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Performance, Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review

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Abstract
Construction of pavement on weak or soft soil is highly risky because such soil is susceptible to differential settlements, poor shear strength, and high compressibility. In developing countries like Ethiopia transportation facilities are very important for sustainable development. However, a better performance of the agricultural sector in particular as Ethiopia's economic growth is highly dependent on it, and the sustainable economic growth of the country at large would be achieved through an improvement of the basic infrastructure. Consequently, the road network has been identified as a serious bottleneck for the economic development of the country. An appreciable part of Ethiopia is covered by expansive soil. Most of the roads constructed and proposed as well as substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. The roads on this type of soils fail before their expected design life, in some cases after few months of completion. It has been reported in 2004 that Addis Ababa City Roads Authority had annual expenditure of around 300 million Ethiopian Birr for road construction and maintenance out of which more than 30 million Ethiopian Birr was expended for routine maintenances which is too big and require special attention. 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. Major trunk and lower class universal rural access roads failed with in liability period where subgrade soil is black clay soil, but researches show that various treatments such as mechanical, lime and chemical stabilization has been implemented. Moreover, based on the pavement survey, the CBR criteria couldn't result in reliable solution in case of pavement on expansive subgrade. Thus additional Stability Criteria should be adopted to resist the heaving condition. This paper aims to present a review on the performance, problems and possible remedial measures practices for roads constructed on these problematic soils in the country. Finally, emphasis 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. Thus, those concerned bodies shall decide to accept and control the risk associated with construction on this soil or not, or to decide that more detail study is required to allow for extra design and construction pre-emptive measures once the potential problem has been identified and the end user convinced of the cost-savings in adopting a pro-active approach.
Keywords: Expansive soil, Subgrade, Stabilization, Pavement, Road construction

1. Introduction

Recently, Ethiopia has become one of the fastest growing non-oil producing economies in the world [3]. Among others, the construction sector is instrumental in catapulting the nation to higher levels of development [1]. The construction of roads is one of the major focal areas of the government to fast-track economic growth, as it provides the dominant mode of freight and passenger transport. Although the vehicle population growth rate per annum is increasing [9], the number of total vehicles remains low compared to other developing countries. Currently road density and number of vehicles per 1,000 population in Ethiopia are low compared with other African countries (Table 1) [14].

In 1951, when the Ethiopian Roads Authority was established, the total road network which was built mainly during Italian invasion was 6,400 km. Through the expansion of the rural road network to facilitate relief operation activities to drought and famine affected areas in 1970s and 1980s, the road network has been increasing over years to reach 36,496km in 2004, of which 4,635 km (13%) are paved and the remaining 31,861 km (87%) are unpaved [5]. All roads, whether they are built above or below the ground surface, use naturally occurring soils and rocks as the basic foundation and construction materials. Unlike man-made materials, the properties of these soils and rocks are highly variable and a function of the complex natural processes that occurred in the geologic past. As a consequence, road construction engineers are faced with the challenge of using soils and rocks available near the project site, whose properties are often unknown and variable quality [8]. When the soils within the possible corridor for the road vary in strength significantly, it is clearly desirable to locate the pavement on the stronger soils, if this does not have other constraints. Thus, since the selection process of route corridor influence the pavement structure and the construction costs, a thorough investigation should be done on the characteristics of subgrade. Currently, different construction activities are taking place in the road sector on a subgrade of expansive soil type due to its wide occurrence (covers about 40% surface area) in Ethiopia [2, 4, 11, 13].

Table 1: Paved Road Density per 1,000Sq. km and Vehicle Population per 1,000 People in Selected African Countries [14]

	Ethiopia	Uganda	Kenya	Ghana	Nigeria	Botswana	South Africa
Road density by area, km/1000km2 in 2001	4	8	13	58	65	10	60
Motor Vehicles, per 1000 people in 2009	4	8	23	30	31	133	162

Expansive soils are clayey soils, mudstones or shales that are characterized by their potential for volume change on drying and/or wetting. Usually the clay content is relatively high and the clay mineral montmorillonite dominates. They are characterized by their high strength when dry; very low strength when wet; wide and deep shrinkage cracks in the dry season; high plasticity and very poor traffic ability when welled. Whenever insufficient attention is given to the deleterious properties of expansive soils, the results will be premature pavement failure evidenced by undulations, cracks, potholes and heave [24].

