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STABLIZATION OF EXPANSIVE SOIL

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INTRODUCTION

Expansive soil, also called shrink-swell soil, extensively exists in arid and semiarid regions of the world and cause great damage to infrastructure and buildings costing a lot of money to repair every year [1,2]. Depending upon changes in water content of the soil, expansive soil having high amounts of clay particles is prone to volume changes (swelling and shrinking) of up to thirty percent or more. Moisture content of these soils can be changed due to drought, rain, rise and fall in the ground water table, leakage of sewer lines, plumbing leaks, evapo-transpiration of vegetation, irrigation etc. Soils with smectite clay minerals, including montmorillonite and bentonite can adsorb very large amount of water between its crystalline sheets and therefore have the most dramatic shrink-swell capacity.

On absorption of water, expansive soil swells and cause ground heave and lifting of building or other structure. Strength of expansive soil is reduced on swelling. The direction and magnitude of movement of moist expansive soil will be greatest where the magnitude of the confining pressure is the smallest. Near-surface soil has higher expansion potential than that at depth because confining pressure of soil increases on increasing depth. Structures constructed on expansive soil also exert confining pressure. When pressure exerted by the expanding soil exceeds the confining pressure, upward movement of soil in the form of heave takes place. Generally lightly loaded interior floors have higher heave than the building perimeter. Due to nonuniform wetting, expansive soil with higher moisture content also forms bigger heave. This pattern is known as differential heave. If the expansive soil cannot swell freely, it will exert pressure on surrounding structures causing damage or complete destruction of the surrounding structure. Swelling of expansive soil foundation can cause tilts, deflections and bending of structures built on it.

Expansive soil shrink and collapse when water is removed and can result in differential settlement. During summer, plastic clay having liquid limit varying from 33 to 50 showed extensive shrinkage cracks exceeding 10 mm width on the surface. Shrinkage cracks developed on removal of moisture from the soil provide an important indication of expansive soil activity at the place. Swell-shrink behaviour is not fully reversible processes [3]. On wetting, cracks in expansive soil do not close-up fully which allow more access to water for the swelling process. Swelling pressure further get enhanced if these shrinkage cracks get filled with sediment.

Differential settlements in foundation are caused by consolidation or settlement-collapse of fill. Spatial variability of soil expansiveness, non-uniform initial moisture conditions and changes in initial moisture equilibrium causes differential movements of foundation which are responsible for structural damage. Continuous change in soil volume can cause movement and failure of foundation and structural damage to roads, pavements, railways, water reservoirs, houses, etc. built on expansive soil. Expansive soil is highly plastic having plasticity index greater than 50.

Expansive soil is not suitable for construction purposes because of poor workability for compaction, high compressibility and inadequate shear strength for required slope stability. By ground monitoring, problem due to presence of expansive soils must be taken into consideration during the design and construction of infrastructure projects

Stablization of Expansive Soil

Extensive geotechnical studies have been carried out for the improvement of expansive soil. For effective management of expansive soil, it is necessary to analyse soil properties and temporal and spatial water content variations of the soil. Methods of stabilizing soil to gain required engineering specifications range from mechanical to chemical stabilization. Foundation problems can generally be avoided by stabilizing the moisture content of

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the foundation soils. Stabilization of expansive soil for improving soil properties is done by mixing with chemical additives, soil replacement, compaction control, moisture control, surcharge loading, thermal methods, etc. Prior to placement of the foundation, the upper several feet of expansive soil can be removed and new non-expansive material be imported and compacted to create a stable layer of soil or non-expansive soils may be mixed with expansive soil to lower the expansion potential to an acceptable level. Slurry of smectite and kaolinite were mixed together at ratios corresponding to 0%, 20%, 50%, 70%, 80%, 90% and 100% by weight of smectite. It was reported that swelling behaviour became less pronounced with decreasing smectite content [4].

