were studied. Initially the chemical and physical properties of the untreated soil were determined. Then the soil was mixed with the additives at 3%, 6% and 9% by dry weight of the soil Fixed percentages of lime (3% and 5%) plus different percentages of cement were also mixed with the soil. The results showed that the addition of 6% lime reduced the swell percentage and swell pressure to zero. Heat treatment reduced swelling potential to zero. Further, the liquid limit of all treated samples except for samples treated with 5% lime +- cement showed an initial increase at the addition of 3% stabilizer, followed by gradual decrease. The samples treated with 3% cement, 3% lime and 3% Sarooj showed an initial increase in plasticity index. However, with further additions, the plasticity index gradually decreased. On the other hand, the samples treated with combinations of lime and cement exhibited an initial reduction at (3% lime+3% cement) and (5% lime+3% cement) followed by a general increase with further additions. The study also showed that calcinations of the soil at 740^{o}C and 780^{o}C for 30 and 60 min resulted in the reduction of the swelling potential to zero.

Yucel Guneya, DursunSarib, Murat Cetinc, Mustafa Tuncan et al [2005] investigated the impact of cyclic wetting and drying on swelling behavior of lime-stabilized clayey soils. Swelling potential and swelling pressure tests were carried out on soil mixtures with various amounts of kaolinite–bentonite clays, and on a high plasticity clayey soil sample. The tests were repeated after the addition of lime to the lime-treated samples in different proportion. In each cycle the tested samples were allowed air dry to their initial water content thus shrinking to their initial height, which is called 'partial shrinkage' method. The results showed that the initial beneficiary effect of lime stabilization was lost after the first cycle and the swelling potential increased at the subsequent cycles. On the other hand, the swelling potential and the swelling pressure of the untreated soil samples started decreasing after the first cycle and they reached equilibrium after the fourth cycle.

A. Pe´rez-Espinosa, J. Moreno-Caselles et al [2006] aimed to study the influence of the organic wastes derived from the winery and distillery industry (grape stalk (GS), grape marc (GM), wine lees (WL) and exhausted grape marc (EG)) and the soil type (clayey-loam (S1), loam (S2) and sandy textured (S3)) on different soil characteristics, especially the carbon and nitrogen mineralization. The evolution of C mineralization fitted a first-order kinetic for all amended soils. An initial increase was observed in the specific respiration (qCO2) at the beginning of the experiment. However, afterwards, the evolution in the qCO2 tends towards the values of the control soil due to the pattern of the soil to recover its initial equilibrium status. The addition of these materials in the soils produced a slight increase of the inorganic nitrogen content, except in the case of GS and EG in most of the studied soils. The use of GS as amendment produced an inhibition in the N mineralization in the three types of soils studied. Organic matter mineralization was probably influenced by soil type, the sandy soil favoring more the N and C mineralization processes than the clayey-loam and loam soils.

Sayyed Mahdi Hejazi et al [2006] studied the history, benefits, applications; and possible executive problems of using different types of natural and/or synthetic fibers in soil reinforcement through reference to published scientific data. He investigated why, how, when; and which fibers have been used in soil reinforcement projects. The author concluded that the strength of fiber reinforced soil increased with increase in aspect ratio, fiber content, fiber modulus; and soil fiber surface friction. Laboratory tests also demonstrated that shear strength also increased and peak-post strength loss was reduced when discrete fibers were mixed with the soil. Also a comprehensive literature review showed that using natural and/or synthetic fibers in geotechnical engineering is feasible n six fields including pavement layers (road construction), retaining walls, earthquake engineering, railway embankments, protection of slopes; and soil-foundation engineering.

Yi Cai et al [2006] proposed mixture of polypropylene fiber and lime for ground improvement in order to reduce the brittleness of soil stabilized by lime only. He made 9 groups of soil specimens and tested them at three different percentages of fiber content (i.e. 0.05%, 0.15%, 0.25% by weight of the parent soil) and three different percentages of lime (i.e. 2%, 5%, 8% by weight of the parent soil). He subjected them to unconfined compression, direct shear, swelling and shrinkage tests. He concluded that the addition of the mixture of polypropylene fiber and lime caused beneficial changes in the above engineering properties of clayey soil used in this investigation.

The unconfined compressive strength, cohesion and friction angles increased while increasing the length of curing. The optimum gain in strength appeared to be with about 5% lime. He finally concluded that the technique of fiber reinforced lime soil is a very effective method of ground improvement, which improves the strength, swelling–shrinkage potential and toughness of soil and consequently, enhanced the stability and durability of infrastructures such as foundation and road bed.

Nurhayat Degirmenci et al [2007] described the application of phosphogyp sum with cement and fly ash for soil stabilization. Atter berg limits, Standard Proctor compaction and unconfined compressive strength tests were carried out on cement, fly ash and phosphogyp sum stabilized soil samples. Treatment with cement, fly ash and phosphogyp sum generally reduces the plasticity index.

The maximum dry unit weights increased as cement and phosphogyp sum contents increased, but decreased as fly ash content increased. Generally optimum moisture contents of the stabilized soil samples decreased with addition of cement, fly ash and phosphogyp sum. Unconfined compressive strengths of untreated soils were in all cases lower than that for treated soils. The cement content had a significantly higher influence than the fly ash content. It was further concluded that the treatment with phosphogyp sum fly ash and cement generally reduces the plasticity index. Principally, a reduction in plasticity is an indicator of improvement. The maximum dry unit weight of the soil increased with the additive content. Fly ash on the other hand decreased the maximum dry unit weight.

