Expansive soils in Ethioipa: a Review

Bantayehu Uba Uge
MSc, School of Civil Engineering, Hawassa University, Hawassa, Ethiopia
Email: ubabanti@gmail.com/bantayehuu@hu.edu.et

Abstract

Expansive soil covers an appreciable part of Ethiopia. It constitutes a real financial risk and disruption to the quality of life. Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. Engineering design of such structures in and on this soil must recognize and accept the complexity of the material behavior of the ground. The soil must firstly be investigated and if it exhibits swelling characteristics it has to be tested and classified. A number of reports about the characteristics, behavior, stabilization and effects on structures of expansive soil have been done on different towns of the country over the years but no compiled and comprehensive review has been published. Thus the aim of this paper is to present a review on characteristics, behavior, stabilization of expansive soil in Ethiopia and its effects on the structures with suggestion of possible remedial measures. It will provide technical overview and useful information to the engineers and researchers who will work for the betterment of research activities in this field in future. Moreover, the client, policy makers and other concerned bodies will be aware of the potential problem associated with construction on this soil and search for alternative remedial measures applicable to control the risk and cost-savings.

Keywords: *Expansive soil, Swelling, Shrinkage, Stabilization, Effect on structure.*

1. Expansive soil and its problem in Ethiopia

1.1. General Background

Ethiopia is a rapidly growing country that has been scoring a double digit economic growth for a decade. The availability of untapped natural resources coupled with its being the second populous country in Africa further makes the nation advantageous. Among others, the construction sector is instrumental in catapulting the nation to higher levels of development.According to the Ministry of Construction the construction industry scored tremendous achievements in the last 25 years in accelerating the nation's economic growth.That means of transforming the agricultural-led economy to the industry led one, which needs shifting agricultural labor to that of manufacturing and service, enables the nation to obtain demographic dividend. This, in turn, indicates the vitality of the expansion of urbanization which needs more construction work.Currently, the construction industry has marvelous impact on the Growth Domestic Production by creating value chains with other sub sectors such as cement industries, small scale enterprises.The construction industry has been playing crucial role in expanding infrastructures such as roads, schools, health centers, real estates, irrigation, residential houses and the like. Hence, it created job opportunities for hundreds of thousands allover the country and established value chains through facilitating markets to cement industries and small scale enterprises. As rapidly growing economy, the nation aims at cultivating the sector so that it would meet its development ambition. [1]

As investment in infrastructure development forms a significant portion of the global economy, expansive soils are a prime focus of research in geotechnical engineering and soil science. The road network in Ethiopiahas been identified as a serious bottleneck for the economic development of the country, as it provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important [12]. Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. [2, 5, 14, 17, 18, 19, 32, 33, 40, 41]

Expansive soils widely occur in Ethiopia and are notorious for posing a wide range of problems in the construction sector. Two foremost topics in expansive soil research are (1) characterization and (2) treatment or stabilization. While the first deals with identification and quantitative analysis of expansive soils, the second strives to improve their geotechnical characteristics (such as reducing their swelling and shrinkage potential). Site characterization is a prerequisite at the onset of any construction, also to promote a better land-use planning. A comprehensive geotechnical investigation ensures an optimal planning, design, construction and satisfactory functionality of structures [17, 41].

Engineering problems related to expansive soils have been reported in many countries of the world as 3% of the world land areabut are generally most serious in arid and semiarid regions.As a result, highly reactive soils undergo substantial volume changes associated with shrinkage and swelling processes. Consequently, many engineering structures suffer severe distress and damage.Cracked foundations, pavements, floors and basement walls are typical types of damage done by swelling soils. Every year they cause billions of dollars in damage.Expansive soils are not as dramatic as hurricanes or earthquakes and they cause only property damage, not loss of life. They act more slowly and the damage is spread over wide areas rather than being concentrated in a small locality. [24, 38].

1.2. Distribution of Expansive soils in Ethiopia

Distribution of expansive soil is generally a result of geological history, sedimentation and local climatic conditions.Aridclimatic conditions and severe weathering environment prevailing in north eastern part of Africa promote the widespread occurrence of expansive soils in this region[31].In Ethiopia, covering nearly 40% surface area of the country [15], expansive soils are observed in area such as central Ethiopia, following the major trunk road like Addis Ababa - Ambo, Addis Ababa - Weliso, Addis Ababa - Debere Berehan, Addis Ababa - Gohatsion, Addis Ababa - Mojo. Also the cover the area like Mekelle, Bahirdar, Gambela, Arba Minch and the most Southern, South-west and south-east part of the capital Addis Ababa area in which the most major recent construction are being carried out. The distribution are shown in figure 1. [2, 5, 6, 33, 36, 41]

