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Impact of Cyclic Wetting and Drying on Swelling Behaviour of Stabilised and Non-Stabilised Soil- A Review Study

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Abstract — *Expansive soils in semi-arid climates must be mitigated to minimize potential structural damage to the overlying structures due to swell-shrink behavior caused by climatic changes. The expansive soil in this study was amended by sand which reduced the swell-shrink potential significantly. Increase in the construction activities has enhanced the demand for aggregates which lead to the liberation of huge amount of quarry dust consequently. Highway construction is one of the prominent fields for the use of quarry dust in abundance. However, presence of expansive soil in the most of integral part of India leads to questioning on the suitability of quarry dust for pavement construction. Hence, an attempt has been made to understand the potential of quarry dust cushion to prevent seasonal swell–shrink in expansive soil. Comprehensive studies of linear swell and cyclic swell–shrink of expansive soil with the use of lime treated quarry dust cushion of different thickness have been carried out. The results revealed that increase in the thickness of lime treated quarry dust cushion significantly reduces the swell strain of the expansive soil. The present review study proposed that impact of cyclic wetting and drying on swelling behavior of stabilised and non-stabilised soils.*

Keywords*- Cyclic Effect, Expansive Soil, Non-Stabilised Soil, Stabilised Soil*

I. INTRODUCTION

1.1 General

Expansive soil deposits are problematic for engineering structures because of their swelling and shrinkage. These soils occurring above the water table swell with increase in moisture content and shrink with decrease in moisture content. This swell-shrink behaviour causes differential movements accompanied by strength reduction, causes severe damage to the foundation and to the structures which are founded on these types of soils. The predominant reason for this swell shrink behaviour is seasonal variations as the soil swells during rainy season and shrink during summer. In India, black cotton soils cover a surface area of nearly 20% and are found in the states of Maharashtra, Gujrat, Rajasthan, Madhya Pradesh, Uttar Pradesh, Karnataka, Andhra Pradesh, Tamilnadu. These are derived from the weathering action of basalts and traps of Deccan plateau. However, their occurrence on granite, gneiss, shales, sandstones, slates and lime stones is also recognised.

Expansive soils are highly fertile for agriculture purposes but they are treacherous for the pavements, runways, embankments and light to medium loaded residential buildings resting on them due to high swelling and shrinkage potentials of these soils caused by the moisture fluctuations. This swelling shrinkage behaviour causes damage to the foundation systems, structural elements and architectural features. The reason for this behaviour is the presence of heaving mineral known as montmorillonite which possess an expanding lattice structure. This clay mineral expands when it comes in contact with moisture. Those areas that have surface deposit of clay, and climate characterised by alternating periods of rainfall and draught, causes significant instability because of their wetting and drying cyclic process. Soils rich in these minerals occur in many places all over the world especially in arid and semi-arid regions.

In arid and semi-arid areas of the world, moisture and rainfall amount varies considerably in different seasons, structures like small buildings and highways constructed on expansive soils are encountered with periodic swelling and shrinkage cycles (Basma, 1996). Cracks and breakups are formed due to swelling of expansive clays in roads, pavements, building foundations, irrigation systems, slab-on-grade members channel and reservoir linings, sewer lines and water lines (Çokça, 2001). In the United States, structures seated on expansive soils cause an estimated cost of more than 15 billion dollars due to damage caused from the soil (Al-Rawas, 2006).

Determination of swell potential of expansive soils is generally done by one cycle of wetting although it has been shown that behavior of expansive soils is considerably affected by the number of wetting-drying cycles. One should take the effects of number of cycles on the swelling and shrinking behavior of expansive soils into consideration since continuous wetting-drying cycles are observed in soils in nature as a result of environmental effects (Tawfiq and Nalbantoğlu, 2009). Changes in the swelling behavior of natural expansive soils due to wetting-drying cycles are well documented but studies performed to see the influence of cyclic wetting and drying on the swelling behavior of chemically stabilized soils are insufficient. The long-term behavior of foundations and earth structures should be assessed, employing chemically stabilized soils, by performing such a study (Rao et al., 2001).

