

**Ameliorated Design and Construction Techniques
of Pavements on Expansive Soils**

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Notation

D-1	Kenyan Method
D-2	Tanzanian Method
D-3	South African Method
D-4	Australian Method
D-5	TRN31 Method
D-6	AASHTO Method
E-1	Excavation and Replacement
E-2	Stabilization
E-3	Remolding and Re-compacting
E-4	Minimizing the moisture variation
E-5	Pre-wetting
γ_d	Dry density
W_L	Liquid Limit
W	Natural water content
PI	Plastic index
$\Delta e, \Delta w$	change in water content & void ratio resp.
S_p, σ_f	Swelling Pressure
σ_o	Applied Pressure
$\Delta z, \rho, \Delta h$	Heave
F_i	Reduction Factor (as per South Africa)
C_c	Compressibility index
e_0	initial Void Ratio
C_s	Swell index

Z_i thickness of sub layer i

Cs

Abstract

The main cause of the economic losses incurred for pavements built on swelling subgrade is the lack of appropriate selection of the design and construction method adopted to alleviate the swelling phenomena. The extent of the problem depends mainly on the degree of expansiveness of the soil and the corresponding climatic conditions. Current situation Ethiopia shows that random selection of design & construction methods is widely practiced despite the various soil and climatic condition. Most of the practices aim at undefined use of the design and construction method that results in uneconomical and unsafe pavement design. The effectiveness of the methods depends also on the selection of the design depth, a design depth that suits the technical and economical conditions.

Chapter two consists the review of the performance and suitability of the various design and construction method adopted in most part of the world including Current practices in this country.

In Chapter three, an attempt has been put to see the consideration of potential expansiveness and assessment of the various prediction methods of heave and swelling pressure for the existing experimental values.

Based on the appropriate values of swelling pressure, considered for each cases of potential expansiveness, an appropriate design depth has been recommended. In chapter four, the various design and construction methods have also been evaluated to suit the various degree of expansiveness of the soils and climatic condition of an area. In the last portion of the thesis, an attempt is made to select the most suitable design and construction methods, based on the performance and economic criterion, for each case of expansiveness under the local conditions.

CHAPTER ONE

1. INTRODUCTION

1.1 Back ground

The major concern with the failure of pavements, built on expansive soils, exists all over the world. The primary problem that arises with regard to expansive soils is the deformations that are significantly greater than elastic deformation of the pavement, uneven pattern of movement of such magnitude as to cause extensive damage to the pavements. Due to such failures, serious direct and indirect economic losses had been recorded.

Expansive soils cause more damage to structures, particularly light buildings and pavements, than other natural hazards, including earthquake and floods [8]. However, the potential problems related to expansive soils in some area are not as severe as the problems encountered in another areas. This is because of the peculiar behavior of the expansive soil in which their characteristics vary with the topography, geology, and climatic conditions. Thus the extents of the problems were categorized into different geographic areas.

Case study reports in the North America, Southern Atlantic and Gulf Coastal Plain States reveal that the pavements underlay by these sub-grade experience warping phenomena to varying degrees.

Especially the pavements of west Dallas, Texas were subjected to heaving of 12cm due to the differential vertical movement of swelling sub grade. The warping phenomena accompanied by differential expansion of pavement causes successive waves that extend across the pavement section. Damage to pavement in terms of various phenomena had also been recorded in South Africa, Australia, Zimbabwe, Kenya, Tanzania, and Israel.

In order to mitigate the problems, with the wide distribution and large extent of variation in the environmental conditions, different countries develop their own design criterion and construction procedures.

In Ethiopia, in which more than 10% of the total area is covered by this soil [34], the above failure problems have also been recorded. Most of the previously built roads show sever unevenness along significant length with or without cracking, and on some of the recently constructed roads (e.g. Addis-Jimma, Mekelle City roads, the existing Addis Ababa airport pavements) show longitudinal cracks parallel to road close to the shoulders, localized failure of pavements associated with disintegration of road surface.

All the above failure cases were resulted from the deficiency in design or construction procedures adopted for the swelling sub grade. That is the design and construction approach adopted for areas with high degree

of expansiveness became economically unrealistic to be used in areas of low or medium swelling sub grade.

To this end, due to the adverse economic losses incurred and uneven use of design and construction methods, there is a need to account for appropriate selection of design and construction practices defined on the various manuals based on the degree of expansiveness of the soils and climatic condition of an area.

1.2 Objective

Due to the availability of different design and construction methods developed in various countries, and the lack of defined use of design and construction procedure in the country, an attempt will be made, in the thesis, to:

- Evaluate the suitability and applicability of the current design and construction methods with the variable degree of expansiveness
- Evaluate their applicability in terms of economic advantage
- Propose a suitable design and construction method based on the degree of expansiveness of the soils and climatic condition of an area

1.3 Scope of study

In this thesis, an attempt was made to consider the expansive clays on the different site of the country for the climatic and topographic variations. The test results

of the samples were obtained from Northern, central and southwestern part of the county's, particularly [34]:

- Addis Ababa airport project (**Semi arid and humid**)
- Mekelle town road project (Semi **arid and humid**)
- Addis-jimma road project (**Moderately, humid**)
- Addis-dessie-weldia road project (**Moderately, humid**)
- Tekeze humera road and airfield project (**Arid**)

All the test results were made based on the most conventional test procedures despite the current more sophisticated and advanced technological procedures. Moreover, due to the limitation in Data and time, the research is limited to the design and construction practice on flexible pavement.

Chapter two

2. Review of Design And Construction Methods

2.1 Design Conditions

2.1.1 General

The general criteria for the design of pavements on expansive soil are similar in nature to those used for other engineering structure, namely safety against failure, minimal deformation and economy. This is achieved through designing or constructing the pavement to a reduced heave of the soil beneath the pavement to a level that will not affect the performance of the pavement. The fulfillment of these criteria usually require the consideration of the following aspects:

- Evaluation of equilibrium condition of the sub grade before and after construction,
- Determination of sub grade strength and maintenance condition,
- Evaluation of the effect of swelling potential of the clay developed due to the change in sub grade moisture condition after construction.

There are several pavement design methods that were developed in various countries based on the different factors prevailing on the respective local conditions.

In case of pavements on expansive clays, the peculiar properties of the clay has led to the development of number of design and mitigating construction methods

based on the clay strength at extreme moisture condition. The most commonly used design methods would be discussed below.

2.1.2 The CBR based design method

This is usually practiced in U.S.A, Australia, Isreal, and Britain. Its applicability is based on the choice of CBR value with respect to the prevailing condition. In U.K, CBR value is selected on the basis of final moisture, suction value or equilibrium moisture content [18]. In Australia, CBR is normally obtained from tests after soaking, as suggested by U.S corps of engineers, [18] but lately the British approach is recommended. In Israel, it is customary to select CBR value as result of tests after soaking. In Usual practice it was recommended to use the soaked CBR value corresponding to initial density of 90% of modified AASHTO MDD and moisture content of order of magnitude of plastic limit [19].

However, the approach based on CBR range relevant to swelling clay, (2-5%), differs from one another due to the variation in experimental procedures that influence the design process. The difference is small for light traffic, whereas for heavy traffic, larger difference can be obtained. This method has a disadvantage in the accurate estimate of equilibrium moisture and suction values. Recent development in England shows the CBR based curves are no longer in use; rather, they use a method

for the design of flexible pavement based on maximum thickness of surfacing and base from a given traffic. The curves developed based on CBR are more suitably used for determination of sub base thickness.

In Israel, they were using the original curves of the corps of engineer (USA). But, lately, new curve for design of pavements based on British system & Pelties equation for wheel load of 6ton was developed [16]. However, the previous design curve and the new curve have made a difference of 5 to 15cm thickness for the range of CBR (2-5%). For medium traffic, the new curves are similar to British whereas for heavy traffic, the Corps of Engineer's curve leads to a relatively smaller pavement thickness than the British system. Since design procedure based on testing on a limited placement conditions may be misleading for expansive soils, most of the practices in Israel lead to decrease the pavement thickness based on 4 days soaked CBR by 20% for arid regions.

Thus, the following disadvantages could be accounted for this procedure.

1. The methods based on CBR of soil compacted at estimated equilibrium moisture and density may be in error for the reason that soils may be compacted in the field dry of the equilibrium moisture.

2. The methods do not consider the different strength obtained for samples compacted at equilibrium moisture as compared to those that have been allowed to swell to equilibrium moisture.
3. Below pavements, the moisture content after a number of years exceeds the plastic limit and compaction at moisture above the plastic limit is impractical.
4. During the capillary wetting process, the clay is allowed to swell under a negligible vertical load and lateral pressure so that it loses a large part of its strength.
5. During thickness determination, there could be drop in CBR value and increase of traffic which result in failure of pavement even under light traffic.

In any cases these methods could give thicker pavement thickness than the other methods.

2.1.3 Design Method based on Shear Strength

This method was developed for the Texas Highway Department. The curves were developed for the given traffic, shear-strength and CBR values. The method involves the analysis of results of tri-axial shear test carried out according to the special Texas procedure, based on the choice of pavement thickness and the failure envelope of the soil. The failure envelope is compared with the standard envelopes. It is suitable for pavements with poor drainage facilities, where free rainwater

collects at the sides and wets the sub grade clay due to suction gradient.

But the method has the following demerits:

- Since it is empirical, it requires long period of time for its execution
- It requires complicated equipment
- It gives a Mohr envelope different from the routine tri-axial tests and hence there could be difficulty to interpret the conditions.

With regard to swelling clays, it gives smaller thickness, which is similar to light traffic in the previous methods.

