Behaviourial Study of Expansive Soils and its Effect on Structures–A Review

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ABSTRACT: In the past, considerable interest has been developed in the problems of expansive soil and its effect on the structures, but comparatively very little has been studied to understand its behavior and effect on the structures. A number of reports about the characteristics, behavior, stabilization and effects on structures of expansive soil have been published over the years but no comprehensive review has been published specially during the last decade. Thus the aim of this paper is to present a review on characteristics, behavior, stabilization of expansive soil and its effects on the structures. Up to certain extant its nature and mechanics is understood and tried to stabilized by different techniques. Mainly this soil is stabilized with lime and fly ash and with the addition of certain chemicals gives very good performance even in the adverse conditions. But very little work has been done on its effects and remedial measures on the structures. The study will give technical overview and useful information to the engineers and researchers who will work for the betterment of research activities in this field in future.

Key Words: Expansive soil, stabilization, flies ash, effect, structures, characteristics

I. INTRODUCTION

Expansive soils are mostly found in the arid and semi-arid regions and it covers very large area of the world. It covers nearly 20% of the landmass in India and includes almost the entire Deccan plateau, Western Madhya Pradesh, parts of Gujarat, Andhra Pradesh, Uttar Pradesh, Karanataka, and Maharastra. The swelling soils are commonly known by the name of Black Cotton Soils. For swelling to occur, these soils must be initially unsaturated at some water content. If the unsaturated soil gains water content, it swells. On the other hand, if a decrease in water content occurs the soil shrinks. The presence of montmorillonite clay in these soils imparts them high swell–shrink potentials.[38][39][7]

The Malwa region occupies a plateau in western Madhya Pradesh and south-eastern Rajasthan, with Gujarat in the west. To the south and east is the Vindhya Range and to the north is the Bundelkhand upland. The plateau is an extension of the Deccan Traps, formed between 60 and 68 million years ago at the end of the Cretaceous period. In this region the main classes of soil are black, brown and bhatori (stony) soil. The volcanic, clay-like soil of the region owes its black colour to the high iron content of the basalt from which it formed. The other two soil types are lighter and have a higher proportion of sand.

As the Malwa region is mainly dominated by Black Cotton Soil, it is one of the types of expansive soil, which has a potential for shrinkage and swelling under changing moisture conditions. The lightly loaded structures and pavement are more sustainable to the damage by the differential movement caused by the expansive soil. Various types of distress in buildings are occurs, which are provided with conventional open foundation, raft foundation or latest under reamed pile foundations. Similarly in the pavements large cracks occur due to the non-consideration of the expansive behaviour of subgrade.[34] [35] [36].

II. LITERATURE REVIEW

The expansive soil in Malwa region, Madhya Pradesh, India especially posses a problem to many Structures and National Highways constructed which is caused due to presence of mineral Montmorillionite. The authors presented the case study about the Performance, Problems, and Remedial measures for the Structures Constructed on expansive Soil. The swelling characteristics of expansive soil and its effects on the structures are being revealed.

The effect of adding Gypsum, Crude oil and Laying CNS (Cohesive Non-swelling) layer on expansive soil is studied. In areas with very less probability of seismic activities, vibratory ground improvement can reduce the potential for liquefaction and ground deformation due to lateral spreading. Various tests are performed on the expansive soil to determine its Swelling Pressure test, Triaxial Compression Test, Optimum Moisture Content, Conducting Field Density, Liquid Limit, Plastic Limit, Shrinkage Limit, Specific Gravity etc.[46][47]

The experimental results seeks to explore and explain the phenomena causing swelling and the attendant damage based on a local setting, and on the basis of this study various multiple remedial measures are given to overcome the swelling of expansive soils by different means and it is found that swelling pressure decreases with increase in bearing capacity of soil by addition of Gypsum, Crude oil, Laying CNS layer and use of Under-reamed piles (single bulb) under economical consideration.[1].[34] [35].[36].

Authors provided an overview of these features and include methods to investigate expansive behaviour both in the field and in the laboratory together with associated empirical and analytical tools to evaluate expansive behaviour. Following these remedial measures for pre and post constructions are highlighted for both foundations and pavements together with methods to ameliorate potentially damaging expansive behavior. [1] .[34] [35].[36]

The engineering properties of expansive soil are controlled by especial mineral components and chemical constitutions. To study the mechanism of the reaction among expansive clay granules, lime and pulverized fuel ash, some analyses on the original expansive soil and the expansive soil modified by lime and pulverized fuel ash were carried out with SEM, and the connection points of granule were analyzed with at the same time. After the expansive soil is modified by lime and pulverized fuel ash, its agglutinate has an obviously increase of Ca 2 +, makes an improvement of connections between granules and reduces the expansibility and contractility of soil. [8]

Clay soils are usually subjected to a time dependant strain under load. This strain is mainly a function of the rate of pore water pressure dissipation which in turn depends on the permeability of the soil mass. Therefore, consolidation is a term used to describe the volume change of the soil mass due to pore water pressure dissipation. To evaluate the swelling and consolidation behavior of expansive soils of Addis Ababa and their interdependence using one dimensional consolidation theory of Terzaghi. In the course of the research work consolidation-swell test was carried out on a number of samples of expansive soil obtained from different parts of Addis Ababa. The swelling and consolidation characteristic of the soil is determined from the laboratory tests. Ranges of values of the consolidation parameters are also obtained. The swelling behavior is found to influence the consolidation characteristics of expansive soils.[30][37]

Several groups of direct shear tests of expansive soil samples were carried out by improved direct shear apparatus. The results of the characteristics of the ultimate shear stress and residual shear stress at the interface of expansive soil-structure are presented. Ultimate and residual shear stresses are, respectively, linear relations with vertical loads, viz, the both shear stresses increase with the increase of vertical loads; the increase of vertical loads contribute more to the increase of residual shear stress than that of ultimate one. Ultimate shear stress at the interface is approximately linear relation with water content, viz, decreasing with the increase of water content, so does residual shear stress; the change of ultimate shear stress is much more sensitive to the change of water content, viz, water content has much more influence on ultimate shear stress than residual shear stress. Both ultimate and residual shear stresses have approximately linear relation with dry density, viz, the shear stresses increase with the increase of dry density.

