



SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

**ASSESSMENT OF DAMAGES CAUSED BY EXPANSIVE SOIL ON BUILDINGS
CONSTRUCTED IN BAHIR DAR**

BY
TIBEBU SOLOMON MAMO

DECEMBER 2015



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CONSTRUCTED IN BAHIR DAR**

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*Submitted in partial fulfillment of the
requirements for the award of the degree*

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By

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DECEMBER 2015

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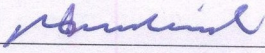
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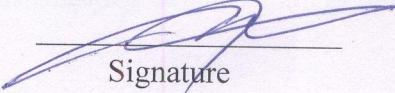
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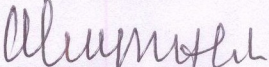
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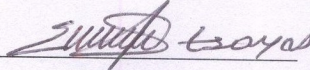
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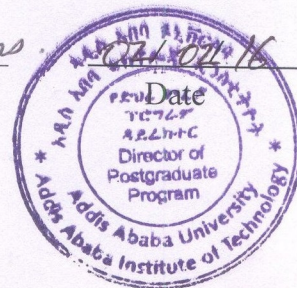
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ABSTRACT

In this study it has been tried to assess the extent of damages caused by expansive soil on buildings constructed in Bahir Dar. Seventy Eight buildings were randomly selected from 20 different expansive soil locations. The assessment showed that out of those 78 buildings 68(87%) of them are adversely affected. In most buildings more than one building components are damaged. The damage has been analyzed and interpreted systematically with respect to type of foundation, wall, floor, pavement, door, window and fence. The extent of damage is very high on pavements and decreases when we proceed to walls, floors and foundation in their respective orders.

The study showed that the main cause of failure is fluctuation of ground water table. In addition to this poor surface drainage, presence of trees and vegetation close to buildings, damaged utility lines and improper design also have great contributions.

Based on the causes of failures and other factors attempt was made to propose remedial measures for already damaged buildings constructed in expansive soil locations of the study area. In addition to this suitable foundation types and construction details have been also proposed for new buildings to be constructed in these areas.

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LIST OF SYMBOLS AND ABBREVIATIONS

USCS	Unified Soil Classification System
AASHTO	American Association of State Highway and Transportation Officials
H_d	Depth of desiccation
H_s	Depth of seasonal moisture fluctuation
Q_u	Ultimate bearing capacity
Q_s	Ultimate skin friction
Q_b	Ultimate base resistance
C_u	Undrained shear strength of the soil along the pile shaft
α	Adhesion factor
A_b	Pile base area
N_c	End bearing capacity factor
C_{ub}	Undrained shear strength of the soil below the pile base
F_u	Soil uplift pressure
β	Uplift factor
SP	Soil swelling pressure
Z_a	Depth of active zone
Q_d	Super structure load
CEC	Cation Exchange Capacity
ω	Natural moisture content
LL	Liquid limit
PI	Plasticity Index
NMC	Natural Moisture Content
CL	Inorganic clay of low plasticity
OL	Organic silt or clay of low plasticity
CH	Inorganic clay of high plasticity
OH	Organic silt or clay of high plasticity
MH	Inorganic silt of high plasticity
CIS	Corrugated Iron Sheets
HCB	Hollow Concrete Block

CHAPTER 1: INTRODUCTION

1.1 Background

Expansive soils are clay soils that contain clay mineral called Montmorillonite. Such soils are capable of absorbing great amount of water and expand. The expansive nature of the clay is less near the ground surface where the profile is subjected to seasonal and environment changes. The more water they absorb the more their volume increases. Expansive soils also shrink when they dry out. Fissures in the soil can also develop. These fissures help water to penetrate to deeper layers. This produces a cycle of shrinkage and swelling that causes the soil to undergo great amount of volume changes. This movement in the soil results in structural damages especially in lightweight structures such as one or two story buildings, warehouses, retaining walls, sidewalks, driveways, basement floors, pipelines and foundations.

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 the arid and semi-arid regions. Damages are usually manifested through crack of floors and walls, stacked windows and doors, bulged floors and tilted walls and structures. The magnitude of the damages can be extended even to the extent of failure of one or all structure by decreasing the structural safety of the building. Maintenance and repair cost can also exceed the original cost of the foundation and creates financial burden to the owner. Generally, the damage will result in economic loss for building owners and the country at large. In previous years engineering properties and distribution of expansive soils in and around Bahir Dar have been studied. However; nothing has been done so far with regard to study of damages of buildings due to expansive soils. As shown in Fig1.1 below, it is not unusual to see cracked fences, displaced pavements, heaved and/or cracked road side walkway in the city.



a. Cracked pavement and separation of masonry foundation from grade beam



b. HCB fence wall separated from corner column



c. Displaced walkway



d. Bulged and disintegrated road side walk way

Figure 1.1 Samples of affected civil engineering structures in the study area

Thus, this research will try to identify damages caused by expansive soil on buildings and other civil engineering structures constructed in and around Bahir Dar city and propose remedial measures for already damaged buildings. It will also provide procedures and methodologies to prevent damage of new constructions.