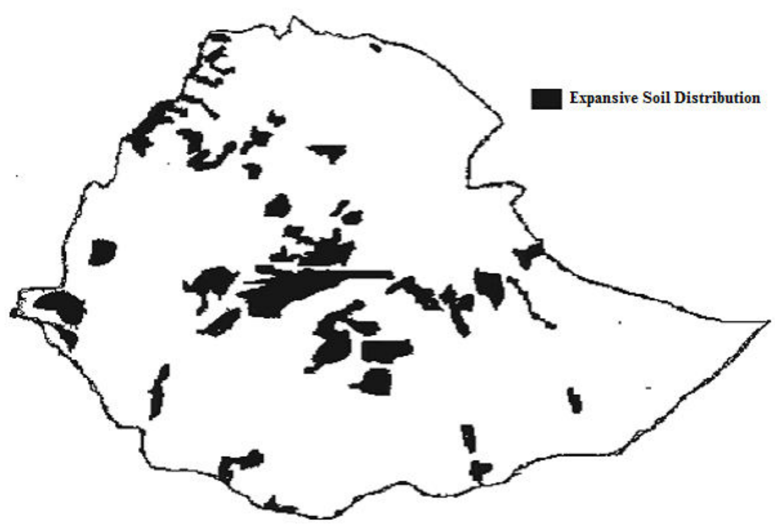

Figure 1. Distribution of Expansive Soils in Ethiopia [33]

Expansive soils contain the clay mineral montmorillonite with claystones, shales, sedimentary and residual soils are capable of absorbing great amount of water and expand. They are sometimes called black cotton soils, shrink-swell soils, swelling soils, adobe, clay, or caliche soils. They are widely distributed especially in the highlands. Known as vertisols, they are present in the central, north-eastern highlands and western lowlands. They are fertile and used intensively for agriculture. It is estimated that 7.6 million hectares of vertisol area located in the highlands with a height of greater than 1,500 m above sea level. The remaining area (over 5 million hectares) is located at elevationsbelow 1,500 m. The general slope range of the landscape on which vertisols occur is 0 – 8%. They are more frequent in 0 -2% slope range and are usually found in landscapes of restricted drainage such as seasonal inundated digressional basins, alluvial and colluvial plains, undulated plateaus, valleys and undulating side slopes [7, 13, 14].

Montmorillonite is a product of weathering of iron and magnesiumrich parent materials and is one of the most common smectiteminerals found in soils. Sincethe study area is located within the central plateau of Ethiopia, whichis covered by rocks of volcanic origin where mafic rocks like basalt areabundant, occurrence of montmorillonite in the study area can be favored by the environmental conditions. Nontronite is also acommon smectite mineral found in soils and weathered bedrock,whose formation is favored by alkaline to neutral pH environments, aswell as by availability of iron and calcium minerals

1.3. Expansive soils problem in Ethiopia

The fact that expansive soils are a major engineering problem makes their study an important research aspect due to the accruing cost involved in terms of economic loss when construction is undertaken without due consideration to the probability of their presence. The lack ofinformation about the presence of expansive soils may lead to the mistake in structural foundation design, resulting in one of the factors of damage.The most obvious way in which expansive soils can damage foundations is by uplift as they swell with moisture increases. Swelling soils lift up and crack lightly-loaded, continues strip footings, and frequently cause distress in floor slabs. Because of the different building loads on different portions of a structure's foundation, the resultant uplift will vary in different areas. The biggest problem is that of differential water content. Source of water in developed areas are not limited to temporal weather cycles, but can be introduced by people. A frequent source of damage is the differential swelling caused by pockets of moist soil adjacent to dry soil. For example, lawn and garden watering creates a moist zone on the exterior of a foundation, whereas the interior is dry; this creates differential swelling pressure on foundation elements. There is frequently a moisture differential between the soils beneath a house and those that are more directly exposed to changes in the weather. Cesspools, leaky pipes, and swimming pools are other common sources of water. [21, 24, 30, 39].

Addis Ababa is witnessing large population growth in the past decadesand rapid expansion in all directions, engulfing much farmsteads andwoodland into urbanized areas. Much construction activities aretaking place in the study area (particularly CMC and Bole) andproblems due to expansive soils are frequently reported [15].Afework Sisay [2], under his study on damageassessment of buildings constructed on expansive soils of Addis Ababaon the houses in Bole, Olympia, Nifasilk, Lafto, Old Airport, Mekanisa, Gergi and Bole bulbula localities of the city, has found 64% of the randomly surveyed buildings to be adversely affected.84 % of the damaged buildings lack drainage system or the drainage system provided is inadequate.He has also reported that 67 % of the buildings wall constructed from hollow concrete block showed crack and 40% of the buildings wall constructed from brick wall also showed crack with 88% of the buildings with masonry foundations had been damaged. Moreover, his indepth investigation on Ethiopian Airlines Maintenance hangar building has indicated the poor subsurface drainage condition resulted in moisture equilibrium disturbanceto cause up lift of the continuous deep beam to pushing the truss member through steel column, as a result one of the truss elements failed.The clay content of the soil is found to be as high as 80% and the amount of montmorillonite for Addis Ababa expansive soil is 70-80%for black clay and 70-75% for gray clay [33]. The same study indicated illite and kaolinite have 10-15% and 10-30% mineral content eventhough the lateritic clay soils with kaolinite clay miniral has been reported to be available in the country [20, 42]. According to Mesfin Kasa [31] the compression index of the Addis Ababa expansive soil is within the range of 0.3-0.4 with the coefficient of consolidation of the undisturbed samples varies from 0.139-0.356m2/year.

In-depth Investigation of Relationship Between Index Property and Swelling Characteristic of Expansive Soil in Bahir Dar – an important center of Amhara National Regional state where development activities are flourishing and the town is expanding in all directions (except to lake Tana), by Dagmawe Negussie [11] has shown the soil under interest is plastic clay which has a high volume change capacity between wet and dry states.Based on Tibebu Solomon's [40] assessment on randomly selected buildings from 20 different locations in the same town87% of them are adversely affected. In most buildings more than one building componentsare damaged due to poor surface drainage, presence of tress and vegetation close to buildings, damagedutility lines and improper design.