The differences of effects of vertical load, water content and dry density on ultimate and residual shear stress indicate the differences of beginning and development of the both shear stresses. [27]

The problems associated with expansive soil are related to bearing capacity and cracking, breaking up of pavements, and various other building foundation problems. Such soils are common in Australia, India and South Africa. The effect of gypsum and addition of dune sand on swelling pressure is studied and it is found that swelling pressure decreases with addition of dune sand and gypsum. Addition of gypsum will reduce the swelling pressure. Limit the foundation depth if swelling soil is at some depth so that distance between foundation and swelling soil will be more and as the distance is more there are less chances of cracks in building. Take effective measures to maintain moisture equilibrium in foundation soil. Add dune sand in the existing swelling soil. Swelling pressure increases with increase in dry density and decreases with increase in molding water content. Swelling pressure also decreases due to addition of gypsum and dune sand. Various remedial measures are presented in the paper to overcome the problem of swelling pressure.[33] [40]

Clay soils start to crack from the ground surface as metric suction increases. The low confining pressures near the ground surface allows clay soils to commence cracking at relatively low metric suctions. The cracks generally become closed with depth as the confining pressure increases. It is difficult to estimate the hydraulic conductivity and the water storage properties of the cracked clay. If a soil contains cracks its physical behavior can be assumed to be bi-modal in character. The bi-modal soil behavior will be exhibited in the soil–water characteristic curve which in turn, affects the calculation of water storage as well as the hydraulic conductivity function. The magnitude of soil metric suction change increases with increasing crack volume, both for evaporation and infiltration conditions. When there is a substantial volume of cracks in the soil, the metric suctions are essentially uniform along the ground surface. The same behavior is observed for both the evaporation and infiltration and whether the initial suction is higher or lower than the air-entry value of the cracked soil. Cracked soil can be treated as a continuum and that the SWCC and hydraulic conductivity functions can be represented as a bi-modal function. Certain aspects of cracked clay behavior such as volume change, anisotropy, and hysteresis, have not been incorporated into the continuum model of this study, and further studies are needed to evaluate the impact of these cracked soil behavior characteristics on unsaturated flow, suction variation, and soil deformation. [22][40]

Stabilization is the process of improving the properties of soil by changing its gradation. Two or more types of natural soils are mixed to obtain a composite material which is of superior to any of its components. To achieve the desired grading, sometimes the soils with coarse particles are added or the soils with finer particles are removed. The blended soil possesses both internal friction and cohesion. When properly placed and compacted, the blended material becomes stable and also load carrying capacity is increased. The test results of liquid limit and plastic limit for three soils. From these figures for all the soils it is observed that as percentage of fly ash increases there is marginal reduction in liquid limit and almost no change in the plastic limit. Whereas with addition of lime to the three expansive soils showed marked decrement in liquid limit and reasonable increasing plastic limit, overall addition of lime showing good reduction in plasticity index of soils. This is of very desirable property of expansive soils to be used as a subgrade in road construction. There is a good improvement in unconfined compression strength of clay at about 4% addition of lime to three expansive soils after 4% of lime addition to the soils caused reduced values of strength. From the above discussions a few conclusions are drawn.

- Addition of lime and fly ash shown good decrement in plasticity index of soils.
- Addition of lime of 4% as shown good improvement in strength and it is about 40% to 60%.
- The swell pressure of lime treated expansive soils has reduced about four time at about 10% addition of lime. [4]

Extensive laboratory / field trials have been carried out by various researchers and have shown promising results for application of such expansive soil after stabilization with additives such as sand, silt, lime, fly ash, etc. As fly ash is freely available, for projects in the vicinity of a Thermal Power Plants, it can be used for stabilization of expansive soils for various uses. The paper describes a method adopted for placing these materials in layers of required thickness and operating a “Disc Harrow”. A trial embankment of 30m length by 6m width by 0.6m high was successfully constructed and the in-situ tests carried out proved its suitability for construction of embankment, ash dykes, filling low-laying areas, etc.[28]

Pandian et.al. (2002) studied the effect of two types of fly ashes Raichur fly ash (Class F) and Neyveli fly ash (Class C) on the CBR characteristics of the black cotton soil. The fly ash content was increased from 0 to 100%. Generally the CBR/strength is contributed by its cohesion and friction. The CBR of BC soil, which consists of predominantly of finer particles, is contributed by cohesion. The CBR of fly ash, which consists predominantly of coarser particles, is contributed by its frictional component. The low CBR of BC soil is attributed to the inherent low strength, which is due to the dominance of clay fraction. The addition of fly ash to BC soil increases the CBR of the mix up to the first optimum level due to the frictional resistance from fly ash in addition to the cohesion from BC soil. Further addition of fly ash beyond the optimum level causes a decrease up to 60% and then up to the second optimum level there is an increase. Thus the variation of CBR of fly ash-BC soil mixes can be attributed to the relative contribution of frictional or cohesive resistance from fly ash or BC soil, respectively. [28][41]

A similar study was carried out by Phanikumar and Sharma in (2004) and the effect of fly ash on engineering properties of expansive soil through an experimental programme. The effect on parameters like free swell index (FSI), swell potential, swelling pressure, plasticity, compaction, strength and hydraulic conductivity of expansive soil was studied. The ash blended expansive soil with flyash contents of 0, 5, 10,15 and 20% on a dry weight basis and they inferred that increase in flyash content reduces plasticity characteristics and the FSI was reduced by about 50% by the addition of 20% fly ash. [28]

An experimental investigation was undertaken to study the effects of lime-stabilized soil cushion on the strength behavior of expansive soil. In the present investigation, a series of laboratory tests (Unconfined compression tests and CBR tests) were conducted on both expansive soil alone and expansive soil cushioned with lime-stabilized non-expansive cohesive soil. Lime contents of 2, 4, 6, 8 and 10% by dry weight of cohesive non-swelling soil was used in the stabilized soil cushion. Both expansive soil and lime stabilized soil cushion were compacted to Standard Proctor’s optimum condition with thickness ratio 2:1. Tests on cushioned expansive soils were conducted at different curing and soaking periods i.e., 7, 14, 28 and 56 days. The test results revealed that maximum increase in strength was achieved after 14 days of curing or soaking period with 8% of lime content.

