



**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**ASSESSMENT OF DAMAGES CAUSED BY EXPANSIVE SOIL ON ROADS  
CONSTRUCTED IN ADDIS ABABA**

By.

**DESALEGN WORKIE MELAK**

2022

Addis Ababa, Ethiopia

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**School of Civil and Environmental Engineering**

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**MASTER OF ENGINEERING PAPER WORK**

By

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ADVISOR: HENOK FIKRE (Dr.-Ing)

**ASSESSMENT OF DAMAGES CAUSED BY EXPANSIVE SOIL ON ROADS  
CONSTRUCTED IN ADDIS ABABA**

**A project**

**Submitted in partial fulfillment of the requirement for the Degree of Master of  
Engineering in Civil Engineering (Geotechnical Stream)**

**By**

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## DECLARATION

First, I declare that this paperwork is my original work and that all sources of materials used for this paper have been properly acknowledged. It has been assisted by Dr:-Ing. Henok Fikre and submitted to Addis Ababa Institute of Technology department of civil and environmental engineering geotechnical stream.

Desalegn Workie

Name



Signature

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I would like to express my deepest appreciation to the Ethiopian Roads Authority for sponsoring us to attain our second-degree program at the Addis Ababa Institute of technology.

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Finally, my special praise will go to my family, brothers, sisters, and dears who are close and stands with me throughout my life for every success.

## ABBREVIATIONS

AAiT	Addis Ababa Institute of Technology
AACRA	Addis Ababa City Roads Authority
AASHTO	American Association of State Highway and Transportation Officials
AMCE	Auto Manufacturing Company of Ethiopia
CBR	California Bearing Ratio
CS	Collectors Streets
DCP	Dynamic Cone Penetrometer
DPI	Dynamic Penetration Index
EBCA	Ethiopian Building Construction Authority
ERA	Ethiopian Roads Authority
GIS	Global Information System
LL	Liquid Limit
LS	Local Streets
MDD	Maximum Dry Density
Mn/DOT	Minnesota Department of Transportation
PAS	Principal Arterial Street
PI	Plasticity Index
USCS	Unified Soil Classification System
SAS	Sub Arterial Street

## Abstract

Roads are one of the basic infrastructures and serve as means of a communication system for any country. The investment budgeted and the cost for original construction and repair of roads of our country is relatively high.

Most of the time road lines constructed in our country failed early before functioning the design life. This is because of various problems arising from different causes. Among these roads which are failing before serving its design life is the Addis Ababa Roads. The main reason is that large areas of these roads are constructed on problematic expansive soils. This is due to improper construction and operation of the road.

It is well known that Addis Ababa is a populated and investment area as it is the capital city of Ethiopia. As a result, the roads in Addis Ababa serve or carry the highest daily traffic in the country. These roads were constructed and opened to traffic in different years accordingly. The design pavement life was estimated at 15 and above years, however; pavement structure failures have been observed since construction time, within the first few years after opening to traffic.

From the end of construction to date, the Addis Ababa roads are repeatedly under periodic maintenance. Considerable resources were spent during this period on periodic maintenance, but without solving the basic problem. This maintenance is not working as each maintained section is failing within a short period, hence, it needs to investigate the root causes of the failure to come up with an appropriate solution.

This paper tries to present some issues of geotechnical cases for roads built on expansive soils. Some case study sites, representatives knew problem-areas in Addis Ababa were carefully selected for geotechnical site investigation. The field exploration consisted of detailed observation and measurement of damaged roads. These road damages have been identified and characterized based on the theoretical aspect of soil property and its effect on construction. This work was also have been used any secondary data concerning the study area as a baseline and it was helped as an input.

Field investigations which include visual condition survey, DCP test, Benkelman Deflection measurement, and other methods were conducted to investigate causes of failure.

Finally, based on the investigation, all causes of road failure are identified. Based on the identified damage types and their causes, maintenance and rehabilitation mechanism or techniques are recommended and suggested.

**Key Words: Pavement Failure, Condition Survey, CBR, Maintenance, DCP, Deflection**

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## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1. Background

The Road network in our country Ethiopia is poor and slowly developing. This problem is clear for all individuals and it is common to both urban and rural areas of the country. Especially in urban areas because of the high population and their movement, existing roads are not sufficient and satisfactory both in quality and quantity. The quality of roads can be affected by different things. The soil on which the roads are constructed, economy, and the implementing quality of road project construction are the most important factors of determining the final road performance. The characteristics of foundation soil can have a large effect on road infrastructure. Those roads constructed on expansive soil need full attention during design, construction, and operational time.

Expansive soils are generally characterized by the presence of clay minerals of the montmorillonite (smectite) group. Such soils pose problems in civil engineering works due to their ability to withstand large surfaces. Volume changes with changes in moisture content, which expands and shrinks as soil moisture changes. The expansive nature of the clay is less near the ground surface where the profile is subjected to seasonal and environmental changes. The more water they absorb the more their volume increases. Expansive soils also shrink as they dry. Fissures in the soil can also develop. These fissures help water penetrate deeper layers. This produces a cycle of shrinkage and swelling that causes the soil to undergo a great number of volume changes. This movement in the soil results in structural damages especially in lightweight structures such as one and two-story buildings, warehouses, retaining walls, sidewalks, driveways, basements, pipelines, and foundations[3].

Expansive soils cover large areas of Addis Ababa city. According to the zonation system, Eastern, Southern, and parts of Western Addis Ababa, the soil is characterized as expansive. And due to this problematic soil, significant damages to lightweight structures like irrigation systems, water lines, sewer lines, buildings, roads, and other structures are observed. The damage caused by expansive soils tends to invest the country in billions annually. However, behind it is evident the lack of knowledge of the behavior of the road subgrade expanding road platform the damages of pavements mainly due to the uplift forces and heave following wetting of the soil. Therefore, the early identification and understanding of such soil are necessary to avoid costly problems.

Engineering problems due to expansive soils have been reported in many countries all over the world, costing millions of dollars due to severe damages of structures. These damages are most common, especially in arid and semi-arid regions[15].

Damages are usually manifested through the crack of floors and walls, stacked windows and doors, bulged floors and tilted walls and structures of buildings and on-road structures like rutting, longitudinal and transversal cracks, block cracks, edge failure, corrugation, bulge, shoving, etc. are observed. The number of damages can be extended even to the extent of the failure of one or all structures by decreasing the structural safety of the building, road, or any infrastructure. In some cases, maintenance and repair costs may also exceed the original cost of the construction and cause an additional financial burden on the concerned bodies. In general, the damage will result in economic loss for clients and the country at large[15].

This project aims to study the causes of failures of roads constructed on expansive soils of central parts of Ethiopia where expansive soil is prevalent. The present asphalt road surface condition needed some sophisticated tools to systematically identify pavement distresses which enable stakeholders to take remedial action. Having a good understanding of the causes of the failure of roads, anyone can take proper remedial measures like revising designing methods, construction methods, and maintenance of roads appropriate for the area. This in turn will be helpful for the road authority and the road users in particular and the whole of the country at large by reducing the maintenance and vehicle running costs.

## **1.2. Statement of the Problem**

In any construction, failure could occur both before and after serving its design life due to different reasons. Like other construction, roads are one of the highly exposed to damaged types of construction in our country. This is as a result of its lightweight structure type and directly contacting the foundation soil, drainage, and exposure to different load types.

The major causes of failure and destruction during the construction and service of any infrastructure are related to the expansive soil which is constructed on it. Population centers and development areas like Addis Ababa obviously lead to the question of how much damage will be sustained by the buildings and other infrastructures constructed or being constructed. Therefore, it is necessary to understand the properties of the soil and handle the problem related to expansive soil. The first step to handling the problem related to road failure is identifying the root cause and characterizing them. Therefore, all road damage

types due to expansive soil will be assessed wisely in detail, and in addition, solutions to the problem will be suggested.

### **1.3. Objectives**

#### **1.3.1. General Objective**

The general objective of the study is to assess damages caused by expansive soils of roads constructed in Addis Ababa city.

#### **1.3.2. Specific Objectives**

The specific objectives of this paper include the following:

- Determine the engineering material properties of the study area soil.
- Investigate the suspected causes of road damages constructed on expansive soils of Addis Ababa
- Conduct condition survey data from selected areas on the road section under investigation.
- Study and assess the pavement stress types and their extent.
- Assess the maintenance practice in the study area

In general, all the necessary data has been collected through a different mechanism from selected road sections.

Finally, based on the investigated information and results found, conclusions and recommendations are made.

### **1.4. Research Question**

The questions that have been answered at the end of the study are listed as follows:

1. What are the estimated engineering material properties of the damaged road section profile/layer?
2. What are the causes of road pavement failure which is related to foundation soil?
3. What are the types of road damages observed on roads constructed on expansive soils in Addis Ababa?

4. How are the maintenance practice and application mechanisms trained by the concerned bodies in the study area?
5. What are the effective mechanisms used to maintain the damaged pavement section?

### **1.5. Significance of the Study**

The outcome of this research will be used as an input for the design of different structure foundations and roads that will be constructed in Addis Ababa where expansive soils are found. This will contribute a great role for different contractors who involve in the construction of buildings, roads, and different infrastructures in this town. This study is also basically used to know road damage types due to the problematic expansive soil and to maintain the damaged section effectively. And it will also help as an insight for researchers to study further.

### **1.6. Scope of the Study**

Thematically, the research is geared towards assessing road damages caused by expansive soils on roads constructed on problematic soil, and those are found in some specific locations of Addis Ababa city but does not consider the detailed assessment throughout the whole areas of the city. Regarding data collection, visual condition surveys and DCP are vital to collect and identify the pavement damages there.

### **1.7. Limitations of the Study**

The nature of the study requires sufficient data of the specified area and the integration of secondary data with the primary data. The soil material property shall be directly investigated from the exact point of the existing already failed area of each location. But, the selected road pavements are serving transportation throughout the day and night time. This is one of the challenges to take the required sample from the corresponding distress points. In addition to that, it is also difficult to gate the DCP test machine for all the tests because there is a single machine in AACRA, and its reserved and limited in the specification. All these are limit the validity of the study

## 1.8. Description of the Study Area

### 1.8.1. Location

Addis Ababa lies at an elevation of 2,300 meters and is a grassland biome, located at  $9^{\circ}1'48''N$   $38^{\circ}44'24''E$  Coordinates, The city lies at the foot of Mount Entoto and forms part of the watershed for Awash. From its lowest point, around Bole International Airport, at 2,326 meters above sea level in the southern periphery, the city rises to over 3,000 meters in the Entoto Mountains to the north.(Global Information System-GIS)

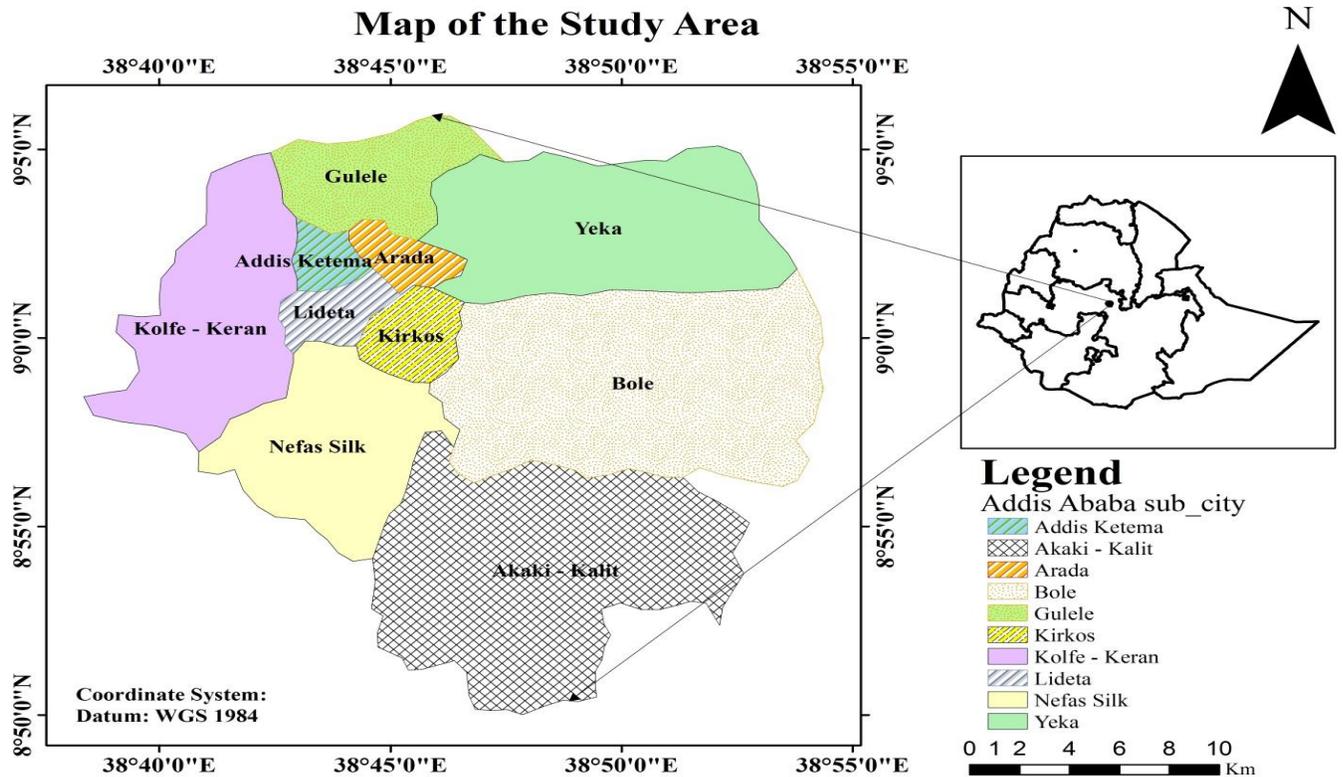


Figure 1.1 Map of the study area

### 1.8.2. Climatic Condition

Addis Ababa has a sub tropical highland climate and the city has a complex mix of highland climate zones, with temperature differences of up to  $10^{\circ}C$  ( $18^{\circ}F$ ), depending on elevation and prevailing winds. The high altitude moderates temperatures year-round, and the city's location near the equator mean temperatures are very consistent from month to month. As such the climate would be maritime if its elevation was not taken into account, as no month is above  $22^{\circ}C$  ( $72^{\circ}F$ ) in mean temperatures. Mid-November to January is an occasional rainy season. The highland climatic regions are characterized by dry winters and it is the dry season in Addis Ababa. During this season, daily high temperatures generally do not exceed  $23^{\circ}C$  ( $73^{\circ}F$ )

and nighttime low temperatures can drop to freezing. The short rainy season extends from February to May. In this period, the difference between daytime maximum temperatures and nighttime minimum temperatures is not like this as good as at other times of the year, with minimum temperatures between 10 and 15 °C (50–59 °F). At this time of year, the city experiences warm temperatures and pleasant rains. The main rainy season extends from June to mid-September; it is the country's main winter season. This period coincides with summer, but the temperatures are much lower than at other times of the year due to frequent rains and hail, heavy cloud cover, and few hours of sunshine. This time of year is characterized by dark, cold, and humid days and nights. The autumn follows is a transitional period between the wet and dry seasons. The highest temperature on record was 32 °C (90 °F) 27 August 1996, while the lowest temperature on record was 0 °C (32 °F) on 23 November 1999. Throughout the year, 1,160 mm (46 in) of rainfall, with a maximum from June to September, is the only remarkably rainy period. From November to February, there is little rain, and rare showers occur; from March to May, afternoon showers become a bit more frequent, occurring for 7/10 days per month, while in July and August, they occur nearly every day.