1.2 Objective of the thesis

The main objective of this research is to assess the extent of the damage of buildings constructed on expansive soil in and around Bahir Dar and propose possible solutions.

To achieve the main objective the research will have the following specific objectives.

- Evaluate the extent of damage of buildings which are constructed on expansive soil area of Bahir Dar,
- Identify the major causes for heaving and shrinkage of expansive soil in the study area.
- Propose remedial measures, with respect to expansive soil, for already damaged bldgs.
- Propose preventive measures (methodologies and construction procedures) for new buildings to be constructed in the study area.

1.3 Scope of the Study

This study will focus on assessing damage caused by expansive soil in and around Bahir Dar city.

1.4 Organization of the thesis

This thesis is organized in six chapters as follows.

Chapter 1 presents general description about the thesis. This includes background, general & specific objectives and thesis overview.

Chapter 2 presents literature review on properties of expansive soils, their distribution around the world, characteristics of Ethiopian expansive soils, factors affecting swelling behavior of these soils, types of distresses caused by them, possible causes of damage, methods used to prevent building damage due to expansive soil and remedial measures.

Chapter 3 discusses the methodologies followed to collect the required data, how the sample size has been determined and the implemented method of analysis.

Chapter 4 discusses the data collection, analysis and results. This includes summarizing all previously conducted researches in the study area in relation to expansion soil, identifying their locations, collecting & analyzing data from randomly selected sample buildings and evaluating the design methodologies followed by design office working in the study area.

Chapter 5 discusses possible causes of failure with their respective proposed remedial measures. It also discusses proposed design & construction methodologies for new buildings.

Chapter 6 contains conclusions and recommendations.

The last sections contain references used in this thesis work and annexes.

CHAPTER 2: LITERATURE REVIEW

2.1 General

Soil is a mixture of various sizes of particles like gravel, sand, silt and clay. Gravel and sand are the coarse fractions and they are considered inert materials because of their insignificant activity. In contrast, clay and silty clays are particles of ultra-fine size in the form of platelets. They carry an unbalanced negative electric charge on their surface. This electric charge and large specific surface they possess render them highly active. They can absorb water as well as the positively-charged ions from the salts in water to neutralize the electric charge they carry on their surface. The amount of water absorbed depends on the type of the clay mineral present in the soil. Three most common minerals present in clay are Kaolinite, Illite and Montmorillonite and their capacity to adsorb water increases in that order, therefore, the greater the percentage of Montmorillonite mineral present, the greater would be the expansive nature of the soil ^[7].

2.2 What are expansive soils?

Expansive soils are clay soils containing considerable amount of Montmorillonite mineral which has a potential for shrinking or swelling due to changes in its moisture content.

Expansive soil can be classified in to two groups with respect to the parent materials. The first group comprises the basic igneous rocks, such as the basalts of Deccan plateau in India, the Dolerite sills and dykes in the central region of South Africa and Gabbros and norities of west of Pretoria north, Transvaal. In these soils the Feldspar and Pyroxene minerals of the parent rocks have decomposed to form Montmorillonite and other secondary materials.

The second group comprises the sedimentary rocks that contain Montmorillonite as a constituent which breaks down physically to form expansive soils. In North America, bedrock shale found in the Pierre Formation and more recent Laramie and Denver Formations are examples of this type of rock. In Israel, there are the marls and lime stones and in South Africa, the shale of the Ecca Series ^[4].

2.3 Why expansive soils are problematic?

In wet seasons, 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 an upward pressure on the foundation. This pressure that the soil applies on the foundation is called swell-pressure. If the footing transfers a 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-storeyed 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 develop cracks, it is hardly possible to rehabilitate it without significant expense. Building a house for most people is a lifetime venture and if it occurs on an expansive soil, the investment needs to be safeguarded. Therefore, there is need for the public to be aware of the implications of building on expansive soils, in order to identify the problem at an early stage rather than regret later ^[7].

2.4 Distribution of expansive soils around the world

Expansive soils are found throughout many regions of the world, particularly in arid and semi-arid regions, as well as where wet conditions occur after prolonged periods of drought. Their distribution is dependent on geology (parent material), climate, hydrology, geomorphology and vegetation.

As shown in figure 2.1 expansive soils are widespread in the African continent, occurring in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria etc. In other part of the world cases of expansive soils have been widely reported in USA, Australia, Canada, India, Spain, Israel, Turkey, Argentina, Venezuela etc ^[12]. In these countries, or significant areas of them, the evaporation rate is higher than the annual rainfall creating a moisture deficiency in the soil. Subsequently, when it rains the ground swells and increases the potential for heave to

occur. In semi-arid regions a pattern of short periods of rainfall followed by long dry periods (drought) can develop, resulting in seasonal cycles of swelling and shrinkage ^[10].