1. The maximum increase in strength of expansive soil is achieved by using lime stabilized soil cushion at lime content of 8% at a given soaking or curing period investigated. Further increase in lime content results in a marginal decrease in the strength of expansive soil.

2. Also, increase in strength of cushioned expansive soil becomes maximum after 14 days of soaking or curing period irrespective of lime contents used in the stabilized soil cushion. With increase in soaking or curing period beyond 14 days, no appreciable change in the strength is observed.

3. The durability of the expansive soil cushioned with LSRS with 6 and 8% lime content is almost same for 14 days curing period. As the strength is maximum at 8% lime content, the optimum lime content for the stabilized soil cushion may be taken as 8%.

4. At optimum content of lime and soaking or curing period of 14 days, the unconfined compressive strength of BC cushioned with LSRS increases to 6.56 and 4.24 times than that of BC alone in soaked and unsoaked conditions respectively.

5. Use of lime stabilized RS as cushion layer on BC increases the CBR value to 7 and 2.7 times of the BC soil under soaked and unsoaked conditions respectively at optimum lime content. [13]

A comparative analysis is made of technical solutions pertaining to stabilization of the design position of underground pipelines with the product being transported at a positive temperature in regions of permafrost propagation. A new scheme developed by the JSC Fundamentproekt for stabilization of the position of a pipeline, which permits its uniform in-service settlement, is discussed. [20][44]

Maximum Unconfined compressive strength was obtained at 20% fly ash mix with clay and further addition of fly ash reduces the strength. The CBR values of clay-fly ash mixes, tested under un-soaked conditions, shows peaks at 20% and 80% ash content. Similar results were obtained by Pandian (2004). Fly ash has good potential for use in geotechnical applications. The relatively low unit weight of fly ash makes it well suited for placement over soft or low bearing strength soils. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties, etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, fill behind retaining structures, etc. [5]

Laboratory test results show that the soil index properties get transformed by adding fly ash and lime which makes expansive soil less plastic and increases its workability by colloidal reaction and changing its grain size. The addition of fly ash lime reduces the plasticity characteristics of expansive soil .The liquid limit, plastic limit, plasticity index, linear shrinkage decreased drastically and shrinkage limit increased with the addition of fly ash-lime .The liquid limit, plasticity index, linear shrinkage are found to be lower for samples cured compared to fresh mixes of clay fly ash lime. The free swell index value and swelling pressure is found to decrease with either increase in lime or fly ash content. These values further decreased with curing period and increase in curing temperature. Grain size distribution of soils were altered by the addition of admixtures(fly ash and lime).The silt and sand fraction increased with increase in the amount of lime. Curing temperature and curing period are drastically changed the grain size in the mixes. Initially the grain size composition was 69% clay 29% sand and 2% of silt particle. But after stabilization of expansive soil with 80% fly ash 8% lime mix at 75^0C and after 30 days of curing the clay percentage reduced to 1%, percentage of silt came to 2% and fine sand become 97%.The increase in the particle size is due to the aggregation of small size particles. Increase in curing temperature and curing period favors in flocculation and aggregation of particles resulting in an more shifting of grain size towards coarser fractions. This type particle growth can be attributed to formation of cementation compounds. [6]

This paper evaluates the correlations of two physicochemical properties, pH and surface conductance, with the behavior of the SWCCs of four natural expansive soils and four stabilized soils. The effects of chemical stabilization and curing time on the SWCCs are also analyzed. The SWCCs and the corresponding parameters were obtained from pressure plate tests and a fitting model. Four highly clayey expansive soils and two stabilized soils with two different curing times were investigated to study the correlations of their physicochemical and mechanical characteristics with SWCCs. Pressure plate tests were performed to obtain SWCCs with a measurement range up to 1,000 kPa. [9][6]

The author in conjunction with coworkers (S. N. Emel'yanov and M. Dobrov) has developed the "Status" stabilizer/water-repellant with an anion-active effect for improvement of the properties of clayey soils, and investigated a procedure for its application. Deformations caused by the frost heaving of the clayey soil treated with the "Roadbond" and "Status" stabilizers were 15 and 35% lower, respectively, than those of the untreated soil. This suggests that treatment of the soils with a stabilizer during compaction will lead to a reduction in the overall deformation caused by frost heaving. According to observations performed over a period of 3-5 years, no failures and deformations have occurred on the stabilized sections of these roads. Moreover, the bearing capacity of the soils has been increased by a factor of 3-5. [16]

The soil will be treated by using sodium silicate and lime with different percentages. An experimental program was designed to study the behavior of soil as the percent of additive agent changes. The results showed that; the geotechnical properties have been improved when soil is treated by mixing lime and sodium silicate. The initial consumption of lime is of 4 and 2 % for sodium silicate. The reaction time is a significant parameter where strength improves as time increases.

On the basis of the findings of this study, soil treated with LSS-mix is recommended to be used to improve soil.

1. Shear strength increases as LSS content increases.
2. The reaction time is significant as the strength at 28 days is greater than at 7 days.
3. Variations in pH of the LSS-mix–soil mixtures can be used to monitor the development of pozzolanic reactions with time.
4. Treating soil with LSS reduces the sensitivity of shear strength toward variation in the degree of saturation.
5. The overall strength increases even at higher saturation levels due to pozzolanic reactions.
6. The plasticity index decreases by significant amount as sodium silicate content increases.
7. The soil has improved, the swelling potential has decreased and the percent of free swell has decreased by significant amount after treatment. The maximum reduction has been found at the mix of 6 % lime and 2 % sodium silicate.
8. The CBR has improved when the soil treated by LSS-mix at the mix of 6 % lime and 2.5 sodium silicate. [25][5]