Table 1.1 Addis Ababa climate data

<u>Climate Data for Addis Ababa</u>													
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year
Record High °C	28	27	30	28	30	28	30	29	30	29	29	32	32
Average High °C	21.7	22.7	23	22.9	23.5	24.5	25.4	24.8	25.2	23.4	20.7	20.7	23.21
Daily Mean °C	16.2	15.7	14.8	14.9	15.4	16.6	17.9	17.9	18	17	15.9	15.8	16.34
Average Low °C	10.7	8.7	6.7	7	7.4	8.7	10.5	11.1	10.8	10.6	11.1	11	9.53
Record Low °C	4	2	0	0	1	1	3	6	6	1	0	6	0
Average Rainfall mm	149	27	7	7	13	30	58	82	84	138	280	290	1,165
Average Rainy Days	18	4	1	1	3	5	7	10	10	20	27	26	132
<u>Average Relative Humidity (%)</u>	71.5	47.5	48	45.5	47	51.5	47.5	54.5	53	67.5	79.5	79	57.67
<u>Mean Daily Sunshine Hours</u>	5	8	9	9	9	9	8	7	8	6	3	3	7

### 1.8.3. Addis Ababa Road Network

Ethiopia's capital city Addis Ababa is developing its road network with a series of projects underway. At present Addis Ababa's road network extends for a **total of 5,915km**, compared with 5,365km in 2014. Meanwhile, 2,616km of the city's roads are surfaced with asphalt, around 44% of the total network. Much of the road expansion and maintenance program has been devised by the Addis Ababa City Roads Authority (AACRA).

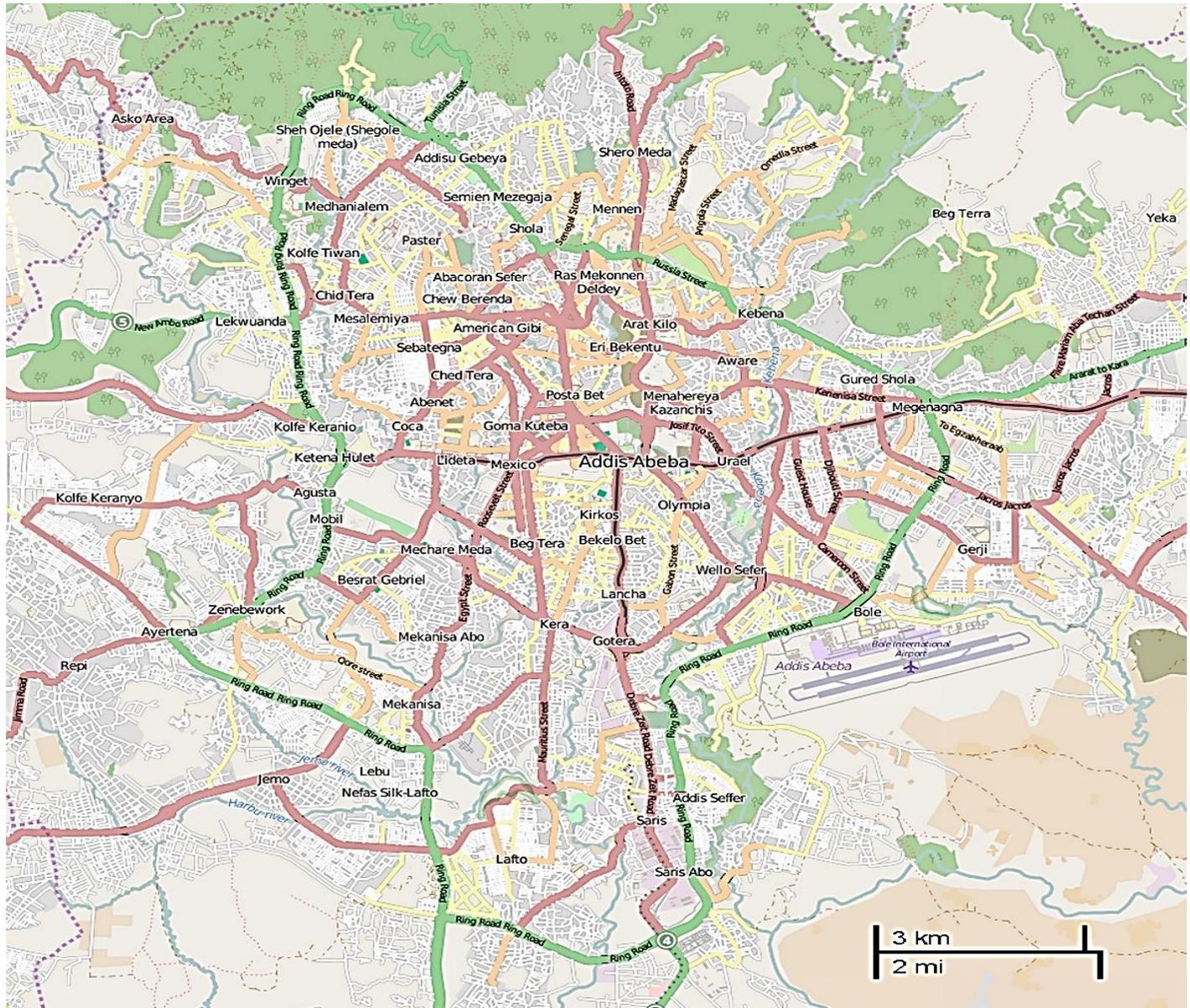


Figure 1.2 Addis Ababa Street Map

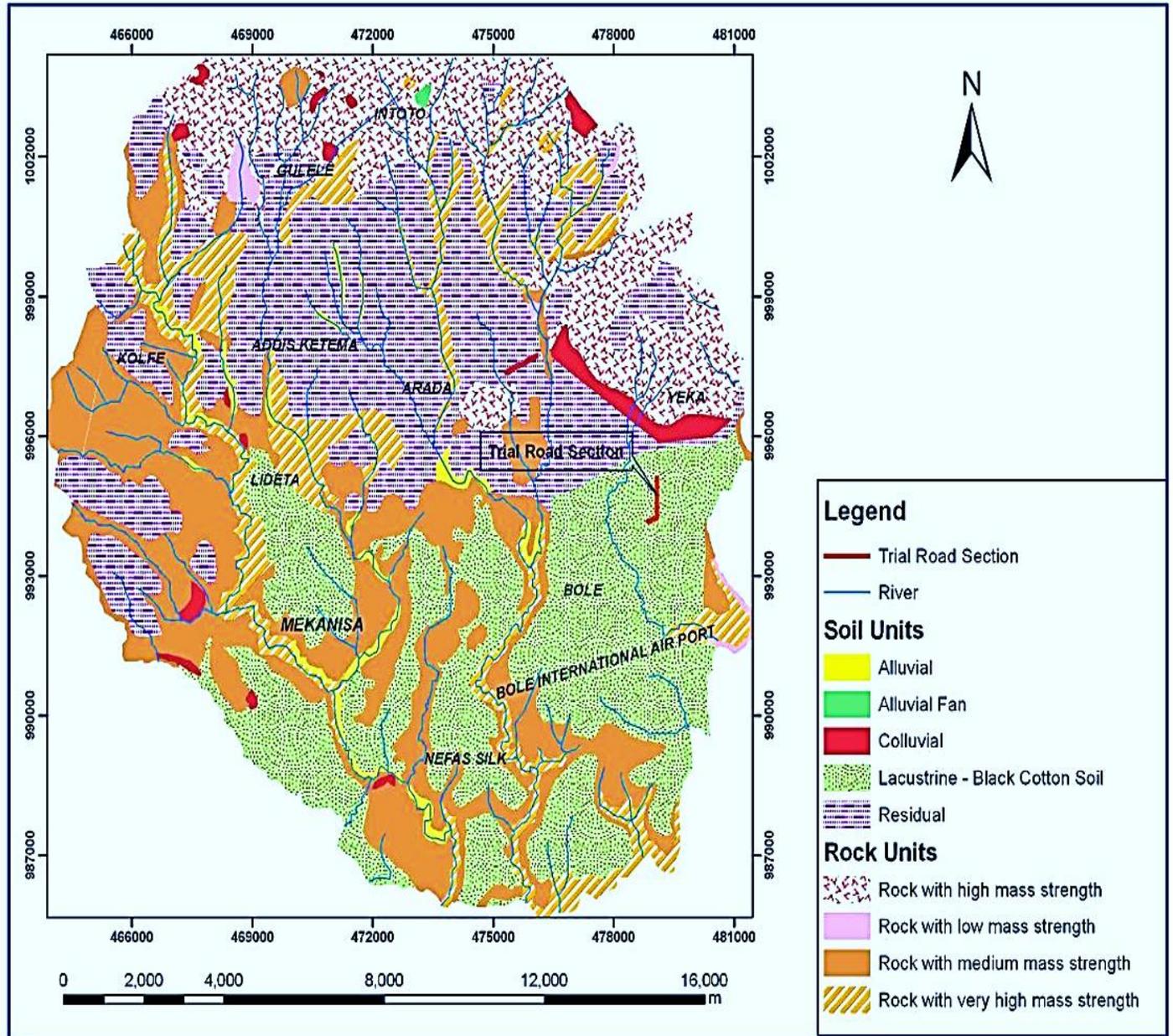


Figure 1.3 Engineering soil map of Addis Ababa (Kebede Tsehayu et al.)

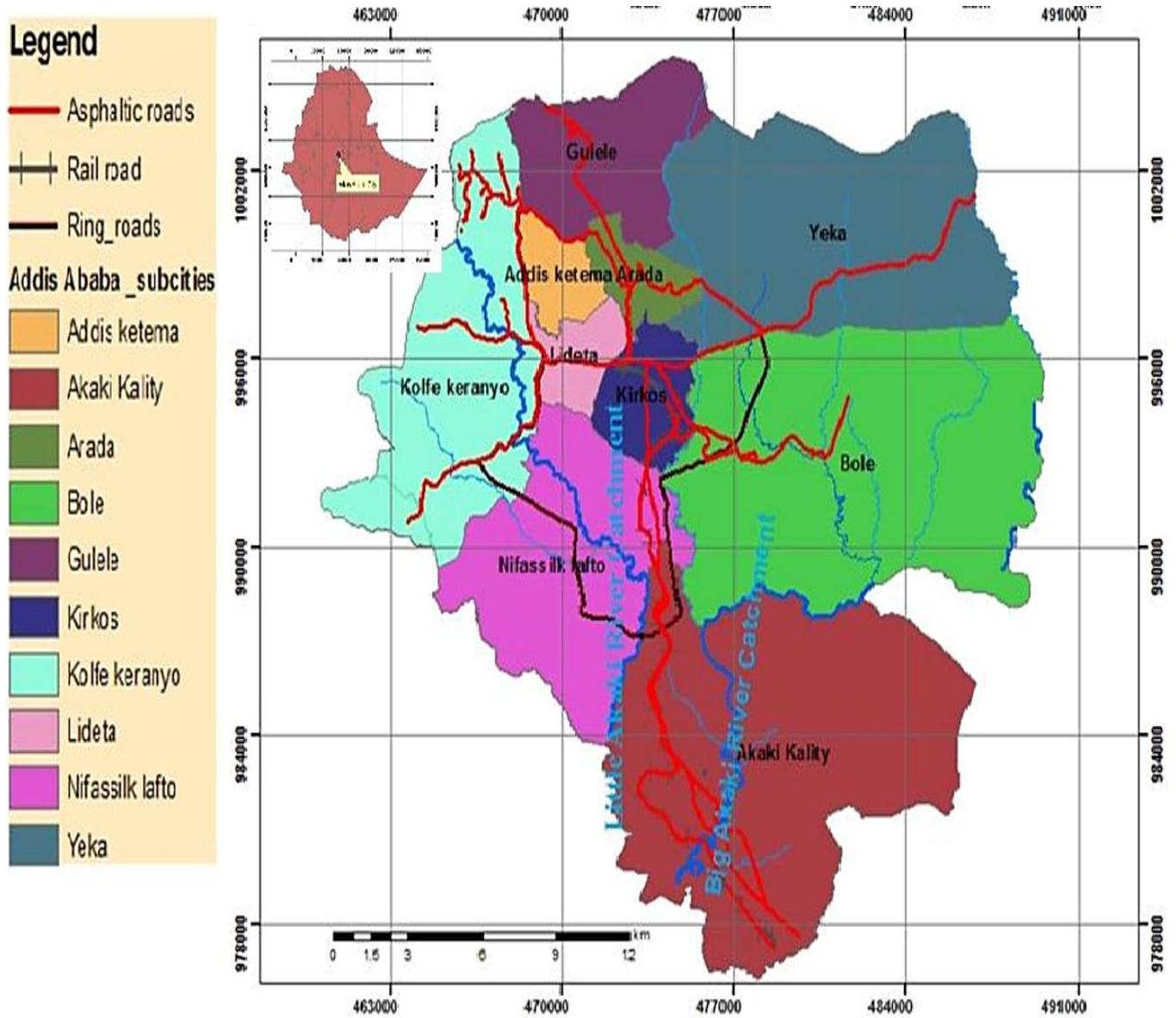


Figure 1.4 Addis Ababa location, sub-city, and main roads

## **1.7 Organization of the Research**

This research document is arranged into five chapters. Chapter one is the introduction and consists of the background of the study, problem statement, research objective, research question, the significance of the study, the scope of the study, limitation of the study, description of the study area, the definition of terms and the organization of the study. Chapter two is a literature review of general and specific cases which are related to the project topic. This chapter presents the nature of expansive soil and its effect on constructions, distress on pavements, possible cases of pavement distress, distress types, and Dynamic cone penetrometer test machine and its purpose in field test of soil properties determination. Chapter three, In this chapter, the primary and secondary data and test results are organized and mentioned. Soil properties of the selected area and the observed road defects are clearly identified and presented there. Chapter four includes the interpretation of data and findings. Possible causes of pavement distress are discussed and some remedial measures are listed. The final chapter five consists of the conclusion and recommendation.

## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1. Expansive Soils

Expansive soil is a term generally applied to any soil or rock material that has a potential for shrinking or swelling under changing moisture conditions [1]. Soils with a high percentage of swelling clay have a very high affinity for water partly because of their small size and partly because of their positive ions [2]. The swelling behavior is generally attributed to montmorillonite, a lattice clay mineral that expands in expansive soils. According to Chen [3], montmorillonite consists of a central octahedral sheet, usually occupied by aluminum or magnesium, sandwiched between two sheets of tetrahedral silicon sites to give a 2 to 1 lattice structure. The three-layered clay mineral, as shown in Figure 1, has a structural configuration and chemical composition that allows a large amount of water to be adsorbed in the interlayer and peripheral positions on the clay crystalline, resulting in the remarkable swelling of the soil, [4].

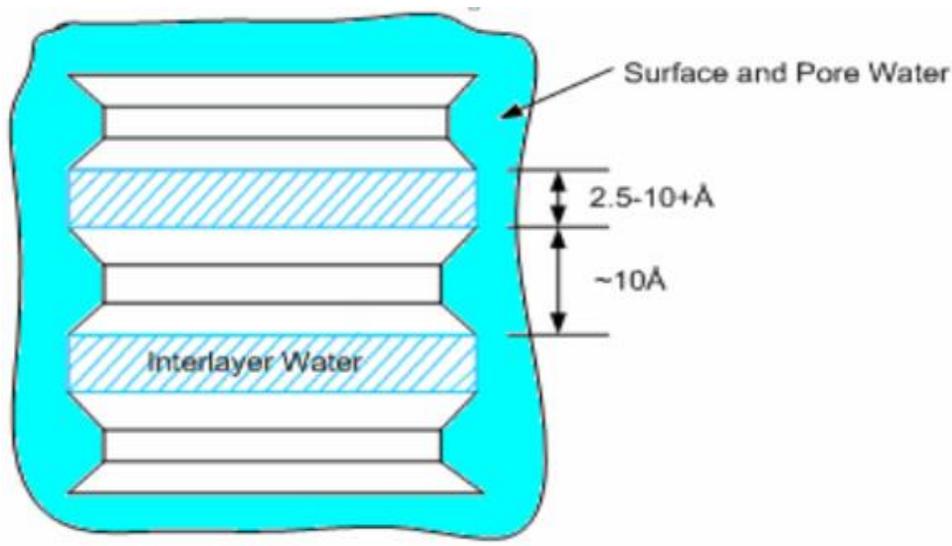


Figure 2.1 Structure of montmorillonite clay mineral

#### 2.2. How Can Expansive Soil Affect Structures?

As the soil gets into moist, expansive soil will absorb water and swell up; as a result, the whole ground level rises. This increase in ground level is usually called free-field heave. However, if a structure is built on such a soil deposit, the foundations form an obstruction to the soil to freely move up, and consequently,

the soil applies upward pressure on the foundation. This pressure that the soil applies to the foundation is called swell pressure. If the footing transfers downward stress which is smaller than the swelling pressure, the footing moves upward. These upward and downward movements of foundations become cyclic seasonal movements during the entire life span of the structure. These cyclic movements tend to tear up the walls and eventually destabilize the whole structure. Light structures, such as single or double-story residential buildings, pavements, etc. which generally transmit smaller stresses to the soil than the swell-pressure are those that suffer the damage most.

Once the structure develops cracks, it is hardly possible to rehabilitate it without significant expense. Building a house and roadways for most people is a lifetime venture and if they occur on expansive soil, the investment needs to be safeguarded. Therefore, there is a need for the public to be aware of the implications of building and roads on expansive soils, in order to identify the problem at an early stage rather than regret later [7].

According to the study by Nelson and Miller [6], there are different geotechnical techniques to identify expansive soils. As the result of the surface study, the geological and geomorphological descriptions are more advantageous indicators of expansive soils. The surface examination has been considered first because of its importance in the determination of subsurface exploration. Field estimates of volume change potential can be made by looking at desiccation cracks (Figure 2.2). The development of drying cracks on the soil surface is evident during periods of drought. The degree of swelling potential determines the size of the cracks, [2]. The large swell potential is indicated by large and more frequent polygonal arrangements of cracks while low shrink/swell means that the potential for shrinkage cracks developing is low. Soils containing expansive clays become very sticky and plastic when wet and adhere to the soles of shoes or tires of vehicles. They are also relatively easy to roll into small threads. The surface examination by visual-manual descriptive of the soil must be followed according to ASTM [5]. This standard insists, among other things, the reporting of the color, moisture condition, consistency, structure, and particle sizes.



Figure 2.2 Expansive soil showing withering cracks.

The geological description is usually obtained by the study of the site history and geological maps. Information on the maps can give a valuable idea of the soil composition as the preliminary information for further investigation, [8]. The geo-morphological description includes a host of many things such as groundwater table situation, soil physical properties such as color, consistency, surface texture, structure and texture groups, etc. Most of the physical and mechanical properties relevant to providing indicators of swelling potential are obtained perform property tests of geotechnical indices such as Atterberg limits, unit weights, and particle size distribution. Other direct tests to determine swelling potential include volume change tests (free swelling and swell in odometer test), swelling pressure test, and mineralogical compositions by x-ray diffraction (XRD) test. Indirect methods for determining the swelling characteristics of soils are essentially based on mathematical correlations of certain Physico-chemical properties and mineralogical composition. They empirically correlate soil index parameters such as water content, dry density, Atterberg limits, clay content, etc. To expansiveness. Nayak and Christensen [9] gave statistical relationships for swell percent (S) and swelling pressure (P) as:

$$S = (2.29 \times 10^{-2})(I_p)^{1.45} \times \frac{C}{w_i} + 6.39 \quad (1)$$

$$P = 2.5 \times 10^{-1})(I_p)^{1.12} \times \frac{C^2}{w_i^2} + 25 \quad (2)$$

Where,  $S$ : is the swell percent,  $P_s$ : is the swelling pressure in  $\text{KN/m}^2$ ,  $IP$ : is plasticity index,  $C$ : is the clay content,  $w_i$ : is the initial water content.

The detection and evaluation of swelling property is an important factor in the design and construction of pavements on expansive soils. The determination of the swelling capacity according to the Casagrande plasticity table is shown in Figure 3 proposed by Chleborad et al [10]. It is observed that soils with high swelling potential are traced in the typical domain of montmorillonite. Uline marks the upper limit of natural soils, so no land should trace above Uline. Another method to characterize problematic soil is to use the activity method developed by Cartel and Bentley [11].

**Table 2.1 Expansive characterization of soil**

Range	Free swell %
Expansive	> 100
Marginal	50-100
Non expansive	<50

The proposed classification chart is shown in Figure 2.3. The activity term in the Figure is defined as follows:

where  $PI$ : is plasticity index,  $C$ : is colloids (or clay) content.

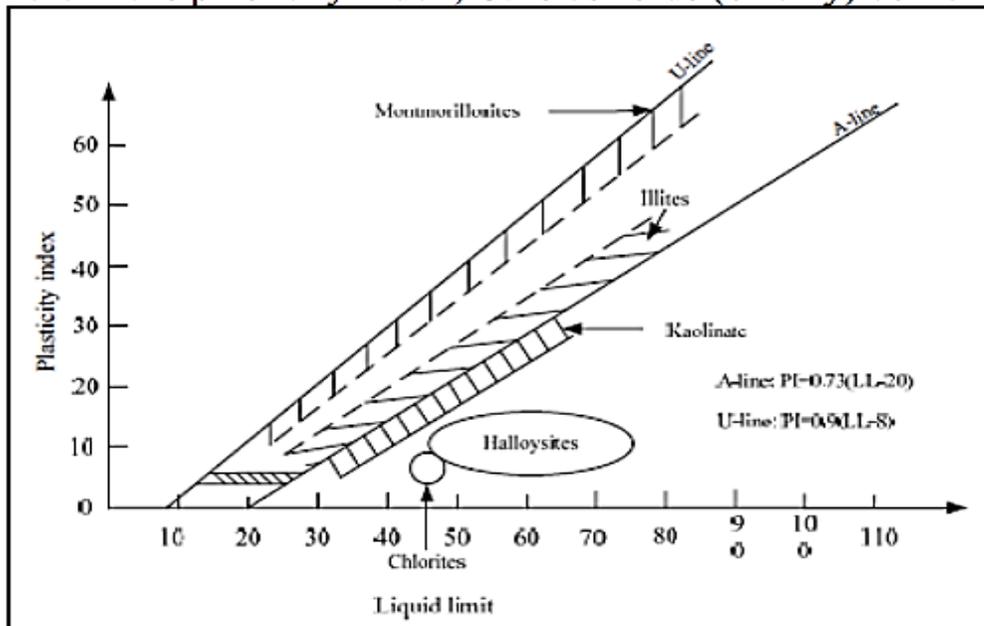


Figure 2.3. The plot of clay minerals on Casagrande's chart,

### **2.4.1. Distress**

Distress is an important factor in pavement design and management. In the empirical methods, each failure criterion should be developed separately to take care of each specific distress.

### **2.4.2. Types of Distress**

- i. Alligator or fatigue cracking
- ii. Block cracking
- iii. Joint reflection cracking from concrete slab
- iv. Lane/Shoulder drop off or heave
- v. Longitudinal and transverse cracking
- vi. Pumping and water bleeding
- vii. Rutting
- viii. Swell
- ix. Edge failure

#### **2.4.2.1. Alligator or Fatigue Cracking**

Simply put, alligator cracking occurs when the pavement supports loads that the supporting structure cannot support. As with any surface, put enough pressure on the asphalt and it will crack. Asphalt road finish levels required a desirable foundation to withstand traffic smoothly. If small cracks of pavement damage are not treated, they allowed moisture to spread the base and subfloor. The top face of the pavement can no longer bear the weight of vehicles, so the widespread cracking form of alligator asphalt happens.



Figure 2.4 Alligator crack

#### **2.4.2.2. Cracking**

Repeated traffic loading is the main cause of crack development. Cracks are classified into different types named as fatigue, block, edge, longitudinal, reflection, and transverse, depending on the shape of the cracks and the location of crack development.

##### **Block cracking**

Block Cracking is **a series of interconnecting cracks that form in a roughly rectangular pattern**. It can occur in both concrete and flexible road pavements.

Block cracking is mainly caused by shrinkage of the asphalt concrete and daily temperature cycling, and it is not load associated. The appearance of cracks in the blocks usually indicates that the asphalt has hardened significantly. Block cracking normally happens over a large portion of the pavement surface.



Figure 2.5 Block cracking

### **Longitudinal and transverse cracking**

Longitudinal cracks are parallel to the pavement's centerline or along the roadway direction. Whereas, transverse cracks extend across the pavement at roughly right angles to the centerline of the pavement or direction of the roadway line.

Longitudinal cracks are caused by poorly constructed paving lane joint, temperature cycling, reflective cracking in a base layer, or volume changes in the subgrade.

Longitudinal cracks caused by sub-grade movement will generally be quite long and can meander across the carriageway. These can occur because of poor construction practices, swelling in the plastic subgrade, or embankment materials, and the settlement or collapse of embankments.

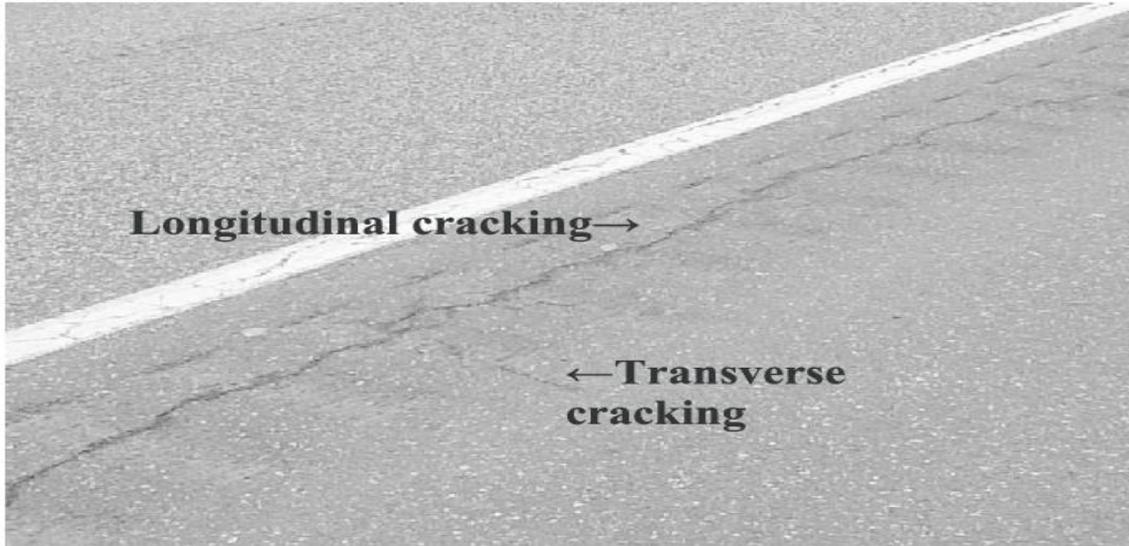


Figure 2.6 Longitudinal and Transverse cracking

#### **2.4.2.3.Patching and Potholes**

When a portion of pavement surface is removed and replaced with additional material applied to the pavement after original construction, it is called patch deterioration. Potholes are bowl-shaped holes in the pavement surface with various dimensions.