Raymond N. Yong, Vahid R. Ouhadi et al [2007] used physicochemical (reaction) factors to explain the general basic causes of the deterioration of support capability for these types of soils. The presence of palygorskite and sepiolite in marl soil provided it with some very unique features in its natural state, particularly when it is stabilized with lime or cement. The formation of an expansive mineral, ettringite, as a transformation product of palygorskite increased the swelling potential of the stabilized soil. A set of physio-chemical and mechanical experiments, which included slake durability, specific surface area measurement (SSA), California bearing ratio (CBR), atter berg limits testing, and X ray diffraction (XRD), were performed. In addition, the impact of curing on the stabilized soil behavior was investigated.

The results showed that the immersion of the natural marl reduced the dry CBR value to at least one-fourth the dry value. Furthermore, the XRD results indicated that with increasing time and availability of dissolved aluminum and sulfate, ettringite forms in stabilized soil and then the rate of ettringite growth increases. Based on the findings of these experiments, the various interactions, reactions and factors contributing to the stability and instability of marl soils, and lime/cement stabilized marls were discussed. It was concluded that the general traditional soil stabilization evaluation methods were not capable of accounting for the failures that occur in stabilized marl. It was shown that soil mineralogy and pore fluid analysis, in conjunction with X-ray diffraction testing, can be combined to provide a set of practical ways to monitor the possibilities of these failures.

S. BanuIkizler et al [2008] studied role of expanded polystyrene (EPS) geo foam in accommodating soil expansion and hence reducing swelling pressures on adjacent structures. He proposed several hypothetical cases whereby reductions on the transmitted lateral pressures due to expansive soils were examined for different thickness of EPS geo. Also although the purpose of the study was to reduce lateral swelling pressure, it was observed that vertical swelling pressure was also reduced. Furthermore, in all of the laboratory tests, the vertical swelling pressures were greater than the lateral swelling pressures.

The reason for this result was believed to beanisotropic behavior of the clay in swelling process because of its placement and compaction in the experimental test box. Also, more importantly the lateral and vertical swelling pressures reduced as EPS geo foam thickness increased. Further placing EPS geo foam between the structure (e.g. retaining wall) and the expansive soil was effective in reducing lateral pressures due to swelling and that as the swelling pressures reached a peak value, it dropped a little, and remained constant.

Valéry Ferber, Jean-Claude Auriol, Yu-Jun Cui, Jean-Pierre Magnan et al [2008] presented the experimental results and a micro structural interpretation of swelling tests performed on four clays, compacted at different water contents and dry densities. The influences of dry density and water content on the swelling potential were described, showing the coupled effect of these two parameters. In order to quantify this coupling, the initial air void ratio was defined and it was observed that this air void ratio had an apparent linear relationship with the void ratio after swelling.

This observation enabled analyzing all the tests in a synthetic manner, by plotting the origin ordinate and the slope of the linear relationships versus the initial hydrous state. Moreover, one of the clays microstructure was analyzed using mercury intrusion porosimetry (MIP). The results showed that swelling lead to micro pores increased and macro pores decreased. In addition, micro pores volume increase did not depend on the initial dry densities, whereas the macro pores volume increases didn't. For further discussion, a simplified micro structural model was proposed allowing the interpretation of the soils welling using MIP results. The comparison between the model prediction and the microstructure observation supported the interpretation of the swelling tests and showed that the origin ordinate and the slope of the relationship between the initial air void ratio and the final void ratio could be linked to micro pores and macro pores volume variations. However, the comparison also showed that the simplified micro structural model presented some limitations when applied to very dry or wet soils.

A. Seco, F. Ramírez, L. Miqueleiz, B. García [2009] conducted an experimental study in the stabilization of an expansive soil, consisting of the reduction of its swelling capacity and the improvement of its mechanical capacities by the addition of by-products and waste materials of industrial origin in a local area in Spain. This achieved the double objective of reducing the problems of this type of soil, and also of providing a use for the additives, thus eliminating the economic and environmental cost involved in managing them. From the point of view of expansivity, it was possible to reduce it to levels well below what Spanish legislation contemplates for expansive soils. As to the improved mechanical capacities of the soil, all treatments tested offered improvements of between two and four times the compressive strength of the untreated soil. Of the waste materials, the most notable is the behavior of Rice Husk Fly Ash, highly effective in stabilizing soil from the two aspects considered in this experiment.

B. V. S. Viswanadham et al [2009] reported the results of laboratory study performed on expansive soil reinforced with geo fibers and demonstrated that discrete and randomly distributed geo fibers were useful in restraining the swelling tendency of expansive soils. Swelling characteristics of remolded expansive soil specimens reinforced with varying fiber content (f ¼ 0.25% and 0.50%) and aspect ratio (l/b ¼ 15, 30 and 45) were studied. One dimensional swell-consolidation tests were conducted on oedometer specimens. Reduction in heave and swelling pressure was the maximum at low aspect ratios at both the fiber contents of 0.25% and 0.50%. Finally, the mechanism by which discrete and randomly distributed fibers restrain swelling of expansive soil was explained with the help of soil–fiber interaction.