Soil stabilization is one of most important for the construction which is widely used in connection with road pavement and foundation construction because it improves the engineering properties of soil such as strength, volume stability and durability. In the present investigation is to evaluate the compaction and unconfined compressive strength of stabilized black cotton soil using fine and coarse fly ash mixtures. The percentage of fine and coarse fly ash mixtures which is used in black cotton soil varied from 5 to 30. In the study concludes that with percentage addition of fine, coarse fly ash improves the strength of stabilized black cotton soil and exhibit relatively well-defined moisture-density relationship. It was found that the peak strength attained by fine fly ash mixture was 25% more when compared to coarse fly ash. It was observed that with the increase in water content the dry density decreases up to 20-30% moisture content and with further increase in water content the dry density decreases gradually. The maximum dry density is in the range of 1.35 g/cc for 95% soil and 5% fly ash mixture and lowest density was about 0.6g/cc for 70% soil and 30% fly ash mixture. This variation of density is primarily due to alteration of gradation of soil mixtures. The decrease of the maximum dry unit weight with the increase of the percentage of fly ash is mainly due to the lower specific gravity of the fly ash compared with expansive soil and the immediate formation of cemented products by hydration which reduces the density of soil. The decrease in dry density with increase in fine fly ash content is due alteration of gradation of soil mixtures. Whereas decrease in dry density with the increase in coarse fly ash mixture was attributed due to cat ion exchange between additives and expansive soil which decreases the thickness of electric double layer and promotes the flocculation. [2][45]

The researchers has reported the occurrence of substantial irreversible components of either wetting induced swelling drying induced shrinkage during cycles of wetting and drying performed on unsaturated highly expansive clays containing active clay minerals such an montmorillonite. This form of irreversible behavior cannot be represented by existing elesto-plastic models of unsaturated highly expansive clays was fundamentally different to that of unsaturated non-expansive clays, and that the constitutive models developed for unsaturated non-expansive clays were inappropriate. The experimental results suggested that unified modeling for both unsaturated highly expansive soils and unsaturated non-expansive soils is desirable. A new constitutive modeling framework is therefore proposed. In the modeling framework new forms of stress variables, with conjugate strain increment parameters are used for the first time. The behavior of unsaturated highly expansive clays was fundamentally different to that of unsaturated non-expansive clays and that the constitutive model developed for unsaturated non-expansive clays were inappropriate for unsaturated expansive clays. Given the high cost of damage to buildings,structures and roads caused by unexpected ground movements associated with unsaturated highly expansive clays and the increasing use of compacted expansive clays for engineered barriers for environmental protection and other purpose. It was considered important to investigate further the behavior of these soils. A conceptual model for the fabric of compacted highly expansive clays is proposed and three levels of fabric are clearly identified. The feasibility of occurrence of unsaturated conditions within all three levels of fabric is explored, which helps in checking the appropriateness of assumptions employed in constitutive models such as that proposed by Gens and Alonso(1992). [37]

The climatic zones where residual soils occur are often characterized by alternate wet and dry seasons. Laboratory studies of earlier workers have established that the alternate wetting and drying process affects the swell-shrink potentials, water content, void ratio and particle cementation of expansive soils. The influence of cyclic wetting and drying on the collapse behaviour of residual soils has not been examined. This paper examines the influence of alternate wetting and drying on the collapse behaviour of compacted residual soil specimens from Bangalore District. Results of such a study are useful in anticipating changes in collapse behaviour of compacted residual soil fills. Experimental results indicated that the cyclic wetting and drying process increased the degree of expansiveness of the residual soils and reduced their collapse tendency. Changes in the swell/collapse behaviour of compacted residual soil specimens from wetting drying effects are attributed to reduction in water content, void ratio and possible growth of cementation bonds. Cyclic wetting and drying increases the degree of expansiveness and reduces the collapse tendency of residual soil specimens. Though swell potentials of the compacted residual soil specimens showed a slight increase, their swell pressures significantly increased upon cyclic wetting and drying. The collapse potentials of the compacted residual soil specimens reduced by three-folds upon cyclic wetting and drying. The cyclic wetting and drying process reduced the void ratio and water content of the compacted residual soil specimens, which increased their expansivity. The reduction in collapse potential of the compacted residual soil specimens upon cyclic wetting and drying is attributed to reduction in void ratio and perhaps growth of cementation bonds. Based on laboratory results it is recommended that residual soil fills should be compacted on the wet side of OMC at a given dry density, as laboratory specimens compacted at this condition exhibited marginal swell and collapse potentials (2%) after cycles of wetting and drying. [24]

Expansive soils cause serious problem in the civil engineering practice due to swell and shrinkage upon wetting and drying. Disposal of fly ash, which is an industrial waste in both cost-effective and environment-friendly way receives high attention in China. In this study, the potential use and the effectiveness of expansive soils stabilization using fly ash and fly ash-lime as admixtures are evaluated. The test results show that the plasticity index, activity, free swell, swell potential, swelling pressure, and axial shrinkage percent decreased with an increase in fly ash or fly ash-lime content. With the increase of the curing time for the treated soil, the swell potential and swelling pressure decreased. Soils immediately treated with fly ash show no significant change in the unconfined compressive strength. However, after 7 days curing of the fly ash treated soils, the unconfined compressive strength increased significantly. The relationship between the plasticity index and swell-shrinkage properties for pre-treated and post-treated soils is discussed. Based on the experimental study of the stabilization of Hefei expansive soil using fly ash and lime-fly ash, the following conclusions can be drawn:

1. Fly ash and lime-fly ash treatments reduce the swell potential and shrinkage of the soils. The free swell, swell potential, swelling pressure, and linear shrinkage decreased with the increase in fly ash and lime-fly ash content. The swell potential and swelling pressure of both fly ash and lime-fly ash treated soils decreased with increase in curing time.

2. With an increase in fly ash and lime-fly ash content, the optimum water content and the maximum dry unit weight decreased.

3. There are negligible changes in the unconfined compressive strength with the increase in the fly ash content without curing. However, with the addition of lime, shear strength increased significantly. The optimum content of fly ash is found to be 9–12% for the treated soils with curing time of 7 days.