II. LITERATURE REVIEW

There are many factors that govern the expansive behaviour of soils. The initial factors are the availability of moisture and the amount of clay particles in the soil. Other factors affecting the expansive behaviour include the type of soil, the condition of the soil in terms of dry density and the moisture content, the magnitude of the surcharge pressure and the amount of non-expansive material. In general, the swelling potential increases as the dry density increases and the water content decreases (Hanafy, 1991; Fredlund and Rahardjo, 1993; Marinho and Stuermer, 2000; Ferber et al., 2009). The behaviour of expansive soils under cycles of wetting and drying has been the subject of intensive investigation during recent years. A number of researchers, such as Rao and Satyadas (1987) and Chen (1988), have subjected remoulded clay samples to full swelling and then allowed them to dry to their initial water content. By repeating this procedure, the soil showed signs of irreversible deformation after each cycle of wetting and drying. Dif and Blumel (1991) found almost no volume change in remoulded clay after at least three or four drying and wetting cycles. Many researchers, such as Wheeler et al. (2003), Alonso et al. (2005), Nowamooz and Masrouri (2008), have studied the behaviour of expansive soils during wetting and drying cycles by controlling the suction. Tripathy et al. (2002) studied the wetting and drying behaviour in terms of the void ratio and the water content. Several investigations have shown the behaviour of expansive soils under chemical influence (Alawaji, 1999; Musso et al., 2003; Di Maio et al., 2004; Rao and Shivananda, 2005; Rao and Thyagaraj, 2007a, 2007b; Casttellanos et al., 2008; Siddiqua et al., 2011). The hydro-mechanical behaviour of compacted swelling soils at ambient temperature has been studied by a number of researchers, such as Cui et al. (2002), Lloret et al. (2003), Cekerevac and Laloui (2004), Cuisinier and Masrouri (2005), Tang et al. (2008), Wang et al. (2013). They concluded that heating has a significant effect on the mechanical behaviour of expansive soils. However, to the authors' knowledge, no research studies have ever been reported in literature on the effect of different types of wetting fluids on the behaviour of clay soil during cycles of wetting and drying. The main objective of this study, therefore, is to investigate the effect of different types of wetting fluids on the wetting and drying behaviour of clay soil. The results of this experimental study will be presented in terms of the volumetric deformation and the void ratio-water content relationship. The effect of surcharge pressure on the swelling behaviour will also be studied. It will be shown that it is possible to minimize the effects of volume changes during wetting and drying by conducting appropriate tests to characterize the potential of the swelling and shrinkage of expansive soils, taking the necessary precautions and designing a suitable foundation system.

III. MECHANISMS OF SWELLING

Swelling of clay minerals is directly related with diffused double layer and cation exchange capacity of them.

3.1 Diffuse Double Layer of Clay Minerals

The negatively charged clay particle surface and the concentration of positive ions in solution adjacent to the particle form what is referred to as a diffuse double layer or DDL (Bohn et al. 1985). Overlapping DDLs between clay particles generate inter-particle repulsive forces or microscale "swelling pressures". Interaction of the DDL and, hence, swelling potential, increases as the thickness of the DDL increases (Mitchell, 1976). The thickness of DDL isassociated with valence of cations, concentration of cations, temperature and pH.

a) Effect of valence of cations: The lower valences of cations result in increase in DDL thickness. Thus, for the same soil mineralogy, more swelling would occur in a sample having exchangeable sodium (Na+) cations than in a sample with calcium (Ca2+or magnesium Mg2+) cations (Nelson and Miller,1992).