#### **2.4.2.4.Surface Deformation**

Two specific types of surface deformation are rutting and shoving. Rutting is a longitudinal surface depression caused by traffic loading. Shoving is the longitudinal and vertical displacement of a localized area of the pavement surface, caused by braking or accelerating vehicles. It is usually found at intersections or on hills or curves.

##### **Rutting**

When a permanent deformation or consolidation builds up in asphalt is called a Rutting. This is usually seen from the wheel path dug into the road. The rut can be triggered by a lack of adequate densification, inadequate pavement thickness, and poor asphalt mixes. Some of the typical causes of the rutting can be lack of proper mix design or manufacture (e.g., when a large amount of asphalt content, traffic load too high, an insufficient amount of corner aggregate particles) Subgrade rutting Subgrade changes under load.



**Figure 2.7 Rutting crack type**

### **Swell**

Swelling soils, also known as expansive soils, are ones that swell in volume when subjected to moisture. If this increased pressure exceeds surcharge pressure (including the weight of the overlying pavement) the soil will expand in volume to a point where these pressures are once again in balance.

#### **2.4.2.5.Surface Defects**

The most common surface defects are bleeding, polished aggregate, and raveling. Bleeding is the presence of excess bituminous binder on the surface of pavement which occurs in the wheel paths. Polished aggregate is the condition of a pavement when the surface binder is worn away and the coarse aggregate is exposed.

Raveling is the wearing away of the pavement surface caused by dislocating of aggregate particles and loss of asphalt binder. It ranges from loss of fine aggregate to loss of some coarse aggregate and ultimately to a very rough and pitted surface with obvious loss of aggregate.

#### **2.4.2.6.Miscellaneous Distresses**

Lane-to-shoulder drop-off and water bleeding and pumping are two types of miscellaneous distresses. When there is an elevation difference between the pavement surface and the outside shoulder is called lane-to-shoulder drop-off. The main reason for this distress is the settlement of the shoulder due to pavement

layer material differences. The bleeding of water and the pumping of fine materials occurs under the pavement through the cracks. Determining this failure and its reasons are necessary to facilitate correction in a design and construction mix for future projects. Types of pavement distress are indications of the cause of the pavement failure. It has been noted by different researchers. That, pavement distress (like ruts, Potholes, Raveling/freights, cracks) exhibited on the road surfaces were related to possible causes. According to (Woods and Adcox, 2004), pavement failure can be considered as a structural, functional, or material failure or a combination of these factors. Structural failure is the loss of load-bearing capacity, where the flooring is no longer able to absorb and transmit the wheel loading through the structure of the road without causing further deterioration. There were different possible causes for these types of road pavement failures.

### **Lane/Shoulder drop off or heave**

A shoulder or pavement edge drop-off refers to a defect of road geometry where the elevation change (vertical distance) between the travel lane and its adjacent shoulder, or between two travel lanes, exceeds acceptable limits. Because of the drop-off, the driver may move out of the travel lane.



Figure 2.8 Drop – significant grade due to erosion

Generally, the common types of road damages and the possible causes of this distress are summarised in the following table.

Table 2.2 Common type of pavement distress and its possible causes

Distress	Possible causes
Potholes	-Localized disintegration of the pavement surface. -Continued deterioration of another type of distress. Segregation, cracks, or failed patches may serve as the start of a pothole. -Poor mixtures and weak spots in the base or subgrade accelerate pothole failures.
Raveling	-the poor quality mixture -traffic loading
Rutting	-Instability of base surfacing. -Post-construction compaction. -Deformation or consolidation of any of the pavement layers or subgrade.
Alligator crack	-Inadequate pavement thickness -Fatigue failure due to brittle base
Longitudinal crack	-Cut/fill differential settlement -Fatigue failure of asphalt concrete
Transverse crack	-Reflection of shrinkage cracking
Shoving	-Inadequate pavement thickness -Poor bond between layer
Corrugation	-Instability of asphalt concrete or base course

Pavement failure is quantified by its extent (length of road affected) and its severity. The level of quantified damage is divided into three i.e., Level -1, Level -2, and level -3, ERA manual.

Table 2.3 Road pavement failure quantifications

Damage	Pavement failure severity		
	Level – 1	Level -2	Level -3
Deformation/rutting	Perception to user but small depth <2cm	Sever deformation, localized subsidence or rutting $2 \leq d \leq 4$ cm	Deformation severely affecting safety or travel time $d > 4$ cm
Crack	Hairline cracks in wheel path or centerline	Open or branching cracks	Markedly branched or wide-open cracks
Crazing	Fine crazing with no loss of materials large mesh (>50cm)	Tighter crazing (<50cm)	Very open crazing forming blocks (<20cm) accompanied by loss of materials
Patch and repair	Rebuilding of pavement	Surface work-related	Surface work-related
Pothole	A number less than 5 diameter not more than 30cm (per 100m of pavement)	Number 5 to 10 diameter 30cm to 100cm (per 100m of pavement)	Number >10 diameter 30cm to 100cm (per 100m of pavement)
Raveling	Localized	Continuous	Continuous and road base visible

### 2.5. DCPT (Dynamic Cone Penetration Test)

A dynamic cone penetration test or DCPT is a quick, simple, and low-cost test that is extensively used by many agencies around the globe to measure the strength of compacted material of unbound granular and sub-grade layers with reasonable accuracy.

DCP testing is used to determine the strength of the subsurface and the design load of the soil. The engineers perform the testing in-situ to give an estimation of the load-bearing capacity that soil can withstand, by measuring the extent of penetration into the ground of a calibrated tip or cone.

Since 1993, the DCP has been used by Mn/DOT as an acceptance tool for the compaction of pavement edge drain trenches. The penetration of the lower shaft into the soil after each hammer drop. This value is recorded in millimeters (inches) per blow and is known as the DCP penetration index (DPI).

### **Benefits of DCP**

One can collect information from a lot of points relatively quickly, so you can see how soil conditions vary across the site and respond accordingly. One gets accurate and precise information on the soil conditions in the field and at construction time.

Nowadays DCPT is commonly used during construction for the following purposes.

- To control the quality of construction
- To determine in situ CBR value
- To evaluate the quality of flexible pavement

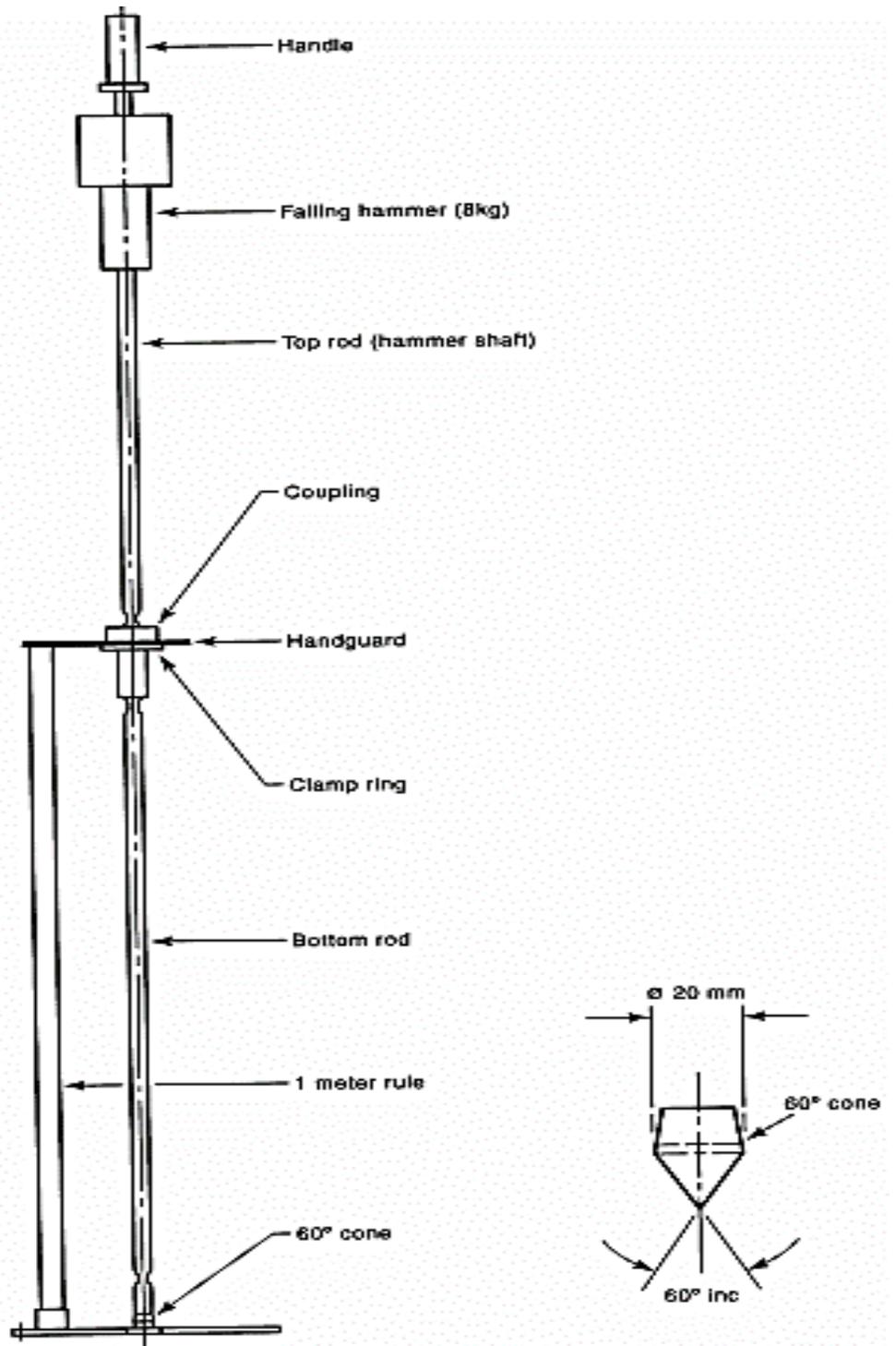


Figure 2.9 Dynamic cone penetrometer

### 2.5.1. Calculation of CBR Value from DCPT Result

Follow the below-mentioned step-by-step procedure to calculate the CBR value using the DCPT result.

Procedure

1. Record the initial reading on the dynamic cone penetrometer scale.
2. Calculate the value of penetration (in mm) for each blow by subtracting the previously recorded reading (i.e. reading on the scale) from the current reading.
3. Calculate the cumulative depth of penetration (in mm) for each blow by adding all the previous individual depth of penetrations.
4. Draw a chart using the data of cumulative depth of penetration and number of blows.
5. This step is about identifying the depth of each layer. Identify the slope change of the penetration curve. Every change in slope represents a change in layer type.
6. After identifying each slope change, calculate the average penetration/blow for each slope change and calculate the thickness of each layer.
7. Use the following equation and determine the corresponding CBR value of each layer.

$$\log_{10} \text{CBR} = 2.48 - 1.057 \log_{10} (\text{DCPI}_{60})$$

8. To know the variation of the CBR value across the depth, draw another semi-log chart with CBR values on a logarithmic scale as abscissa (x-axis) and depth of penetration on the ordinary scale as ordinate (y-axis).

## CHAPTER THREE

### 3. DATA COLLECTION, PROCESSING, AND RESULTS

#### 3.1. Sampling and Data Collection

Under the process of data collection, the following activities were conducted to keep the quality of data for achieving the objectives of the study.

1. Sources of data were identified
2. Mechanisms of getting any required information for this paperwork have been organized.
3. Especial, site visual condition survey and DCP test, secondary laboratory and research result data were used.

In order to achieve the objective of this research, a site conditional survey and DCP test are conducted on selected sites. On the other side, secondary laboratory experimental data which is already done on some selected and representative areas of the proposed sites were taken and used. These data are found from the research result of “INVESTIGATIONS ON THE EXPANSIVE SOILS OF ADDIS ABABA” by Alemayehu Teferra and Solomon Yohannes (Civil Engineering Department Addis Ababa University) which is evaluated in different layers of soil material, with respect to its standards and manuals. The other secondary data were collected from AACRA road maintenance, road asset, and laboratory staff. The characteristics of the material data are examined in accordance with standards methods of testing road construction materials and American Association of State Highway and Transportation Officials (AASHTO), American society for testing and materials (ASTM), Ethiopian Road Authority (ERA) Manual, and Addis Ababa City Road Authority (AACRA) manuals.

#### 3.1.1. Soil Material Strength and Engineering Property Test Data

In this study to characterize the causes of road damage determining the engineering properties of sub-grade soils is very important. Having this soil property, one can match the types of failure with its possible causes. In order to know the properties of soil in the study area, two types of methods have been used. The first one is the direct Dynamic cone penetrometer (DCP) field test and the other is secondary data of laboratory tests which were conducted by researchers (“INVESTIGATIONS ON THE EXPANSIVE SOILS OF

ADDIS ABABA” by Alemayehu Teferra and Solomon Yohannes (Civil Engineering Department Addis Ababa University)) and other concerned bodies (AACRA).

### **INVESTIGATIONS`USING LABORATORY TEST**

The study has focused on the eastern and southern parts of Addis Ababa, where expansive soils are predominant. In that study, laboratory tests on samples taken from six different locations are conducted. Correspondingly different areas of road damage located within the region where the soil was investigated were assessed.