4. A simple plasticity index ratio method has been put forward for the prediction of the swell-shrinkage properties of treated expansive soils with fly ash and lime-fly ash. [12]

The impact of the variation in compaction condition on the swelling and shrinkage behavior of three soils has been examined. Two natural soils, namely red soil and black cotton soil, and one artificially mixed soil sample of commercial bentonite with well-graded sand, were studied. Compaction curve for Standard Proctor conditions were plotted and four compaction conditions were selected. Experimental results showed that clay mineralogy dominates over compaction conditions in influencing the swelling and shrinkage behavior of the tested soils. Monitoring of void ratio (e)-water content (w) relations during shrinkage showed that soil specimens generally shrunk in three distinct linear stages. A small reduction in void ratio occurred on reduction in water content during the first shrinkage stage and was termed as initial shrinkage. In second stage, void ratio decreased rapidly with reduction in water content and was termed as primary shrinkage. In third and final stage, reduction in water content is accompanied by a marginal change in void ratio and it’s called residual shrinkage. Irrespective of initial compaction conditions studied, the transition from primary to residual shrinkage for all the specimens occurred within a narrow range of water content (10–15%).

The conclusions for all the test results can be summarized as follows,

(1) The clay mineralogy dominates over compaction condition in influencing swell behavior of the tested clay soils. Presence of montmorillonite in black cotton (BC) soil caused it to swell much more than the compacted red soil specimen predominated by kaolinite despite possessing lower dry density and higher water content values.

(2) Monitoring of e-w relations during shrinkage showed that soil specimens generally shrunk in three distinct linear stages namely initial, primary and residual shrinkage.

(3) For all three soils studied, the transition from primary to residual shrinkage occurs within a narrow range of water contents (10–15%) and is irrespective of initial compaction conditions.

(4) The transition water content was close to the shrinkage limit water content in case of red soil and BC soil specimens.

(5) BC soil with higher liquid limit and plasticity index is characterized by a larger slope in the primary and residual shrinkage regions implying that void ratio changes more rapidly with changes in water content for this expansive soil specimen during shrinkage process. [23]

Authors presents an experimental study performed on four types of soils mixed with three types of nano-material of different percentages. The expansion and shrinkage tests were conducted to investigate the effect of three type of nano-materials (nano-clay, nano-alumina, and nano-copper) additive on repressing strains in compacted residual soil mixed with different ratios of bentonite (S1 = 0 % bentonite, S2 = 5 % bentonite, S3 = 10 % bentonite, and S4 = 20 % bentonite). The soil specimens were compacted under the condition of maximum dry unit weight and optimum water content (w_{opt}) using standard compaction test. The physical and mechanical results of the treated samples were determined. The untreated soil values were used as control points for comparison purposes. It was found that with the addition of optimum percentage of nano-material, both the swell strain and shrinkage strain reduced. The results show that nano-material decreases the development of desiccation cracks on the surface of compacted samples without decrease in the hydraulic conductivity. The mixtures of soil and nano-materials enhance the engineering properties of soils (i.e., compaction characteristics, volumetric shrinkage strain, volumetric expansive strain, and the CIF). Insoluble nano-material does not give chemical reaction with soil by just mixing with water. The addition of some type of nano-material such as nano-clay does not produce significant improvement in soil. However, nano-clay content exceeding certain limits has a negative effect. The improvement by nano-copper was more positive than nano-alumina in terms of expansive and shrinkage strain. This is possibly because the particle density of nano-copper is greater than nano-alumina which increases the specific gravity of the soil– nano-material mixture leading to increase in the maximum dry density of the mixture. The increase in the dry density subsequently leads to decrease in the soil shrinkage and expansive strains. Moreover, the increase in the content of agglomerated particles leads to decrease in the dry density and increase in voids which increase the water content. Therefore, the shrinkage and swell strain also increases. Since the size of nano-copper particles is more than two times size of nano-alumina particles, the nano-copper less agglomeration than nano-alumina thus improving the soil better than nano-alumina. The addition of nano-materials more than the optimum value causes agglomeration of particles that produce negative side effects on the mechanical properties of the soil. The additive of nano-materials does not reduce the hydraulic conductivity of soils. This different from other stabilizer materials which decrease the crack development and increase the hydraulic conductivity (i.e., fiber). [10][42]

Compacted clay soils are used as barriers in geoenvironmental engineering applications and are likely to be exposed to salinization and desalinization cycles during life of the facility. Changes in pore fluid composition from salinization and desalinization cycles induce osmotic suction gradients between soil–water and reservoir (example, landfill/brine pond) solution. Dissipation of osmotic suction gradients may induce osmotic swelling and consolidation strains. This paper examines the osmotic swelling and consolidation behaviour of compacted clays exposed to salinization and desalinization cycles at consolidation pressure of 200 kPa in odometer assemblies. During salinization cycle, sodium ions of reservoir fluid replaced the divalent exchangeable cat ions. The osmotic swelling strain developed during first desalinization cycle was 29-fold higher than matric suction induced swelling strain of the compacted specimen. Further, the diffusion controlled osmotic swelling strain was 100-fold slower than matric suction-driven swelling process. After establishment of ion-exchange equilibrium, saturated saline specimens develop reversible osmotic swelling strains on exposure to desalinization cycles. Likewise the saturated desalinated specimen develops reversible osmotic consolidation strains on exposure to cycles of salinization. Variations in compaction dry density has a bearing on the osmotic swelling and consolidation strains, while, compaction water content had no bearing on the osmotic volumetric strains. Dissipation of osmotic suction gradients have a profound influence on the osmotic swelling and consolidation strains developed by saturated clay specimens. Compacted specimens wetted at 200 kPa were exposed to salinization by contacting the specimens with 4 M sodium chloride solution. Desalinization was achieved by contacting the saline specimens with distilled water. The salinization cycle induced replacement of divalent exchangeable cat ions by sodium ions. The osmotic swelling strain developed during first desalinization cycle was 29-fold larger than that developed by the compacted specimen on wetting with distilled water at consolidation pressure of 200 kPa. The osmotic swelling process was 100-fold slower than the matric-suction induced swelling, primarily as the former process is diffusion controlled. Experimental results also indicated that after ion-exchange equilibrium was established, reversible osmotic swelling strains developed during desalinization cycles. Likewise reversible osmotic consolidation strains developed during salinization cycles. Variations in dry density of the compacted clay specimens had bearing on the osmotic swelling and consolidation strains subsequently developed by the saturated specimens on exposure to desalinization and salinization cycles. Experimental results demonstrated that variations in compaction water had no bearing on the osmotic swelling and osmotic consolidation strains subsequently developed by the saturated saline and desalinated specimens. [26]