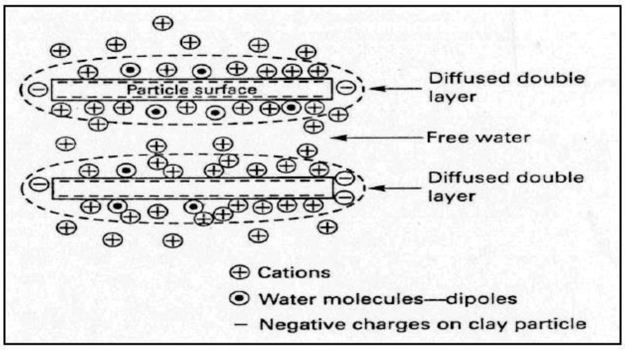

Figure 1: Double Layer of Clay Minerals (after Oweis and Khera, 1998)

b) Effect of concentration of cations: The high concentration of cationsnear the surface of clay particle creates a repulsive force between the diffuse double layer systems (Chen, 1975). In general, a thicker DDL and greater swelling are associated with lower cation concentrations (Mitchell, 1976).

c) Effect of temperature: An increase in temperature cause an increase in DDL thickness, thus temperature change has effect on strength, compressibility and swelling of soils (Mitchell and Soga, 2005).

d) Effect of pH: Hydroxyls (OH)- are exposed on the surfaces and edges of clay particles. The tendency for hydroxyls to dissociate in water, "SiOHSiO + H" is strongly influenced by pH. The higher pH, the greater is the tendency for H to go into solution, and the greater the effective negative charge of the particle. Alumina, exposed at the edges of clay particles, is amphoteric (capable of functioning either as an acid or a base), and it ionizes positively at low pH and negatively at high pH. As a result, positive diffuse layers can develop at the edges of some clayparticles in an acid environment which promotes a positive edge to negative surface interaction, often leading to flocculation from suspension (Mitchell and Soga, 2005).

3.2 Cation Exchange Capacity (CEC)

Cations that neutralize the net negative charge on the surface of soil particles in water are readily exchangeable with other cations. The exchange reaction depends mainly on the relative concentrations of cations in the water and also on the electrovalence of cations (Terzaghi, Peck and Mesri, 1996). The cation exchange capacity is the quantity of exchangeable cations required to balance the negative charge on the surface of the clay particles. CEC is expressed in milliequivalents per 100 grams of dry clay (Nelson and Miller,1992).

Table 1: CEC of Principle Clay Minerals (Terzaghi, Peck and Mesri, 1996)

Mineral	CEC (meq/100g)
Kaolinite	3-10
Illite	20-30
Montmorrilonite	80-120

Several investigators have attempted to understand the characteristics andmechanism of swelling of expansive soils.

Grim (1959) presented the mineralogical details of clayey soils. It was reported that argillaceous materials are composed essentially of extremely small particles known as clay minerals. Chemically, clay minerals are silicates of aluminium and/or iron and magnesium. Most of the clay minerals are crystalline and have sheet or layered structure. Some clay minerals have elongate tubular or fibrous structure.

Taylor (1959) described the electrical charges carried by soil colloids and the influence of exchangeable cations on the forces arising from these electrical charges in terms of the theory of diffuse double layer. Isomorphous substitution of ions within clay crystal, broken bonds and replacement of hydrogen of exposed hydroxyls are the main source of negative charge on mineral surfaces. The exchangeable cations of the clay water system are attracted towards the negatively charged particles and form a diffuse layer of positive charge.

Low (1959) explained the swelling based on the double layer theory and Van't Hoff's law. The swelling of clays is due to the difference in osmotic pressure between the mid plane between adjacent particles and external solution. In clay-water system, the electric field of clay particles serves the purpose of semi permeable membrane which allows water to enter into the zone of high ion concentration near particle surface but not the cation and causes clay to swell.

According to Ladd (1959) osmotic pressure can act in clays since there exists difference in solute concentration in double layer and outside solution and osmotic pressure concept can satisfactorily explain a good portion of swelling for samples compacted wet of optimum. On dry side of optimum, swelling is influenced by other factors in addition to osmotic pressure.

As referred by Mitchell (1993), Low (1961) described five possible mechanism of soil-water interaction that would in turn influence volume change behaviour. These include hydrogen bonding, hydration of exchangeable cations, attraction by osmosis, dipole attraction and van der wall forces. Bolt (1956) considered the swelling pressure as equal to the difference between the osmotic pressure in the central plates and the osmotic pressure in equilibrium solution.