Stablization by conventional additives

Chemical remediation of expansive soils is being used as a conventional technique to improve the engineering properties of expansive soils [5,6]. Chemical stabilization is done by using various additives such as cement, basalt, furnace slag, lime, fly ash, polymer, etc. [7-14]. Remediation of expansive soil with these chemicals alters the clay mineralogy, improve soil strength and reduce the shrink-swell potential thus making it suitable for geotechnical applications [15-18].

Fly ash is defined as siliceous and aluminous materials consisting of oxides of silicon, aluminium and iron and unoxidized carbon. Class C and class F are two major classes of fly ash. Class C fly ash is produced from burning of anthracite or bituminous coal while class F is produced from burning of lignite and sub bituminous coal. Flyash was added to expansive soil at 0-25% and cured for 7days and 28 days, after which they were subjected to Oedometer free swell tests. The plasticity index and swelling potential of the soil decreased with increasing amount of fly ash and curing time. The optimum amount of fly ash is reported to be 20% for decreasing the swell potential. Silt size of fly ash particles also contribute for improving physical properties of expansive soil. Divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+} etc.) present in fly ash flocculate clay particles of expansive soils. Fly ash is puzzolana, which in the presence of moisture reacts chemically and forms cementatious compounds with expansive soil and improve its strength and compressibility characteristics. Both high calcium and low calcium fly ashes are effective in stabilizing expansive soils [19,20].

On mixing expansive soil with fly ash, plasticity, optimum moisture content (OMC), hydraulic conductivity and swelling properties (free swell index, swell potential and swelling pressure) of the blends decreased but undrained shear strength increased with an increase in fly ash content. On addition of 20% of fly ash to expansive soil, the free swell index was reduced by about 50%. On mixing with fly ash, maximum dry unit weight got increased, which in turn reduces the hydraulic conductivity of expansive soils. The resistance for penetration of water in expansive soil blended with fly ash increased significantly with an increase in fly ash content. The tests carried out with different proportion of fly ash indicated that the workability is maximum with 25% of fly ash. For proper mixing of fly ash in soil, soil having moisture content above 7% should be dried by spreading it on the surface [21].

Black cotton soils, which are highly clayey expansive soils were stabilized by mixing with lime and fly ash. Compressibility and plasticity of black cotton soil were improved with the addition of Lime and Fly ash [15]. Pandian et.al. [22] studied the effect of two types of fly ashes (Raichur fly ash (Class F) and Neyveli fly ash (Class C)) on the california bearing ratio (CBR) characteristics of the black cotton soil. The low CBR of black cotton soil is due to its low strength. CBR of black cotton soil is contributed by cohesion of finer particles while CBR of fly ash is contributed by its frictional resistance. The addition of fly ash to black cotton soil increases the CBR of the mix due to the frictional resistance from fly ash in addition to the cohesion from black cotton soil. Strength of black cotton soil increases with the increase in the fly ash content due to puzzolonic reaction of fly ash forming cementitious compounds resulting from bonding between black cotton soil and fly ash particles [22]. It is reported that swelling potential of expansive soil stabilized with fly ash and lime is decreased and optimum moisture content is increased [13].

Lime is very effective and widely used chemical stabilizer for expansive soils[23]. Stabilization of expansive soils with lime increase the bearing capacity and reduce the volumetric fluctuations of the soil. Vertical strain of lime treated expansive soil get decreased. Swell potential decreases and unconfined compressive strength increases on increasing the concentration of lime used to stabilize the expansive soil. Addition of lime to the soil in the presence of water causes flocculation-agglomeration in which the positive charged calcium ions react with negative charged soil particles which allow the small clay particles to clump together into larger particles. Remarkable reduction in swelling capacity was obtained when mixture of lime and MgO were added to expansive soil [24]. Expansive soil was stabilized by mixing it with fly ash, lime, mixture of fly ash and lime and mixture of lime, fly ash and polyester fiber. 1-10% of lime, 1-20% of fly ash and 0.5-2% of polyester fiber was mixed with expansive soil. After curing for 7, 14 and 28 days these stabilized soil samples were tested for compaction test, unconfined compression tests and split tensile tests. After curing for 28 days, mixture of lime, fly ash and polyester fiber was reported to be very effective in stabilizing the expansive soil [25]. The use of fibers provide immediate strength while lime or cement facilitates the curing process. The mixing of lime with clay minerals decreases plasticity and allows the fibers to mix within the clay matrix. Plasticity of soil decreases due to the cationic exchange between calcium ion and the clay minerals.