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. Like in Ethiopia, the destructive effects caused by these soils have been reported in many countries around the world, including USA, Australia, South Africa, India, Canada, Israel, Sudan, and China, but are generally most serious in arid and semiarid regions. Life time, performance and environmental compatibility of lightweight engineering infrastructures are detrimentally influenced (in terms of time, and money both at the construction and maintenance stages) [9, 10]. The effects on buildings constructed on reactive soils with inadequate footings can be dramatic. Road subgrades can be viewed as the footings/ foundations for road pavements, and if these footings are not adequate, structural damage can occur. Cracking of foundations, walls, driveways, swimming pools, and roads costs millions of dollars each year in repairs [16, 23, 23].

For example, Ethiopian Roads Authority (ERA) was forced to decrease the maximum speed limits below the original design speeds at many localities for instance on the main road connecting Addis Ababa and Jimma town [5,11]. Costly and repeated maintenance requirements were also frequently demanded as a result of such problems. Problems of clogging of road side ditches and culverts are common difficulties that demanded the allocation of high budgets for the clearing and maintenance of such drainage structures every year [7]. Moreover, a gully formation is associated with the poor permeability and erosion susceptibility nature of these soils. This poses negative and serious economic as well as environmental problems. Scouring drainage structures seriously affects the overall performance of road infrastructures in many localities. Expansive soils are cause of slope failures due to swell and reduction in strength [10].

Roads build on expansive soil fails prematurely primarily because of the highly variable properties of expansive clays due to moisture fluctuations throughout the year. Failures occur as a result of variations in strength and stiffness or subgrade volumetric change or both. It is important to characterize these variations and predict their effects on pavement performance [26]. Pavement performance evaluation is an important activity in the maintenance and rehabilitation works. It includes evaluation of existing distresses, road roughness, structural adequacy, traffic analysis, material testing and study of drainage condition [12].

2. Factors Governing Pavement Performance on Expansive Clays

Worldwide experience has shown that pavements on expansive soil often require costly rehabilitation before the end of the design life. This is due to the fact that the performance of a pavement is a function of the controlling factors for its structural and functional design [25]. Pavement performance is expressed in terms of pavement materials and thickness. Although pavements fail from the top, pavement systems generally start to deteriorate from the bottom (subgrade), which often determines the service life of a road. Subgrade consists of the naturally occurring material on which the road is built, or the imported fill material used to create an embankment on which the road pavement is constructed. Subgrade performance generally depends on two interrelated characteristics: (1) Load-bearing Capacity: The ability to support loads is transmitted from the pavement structure, which is often affected by degree of compaction, moisture content, and soil type; (2) Volume Changes of the Subgrade: The volume of the subgrade may change when exposed to excessive moisture or freezing conditions.

Plastic clays termed as expansive soils or active soils exhibit volume change when subjected to moisture variations. Swelling or expansive clay soils are those that contain swelling clay minerals (such as montmorillonite and smectite) and can often be scientifically referred to as Vertosols. Vertosols are soils that contain clay minerals which, because of their natural physiochemical properties, possess a net negative electrical charge imbalance that attracts the positive pole of dipolar water molecules and cations [7, 8, 23]. In terms of the AASHTO soil classifications, black cotton soil is classed as A-7-6. In addition, expansive soils have high degree of shrink - swell reversibility with change in moisture content and its expansiveness is controlled by three elements: the type of clay minerals, the change in moisture content (active depth), and the applied stresses (embankment loading). However, in shallow structures (i.e., pavements), the moisture-induced variation is most important. The best method of characterizing this behavior is through use of suction-based coefficients [16].

Expansive soils will only react if there is a change in moisture content, to cause either shrinking or swelling. The change in moisture content (or suction) controls the actual amount of swell that a particular soil will exhibit under a particular applied stress. This change in moisture content is brought about by climatic extremes. The active depth is the depth over which seasonal moisture changes are observed. Influential objects such as trees and urban drainage can cause changes in the active depth profile, and consequently result in pavement deformation. Trees cause deep drying of the clay profile by suction, well beyond the design depth. In addition, trees produce increased soil moisture changes throughout the clay profile. This drying often causes significant clay shrinkage and cracking of road pavements. This is exacerbated by drought as the tree roots seek moisture from the clay soils. Climatic variations cause natural variations in ground moisture. Other factors such as water, sewer or storm water pipes which leak, cause wetting of soil and swelling (heave). This is often localized and can distort the shoulders causing settlement and failures [23].