2.1.4 Criterion based on soil classification

This design method is based on the classification of the clays. The most popular method was the AASHTO design methods, which makes use of group index. This method Of course, it is simple and speedy in design. However, it shares the disadvantage that the group of swelling clays (A-7) lies around a maximum group index of 20, corresponding to a CBR of less than 5%, which is more general to see the different clays within the category.

Moreover, for range of swelling clays (with group index 15-20), this method leads to a smaller pavement thickness than the other methods.

2.1.5 Design method based on stability and swelling phenomena

This was developed for flexible pavement design process in California Division of Highway. This is based on the calculation of optimum pavement thickness taking account of stability and swelling. The stability is checked for two components namely: resistant value(R), cohesion value(c). In large number of states in USA, it is customary to construct pavement of standard thickness on heavy soil using the R-value method. That is, there is a tendency to improve the sub grade to some depth in order to get a more resistant sub grade. The thicknesses calculated on the basis of these values are compared with the value necessary to combat swelling or heaving of sub grade and an optimum value is selected.

2.1.6 Design method based on dynamic modulus of elasticity

This method considers the dynamic modulus of elasticity of the pavement layers, which govern the total pavement and individual layer thickness. This method is based on principle of limiting magnitude of strain produced at two critical locations in the pavement. The design method is widely used as a shell method, and the modulus is obtained for the clay sub grade after swelling.

In Ethiopia, the design methods widely practiced are derived from those methods, which base their procedure as

CBR (soaked) with an improved sub grade conditions. But, the pavements appeared to be with some defects, and some of the pavements fail after some period. This implies, as far as the swelling behavior of the soils is concerned, The CBR based design couldn't guarantee a good performance unless it is considered with the basic factor of stability and swelling phenomena. Since the strength of sub grade can change with time as result of moisture changes in the soil, in case of the pavement built on expansive soils, the whole design attempt aims at maintaining the sub grade moisture condition at the optimum.

2.1.7 Theoretical Approach For Pavement Design

The objective in constructing any pavement is to provide a pavement satisfying the design criterion and possessing such uniform characteristics of quality that will have maximum serviceable life with minimum maintenance. It is also a process of developing the most economical combination of pavement layers in relation to thickness and type of material, to suit the soil foundation and the cumulative traffic to be carried during the design life.

In most design processes, a mechanistic rational approach is applied to provide a rational relationship between construction, material specification and design of pavement structure. This will enable to eliminate the premature failures due to the inability to incorporate

variations in material and construction in the design procedure.

According to Yoder and Witzak [11], for any pavement design procedure to be completely rational in nature, three elements must be fully considered:

1. The theory used to predict the assumed failure or distortion parameters
2. The evaluation of material properties applicable to selected theory
3. Determination of the relationship between the magnitudes of parameters in question to the performance level desired.

Thus, overall concepts of pavement design include the consideration of functional performance, structural performance and safety. The structural performance of a pavement relates to its physical condition, i.e. the occurrence of cracking, rutting, joint faulting, and other conditions that would adversely affect the load carrying capacity of a pavement structure such as strength of sub grade, traffic conditions, design life.

Accordingly the functional performance of a pavement implies how well the pavement serves the users i.e. the riding quality or serviceability.

As a general approach, the design process considers the following steps:

1. Foundation analysis: -development of input values for analysis. These include the strength/ stiffness determination, where appropriate, and evaluation of volume change, swelling and frost heave, drainage condition
2. Structural performance analysis: -selection of trial design methods. Each methods analyzed include initial estimates of layer thickness required; overlay thickness for an existing pavement, and pavement material characteristics. These are analyzed through the pavement response and a performance characteristic verses the expected damage over time.
3. Evaluation of technical viable alternative: -an engineering and life cycle cost analysis of the alternatives.

2.1.7.1 Design parameters

A good consideration of design parameters determines the basic design criterion to be fulfilled in order to make the performance of the pavement viable to the user. The parameters of design are those factors, which defines the structural and functional performance of a pavement.

The correlation of basic clay properties relevant to pavement design, obtained with the aid of simple index tests, allow the evaluation of factors that govern the design of pavements and selection of design values for projects in expansive clays.

These parameters include: thickness and width of pavement, traffic conditions, material of construction, Sub grade conditions, environmental factors, drainage and permeability conditions, reliability and serviceability, construction techniques, shoulder design and life cycle costs.

As far as the context of the research is concerned, the effect of swelling on the functional performance is considered, as it affects sub grade soil strength and design life of the pavements.

a. Traffic condition

One of the most common causes of premature pavement failure is the incorrect estimate of traffic loading. The damage by the traffic loads, on the pavements, depends on the axle loads of the vehicles. Exact relationship is approximate by fourth power damage law for most practical application.

b. Sub grade Strength

The soil immediately below the pavement is generally referred to as sub grade, specifically, the soil below a depth of 60cm of formation level.

The strength of sub grade at any point must be regarded as the lowest strength present in the top 60cm of soil at that point [10], since a measure of the strength at the surface of sub grade may be misleading. The most important factor, which controls the pavement thickness,

is the strength of the sub grade soil. This, in turn, depends on type of soil, its moisture content, and the level of compaction achieved during construction. The thickness of pavement required to carry a particular traffic load is very sensitive to sub grade strength. It is important to estimate the strength of sub grade under most likely adverse conditions. Although important sub grade parameters obtained through a geotechnical investigation is considered, pavement design based on the response of the soil to short-term loads may dramatically affect the pavement especially when the pavement is constructed over expansive soil. Moreover, due to the influence of the climatic variation on the soil property, a design value of CBR should be considered for the additional effect of swelling.

c. Shear strength and Atterbeg's limits

The shear strength properties of expansive black clays are important factors, like the swelling behavior, in the design of pavements. Most of the efforts made on these soils are mainly concentrated towards finding a solution to the swelling behavior associated with the soils. Nevertheless, the strength behavior of expansive black clays need not be over looked since, such factors as swelling and fissures, influence the strength significantly and their effects are difficult to be accounted in most laboratory shear tests [11]. The

residual strength of these soils depends primarily on the mineral composition, which, for practical purpose, is best manifested in plasticity characteristics. Different relationships have been set to predict the shear strength characteristics of these soils from the plasticity characteristics, [3], [14], [5].

d. Active Zone of Movement

In the design of pavement on expansive soil, the concept of active zone of movement is highly considered so as to fix the appropriate design procedure towards the effect of swelling on the prevailing condition.

This depth which is subjected to potential movement is measured from surface and extends up to a great depth (i.e. up to which the moisture verse depth profile is constant, in some areas it extends up to 6m[9]. This depth of active zone is considered to be a result of high volumetric swell characteristics exhibit through out the soil.

This depth constitutes two zones, namely, seasonal variation and potentially active zones.

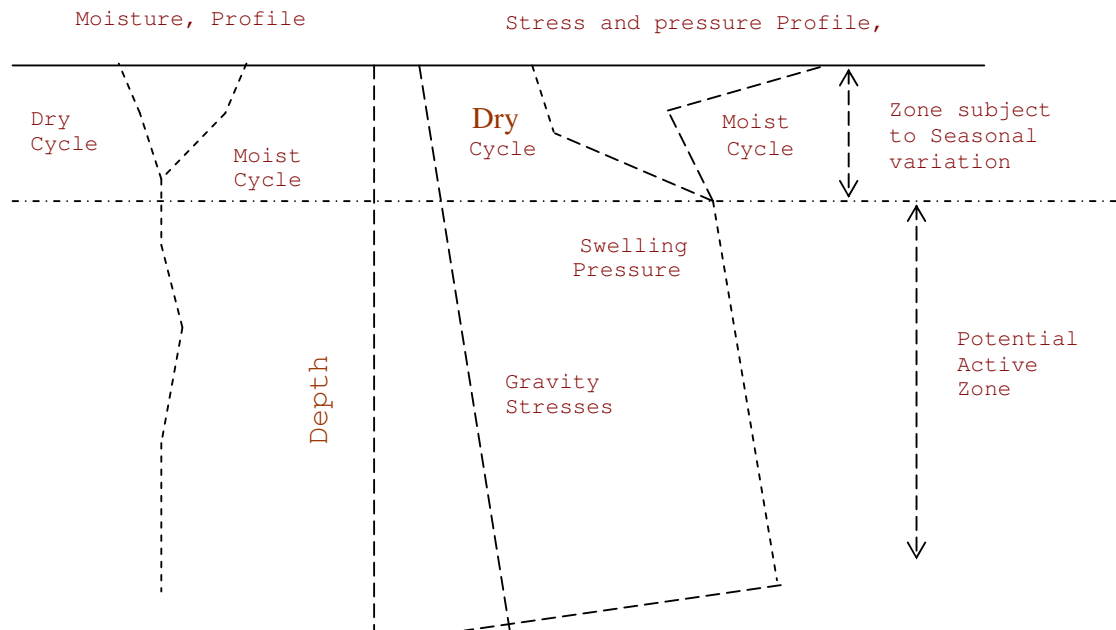


Fig 1. Active Zone Of Movement,
[Ronald F.RD, TRR 1137,Dallas]

The concept of deep active zone and the one that is subjected to seasonal moisture variation is shown in figure1. The swell pressure for the upper soils is seasonally variable depending on soil moisture, whereas below the seasonal zone the swell pressure can be higher than the available gravity stresses for significant depths. The moisture content of soil below the zone of seasonal moisture variation is usually 2 to 4% below the plastic limit and becomes drier with depth. The zone of seasonal moisture variation is relatively shallow, i.e. approximately 2.4 to 3m[12], below the surface. The shallowness is attributed to site topography, which

enhances the surface drainage propensity of surface soil to swell and decrease their permeability.