According to Gebremedhin Berhane [18], the main geotechnical problems that affect design and related infrastructure development in Mekelle town are found to be presence of expansive soil, cyclic weak and strong rock units with depth, and variable weathering profile.Even though portion of the existing buildings in the town are dominantly founded on the limestone-marl-shale intercalation, limestone and dolerite units, large part of the town is covered by soil of up to more than 10m thick. The soils are lithologically grouped into clay, silt, sandy clay/silt and clayey/silty sand soils. Clay soils are generally dark / black in color, mainly observed in the northern part of the town and partly in the central part. He also found that the consistency index of most soils is above unity and their liquidity index is below zero, indicating the swelling behavior of most of the soils in the area. The free swell of the soils of the area is highly variable from 0 to as high as 70%, indicating the potentially expansive behavior and needs considerable attention in design of even light engineering structures.

Gravel and all weather earth roads are selected as pavement types for the Universal Rural Road Access Program (URRAP) which is aimed at connecting all kebeles (Villages) to nearby higher-class road using all weather pavement solutions which the government has implemented as part of the growth and transformation plan. Tewodros Alene [41] on his test section proposal entitled "Experimental Treatment Options for Expansive Soils on Unpaved Roads" has prepared different trial options forconstruction in expansive soils with various treatments for lower class rural access roads along the Chancho-Ginchi road. In this research different types of soil stabilization techniques have been used such as mechanical, lime and chemical stabilization of the problematic soil. However, he addedemphasis should be given to the importance in construction in this kind of soil of strictly applying engineered design of geometric, drainage, pavement thickness, material selection and proportioning.

Over the past 13years,40% of the total road sector developmentexpenditure in Ethiopia was allocated torehabilitation and upgrading of trunk roads withadditional 11% utilized to maintenance worksalone. [12]. Paved roads in tropical and subtropical climates often deteriorate in different ways to those in temperate regions, because of the harsh climatic conditions, lack of proper design and quality control, high loads and inadequate assessment for identifying causes of distresses before carrying out maintenance and rehabilitation.Fiker Alebachew [17] has focused his research on making assessment of asphalt pavement condition, identifying causes of pavement distress and proposing maintenance options for the arterial roads of Addis Ababa. He has found raveling, corrugation, Bumps and sags being the most dominant type of distresses constituting more than 75% of the distress densities.However, many roads on southern zone of the city were constructed on expansive soil subgrade of high swell potential without due treatment which consequently reduce the pavement performance [17, 34]. According to Addis Ababa City Roads Authority's 2004 report, the Authority had annual expenditure of around 300 million Birr for road construction and maintenance out of which more than 30 million Birr was expended for routine maintenances. Such expenditure for construction and maintenance of the Addis Ababa roads is obviously too big and require special attention.

Fekerte Arega et.al. [14] on their study in the central part of Ethiopia, in the upper valley of the Awash River which drains northern part of the Rift Valley, where relatively plain to hilly, undulating and steep mountain topography prevails about 1500-2500m elevation above sea level, have reported predominantly black, highly plastic and expansive clay are found during the section from Addis Ababa to Modjo town covering extensive area with varying thickness. Addis Ababa – Awash Express way also passes through this stretch. It is now being under maintenance after few years' services. In these soils prominent desiccation cracks are evident in dry periods.

The study of Melik Yunus [31] conducted on Modjo–Edjere road project where subgrade soil is black clay soil showed failure of the road with in liability period showing longitudinal cracks on carriage way andshoulder of the road. With both disturbed and undisturbed soil samples brought from the site for laboratory tests both for subgrade soil andreplacement materials, he found that replacement depth of 60cm which wasmadefor the road under study is insufficient to counter balance upward swelling pressure from nativesubgrade soil.Replacement depth was determined from measured swelling pressure and compared to the crackdepthactually measured onthe field. Moreover, it was also seen that overburden pressure of the pavement structure isless than measured swelling pressures.

With objective to study the potential benefits obtained by the use of chemical stabilization to render a typical expansive clay soil intended for road sub grade construction, by increasing its bearing capacity and decreasing its plasticity and Controlling of volume changes, Reshid Musema [36] chosen to check lime as stabilization on the Adura-Burbey DS6 Road Segment located on the south western part of the country named Gambella regional state.The project road begins at adura village around 150km away from the Gambela town and ends at Burbey village,found 45km west of adura village, at the Ethio-Sudan border, Baro River. It is found at the lowland part of the country, which is characterized by Flat terrain.

2. International Experience and Response to the problem

The losses due to extensive damage to structures founded on expansive soils are estimated to be in billions of dollars all over the world.These soils pose the greatest hazard in regions with pronounced wet and dry seasons. The ASCE estimates that 1/4 of all homes in the United States have some damage caused by expansive soils [23, 30].The damage turns to be more than double the cost associated with repair to damage from floods, hurricanes, tornadoes, and earthquakes [6]. Damage to structures in South Africa is commonly related to soil characteristics, with expansive and collapsing soils causing the most problems. A rough estimation for South African government funded low cost housing for 2008/09 puts the figure at about R2bn additional costs for all problem soils [3, 46]. A low level of awareness by both authorities, builders and the public at the time, is indicated. Shrinkage desiccation by sidewalk tree roots beneath roadways and housing, in London, for example, lead to tree removal to reduce costly insurance claims against the local municipality.The most common method of remediation in the Italian case, entailed underpinning, but this added 20% to the initial building costs. Structural damage was also found to be primarily due to desiccation shrinkage [46].