The tests on oedometer specimens reinforced with polypropylene fiber of varying dosage and aspects ration showed that heave was reduced more at lower aspect rations than at higher aspect ratios. Reduction in swelling can be attributed to replacement of swelling clay by fiber and resistance offered by fiver to swelling through clay-fiber contact. Swelling as well as swelling pressure decreased with increasing fiber content (f) for all aspect ratios.

Cao Li-wen et al [2009] made an experimental research on geotechnical behaviors of compacted clay influenced by metal caution. Considering orthogonal experiment method as design technique method, on the basis of leachate water quality analysis, the author discovered the influence of main kind caution in leachate from MSW landfill on compacted clay geotechnical behaviors, including permeability, strength and plasticity.

The research were carried out as follows: by changing the thickness of diffusion electric double layer and the adsorb ability of polar water molecular, density and valence state of metal caution, make soil particles agglomerate or disperse, and result in varying clay plasticity, intensity and permeability. Experimental results concluded ion concentration and valence state changed clay plasticity.

Clay plasticity index increased with ion concentration growing when taking low concentration and low valence state ion as permeating solution, while, decreased with ion concentration of high valence state rising. Clay permeability changed with the concentration and valence state of metal ion varying. In general, the permeability coefficient of clay seeped in metal ion solution was higher than that of pure water

Işık Yilmaz et al [2009] proposed the use of gypsum as an additive for stabilization of swelling clay soils. The author studied a number of stabilizing techniques such as lime, cement, and fly-ash for treatment of expansive dry soils and because the use of gypsum as a stabilizing agent was not clear, he studied the performance of gypsum as an additive for the treatment of expansive clay by means of swell potential and strength. Different quantities of gypsum such as 2.5%, 5%, 7.5% and 10% by mass were added to clay with bentonite and compacted with optimum water content obtained from earlier experiments conducted by the author. He performed the Atter berg limits, free swell and unconfined compressive strength tests on treated as well as untreated samples. After curing the specimens for 7 days, changes in plasticity, swell percentage and strength parameters of treated and untreated samples were obtained and finally concluded that gypsum can be used as a stabilizing agent for expansive clay soils effectively.

M. R. Abdi et al [2009] investigated the possibility of strength enhancement of clays reinforced with geo grids embedded in thin layers of sand. The test results for the clay, clay-sand, clay-geo grid, sand geo grid and clay-sand-geo grid were presented and discussed. Thin sand layers with thickness of 4,6,8,10,12 and 14mm were used to quantify their effects on the interaction between the clay and the geo grids. In this regard effects of sand layer thickness, normal pressure (i.e. confinement) and transversal members of geo grids were investigated. All the tests were conducted using saturated clay with no drainage allowed.

Test results indicated that provision of thin layers of sand for encapsulating the geo grids were very effective in improving the strength and deformation characteristics of saturated clay. Maximum strength enhancement was derived at an optimum sand layer thickness of 10 mm which proved to be independent of the magnitude of the normal pressure used. Also, for a particular sand layer thickness, increasing the normal pressure resulted in enhanced strength improvement. Results also showed that removal of the geo grid transversal members resulted in reducing the strength of the reinforced samples by 10% compared to geo grids with transversal members. Encapsulating geo grids in thin layers of sand not only improved the performance of clays if used as backfill but also provided drainage paths preventing pore water pressure generation on saturation of the backfill.

SulaphaPeethamparan et al [2009] presented a study of the physiochemical interaction of a high free lime (CaO) content cement kiln dust (CKD) with expansive Na-montmorillonite clay. Moist compacted specimens of the

CKD-treated clay, the clay alone, the CKD alone, and (for comparison) the clay treated with 7% CaO were each cured for periods upto 90 days and examined by XRD, TGA, and SEM techniques. The results for the CKD-treated clay indicated that calcium hydroxide, derived from the CaO present in the CKD, was extensively adsorbed on the surfaces of the clay flakes, but apparently only limited pozzolanic reaction occurred. With research the author found that the specimen underwent extensive physiochemical changes and was presumed to lead to stabilization and strength development.

M. A. Bustamante, M. D. Pe´rez-Murcia, C. Paredes, R. Moral, Thilde Bech Bruun, Bo Elberling, Bent T. Christensen et al [2009] examined the liability of Soil Organic Carbon (SOC) in tropical soils with contrasting clay mineralogy (kaolinite, smectite, allophaneand Al-rich chlorite). Soil was sampled from A horizons at six sites in humid tropical areas of Ghana, Malaysian Borneo and the Solomon Islands and separated into fractions above and below 250 mm by wet sieving. Basal soil respiration rates were determined from bulk soils and soil fractions. Substrate induced respiration rates were determined from soil fractions. SOC liability was significantly influenced by clay mineralogy, but not by clay content when compared across contrasting clay minerals.

The liability of SOC was lowest in the allophonic and chloritic soil, higher in the kaolinitic soils and highest in the smectitic soil. The results contrasted with conventional concepts of the greater capacity of smectite than of kaolinite to stabilize SOC. Contents of dithionite-citrate-bicarbonate extractable Fe and Al were inversely related to SOC liability when compared across soil types. A stronger inverse correlation between content of ammonium-oxalate extractable Fe and SOC liability was found when considering the kaolinitic soils only and the authors concluded that the content of active Fe (hydr-) oxides controlled SOC stabilization in the kaolinitic soils. Results suggested that the validity of predictive models of SOC turnover in tropical soils would be improved by the inclusion of soil types and contents of Fe and Al (hydr-) oxides.