Hence an awareness of the full potential of the active zone is necessary if an accurate prediction of surface movement is to be made. Moreover, it is more useful in the design process of pavement subject swelling soil.

e. Depth of Treatment

The fundamental requirement of pavement is based on the fact that the surface shall not deflect to such an extent that it fails to regain its original profile. The deflection of any layer of the pavement is a function of the stress applied. Accordingly the strength of each layer would be reduced with increased depth.

Although the necessary condition for the natural sub grade upon which the pavement is laid shall be strong enough to resist the stresses, the excavation, that must be taken place prior to construction of pavement, has to be the depth considered so that the sub grade has the ability to withstand the stress transferred to it (i.e. 't' in figure 2).

This needs the following consideration:

- Determination of depth of treatment
- Relationship of strength to depth
- Determination of economical critical depth at which new types of treatment must be utilized.

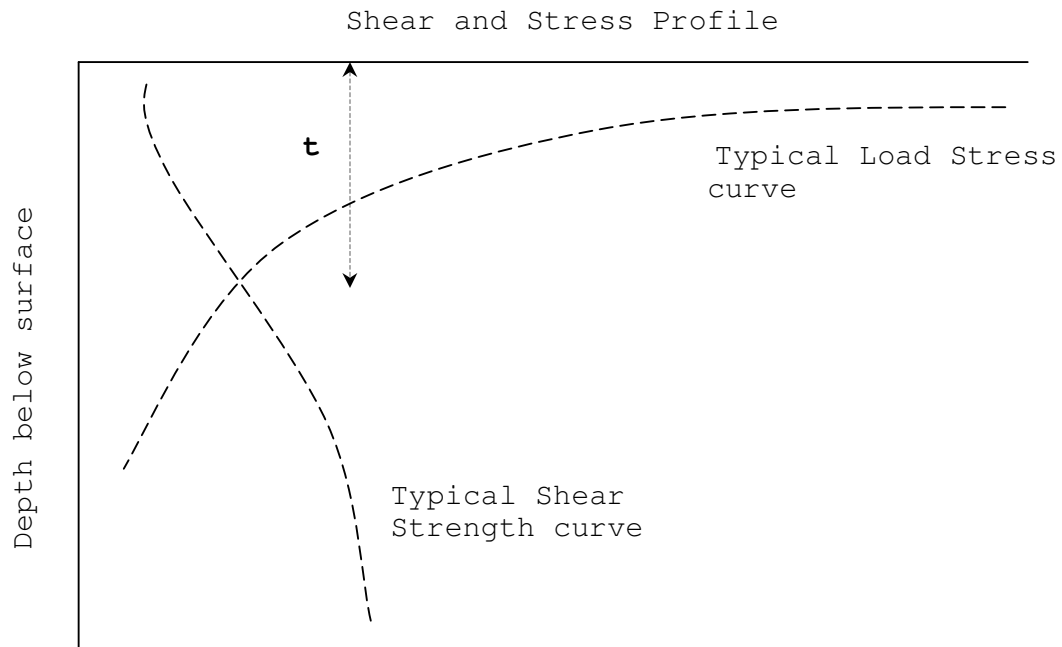


Fig 2. Typical Shear strength–depth relationship and depth of treatment [26]

The thickness computed on the basis of the above consideration is, then, compared with the value necessary to prevent swelling of sub grade, and then, an optimum value is adopted [26]. That is the depth determined from shear strength and applied stress relationship, and the depth computed from the total heave verses applied load. The determination of a depth required to combat swelling will be discussed later.

2.1.7.2 Effect of Swelling in Design

From the previous discussion, it was proven that the type of soil underneath, the moisture content and the

compaction condition controls the sub grade strength. But some soils exhibit properties of high swell upon saturation and shrinkage when dry. Such soil requires special attention and may be necessary to resort to uniform construction technique to combat shrinkage and swell. They exhibit the unique property of shrinkage when water is removed from them by drainage or desiccation. In these cases, the common procedure is to make certain that the soil remain wet to combat volume change due to drying out. Therefore, the factors being considered in design should also recognize the effects of environment on pavement performance in situation where swelling clay are encountered. If a highly swelling soil is encountered, it is essential that it will be compacted at moisture content near or slightly in excess of optimum amount. In this way, swell, although it will not be stopped, will be minimized. The major influences of swelling on the pavement are seen in its serviceability loss. The differential effect on longitudinal profile of road surface and the potential in smoothness is resulted from the swelling effect.

Thus the presence of swelling type of soil at the underneath of pavement affects:

- The design/serviceable life of pavement
- The design strength of sub grade

- The design or required thickness of material for the pavement

Since roughness, which results from the swelling phenomena, is such an important consideration in the design of pavement, the change in roughness condition will control the life cycle of pavements. In this regard, the effect of swelling soil is to reduce the predicted service life of pavement. Thus, because of serviceability loss due to swelling, an overlay design and prior maintenance strategy will be required before the end of the designed performance period. Thus the required design life and the thickness loss as a result of swelling may be estimated as follows [1]:

a) Design life:

Let initial service life be t_1

Service life as a result of Serviceability loss,

-Due to Swelling be t_2

-Due to Traffic be t_3

Thus, the corresponding performance period will be:

$$= t_1 - (t_2 + t_3)$$

b) Thickness loss (amount added to the thickness of normal design). Thickness loss as result of:

-Serviceability loss due to traffic, ESAL be d_1

-Serviceability loss due to swelling be d_2

Thus, the total sum ($d_1 + d_2$) will be the required loss thickness.

2.2 Construction Practices

2.2.1 General

Construction method can also be an important factor like the design approach, since the adverse effect of Swelling can be aggravated by the variation on placement condition of the pavement.

2.2.2 Common Practice in the World

There are various techniques most commonly practiced in the world so as to strengthen the sub grade and reduce the influence of swelling clays. The most commonly used practices mainly focus on the sub grade treatment before the placement is constructed.

These include:

- Excavation and Replacement
- Stabilizing the sub grade using chemical or mechanical processes
- Minimize the moisture changes and subsequent movements
- Increase of surcharge on clay sub grade

a) Excavation and Replacement of the problem soil

It is one of the best methods to provide stable foundation material. It is most widely practiced method all over the world. It reduces and controls the fluctuation of moisture content in the underlying clay layer so as to reduce the heaving problem. However, it should be economically feasible if the availability of

borrow site and depth of active zone is reasonable. Moreover, the replacement can be activated through a higher density to give high bearing support.

However, it would be an effective method if the following requirements were satisfied:

- i) Economical hauling distance and locally available borrow source
- ii) Back fill material is good quality and impermeable enough not to act as drain
- iii) Moisture infiltration to underlying soil is controlled

In this country, this method is the most widely accepted method, but the economic depth of replacement is always questionable due to the undefined use of the different design recommendation. Most of the warped pavements in west Dallas were made based on these techniques but it could not revive the warping phenomena. Recent phenomena at Addis jimma road pavements could also confirm that the application of this method is limited to certain conditions.

b) Changing characteristics of expansive soil

This is done through stabilization of the soil by lime or cement and by remolding & re-compacting the soil. That is, changing the behavior of the expansiveness by chemical and physical processes respectively.

i. Lime/cement stabilization

This is a process of changing the basic engineering characteristics of the expansive soil using chemical agents. The stabilization of the soil is done by adding 2 to 8% by weight of lime to the soil through different application technique so as to reduce the plasticity of soil and it's swelling potential. Lime, drastically, reduces the plasticity index, raises the shrinkage limits of the clays and modifies the particle size distribution (by agglomeration of clay particle). Based on the experience obtained from Florida, Oklahoma and other states of USA lime stabilization not only transformed the soil to a non swelling, friable mixture but also improved the structural capacity of the treated layer. However, due to the slow chemical process, the depth of treatment is generally limited to about 20 to 30cm in a single shift and, in deep plowing or pressure injection, it could extend to 60cm.

Moreover, it may be cheaper than the other technique if careful application method is used and a good mix with in the active zone is achieved.

It should be noted that the treated clay would be at least good type of quality that has CBR of 10 to 15%.

However, it has the following limitation:

- Depth of influence is not greater than 30cm

- It suffers the difficulty to obtain a unique and intimate mix unless special equipment is used.
- It could not be used in wet weather due to its sticky nature
- It suffers a slow chemical reaction to get good shear strength with in a limited time than the cement-stabilizing agent.

Accordingly, Cement stabilization is similar to that of lime. These include a reduction of liquid limits, plasticity index and potential volume change, an increase in shrinkage limits, and shear strength. Cement treated soils can exhibit higher strength gain than lime treated soil, due to the slow cementation reaction of lime. However, the application of both stabilization processes requires a special equipment so as to get a good mixture of the required results. The use of cement requires more care as compared to lime, since it couldn't be used again once it gets set. A lot of good results had been gained in the application of this technique in USA, South Africa, china and other part of the world, but they has the difficulty to alter the soil behavior completely and obtain a reduced swelling potential for the full depth of moisture fluctuation zone. However, it has the disadvantage that it may not be hydrated sufficiently to produce the complete pozzolanic reaction.

ii. Remolding and re-compacting

This method consists of ripping and scarifying of the in-place expansive soil to change the natural structure of the material (physical alteration) and re-compacting with good moisture and density to minimize the expansion potential. Since the depth of influence is not great and the actual alteration of the soil is limited, it may be considered as a minimal effect in the treatment alternative. This is highly recommended in the South African practices, but limited to certain soil conditions.