As referred by Agrawal (1977), Seed et al. (1962) have classified the conditions that give rise to swelling tendency into two general categories(viz.) which are physio-chemical and mechanical. Physio-chemical factors are functions of interparticle electrical forces, particles structure, and pore fluid composition. Mechanical factors include the effect of elastically deformed particles and the compression of air in voids during imbibition of water.

3.3 Factors Influencing Swelling

According to Nelson and Miller (1992), swelling mechanism of expansive clays is complex and is influenced by some factors. Many of these factors also affect physical soil properties (such as plasticity and density) or are affected by them. Shrink-swell potential of a soil is considered to be influenced by the factors which can be considered in three different groups. These groups can be listed as follows:

- Soil Characteristics: Characteristics of soil by which the basic nature of the internal force field is influenced.
- Environmental Factors: Changes that may occur in the internal force system can be influenced by some environmental factors. These factors also influence the shrink-swell potential of a soil.
- State of Stress: The aforementioned factors are given in Tables 2, 3 and 4, in short.

Table 2: Soil Properties that influence shrink-swell potential (Nelson and Miller, 1992)

Clay Mineralogy	Montmorillonites, vermiculites, and some mixed layer minerals cause volume changes. Although Illites and Kaolinites are usually non expansive, these minerals cause volume changes when particle sizes are extremely fine
Soil Water Chemistry	Swelling is decreased by the increase in cation concentration and cation valence. For example, Mg+2 cations in the soil water would result in less swelling than Na+ ions.
Soil Suction	Soil suction is an independent effective stress variable, represented by the negative pore pressure in unsaturated soils. Soil suction is related to saturation, gravity, pore size and shape, surface tension, and electrical and chemical characteristics of the soil particles and water.
Plasticity	In general, soils that exhibit plastic behaviour over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinking. Plasticity is an indicator of swell potential.
Soil Structure	Flocculated clays tend to be more expansive than dispersed clays. Cemented particles reduce swell. Structure is altered by compaction at higher water content or remoulding. Kneading compaction has been shown to create dispersed structures with lower swell potential than soils statically compacted at lower water contents.
Dry Density	Higher densities usually indicate closer particle spacing, which may mean greater repulsive forces between particles and larger swelling potential.

Table 3: Environmental Conditions that influence shrink-swell potential (Nelson and Miller, 1992)

Initial Moisture Conditioning	A desiccated expansive soil will have a higher affinity for water, or higher suction, than the same soil at higher water content, lower suction
Climate	Amount and variation of precipitation and evapotranspiration greatly influence the moisture availability and depth of seasonal moisture fluctuation. Greatest seasonal heave occurs in semiarid climates rather that have pronounced, short wet periods
Groundwater	Shallow water tables provide a source of moisture and fluctuating water tables contribute to moisture
Drainage and manmade water sources	Surface drainage features, such as ponding around a poorly graded house foundation, provide sources of water at the surface; leaky plumbing can give the soil access to water at greater depth.
Vegetation	Trees, shrubs, and grasses deplete moisture from the soil through transpiration, and cause the soil to be differentially wetted in areas of varying vegetation
Permeability	Soils with higher permeabilities, particularly due to fissures and cracks in the field soil mass, allow faster migration of water and promotes faster rates of swell
Temperature	Increasing temperatures cause moisture to diffuse to cooler areas beneath pavements and buildings

Table 4: Stress Conditions that influence shrink-swell potential (Nelson and Miller, 1992)

Stress History	An over consolidated soil is more expansive than the same soil at the same void ratio, but normally consolidated. Repeated wetting and drying tend to reduce swell in laboratory samples, but after a certain number of wetting-drying cycles, swell is unaffected.
	The initial stress state in a soil must be estimated in order to evaluate the probable consequences of loading the soil mass and/or altering the moisture environment therein. The initial effective stress can be roughly determined