A. L. Gotman and M. N. Khurmatullin et al [2010] conducted investigations at two experimental sites at a plant owned by the Production Union "Khimvolokno" in Ufa, and included installation of soil-cement piles in clayey soils by the jet grouting method using equipment manufactured by the Casagrande Co., and their testing under a static impressing load. The procedure used to install a soil-cement pile with determination of hardening times and evaluation of the strength of the material in the shaft of the pile was found out. The optimal length of the piles with the condition whereby equality was achieved between the strengths of the soil and material was determined. Further the performance characteristics of foundations in the form of single piles and pile groups were found out. The strength and deformability parameters of the soil bed strengthened by the soil-cement piles.

Mohamed M. Mekkawya, David J. White, Muhannad T. Suleiman, Charles T. Jahren et al [2010] Completed field study in Iowa showing that many granular shoulders overlie clayey sub grade layer with California Bearing Ratio (CBR) value of 10 or less. When subjected to repeated traffic loads, some of these sections developed considerable rutting. Due to costly recurring maintenance and safety concerns, the authors evaluated the use of biaxial geo grids in stabilizing a severely rutted 310 m tests section supported on soft sub grade soils. Monitoring the test section for about one year, demonstrated the application of geo grid as a relatively simple method for improving the shoulder performance.

The field test was supplemented with a laboratory testing program, where cyclic loading was used to study the performance of nine granular shoulder models. Each laboratory model simulated a granular shoulder supported on soft sub grade with geo grid reinforcement at the interface between both layers. Based on the research findings, a design chart correlating rut depth and number of load cycles to sub grade CBR was developed. The chart was verified by field and laboratory measurements and used to optimize the granular shoulder design parameters and better predict the performance of granular shoulders.

Mohamad Nidzam Rahmat, Norsalisma Ismail et al [2010] conducted investigations on wastepaper Sludge Ash (WSA), an industrial by-product from the paper industry which can possibly be utilized to modify certain engineering properties of soils for specific uses to conserve non-renewable natural resources. Sulphate-bearing clays (Lower Oxford Clay, LOC) stabilized with various stabilizers on the basis of WSA (such as WSA–lime, WSA–Portland cement and WSA–ground granulated blast furnace slag) under controlled laboratory conditions. The stabilizers reduced the plasticity index (PI) and maximum dry density (MDD),increased the optimum moisture content (OMC) of LOC. The compressive strength of these stabilized clay was comparable to the clay stabilized by the traditional stabilizer lime (CaO) and was better when WSA was combined with ground granulated blast furnace slag (GGBS) and with Portland cement (PC). This system also performed better in terms of linear expansion. The results therefore indicated environmental, economic, as well as technological benefits in utilizing WSA as soil stabilizer.

Abd El Megeed Kabasy Mohamed et al [2012] studied the addition of hay of wheat to a type of clayey swelling soil to improve and stabilize its characteristics. Old houses in Egyptian villages were built with clay mixed with hay as a cementious agent between clay particles. The hay ratio used in the present study was 0.5%, 1% and 1.5% by weight of the clayey soil. The soil used in the study represents a type of swelling clayey soil. Index, strength and swelling properties tests were carried out on the clay–hay mixture. The results showed that the shear strength increases with the increase of hay ratio till approximately 1% hay addition. The indirect tensile strength for air dried samples increased as well. The deformation due to the swelling potential also decreased to about 20%.

Juan M. Manso, Vanesa Ortega-López, Juan A. Polanco, Jesús Setién et al [2012] studied the properties of Ladle Furnace Slag (LFS) and the characteristics of several clayey soils susceptible to improvement with additions of this by-product. The behavior of the different soil and slag mixes was similar to the behavior of the soil and lime mixtures reported in the literature. The results of a series of test reported improvements in various geotechnical properties, such as the plasticity index, expansiveness, bearing capacity and durability.

Mo Zhang, HongGuo, Tahar El-Korchi, Guoping Zhang, Mingjiang Tao et al [2012] studied the stabilization of lean clay with metakaolin based geopolymer at different concentration (ranging from 3 to 15 wt.% of unstabilized soil at its optimum water content) to examine the feasibility of geopolymer in stabilizing soils. Geopolymer stabilized soil specimens were characterized with compressive strength testing, volume measurements during curing, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD). The testing results indicated that with geopolymer concentrations, compressive strength, failure strain and Young's modulus of the stabilized soil specimens increased, and shrinkage strains during curing decreased. The micro structural analyses confirmed the formation of geopolymer gels in the stabilized soil, and showed the soil tended to form more homogeneous and compact microstructures after stabilization. This study illustrated that metakaolin based geopolymer can be an effective soil stabilizer for clayey soils. Further studies on the long-term performance of geopolymer stabilized soils, the use of geopolymers synthesized from industrial wastes, and the financial and environmental cost of applying geopolymer in soil stabilization were worth being conducted.

R. G. Kochetkova et al [2012] presented the influence of modern stabilizers on improved properties of clayey soils. He investigated the role of Surface-active agents (SAA), as hydophobizing additive which made it possible to eliminate the ability of the soils to actively interact with water by neutralizing surface-tension forces, to improve the property of clayey soils with a high specific surface. He mentioned that when small additives of cement – from 2 to 6% were introduced to clayey soils, the optimal moisture content and maximum dry density of the soil remained unchanged but its water-induced softening diminished and the compressive and bending strengths along with elastic modulus of the soil increased. In his studies he found that for a soil sample treated with a stabilizer, the elastic modulus of 27.6MPa amounted to 37.3 MPa with the introduction of a stabilizer and cement. He then, with further results to strengthen the argument, stated that the use of “Status” stabilizer has made it possible to develop technical specifications for the adopted and proven procedures and also recommended the stabilizer as an active water repellant for enhancing the properties of clayey soil.