3. Distress Assessment, Evaluation and Response

The major causes for pavement distresses can be grouped in to three categories. The first is due to overloading that includes excessive gross loads, high repletion of loads and high tire pressure. Second climatic environmental conditions may cause surface irregularities and structural weaknesses on the pavement. For example volume change of soil due to wetting and drying resulting from improper drainage may be the prime cause of pavement distress.

A third causes may be disintegration of the paving materials due to method of construction and quality of construction material. Use of contaminated aggregate and inadequate construction supervisor are also factors that may aggravate pavement distress. Lack of maintenance will further aggravate pavement distress [12].

Distresses identified during condition surveys can be grouped in to three major categories of possible causes (1) *Load Associated Distress*:- expressed in terms of Alligator cracking, Corrugation, (Bumps & sags) Edge cracking, Patching load cause distress, Potholes, Rutting, Slippage cracking; (2) *Climate /Durability Associated Distress*: - Bleeding, Block cracking, Joint reflection cracking, Line cracking /longitudinal/ transversal/, Patching of climate/durability swell caused distress, Weathering and raveling, Shoving; (3) *Drainage/ moisture Associated Distress*:- Bumps & sags, Lane/ shoulder drop off, Depression, Swell). With the exception of safety considerations associated with the surface coefficient of friction and glare all forms of distress can be related individually or collectively to rupture, distortion, and disintegration modes of failure [12].

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. These new sections developed similar distress [17].

Over the past 13 years, 40% of the total road sector development expenditure in Ethiopia was allocated to rehabilitation and upgrading of trunk roads with additional 11% utilized to maintenance works alone. This problem urges the need for wider application of cost effective and environmentally friendly technologies of improving soil properties to be customized and adopted to the current road construction trend in the country [6]. 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 [6].

a) b) c)

Figure 1(a) Slippage cracks, (b) Swelling- upward displacement of a pavement, c) Sag in asphalt pavement [12]

a) b) c)

Figure 2 (a) Urban trunk road under the influence of black cotton soil, Rutting occurred on the surface. (b) Rural trunk road - Vertical rutting of pavement edge. (c) Heavy vehicles hauling lime-stone have been passing in Abay. Travelling speed is lower than walking speed. [15]

Further investigation indicated the foundation soil was potentially active, with high variations in the moisture conducting to high changes in volume. The investigation indicated that in appropriate materials were used for construction besides the fact that no improvement of the foundation soil was considered. Field Disturbed samples were collected from test trenches. The samples were tested in laboratory to determine moisture besides other testing such as Atterberg Limits and particle size distribution. The investigation indicated the road foundation consisted of African black cotton soil with high content of montmorillonite, with some kaolinite and halloysite. The foundation soils were characterized as high to very high degree of expansiveness due to high variation of the moisture content (between 24 and 53%) and medium to high potential swell. The Atterberg limits indicate the foundation soil consisted of high plasticity clay soils (with the Liquid Limit LL and Plasticity Index PI varying between 43 and 103, and 9 and 54 respectively). Estimation of the expected heave along the investigated road sections show values ranging between 24 mm and 70 mm. The fill materials in the road shoulders consisted of volcanic ash and tuffaceous material, replaced by red silty clay in sections where partial replacement technique was used. The fill materials were also high plasticity soils with LL higher than 50 with high swelling potential. The materials used were not adequately inert and no measures were taken to minimize the movements with in themselves, conducting to additional heave. The drainage control along the road was also in adequate, ponding water at the toe of the road being observed in some areas [18].