Expansive soils are clays which undergo large shrinkage and swelling movements as a result of change in subsoil moisture. Previous methods for the design of footing systems to minimize distortion and cracking in building constructed on expansive soil have been based on idealized mathematical models. These models inherently simplify the complex nature of expansive soil behavior. An alternative probabilistic design approach, based on data derived from many built and tested footings is proposed, and has a number of significant advantages over traditional deterministic methods. Relevant data required for this project were obtained from six local councils within the Adilede municipal area. The probabilistic approach enables the level of risk associate with each individual design to be quantified, whereas the current deterministic design methods give no indication of the associated risk. A probabilistic approach enables the design engineers and the client to make informed decisions regarding the desired level of risk and the economic cost, which is likely to reduce the possibility of future litigation. [29]

A field site was established in 1993 near Newcastle, Australia, as part of a long-term study into expansive soil behavior. The primary objectives in establishing the site were to collect high quality data with which to check current design methods for lightly loaded building foundations and to develop improved understanding of the physical processes that drive unsaturated expansive soil behavior. The site was instrumented to allow measurement of soil water content, soil moisture suction, and ground movement to depths of 3 m. The site was provided with two ground covers to simulate moisture boundary conditions due to the presence of typical structures. This paper presents some of the more important findings from the 7 years of data acquired so far. These include a qualitative assessment of the overall site behavior, and quantitative observations of the range of total suction and water content changes with depth, the depth to which moisture changes occur, and the contributions to surface movement from ground movement at various depths. The shape of a mound developed beneath a flexible cover on an initially dry site is examined, and the effects of a large tree on moisture changes are reported. [32]

Focused on the sensitivity to climate change and the special mechanical characteristics of undisturbed expansive soil, an elasto-plastic damage constitutive model was proposed based on the mechanics of unsaturated soil and the mechanics of damage. Undisturbed expansive soil was considered as a compound of non-damaged part and damaged part. The behavior of the non-damaged part was described using non-linear constitutive model of unsaturated soil. The property of the damaged part was described using a damage evolution equation and two yield surfaces, i.e., loading yield (LY) and shear yield (SY). Furthermore, a consolidation model for unsaturated undisturbed expansive soil was established and a FEM program named UESEPDC was designed. Numerical analysis on solid-liquid-gas tri-phases and multi-field couple problem was conducted for four stages and fields of stress, displacement, pore water pressure, pore air pressure, water content, suction, and the damage region as well as plastic region in an expansive soil slope were obtained. [11][43]

The effect of Soil–Structure Interaction (SSI) on Park and Ang Damage Index in a Bilinear-SDOF model is investigated under seismic loading. This is done through an extensive parametric study. Two non-dimensional parameters are used as the key parameters which control the severity of SSI: (1) a non-dimensional frequency as the structure-to-soil stiffness ratio index and (2) the aspect ratio of the structure. The soil beneath the structure is considered as a homogeneous elastic half space and is modeled using the concept of Cone Models. The system is then subjected to three different earthquake ground motions as the representative motions recorded on different soil conditions. The analysis is done directly in time domain using direct step-by-step integration method. The results are presented in the form of damage spectra for a wide range of key parameter variations. It is observed that generally SSI increases the damage index before a threshold period which is closely related to the predominant period of the ground motion. It means that the conventional fixed-base model underestimates the damages sustained by buildings having periods less than this threshold period. In particular, the SSI substantially increases the damage index of short-period buildings located on soft soils. It is also observed that increasing the aspect ratio of the structure increases this effect. However, the trend is reversed after the threshold period. [21]

Although the assessment of the expansive potential of clay soils has been the subject of active research for the past 40 years, its treatment in routine geotechnical practice around the world remains inconsistent. This paper describes the shrink swell test, which is used routinely in Australian geotechnical practice as the principal method for the experimental assessment of the expansive potential of clay soils. The test procedure and its underlying assumptions are described and discussed in the context of the historical development of the test and its routine application. It is shown that the shrink swell test is a simple and economical means of assessing soil expansiveness, which is achieved largely through the adoption of several simplifying assumptions that effectively circumvent the measurement of soil suction. The significance of these assumptions is discussed, and it is concluded that the shrink swell test can be conveniently and reliably employed to guide the routine design of foundations in expansive soils. The shrink swell test is a simple and economical laboratory test that is performed on undisturbed clay soil samples to yield a reactivity index that enables free surface ground movements to be predicted. It has been employed in routine geotechnical practice in Australia for the past 20 years, and during that period, it is considered to have served the Australian geotechnical industry well. The successful, widespread adoption into Australian industry practice is due to several factors. Firstly, it has a rational and intuitive basis, making it attractive to practicing geotechnical and structural engineers. In particular, the test evaluates the soil over the full range of volume change, not just the swell or the shrinkage phase, thereby making the method independent of the initial moisture state of the soil. Secondly, it involves a simple and economical laboratory test that can be performed on a routine basis, without adding excessively to the cost of light residential construction. The inherent simplicity of the shrink swell test derives from several important simplifying assumptions that effectively avoid the physical measurement of soil suction. On the basis of available research, and a qualitative assessment of the successful employment of the shrink swell test in routine practice, the error introduced by these assumptions is considered to be acceptably small. [31]

A method for the installation and the range of application of limestone drains, their design characteristics and special engineering features, and equipment for their fabrication are presented. Test requirements are outlined for determination of computed characteristics of soft saturated clayey soils. A procedure is presented for analysis of total-settlement characteristics and prediction of secondary settlement during preconstruction consolidation under load and deep stabilization by reinforcing limestone drains. [17]