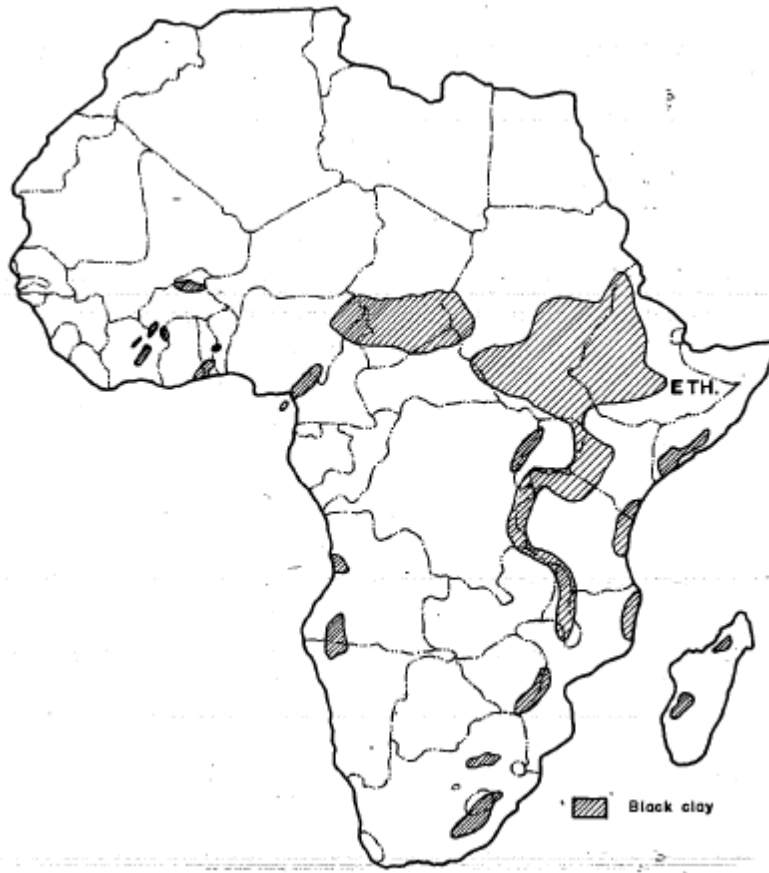


Figure 2.1 Distribution of expansive soils in Africa ^[12]

2.5 Distribution of expansive soils in Ethiopian

Expansive soil is known to be widely spread in Ethiopia. Although the extent and range of distribution of this problematic soil has not been studied thoroughly: the southern, south-east and south-west part of the city of Addis Ababa areas and central part of Ethiopia following the major trunk roads like Addis-Ambo, Addis-Woliso, Addis-Debre Berhan, Addis-Gohatsion, Addis- Modjo are some of the areas covered by expansive soils. Areas like some part of Mekele, Gondor, Bahirdar, Debreberihan and Gambela are also known to be partly covered by expansive soils ^[16].

2.6 Soil-moisture relationship of expansive soil

2.6.1 Effect of stratum thickness

Laboratory research has been done by Chen (1975) to explore the effect of stratum thickness on the amount of volume change and swelling pressure. In this series of tests, the sample thickness ranged from ½ to 1½ inches. The samples were compacted to uniform moisture content & density and sufficient time was allowed for complete saturation of the thickest sample.

The test result showed that the magnitude of the volume change is proportional to the sample thickness and the percentage of volume increase remains constant ^[4].

2.6.2 Effect of moisture content and dry density

Expansive soils will not be subjected to volume change unless there is an increase in moisture content. A drier soil will swell more than a wet soil. Chen has further extended his laboratory research to determine the effect of increasing the initial moisture content on the volume change as well as swelling pressure. Different samples were compacted at constant density but varying moisture contents and the following results were observed:

- Soil with low moisture content swell most
- The swelling pressure required for zero volume change remained practically constant
- For moisture content slightly higher than optimum moisture content, the volume change should be negligible

As indicated above high moisture content soil will experience less uplift, but the pressure required to maintain constant volume change will not be altered. This also indicates that the commonly accepted procedure of prewetting the foundation excavation to eliminate the swelling characteristics is not a reliable procedure. Prewetting can only serve to decrease the amount of swelling. A foundation placed on such soil will still require the same amount of dead load pressure ^[4].

Researches also show that when dry density decrease, swelling pressure rapidly approaches zero and when dry density increases, swelling pressure rapidly increases and approaches

infinity. Therefore, swelling pressure of clay soil is independent of initial moisture content, degree of saturation and thickness of the stratum. Therefore, dry density is the only factor that affects swelling pressure of clay soils [4].