Swell pressure was reduced on stabilization of expansive soil with lime, cement and mixture of lime and cement. On heat treatment of stabilized soil swelling potential is reported to be reduced to zero. Lime is reported to be better stabilizers than cement [26]. Texture of expansive soil changed when it was stabilized by adding 4%-6% of lime and 40%-50% of fly ash by dry weight of soil. On mixing of lime, plastic limit of expansive soil got increased and on mixing of fly ash, liquid limit of expansive soil got decreased, thus decreasing the plasticity index of stabilized soil in both the cases. Addition of lime and fly ash decreased the maximum dry density, free swell and swelling capacity of stabilized soil, which further got decreased on increasing the amount of lime and fly ash. Percentage of coarse particles, optimum moisture content and CBR value of stabilized soil got increased on increasing the amount of lime and fly ash [27].

Lime stabilization of expansive soil was done not by adding lime to expansive soil but by precipitation of lime in soil by successive mixing of calcium chloride and sodium hydroxide solutions with the expansive soil. Unconfined compressive strength (UCS) of the expansive soil stabilized by lime precipitation got increased, plasticity index got reduced and swelling potential got controlled. The sequential mixing of expansive soil with calcium chloride solution followed by sodium hydroxide solution was reported to be more effective than mixing of expansive soil with sodium hydroxide solution followed by calcium chloride solution [28-31].

Lime or other calcium-based soil treatment methods are not effective on expansive soils having high sulfate content. Rice husk ash, groundnut shell ash, silica fume, amorphous silica, bagasse ash and polymers are reported to stabilize expansive soil with high sulfate content. For stabilization of sulfate rich expansive soil, class F fly ash, bottom ash, polypropylene fibers, nylon fibers and mixture of fibers with ash were added to the soil and cured for 14 days. Volume change property tests including volumetric free swell, volumetric shrinkage strain and vertical swell pressure tests were done on these stabilized soils. Sulfate rich expansive soil stabilized with ash and fiber showed improvements in reducing swelling, shrinkage and plasticity characteristics. Sulfate rich expansive soil stabilized with class F fly ash mixed with nylon fibers showed very remarkable improvement in volume change behavior [32-34].

On addition of hay of wheat, the shear strength and tensile strength of expansive soil increases with the increase of hay ratio till approximately 1% of soil weight and deformation due to the swelling potential also decreased to about 20% [35].

Stablization by industrial waste:

Stabilization of expansive soil by the addition of waste materials of industrial origin, such as rice husk ash serve double objective of remediation of expansive soil and reducing the cost of managing them. Addition of lime, MgO and rice husk ash (rha) to expansive soil is very effective in stabilizing expansive soil, reducing its swelling capacity and improving its mechanical properties. In comparison to untreated soil, compressive strength of expansive soil treated with these materials increased two to four times. Compressive strength increased remarkably on stabilization of expansive soil with mixture of lime-rha and MgO-rha. Stablization of expansive soil with mixture of rha and fly ash, lime sludge or cement in various proportions also improved CBR, UCS and OMC of expansive soil [36-38].

Stabilization of black cotton soil was done by blending it with different percentages by weight of bagasse ash (3%, 6%, 9% and 12%). The maximum dry density, optimum moisture content, CBR value and unconfined compressive strength of stabilized soil kept on increasing upto 6% replacement by bagasse ash. Engineering properties of black cotton soil were effectively improved with replacement by 6% of bagasse ash. Pozolonic property of bagass ash due to presence of amorphous silica in it helps in bonding the soil grains together for better shear strength [39].

Stablization studies on black cotton soil were done by mixing it with different percentages (4%, 8% and 12%) of bagasse ash and cement. Maximum increment in values of density, CBR and UCS of black cotton soil were reported when mixture of 8% bagasse ash and 8% cement by weight were added to expansive soil [40].