In Situ Conditions	through sampling and testing in a laboratory, or by making in situ measurements and observations
Loading	Magnitude of surcharge load determines the amount of volume change that will occur for a given moisture content and density. An externally applied load acts to balance inter-particle repulsive forces and reduces swell
Soil Profile	The thickness and location of potentially expansive layers in the profile considerably influence potential movement. Greatest movement will occur in profiles that have expansive clays extending from the surface to depths below the acting zone. Less movement will occur if expansive soil is overlain by non-expansive material or overlies bedrock at a shallow depth

3.4 Identification of Expansive Soils

Various guidelines to determine the potential of swelling of expansive soils by measureable engineering soil properties are presented in this chapter. The most common soil properties use to determine the swell potential of expansive soils include activity, Atterberg limits, clay fractions, colloidal content, plasticity index, probable swell percent, shrinkage limit and theshrinkage index. There are numerous guidelines posted in the literature; however, the ones presented in this section are the major highlights that have been made throughout the past 50 plus years. Regardless of the swell potential classifications, it was found that once the swell potential is considered “medium” or “marginal”, the potential for a geotechnical hazard is significant.

In 1948, Skempton proposed a methodology to classify expanse potential for all types of soil. His methodology uses the percent of clay fraction (percent passing 0.002 mm) and the plasticity index. Shown in Figure 2 is the swell potential related to the plasticity index and the clay fraction.

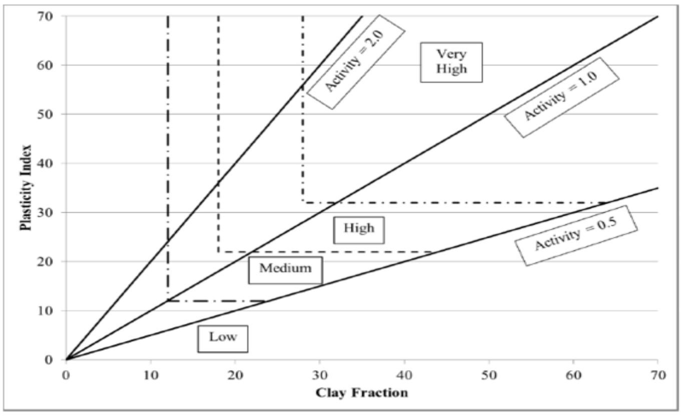

Figure 2: Swell potential related to PI and CF (Skempton 1953).

3.5 Remedial Measures to Expansive Soil

3.5.1 Soil Replacement

It consists of removing expansive soil entirely or to a considerable depth and backfilling with granular materials (Zeitlen, 1969; Chaturvedi, 1977; Ordemir et al., 1977; Snethen et al., 1979; Chen, 1988). This method is practicable only when expansive soil extends to a shallow depth and granular material is available in abundance in the vicinity of construction. In case of partial replacement, care should be taken to prevent the entry of surface drainage into the underlying expansive soil.

3.5.2 Application of Surcharge Pressure

In this method, the expansive soil is loaded with a pressure equal to or greater than the swell pressure to counteract swelling. However, this method can be adopted in low swelling clays and for structures where adequate superimposed loads can be exerted on the foundation. Chen (1988) claims that at a relatively shallow depth beneath the foundation, the intensity of added stress are small and swelling may occur below this level.

3.5.3 Pre-Wetting

The principle of pre-wetting is based on the assumption that if soil is allowed to swell by wetting prior to construction and if the high soil moisture content is maintained, the soil volume will remain essentially constant, achieving a non-heave state; therefore, structural damage will not occur. Pre-wetting is usually done by method of ponding. Some successful and unsuccessful application of this method are reported (Mc Dowell, 1965; Blight and Wet, 1965; Williams, 1965; Bara, 1969; Gromco, 1974; Datye, 1977; SubbaRao and Satyadas, 1980) and it is generally felt that a great deal of time is required to stabilise the required thickness of highly impermeable expansive soil bed (Snethen, 1979; Chen,

1988). In order to quicken the process and to facilitate wetting with depth, a grid of boreholes can be installed before ponding (Blight and Wet, 1965; SubbaRao, 1986).
It has also been felt that it is possible to change the swelling characteristics of expansive soils by means of flooding a given site with proper choice of electrolyte solution of expansive soils by means of flooding a given site with proper choice of electrolyte solution. (Katti, 1966; Ho, 1968; Frydman, 1977; SubbaRao, 1994).