2.6.3 Effect of depth of moisture fluctuation

The thickness of expansive soil layer below the ground surface and the depth to which the season moisture varies, called the ‘Active depth’, greatly influence the amount of heave the ground would undergo. Figure 2.2 shows the seasonal moisture variation and the active depth of homogeneous soil. Below the active depth, the soil water content is considered to remain constant; therefore, foundations situated within the active depth are subject to distress from soil volume change [7].

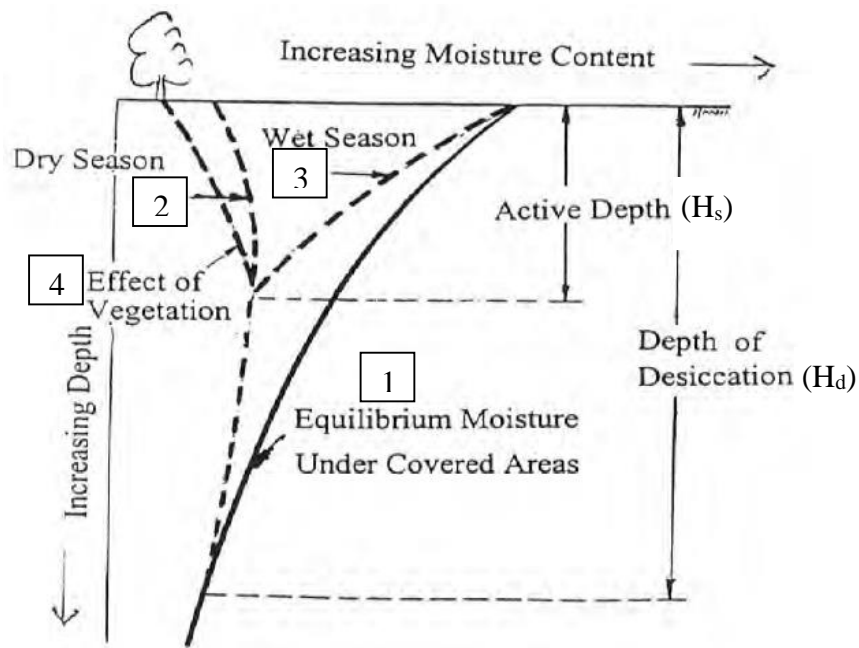


Figure 2.2 Seasonal moisture variation [7]

In a covered area, the moisture profile is shown by curve 1. There is no gain or loss of moisture to the atmosphere. The moisture content of the soil decreases with depth. Curve 2 indicates the moisture content variation in uncovered natural condition. Evaporation causes loss of moisture in the soil near the ground surface. However, the influence of evaporation decreases with depth and at some depth, H_d , the moisture content equilibrium remains the same as the covered

condition. The value of H_d depends on the climate condition, the type of soil and the location of the water table. This depth represents the total thickness of material which has a potential to expand because of water deficiency. It is impossible to determine the value of H_d . the hotter and drier the climate, the greater the depth of desiccation. The maximum depth of H_d is equal to the depth of the water table and the minimum depth is equal to the seasonal moisture fluctuation depth described below.

During wet months with heavier precipitation and higher humidity, the moisture content of near surface soil increases and the moisture profile represented by curve 2 alters its shape to curve 3. Another case is plantation of trees and shrubs which further reduce the moisture content of the soil and this condition is designated by curve 4.

The depth of seasonal moisture content fluctuation, H_s , indicated in figure 2.2 depends on the variation of surface moisture, permeability of the soil, and climatic conditions. In areas where precipitation and evaporation are fairly constant, the H_s depth may be only few meters. When a long drought is followed by an intense rainfall, the H_s depth will be very deep.

It should be noted that man-made environments such as watering of lawns, discharge of roof drains, formation of drainage channels and swales, and possibility of utility line leakage will also increase the value of H_s [4].

2.7 Types of foundation distresses

When a building is constructed on an expansive ground surface evaporation and temperature variations are retarded below it. As a result, patterns of soil movement under the building are identified on the basis of short-term and long-term effects. This soil movement will create the following foundation distresses:

2.7.1 Edge heave

In the short-term, i.e., just after the construction is complete, below the center of the building, moisture variation remains small while at the edges, seasonal moisture change continue to occur. If the building is constructed during the dry season, in the wet season that follows, soil

around the building absorbs rain water and swells pushing up the peripheral foundations. This effect is called the edge heave ^[7]. Edge heave can also be initiated due to local effects, such as, sprinkling of water for vegetation around building, leaking utility lines and ponding of surface water due to poor drainage system.

In addition to moisture variation, edge heave can be initiated by effect of confinement of the foundation system. For example, the exterior corners of a uniformly-loaded rectangular slab foundation will only exert about one-fourth of the normal pressure on a swelling soil of that exerted at the central portion of the slab. As a result, the corners tend to be lifted up relative to the central portion ^[24].

In this case, the cracks develop from the lower region and transverse diagonally upward being wider at the bottom and narrower at top as illustrated in Figure 2.3.

