Strength Characteristics Of Tropical Expansive Soil – A Review

Jemal Aliy Gobena, S. Suppiah

Abstract: Structures constructed on black cotton soils are susceptible to cracking, and differential settlement leading to disasters and adverse economic conditions. This is due to the alternate swelling and shrinking behavior of this type of soils. Expansive soils can be stabilized with the help of different admixtures such as lime, cement and other similar materials leading to increasing the shear strength of the soil. Stabilizing expansive soil is essential since it improves various properties, resulting in improved performance of structures found on swelling soils. In the present study, numerous admixtures adopted by different researchers and their limitations are summarized.

Index Terms: Black cotton soil, Bearing capacity, Stabilization, Swell, Crack, Remedial measure.

1 INTRODUCTION

Interestingly, most deserts are located near either the Tropic of Cancer (the Sahara desert, the Iranian desert, the Thar desert, and the North American desert) or the Tropic of Capricorn (the Kalahari desert, Namib desert, Atacama desert, and the Australian desert). The earth is hottest at tropics than at equator because, sunlight falling on the equator generates increasing air currents that help in the formation of clouds over equatorial regions, which then cause rain and thunderstorms (Charlie, 1984). This is why the areas lying on the Equator experience lower temperatures, and are not the hottest on the planet. Expansive soils are major problematic soils of most tropical countries. Due to the presence of montmorillonite, black cotton soils easily expand with variation in moisture and difficult to use for any type of construction. These soils swell when in contact with moisture and shrink on drying and vice versa (Sherwood, 1993). Soil deposits are usually widespread and making it impossible to avoid or detour during the construction of engineering projects. Many foundations of low rise buildings and highways have been reported damaged due to the seasonal change in volume (i.e. swell and shrinkage) of these soils (Chen, 1988). These soils have reportedly inflicted billions of dollars in damages and repairs annually to earth structures and facilities. Table 1 presents some estimated cost of damages due to the heave of black cotton soil on facilities of some countries. Meager research work has been done on black cotton soils.

- *Jemal Aliy Gobena is currently pursuing Ph.D. degree program in Civil engineering in Veltech Rangarajan Dr.Sagunthala R&D institute of Science and Technology, Tamil Nadu–600 062, India. PH-+917397307051. E-mail: jemalaliy2018@gmail.com*
- *Dr. S. Suppiah is currently working as Professor in the Department of Civil Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India. PH-+919944079879. E-mail: drsuppiah@veltech.edu.in*

However, this rather useful information is scattered in various publications and the need to bring this scattered information together has long been felt (Bell F., and Culshaw M. (2001)). The magnitude of soil shrinkage increases with the amount of clay-sized particles in the soil. Sand and silt-sized particles reduce total shrinkage because they dilute the clay and decrease the volume of water held by the soil. Generally, a soil deposit having a layer of illite or montmorillonite as the dominant clay mineral shrinks more than the soils having other clay minerals (Yong and Warkentin, 1975; Chen, 1988). Expansive soil is found in the dry and semi-dry areas of the world. These soils are residually derived from basalt, genesis, basic volcanic ash, calcareous alluvium and sedimentary rocks containing calcareous shale, lime stone, slates and sand stones (Humad, 1987).

Table. 1- Estimated cost of damages due to black cotton soil.

Country	Amount (US$)	Reference
UK	>2.166billion	[8]
China	>15.77 million	[29]
France	> 2.71 billion	[48]
India	several million	[16]
Saudi Arabia	> 300 million	[38]
Sudan	>6 million	[33]
USA	>2 billion annually	[28]

The failure mechanism is significantly influenced by soil moisture content. The relationship between moisture content and other soil parameters is not clearly underestood, but most of the researchers described as a soil moisture content affect the strength of the soil. The soil compactness and strength idecrease as the moisture content increases (Mehrez, 2015). The excessive variability of physical, and chemical processes results in to breaking down of rock masses. Due to physical processes, decreasing of particle size, increase in surface area, and the bulk volume proportionally increases. The mineralogical composition of the soil can be affected by chemical and biological processes which can cause changes in physical, and chemical properties of the soil. Robinson (1949) acknowledged two main stages in chemical weathering.

The primary phase has to do with the demolition of mineral phases and the next phase is the creation of ancillary products. These two stages include action of different procedures resulting in two key types of materials of morphogenic concern, namely, (a) weathering residues and secondary materials that occur onsite (residual soils) and (b) materials which are conveyed before deposition (transported soils).

2 STRENGTH CHARACTERISTICS OF TROPICAL EXPANSIVE SOILS

2.1 The main characteristics of black cotton soil are:

a. Shows heave and crack as geo-environmental phenomena.
b. Contains the ability to swell and contract with alteration in moisture content.
c. Contains high percentage of montmorillonite mineral.