Hence, the limited influence of zone on the volume change can guarantee its applicability for soil exhibiting low swell potential and non-humid climatic condition.

c) Minimize the moisture changes and subsequent movements

This is achieved through confining the expansive clays under improved sub grade, or Use of horizontal and vertical barrier to place the soil at equilibrium moisture content.

i. Use of Horizontal or Vertical Barrier

The basic principle in using moisture barrier is to move edge effects away from the pavement and minimize the fluctuation of moisture through the increased time due to the increased path length for water migration.

As early as 1993, the Texas Highway Department used asphalt membrane to prevent surface water from entering

the expansive sub grade. Waterproof membranes, particularly continuous catalytically blown sprayed asphalt has been used successfully in many state Highway Departments. Asphalt membrane is applied over the entire sub grade, down the verge of slope and up to the back slope to a vertical ditch (i.e. about 40cm above the ditch). In Israel, membrane under pavement laid directly on the subgrade has been used. This method has been widely used for airfield pavements.

Therefore, according to the research made by the Colorado department of highway on the test sections, the use of horizontal asphalt membrane outperformed all other preventive measures. The sub grade on those sections remained close to the construction moisture content with little evidence of swell.

Similarly, the use of vertical barrier could be more effective in retarding lateral moisture migration and edge effect. This is also a successful method to decrease differential movements. The Texas highway department and, San Antonio have experienced using vertical waterproof membrane (up to a depth of $\frac{1}{2}$ to $\frac{2}{3}$ of the active zone) and obtain a good performing pavement with a reduced roughness. Moreover, using a 30cm impermeable improved sub grade layer [24], and placing the soil at moisture content near optimum (close to plastic limit), the seasonal moisture change could be reduced.

ii. Surcharging

Based on the swelling pressure of the underlying clays, placing a substantial thickness of non-swelling material over expansive clay could also reduce heave. According to the reports on pavements on the California state, one criterion for pavement design is based on the pavement thickness necessary to prevent swelling.

iii. Pre-wetting

This method is aimed at flooding the in-place soil to achieve swelling prior to construction. This is achieved by increasing the soil moisture to a degree that will prevent harmful heaving upon successful wetting. It had been used in some part of the world, USA, South Africa, Zimbabwe. However, In view of past experience and actual case studies, it has the following demerits:

- It is extremely difficult to saturate high plasticity clay with in a reasonable period of time, and swelling may continue after construction for partial saturation
- The soil can undergo a serious reduction in bearing capacity as the soil become saturated
- The areas and depth of treatment will be very limited.

Though, this method may play an important role in reducing heave in structures like building, it is doubtful that it could be used for pavement.

2.2.3 Common Practice in Ethiopia

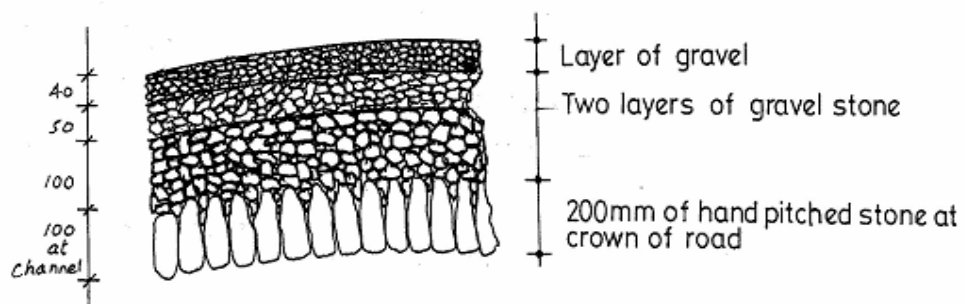
The most commonly practiced construction methods are the use of replacement, modification of shoulder and stabilizing with lime on some part of the runway section of the existing airports. Most of the recently adopted design and construction procedures recommend the use of 50cm replacement and increasing the shoulder width to 1.50 or 2meters. However, in most part of the pavements, a lot of failure phenomena had occurred. This reveals the application of the different technique is limited to the prevailed environmental and soil conditions. In Ethiopia, there is a practice to reduce the moisture change under pavement by providing barrier achieved through:

- Extended shoulder width (at least 2m)
- Impermeable pavement and shoulder
- Impermeable side ditch and located far away from pavement

2.2.4 Pavement Condition Survey

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. In Ethiopia, most of the pavements were constructed on expansive soils, e.g. the existing road pavement and the Addis Ababa airport. As far as the road

pavement in Ethiopia is concerned, most of the roads were constructed during the Italian invention. They were of the Telford type for the reason that, during that period the development of pavement design is mainly the Telford's and macadam's [17] type of pavements.



Telford's road structure

It is evident that from the time of their construction, most of the road pavements in the county had not failed though they were built on expansive soils. This is due to the functional resistance of Telford type of pavement to the effect of swelling.

Telford's pavements (1757-1874) were mainly a four layer pavement made up of big size stone (boulder) as foundation varying from 17-22cm to develop a firm base, 7cm size 10cm thick angular broken stone, 5cm thick broken stone, 4cm thick wearing surface and cross drains under the foundation layer at 90m interval. Moreover, the finished surface has a cross slope of 1 in 45, the end width treated with lime concrete, made up of lime & stone

aggregate and the total thickness was made to 38-41cm.it can be revealed that the pavement formation had an influence on the adverse effects of swelling. That is:

- 1) The Telford foundation layer, being of larger sized stone behave like semi-flexible pavement, which has more resistance to swelling pressure.
- 2) The cross drains provided and the open space (void) due to the large size stone makes the sub grade moisture variation minimized, which helps in strengthening the sub grade from the moisture and temperature variation.
- 3) The end width of the lime aggregate concrete laid on either side of the pavement provide lateral stability to the road structure and also prevent the ingress of water to the structure.
- 4) The open space between the large sized boulder and the cross slope at the top surface helps the movement of water ingresses to the pavement at ease and to move out without altering the moisture condition of the sub grade.

However, with increase in rate and volume of traffic population and poor maintenance strategy that alter the ground condition, the pavements were subjected to lots of failures. That is why the recent development in pavement structure considers the stress distribution verses layer thickness. The pavement condition survey at the Addis Ababa -weldia road project [30] 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 [28]. 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 sever 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.

The pavement deficiency condition on the old Addis Ababa international airport [29] 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 with in 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 increased 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 general, the investigation made on the site reveals that:

1. Surface grade of the runway and taxiway pavement are very uneven due to the prevalence of substantial heaves and swells caused by unequal volume changes in the sub grade soils.

2. The sub grade soils immediately beneath the pavement in all areas are essentially expansive black clay with liquid limits and plasticity index of 115 and 60 respectively. The material has a high volume change potential, shrinkage with decreasing moisture contents and expanding with increasing moistures.
3. During the wet and dry season, moisture content of the runway subgrade varies with depths approximately four meters from the pavement surface. These values represent the range of seasonal moisture fluctuation. In addition expansive pressure in order of 150 to 450kpa would be generated in the sub grade, and vertical movements in the order of 10 to 20cm resulted due to volume change.
4. Sub grade moisture contents in the terminal and service apron show a relatively small fluctuation with depth and couldn't appreciably varied under these relatively large paved areas. Due to this reason they appear to be in very good condition.

Moreover, sever longitudinal cracks were prominent along the outer edges of paved shoulders and decrease towards the inner edges. The cracks appear to have resulted from shrinkage and expansion of sub grade soil due to excessive moisture fluctuations.

Many of these cracks have been previously sealed with bituminous material, but reopened. Transverse runway and

taxiway heaves occur at the location of underground electric conduits, which cross the pavement.

A summary of the most common distress mechanism occurred in most of the pavements, built on expansive sub grade, and design condition of the existing pavements is shown in the following tables.

Table of pavement condition survey

Table of design conditions

Chapter Three

Analysis of Potential Expansiveness

3.1 General

In any design problem involving expansive soils, it is essential to identify the soil in question and quantify its properties including its degree of expansiveness. The degree of expansiveness would also depend on the prevailing climatic and environment condition.

Based on the correct identification of expansiveness of the soils, it can be ensured to adopt suitable design and construction techniques. Therefore, there is a definite need to establish an appropriate method to estimate the degree of expansiveness of a soil at a site. In the past, many attempts have been made to establish a meaningful correlation between swelling properties and index properties [12]. The most common methods are those based on simple index test, and clay content. However, due to the difficulty to determine clay fraction in the laboratory, the use of atterberg limits to predict the swell potential is the most common approach.

Among the various relationships used in analyzing the potential expansiveness of expansive soils, the modified plasticity chart (Darshanamurphy and Raman, 1975)[14] is selected for its ease of simplicity. The degree of the expansiveness of the soils considered in the research is shown in table3.

3.2 Prediction of Swelling pressure and Heave

For practical applications, many investigators have developed empirical relationships for predicting heave and swelling pressure. Although the use of empirical methods have major disadvantage in their use, they can be used as a primary indicator of expansiveness so as to devise the appropriate design and construction strategy. The application of those correlation which have been developed to predict the heave or swelling pressure that an expansive soil can induce, was conducted in ways to imply various degree of accuracy [16].

An appropriate prediction of the heave and swelling pressure is more valuable as the detrimental volume increase could be controlled with sufficient surcharge load applied on the soil under a predetermined value of swelling pressure.