To determine the geotechnical properties of the existing soils, samples were taken from the following sites [13].

- 1) Old Airport—Highr 24, Kebele 13.
- 2) Bole Road (near Commercial School Alumina Association) ---- Higher 18, Kebele 26.
- 3) Near Civil Aviation Radio Transmission Station ---- Higher 17, Kebele 23.
- 4) In front of Auto Manufacturing Company of Ethiopia (AMCE) ---- Higher 17, Kebele 24.
- 5) In the compound of Yared Church (Nifas Silk) ---- Higher 19, Kebele 50.
- 6) In the compound of Ethiopian Building Construction Authority (EBCA) ---- Higher 19, Kebele 47.

Laboratory tests consisting of specific gravity, moisture content, total unit weight, dry unit weight, Atterberg Limits, free swell, swelling pressure, and activity were carried out for the soil samples. The results are given in Table 3.2.

Table 3.1 Laboratory test results for some selected areas [13].

Location	Depth (m)	Colour	Specific Gravity Gs	Natural moisture $\omega$	Total unit weight $\gamma$	Dry unit weight $\gamma_d$	Liquid limit $\omega_l$	Plastic limit $\omega_p$	plasticity Index Ip	shrinkage limit $\omega_s$	Free swell	Swelling Pressure	Clay content	Activity
AMCE	1.20	black	2.63	38.60	18.40	13.30	102.00	24.00	78.00	12.00	130	125	50.00	1.60
	2.00	grey	2.60	32.60	18.50	13.90	123.00	30.00	93.00	9.00	120	125	70.00	1.30
Bole road	1.00	black	2.65	32.40	17.90	13.50	110.00	35.00	75.00	12.00	150	188	60.00	1.30
	2.00	grey	2.64	34.80	18.30	13.60	108.00	22.00	76.00	13.00	140	220	55.00	1.40
Civil Avation	1.20	black	2.66	36.70	18.20	13.30	94.00	22.00	72.00	10.00	130	157	45.00	1.60
EBCA	1.00	black	2.69	30.20	18.20	14.00	101.00	26.00	75.00	9.00	140	251	30.00	1.50
	3.00	grey	2.48	34.80	18.00	13.40	87.00	15.00	72.00	10.00	90	94	40.00	1.80
old air port	1.00	black	2.78	39.30	18.20	13.10	98.00	30.00	68.00	14.00	140	235	50.00	1.40
Yared church	1.00	black	2.69	40.00	17.60	12.60	114.00	25.00	89.00	11.00	125	94	60.00	1.50
	2.00	grey	2.56	32.00	17.70	12.60	107.00	25.00	82.00	8.00	170	188	47.00	1.80

Expansive soils are generally characterized by the presence of clay minerals of the montmorillonite (smectite) group. Such soils give rise to problems in civil engineering works because of their capacity to undergo large volume changes with changes in moisture content, which expand and shrink when the moisture in the soil varies.

These soils are either black or grey in color with thickness ranging from a few centimeters to several meters depth. The topsoils are characterized by black color and some soils with a depth greater than a meter are likely grey.

Table 3.2. Percentage of montmorillonite present in the soil samples tested

Location	Depth (m)	Colour	Amount of montmorillonite (%)
MCE	1.20	Black	50.00
	2.00	Grey	45.00
Bole road	1.00	Black	46.00
	2.00	Grey	78.00
Civil Aviation	1.20	Black	75.00
EBCA	1.00	Black	2.69
	3.00	Grey	2.48
old Airport	1.00	Black	2.78
Yared church	1.00	Black	2.69
	2.00	Grey	2.56

### Discussion of Lab Results

The investigation test results are plotted on the plasticity and Activity Charts (Figure 3.1 and Figure 3.2)

Those figures show that:

- ❖ All samples are inorganic clays of high plasticity
- ❖ All samples are located between Activity 1 and 2
- ❖ There is no clear distinction between the black and grey soils with regard to plasticity and activity.

### Swelling Potential

The swelling potential of the samples is calculated according to the empirical formula of Anderson [12].

$$S = 0.23I_p - 3.12$$

Where S = Swelling potential

$I_p$  = Plasticity Index.

Anderson has correlated swelling potential with the degree of expansion as given in Table 3.3.

Table 3.3. Relationship between swelling potential and degree of expansion according to Anderson (12)

Degree of Expansion	Plasticity Index ( $I_p$ )	Swelling Potential (S)
Low	20	1.5
Medium	20 – 31	1.5 – 4.0
High	31 – 39	4.0 – 6.0
Very high	>39	>6.0

The swelling potential and the degree of expansion of the soil samples are given in Table 3.3.

We can see that in Table 3.3, all sample soils indicate having a very high degree of expansion.

### Swelling Pressure

The swelling potential is derived from or manifested by potential pressure. Since swelling pressure is the actual pressure required to keep the volume of swelling soil constant. The sample test finding shows that both the black and grey soils can induce high swelling pressure.

Table 3.4. Swelling Potential and degree of expansion of the tested samples [13].

Location	Depth (m)	Colour	Amount of montmorillonite (%)	Plasticity Index $I_p$	Swelling Potential $S_p$	Degree of Expansion
AMCE	1.20	Black	50.00	78.00	14.9	Very high
	2.00	Grey	45.00	93.00	18.3	Very high
Bole road	1.00	Black	46.00	75.00	14.1	Very high
	2.00	Grey	78.00	76.00	14.4	Very high
Civil Aviation	1.20	Black	75.00	72.00	13.4	Very high

<b>EBCA</b>	1.00	Black	2.69	75.00	14.1	Very high
	3.00	Grey	2.48	72.00	13.4	Very high
<b>old Airport</b>	1.00	Black	2.78	68.00	12.5	Very high
<b>Yared church</b>	1.00	Black	2.69	89.00	17.5	Very high
	2.00	Grey	2.56	82.00	15.9	Very high

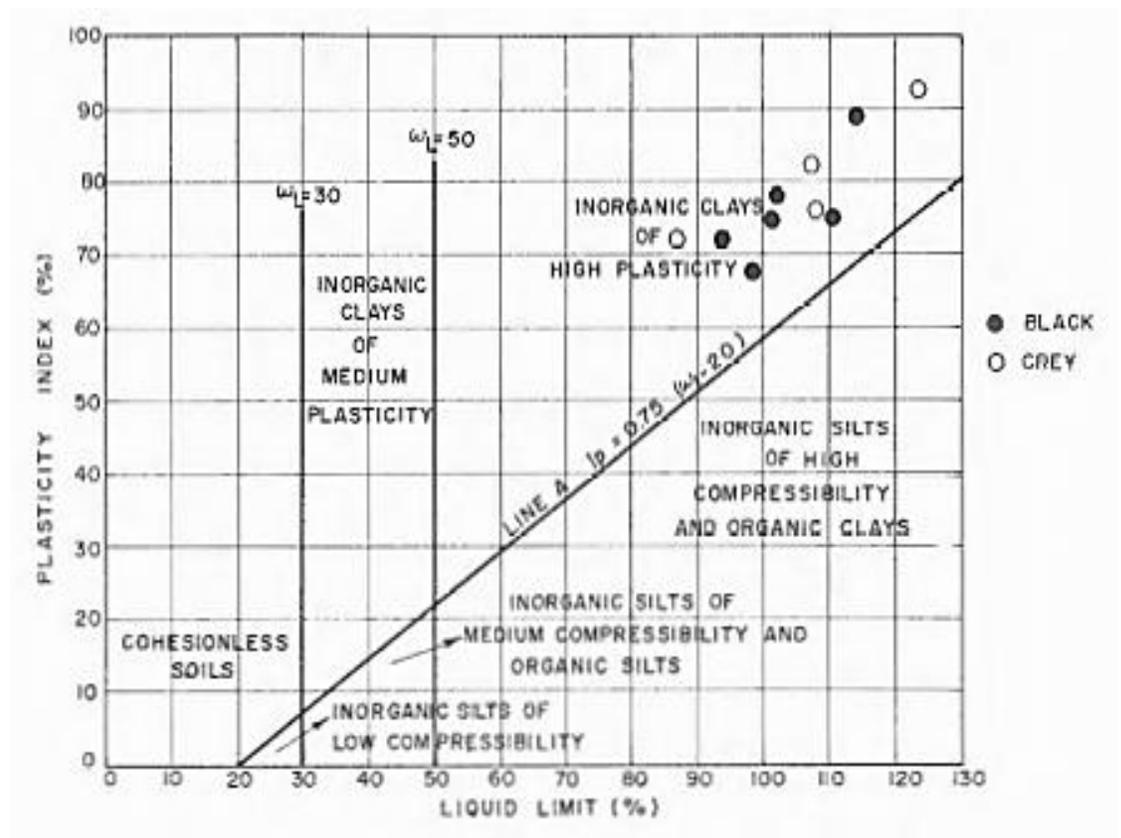


Figure 3.1. Plasticity Chart

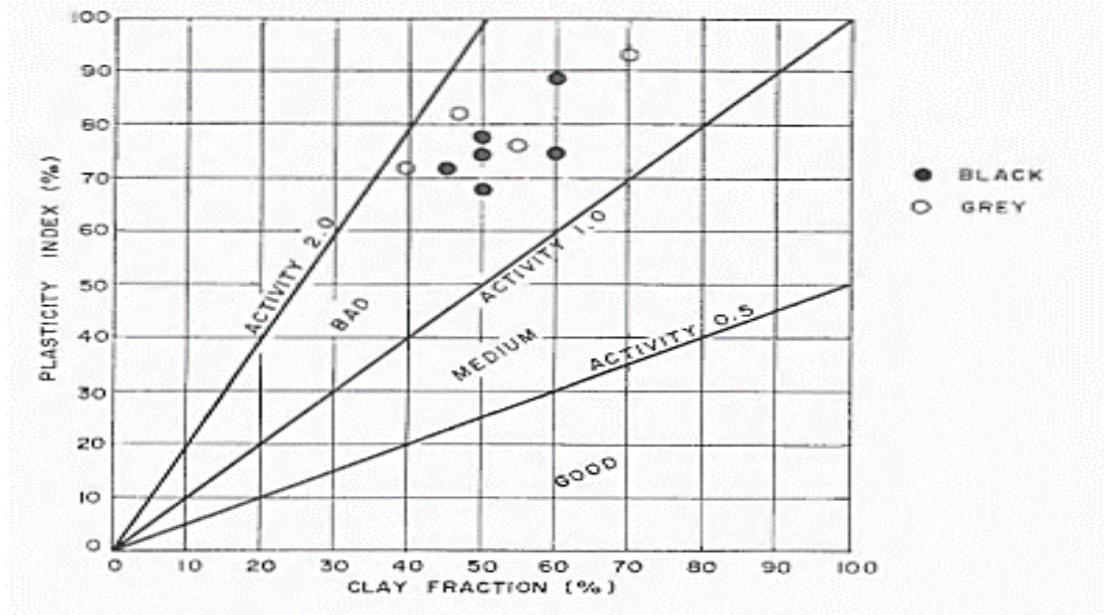


Figure 3.2. Activity Chart

The other soil investigation data results are collected from the Akaki Kaliti site conducted by AACRA staff researchers for sub-grade material characterization and strength improvement and Jemo 2 site investigated by our group during soil exploration class. These sites are also poor sub-grade and black cotton expansive soils. The engineering material property laboratory test results are summarized as follows.

Table 3.5 Laboratory test result for Akaki and Jemo

Location	Depth (m)	Natural Moisture content	Liquid limit	Plastic limit	Plasticity index	Free swell	Specific gravity
Akaki Kaliti		27	102	48	54	140	2.6
Jemo	1.5	28.2	152	39	113	130	2.51
	3	43	103	56	47	120	2.76

## Test results from dynamic cone penetrometer (DCP) test

Our country's previous practice shows that dynamic cone penetration (DCP) tests are widely conducted on bridge design. Even though, the DCP test is very quick and easy to conduct the test result is used with other field and laboratory test results. In this study, DCP tests were used to determine the material strength of road profiles for some selected sites. The test results of the existing road section sub-grade CBR value are relatively large. This is happened due to the modified nature of the soil during the construction and service period. The CBR value of expansive soils or weak and unsuitable soils in the natural condition is very small (less than 5%). On the other hand, the CBR values of good materials give a large value.

Table 3.6. Tabulated correlation of CBR versus DCP index

DCP Index mm/blow <sup>A</sup>	CBR %	DCP Index mm/blow <sup>A</sup>	CBR %	DCP Index mm/blow <sup>A</sup>	CBR %
<3	100	39	4.8	69–71	2.5
3	80	40	4.7	72–74	2.4
4	60	41	4.6	75–77	2.3
5	50	42	4.4	78–80	2.2
6	40	43	4.3	81–83	2.1
7	35	44	4.2	84–87	2.0
8	30	45	4.1	88–91	1.9
9	25	46	4.0	92–96	1.8
10–11	20	47	3.9	97–101	1.7
12	18	48	3.8	102–107	1.6
13	16	49–50	3.7	108–114	1.5
14	15	51	3.6	115–121	1.4
15	14	52	3.5	122–130	1.3
16	13	53–54	3.4	131–140	1.2
17	12	55	3.3	141–152	1.1
18–19	11	56–57	3.2	153–166	1.0
20–21	10	58	3.1	166–183	0.9
22–23	9	59–60	3.0	184–205	0.8
24–26	8	61–62	2.9	206–233	0.7
27–29	7	63–64	2.8	234–271	0.6
30–34	6	65–66	2.7	272–324	0.5
35–38	5	67–68	2.6	>324	<0.5

<sup>A</sup> For DCP Index in units of in./blow, divide by 25.4.