Expansive soil was treated with different percentages of cement (i.e., 0, 2, 4, 6 and 8%) admixed with 0, 2, 4, 6 and 8% of bagasse ash by dry weight of soil and density, CBR values and UCS were measured. A blend of 8% of cement and 4% of bagasse ash was recommended for treatment of black cotton soil for use as a sub-base material [41]

It is reported that shear strength is increased and hydraulic conductivity is decreased on stabilizing soil with upto 6% of cement –klin dust by weight of soil[42]. Scrap tire are low-cost and effective soil stabilizer [43].

Industrial effluent discharged on the soil can improve or degrade engineering properties of soil thus affecting the stability of the supported structure. Detrimental effect of contaminated soil can cause extensive cracking damage to the floors, pavement and severe foundation failures resulting in considerable damage to structure built on it. Improvement in engineering properties of soil, results in value addition to the industrial wastes by being used as a stablizer but if industrial effluent degrade engineering behaviour of soil then solution for decontamination of soil is to be searched. The effect of textile effluent, tannery effluent and battery effluent on the CBR of expansive soil is reported by Narasimha Rao *et al*. [44].

Expansive soil was treated with textile effluent, tannery effluent and battery effluent at 0%, 20%, 40%, 60%, 80% and 100% by dry weight of the soil. CBR was determined corresponding to both 2.5 mm and 5.0 mm penetrations. The CBR of soil treated with tannery or textile effluent increased at 2.5 mm penetration and 5.0 mm penetration, which further increased with percent increase of effluent. Addition of battery effluent decreased CBR of expansive soil at 2.5 mm penetration and 5.0 mm penetration. The maximum percentage increase or reduction of CBR occurs when soil is treated with 100% of effluent.

The maximum percent increase in CBR values corresponding to 2.5 mm penetration and 5.0 mm penetration were about 50% and 45% respectively when the soil was treated with 100% tannery effluent. The maximum percent increase in CBR values corresponding to 2.5 mm penetration and 5.0 mm penetration are about 45% and 40% respectively when the soil was treated with 100% textile effluent. The maximum percent decrease in CBR values corresponding to 2.5mm penetration and 5.0mm penetration were about 21% and 17% respectively when the soil was treated with 100% battery effluent. Textile and tannery effluents can be used for stabilization of expansive soil but Battery effluent is contaminating the soil.

Engineering properties of soil are controlled by thickness of diffused double layer, which is affected by pore fluid chemistry such as, electrolyte concentration, valency of ion, radius of hydrated ion etc. Treatment of soil with industrial effluents changes the pore fluid chemistry, which in turn changes engineering properties of soil.

On mixing of soil with tannery effluent, chromium ion present in the tannery effluent got adsorbed on to the clay particles, resulting in increasing the dry density of clay and decreasing double layer thickness. The reduction of the double layer thickness brings the clay particles closer and enhance stronger bonding between clay particles, which in turn increases the CBR values of the soil.

On mixing expansive soil with textile effluent, the dry density of soil got decreased and optimum moisture content got increased. The chlorides in the textile effluent is attracted to the lower valence metallic ions in the clay mineral and causes decrease in double layer thickness. The decrease in double layer thickness causes increase in attractive forces leading to flocculated structure which causes dry density to decrease. Water holding capacity of soil got increased due to retention of water within the voids of flocculated structure, which in turn increases optimum moisture content. Strong bonding between clay mineral and dyes and cellulose of textile effluent may be responsible for increase in CBR Values of soil treated with textile effluent.

On mixing expansive soil with battery effluent, sulphate ions present in battery effluent got adsorbed on to the clay particles, making the surface of clay particles negatively charged. Negatively charged clay particle surface can hold more quantity of water as double layer resulting in expansion of double layer thickness and increase in the distance between individual soil particles. Increased distance between clay particles reduces attractive forces for holding the soil particles togather. Weak chemical bonding between clay minerals due to increased distance between them reduce the CBR values of soil.