3.2.1 Prediction of Swelling Pressure

Many relationships have been established in various researches by which swelling pressure can be estimated based on index properties and physical state of soil. Some of these relationships are given below:

1. Komornik and David, 1969

$$\text{Log (Sp)} = 2.132 + 0.0208 * w_L + 0.000665 * \gamma_d - 0.0269 * w. \quad (1)$$

Where, Sp: swelling pressure in kg/cm²

w_L : liquid limit in %

γ_d : dry density in kg/m³

w : moisture content in %

2. Nayak and Christensen (1970)

$$Sp = 0.035857 (PI)^{1.12} (J/W)^2 + 3.7912 \dots \dots \dots (2)$$

Where, Sp: swelling pressure in kg/cm²

PI: plasticity index in %

J/W: a value that represent clay fraction and moisture content

3. Vijayavergiya and Ghazzaly (1973)

$$\text{Log } Sp = 1/12 [0.4 * w_L - w - 0.4] \dots \dots \dots (3)$$

$$\text{Log } Sp = 1/19.5 [\gamma_d + 0.65 * w_L - 139.5] \dots \dots \dots (4)$$

Where, Sp: swelling pressure in kg/cm²

w_L : liquid limit in %

γ_d : dry density in pounds per cu.ft (pcf)

4. Brackley (1983)

$$Sp = 2.7 - 24 (e_i / p_i) \dots \dots \dots (5)$$

Where, Sp: swelling pressure in kg/cm²

e_i : void ratio

p_i : plasticity index

Although the relationship were developed for temperate climatic condition, their validity have been verified in the African tropical black clays like Tanzanian soils [35]. Some of the relationships have been selected for their simplicity, wide acceptance and practical significance to field applications. Due to the similarity of the prevailing condition in Tanzanian and the existing

soil condition considered in this research, the suitability of the above equations have been evaluated by comparing estimated and measured values. According to the research made for Tanzanian clays [14], and those of the results from Addis Ababa airport and Addis-jimma road projects, the following measured range of values has been taken for comparison.

For the Tanzanian soils

Low swelling pressure-----less than 50KPA

Medium swelling pressure-----50 to 140KPA

High swelling pressure-----150 to 250KPA

Very high swelling pressure-----greater than 250KPA

For the local soils, very high, soil conditions [27]:

Addis Ababa airport -----220 to 450KPA

Addis-jimma road -----500 to 585KPA

Thus, the comparison of measured and the estimated values are as shown in tables 4a to4f and figures4.

TABLE FOR FIELD DATA FOR SWELLING PRESSURE

TABLE FOR FIELD SWELLING PRESSURE

TABLE FOR SWELLING PRESSURE

From the above figures, the following observation can be made:

1. Most of the values for the very high swelling soils are represented by Equation [4] with in the range of 250 to 500kpa.

2. Most of the data for high swelling soils are represented by equation three and five with in the range of 150 to 250kpa

3. Most of the data for medium swelling soils are represented by equation one

Thus based on the above comparison, taking account of the major parameters, which control the swelling pressure, Equation [4] can give best estimate of swelling pressure for clays with very high swelling potential, Equation [3] & [5] for high swelling, and Equation [1] for medium swelling clays. Hence the equation could be used to estimate swelling pressure for those sites where only the consistency limits and physical state of the soils are available and laboratory determination of swelling pressure is not possible.

Hence the predicted values in table 5 are taken for the analysis of design depths required to combat the total heave developed for each case of expansiveness, which will be discussed in the next chapters.

Table 5. **Predicted Values of Swelling Pressure**

Degree Of Expansiveness	Swelling Pressure In KPA	Void Ratio [27]
Very High	500	0.905
High	250	0.84
Medium	150	0.67

3.2.2 Prediction of Heave

In general heave represents the volumetric change ($\Delta H/H$) of the expansive subgrade.

There are different methods of heave prediction developed based on various assumption. Some of these are:

1. Heave prediction based on Soil Suction Tests [19]

$$\rho = \sum \frac{z_i [C_{mi} \Delta \log (U_a - U_w) + C_{ti} \Delta \log (\sigma - U_a)]}{(1 + e_o)_i} \text{ ----- (6)}$$

Where,

$U_a - U_w$ is the soil suction, C_{mi} is matrix index

$\sigma - U_a$ is the effective stress, C_{ti} is stress index

2. Heave prediction based on CLOD Test Method [19]

$$\Delta z_i = \frac{C_w \Delta w}{1 + e_o} z_i, \quad \Delta z_i \text{ is the heave ----- (7)}$$

Where, C_w is the index of volumetric compressibility (Δe) with respect to change in water content (Δw) and z_i is thickness of sub layer under consideration, e_o is the void ratio.

$$C_w : \Delta e / \Delta w ,$$

3. Heave prediction based on oedometer tests [19]

$$\rho = \sum \frac{z_i C_s \log (\sigma_f / \sigma_c)_i}{(1 + e_o)_i} \text{ ----- (8)}$$

C_s is the swell index (slope of rebound curve)

σ_f is the applied stress, σ_c is the swelling pressure

z_i is thickness of sub layer under consideration.

4. Heave prediction based Van Der Merwe's method [15]

It is an easy and widely accepted formula using potential expansiveness and reduction factors, developed for South African condition, to account for decreasing heave with depth.

According to Van Der Merwe,

$$\rho = \sum F_i * PE_i \text{-----} (9)$$

Where F_i is the reduction factor for layer i determined from oedometer tests made in South Africa.

PE_i is potential expansiveness for layer i

Very high: $PE = 1$ in .per foot depth

High: $PE = \frac{1}{2}$ in.per foot depth

Medium: $PE = \frac{1}{4}$ in.per foot depth

However, despite the existence of various methods to predict heave, there could be limitations to conduct the necessary tests (e.g. suction indices) so as to get the required parameters in the empirical equations. Due to these reasons and in the absence of more reliable information, it is, therefore, recommended that the empirical or closed form solution could be used in heave prediction. In most practical problems where there is an absence of more reliable information, heave is predicted by the following equation derived from one dimensional consolidation laboratory curve [18],

$$\Delta h = C_s * H * \text{Log} [\sigma_f / \sigma_o] \text{-----} (10)$$

Δh : heave, C_s : Swell index, H : height of stratum,

σ_f : swelling pressure, σ_o : acting stress

According to Chen, 1988, a differential uplift of $\frac{3}{4}$ of an inch can, generally, be tolerable.

Swell index, which is the slope of the rebound curve, can also be predicted by the following empirical equation. Based on the test results [27] the following Equation is valid for the soils considered in this research, like Addis Ababa soils as seen in the following table.

In addition, the swell index is expressed as function of compressibility index that can be correlated as [3]:

$$C_c = 0.0046 * (LL - 9), \text{ and } C_s \sim (1/5 \text{ to } 1/10) * C_c$$

Where, LL is the liquid limit

Table 6. Comparison of the predicted and measured value

Location	Liquid Liquid	Predicted Value (C_c)	Measured Value (C_c)
Addis-jimma road	52-85	0.20-0.35	0.23
Addis Ababa airport	96-114	0.40-0.485	0.45-0.50
Brazilian soils	60-80	0.23-0.33	0.21-0.30

Suitability of the equation from the consolidation curve is the most popular approach as seen in Table7.

Comparison of the predicted and measured value of field heave for a stratum of 3m is shown in the following table7.

Table 7

Chapter Four

Evaluation of design and Construction methods

4.1 General

Most of the failures noted on the pavements result from improper design or construction method adopted for the particular soil condition. This shows that the applicability of any design or construction method adopted for pavements on expansive sub grade is a function of the environmental conditions that prevailed on the site. The current design and construction methods adopted in the country would be evaluated with respect to the existing soil and environmental condition.

4.2 Design Methods

There are several designs and associated construction methods developed based on different criteria.

In Ethiopia, the most commonly used pavement design methods are:

- 1) TRN31, 1993
- 2) Kenyan Design Methods
- 3) AASTHTO Design Methods
- 4) Tanzanian Design Methods
- 5) South African Design Methods
- 6) Australian Design Methods

The assumptions and recommendations of each design methods are given below.

1. Kenyan Design Method

It is developed based on the following assumptions & recommendations:

1.The material forming the sub grade should satisfy the following criteria:

- i) CBR at 100% MDD and 4days soak $\geq 5\%$
- ii) Swell at 100%MDD and 4 days soak $< 2\%$
- iii) Organic matter $< 3\%$

2.The pavement would be placed at equilibrium moisture content so that the sub grade strength is measured at a moisture content of 4 days soak or at O.M.C+3% for rainfall greater than 500mm, on impermeable condition and at a moisture content of O.M.C or Plastic limit for rain fall less than 500mm on highly permeable conditions.

3.Type of pavement recommended for expansive soil is flexible type.

4.Limit the compaction requirement for at least 97 to 98% of MDD (standard) and 100%MDD (modified)

5.It recommends thickness of pavement varying 35cm to 75cm for given traffic, maximum axle load of 13ton and CBR (2--5%).

6.It recommends an improved sub grade of minimum of 30cm to 60cm.