3.5.4 CNS-Layer Technique
This technique is developed by Katti (1969). Field observations by Katti and his colleagues indicated that even in the case of swelling soils, the swelling phenomenon is confined only within a small depth, 1.0 to 1.5 m below the surface of expansive soil and on its own can develop enough cohesion to counteract swelling pressure. Based on this observation, it is found that if an environment similar to that existing at 1 m depth in the black cotton soil with equivalent cohesion is produced and at the same time the system used in producing this environment does not swell or exert swelling pressure, then it may be possible to counteract the swelling pressure and heave of a swelling soil mass.
Hence, it has been proposed to interpose adequate thickness of cohesive non-swelling layer between the structure and the swelling soil base. When such a layer comes into contact with B.C. soil prior to saturation, it develops an electrical environment at the interface and below. This environment and the weight of the CNS together helps in developing absorbed water bonds during saturation in the black cotton soil system. Further, it is stated that due to development of cohesive forces by CNS and to some extent its weight, effect a reduction in the void ratio of the expansive soil at the interface, thereby increasing the expansive soil cohesion, although the cohesion of CNS and that developed in swelling soil at the interface need not necessarily be the same. Under the influence of a certain minimum thickness of CNS layer, the void ratio and the consequent increase in the expansive soil cohesion reach the requisite limits needed for counteracting the swelling pressure of the soil.

3.5.5 Chemical Stabilization
The oldest and widespread method of ground improvement is using chemical admixtures for soil stabilization (Chen, 1975). To stabilize expansive soils, generally, lime, cement and fly ashare used as admixtures. Physical and chemical conditions of the natural soil, workability of agent, economic and safety constraints, and specific conditions of the construction are the factors that affect the application of these agents (Fang, 1991).

IV. PREVIOUS STUDIES ON CYCLIC SWELL-SHRINK BEHAVIOUR OF SOILS

4.1 General
In the previous studies two methods have been used for determining the cyclic swell-shrink behaviour of expansive soils. These are the full swell-full shrink and full swell-partial shrink (Guney et al., 2007)
Full Swell-Full Shrink: Samples are allowed to swell until the primary swell completed or no more swell is observed, and dried fully or until the water content comes below the shrinkage limit.
Full Swell-Partial Shrink: Samples are allowed to swell until the primary swell completed or no more swell is observed, and dried to their initial moisture content.

4.2 Studies on Non-Stabilized Soils
Day, (1994) performed cyclic swell-shrink tests on silty clay soil with liquid and plastic limits of 46% and 24%, respectively. Full swell-full shrink tests were conducted where the soils were allowed to dry below their shrinkage limit. The author found out that full swell-full shrink cycles caused an increase in swell potential and this increase was explained by destruction ofthe flocculated structure of clay and formation of more expansive and permeable soil having a dispersed structure.
In the study performed by Al-Homoud et al, (1995), expansive characteristicsof soils which were exposed to swell-shrink cycles were investigated. Tests were conducted on six different soils with liquid, plastic, and shrinkage limits varying between 65-90%, 15-40% and 10-20%, respectively. During the experiments full swell-partial shrink method were used. The results showed that as the number of cycle increases, swell potential decreases. Furthermore, it was noted that first cycle caused the maximum reduction in swelling potential and swell percent reached to equilibrium after conducting 4-5 cycles. The authors explained the swell reduction with the soil particles' rearrangement.
Basma, (1996) studied on four different soils to determine the effect of cyclicswell–shrink on expansive soils. Both partial and full shrink methods were applied. For partial shrink, samples were allowed to dry at room temperature, and for full shrink, samples were exposed to sunlight. The results of the experiments showed that an increase in the swell potential was observed after full shrink and a decrease was seen after partial shrink. Swell potential came to a constant value at the end of 4-5 cycles. Apart from the other researchers, Basma (1996) performed ultra sound investigation test on samples, and found out that void ratio of samples that were exposed to full shrink cycles increased and that of ones which were exposed to partial shrink cycles decreased.