Tewedros [25], has used visual inspection and passability criteria to be the preferred performance evaluation. The bearing capacity of the road material is reduced by moisture to such an extent that it becomes too low to support the vertical loads imposed on the road by a vehicle, resulting in shearing. In addition, the surface of the road becomes so slippery when wet that the wheels of the vehicles lose traction and the vehicle starts slipping to the extent that it becomes dangerous or impossible to make progress. This is a result of the lack of shear strength in the upper parts of the wearing course or inadequate friction between the vehicle tyre (often soil covered) and the wearing course material. Slipperiness can be a problem, even with soils with a high bearing capacity but with little friction-generating aggregate.

According to Fikir [12] under his study on Pavement Distresses on Addis Ababa City Arterial Roads, Causes and Maintenance Options from April to December 2004, he observed that around seven types of distresses (Weathering & Raveling: 54.29%, Corrugation: 12.68%, Bumps & Sags: 9.25%, Lane/Shoulder Drop-off: 7.34%, Patch & Utility Cut Patching: 6.1%, Shoving: 4.39% and Alligator Cracking: 3.84%) contribute more than 95% of the pavement defects in the five arterial Test Roads. The main reason for some distresses like alligator cracking to be ranked low is due to the fact that the Addis Ababa City Roads Authority usually patches cracked asphalt pavements immediately after the rainy seasons.

The visual Condition survey was also made by Fikir [12] in order to measure various types and degrees or severity of distress. The measured components are surface defects (such as longitudinal joint cracks, potholes, raveling, bleeding and lacy edge), permanent deformation or distortion, fatigue cracking and patch deterioration. Walking along the Test Road section, distresses were measured using proper parameters such as fatigue cracking (sq.mt), bleeding (sq.mt), corrugation (sq.mt), depression (sq.mt), longitudinal and transverse cracking (linear mt), patch deterioration (sq.mt), potholes (number), raveling and weathering (sq.mt), rutting (sq.mt), slippage cracking (sq.mt), and swell (sq.mt) with the help of measuring wheel, measuring tape and camera (Figure 3). The Pavement Condition Index (PCI) is determined by measuring pavement distress with a numerical indicator based on a scale of 0 to 100.The following pavement condition ranking is given to PCI values: 0-10(failed); 10-25(very poor); 25-40(poor); 40-55(fair); 55-70(good); 70-85(very good); 85-100(excellent). Large deflection, low PCI values and consequently higher distress densities are observed in test sections having high swell potential. This indicates that the swell potential of the sub grade soil has significant impact on the pavement functional and structural conditions.

a)  b)  c) 

Figure 3 (a) and (b) Visual Condition Surveys [12]; (c) Test pit on Addis - Jimma Road [5]

Pavement condition involves the following four major components: (1) ride comfort (2) load carrying capacity (3) safety, and (4) aesthetics. In general, a good pavement rides well, carries traffic satisfactorily, and provides a safe tire interface for both rolling and stopping, and has pleasing appearance to the pavement manager and user as well. As there is no formula for considering all the above components in a precise manner, different people give more or less emphasis on any of the above factors depending on their particular situation [4, 12]. According to the survey made by Fikir [13], even some of the existing surface drains are not properly functioning. On the other hand, the Addis Ababa Roads Authority's traditional maintenance practice until now, to repair damaged pavements, is patching or providing additional thickness of asphalt without an attempt to improve the drainage conditions. He added, the pavement design and construction practice must be modified in such a way to have structural pavement layers capable of draining free water rapidly after its entry. The design and construction practice adopted in the Addis Ababa Ring Road can be good example.

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. 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 [12, 21].

The pavement condition survey at the Addis Ababa –Weldia road project [25] could also reveals that the unevenness, rutting, coring action were mainly result of the expansive nature of the sub grade soil. Current situation at Addis-Jimma road project also reveals also that a series of longitudinal cracks were noticed in the completed shoulder and embankment [5]. Such phenomena on the pavement includes a vertical crack visible at corner and edge of the asphalt, main cracks extending through sub base to original shoulder and into the firm material below, deformation of shoulder and multiple cracking from edge to toe, coring activities & highlighted depression in right hand & left lane. There is also evidence from the investigation that the movement can be severe enough to send crack to the base of embankment, effectively splitting it from the main carriage way and the swelling has resulted in the entire embankment moving vertically upward. These movements began at toe of the embankment and progresses along the base to the existing road. They occur in longitudinal parallel series, decreasing in depth and width. Different proposal have been set to rectify the cause, but they all lay on the expansive properties of the clay material and the inadequacy of construction technique to mitigate the moisture ingress from the surrounding area [25].