Stablization by polymers

Polymers are reported to improve engineering properties of expansive soil [45-48]. Polymers are useful in restraining the swelling tendency of expansive soils because soil–polymer interaction reduce heave and swelling pressure of expansive soil

Environment friendly polypropylene homopolymer was used as a nanofiller to obtain a coherent nanocomposites material with expansive soil [49]. The stabilization of expansive soil by polymer to form nanocomposite material is effective in increasing the long-term stability and strength of expansive soils. 5, 10 and 15% of polymer by dry soil mass, was added to the swelling soil samples and were preserved for different curing time (3, 7 and 28 days) before testing for strength and durability. Polymer dispersed homogeneously within the clay layers and interacted with components of expansive clay to produce a new matrix in the form of nanocomposite material. The polymer modified the microstructure of the clay and altered the texture of the clay by reducing the fine particles. The produced nano-composites increased both the cohesion and the electrostatic attraction between adjacent particles. The sizes of the nanocomposites formed within the clay layer increased with the increase of the polymer concentration. The size of nanocomposites increased from 10 nm to 23.5 nm on increasing polymer concentration from 5% to 15%. On increasing the curing time, size of nanocomposites did not increase but the nanocomposites were effectively hardened. Increasing the curing time distinctly increased the stress and decreased the vertical strain because of the increase in strength of treated samples.

On mixing of polymer, swelling pressure and free swell % of expansive soil is reported to decrease significantly, which further decreased on increasing the size of nanocomposites and curing time. At 15% of polymer content and 28 days of curing, the reduction in the free swell was found to be 90%, Whereas reduction in free swell was around 16% for sample stabilized with 5% of polymer and cured for 3 days. The swelling pressure was reduced by 86% for 15% of polymer content and 28 days of curing, whereas, after 3 days curing the swelling pressure was reduced by 13% for 5% of polymer content [50].

Addition of polymer to form nanocomposite materials considerably reduced the volumetric shrinkage strain of expansive soils, which further decreased on increasing the size and curing time. Expansive soil stabilized with 15 % polymer and cured for 28 days showed volumetric shrinkage strains of 0.3%. Formation of nanocomposites reduced liquid limit and plasticity index of expansive soil and it kept on decreasing with increasing the polymer content and curing time. The induced nanocomposites within the swelling clay can be attributed to non-plastic properties. The reduction of plasticity index indicated to the increase in soil strength and the decrease in the swelling potential [51]. The modulus of elasticity of stablized expansive soil kept on increasing on increasing the polymer content and curing time indicating that formation of nanocomposites remarkably improved the stiffness of expansive soil. The maximum dry density of treated soil decreased with increasing polymer content because the volume of soil sample increased due to formation of nanocomposites and the weight of soil sample was decreased due to loss of water and formation of hydrophobic material via ion-exchange mechanism. The optimum moisture content (OMC) of treated soil also got decreased with increasing polymer content. The unconfined compressive strength of stabilized soils got increased with increasing polymer content and curing time. High toughness of treated samples is due to high value of unconfined compressive strength (ranging from 100 to 200Kpa). The unconfined compressive strength increases rapidly within the first 7 days, after that small increment was observed upto 28 days of curing.

Resistance to immersion (RI) tests were done to study the effect of immersion in water on durability of stabilized soil samples. RI is the ratio of unconfined compressive strength of soaked samples to unsoaked sample. Value of RI increased on increasing polymer content and curing time. On immersion in water, unconfined compressive strength of soil sample stabilized with 5% polymer and cured for 28 days reduced considerably as is indicated by value of RI lower than 80%. Soil sample stabilized with 15% of polymer and cured for 28 days were considered to be water resistant and durable because the value of RI was found to be higher than 80% [52]. The stabilized soil samples were impermeable to water because increased bonding between soil particles and polymer produced a durable hydrophobic material by filling the voids therefore the hydraulic conductivity is decreased [53].