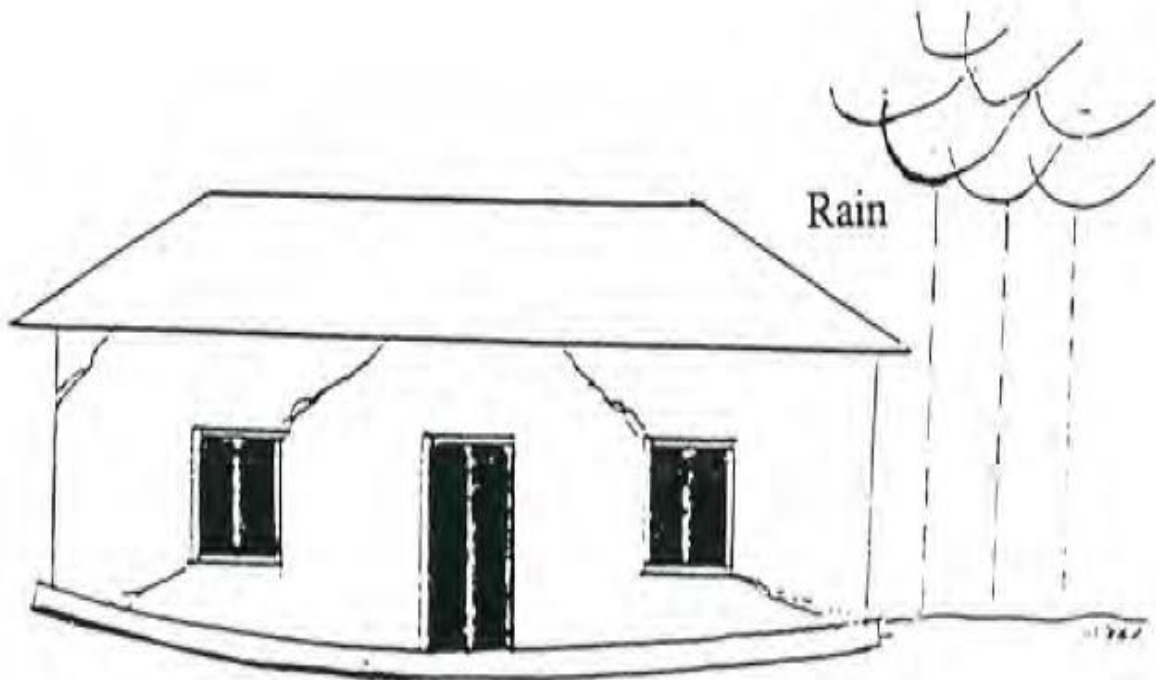


Figure 2.3 Edge heave condition ^[7]

2.7.2 Edge shrinkage

Like edge heave, edge shrinkage is also a short-term effect. If the building is constructed during the wet season, in the dry season that follows, soil around the building loses the absorbed rain water and the soil leaves the peripheral foundations. This effect is called the edge shrinkage. Presence of big trees closed to building will also cause edge shrinkage. Especially during the dry season when moisture available for roots to suck is the least, trees absorb water from the nearby foundation soil through their root system and cause shrinkage of soil.

In the edge shrinkage condition as shown in figure 2.4 below, cracks propagate diagonally across from top to bottom being wider at the top and narrower towards the bottom of the structure ^[7].