The Civil Engineering Department and the Building and Road Research Institute (BRRI) at the University of Khartoum have conducted extensive research on the engineering properties of expansive soil's related damage, design methods or reducing potential damage, and its distribution in Sudan [44]. Expansive soil damages have occurred to roads, buildings, and water and sewer pipes located in various parts of Khartoum, especially the southern parts where the surface is underlain by a 2-3 m thick layer of expansive soils. Many one and two story buildings utilizing shallow foundations have been extensively damaged. Uplifting of floors is common throughout the city. Repairs are estimated by the writers to cost millions of U.S. dollars per year. The case studies for Asalaya Sugar Factory about 280 km south of Khartoum, Gezira Tannery 250 km south of Khartoum, Alazhari Road andAlarda roadconnecting Omdurman with Khartoum can be considered [28, 45].

In Botswana, the construction of a large sports complex and stadium is built on transported soils derived from surrounding weathered Mesozoic basalts [30].The complex, however, also includes administration buildings, change rooms, store rooms, tennis courts, boundary walls, etc. Despite the design engineers taking specific precautions to minimize potential damage to these structures, nearly all of them illustrate distress of various forms and degree. The typical precautions taken were , among others, to place structures on soil rafts, to provide vertical moisture barriers in the form of plastic sheeting at the edges of the rafts, to provide flexible joints for wet services, to provide concrete aprons around buildings, to construct reinforced concrete groundbeams and ringbeams above windows and to pay attention to the control of stormwater on the site. Generally single storey structures were not articulated to cater for differential movements with in the structures.

Charles Lucian [9] under his study on in the coastal belt of the tropics in the semi-arid regions of East Africa, Tanzania, of all surveyed properties, 80% of them had developed cracks on the floor and walls. He also added, apart from the expansive soil, the defects may originate from inadequate design, poor materials, poor job-site construction or multiple of the factors. The study byJulius K. M'Ndegwa [26]indicated that the increase in CBR values for Kenyan expansive soil mixed with cane molasses above those of neat expansive soil was an indication that cane molasses caused the increase in soil strength and therefore it stabilized expansive clay soil. Omer Zakaria Mohamed et al. [34] in Egypt tried to study the effect of lateral expansive pressure of retaining structures.There is no reliable method presently available that allows for the designer to predict the lateral pressures on retaining structures or basement walls due to swelling soils. While, for non-expansive soils there are many methods available to design professionals by which they can predict the lateral earth pressures expected to be acting on retaining structures. When geotechnical engineers are faced with swelling type soils, the engineering properties of this problematic soil may be improved to make them suitable for construction. The lateral swelling stress values (¯lat) from experimental results don't agree with the stress values from previous theory (aɤ√Ka - 2c√Ka), this is due to the deference between the chemicals component of soil, type of soil minerals and its quantities in soil, condition of experiments , type of taking measurements,…,etc. Maximum lateral swelling on retaining walls equals 3.2kg / cm2 and it occurs at 60.0cm from the ground surface after two days at (W= 0.43 , γ = 1.74 t/m3).

The expansive soil in Malwa region, Madhya Pradesh, India especially possess a problem to many Structures and National Highways constructed which is caused due to presence of mineral Montmorillionite [37, 44].It appears that in South China, Yunna and Southern Kwangsi where montmorillonite clays were found, have the most severe swelling problems [7, 10]. In other regions, the reported damage has been caused mainly from shrinkage rather than heaving. Chinese engineers attempted to minimize the damaging effect of swelling soils by placing the foundation in a zone not affected by climate change. The deep-seated high swelling clays found in the frozen mining shafts at Huainan present an interesting problem where engineers will have to deal with the swelling problem and frost heave problem at the same time.

Approximately twenty percent of the surface soils in Australia can be identified as expansive clay [27]. The majority of these expansive soils are located within the 250 to 1000 mm isohyets, extending from North-Western Australia, through the eastern states and into the South-East of Australia.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 [21].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.

According to Aqeel, A.'s[4] study on Investigation of expansive soils in Obhor Sabkha, Jeddah-Saudi Arabia, no proper attention being paid to the type of clay minerals in Saudi Arabia or to their expansion potential, although sabkha soil covers large and strategically important areas along the Red Sea and Arabian Gulf coasts in Saudi Arabia, which is a crucial step prior to any construction.The expansive and sabkha soils are characterized by a large seasonal variation in soil moisture content leading to a large change in the volume and the consistency of the soil and, thus, causing serious damages to buildings and infrastructure. His results indicated that a considerable part of the study area has high expansion potential with active clay minerals (14.24 % montmorillonite).