Construction of building and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements, poor shear strength, and high compressibility. Various soil improvement techniques have been used to enhance the engineering properties of soil. Soil reinforcement by fiber material is considered an effective ground improvement method because of its cost effectiveness, easy adaptability, and reproducibility. Hence, in the present investigation, papyrus fiber has been chosen as the reinforcement material, and it was randomly included into the soil at four different percentages of fiber content, i.e., 5, 10, 15, 25% by volume of raw soil. The main objective of this research is to focus on the strength behavior of soil reinforced with randomly included papyrus fiber. Direct shear, consolidation, and displacement tests were performed on papyrusreinforced specimens with various fiber contents. The results of these tests have clearly shown a significant improvement in the failure deviator stress and shear strength parameters (c and ϕ) of the studied soil with a percent addition of 10% (the preferred percent). Moreover, this addition ratio reduced the displacement of the soil under loading. It can be concluded that papyrus fiber can be considered an appropriate soil reinforcement material. [18]

A solution is presented for calculation of the total settlement of a strip foundation with allowance for additional stresses, which develop in the region under consideration due to displacement of the loaded section of the boundary, and can be determined by solving the second basic boundary problem of the plane theory of elasticity for a half plane. Expressions for the strain components of the second basic boundary problem are presented in closed form, and formulas are derived for calculation of settlement due to a uniformly distributed load. Settlements of the bed, which is composed of sandy and clayey soils, are calculated. [19]

A solution is examined for one of the problems of large cities − closure and recultivation of landfills containing solid domestic wastes. Landfills are situated in unfavorable areas frequently in slide-prone sections. Modern geotechnologies in combination with use of different materials for the final coverings are cited for a recultivation example of a landfill in the Adlersk district of Sochi. [15]

Results are presented for numeric analysis of the performance of pile foundations with low and high rafts using an elasto-plastic model of a bed with independent strain hardening. The safety factors used for design of pile foundations in European and domestic regulatory literature are analyzed. [14]

III. CONCLUSIONS

From the reviewed literature it was observed that most of the studies have been done on behavior, stabilization and characteristics and engineering properties of expansive soil.
Stabilization has mostly done with lime and fly ash. Some researchers have used some other chemicals like gypsum, bentonite, crude oil, CNS layer etc. together with lime and fly ash.
Various characteristics of expansive soil have been determined by the researchers and the work was concentrated on reduction in swelling and shrinking properties by using chemical admixtures or by compaction.
More problems associated with expansive soil are related to very low bearing capacity, cracking and breaking up of pavements and various other building foundations.
Expansive soil cause serious problems in the engineering practice due to swell and shrinkage upon wetting and drying.
Negligible work has been done on expansive soils on the behaviour and its effects structures. Although there have been instances in the area where foundations and other concrete work have fractured and been displaced, but the exact cause is not known and remedial measure are also not properly implemented.

Further research is required in this direction to know the exact cause and remedial measures against the failure of structures because of unpredictable behavior and characteristic.

REFERENCES

[1] Kartikey Tiwari, Sahil Khandelwal, Aman Jatale, 2012, *Performance, Problems and Remedial Measures for the Structures Constructed on Expansive Soil in Malwa Region, India*, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 12, December 2012)

[2] Gyanen. Takhelmayum, Savitha.A.L, Krishna Gudi, 2013, *Laboratory Study on Soil Stabilization Using Fly ash Mixtures*, International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 1, January 2013

[3] Murat Mollamahmutoglu, Yuksel Yilmaz and Ahmet Gürkan Güngör, *Effect of a Class C Fly Ash on the Geotechnical Properties of an Expansive Soil*

[4] T. L. Ramadas, N. Darga Kumar, G. Yesuratnam , 2011, *Geotechnical characteristics of three expansive soils treated with lime and fly ash*, International Journal of Earth Sciences and Engineering, ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp. 46-49

[5] Bidula Bose, 2012, *Geo-Engineering Properties of Expansive Soil Stabilized with Fly Ash*, EJGE Vol. 17 [2012]

[6] Bidula Bose, 2012, *Effect Of Curing Period and Temperature on Characteristic of Expansive Soil*, IJETED, Issue-2, Vol-4, (May 2012)

[7] Pamela Jo Thomas, 1998, *Quantifying Properties and Variability of Expansive Soils in Selected Map Units*, A Ph.D. thesis

[8] DAI Shaobin, SONG Minghai, HUANG, Jun2005, *Engineering Properties of Expansive Soil*, Journal of Wuhan University of Technology - Mater. Sci. Ed. Vol. 20 No. 2 Jun. 2005

[9] Botao Lin, Amy B. Cerato, 2012, *Investigation on Soil–Water Characteristic Curves of Untreated and Stabilized Highly Clayey Expansive Soils*, Geotech Geol Eng (2012) 30:803–812

[10] Mohd Raihan Taha, Omer Muhie Eldeen Taha, 2012, *Influence of nano-material on the expansive and shrinkage soil behavior*, J Nanopart Res (2012) 14:1190

[11] LU Zai-hua, CHEN Zheng-han, FANG Xiang-wei, GUO Jian-feng, ZHOUHai-qing, 2006, *Structural Damage Model Of Unsaturated Expansive Soil And Its Application In Multi-Field Couple Analysis On Expansive Soil Slope* ,Applied Mathematics and Mechanics (English Edition), 2006, 27(7):891–900

[12] Fusheng Zha Æ Songyu Liu Æ Yanjun Du Æ Kerui Cui, 2008, *Behavior of expansive soils stabilized with fly ash*, Nat Hazards (2008) 47:509–523

[13] Jagadish Prasad Sahoo, Pradip Kumar Pradhan, 2010, *Effect of Lime Stabilized Soil Cushion on Strength Behaviour of Expansive Soil*, Geotech Geol Eng (2010) 28:889–897

[14] V. V. Babanov and V. A. Shashkin, 2012, *Design Analysis of the Functioning of Pile Foundations with Low and High Rafts and Consideration of Nonlinear Bed Performance*, Soil Mechanics and Foundation Engineering, Vol. 49, No. 2, May, 2012 (Russian Original No. 2, March-Apr., 2012)