Doostmohammadi et al, (2009) investigated the effect of cyclic wetting –drying on swelling potential and swelling pressure of mudstone composed of sediments with silt and clay sized particles. Full swell-full shrink tests were applied on samples and the results showed that both swell potential and pressure increased. The tested samples were taken from an area where the hydroelectric power plant called Masjed-Soleiman had been constructed. Power house of that project intersected with mudstone interlayers. In order to monitor the swell pressure on concrete linings, during construction of the power house, total pressure cells were installed behind linings. Records were taken during six-year period to evaluate the cyclic swell-shrink behaviour of mudstone. The results of the laboratory and field tests were consistent in showing an increase in swell potential after cyclic wetting-drying.

4.3 Studies on Stabilized Soils

Rao et al, (2001) studied the effect of wetting-drying cycles on the lime-treated soil's index properties. Hydrometer and Atterberg limit tests were applied to lime-treated soil. Hydrated lime was used in the experiments with the percentages 2%, 4% and 7%. Full swell-full shrink method was used and specimens were exposed to 20 wetting – drying cycles during the tests. At the end of the experiments, clay content and liquid limit increased and plastic limit and shrinkage limit of treated samples decreased. The author explained the corresponding increase and reduction in the index properties by breakdown of cementation and flocculation of particles and by the increase in the thickness of diffuse double layer.

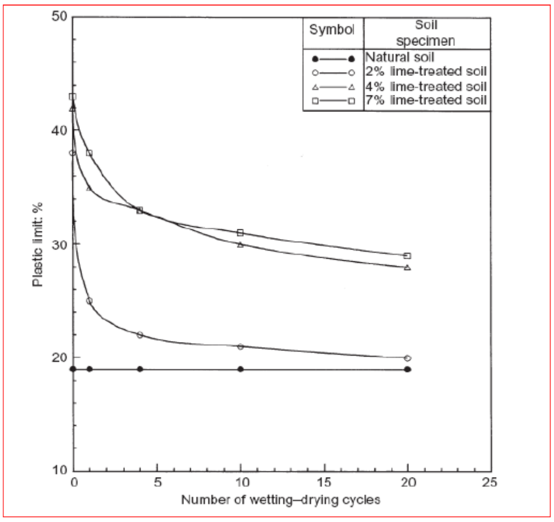

Figure 3: Effect of wetting-drying cycles on plastic limit of lime treated soils (Rao, 2001)

Another study was also performed by **Rao et al, (2001**) on lime-treated expansive soils. This time,the effect of cyclic wetting – drying cycles on swell potential of lime treated expansive soils was investigated. Full swell-full shrink method was used as in the previous study. The results of the experiments indicated that the effect of lime treatment was partially reduced after four wetting-drying cycles.

Guney et al, (2007) also conducted cyclic swell – shrink tests to determine the long term behaviour of lime-treated clayey soils. During the tests, samples were dried to their initial moisture content. Tests were carried out on three different soils. During the study two different proportions of lime; 3% and 6%, were used. At the end of the tests, swell potential of untreated Soils reduced in the first cycle and reached to equilibrium after the fourth cycle. However, swell potentials of 3% and 6% lime treated soils increased (fig 4).

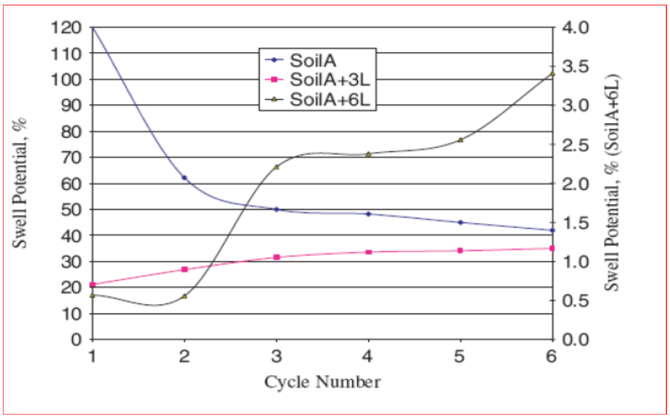

Figure 4: Change of Swell Percent for Soil A and lime treated Soil A (Guney et al, 2007)

The beneficiary effect of lime stabilization in controlling the swelling potential of lime treated soil is partially lost on subjecting them to cycles of wetting and drying. Author explained that this behaviour is a result of cyclic wetting and drying, which leads to gradual destruction of pozzolanic reaction of lime treated specimens and partial breakdown of inter-particle cementation.