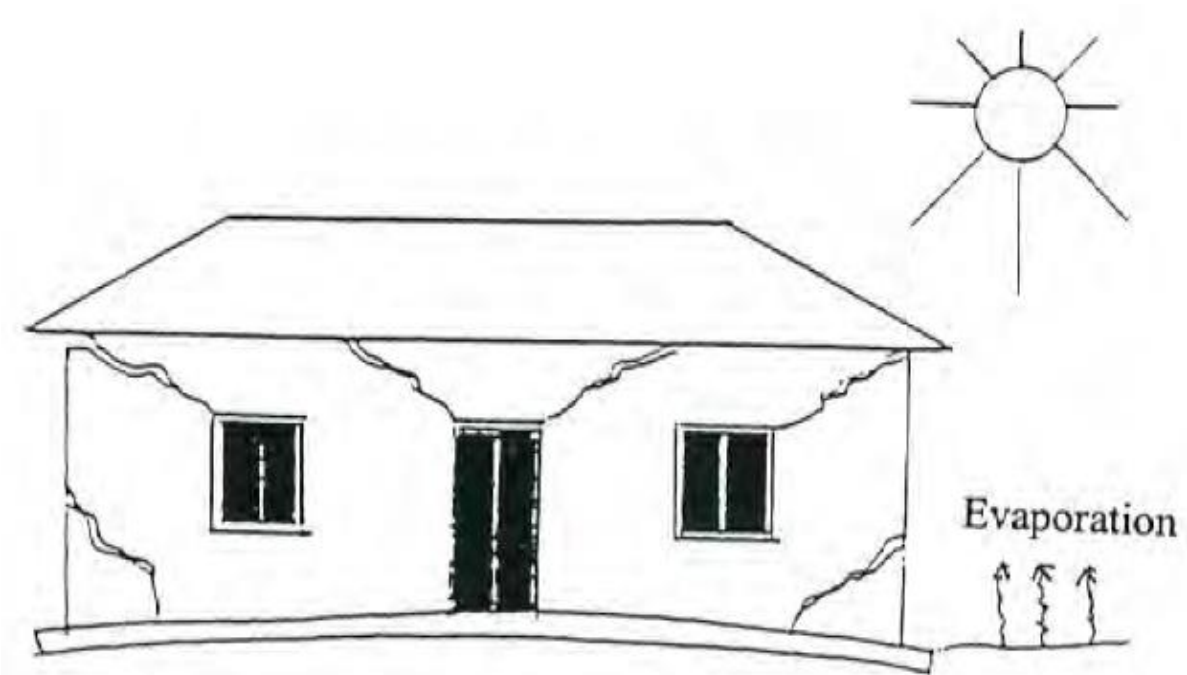


Figure 2.4 Edge shrink condition ^[7]

2.7.3 Central heave

In the long-term, moisture starts continuously accumulating under the center of the building being drawn up from the ground water at depth by capillary action until an equilibrium moisture condition is attained. This means that the soil under the building continuously swells with time and finally attains a mound shape while at the edges; the seasonal effects continue

to occur. This is termed the central-heave condition. As a consequence of this, the foundation gets only a partial support from the soil at the center as shown in Figure 2.5. The height of the mound formation depends on the area of the soil covered by the building and also the active depth. Cracking of walls start in the upper region and traverse downward.

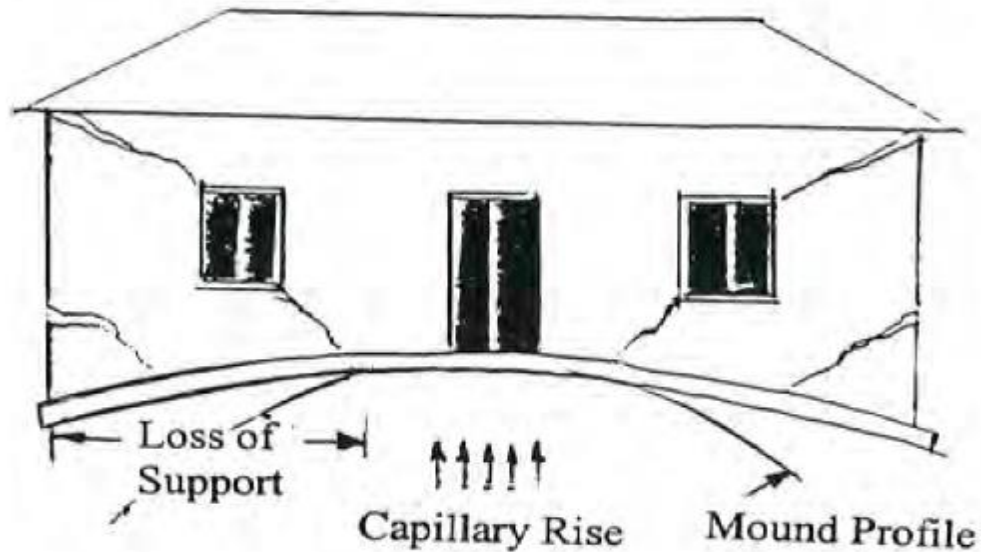


Figure 2.5 Central heave condition ^[7]

2.8 Identifications of damage due to expansive soil

The most obvious identifications of damage to buildings are doors & windows that get jammed, uneven floors and cracked foundations, floors, masonry walls, ceilings & pavement around buildings ^[5].

The degree of damage based on observed cracks ranges from hairline cracks, severe cracks, very severe cracks to total collapse. As it has been explained in previous section the pattern of the cracks depends on whether it is a dooming heave or a dish shaped lift heave ^[5]. In both cases vertical, horizontal and/or diagonal cracks will be developed along walls and floor area. This intern has a great effect on functionality of doors and windows.

2.9 Possible cause of damage

2.9.1 Climate

Seasonal changes in rainfall were typically the principal cause of the change of soil moisture. This led to downward movement during summer and upward movement during winter. The consequent rising and settling of ground surface occurred in the dry and wet seasons resulting in seasonal subsidence and seasonal recovery respectively.

The results and observations by most of the researchers suggested that expansive soils which experienced periodic swelling and shrinkage during alternate wet and dry seasons caused considerable damage to structures founded on them. The damage to structures built on expansive soil in wet climates usually occurred during drought period and damage to structure built on dry climate occurred during rainy season ^[17].