Tekeste Gebrehiwot [25] on his study on Ameliorated Design and Construction Techniques of Pavements on Expansive Soils stated that pavement deficiency condition on the old Addis Ababa international airport reveals also that the poor condition of runway & taxiway results from the combination of the effect of highly expansive sub grade soils, poor surface and subsurface drainage condition. Reviews of the construction report made on the site reveals that considerable difficulty were encountered during construction of these facilities due to wet weather condition. During the investigation, it was observed that pavement cracking is concentrated almost entirely within the paved shoulder areas. It was also observed that the major deficiency occurred along the paved shoulder areas, which have longitudinal 'French drains', were resulted from inefficient drains and deficient shoulder conditions. It was also noted that the heaving of the pavement over each of the several electric duct lines, that cross under the runway pavement and intersect the lateral drains, result from expansion of the sub grade soils due to increase in moisture content of the water penetrating to the interior portion of the pavement. Some of these extended for the full width of the pavement.

In Addis Ababa-Jimma road there are fill areas with expansive soils in Awash plain areas up to a height of 3m. Actually enough data was not found about the performance of the road immediately or few years after construction. But the old road does not show any kind of longitudinal cracks that are observed on the newly rehabilitated roads. Instead rutting and potholes are easy to find on the old road, which are related to lack of periodic maintenance and aging of the road (has already passed its design life) [5].

Fekerte Arega et.al. [10] 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 [18] 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 and shoulder of the road. With both disturbed and undisturbed soil samples brought from the site for laboratory tests both for subgrade soil and replacement materials, he found that replacement depth of 60cm which was made for the road under study is insufficient to counter balance upward swelling pressure from native subgrade soil. Replacement depth was determined from measured swelling pressure and compared to the crack depth actually measured on the field. Moreover, it was also seen that overburden pressure of the pavement structure is less 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 [24] 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.

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 [26] on his test section proposal entitled "Experimental Treatment Options for Expansive Soils on Unpaved Roads" has prepared different trial options for construction 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 added emphasis 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.

As far as the pavement condition survey and the performance of the pavement in this country is concerned, the most practiced moisture control technique, adopted for pavement on swelling sub grade, is achieved by using the following techniques (i.e. as a horizontal barriers): (a) Impermeable and extended shoulder width (at least 2m) (b) Impermeable side ditch located far away from the pavement However, it is very difficult to categorize as an independent method, but it should be considered in association with the other techniques [25].

The pavement condition survey for the pavements built during the Italian period indicates that the telford type of pavement could be used as a possible solution for expansive subgrade under low traffic condition. Based on Tekeste's [25] investigation current situation at Addis-Jimma road project shows that the application of Transport Research Road Note - TRN31- method could not revive the sever failure cases encountered in the area. Moreover, the application of AASHTO Method in most parts of the USA could not give a good performing pavements, Rather, due to recurrent failures, most of the states (e.g. Monisotta, illions, etc.) tried to develop or modify the method to suit their condition. The Application of the Transport Construction Design Enterprise (Ethiopia) –TCDE - or Kenyan design method for the relocated road pavement of the Giligel Gibe did not cause any failures despite the nearby Addis-jimma road. Addis Jimma Road Project, Addis Dessie Road Project, Weldia Zalemebasa Road Project, and Addis Ababa Airport Project on medium to very high degree of expansiveness with similar traffic condition (7.5×10^6 ESA), similar CBR values for most expansive clays of 2 to 5% under varied soil and climatic conditions were assessed. Since the performance of the swelling sub grade is influenced by placement condition of the pavement, the kinds of construction procedures to be used in swelling sub grade are the most influential factors to be considered in pavement engineering. Based on the pavement survey, he found the CBR criteria couldn't result in reliable solution in case of pavement on expansive subgrade. He added Tanzanian design method which uses variable design and construction procedures for the swelling sub grade based on their degree of expansiveness to be more reliable and economical than the other methods for swelling subgrade conditions under all cases of degree of expansiveness.