[15] M. B. Marinichev and A. Yu. Marshalka, 2012, *Geotechnical Problems with Recultivation of Domestic-Waste Landfills*, Soil Mechanics and Foundation Engineering, Vol. 49, No. 5, November, 2012 (Russian Original No. 5, September-October, 2012)

[16] R. G. Kochetkova, 2012, *Influence of Modern Stabilizers on Improved Properties of Clayey Soils*, Soil Mechanics and Foundation Engineering, Vol. 49, No. 1, March, 2012 (Russian Original No. 1, Jan.-Feb., 2012)

[17] V. P. Konovalov, S. G. Bezvolev, and P. A. Konovalov, 2012, *Preconstruction Consolidation of Weak Saturated Clayey Soils by Reinforcing Limestone Drains*, Soil Mechanics and Foundation Engineering, Vol. 48, No. 6, January, 2012 (Russian Original No. 6, November-December, 2011)

[18] Aqeel Al Adili, Rafig Azzam, Giovanni Spagnoli, and Joerg Schrader, 2012, *Strength of Soil Reinforced with Fiber Materials (Papyrus)*, Soil Mechanics and Foundation Engineering, Vol. 48, No. 6, January, 2012 (Russian Original No. 6, November-December, 2011)

[19] A. N. Bogomolov and A. N. Ushakov, 2012, *Calculation of Settlements for a Strip Foundation*, Soil Mechanics and Foundation Engineering, Vol. 48, No. 6, January, 2012 (Russian Original No. 6, November-December, 2011)

[20] N. B. Kutvitskaya, O. V. Gorbunova, V. D. Kaurkin and A. V. Ryazanov, 2011, *Stabilization of the Position of an Underground Pipeline in Permafrost*, Soil Mechanics and Foundation Engineering, Vol. 48, No. 5, November, 2011 (Russian Original No. 5, September-October, 2011)

[21] Mofid Nakhaei, Mohammad Ali Ghannad, 2008, *The Effect of Soil–Structure Interaction on Damage Index of Buildings*, Engineering Structures Volume 30, Issue 6, June 2008, Pages 1491–1499

[22] Delwyn G. Fredlund, Sandra L. Houston, Quan Nguyen, Murray D. Fredlund, 2010, *Moisture Movement Through Cracked Clay Soil Profiles*, Geotech Geol Eng (2010) 28:865–888

[23] Anil Kumar Mishra, Sarita Dhawan, Sudhakar M. Rao, 2008, *Analysis of Swelling and Shrinkage Behavior of Compacted Clays*, Geotech Geol Eng (2008) 26:289–298
[24] SUDHAKAR M. RAO and K. REVANASIDDAPPA, 2006, *Influence of Cyclic Wetting Drying on Collapse Behaviour of Compacted Residual Soil*, Geotechnical and Geological Engineering (2006) 24: 725–734
[25] Omer Nawaf Maaitah,2012, *Soil Stabilization by Chemical Agent*, Geotech Geol Eng (2012) 30:1345–1356
[26] T. Thyagaraj, Sudhakar M. Rao, 2013, *Osmotic Swelling and Osmotic Consolidation Behaviour of Compacted Expansive Clay*, Geotech Geol Eng (2013) 31:435–445
[27] XIAO Hong-bin, ZHANG Chun-shun, HE Jie, FAN Zhen-hui, 2007, *Expansive Soil-Structure Interaction and its Sensitive Analysis*, J. Cent. South Univ. Technol. (2007)03−0425−06
[28] S. Bhuvaneshwari, R. G. Robinson, S. R. Gandhi, 2005, *Stabilization of Expansive Soils Using Flyash*, Fly Ash India 2005, New Delhi
[29] R. Barthur, Postgraduate Student, University of Adelaide, M.B. Jaksa, P.W. Mitchell, *Design of Residential Footings Built on Expansive Soil Using Probabilistic Methods*
[30] Mesfin Kassa, 2005, *Relationship between Consolidation and Swelling Characteristics of Expansive Soils of Addis Ababa*, MS Thesis
[31] Stephen G. Fityus, Donald A. Cameron, and Paul F. Walsh, 2009, *The Shrink Swell Test*, Geotechnical Testing Journal, Vol. 28, No. 1, Paper ID GTJ12327
[32] S. G. Fityus, D. W. Smith and M. A. Allman, 2004, *Expansive Soil Test Site Near Newcastle*, 10.1061/(ASCE)-1090-0241(2004)130:7(686)
[33] N. K. Ameta, D.G. M. Purohit, A. S. Wayal , 2007, *Characteristics, Problems and Remedies of Expansive Soils of Rajasthan, India*, EJGE 2007
[34] John D. Nelson and Debora J. Miller. *Expansive Soils–Problems and Practice in Foundations and Pavement, Engineering*. Department of Civil Engineering, Colorado State University.
[35] Chen, F.H. (1988). "*Foundations on Expansive Soils"*, Elsevier publications Co., Amsterdam.
[36] Dr. B.C. Punmia, Ashok Kumar Jain, Arun Kr. Jain, *Soil Mechanics and Foundations Engineering*
[37] Radhey Shyam Sharma, 1998, *Mechanical Bahaviour of Unsatuarated Highly Expansive Clays, Ph. D. Thesis*
[38] Jacoby and Devis, *Foundations of Bridges and Building*
[39] G. Venkatramaiya, *Geotechnical Engineering*
[40] Alam Singh and G. R. Choudhary, *Soil Engineering-Theory and Practice*
[41] R. Kaniraj, *Design Aids in Soil Mechanics and Foundation Engineering*
[42] Bowles, *Engineering Properties of Soil and Their Measurement*
[43] Tyler, *Fundamentals of Soil Mechanics*
[44] Terzagi, Theoretical Soil Mechanics
[45] Nainan Kurian, *Design of Foundation Systems, Principle and Practice*
[46] Narayan V. Nayak, *Foundation Design Manual*
[47] Various IS codes like IS 9198 : 1979, SP 36 : Part 1 : 1987, SP 36 : Part 2 : 1988, IS 1498 : 1970, IS 1988 : 1982, IS 2720 : Part 1 to 41, IS 4332 : Part 1 to 10, IS 10074 : 1982, IS 11550 : 1985 etc.