Though there are several methods that have been used to recognize the presence of expansive soils a need of a fast and relatively cheaper methods continues to be a necessary undertaking.Their identification, effects on structures as well as countermeasures and additional construction costs to prevent structural damage are now well understood [39].The need arose to search for a suitable technology that can be used to stabilize these soils and use them for construction. The technology should minimise, as much as possible, the construction costs that would be incurred [41]. The distress of the road in Ethiopia consisted of longitudinal cracking of the shoulders and of the asphalt in the outer portion of the roadway blamed on the foundation soils. To prevent further damages new sections of the road were constructed on improved foundation material by replacing the black cotton soil layer in the foundation of either side of the roadway with imported material leaving the middle portion of the road untouched [34].

The Judicious choice of alignment can minimize the severity of the problem due to expansive soils, if good reconnaissance surveys are made. For example, if the alignment can be adjusted problems may be mitigated by such approaches as minimizing cuts and areas of poor drainage. In places expansive soils can be ripped and scarified to destroy the natural structure of the materials and can be subsequently recompacted with good moisture and density control to minimize the expansion potential. This method is well known and widely practiced [13]. In some instances sand has been added to the soil prior to recompaction to decrease swell potential. Lime is the most effective and widely used chemical additive for expansive soils [5, 12, 19, 24, 28, 36, 41, 46]. It has been demonstrated to be effective when thoroughly mixed with pulverized clay materials in percentage ranging from 3 to 6%. The depth of treatment is generally limited to about 20 to 30cm in a single lift. Deep plowing techniques have been extended to a depth 60cm. In china, expansive soils were mixed with the lime and fly ash, and then wrapped with flexible, reinforced material such as geotextiles or woven bags. The composite was then compacted [7, 9, 13, 19, 44]. Therefore, the non-expansive soil was filled in and compacted on the slope to prevent erosion and infiltration of rain water. Finally, plants with shallow roots were planted on the slope surface to intercept precipitation. This Chinese practice can be adopted effectively in Ethiopia.

During previous time, the maintenance and rehabilitation works in Addis Ababa follows more of a traditional practice. No proper pavement evaluation was done in advance or during maintenance and rehabilitation. The current maintenance and rehabilitation practice also depends more on visual observation and functional evaluations such as surface roughness and visual survey at network level rather than detail pavement evaluation at project level [17]. Later on the same roads were simply overlaid without strengthening the bottom weak layers. Such defective works are affecting the pavement performance until now since no appropriate remedial action is taken. Based on the pavement survey, the CBR criteria couldn't result in reliable solution in case of pavement on expansive subgrade [40].

Based on the study on Sudan, the developed design guide recommends removal of natural expansive soils to a depth not less than 1.5m and to improve the subgrade soil by placing suitable fill materials of min. CBR 10% and thickness 0.6 to be constructed in layers of 20cm thickness to counteract swelling. The fill materials thickness depends on the measured swelling pressure of the subgrade expansive soil. It is recommended to use of geotextiles incorporated within the fill layers to increase the stability and strength.

To achieve adequate drainage, proper surface slopes in both longitudinal and transverse directions should be maintained. The transverse slope should be directed towards the side drains of impermeable walls and bed. For water in subsoil it is recommended to use filter layer of well graded gravel or crushed stones (chipping) of 20 cm min. thickness directly below the subbase course. A perforated pipe of diameter not less than 15 cm and longitudinal slope 1:30 is to be placed in the far end of the filter layer. Filter columns of well graded gravel, 20 cm min. width can be used over the pipes to the level of the base.

It is recommended to use dense asphalt concrete mixture of impervious surfacing of low void content. Design details of the base and subbase should be as per pavement design methods based on the subgrade soil strength and traffic loading.

Except for removing the expansive soil, the only foundation system which has generally performed satisfactorily in Sudan under most conditions have been properly designed and constructed free-standing pile-supported structures, utilizing suspended grade beams and suspended floors.This construction allows maximum downward force on the piles while allowing swell to occur without upward pressure on the floors and grade beams. A modification being successfully used in Sudan by local engineers and builders, shown in Fig. below, utilizes individual footings located 3 m centers and placed at the bottom of 4 m deep hand dug pits (actual depth depends on the thickness of expansive soil layer or depth of shrinkage cracks).

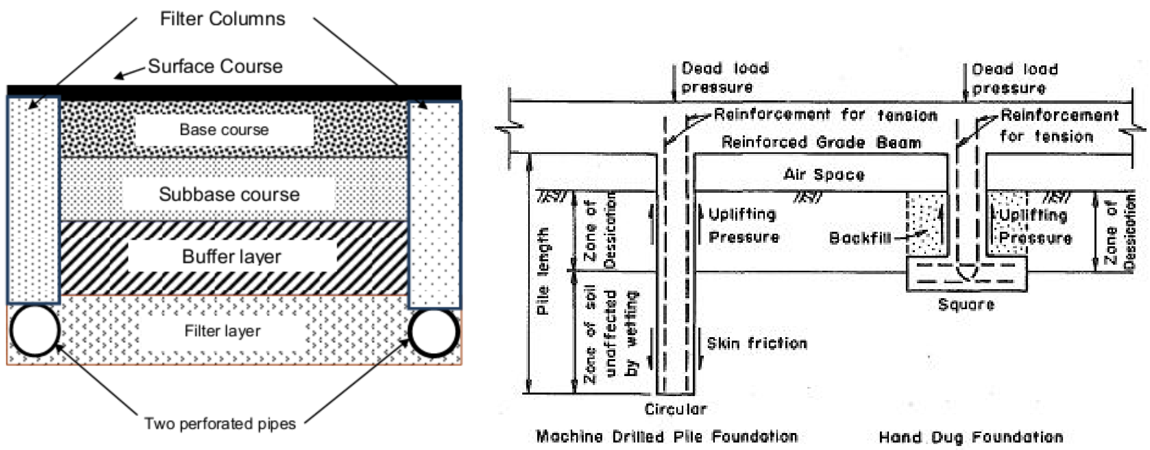

Figure 2 Recommended Pavement Structure for Roads andtypical Free Standing Foundation Systemson Expansive Clay Soils [28]