Based on the results and findings of Nibret Chane [19] on Geotechnical Characterization of Sub grade Materials for Pavement Construction, A case Study on Aposto – Wondo – Negele Road Upgrading Project, Contract 2: IrbaModa ~ Wadera Road Construction, removal and replacement, in situ treatment, rock fill with geo textiles and underground drains have been recommended for the unsuitable subgrade section where low bearing capacity and higher volume change property of the soils with varying moisture content is observed. It was also mentioned that side drains in such sections should be avoided or if this is not possible, they should be as shallow as possible and located as far away as practicable from the toe of the embankments.

4. Development of Remediation Strategies

Expansive soils exhibit exceptionally low strength and tend to swell when they become wet; and they are highly brittle and shrink when they become dry. Their susceptibility to moisture variation results in two main types of damage through seasonal wet and dry cycles: (1) Fatigue cracking, rutting and subgrade shear failure due to inadequate support; (2) Excessive roughness, swelling and severe longitudinal shrinkage cracking due to volume change. Many remediation strategies can be used to improve the detrimental properties of expansive soils, such as shrink-swell and low shear strength. In the Remediation module, six modification strategies are grouped into two categories: (1) To improve subgrade strength and stiffness, which include stabilization, geosynthetics reinforcement, undercut and backfill; and (2) To minimize moisture variation induced swell/shrink problems, which include moisture control, deep dynamic compaction and decreasing clay content in addition to those three included in category 1. Appropriate methods will be recommended from either or both categories (Figure 1). The user has the choice to decide which one(s) to be considered and analyzed for the original design [32].

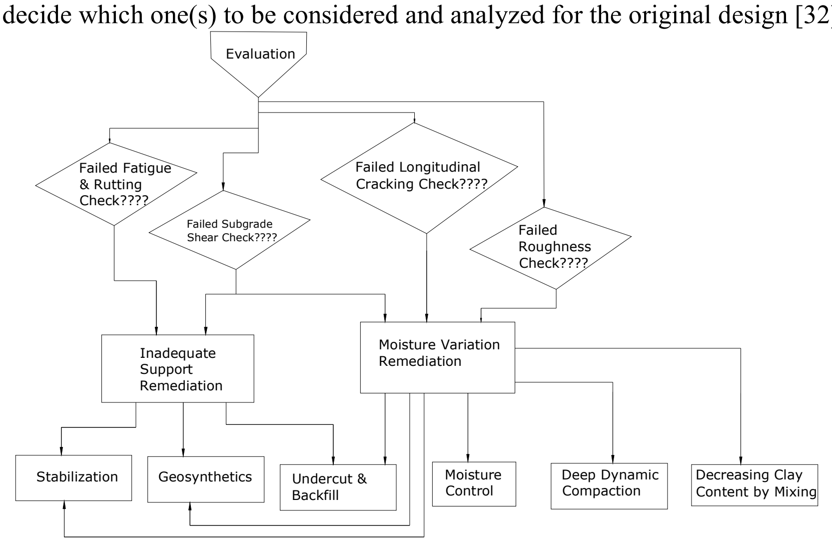

Figure 1 Schematic of Remediation Strategies [32]

Accordingly, the ERA manual proposes the following countermeasures: (1) alignment improvement (avoiding areas of black cotton soil), (2) excavation/soil replacement (replacing black cotton soil with good quality materials along the road route), (3) limestone stabilization (stabilizing by mixing lime into the black cotton), and (4) minimization of water content changes (implementing measures to prevent water infiltration). Out of these, (2) excavation/soil replacement is the most effective method, and it is recommended that this is applied as much as possible. Table 2 shows the black cotton countermeasures that have been adopted in recently completed projects and projects currently being implemented [15].

Table 2: Black cotton soil measures example in Ethiopia [15]

Road	Control strategy
National road A	Replacement 800mm
National road B	Replacement 500 – 1500mm Setting of the wall with the low density polyethylene sheet.
National road C	Replacement 1000 – 3000mm Reinforcement of the wall with the sheet for block of water.
National road D	Replacement 800 – 1500mm
Standard of ERA	Replacement of 1,000mm by high quality materials.(more than CBR5) Black cotton soil remained in the lower layer, it take a measures what does not have to change a moisture content.

Construction on the line of an existing formation can be an advantage, provided sufficient formation height is achieved as it is liable to provide moisture conditions close to equilibrium. However, good performance has also been achieved on sections of new alignment. 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 [7].