7.It recommends a total surcharge height of 60cm to 120cm on the expansive soil with side slope of 1:4

8.It recommends a shoulder should be sealed and extends up to 2m or equal to active zone

9.The Culverts and drain pipes should be far away and placed with non permeable, gravelly material

10.It recommends construction techniques like:

- Avoid the expansive soil by realignment

- Excavate and replacement to maximum of 1m

- Lime Stabilization

- Minimize moisture changes and potential swelling by improving the sub grade or surcharging

2. Transport Research Road Note (TRN31, 1993)

It is developed based on the following assumption & recommendations:

a. The sub grade moisture content of O.M.C for mean annual rainfall greater than 250mm(soaked CBR), and 80% of O.M.C for rainfall less than 250mm(CBR at O.M.C)

b. The pavement is impermeable and properly sealed, with sub grade of $CBR \geq 8\%$

c. An improved pavement of 40cm at design moisture content near equilibrium and CBR

d. The expansive material should be replaced with non-expansive impermeable soil to the design depth, i.e. 1.5 to 2m, which is affected by the seasonal moisture.

e. It recommends a pavement thickness, for maximum axle load of 13 ton, for (CBR =2%) 70cm to 92.5cm, and (CBR=5%) for 57.5cm to 80cm

3. Tanzanian Design Methods

It is developed based on the following assumption & recommendations:

1. It considers the effect of higher class of traffic, i.e. greater than 13 axle ton
2. It recommends a defined procedure to be followed in the design process for pavement on expansive soils based on their level of adverse effect.
3. It considers the results of the various researches made on Kenya, U.S.A, U.K, and TRN31, SOUTH AFRICA.
4. It assumes a design depth (0.60 to 1.20m) up to which the traffic has no effect on the sub grade strength
5. It considers design CBR value at design moisture content and soaked condition.
6. It requires the sub grade strength of $CBR \geq 15\%$, maximum swell of 2 %
7. It recommends a pavement thickness of 30cm to 60cm
8. It considers different cases of drainage and shoulder condition to reduce the effect of expansiveness, at a distance of 4m to 6m from toe of embankment, for side drains
9. It recommends alternative methods of construction over expansive soils for different degrees of expansiveness:

-For low to medium expansive clays, minimum cover of 1m, flatter side slope (1:6), sealed and wider (2m) shoulder

-For the high swelling clays, for fill greater than 2m, replace 0.6m for section outside the surface width and for fill less than 2m replace the whole width of 0.6m, widen shoulder with flatter side slope.

4. South Africa (TRH4) Design Methods

It is developed based on the following assumption & recommendations:

- a. A sub grade of sufficient strength, improved by 15cm of selected material
- b. It recommends a design depth of 80cm to 120cm for different class of roads.
- c. It considers CBR value of the sub grade under the material depth, and soaked value for wet condition, increased value for dry areas with compaction of 80 to 90 %MDD
- d. It recommends a thickness of pavement up to 450mm, with extended pavement layers to the extreme of the shoulder sealed.
- e. It assumes an effective drainage to be considered in the structural procedure to prevent the pavement not to be saturated.

5. Australian Design Methods, DMR, Form 76

It is developed based on the following assumption & recommendations:

- a. It requires the determination of sub grade CBR at design moisture of optimum.
- b. It determines the required total thickness of pavement by an empirical formula with design CBR, traffic values.
- c. It considers different cases of pavement condition with an improved sub grade of greater CBR.
- d. It recommends higher pavement thickness on the sub grade soil type with consideration of deflection and roughness.

6. AASHTO, 1993

It is developed based on the following assumption & recommendations:

- a. It assumes sub grade strength measured in Sub grade Modulus than CBR
- b. It determines the layer thickness for the pavement based on the layer coefficient that depends on the regional factors
- c. It determines the pavement thickness in terms of the structural number, and the loss due to the traffic and swelling condition by assigning pavement serviceability index factor
- d. It recommends a sufficient cover to reduce the effect of swelling

e. It gives 50% more thickness than those methods developed for developing countries

f. The structural number is calculated as a function of reliability, standard deviation, traffic, sub grade modulus, and pavement serviceability index

g. It recommends a reduced service life for the pavement due to swelling

Generally the recommendations of the different methods are summarized in Table 8.

SUMMARY OF THE ASSUMPTIONS AND RECOMMENDATIONS

Table 8

4.2.1 Evaluation of Design Methods

The comparison of the various design methods and their suitability for swelling sub grade of varying degree of expansiveness, are made on a typical selected sites. The sites are selected to have a particular degree of expansiveness, CBR, traffic and other relevant parameters so that each design approach is analyzed to give its corresponding pavement thickness and the related recommendations. Valid comparisons between the different methods are difficult to make. However, if common factors of safety and criteria for pavement failure were shared by all methods, a comparison based on the following factors could be used for evaluating the suitability of the methods.

- Performance of the methods in their application as function of the assumptions and recommendations included in the methods
- Economical aspects in terms pavement thickness

Moreover, each site is analyzed for 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. The input parameters used for the comparison purpose are given in Table 9.

Table 9. Input parameters for comparison purpose

Site	Degree of Expansiveness	Traffic Condition	CBR values	Remark
Addis Jimma Road Project	Very high	7×10^8 ESA	2 - 5 %	
Addis Dessie Road Project	High	7.5×10^8 ESA	2-5%	
Weldia Zalemebasa Road Project	Medium	8.5×10^8 ESA	2-5%	
Addis Ababa Airport Project	Very high		2-5%	

a. Comparison based on performance

The performance of any pavement is function of the design approach adopted for the prevailing pavement condition. This depends on the assumptions and recommendations made in the methods. For example, in areas where the degree of expansive is low to medium, the design method, which assumes the general case of high expansiveness, like AASHTO, can adversely affect its economical performance. Conversely, the design approach, which assumes general case of expansiveness, might give insufficient strength to resist the very high magnitude of swelling. In most design methods, the failure criteria are not even clearly defined that will influence the effectiveness of the methods. Current situation at Addis-Jimma road project shows that the application of 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 the to recurrent failures, most of the states (e.g. Monisotta, illions, e.t.c) tried to develop or modify the method to suit their condition.

The Application of the TCDE or Kenyan design method for the relocated road pavement of the gili-gel gibe did not cause any failures despite the nearby Addis-jimma road.

In most of the application of the above methods, only economical evaluation were assumed, but it does not guarantee good performance, but failure criteria that suit the subgrade conditions should also be seen.

b. Comparison based on their recommendation

1.AASHTO Methods

The performance of the pavements designed based on this method considers a general case for high swelling clays by assuming a serviceability index factor for swelling conditions. It is suitable in moderate to humid climatic conditions since the structural number used in the methods were more applicable in areas where humid climatic condition is predominant. Thus the resulting thicker pavement thickness and unclear construction recommendation for the various soil condition makes the method uneconomical for all case of expansiveness.

2. Australian Method

It assumes a design value of CBR for different climatic conditions. It considers a general case of swelling clays regardless of the degree of expansiveness. It requires improved subgrade before any design processes. It recommends different thickness for a given CBR value. But the CBR value could not guarantee good results for all case of swelling conditions. Thus it is more applicable in medium swelling clays under any climatic conditions.

3. South African Design Method

According to this method, pavement thicknesses are obtained by considering a design depth those influences only the traffic stress conditions irrespective of the degree of expansiveness. It is suitable for moderate climatic condition since the empirical relationship used in analysis is based on similar climatic condition.

4. Kenyan Method

This is the most widely practiced pavement design method in this country. It could be applicable in arid to moderate climatic condition. It gives a reasonable pavement thickness for an improved sub grade of swelling clays. However, it considers a general case of swelling soil condition regardless of their degree of potential expansiveness.

5. Tanzanian Method

One of the peculiar considerations in this method relies on the soil condition to varying degree of expansiveness. Moreover, it could give a reasonable thickness for any traffic condition and CBR value at suitable climatic condition ranging from humid to semi arid condition. It recommends variable design and construction procedures for the swelling sub grade based on their degree of expansiveness.

6. TRN31 Method

This method considers an improved and impermeable subgrade condition. It was developed for tropical areas where moderate climatic condition is predominant.

Although it gives more thickness than the other design methods, it considers a general case of swelling soil condition despite the degree of expansiveness. It is suitable for medium to high swelling clays.

Generally a summary of the comparison of the methods based on the above criteria is shown in Table 10.

C. Comparison based on thickness

Comparison of the different methods can also be made based on the resulting thickness by considering soil and climatic conditions.

I. Based on AASHTO Methods

According to this method, the following swelling factors are considered.

- Dry climatic conditions

Very high, high, medium---0.3, 0.25, 0.2 respectively

- Moderate climatic conditions

Very high, high, medium---0.2, 0.15, 0.15 respectively

- Humid climatic conditions

Very high, high, medium----0.2

Moreover, the following values are assumed for the local conditions.

Modulus of material:

For surfacing (2450MPa), base (294MPa), subbase (196MPa) and subgrade (49MPa).

Reliability & standard deviation----95%, 0.35 for most flexible pavements. According to the method, the thicknesses are determined by setting the structural number on each layer (SN).

$SN = a_1 * D_1 + a_2 * D_2 + a_3 * D_3$, where a_1 , a_2 , a_3 & D_1 , D_2 , D_3 are layer coefficients and layer thickness respectively.

According to the manual, the values of the coefficients are assumed as 0.44, 0.14, 0.11 for a_1 , a_2 , and a_3 respectively.

Similarly, initial, final and total serviceability indices are assumed as 4.6, 2.5, 2.1 respectively.

Thus the thickness determination for each case of swelling is as follows.

Swell factor---0.2

For surface layer:

Loss due to traffic= $1.89(2.1-0.2)$

- $SN_1=2.9, D_1=SN_1/a_1=17.78\text{cm}$

- $SN_1^*=0.44 \times 7=37.65\text{cm}$

For sub base layer:

- $SN_2=3, D_2=10\text{cm}$

- $SN_2^*=a_2 \times D_2=0.56, D_3=35.5\text{cm}$

Thus, the total thickness would be 63.5cm

Accordingly for the other swell factors (0.3,0.25,0.15), the corresponding thicknesses are 69.9,66.8,63.5cm respectively.

II. Based on Kenyan methods

According to this method, the following classification is assumed for the given input values.