Rao A. & Rao M., (2008) investigated the effect of cyclic drying-wetting on the swelling behaviour of expansive soil stabilized by using fly ash cushions that were treated with cement and lime. Full swell-full shrink procedure was applied during the tests. Reduction in swell potential was observed at the end of the tests. The reduction in swell potential increased with an increase in cushion thickness. Also fly ash cushions treated with cement showed more reduction in heave compared to the ones treated with lime. Swell potential reached to equilibrium after three and four cycles for the fly ash cushions treated with cement and lime, respectively.

In the study performed by **Akcanca & Aytekin, (2011),** effects of wetting – drying cycles on the lime treated samples prepared by mixing sand and bentonite in different percentages were investigated. Only swell pressure testswere performed and samples were allowed to dry until their moisture content reaches to a value slightly smaller than their initial moisture content. Test results showed that there was a partial loss of the beneficiary effect of chemical treatment.

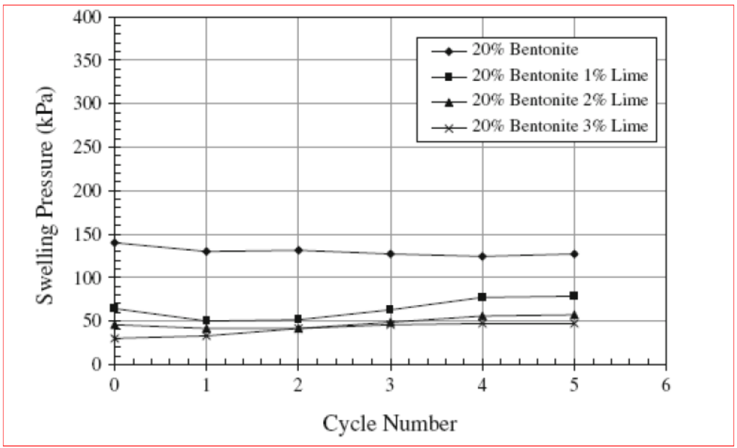

Figure 5: Cyclic swell-shrink behavior of samples containg 20% bentonite treated with lime (Akcanca & Aytekin, 2011) Kalkan

Kalkan, (2011) studied the effect of cyclic swell-shrink on natural expansive clay samples stabilized by silica fume. During the experiments full swell-partial shrink procedures were applied. An improvement in the durability of treated samples against wetting-drying was observed at the end of the tests. Furthermore, the results of the experiments showed that as the percent of the stabilizer increased, swell potentials of samples reached to equilibrium more rapidly.

FatemeYazdandoust,(2010) studied the effect of cyclic wetting and drying on swelling behaviour of polymer-stabilized expansive clays. Partial shrinkage method was used on three soil types stabilized with fibres. The first cycle caused the most reduction in swelling behaviour of all specimens and the value of swelling potential and pressure of treated specimens were less than those quantities of un-treated specimens and reached equilibrium after fourth cycle. By SEM analysis, author mentioned that in the presence of polymers, the particles move closer to each other, to form aggregates and reduce swelling potential.

V. 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.

Utilization of bulk quantity of Industrial waste produced globally is a serious concern in today's era. Nearly 75% of India's total installed power generation is from thermal power station which is 90% coal based, producing tremendous quantity of fly ash as well as pond ash, which requires a large area to dispose off. The bulk utilization of fly ash is only possible by the way of geotechnical application such as embankment construction, backfill material and sub base material. The purpose of this work was to investigate the effect of different types of wetting fluids on the swelling potential of an expansive clay soil during wetting and drying cycles.

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