Vijay Kumar et.al. [29], indicated the use of mechanical alterations seems to be infeasible for large highway or rail project. The only way is chemical alteration done using cement, lime, fly ash or other material; depending upon the use. The technique of fly ash uses the waste materials and hence it is environmentally friendly too. Currently, the use of geo-synthetics is considered to be most effective way of achieving a variety of outcomes. The main reason behind this includes availability of a variety of geo-synthetic with specific material properties. Geotextiles and geo-grids are extensively being used in U.S.A as a subgrade restraint. The use of rigid pavements has proven unsuccessful on expansive soils; so flexible pavement comes into role. However flexible pavement requires effective impervious base, subbase or a membrane below the surface. For flexible pavement to be achieved, documented empirical or mechanistic materials is suggested.

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. Moreover, the use of dense asphalt concrete mixture of impervious surfacing of low void content is also suggested. Design details of the base and subbase should be as per pavement design methods based on the subgrade soil strength and traffic loading. However, the two treatments which have been generally successful 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 [31].

5. Conclusion and Recommendation

Prior knowledge of the type of failure could assist to verify the cause and mechanism of remedial actions. The obviously high expansive potential characteristics of the roadbed certainly requires special design and construction strategies to counter the anticipated damage due to volumetric movements of the roadbed associated with moisture changes. The design of the geotechnical aspects of pavements must consequently focus on the selection of moisture-insensitive, free-draining subbase materials, stabilization of moisture-sensitive subgrade soils, and adequate drainage of any water that does infiltrate into the pavement system.

To avoid moisture-related problems, a major objective in pavement design should seek to prevent the subbase, subgrade, and other susceptible paving materials from becoming saturated, or even exposed to constantly high-moisture levels. The three common approaches for controlling or reducing the problems caused by moisture include:

- Preventing moisture from entering the pavement system.
- Using materials and design features that are insensitive to the effects of moisture.
- Quickly removing the moisture that enters the pavement system.

No single approach can completely negate the effects of moisture on the pavement system under heavy traffic loading over many years. For example, it is practically impossible to completely seal the pavement, especially from moisture that may enter from the sides or beneath the pavement section. While materials can be incorporated into the design which are insensitive to moisture, this approach is often costly and in many cases not feasible (e.g., may require replacing the subgrade). Drainage systems also add costs to the road, as maintenance is required to maintain drainage systems as well as to seal systems for effective performance over the life of the system. Thus, it is often necessary to employ all approaches in combination for critical design situations.

Additionally, various countermeasures could have been specified to minimize the impact of the anticipated movement of the expansive soil on the pavement during construction and after construction while a moisture content equilibrium condition was being achieved. The designers could have stipulated that this equilibrium moisture content be maintained during and after construction as closely as possible. To control swelling of black cotton subgrade soil, it is important to know depth of active zone and the potential uplift pressure of the soil. Depth of replacement can be determined from swelling pressure and also from active depth of moisture fluctuation. Thus, replacement depth shall be determined accordingly for road constructed on black cotton subgrade soil. Replacement materials should counteract swelling pressure from subgrade soil. Hence, replacement materials with higher unit weight should be used to counteract swelling pressure from underlying subgrade soil provided that adequate replacement depth was determined. According to some literatures like Tanzanian design manual, it is recommended to use replacement materials having minimum CBR value of≥ 8%,preferably CBR value≥ 15%.For the design of road pavement thickness, the strength of subgrade were taken in to account at its four days soaking moisture that assumed to simulate the actual wettest condition likely to occur after the road is opened to traffic. CBR tests do not show the actual swelling behavior of the soil and it is advisable to use swelling pressure tests of the subgrade soil in addition to CBR tests.

Review of literature also recommends 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.

There is a definite need for research aimed at developing a reliable and practical method of determining the subgrade moisture content at which paving may be constructed so that future significant underlying clay moisture changes do not lead to excessive pavement distortion. Thus further study is required as investigation of expansive soil is not only necessary for exploring the engineering properties of expensive soils and discussing the expansion mechanism but also indispensable as to the improvement and reinforcement of expansive soils and the discussion of new soil research techniques and methods.

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