For the construction of high use airfields and highways, potential problems from expansive soil can be reduced by excavating the top 1-2 m of potentially expansive soil located below the proposed pavement and either backfilling with nonexpansive soil or the excavated soil can be treated and recompacted back in place at a controlled moisture content and density. The two treatments which have been generally successful in Sudan include mixing lime or cement into the soil to reduce plasticity and potential swell and mixing asphalt or oil into the soil to stabilize potentially expansive soils by retarding water adsorption. The asphalt/oil method was used on the Khartoum to Wad Medani highway while lime/cement was used in the Wad Medani to Kassala and the Wad Medani to Damazin highways. As with structures, surface water should be kept away from road embankments and underlying potentially expansive soils. However, because of the flat ground surface and lack of closely spaced drainage channels across the Clay Plain, long term ponding of rain water behind road embankments may occur every few years or so unless sufficient cross drains are provided [28,45].

For foundations subjected to uplift loadings, such as from transmission line structures and television towers, the analysis should utilize the lowest soil shear strength which may exist during the wet season. For highly expansive soils, shear strength reductions will occur down to the depth of seasonal moisture content fluctuations. However, significant reductions in shear strength should be expected only the upper 1-2 m. With good design, construction and maintenance, these methods havereduced expansive soil damage in Sudan. However, it cannot be over-stressed that the failure to recognize or to underestimate the potential swell and swell pressures has resulted in widespread and extensive damage to structures in Sudan. In some cases site planning could have resulted in considerable economic savings if the structure had been located on nearby nonexpansive soils. However, no structure built on expansive soils was found in this investigation which could be considered as overdesigned with respect to the foundation.

Based on the experience in Botswana [30], it is evident that the precautionary measures had an impact although the extent of differential movement of the foundations has a significant impact on many of the buildings. The installation of the concrete ring beams reduced the tendency for corner cracking but led to cracking parallel to them and between the groundbeam and window-level ring beams. Corner cracking and movement of the ceilings, however, affected internal walls, window frames and many of the floors were cracked.Unfortunately, there also appeared to be inadequate liaison between the engineers and the landscape gardeners, resulting in a lot of the good design being negated by conflicting irrigation design. The later placement of the irrigation system for the gardens resulted in the addition of significant volumes of water adjacent to and on the concrete and block aprons surrounding the structures, leading to differential movement and cracking. Similar problems were related to the location of the drainage systems for the air conditioning units added to the buildings.

In Australia, soil reinforcement by fiber material is considered an effective ground improvement method because of its cost effectiveness, easy adaptability, and reproducibility [21]. In India, a Case Study on Rectification ofdamaged structures on Expansive Soil Deposits, the corrective measures suggested to salvage/rectify the distressed structures were treatment of expansive soil through lime slurry pressure injection (LSPI) process [25]. In addition to LSPI, to maintain moisture equilibrium within the soil beneath the structure, plinth protection apron along with low density polyethylene film laid beneath and concrete curtain wall were constructed all around the structures.All these rectified/ renovated structures wereobserved for more than elevenyears and found to exhibit satisfactory performance.

3. Conclusion and Recommendation

All structures experience various levels of damages during their lifetime. For structures to be economical especially those made of concrete, a certain degree of cracking is inevitable. The damages are due to design faults or no design at all, cheap construction materials, poor workmanship or calamities, poor drainage characteristics, climatic condition and intricate behavior of expansive soils. Serious problems posed by expansive soils to civil engineering structures are well realized by engineers and researchers the world over and reported to cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods.

It was observed that this problematic soil prevails an appreciable part of Ethiopia and most of the studies have been done on behavior, stabilization andcharacteristics and engineering properties.Control and Mitigation of the swell-shrink behavior of expansive soil can be accomplished in several ways,for example by Replace existing expansive soil with non-expansive soil, Maintain constant moisture content and Improve the expansive soils by stabilization.

Foundations on expansive soils must be designed and constructed to adequately resist uplift forces. Special pre-cautions, such as flexible sewer connections and proper site grading, should be taken to prevent water from entering the expansive soil strata. Grade beams and floor slabs should be designed to accommodate soil expansion without transferring uplift forces to the main part of the structure. Buried structures, such as basement walls or petroleum and water pipelines, may be subjected to differential vertical movements and potentially large horizontal stresses. Transportation facilities, such as high-ways, airport runways and railraods, may require sub-base and sub-soil stabilization to reduce differential vertical movements and pavement failure due to loss of soil bearing capacity upon wetting. Engineering geology-type siting studies should also be conducted before final siting since it is one of the most needed and cost effective methods to find the best site when large areas are available for construction.