Pictures of field DCP tests are presented as follow;



The available Dynamic Cone Penetrometer test machine with its bag in AACRA



DCP Test on site

Table 3.7. DCP datasheet and CBR result of Wolo Sefer – St. Urael Road

DCP Data Sheet							
Project:-Wello Sefer- Urael							
Lacation;- 0+160 (RHS)					Personnel:-		
Depth of Zero Point Below The surface:- -					HammerWeight:-8Kg		
Material Classification:-					Weather:-		
Pavement Condition:-Asphalt Road					Water Tabel depth:- N/A		
No of Blows (A)	Total number of blows	Cumulative Penetration (B) mm	Penetration b/n reading (C) mm	Penetrion per blows (D=C/A) mm	Hammer Factor €	DCP Index (F=D*E) mm/blow	CBR (G)
2	2	8	8	4.0	1	4	10
2	4	16	8	4.0	1	4	10
2	6	19	3	1.5	1	2	10
2	8	22	3	1.5	1	2	11
2	10	24	2	1.0	1	1	35
2	12	27	8	4.0	1	4	7
2	14	29	2	1.0	1	1	10
2	16	32	3	1.5	1	2	10
2	18	34	2	1.0	1	1	11
2	20	37	3	1.5	1	2	35
2	22	40	8	4.0	1	4	7
2	24	42	2	1.0	1	1	10
2	26	44	2	1.0	1	1	10
2	28	47	3	1.5	1	2	11
2	30	49	2	1.0	1	1	35
2	32	51	2	1.0	1	1	35

Table 3.8. DCP datasheet and CBR result of Mekanissa (around China Camp or St. Gebrael Church)

DCP Data Sheet							
Project:-Around Mekanissa Store							
Location;-						Personnel:-	
Depth of Zero Point Below The surface:- -					40		Hammer Weight:-8Kg
Material Classification:-						Weather:-	
Pavement Condition:-						Water Tabel depth:- N/A	
No of Blows (A)	Total number of blows	Cumulative Penetration (B) mm	Penetration b/n reading (C) mm	Penetration per blows (D=C/A) mm	Hammer Factor €	DCP Index (F=D*E) mm/blow	CBR (G)
0	0	40	40	-	-	-	-
10	10	80	40	4.0	1	4	60
10	20	109	29	2.9	1	3	80
10	30	151	42	4.2	1	4	60
5	35	204	53	10.6	1	11	20
5	40	254	50	10.0	1	10	20
5	45	310	56	11.2	1	11	20
3	48	386	76	25.3	1	25	8
3	51	498	112	37.3	1	37	5
3	54	633	135	45.0	1	45	4
5	59	872	239	47.8	1	48	3.8



Photos of Mekanissa tested soil and DCP test

Table 3.9. DCP datasheet and CBR result of Torhailoch Subgrade Soil

DCP Data Sheet							
Project:-Torhayloch							
Location;- Muluwengel Church (0+30)							
Depth of Zero Point Below The surface:- -			40		Hammer Weight:-8Kg		
Material Classification:-N/A						Weather:-	
Pavement Condition:- Existing Cobble						Water Table depth:- N/A	
No of Blows (A)	Total number of blows	Cumulative Penetration (B) mm	Penetration b/n reading (C) mm	Punition per blows (D=C/A) mm	Hammer Factor €	DCP Index (F=D*E) mm/blow	CBR (G)
0	0	40	40	-	-	-	-
10	10	79	48	4.8	1	4.8	50
10	20	120	41	4.1	1	4.1	60
10	30	160	40	4.0	1	4.0	60
10	40	195	35	3.5	1	3.5	80
10	50	225	30	3.0	1	3.0	80
10	60	258	33	3.3	1	3.3	80
10	70	302	44	4.4	1	4.4	60
10	80	345	43	4.3	1	4.3	50
10	90	395	50	5.0	1	5.0	50
10	100	485	90	9.0	1	9.0	25
10	110	598	113	11.3	1	11.3	20
5	115	713	115	23.0	1	23.0	9
5	120	833	120	24.00	1	24.0	8
10	130	963	130	13.0	1	13.0	16
5	135	1098	135	27.0	1	27.0	7
5	140	1238	140	28.0	1	28.0	7
3	143	1381	143	47.7	1	47.7	3.9

3	146	1527	146	48.7	1	48.7	3.8
3	149	1676	149	49.7	1	49.7	3.7
3	152	1828	152	50.7	1	50.7	3.7
3	155	1983	155	51.7	1	51.7	3.6

From previous laboratory test data results, the CBR values of original expansive soil are less than 2%. For example, as AACRA staff researcher Lab test results (test method AASHTO T-193) the CBR values of Akaki Kality expansive soil for 10, 30, and 65 blows are 1%, 1.3, and 1.5% respectively.

Table 3.10. CBR values for Akaki Kality expansive soil

BLOWS	LOAD (KN)		CBR(%)		DRY DENSITY Vs SOCKED C.B.R.			
	2.54mm	5.08mm	2.54mm	5.08mm				
10	0.14	0.23	1.0	1.1	No # OF BLOWS	10	30	65
30	0.17	0.26	1.3	1.3	DRY DENSITY	1.32	1.47	1.60
65	0.20	0.33	1.5	1.6	SOAKED C.B.R.	1.0	1.3	1.5

### 3.2. Road Damage Condition Survey

A condition survey is generally defined, as a detailed assessment and identification of all important data of the existed construction or else status and performance by professionals.

A road damaged condition survey is a process of collecting any road condition through visual inspection. During condition survey data like location, road type, and use, asphalt distress in all aspects, drainage condition, environmental data, and other necessary information were carefully collected. This condition survey was focused and taken from eastern and central parts of Addis Ababa, where expansive soils are predominant.

In this study, condition survey data were collected from some selected sites and taken from the AACRA maintenance staff database where its soil properties are characterized. Those specific sites are the eastern and southern parts of Addis Ababa (from Megenagna to Mekanissa).

Table 3.11 Condition Survey datasheet

Route Name	Road Type	Road Width	Specific Location	Defect Type	Damage/crack		Severity		Remark
					L(m)	W(mm)	H	M	
Megenagna to Bole Michael	RR	50	B.Road Bridge meg	Raveling	12	1500	x		with block and longitudinal cracks
Megenagna to Bole Michael	RR	50	near to Airline	Crocodile cracking	3	1500	x		
Megenagna to Bole Michael	RR	50	in front of metrology	Rutting	4		x		
Megenagna to Bole Michael	RR	50	near to Bulbula	Raveling	10	1500		x	with block and longitudinal cracks
Megenagna to Bole Michael	RR	50	near to AACRA lotto	Rutting	5			X	
Megenagna to Bole Michael	RR	50	in front of	Rutting	6			X	
Megenagna to Bole Michael	RR	50	level gust house	Raveling	10	5000	x		with block and longitudinal cracks
Megenagna to Bole Michael	RR	50	in front of Panafric	Crocodile cracking	50	3000	x		with block cracks
Megenagna to Bole Michael	RR	50	Metrology	Crocodile cracking	12	5000	x		
Megenagna to Bole Michael	RR	50	in front of AV.	Crocodile cracking	3	2000	x		
Megenagna to Bole Michael	RR	50	in front of AV.	Crocodile cracking	6	2000	x		
Megenagna to Bole Michael	RR	50	Bole Air Port	Raveling	40	0 to 40	x		
Megenagna to Bole Michael	RR	50	"	Transvers Cracks	7	0 to 40	x		

Megenagna to Bole Michael	RR	50	"	Longitudinal Cracks	15	2 to 20	x		
Megenagna to Bole Michael	RR	50	"	Longitudinal Cracks	10	1 to 20		x	
Megenagna to Bole Michael	RR	50	"	Longitudinal Cracks	30	0 to 40	x		
Japan Embassy To RR	PAS	30	Near Safeway Supermarket	Raveling	7	3000		x	
Japan Embassy To RR	PAS	30	Near 2shi Habesha	Crocodile cracking	10	5000		x	
Japan Embassy To RR	PAS	30	Around Bole Medihanialem Church	Crocodile cracking	15	2000		x	
Japan Embassy To RR	PAS	30	Around Bole Medihanialem Church	Longitudinal Cracks	10	0 to 25	x		
Japan Embassy To RR	PAS	30	Around Bole Medihanialem Church	Longitudinal Cracks	15	0 to 28		x	
Japan Embassy To RR	PAS	30	Around Bole Medihanialem Church	Raveling	5	2		x	
Japan Embassy To RR	PAS	30	Around Oromia Insurance	Longitudinal Cracks	25	0 to 30	x		
From Japan Embassy To RR	PAS	30	Around Oromia Insurance	Rutting	7			x	
From Japan Embassy To RR	PAS	30	Bole Medihanialem Church	Longitudinal Cracks	80	0 to 40		x	
From Japan	PAS	30	Urael Bridge	Longitudinal	20	0 to 30	x		

Embassy To RR				Cracks					
Lem Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	21	7000	x		
Lem Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
Lem Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
Lem Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
Lem Hotel to Anbesa Garaj	SAS	20	Megenagna 40/60 condominium	Fully Damaged	100	7000	x		
24 taxi buy to Megenaga Derarettu building	SAS	20	Megenagna 40/60 condominium	Crocodile cracking	7	4000		x	
Golagol to Ednamall	SAS	25	Around Addis Ababa Int'l New Stadium	Crocodile cracking	4	2000		x	
Golagol to Ednamall	SAS	25	Around Addis Ababa Int'l New Stadium	Crocodile cracking	15	4000	x		
Japan Embassy To RR	SAS	25	Near East Africa Avation	Raveling	10	3000		x	

Japan Embassy To RR	SAS	25	Near East Africa Aviation	Crocodile cracking	7	4000		x	
AMCHE through Egziabherab Church to 138	SAS	25	Around AMCHE	Crocodile cracking	10	3000	x		
AMCHE through Egziabherab Church to 138	SAS	25	Around AMCHE	Crocodile cracking	35	2000	x		with block cracks
AMCHE through Egziabherab Church to 138	SAS	25	Around AMCHE	Crocodile cracking	9	2000	x		
AMCHE through Egziabherab Church to 138	SAS	25	Near western University college	Crocodile cracking	9	5000	x		
AMCHE through Egziabherab Church to 138	SAS	25	Near western University college	Longitudinal Cracks	6	2000		x	
AMCHE through Egziabherab Church to 138	SAS	25	Near western University college	Crocodile cracking	5	3000		x	
AMCHE through Egziabherab Church to 138	SAS	25		Crocodile cracking	15	3000		x	
AMCHE through Egziabherab Church to 138	SAS	25		Longitudinal Cracks	10	3000	x		
AMCHE through Egziabherab Church to 138	SAS	25	Near to AB-HAM	Raveling	30	1000	x		
AMCHE through Egziabherab	SAS	25	Near to agr.Junction	Raveling	6	2000	x		

Church to 139									
127 junction to 181	CS	16		Fully Damaged	20	7000	x		
127 road to 104 road junction	CS	20	Near Jony Garaj	Fully Damaged	50	7000	x		
Bole Bulbula To Medehaniyalem Church	CS	25	Bole Bulbula Bridge	Crocodile cracking	5	3000		x	
Bole Bulbula To Medihanialem Church	CS	25	Bole Bulbula Bridge	Crocodile cracking	10	4000		x	
Bole Bulbula To Medihanialem Church	CS	25	After Bole Bulbula Bridge	Longitudinal Cracks	10	1000		x	
Bole Bulbula To Medihanialem Church	CS	25	Near 40/60 condominium	Crocodile cracking	12	3000		x	
Bole Bulbula To Medihanialem Church	CS	25	Near 40/60 condominium	Crocodile cracking	20	2000	x		
From Bole Bulbula To Medehaniyalem Church	CS	25	Before Bole Bulbula Bridge	Crocodile cracking	10	3000		x	
Bole Michael Church Bridge	CS	25	Bole Bulbula Bridge	Raveling	7	5000		x	
Bole Michael Church Bridge	CS	15	After Bole Michal Church Bridge	Longitudinal Cracks	4	3000		x	
Bole Michael Church Bridge	CS	15	After Bole Michal Church Bridge	Fully Damaged	50	7000	x		
Bole RR To Ruanda Embassy	CS	15	SMMRA HOTEL	Raveling	20	7000	x		

Bole RR To Ruanda Embassy	CS	15	School of tomorrow	Crocodile cracking	15	1000		x	
Bole RR To Ruanda Embassy	CS	15	Near MoHAN	Longitudinal Cracks	3	1000		x	
RR To Ruanda Embassy	CS	15	Near MoHAN	Crocodile cracking	3	2000		x	
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Longitudinal Cracks	25	0 to 30	x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Raveling	20	5000	x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Rutting	6		x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Raveling	15	3000	x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Raveling	25	3000	x		
From Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22		Longitudinal Cracks	30	0 to 20	x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22	channel café	Longitudinal Cracks	15	0 to 20	x		
Bole Medhanialem T junction to RR (Ayat Hospital)	CS	22	Hayat hospital	Longitudinal Cracks	12	0 to 20	x		
Bole Medihanialem	CS	15	Southern side	Crocodile	10	2000	x		

Church				cracking					
Alem building to bole Medhanialem church	CS	15	from to end of the road	Longitudinal Cracks	100	0 to 40		x	
Atlas to Shala	CS	15	Heros café	Rutting	4			x	
Stadium to Getahun Besha bldg.	CS	20	Mechu Bar	Raveling	30	2000		x	
Stadium to Getahun Besha bldg.	CS	20	CCECC Hotel	Rutting	35		x		
Stadium to Getahun Besha bldg.	CS	20	Etete Real State	Raveling	5	2000	x		
Stadium to Getahun Besha bldg.	CS	20	Abay Bank (around Shala)	Rutting	5		x		
Stadium to Getahun Besha bldg.	CS	20	ACLANA Lodge	Raveling	4	2000		x	
St.Gebrael H/1 to 24 taxi mazoria	CS	20	Ethio sentesh yebahel libis bet	Longitudinal Cracks	10	0 to 30	x		
Golagul to sas 120	LS	10	near 118 road	Raveling	20	7000	x		
Golagul to Sas 120	LS	10	near to prominent Eng. solution	Crocodile cracking	6	3000	x		
Golagul to Sas 120	LS	10	Yenegew sew school	Crocodile cracking	5	3000	x		
from Saye Cake to Atlas Hotel	LS	13	RAMADA HOTEL	edge break	25			x	
Saye Cake to Atlas Hotel	LS	10	around Worba apartment	Longitudinal Cracks	5	0 to 25		x	