Toughness index of stabilized soil increased with increase in nanocomposites size and curing time. High value of toughness index is due to increased cohesion. The toughness index was found to be 42% for samples stabilized by 5% polymer contents and cured for 3 days, whereas it reached to 85% for 15% polymer content and 28 days curing time. High value of toughness index indicates to lesser deformation of stabilized soil under external compressive stress. Shear strength of stabilized soil increased on increasing the nanocomposites size and curing time because of improvement in stiffness of stabilized soil [54]. High value of toughness index and shear strength ensure long term stability of treated soil. The polymer stabilization and ion-change mechanism improved the durability of treated samples [55,56],

Commercially available chemical additive, Addicrete P which is supplied by CMB, was mixed with expansive soil at percentages 0.5%, 1% and 2% of unit weight of dry soil mass and were cured for 3, 7 and 28 days. Atterberg limits, standard proctor compaction tests, unconfined compression tests and swelling tests were done on untreated and treated expansive soil to study the effect of additives on the geotechnical characteristics of expansive soil [57]. Liquid limit and plasticity index of treated soil were reported to decrease and it further decreased on increasing Addicrete P content and curing time while plastic limit of treated soil increases on increasing the Addicrete P content and curing time. Free swell, swelling potential and swelling pressure of treated soil were decreasing fast upto 0.5% of Addicrete P content and no significant improvement in swelling peoperties was obtained by mixing higher content of additive. Optimum content of Addicrete P for reducing swelling characteristics of expansive soil can be 0.5%. Swelling values of treated soil is further reduced on increasing curing time. On addition of Addicrete P maximum dry density of treated soil increases and it further increases on increasing the percentage of additive. Optimum moisture content of treated soil decreases on increase in percentage of additive. [57].

Blending, underpinning and grouting techniques are used for remediation of expansive soil. Because of excellent binding properties and high deformability, polyurethane is generally used as grouting material and sealant to reduce seepage [58]. The polyurethane foam is relatively resistant to water absorption and it can be used to displace and exclude water in some geotechnical applications [59]. The use of polyurethane as a filling and lifting agent in soils makes it a promising geosynthetic material. Localized variations in foundation characteristics causes differential settlements in foundation, so localized remediation of foundation will improve the overall performance of foundation. To remediate differential settlement, polyurethane resin is injected incrementally in foundation at discrete locations beneath an existing structure built on expansive soil [60,61]. For injection of resin, no excavation or installation of additional foundation elements is required, because it can be injected in foundation directly under the building through small diameter metal tubes. On injection, resin hardens within a few minutes to a stable polyurethane resin–expansive soil composite material. On injection, resin expands rapidly and expansion pressure it exerts is used to remediate deflected expansive clay foundations by lifting and supporting lightly loaded settled structures, restoring foundation levels and limiting further settlements. Resin is generally injected in a settled soil mass that is shrunken and dessicated,. Resin injection is a reliable remediation process and it has been effectively used in cracked expansive clay soils. The polyurethane injection technique is more cost effective than underpinning. The remediation process is very efficient because of fast curing of resin.

For remediating a sunken foundation, multiple small injections are given so that the lift occurs incrementally. While injecting resin in successive shots, each of these is allowed to expand before the next is delivered. The resin that is injected later compresses the partially hardened resin injected earlier and causes crack in it. Propagation of the resin in cracked expansive soil and extent of crack-filling is unpredictable. With the resin following the weakest path, its propagation is a somewhat non uniform and random phenomenon. It can either propagate through existing cracks or it can create new fractures in the soil. In wider cracks, resin propagates to longer distances and form microvoids. It generally travel more than one metre through wider cracks. The resin can enter cracks as small as 0.2 mm but it can travel not more than a few centimetres in cracks with width of less than 1 mm. Resin in smaller cracks has heterogenous structure.