-Traffic class ----T3

-Pavement type 1 with natural sub-base

For arid and moderate climate conditions and subgrade improvement of 32.5cm to 40cm respectively, the corresponding thicknesses are:

- 35 & 40cm for high and very high swelling potential respectively.
- 32cm for the medium swelling potential

III. Based on Tanzanian Methods

According to this manual, the following assumptions are considered for the given input values.

That is:

- The subgrade is classified as s3
- The traffic class as TLC-10

This method considers a subgrade improved with 30cm in dry/moderate and 45cm in humid conditions, to have CBR value equal or greater than 15%.

Thus, for the above cases, the method recommends the following thickness:

-Dry/moderate climate-----40cm

-Humid climate-----45cm

Accordingly, a summary of the recommended thickness for the other design methods is shown in Table10.

Table 10 for comparison of the methods

From the above table it can be observed that the Kenyan, Tanzanian, TRN31 and Australian design methods could be used as reliable guide for the existing conditions in Ethiopia. However, the Tanzanian design method, which has similar regional factors for local conditions, is more reliable and economical than the other methods.

4.3 Construction Methods

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. That is, one type of methods need not be applicable to all soils with different swelling potential. This is true from the engineering and economic point of view. Hence the applicability of the various techniques should be evaluated with respect to the various soil and climatic condition.

4.3.1 Comparison of Construction Methods

All the various construction methods implemented to alleviate the hazards due to the potential expansiveness of the soil lies with in the context of either minimizing the volumetric changes by removing the soil and replace with suitable material, or changing its characteristics by stabilization.

The widely practiced methods in Ethiopia are the following:

- a) Soil Replacement technique
- b) Reduce the volume change characteristics of the clay by lime stabilization (chemical alteration)
- c) Minimizing the moisture changes and subsequent movements by confining the soil against heave with surcharging

A fourth method, not practiced in Ethiopia, i.e. the use of vertical and horizontal barrier made up of asphalt membrane, is also evaluated.

Thus, the evaluations or comparison of the different construction practices under the various soil and climatic condition will be discussed next.

All the above construction practices are evaluated based on the following criteria:

- Performance of the pavements based on the adopted practices
- Economical considerations of the practices

1. Comparison based on performance

a. Soil Replacement Technique

It is one of the most widely practiced methods all over the world. It aims at creating a stable foundation upon removing the expansive soil and replace with non-swelling material. This, in turn, reduces and controls the fluctuation of moisture content in the underlying clay

layer so as to reduce the heaving problem. However, its effectiveness is limited to certain environmental conditions. In most of the design manuals, replacement of 50 cm to full depth of the active zone is recommended. This is equal to the depth of treatment computed from shear strength concepts. But it may not be economically realistic to apply in any soil and climatic conditions. In the current project of Addis-Jimma, the replacement of the first 50cm couldn't resist the swelling potential of the existing soil and causes sever failures to the pavement. Similarly 60 to 150cm replacement of the soil condition of the existing Addis Ababa airport could not resist the heaving problems. Nevertheless, a good performance was achieved on the relocated route to Gil-Gel-Gibe site by replacing the first 60cm of the sub grade.

Thus the effectiveness of the method is limited to:

- The extent of depth of excavation and thickness of replacement
- Economical hauling distance and local availability of borrow source
- The type of replacement material and duration of replacement

Based on the pavement condition survey discussed in the previous chapters, the method can be used for medium to

high swelling potential clays under any climatic condition.

As far as the current practice in the country is concerned, there is inefficient use of design depth so as to reduce the heave problems at economical depths for the various soil conditions. According to the Tanzanian design recommendations, there are different cases of replacement that depend on the surcharge height and potential expansiveness of the soil.

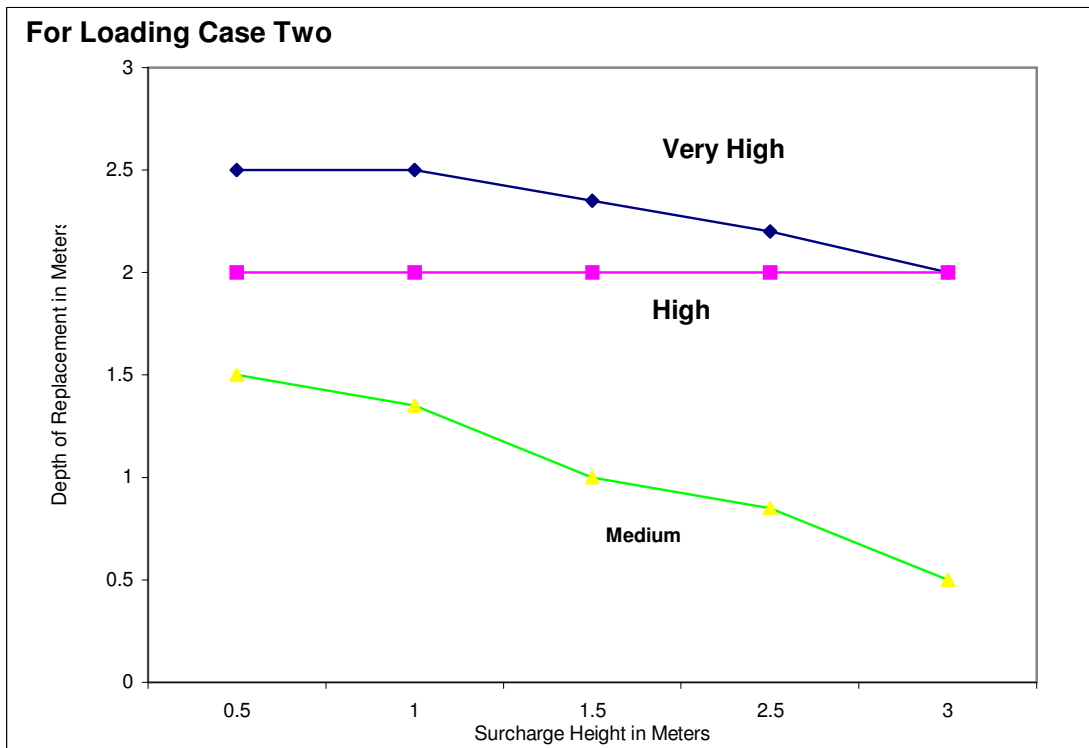
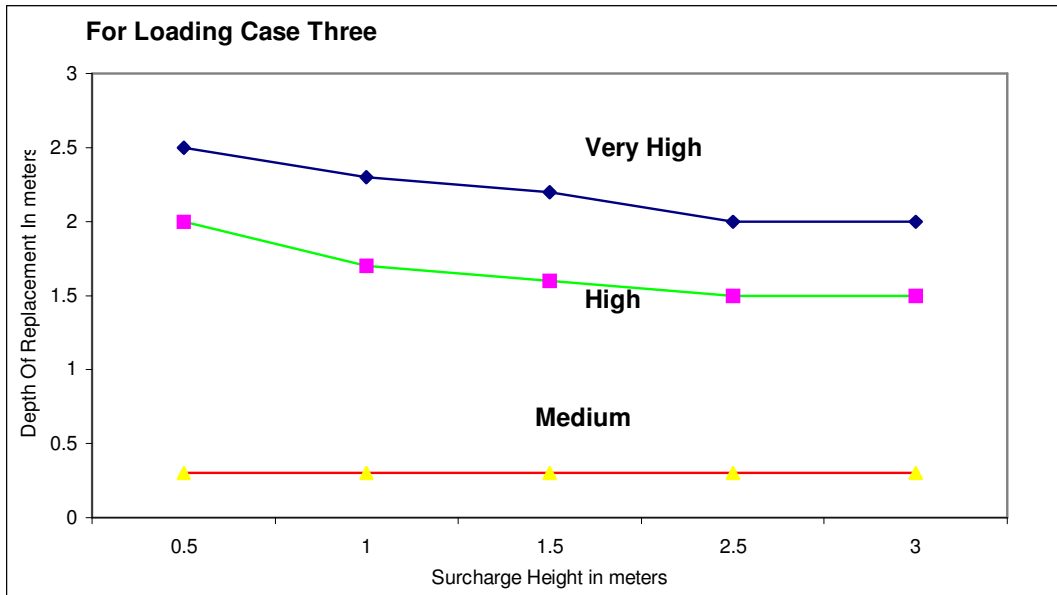
Therefore, It would be necessary to determine the safe and optimum design depth based on the various soil conditions. Accordingly, the soil condition considered in this research are analyzed for different design depth based on the maximum allowable value, assumed in most design methods (2% swell), so that the most economical and safe design depth is selected for the particular soil condition (degree of expansiveness).