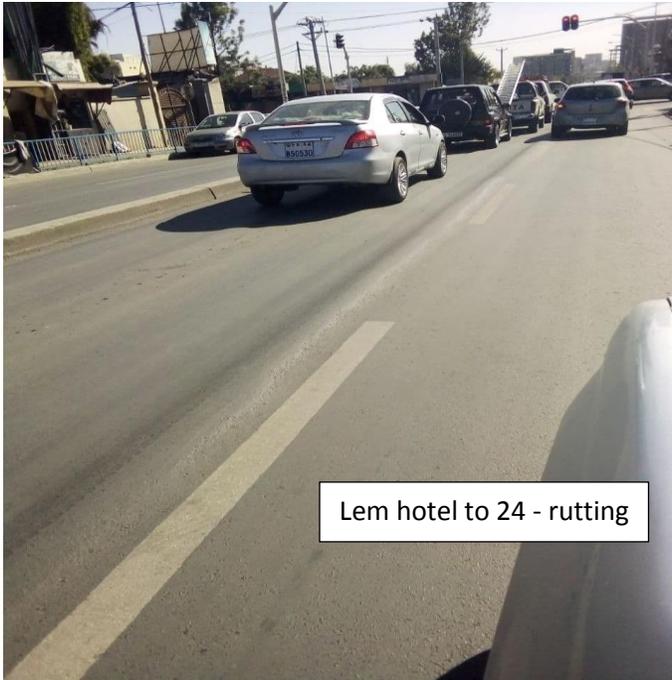
Saye Cake to Atlas Hotel	LS	10	DANISH Refugee council	Longitudinal Cracks	7	0 to 30		x	
Saye Cake to Atlas Hotel	LS	10	above DANISH Refugee council	Longitudinal Cracks	15	0 to 35		x	
Saye Cake to Atlas Hotel	LS	10	above DANISH Refugee council	Longitudinal Cracks	20	1 to 35		x	
AMCHE through EgziarAb Church to 142		25	250m from E/church	Rutting	15			x	
AMCHE through EgziarAb Church to 148		25	Near to Motta	Rutting	8	25		x	

Some evidence of photo samples that are taken from assessed road defects is presented as follows.



Different types of failure observed around Bole airport road

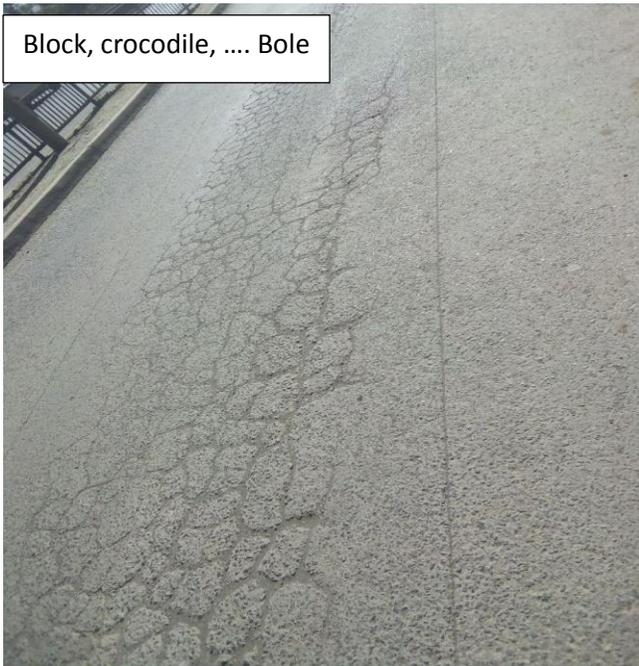




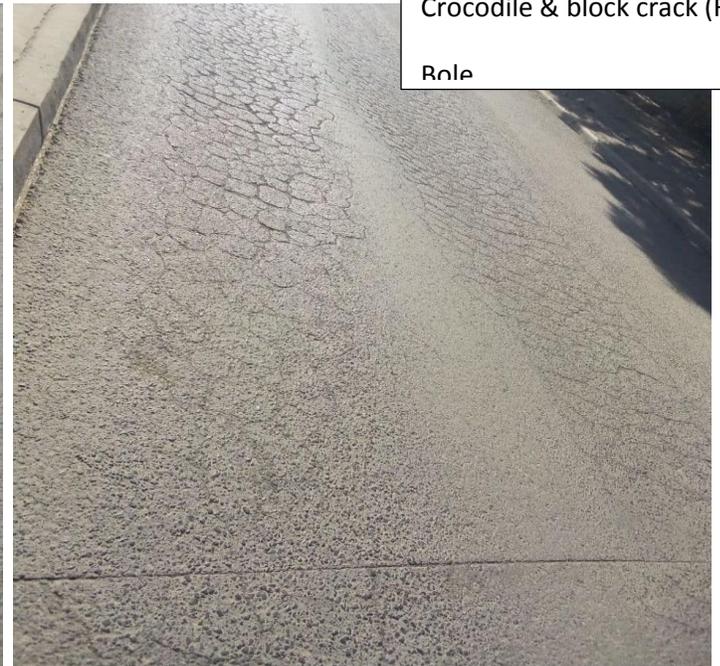
Lem hotel to 24 - rutting



Bole to Bole Michael (CS)- rutting



Block, crocodile, .... Bole

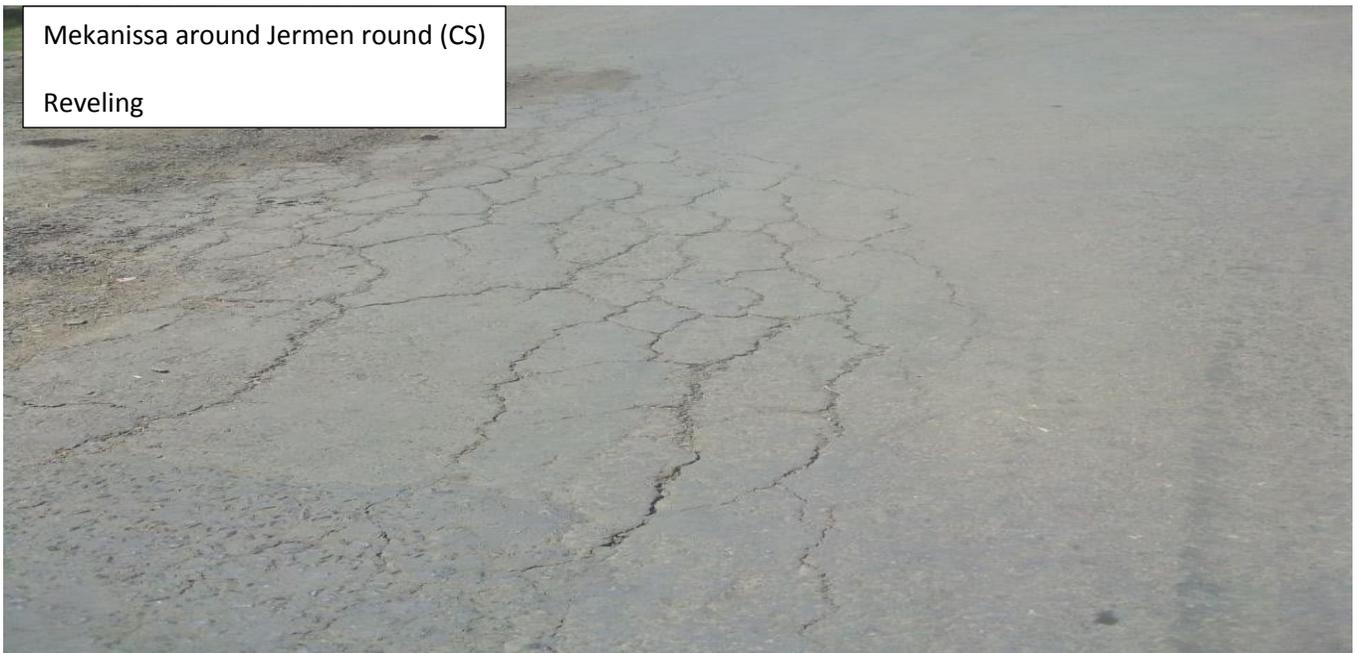


Crocodile & block crack (RR)  
Bole





Emperial (RR)  
Longitudinal crack



Mekanissa around Jerman round (CS)  
Reveling

## CHAPTER FOUR

### 4. INTERPRETATION AND DISCUSSION

#### 4.1. Distress Conditions of the Pavement

##### 4.1.1. Road Pavement Failure and its Impact

Some part of any road network experiences instability due to poor construction, lack of proper maintenance, or the underlying behavior of the soil. Pavement subsidence occurs when the roadway surface no longer retains its original profile and progresses material stresses that cause problems. pavement failure issues encompass cracks, potholes, depressions, ruts, shoves, upheavals, and ravels. The effects of these defects include accidents, loss of time and rapid wear and tear of vehicles, and the consequent loss of financial resources for the maintenance of these cars.

##### 4.1.2. Causes of Road Pavement Failure

The possible causes of road failures were;

- ❖ Insufficient strength properties of bituminous mixes
- ❖ Movement of overloading vehicles
- ❖ Bad drainage condition and
- ❖ Subgrade soil instability
- ❖ Natural disaster.

Due to the lack of appropriate and periodic maintenance of a damaged area, it is gradually increased. As a result, pavement subsidence causes traffic jams, inconvenience, vehicle damage, and accidents. The sub-layer failures of the road asphalt happened were caused by excess groundwater penetrating the base in addition the foundation layers and the engineering properties of the soil were responsible for the subsidence of the road pavement, such as improper compaction, water infiltration by edge breaking, lack of adequate drainage and unsuitability According to (Wazoh, 2016) the defects of roads were possibly caused by deterioration of water pipes passing through the pavement gushing water on the road, indiscriminate disturbance of the road by telecommunications companies, thus leaving room for water to further

deteriorate the An increase in traffic and overloading beyond the carrying capacity of the road by heavy-duty vehicles is another possible factor responsible for the failure of the road.

#### **4.1.2.1. Improper Use and Overloading of Roads**

A sudden increase in traffic load, especially on new roads, where the design relies on light traffic, is a major cause of cracking. After the construction of a good road, traffic of other roads also shifts to that road. This accelerates fatigue failure (alligator cracking). Improper use of roads is a major cause of failure. Excessive loading of the road by overloading vehicles, uncontrolled parking, spillage of petroleum products on asphalt surfaces are just a few examples. Also, major and minor roads now receive traffic loads they were not designed against. After carrying out a traffic study on the Enugu - Port Harcourt road (Osadebe et al, 2013), he realized a high degree of overloading on the road which is one of the major causes of pavement deterioration. This is also the case with many other major and minor roads in the country.

#### **4.1.2.2. Construction with Low-Quality Materials**

The use of poor-quality materials for construction negatively affects the performance of the road. This sometimes occurs in the form of poor classification of aggregates for the base or subbase and poor subgrade with low load-bearing capacity. Base materials with a high fines content were susceptible to loss of strength and load-bearing capacity after wetting (Little and Graves, 1999).

#### **4.1.2.3. Construction with Expansive Subgrade Soil**

Expansive soil as a road subgrade is considered to be one of the most common causes of pavement instability. Longitudinal cracking resulting from volumetric variation in the expansive subgrade is one of the most common distresses that occur on low-volume streets. This type of cracking is initiated by the drying out of the highly plastic subfloor (PI (plastic index) eg; 35) through the pavement structure during the summer. Other forms include fatigue (alligator) cracks, edge cracks, grooves in the wheel path, thrusts, and jumps.

The laboratory test results of the investigated soil are summarized as;

- ❖ All samples are inorganic clays of high plasticity
- ❖ All samples are located between Activity 1 and 2
- ❖ There is no clear distinction between the black and grey soils with regard to plasticity and activity.
- ❖ All sample soils indicate having a very high degree of expansion.

#### 4.1.2.4. Climatic Changes

Climatic factors including rainfall and annual variations in temperature were important considerations in pavement wear. Rainfall has a substantial impact on the stability and strength of the roadway structures for the reason that it disturbs the moisture content of the sub-grade material. The outcome of rainwater on-road asphalts can be damaging because most roadways are designed grounded on a certain period of rainfall data. Vehicles passing on the road exert considerable sudden pressure on the water, this pressure pushes the water further into the road fabric and breaks it up.

This process can be very quick once started. As vehicles pass over the weak spot, the pavement began to crack, and soon the crack is generating multiple cracks. Water then penetrated into surface voids, cracks, and fracture zones. This can deteriorate the structural capability of the asphalt by initiating existing cracks to enlarge. Rainfall can alter the moisture balance and influence pavement deterioration, while sudden temperature changes can affect bitumen aging with the consequent increase in the fragility of the bitumen which causes surface cracks, with the consequent loss of waterproofing of the surface joint.

#### 4.1.2.5. Poor Drainage Condition

In the road construction process moisture is the single most important factor affecting pavement performance and long-term maintenance costs. Therefore, one of the major challenges faced by the designer is to provide a flooring structure in which the adverse effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction/maintenance provisions, and degree of acceptable risk. Excess moisture is known to have a detrimental effect on pavement structures. This also applies to expansive and, to a lesser extent, dispersive soils. Humidity, in combination with other factors, can have a profound negative effect on both the material properties of the subgrade and the overall performance of the pavement. As shown in Figure 4-1, moisture can enter the pavement from a variety of sources. It may seep downward from higher ground, may infiltrate through the surface, or could flow laterally from the pavement edges and shoulder ditches. Capillary action and moisture-vapor movement are also important. Capillary properties are the effect of surface tension and the attraction between water and soil. The movement of vapor is associated with fluctuating temperatures and other climatic conditions.