2.2 Distribution of black cotton soil

Expansive soil occurrence and problems associated with swell - shrink soils have been reported on six continents and in more than 40 countries all over the world. Black cotton soils cover about two percent of dry land of the world and found mostly in arid and semi-arid regions, as well as where wet environments happen after lengthy times of drought. The spreading of expansive soil is dependent on the geology of the area, temperature, hydrology, geomorphology, and type of plants. The countries that have wide coverege of expansive soils, allocating high construction budget from Africa are Ethiopia, Ghana, Kenya, Morocco, South Africa, and Zimbabwe; from Asia; Burma, China, India, Iran, Israel, Japan, and Oman; from America; Argentina, Canada, Cuba, Mexico, Trinidad, the USA, and Venezuela; from Europe; Cyprus, Germany, Greece, Norway, Romania, Spain, Sweden, Turkey, and UK; and Australia (Aitchison, Metcalf, and Richards, 1962). Factors influencing the magnitude of shrinkage include, the location of deposition, which determines the particle arrangement, overburden stress and the magnitude of weathering. Overburden pressure combines the sediments and reduces the water content because of which the amount of shrinkage is affected. Frequent phases of drying and saturating will overcome the effect of depositional environment for surface soil. The total shrinkage of a soil with a random soil fabric is less than that of a soil with parallel particle orientation (Yong and Warkentin, 1975). Mitchell (1993) and Chen (1988) have concluded that though swelling and shrinkage of black cotton soil is interconnected, it is unclear, if extremely swelling clays also show equally high shrinkage upon drying. It is hence ambiguous, if swelling can be treated as an image reflection of shrinkage. Fleureau et al. (1993) have reported the drying and saturating ways of soil slurries with initial water content is 1.5 times the liquid limit. Knowing the values of suction, soil properties for example void ratio, water content, and degree of saturation were measured during drying and wetting. It was observed that the hysteresis between drying and wetting paths depends on the measured range of suction values. Hysteresis was observed in associations for wetting and drying paths at moisture contents greater than the shrinkage limit of the soil. All additional factors (overburden pressure, dry density) being the same, the magnitude of shrinkage of a given soil increases with the increase in the initial water content (Chen, 1988). High swelling clays containing the montmorillonite mineral have high water retention capacity and exhibit higher magnitudes of shrinkage (Yong and Warkentin, 1975). Soils with dispersed fabric shrink less than floculated- fabric. Hence lesser dry densities for random particle arrangement are obtained. External load or applied pressure on soil causes change in fabric towards orientation and hence results in larger shrinkage (Seed et al, 1960; Yong and Warkentin, 1966; Sridharan and Rao, 1971). Most of the clayey soil displays shrinkage and cracking with three dimensional. Cracks form where the cohesion is least and in the wetter portion when the drying is not uniform. A large number of cracks are developed in flocculated clays while a few relatively large cracks are caused in semi-oriented clays with high cohesion (Yong and Warkentin, 1966). The cracking pattern depends on the tensile strength, initial moisture content and amount of inert materials. Higher the initial moisture content and greater the rate of evaporation, larger will be the individual cracks and spacing (Komornik, 1969). iExpansive soils always create problems more for lightly loaded structures than moderately loaded structures (Malhotra, 2013). The problems such as unequal settlement can occur due to swelling and shrinking characteristics of expansive soil under compaction loads

3 REMEDIAL MEASURES

Treated black cotton soils have a lower permeability, higher strength, and lower shrinkage than the untreated soil (Keller, 2011). Stabilization is not the only solution for expansive soil to improve its strength. Mechanical stabilization can be used for improving the strength properties of expansive soil. Structural measures can also be used to reduce expansive soil problems. Some of the principal preventive methods for safe design of building foundations are, deep piers and footings, and rigid slabs. As shown in the table 1, the estimated cost of damages caused by expansive soil varies from country to country. The main properties of soil are strength, compressibility, stability, permeability and durability (Sherwood, 1993, Al-Tabbaa, 2005). Comparison of various soil stabilizing techniques is listed in table 2.