2.9.2 Poor drainage system

Improper drainage is probably the most important factor contributing to soil volume change and subsequent damage to pavements. If water is allowed to stand in drainage ditches close to buildings, it can penetrate down and amplify heave ^[3].

The following can be considered as the main causes of poor surface drainage:

- ✓ Surface runoff not properly drained away from the building
- ✓ Sprinkling of water for grass and shrub plantation
- ✓ Overflow from elevated and/or ground water tank
- ✓ Slope of surrounding area (outside the compound)

2.9.3 Presence of vegetation and big trees

Existence of vegetation, such as fast growing trees in the vicinity of compound walls can sometimes cause cracks in walls due to expansive action of roots growing under the foundation. Roots of a tree generally spread horizontally on all sides to the extent of height of the tree above the ground and when trees are located close to a wall; these should always be viewed with suspicion ^[12].

Trees absorb water from the nearby foundation soil through their root system and cause shrinkage of soil especially during the dry season when moisture available for roots to suck is the least. This is the reason why big trees should not be located within a distance of 1 to ½

times their mature height from the structure, if big trees are felled just before construction, transpiration loss of moisture through leaves is discontinued and the soil moisture accumulates and allows the soil to swell. Therefore, trees have to be cut down far in advance of construction so that soil moisture condition reaches an equilibrium condition. If trees are retained, moisture barriers should be put in place as shown in Figure 2.6 [7].

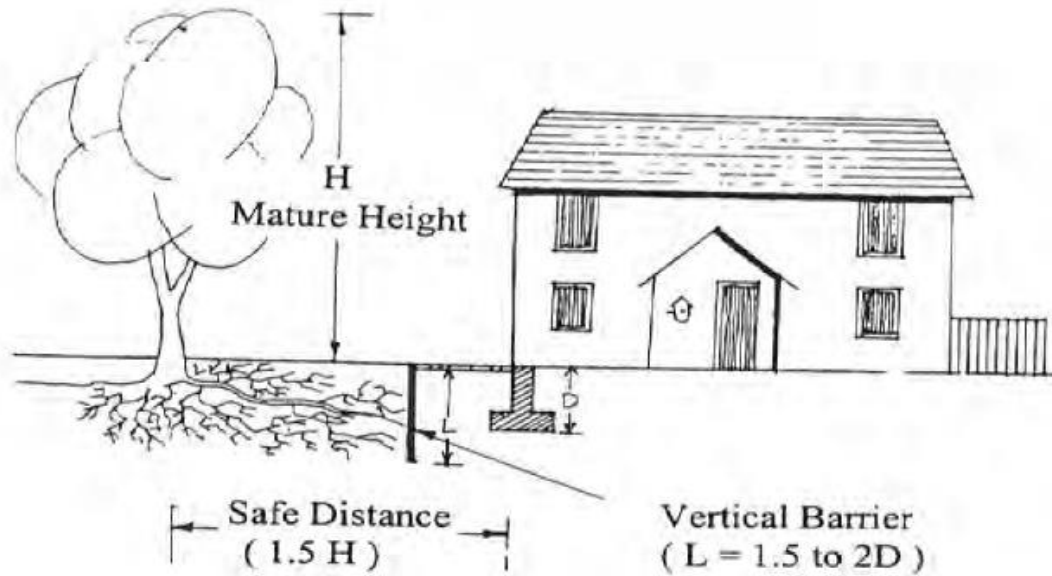


Figure 2.6 Vertical moisture barrier [7]

As shown in figure 2.7 damage caused by a tree is similar to the edge-shirk condition because the soil at the periphery of the building is depleted of water by the tree roots.

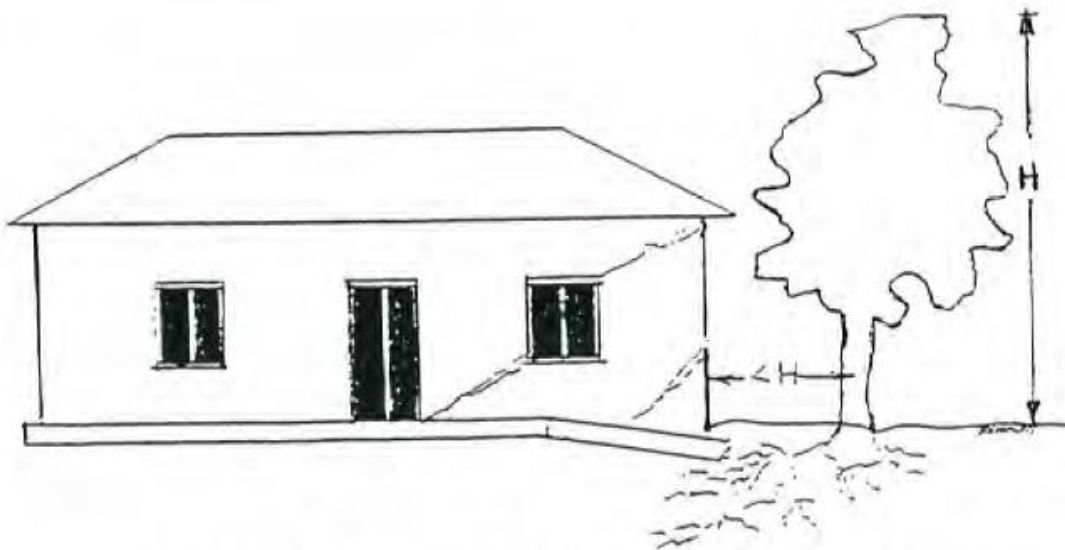


Figure 2.7 Down warping of foundation due to trees close by [7]