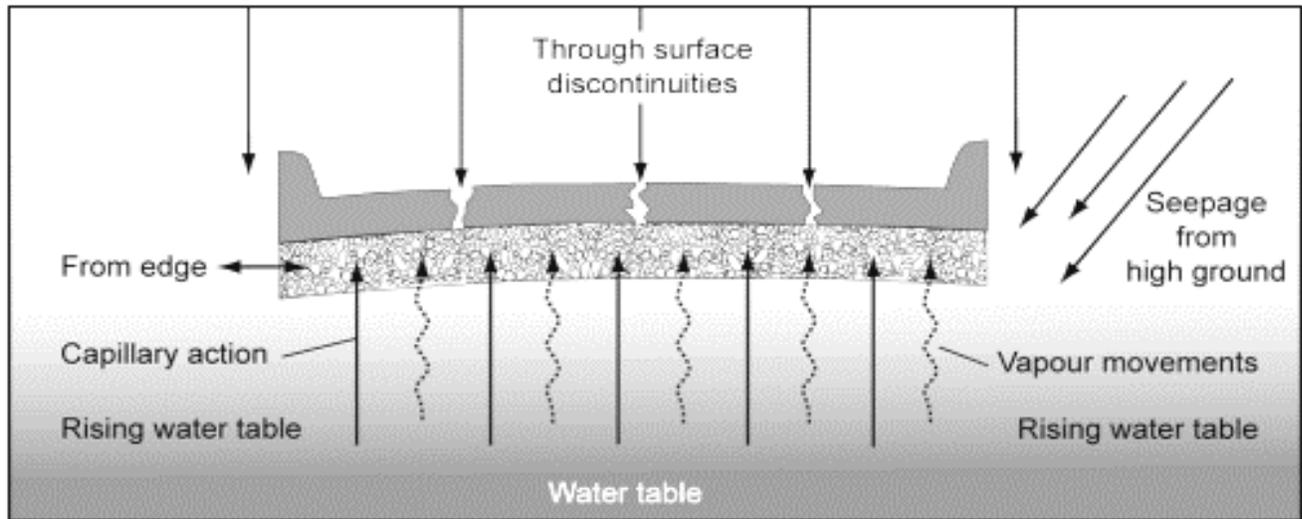


Figure 4.1: Sources of moisture in pavements. Modified from US DOT FHWA (2006)

Table 4.1 Sources of water ingress to, and egress from a road pavement

Means of Water Ingress	Explanation
Through the pavement surface	Through cracks due to pavement failure
	Penetration through intact layers
From the subgrade	Artesian head in the subgrade
	Pumping action at formation level
	Capillary action in the sub-base
From the road margins	Seepage from higher ground, particularly in cuttings
	Reverse falls at formation level
	Lateral/median drain surcharging
	Capillary action in the sub-base
	Through an unsealed shoulder collecting pavement and ground run-off
Through hydro genesis (the aerial well effect)	Condensation and collection of water from vapor phase onto the underside of an impermeable surface
Means of Water Egress	Explanation

Through the pavement surface	Through cracks under pumping action through the intact surfacing
Into the subgrade	Soak away action
	Subgrade suction
To the road margins	Into lateral/median drains under gravitational flow in the sub base
	Into positive drains through cross-drains acting as collectors

Source: ERA Design Manual 2013

Drainage is an important characteristic in determining the ability of a given pavement to withstand the effects of traffic and the environment. Poor drainage conditions on road pavement were of adverse effects and caused failures in different ways. Proper and well-maintained drainage systems provided to road pavements was increased their life span but improper and not well-maintained drainage systems cause pavements to collapse at an early age, greatly reducing their life. When loose bonds or voids appear on the pavement, the presence of moisture greatly increases the rate of road subsidence. Roads were normally designed approximately for a 10 to 20-year life span, but this is drastically shortened with the presence of moisture.

Nowadays, roads are failing while the contractor is still constructing due to drainage problems. It is known that the rate of road degradation increases as the water content of the granular material increases. On rigid pavement (eg., concrete), temperature gradients across the concrete slab can cause structural defects.

Poor drainage reduced the life of the pavement and, if left unchecked, would have serious environmental impacts. There were many approaches to reducing the erosion of exposed surfaces associated with unpaved roads, such as lateral drains, cut embankments, and beaten slopes. Any road would easily concentrate runoff, so roads should be designed and constructed to allow frequent and safe discharges. During rains, some of the rainwater runs off to the surface and some infiltrate into the groundmass as gravitational water until it reaches the water table. Some of the water is recollected in the openings of the soil structure and on the soil surface particles that cannot be drained by usual gravitational means and this reserved water is called Held water. The surface water of the roadway and the wharf must be drained efficiently without letting it seep into the subgrade. Surface water from adjacent land must also be prevented from entering the roadway. Lateral drains should have sufficient capacity and longitudinal slopes to evacuate all collected

surface water. This inappropriate drainage system causes the distress of road structures owing to various reasons.

#### **4.1.2.6. Inadequate Preliminary Geological Investigation**

The problem in the geological investigation is mostly common in some federal roads constructed by the Ethiopian road authority (ERA) and regional roads. The in-situ tests that needed to be conducted on the subgrade were not always done effectively. The outcome of this is either improper design as a consequence of the practice of artificial soil data records of the area or road construction without skilled design. Unfortunately, adequate tests of sub-grade materials are not always done as per the requirements in road construction due to the lack of adequate laboratory facilities and qualified laboratory personnel for the work.

#### **4.1.2.7. Poor Design of Road**

A good road design should not only cater to the present traffic and drainage need but should project and forecast for the possible increase in Traffic. Due to inadequate projection, most roads today were overloaded and were failing because they were not designed to carry the traffic loads in the future.

#### **4.1.2.8. Poor Workmanship**

Most workers on construction sites in Ethiopia were not well trained. It is especially between artisans and craftsmen. Sometimes technicians, technologists, and even engineers did not receive adequate practical training. The inappropriate application of the materials by the workers is mainly due to the ignorance of the works by the workers. Operations such as soil compaction and stabilization were performed inadequately due to a lack of worker knowledge.

## **4.2. Types of Road Pavement Failure Assessed and its Possible Causes**

Flexible pavement is pavements that have an asphalt concrete surface having low or negligible resistance to bending and are quite flexible in their structural action under loads. The instability of one of the layers leads to the complete failure of the pavement system. It is therefore necessary to build each layer with the utmost care and precision. Resilient flooring is subject to stress and deformation due to a number of factors including traffic loading, environment conditions, design problem, construction quality, maintenance application, operation methodology, and aging. As mentioned and clearly presented in the previous chapter most defects of pavements were focused on specific cases which are related to problematic soils. The targeted areas of the study were fitted to the concern. The expansive nature of the representative soils was

high with a CBR value of less than 4% and needs special attention during the design, construction, and operation stage of any infrastructure. Road defects could be started either from structural, geotechnical/subgrade, or both, and they are interrelated. Even though, different pavement defects (like a pothole, small surface cracks, edge cracks, rough surfaces, eroded surface, peeled off surfaces, rutting, raveling, crocodile cracks, block cracks, longitudinal and transverse cracks e.t. c) were observed in the study are only defects related to expansive soil cases were assessed majorly. Some of those observed and selected damages of roads are;

1. Longitudinal Cracks, these cracks were relatively long in length ( $L > 3m$  up to 100m and above) sometimes extended to edges and crack width from minor to 50mm.
2. Transverse Cracks are also cracks extended up to edges of road section with major crack width (up to 50mm).
3. Block Cracks, large
4. Rutting
5. Edge cracks
6. Raveling
7. Crocodile cracks that covered large areas.
8. Totally damaged roads on a large scale

Of course, the above-mentioned road distresses could be structural but the study tried to characterize by their extent of damages. Damages caused by materials other than subgrade and poor construction methodology of each layer could be identified easily and different in character.

In general, the above damage types identified were happened most probably due to the following reasons;

- Design and contraction problem
- Poor drainage system
- Improper maintenance

- Maintenance regularity

### **4.3. The Remedial Measure of Road Damage Caused by Expansive Soils**

In order to rectify the problem of road failure due to expansive soil, every concerned body should have aware of the cause and effect of the problem. Infrastructures by their nature before, during, and after construction involve many different stakeholders and individuals. And also they are large investments of any country. Road infrastructure consumes a large amount of money for both construction and operation/maintenance. To avoid extra expenses due to such types of problems the following activities should be properly implemented.

- Proper design of overall road section and alignments
- Proper drainage design
- Apply construction methodology as per each design standards
- Implement regular supervision
- Avoid any poor activities before, during, and after construction of the infrastructure

#### **4.3.1. Regarding Maintenance**

As we observed in our country practice by the cause of either one or multiple reasons roads have been damaged frequently in different extents. Following this road sectors also have been trying to maintain these defects accordingly. But the maintenance habit seemed to be not applied properly and professionally unacceptable. Especially in Addis Ababa road maintenances is executed without identifying the real cause of the defect. The maintenance application trained and methodology is also very poor and usual.

To avoid poor quality road damage maintenance practice it is better to do the following activity.

- I. Exactly identify and know the real cause of the defect
- II. Clarify the defect type, the extent of damage
- III. Study the type of maintenance to be applied or needs rehabilitation
- IV. State the methodology

- V. Apply the maintenance stepwise and properly
- VI. Inspect the application
- VII. Maintain regularly and on time.

#### **4.3.2. Types of Maintenance**

##### **Cracks**

The necessary repair work will depend on the depth and width of the cracks, particularly if they allow water into the unbound pavement layers. Some minor and hairline cracking usually occurs over the life of pavement; the causes of more before a new surfacing is constructed, it is necessary to determine the serious cracks and properly repair the pavement. Cracks can be classified as active or passive cracks. The proper treatment will depend on the type of crack. As a general rule, the earlier the cracks are repaired and treated, the longer the life of the pavement will be. Total crack movement can be monitored if it is considered that existing cracks may be reflected onto the new surface. The pavement should be evaluated if there is doubt whether a pavement is in an acceptable condition to be resealed or whether it may need to be rehabilitated. If there are signs of pumping, it should be assumed that there is some movement through the crack.

To solve the existing road damage problem;

- ✓ Rectify drainage problem
- ✓ Crack sealing using appropriate material for each case
- ✓ Block remove and replacement
- ✓ Proper and regular maintenance
- ✓ Take further investigation and rehabilitate the fully damaged road sections.
- ✓ Inspect the operation and performance of each road regularly

## CHAPTER FIVE

### 5. CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

In general, the finding of this paper can be summarized as follow;

- ❖ According to the assessed data, all selected sites of soil property resulted that, all samples are inorganic clays (expansive) of high plasticity, traced between activity 1 and 2, black and grey in color, having a very high degree of expansiveness and high swelling pressure. This shows that the material is an unstable or problematic foundation material or subgrade and can possess a large possibility to cause damage if not properly treated.
- ❖ Depending on AASHTO test standard T- 193 and Dynamic Cone Penetrometer test results and the CBR value of the unmodified soil sample for a selected sample is range from 1% to 4%. So, the CBR values of the subgrade are below the minimum which needs treatment of soil or replacement.
- ❖ Dynamic Cone Penetrometer test results of the existing roadshows large CBR value of subgrade which needs further investigation or needs reduction factor to gate the original soil strength property.
- ❖ From condition survey results some of those observed and selected damages of roads are; Longitudinal Cracks, with length (L up to 100m and above) sometimes extended to edges and crack width from minor to 50mm. Transverse Cracks are also cracks extended up to edges of road section with major crack width (up to 50mm). The other types of failures are block Cracks, Rutting, Edge cracks, Raveling, Crocodile cracks which covered a large area, and fully damaged roads on large scale. Note that, there are also other types of defects as a result of other causes.
- ❖ Transverse cracks rarely happen types of the crack of the other types. On the other hand, longitudinal cracks are frequently observed both alone and together with other defects.
- ❖ Most damages have happened where there were poor drainage systems.

- ❖ Road damages were ranged from minor to large and covered all types of roads (collectors to main roads and Ring roads as well.).
- ❖ The maintenance procedure and application methodology of the city road authority are very poor and usual.
- ❖ Addis Ababa City Roads Authority (AACRA) has no organized damage assessment data and going with poor maintenance practice.

## 5.2. Recommendations and Suggestions

Depending on the results of the paper, the following tasks are suggested to all concerned bodies to mitigate or minimize the degree of causes of damage to the road pavement.

- Addis Ababa City Roads Authority should have updated and well-organized research supported data, like representative laboratory test soil property of Addis Ababa roads, condition survey data.
- Drainage system design and utility line installation give special attention to the construction of roads.
- The Addis Ababa City Road Authority has to create opportunities to involve both in maintenance and construction to develop the competitive spirit and efficiency of local contractors in road construction work.
- Future road design & Construction shall avoid subgrade with a high swell or shall incorporate the proper method of treating the expanding insert of the subgrade by excavating it out and replacing it at a depth where the change in moisture is minimal and should provide sufficient cover to overcome swelling pressure due to increased moisture below
- The road maintenance deserves much more emphasis than is usually placed on it in order to protect the investment that has been made on our road system and a maintenance program should be collected be chalked out by the concerned stakeholders well ahead to undertake maintenance work in a timely manner according to the priorities determined according to the conditions of the ground and the funds available.
- Funds required for proper and timely maintenance of the failed section of this road should be provided to the organizations/contractors concerned and also organizations/contractors should have an adequate number of professionals, technical and skilled personnel. Not only

this but also sufficient equipment and machinery are important to undertake maintenance work speedily and effectively.

- Generally, all parties have to take responsibility for risks that happen pre-and-post of road construction work which can reduce the factors which affect the failure of roads.
- Finally, the concerned sector shall give more attention and assess in-depth this area for all parts of Addis Ababa road with sufficient sample area.

In order to avoid poor quality road damage maintenance practice, it is better to do the following activity.

- ✓ Exactly identify and know the real cause of the defect
- ✓ Clarify the defect type, the extent of damage
- ✓ Study the type of maintenance to be applied or needs rehabilitation
- ✓ State the methodology
- ✓ Apply the maintenance stepwise and properly
- ✓ Inspect the application
- ✓ Maintain regularly and on time.

### **5.3. Recommendation for Further Studies**

- Study on road drainage system design and implementation problems in the study area and others.
- Further studies should conduct about the economic impact of road pavement failure due to expansive soil all over the country.
- Assessment of causes of road damage studies together geotechnical engineer with high way structural engineer.
- Studies on the factor of road damage due to seasonal variation of Addis Ababa roads.

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Additional pavement distress photos