Seyed Abolhassan Naeini et al [2012] carried out an experimental investigation on the influence of waterborne polymer for unconfined compressive strength of clayey soils. With the use of nontraditional chemical stabilizers in soil improvement daily, a new stabilizing agent was developed to improve the mechanical performance and applicability of clayey soils. He carried out various laboratory tests including sieve analysis, hydrometer, Atter berg Limits, modified compaction and Unconfined compression tests.

Three clayey soil specimens with different plasticity indexes were mixed with various amounts of polmer (2, 3 and 5%) and compacted at the optimum water content and maximum dry density. The experiments on these samples concluded that the waterborne polymer significantly improved the strength behavior of unsaturated clayey soils. Furthermore, an increase in plasticity index caused a reduction in unconfined compression strength. Results showed that with soils stabilized with 4% polymer had higher unconfined compressive strength than other percentages. The stress-strain plots of the tests showed that as the plasticity increased, the soil yielded a higher strain.

Aly Ahmed et al [2013] researched and investigated the use of recycled bassanite produced from gypsum waste plasterboards to enhance the compressive strength, splitting tensile strength and CBR or weak sub grades clay soils used in roads construction. The author used two specimens of soils that represented wear sub grades soils from two different sites. The research sums up the preliminary investigations of utilizing recycled bassanite in road construction projects. Four different amounts of admixture were mixed with the tested soils and were examined for the compressive strength, tensile strength, CBR, volume change and capillary rise. The results showed that the use of recycled bassanite resulted in a considerable increase in CBR and compressive strength for both the specimens. It also had a significant effect on the reduction of capillary rise in the case of silt by increasing the time, which reduce the possibility for formation of ice lenses and then the susceptibility of stabilized soil for frost heave reached, but had insignificant effect in the case of clay. It enhanced the performance stability of weak clay. These enhanced stability would result in longer service and smaller thickness sections for road construction.

Achmad Fauzia et al [2013] Experimentally investigated the use of utilization waste mineral as stabilizer for a special type of clayey soil stabilization. These minerals were High Density Polyethylene (HDPE) and Glass. His research consisted of various strength tests and soil engineering properties for various contents of HPDE and glass to different types of clayey soil from the various sites in Kelantan, Indonesia. The soil samples were mixed with the different contents of stabilizer at the optimum moisture content of the soil.

The author used 4%, 8% and 12% of stabilizers by their total dry weight. Tests results showed that the maximum dry density decreased and the optimum water content increased when the stabilizer contents increased, and further the CBR values increased when the HPDE and Glass content increased. HPDE and Glass also eliminated the need for expensive borrow materials by improving excessively wet subgrades and promoted cost savings through reduction in the required amount of materials used. Conclusions were also made that these stabilizers solved disposal problems and promoted the sustainability in highway construction.

Azhani Zukri et al [2013] determined the optimum lime content (OLC) required for Pekan soft soil treatment program and its strength. The OLC was determined using Eades-Grim pH test. Another testing that involved in this study are Atterberg Limit, Unconfined Compressive Strength and Standard Proctor Test. From the study, the optimum amount to stabilize the clay soil in this particular area and minimum amount of lime to raise soil pH level to 12 was 4%. The soil strength is reach 116kN/m2 while the maximum dry density and optimum moisture content for treated soil are 16kN/m3 and 13% respectively. Results showed that the optimum lime content obtained for this Pekan Clay was 4%. It is the lowest percentages of lime for stabilizing the particular soil that produces a laboratory pH of 12.

C. Ureña et al [2013] prepared the samples of pure bentonite clay soil mixed with olive mill wastewater, mg-hydroxide and sea water to study the changes in the geotechnical and mineralogical properties of the soil. These additives we taken as the by-products derived from industrial processes, and had the potential to lead towards greater sustainability of the construction process. The soil samples were mechanically tested on its compaction, consistency, bearing capacity and swelling pressures. Test results showed that the non conventional additives reduced the swelling pressures remarkably by 60-87% along with the reduction of the plasticity of the soil sample. Further the addition of these additives promoted a reduction in the amount of montmorillonite present in the due to the caution exchange capability enabled by the introductions of the cautions. Also, the samples treated with at least 10% of additive reached CBR index above 3% which could verify that the soil could be used for embankments in different countries as per code specifications.

Jyoti S. Trivedi, Sandeep Nair, Chakradhar Iyyunni et al [2013] aimed to formulate a model based on Genetic Algorithm which can be used to predict variation in the values of CBR of the Sub-grade Soil with the addition of a specific percentage of Fly Ash. The input values for this study were those which directly affect the CBR values i.e., directly proportional to CBR. It included Liquid Limit (LL), Plasticity Index (PI), Optimum Moisture Content (OMC) &Fraction of Fly Ash added (F.A in %).For analysis of stabilization of soil using fly ash, Evolver 5.7 an add-in software of excel was used. Properties used for analysis were Liquid Limit, Plastic Limit, Optimum Moisture Content and California Bearing Ratio. This model aimed to help all types of agencies involved in road construction like NHAI, Infrastructure Developers and Construction Contracting Organizations to pre-determine the soil stabilization achieved due to fly ash for a particular type of sub-grade soil.