It is recommended that all potential construction sites in the Clay Plain be evaluated for potentially expansive soils problems.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. Moreover, the client, policy makers and other concerned bodies shall be aware of the potential problem associated with construction on this soil and search for alternative remedial measures applicable to control the risk and cost-savings.

References

1. Abebe WoldeGiorgis, 2017. Ethiopia: The Construction Industry in Bolstering Growth. WWW.allafrica.com, 23 February 2017.
2. Affework Sisay, 2004, Assessment Of Damage Of Buildings Constructed In Expansive Soil Areas Of Addis Ababa, MSc Thesis, Addis Ababa University, Ethiopia.
3. Anon (2011) US GS Swelling clays map: Texas http://www.foundationwatering.com/soilmap.aspx
4. Aqeel, A. 2016, Investigation of expansive soils in Obhor Sabkha, Jeddah-Saudi Arabia. Arabian Journal of Geosciences. Arab J Geosci (2016) 9: 314.
5. Awoke Sime Jimilu, 2006, Further Investigation Of Road Failures Constructed On Expansive Soils Of Central Ethiopia Addis Ababa-Jimma Road As A Case Study, MSc Thesis, Addis Ababa University, Ethiopia.
6. Bantayehu Uba (2016). Investigation on the Swelling characteristics and unsaturated shear strength of expansive soils from Arba Minch in Ethiopia. Journal of Geotechnical and Transportation Engineering - vol. 2 (2) pg 51-61.

7. Bin Shi, , Hongtao Jiangb, Zhibin Liua, H.Y Fangc, 2002, Engineering geological characteristics of expansive soils in China Engineering GeologyVolume 67, Issues 1–2, December 2002, Pages 63–71
8. Biruk Haile, 2015, Investigation Into Some Of The Engineering Properties Of Soils Found In Woliso Town, MSc Thesis, Addis Ababa University, Ethiopia
9. Charles Lucian, 2006, Geotechnical Aspects of Buildings on Expansive Soils in Kibaha, Tanzania: Preliminary Study. Licentiate Thesis, Royal Institute of Technology, Sweden.
10. Chen, F H, 1984, The Distribution And Characteristics Of Expansive Soils In China, Proceedings of the Fifth International Conference on Expansive Soils, Adelaide, South Australia, 21-23 May, 1984.
11. Dagmawe Negussie, 2007, In-depth Investigation of Relationship Between Index Property and Swelling Characteristic of Expansive Soil in Bahir Dar, MSc Thesis, Addis Ababa University, Ethiopia.
12. Ehitabezahu Negussie and Abebe Dinku, 2014. Investigation On The Effects Of Combining Lime And Sodiumsilicate For Expansive Subgrade Stabilization, Journal of EEA, Vol. 31, 2014
13. Eleyas Assefa, Li Jian Lin, Costas I. Sachpazis, Deng Hua Feng, Sun Xu Shu , and Anthimos Anastasiadis, 2016, Discussion on the Analysis, Prevention and Mitigation Measures of Slope Instability Problems: A case of Ethiopian Railways, Electronic Journal of Geotechnical Engineering, 2016 (21.12), pp 4101- 4119.
14. Ethiopian Roads Authority, 2013, Pavement Design manual, Addis Ababa, Ethiopia.
15. Fekerte Arega, Freek van der Meer and Harald van der Werff, 2009, Prediction of Volumetric Shrinkage in Expansive Soils (Role of Remote Sensing), Intechopen.com, Advances in Geoscience and Remote Sensing,
16. Fekerte Arega, Freek van der Meer and Harald van der Werff, 2009, Quantifying engineering parameters of expansive soils from their reflectance spectra, Engineering geology V.105 pp. 151 – 160, Elsevier.
17. Fiker Alebachew, 2005, Pavement Distresses on Addis Ababa City Arterial Roads, Causes and Maintenance Options, MSc Thesis, Addis Ababa University, Ethiopia.
18. Gebremedhin Berhane, 2010, Engineering Geological Soil and Rock Characterization in the Mekelle Town, Northern Ethiopia: Implications to Engineering Practice. MEJS Volume 2 (2):64-86, 2010
19. 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
20. Hanna Tibebu, 2008, Study of Index Properties and shear Strength Parameters of Laterite soils in Southern Part of Ethiopia the case of Wolayita Sodo, MSc Thesis, Addis Ababa University, Ethiopia.
21. Hema Kumar. 2007, Development of Soil – EPS Mixes for Geotechnical Applications, PhD Thesis, Queensland University of Technology, Australia.
22. Hussein A. Elarabi, 2004, Factors Influencing Swelling Behavior Of Expansive Soils, BRRJ Vol . 6 December 2004.
23. Jay X. Wang, 2016, Expansive soils and practice in foundation engineering. 2016 Louisiana Transportation Conference, Baton Rouge 02/28 - 03/02/16.
24. Jemal Jibril, 2014, In-depth Investigation into Engineering Characteristics of Jimma Soils, MSc Thesis, Addis Ababa University, Ethiopia
25. J. M. Kate, 2008, a Case Study on Rectification of damaged structures on Expansive Soil Deposits, 6th International Conference on Case Histories in Geotechnical Engineering. Arlington, VA, August 11-16, 2008.
26. Julius K. M'Ndegwa, 2011, The Effect of Cane Molasses on Strength of Expansive Clay Soil. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 2 (6): 1034-1041
27. Karunarathne A.M.A.N., Sivanerupan S., Gad E.F., Disfani M.M. Rajeev P. Wilson J.L. and Li J. 2014, Field and Laboratory Investigation of an Expansive Soil Site in Melbourne. Australian Geomechanics Vol 49 No 2 June 2014
28. Magdi M.E. Zumrawi, 2015, Construction Problems of Light Structures Founded on Expansive Soils in Sudan. International Journal of Science and Research (IJSR) Vol 4 (8) pg 896-901.
29. McKeen, G. R. and Lytton, R. L., 1984, Expansive Soil Pavement Design Using Case Studies, International Conference on Case Histories in Geotechnical Engineering. 17.
30. M B Mgangira and P. Paige-Green, 2008, Evaluation of Damage to a Road and Sports Complex on Expansive Clays. 6th International Conference on Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008. Pg 1-11
31. Melik Yunus, 2015, Performance Of Roads Constructed On Black Cotton Subgrade Soil with Respect To Replacement Materials Type And Replacement Depth (A Case Study On Modjo-Edjere Road), MSc Thesis, Addis Ababa University, Ethiopia.
32. Mesfin Kassa, 2005, Relationship between Consolidation and Swelling Characteristics of Expansive Soils of Addis, MSc Thesis, Addis Ababa University, Ethiopia
33. Nardos Belete , 2015, Evaluation Of One Point Liquid Limit Test For Expansive Clay Soils Of Ethiopia, MSc Thesis, Addis Ababa University, Ethiopia.