No significant increase in swelling potential is reported for resin-injected cracked expansive soil because a significant number of cracks remain unfilled in the resin injected expansive soil which allow much of the excess swelling potential to be relieved. Unfilled crack provide swell relief and prevent the soil mass from swelling excessively. Uncracked expansive soils exert large swelling pressures in a fully confined state and the swelling pressure reduces rapidly when there is even small reduction in confinement. In cracked expansive soil, the cracks causes reductions in confinement, allowing swelling pressure of expansive soil to be reduced significantly even if there is a small volume of unfilled cracks [62]. A reduction of 68% of the peak swelling pressure of clay soil, is reported for a soil with as little as 1% cracks of its total volume. The resin injected expansive soil swelled much less than the noninjected expansive soil because while filling cracks it is creating more cracks by soil fracturing. If resin is injected within the cracked zone, then the resin propagate through existing cracks but If resin is injected below the crack zone then it fills and propagates through relatively few cracks which significantly reduces the extent of crack-filling. In the long term, the possibility of overlifting of the resin-injected expansive clay foundation structure due to rewetting is limited due to presence of a significant proportion of the cracks. Injection of polyurethane resin in cracked zone of expansive soil result in insignificant over-lifting and the risk being further reduced with injection of resin below the cracked zone.

Presence of resin in the cracks, prevents water from penetrating rapidly deeply in the cracked soil mass. Though the resin is not totally impervious to water, but permeability of the injected resin is lower than, or similar to, that of the uncracked clay soil. Resin injection effectively reduce the bulk permeability of a cracked clay soil, impeding sudden wetting and swelling of remediated foundation soils thus reducing the risk of overlifting of the remediated infrastructure, if post-remediation foundation wetting occur.

Natural soils consist of interparticle voids and macro-pores including cracks and holes [63]. Dry expansive soils contains large number of cracks. Crack porosity of dry expansive soil is several orders of magnitude greater than that of uncracked soil. Because of presence of some macrovoids in resin injected cracked expansive soil it remains 4–5 times more permeable than the uncracked soil but its hydraulic conductivity is lower than that of uncracked soil. Therefore, the injected resin will not prevent the soil from hydration, but it may make it less susceptible to rapid rehydration.

Nonexpanding resins (e.g., epoxy or acrylic) have more commonly been employed in grouting [64]. Polystyrene geofoam is also reported to stabilize expansive soil [65]. The stabilization by polypropylene fibers showed improvement in the shear strength with time [66].

Different Percentage of Polymer (RPP) (0.019, 0.04 and 0.06%) were added to expansive soils and were cured for 7 and 14 days periods. Atterberg Limits, CBR, standard compaction, swelling potential and swelling pressure test were conducted on control and treated soil to assess the performance of polymer for stabilization of expansive soil. It is reported that soil treatment with RPP improved CBR and maximum dry density and reduced Atterberg Limits, swelling potential and swelling pressure. The curing periods had no significant effect on plasticity and swelling properties of the treated samples [67].

Application of Nanotechnology considerably improved geotechnical properties of soil. It is reported that after ball milling process natural soil get transformed to nanosoil [68,69]. On decreasing the geometric dimensions of material down to the nanoscale, due to enormous increase of the surface area, the properties of the material changes drastically. Due to catalytic properties of nanocrystalline particles, they react very actively with other particles in the soil matrix. The existence of even a small amount of nanoparticles can result in condsiderable effects on the engineering properties soil. Soils containing nanoparticles with intraparticle voids generally exhibit higher cation exchange capacity and liquid and plastic limits. The existence of nanofibers in soil usually enhances the thixotropic property of soil and increases its shear strength. Due to higher surface area of nanoparticles, a larger amount of water get adsorbed on the surface of soil particles as well as water get accumulated in nanopores which results in an increase of the water holding capacity in soil. Application of nano alumina material beneficially improved the volume change and desiccation crack behaviors of soil [70].

Post construction design option includes deepened footings, thicker slabs and extra reinforcing in concrete if foundation movement on existing structures is noticed. Underpinning also transfer the building loads to deeper and more stable soils. A broad protective pavement around the entire perimeter of the building can be constructed and plants near building are removed to protect the foundation soil from excessive wetting or drying. This perimeter apron diverts all rainfall and drainage away from the foundation soils and at the same time during dry periods, the foundation soils are protected from getting dried.

CONCLUSION

Many additives mentioned in this review are reported to improve the engineering properties of expansive soil. Though polymers are reported to be very effective but very few papers are available on stabilization by polymers. Research on possibility of stabilization of expansive soil by polymers can be explored.

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