Lillian Gungat, Elsa Eka Putri and Jodin Makinda et al [2013] investigated the potential of Oil Palm Shell(OPS) for sub grade improvement. The effects of Oil Palm Shell and its curing time in the mixture of the clay sub grades were examined by series of laboratory tests. The clay soils were mixed with OPS additives at 10%, 20% and 30% of total mix. Modified proctor compaction was performed to get the optimum moisture content and maximum dry density for the CBR sample preparation. Samples were then cured for 7 days, 10 days, 14 days, 20 days and 28 days prior to California Bearing Ratio test to examine the improvement effect. The results reveal that Oil Palm Shell improved the load bearing capacity of the clay soil sub grade due to higher CBR value produced as compared to conventional mix. The highest CBR values obtained from 30% oil palm shell were at 20 days curing period. Thus, it can be concluded that the addition of Oil

Palm Shell to the clay soil can improve the load bearing capacity of sub grade in the pavement construction.

Rimantas Mackevicius et al [2013] analyzed the deformations of ancient churches in Vilnius in Koenigsberg and the possibilities of its stabilization of its grounds with grouting. Foundations of both Cathedrals were constructed on weak soils. The deformations of Vilnius Cathedral were reflected by the cracks in the structures. Previously the underpinning the bored piles of Vilnius cathedral in years 1931-1937 improved the situation. Settlements of Koenigsberg cathedral reached approximately 2.0 m during 6 centuries. Results of laboratory tests with sandy soils from Vilnius Cathedral stabilized with solutions of organic polymers were given. Comparison was done of properties of conventional polymer resins with properties of modified resins. Such properties of solution of resins had been investigated: density, viscosity, pH (alkalinity level), evaporation of components from solution in water and air. It has been concluded that the stabilization of sandy soil under Vilnius Cathedral with grouting and that the stabilization of peaty and clay ground is not possible by grouting.

Takeshi Kamei et al [2013] investigated the use of recycled bassanite, produced from gypsum waste, in conjunction with coal ash as a stabilizer material to improve the strength of very soft clay soil as well as to improve its durability in a wet environment. Additionally, this study investigated the effect of wet–dry cycles, referred in this study as a wet environment, on durability, strength and mechanical properties of very soft clay soil stabilized with recycled bassanite and coal ash. Four different combinations of the bassanite–soil ratios ranging between 0% and 20% as well as three different combinations of the coal ash–soil ratios ranging between 0% and 20% were used. The results showed that the use of recycled bassanite and coal ash significantly increase strength and improve durability. Both strength and durability improved with an increase of bassanite and coal ash content in the soil mixture.

The influence of the wet–dry cycles on mechanical properties, such as water content, dry unit weight and volume changes, was not significant however. Results concluded that both the recycled bassanite and coal ash had a significant effect on the increase in strength and durability improvement of very soft clay soils. The increase in the coal ash–soil ratio content had a significant effect on the formation of ettringite compared to the bassanite -soil ratio content. The formation of ettringite increased with the increase in both the bassanite and coal ash contents in the soil mixture. Thus the samples stabilized with bassanite and coal ash within the investigated limits in this study were durable against the effects of the wet–dry cycles.

Takeshi Kamei, AlyAhmedb, Keizo Ugai [2013] examined the wetting–drying durability of soft clay soil stabilized with recycled Bassanite, produced from gypsum waste. Specifically, the study focused on an investigation of the effects of the moisture conditions on the strength performance and durability of very soft clay soil stabilized with Bassanite and furnace cement mixtures during the wetting–drying cycles, referred to as weathering conditions in this study. Cylindrical stabilized soil specimens were produced and then cured for 28 days. The cured specimens were subjected to different numbers of wetting–drying cycles, and then tested for unconfined compressive strength.

The results showed that the compressive strength increased with an increase in the Bassanite content for the different wetting–drying cycles were investigated. The increase in the Bassanite content was associated with the increase in the dry unit weight, as well as in the decrease in the moisture content of the stabilized specimens for the different wetting–drying cycles investigated.

The compressive strength of the soil stabilized with the Bassanite and furnace cement mixtures gradually decreases with an increase in the number of wetting–drying cycles, and the earlier cycles were seen to have a more negative effect on durability than the later cycles. Generally, the influence of the wetting–drying cycles on changes in the strength, durability and volume of the soft clay soil stabilized with Bassanite and furnace cement mixtures was not significant. This is evidence that the use of recycled Bassanite, produced from gypsum waste to stabilize soft clay soil, achieves acceptable durability, raises the strength performance and improves the engineering properties of soft clay soil in a wet environment. In addition, the effective use of gypsum waste contributed to the development of a sustainable society by reducing the huge quantity of solid waste and establishing a sound environment.

W. R. Azzam et al [2013] illustrated the application of using polymer stabilization in creating a new nano composite material with clay soil. He performed various tests with varying contents of polypropylene to study the behavior on both, microstructure as well as geotechnical clay properties. As many papers were unable to thoroughly explain the technique of nano composites formation by their methods and were not able to predict the nano filter effect on the geotechnical behavior of stabilized clay by such polymer. He modified the clay microstructure by use of polymers to produce nano composite materials with components of clay.