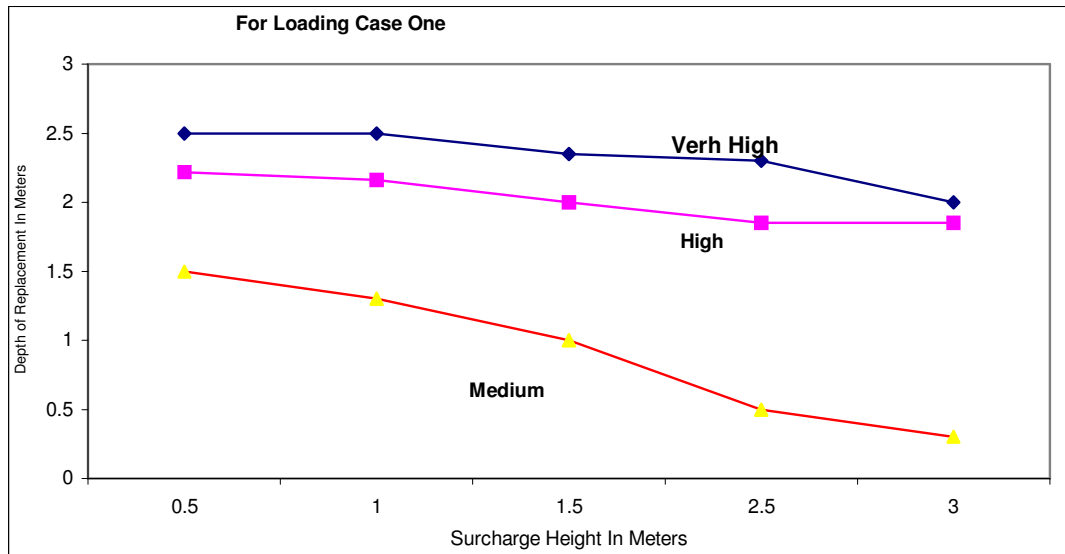
Thus, in the next discussion, the determinations of the optimum value of design depth under the following traffic loading conditions under the different soil conditions are presented. These are Axle load of 13ton, 10tons and 35,625lbs of a maximum take-off weight of aircraft load).

Table of stress

Graphs or sketch

Fig.4 Design Depth of Pavement on Expansive Soils





b. Changing the characteristics of expansive soil

By changing the chemical characteristics of the expansive soils, it could also be possible to reduce the swelling behavior of the soils. This is achieved by adding lime or cement or other additive chemicals. But lime stabilization is widely practiced and will be discussed below.

Lime stabilization

This is one of the possible construction practices in swelling sub grade. In areas where the unavailability of suitable material for replacement is fundamental, the use of this method may result good performance of pavements. In most part of the Usa, Israel, South Africa, the use of this technique is highly practiced, but the suitability of the construction technique is limited to particular soil and climatic conditions, a lot of failure phenomena have been recorded.

As far as the pavement condition survey considered in this research is concerned, failure cases had been recorded on the existing airport, which was constructed with the application of this method. However, in areas where the swelling potential of the soil is not too high, it could result successful pavements like in the case of pavements of South African, Botswana. However, due to the slow chemical process, the depth of influence is generally limited to about 8 to 12 inches in a single shift and, in deep plowing or pressure injections, extended to 2ft.

However, the effectiveness of the method is limited to dry or moderate climatic conditions and in areas where the soil condition is not too high. This is due to the fact that the very high potential characteristics of the soil cannot be eliminated with stabilization processes.

Hence the application of these techniques are effective in the medium to high swelling potential under semi-arid to moderate climatic condition.

c. Minimize the moisture changes and subsequent movements

i. Use of Horizontal and Vertical Barriers

The main advantage of these techniques is to reduce the moisture fluctuations in the sub grade by placing the soil at moisture content near optimum or close to plastic limit.

This is also a successful method to decrease differential movements. Research experience, made by the Texas asphalt institute, advocates that best performance of horizontal membrane is achieved when the following conditions are satisfied. That is:

- Soil profile is relatively dry
- The moisture content profile is relatively uniform with depth
- Ground water table is deep

These techniques are achieved by using impermeable membrane such as Asphalt membrane, polyethylene geotextile membrane. But most of the practices experience the use of Asphalt membrane. Vertical membrane cutoffs have not been used extensively because of the construction problems. But it is a logical and successful method for existing pavements than the horizontal membrane. Moreover, using impervious clay compacted 85% or more of standard proctor density at optimum moisture content, a very effective vertical moisture barrier, than the membranes, can be obtained.

This method could have been a solution to the failure cases of Addis-jimma Road Projects. But the cost estimate of the method has to be evaluated prior to the applications.

Sketch for moisture barrier

However, this method is more effective for soils with medium to high swelling potential and for arid to semi-arid climatic conditions.

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):

- Impermeable and extended shoulder width (at least 2m)
- 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.

ii. Use of Surcharge

This could also be one of the methods to prevent the pavement movement by confining the sub grade. Based on the case reports for the Botswana pavement construction projects, a large crack from toe of embankment was observed after completion of the project. This resulted from the very high swelling soils underneath the embankment. Moreover, surcharge method is most effective when swell pressures are low to moderate and with some tolerable heave.

However, as we saw in the analysis of design depth, it is not viable solution to surcharge a sub grade above 3meters height, due to the settlement conditions. Thus, it could be used for low to medium swelling soils.

Generally, due to their vast applications, the following techniques are evaluated.

- i) Excavation and replacement
- ii) Lime stabilization
- iii) Surcharging by fill
- iv) Moisture barrier (Asphalt membrane), for vertical and horizontal cases

A summary of the evaluation based on performance is presented on table12.

2. Comparison based on economical considerations

Although good performance could be achieved by the above methods, their economic advantage might be meaningful to towards their effectiveness.

Hence all the above methods are analyzed with respect to the following factors:

- 1. Cost of construction
- 2. Estimated time of construction

It should be noted that the cost parameters used, in this analysis, are based on the current prices and appropriate combination of machinerics excluding the managerial cost parameters.

It should also be noted that the cost estimate for the Moisture Barriers is not as easy as those of the common methods; a rough value per unit of measurement is assumed. Thus, to have a clear evaluation of the methods, all the methods are considered by their cost per longitudinal length of the pavement (Birr/m²/km).

Moreover, the following assumption are taken for comparison purpose:

1. Asphalt membrane and impervious clay to be used as moisture barrier
2. Soil Replacement for minimum case of depth of 0.50m (i.e. low to medium swelling potential), and maximum case of depth of 2.5 to 3m (i.e. high to very high swell).

Cost comparison of the above methods based on the preliminary cost estimate is shown on table13.

A Summary of the evaluation of these methods, based on the economical consideration, is shown on table 12.

Moreover, a general summary of the evaluations of the design and construction method is shown in table14.

Table12

Table13

Table14

Hence, base on the above comparison, the following observations can be viewed.

1.The use of lime is possible for the following conditions:

- Scarcity in nearby borrow source
- Hauling distance greater than 20km
- Shallow depth of active zone

2.The use of surcharging technique seems reliable, but it requires the availability of nearby sources and possible up to height of 3 meters.

3.The use of Asphalt membrane moisture barrier is possible only when the application of the other method is limited to less than 30km hauling distance.

In general, to make an effective selection of design or construction methods, it is necessary to adopt an appropriate procedure that would give suitable value of the following parameters:

1. Degree of expansiveness of the site
2. Appropriate CBR design value
3. Appropriate design depth that would combat the possible heave of the area.

Conclusion and Recommendation

4.1 Conclusion

Based on the results of the research, the following conclusions can be made:

1. Prior knowledge of the type of failure could assist to verify the cause and mechanism of remedial actions.
2. Degree of Expansiveness has a detrimental effect on the effectiveness of the design and construction practices.
3. In cases where the laboratory determination of swelling characteristics is difficult, Equation (1), (3), (4), (5), (8) could give a good estimate of heave and swelling pressure values respectively. That is equation (4) & (1) resulted in good values for soils with very high and medium swelling potential respectively. Similarly, for soils with high swelling potential, good result have been obtained from equation (3)&(5).
4. Based on the pavement survey, the CBR criteria couldn't result in reliable solution in case of pavement on expansive subgrade. Additional Stability Criteria should be adopted to resist the heaving conditions.
5. The Tanzanian design method is more reliable and economical than the other methods for swelling subgrade conditions under all cases of degree of expansiveness.
6. The design depth recommended in most of the design methods is limited to 60 to 120cm and insufficient to resist the

heave of very high swelling clays. It has to be increased to maximum of 3m depending on the loading and soil conditions.

7. The surcharge height or replacement depth is limited to maximum of 3 meters since more height would require long term settlement analysis due to the increased stresses.
8. 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.
9. The choice of the appropriate construction method is a function of primarily the climatic variations and soil conditions of variable degree of expansiveness.
10. Based on the evaluation of the methods, the selection procedure is a function of economy and performance

4.2 Recommendation

Based on the results from the research, the following can be recommended:

- 1. The design depth considered in swelling subgrade should be adjusted with respect to the values computed for the various cases of degree of expansiveness.**
- 2. In selecting appropriate design and construction methods, it is more convenient to use the recommendation on table (12) and (14).**

3. The Darshanamurphy and Raman (1975) modified Plasticity chart appears to be a suitable method in the determination of the degree of expansiveness.
4. In using the most common construction technique, soil replacement, the depth of replacement and embankment height should be selected according to the curves provided for each case of soil conditions.
5. The design depth computed in the research is based on the improved subgrade made with 15-20% increased density but further computation could be made for different densities so as to get reduced design depth.
6. The results of the test data taken for the compilation of this thesis consider a representative samples taken at 0.5 to 1.50m to be constant through out the depth. But to get an accurate estimate of the heave and swelling pressure, the testing should extend to account the variation of atterberg limits with depth.
7. Although a flexible pavement design approach is assumed in the thesis, the whole concept can be extended for rigid pavement despite the additional consideration for rigid condition.
8. The conventional method considers CBR value at adverse condition (soaked). But this could give conservative and economically unfeasible conditions for arid climate. For the sake of completeness of the research

the same approach is assumed but the CBR value based design for arid climate should be checked for reduced CBR value.

9. The evaluation and analysis made in the research considers same traffic condition under variable climatic cases but the research should extend to various traffic conditions.
10. During the application of any of the construction methods, it is necessary to supplement a method that would minimize the moisture variation in the subgrade.
11. Undue delay of the construction practices to improve or replace the subgrade increases the effectiveness of the methods.