34. Nikolaou, Sissy and Perlea, Mary, 2008, General Report — Session 8: Projects of Washington, District of Columbia, Maryland and VirginiaForensic Geotechnical Engineering Health Monitoring and Retrofit of Infrastructure, International Conference on Case Histories in Geotechnical Engineering. Pp 15-16
35. Omer Zakaria Mohamed et al., 2014, Experimental study on the effect of lateral swelling pressure of expansive soil on retaining structure, Journal of Engineering Sciences, Assiut University, Faculty of Engineering, Vol. 42, No. 1, January, 2014, pp. 84 – 92, Egypt.
36. Reshid Musema, 2014, Stabilizations of expansive soils with lime (A case study on the Adura-Burbey DS6 Road Segment) MSc Thesis, Addis Ababa University, Ethiopia.
37. Retnamony G. Robinson and Mehter M. Allam, 1998, Effect of Clay Mineralogy on Coefficient of Consolidation. Clays and Clay Minerals, Vol. 46, No. 5, 596-600,
38. Sachin N. Bhavsar, Ankit J. Patel, 2014, Effect of waste material on swelling and shrinkage properties of clayey soil, International Journal of Application or Innovation in Engineering & Management (IJAIEM) Vol 3 (11) pg 200-2006.
39. S. Diop, F. Stapelberg, K. Tegegn, S. Ngubelanga, L. Heath, 2011, A review on Problem Soils in South Africa, Council for Geoscience Report number: 2011-0062
40. Tekeste Gebrehiwot, 2003, Ameliorated Design and Construction Techniques of Pavements on Expansive Soils, MSc Thesis, Addis Ababa University, Ethiopia.
41. Tewodros Alene, 2010, Experimental Treatment Options For Expansive Soils on Unpaved Roads in Ethiopia, 1st AFCAP Practitioners Conference 23rd to 25th November 2010.
42. Tibebu Solomon, 2015, Assessment Of Damages Caused By Expansive Soil On Buildings Constructed In Bahir Dar, MSc Thesis, Addis Ababa University, Ethiopia.
43. Tony Greening, 2014, Development of Pavement Design Standards for Low Volume Roads in Ethiopia, Crown Agents, AFCAP/ETH/005/A, April 2014.
44. VERMA S. K. & MARU S., 2013. Behavioral Study of Expansive Soils and its Effect on Structures–A Review, International Journal of Innovations in Engineering and Technology (IJIET) Vol 2(2) 2013.
45. Wayne A. Charlie, M. ASCE, Mohamed A. Osman, and Elfatih M, AH. 1984, Construction On Expansive Soils In Sudan. Journal of Construction Engineering and Management, Vol. 110, No. 3, September, 1984.
46. Williams, A.A.B.; Pidgeon, J.T.; and Day, P.W. (1985) Problem soils in South Africa – sate of the art. Expansive soils. The Civil Engineer in South Africa, July, 1985 pp. 367-407.

Author Profile

Bantayehu Uba was born in Arba Minch, Ethiopia, 21 October 1984. He received the B.Sc. Degree in Civil Engineering and M.Sc. Degree in Civil Engineering (Geotechnical Engineering) in 2007 and 2011, from Mekelle and Addis Ababa Universities respectively. His present occupation as an academician is Lecturer in the Institute of Technology, School of Civil Engineering, Hawassa University since March 24, 2015. He has also served as part-time Lecturer in Institute of Urban Development Studies, Ethiopian Civil Service University from March 2009 up to Feberuary 2011 and also as Assistant Lecturer at Civil Engineering Department of Technology Faculty, Arba Minch University from September 2007, up to September 2008, Ethiopia. On his professional carrier, he has worked with contractor and consulting private firms in road and building construction and design since September 2009 and now he is serving as a project manager at Santamaria Construction PLC. Since November 2015.