4 CONCLUSION

It is observed that the problematic soil plays a major role in damaging infrastructure in tropical regions. Most of the studies have been reported on the damages caused by black cotton soil and its remedial measures. Control and improvement of the expansion and contraction properties of expansive soil can be attained in several ways, for example, by substituting expansive soil with non-expansive soil, by flooding prior to construction to attain its swell potentials. Stabilization by additives is recommended, if the required strength not attained by mechanical stabilizaion. Significant issues presented by expansive soils to civil engineering structures are well acknowledged by engineers and researchers all over the world. The problems related to expansive soils are bringing more damage to structures, especially light-weight structures, buildings, and asphalt pavements, than any other natural problems, with earthquakes, hurricanes, tornados, and floods. This mentioned problems are scattered in different journals and books. It is recommended to be reviewed and collected for feature reference work. It is recommended that all possible construction sites should be evaluated for potential disaster due to expansive soils. Further research is required in this direction to know the exact cause and corrective measures against the failure of structures at sites consisting of expansive soils. If the black cotton soil is found distributed on a relatively small area, it is more economical to replace this soil by non-expansive soil rather than using additives for stabilizing

Table.2- Comparison of various soil stablizing techniques

S. No.	Method of Stabilization	Advantage	Disadvantage	Reference
1	Mechanical	- Simplest method of soil stabilization - Is used to improve the sub grade of low bearing capacity - Minimized Capital Construction Costs.	- High expense associated with the process - While these methods were available for a various years, more up to date innovation has finally been developed that offers a superior answer to this issue.	[7]
2	Fly ash	- Reduction of swell potential achieved by using fly ash as expansive soil stabilizer - Low cost material - Decrease the swelling properties.	- Dewatering may be required. - The mixture of the Soil-fly ash saturated in water are extremely vulnerable to slaking and strength loss. - The long term strength and durability of the soil can be reduced due to Sulfur minerals which can form expansive soil in soil-fly ash mixture. - Addition of fly ash beyond 20% of dry weight of soil decrease CBR and again increase by increasing fly ash beyond 70%.	[40]
3	Cement	- Reduced Plasticity. - Decreased volume expansion or volume contraction. - Bigger strength.	- Due to complex sequence of unid entified chemical reactions, the pr oc-ess of Cement hydration is a complex.	[7] [24] [14]
4	Rice husk ash	- The better strength can be attained by adding small amount of cement.	- For the soil stabilization, RHA alone cannot be used due to lack of its cementitious properties.	[3]
5	Lime	- Improve the compressive and shearing strength of soils - Increase in soil strength - Decreased plasticity index - Decreased swell potential and volume change - Increased durability	- Stabilized Soils intend to have less moisture percentage, therefore, dewatering may be required. - The long term strength and durability reduced due to Sulfur contents expansive minerals. - Impact on environment - (emission of carbon dioxide)	[24]
6	Electrical	- Improve the properties of soil - used for drainage of cohesive soils	- Highly expensive drainage process compared with other method	[4]
7	Recycled and Waste Products	- The utilization of less expensive Admixtures can lessen the required amount of industrial waste. - benefit of providing an environment friendly - Reusing can avoid the waste of potentially beneficial materials and decrease the consumption of new raw materials, in this manner decreasing: energy usage, air pollution (from burning), and water contamination(from landfilling)	- Air Contamination - Contaminant type and concentration, which determines the amount of reagents used - Moisture content in waste increases costs compared to solid waste	[7]

8	Xanthan Gum	- Xanthan Gum is environmentally eco-friendly than cement . - More economical when used approximately 0.8 – 1.2%. - No adverse effect interms of durability	- Further studies is needed to understand the properties of ions , biopolymer rheology and mineralogy in the reaction.	[45]
9	Saw dust ash	- Saw dust disposal problems can be avoided - More stable structures can be granted in the future by using saw dust. - Addition of saw dust ash upto 12% reduce expansion of soil.	- Further addition of more than 12% (dry weight of soil) of saw dust is not desirable.	[43]
10	Ceramic Dust	- Ceramic dusts are used for stabilizing black cotton soil. - Ceramic dust can be utilized for strengthening the subgrade of flexible pavement. - Save cost of construction	- The ceramic dust may cause health problems.	[26] [49] [50]
11	Brick Dust	- Significant increase in CBR value than lime stabilized soil. - Less cost than conventional base coarse material - Significant increase in Cohesion, angle of internal friction and decrease in plasticity, swelling, maximum dry density and consolidation settlement.	- Clay brick at high temperatures is weakly acidic.	[28] [23] [1]
12	Bagasse Ash	- Highest CBR values obtained when bagasse ash was used in combination with lime. - Improvement in strength, free swell index, and shrinkage index. - It is cost effective, when used in combination with other stabilizers.	- The effect of compaction delay was reported. - Bagasse ash alone is not as such effective than combined effect of bagasse ash and lime.	[38] [49] [29]
13	Waste tyre	- Density, and strength of the soil was reduced by addition of the tire chips to the soil. - Increase in percentage of rubber icrease the internal friction and cohesion - Addition of waste tire showed improvement in CBR. - Reduce the problem of waste tyre disposal. - Increase in crumb tyre reduces the thickness of pavement and cost of construction.	- Further investigation should be done on the long period properties of the mix.	[51] [40]

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