The general properties of the clay were amorphous density at25^{o}C : 0.85 g/cm^3, crystalline density at 25^{o} C: 0.95 g/cm^3 and molecular weight of repeat unit: 42.08 g/mol. The soil specimens were collected from Egypt at a depth of 2-3 m and a groundwater level of about 1.5 below the ground surface. Various test results concluded that the creation of nano composites effectively decreased and absorbed the excess water within the clay samples and thus, modified the clay plasticity. These could also increase the clay stiffness and reduce the compression index. Further, it increased the shear strength of clay and modified the brittle shear failure to a ductile one thereby validating that this technique could be applied to solve the geotechnical stabilization problems in road embankments or slope stabilization.

Shawn T. Lucasa et al [2014] recently studied the effects of promoting fungal abundance in soil to improve its structure. Generally in the agro ecosystems, soil structure played vital role because it governs soil functions such as air and water movement, soil C stabilization, nutrient availability, and root system development. This study examined the effects of organic amendments comprising of different portions of liable and semi-liable C on the microbial community structure and macro aggregate formation in three variously textured soils where the native structure was destroyed. He studied these changes for 82 days under laboratory conditions.

The results showed that regardless of the soil type, formation of large macro aggregates was highest in the sample with higher abundance of the fungi due to an increase in fungal biomarkers in all soils. Also regression analysis showed strong correlation between the formation of large macro aggregates (LMA > 2000 µm diameter) and the relative abundance of the various fungi additives. Results showed that the higher relative abundance stimulated microbial proliferation in general. Hence, the results suggested that organic amendments can be used to manipulate soil microbial community structure to promote aggregation in soils.

CONCLUSIONS

This paper presents the research carried out by various authors on stabilization techniques of clayey soil. From the experimental investigations it was inferred that stabilization with limestone and fly ash chemically changes most clay soils, resulting in

- Marked reduction in shrinkage and swelling properties of clay soils.

- Remarkable increment of Unconfined Compressive Strength.
- Substantial increment of load bearing values as measured by tests such as California Bearing Ratio (CBR), Tri-axial Shear Test and Box Shear Test.
- Significant increase in Tensile and Flexural strength.
- Formation of water resistant barrier with impedes migration of surface water from above and capillary moisture from below.
- Lowering of plasticity in most cases.

Thus, this paper gives a brief insight about various soil stabilization techniques for clayey soils.

REFERENCES

1. L. Gotman and M. N. Khurmatullin, “Performance of piles installed by jet grouting method in clayey soils”, Soil Mechanics and Foundation Engineering, Vol. 49, No. 4, September, 2012.
2. A.M.O. Mohamed, “The role of clay minerals in marly soils on its stability”, Engineering Geology, Vol. 57 (2000), pp. 193–203.
3. Seco, F. Ramírez, L. Miqueleiz, B. García, “Stabilization of expansive soils for use in construction”, Applied Clay Science, Vol. 51 (2011), pp 348–352.
4. Abd El MegeedKabasy Mohamed, “Improvement of swelling clay properties using hay fibers”, Construction and Building Materials, Vol.38 (2013), pp. 242–247.
5. AchmadFauzi,“Utilization Waste Material as Stabilizer on Kuantan Clayey Soil Stabilization”, Malaysian Technical Universities Conference on Engineering & Technology 2012, Part 3- Civil and Chemical Engineering, MUCET 2012.
6. Aly Ahmed, “Recycled bassanite for enhancing the stability of poor sub grades clay soil in road construction projects”, Construction and Building Materials, Vol. 48 (2013), pp. 151–159.
7. Amer Ali Al-Rawas “Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman” Building and Environment”, Vol. 40 (2005), pp. 681–687.
8. AzhaniZukri, “Pekan Soft Clay Treated With Hydrated Lime As A Method Of Soil Stabilizer”, Procedia Engineering, Vol. 5 (2013) pp. 37-41.
9. B.V.S. Viswanadham, “Swelling behavior of a geo fiber reinforced expansive soil”, Geo textiles and Geomembranes, Vol. 27 (2009), pp. 73–76.
10. Ureña, “Magnesium hydroxide, seawater and olive mill wastewater to reduce swelling potential and plasticity of bentonite soil”, Construction and Building Materials, Vol. 45 (2013), pp. 289–297.
11. Cao Li-wen “Experimental research on geotechnical behaviors of compacted clay influenced by metal cation”, Procedia Earth and Planetary Science, Vol. 1 (2009), pp. 1016–1023.

12. Department of Civil Engineering, Democritus University of Thrace, GR-67100 Xanth L Greece "Stabilization of swelling clays by Mg(OH)2. Factors affecting hydroxy-Mg-inter layering in swelling clays", Engineering Geology, Vol. 44 (1996), pp. 93-106.
13. IşıkYilmaz, "Gypsum: An additive for stabilization of swelling clay soils", Applied Clay Science, Vol. 44 (2009), pp. 166–172.
14. J. Prabakara, "Influence of fly ash on strength behavior of typical soils", Construction and Building Materials, Vol. 18 (2004) pp. 263–267.
15. Juan M. Manso, Vanesa Ortega-López, Juan A. Polanco, JesúsSetién, "The use of ladle furnace slag in soil stabilization", Construction and Building Materials, Vol. 40 (2013), pp. 126–134.
16. JyotiS. Trivedi, Sandeep Nair, ChakradharIyyunni, "Optimum Utilization of Fly Ash for Stabilization of Sub-Grade Soil using Genetic Algorithm", Procedia Engineering, Vol. 51 (2013), pp. 250 – 258.
17. Lillian Gungat, Elsa Eka Putri and Jodin Makinda, "Effects of Oil Palm Shell and Curing Time to the Load-Bearing Capacity of Clay Sub grade", Procedia Engineering, Vol. 54 (2013), pp. 690 – 697.
18. M.A. Bustamante, M.D. Pe´rez-Murcia, C. Paredes, R. Moral, A. Pe´rez-Espinosa, J. Moreno-Caselles, "Short-term carbon and nitrogen mineralisation in soil amended with winery and distillery organic wastes", Bio resource Technology, Vol. 98 (2007), pp. 3269–3277.
19. M.R. Abdi, "Strength enhancement of clay by encapsulating geogrids in thin layers of sand", Geo textiles and Geomembranes, Vol. 27, (2009), pp. 447–455.
20. Mo Zhang, HongGuo, Tahar El-Korchi, Guoping Zhang, Mingjiang Tao, "Experimental feasibility study of geo polymer as the next-generation soil Stabilizer", Construction and Building Materials, Vol. 47 (2013), pp. 1468–1478.
21. Mohamad NidzamRahmat, Norsalisma Ismail, "Sustainable stabilisation of the Lower Oxford Clay by non-traditional binder", Applied Clay Science, Vol. 52 (2011), pp. 199–208.
22. Mohamed M. Mekkawya, David J. White, Muhannad T. Suleiman, Charles T. Jahren, "Mechanically reinforced granular shoulders on soft subgrade: Laboratory and full scale studies", Geo textiles and Geo membranes, Vol. 29 (2011), pp. 149-160.
23. Nurhayat Degirmenci, "Application of phosphogypsum in soil stabilization", Building and Environment, Vol. 42(2007), pp. 3393–3398.
24. R. G. Kochetkova, "Influence of Modern Stablilizers on Improved Properties of Clayey Soils", Soil Mechanics and Foundation Engineering, Vol. 49 (2012).
25. Raymond N. Yong,Vahid R. Ouhadi, "Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils", Applied Clay Science, Vol. 35 (2007), pp. 238–249.
26. Rimantas Mackevicius, "Possibility for Stabilization of Grounds and Foundations of Two Valuable Ancient Cathedrals on Weak Soils in Baltic Sea Region with Grouting", Procedia Engineering, Vol. 57 (2013), pp. 730 – 738.

27. S. BanuIkizler, “Laboratory study of expanded polystyrene (EPS) geo foam used with expansive soils”, Geo textiles and Geomembranes, Vol. 26 (2008), pp. 189–195.
28. S. Kolias, V. Kasselouri-Rigopoulou, A. Karahalios, “ Stabilisation of clayey soils with high calcium fly ash and cement”, Cement & Concrete Composites, Vol. 27 (2005), pp. 301–313.
29. Sayyed Mahdi Hejazi, “A simple review of soil reinforcement by using natural and synthetic fibers”, Construction and Building Materials, Vol. 30 (2012), pp. 100–116.
30. Seyed AbolhassanNaeini, “Unconfined Compressive Strength of Clayey Soils Stabilized with Waterborne Polymer”, Journal of Civil Engineering, Vol. 16(6) (2012), pp. 943-949.
31. Shawn T. Lucasa,“Improving soil structure by promoting fungal abundance with organic soil amendments”, Applied Soil Ecology, Vol. 75 (2014) pp. 13– 23.
32. Sulapha Peethamparan, “Mechanism of stabilization of Na-montmorillonite clay with cement kiln dust”, Cement and Concrete Research, Vol. 39 (2009), pp. 580–589.
33. Takeshi Kamei “The use of recycled bassanite and coal ash to enhance the strength of very soft clay in dry and wet environmental conditions”, Construction and Building Materials, Vol. 38 (2013) pp. 224–235.
34. Takeshi Kamei, Aly Ahmedb, KeizoUgai, “Durability of soft clay soil stabilized with recycled Bassanite and furnace cement mixtures”, Soils and Foundations, Vol. 53(1)(2013), pp. 155–165.
35. ThildeBechBruun, Bo Elberling, Bent T. Christensen, “Lability of soil organic carbon in tropical soils with different clay minerals”, Soil Biology &Biochemistry, Vol. 42 (2010), pp. 888-895.
36. Valéry Ferber,Jean-Claude Auriol,Yu-Jun Cui,Jean-Pierre Magnan, “On the swelling potential of compacted high plasticity clays”, Engineering Geology, Vol. 104 (2009), pp. 200–210.
37. W.R. Azzam, “Behavior of modified clay microstructure using polymer nanocomposites technique”, Alexandria Engineering Journal (2013).
38. YiCai, “Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil”, Engineering Geology, Vol. 87 (2006), pp. 230–240.
39. YucelGuneya, DursunSarib, MuratCetinc, Mustafa Tuncan,“ Impact of cyclic wetting–drying on swelling behavior of lime-stabilized soil”, Building and Environment, Vol. 42 (2007), pp. 681–688.
40. ZaliheNalbantog˘ lu, “Effectiveness of Class C fly ash as an expansive soil stabilizer”, Construction and Building Materials, Vol. 18 (2004), pp. 377–381.