2.9.4 Damaged utility structures

Shallow plumbing pipes buried in the zone of seasonal moisture fluctuation, are exposed to enormous stresses by shrinking soils. If water or sewage pipes break, then the resultant leaking moisture can aggravate swelling damage to nearby structures ^[19].

The effect of a leaking water line is dependent on the soil moisture condition in the supporting expansive soil mass prior to the leaking occurrence. Dishing of floor systems due to clay heave under the footings could occur when excessive water is present due to site leakage at the edges of the structure ^[17].

2.9.5 New construction near existing building

When areas are covered by new structures such as buildings, pavements, sidewalks or aprons, evaporation is blocked or is partially retarded. The moisture content beneath the covered area increases due to gravitational migration, capillary action, vapor and liquid thermal transfer and, in the course of several years, the depth of seasonal moisture content fluctuation H_s can approach to depth of desiccation H_d ^[23].

In the same manner if structures around the building have been demolished due to various reasons then covered area around the building will be reduced. This leads to migration of moisture away from building foundation soil until new soil moisture equilibrium has been reached.

Such conditions cause foundation distress depending on type of foundation, moisture content and swelling potential of the soil.

2.9.6 Creep action – foundation on steep slope surface

Expansive soils on slope tend to move down the slope due to soil creep especially when the soil is wet. Soil creep is a very slow movement down the slope, which is not perceptible. However; as shown in figure 2.8, overtime it can be significant and can damage the foundations. The steeper the slope, the greater is this effect. Furthermore, on slope, these soils can cause landside problems. Slopes steeper than about 14° (a residual friction angle of soil) have the tendency to slide, if conditions are favorable ^[7].

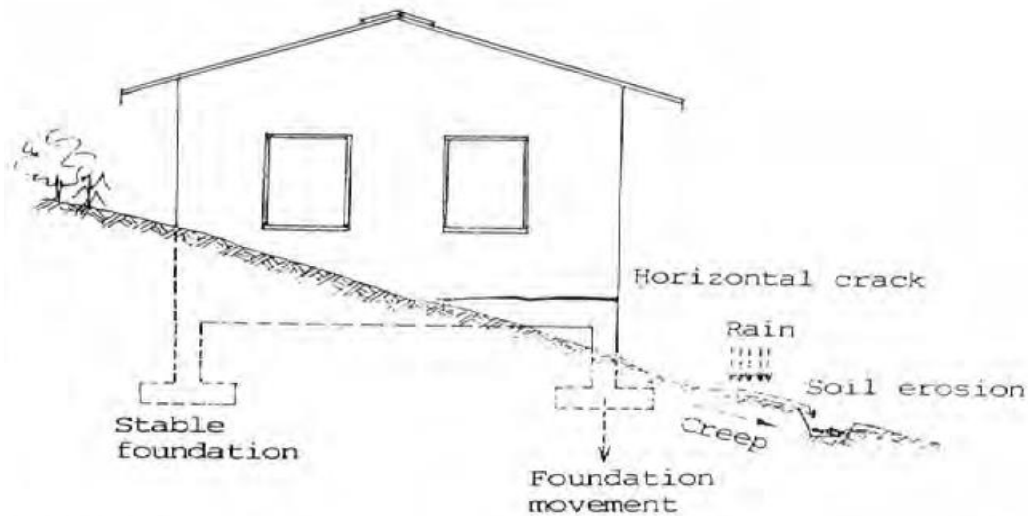


Figure 2.8 Structural damage due to soil creep [7]

2.9.7 Construction interruption

Due to financial problem of homeowners it is a common trend to construct foundation or substructure part in one phase and super structure in the next phase. Buildings are designed to the final stage or condition. Because of construction interruption, the dead load pressure which counterbalances the uplift force gets lower resulting in foundation movement. This results a failure even if the foundation is designed properly with the precautions to be taken for expansive soil [1].

2.10 Method of preventing building damages

In order to minimize or eliminate the danger of damage of buildings because of heave and shrinkage, the following methods shall be used:

2.10.1 Moisture control

The main cause of heaving and shrinkage is the fluctuation of moisture under and around the structure in question. In any site, depending up on the topography, geological and weathering conditions, the natural ground water fluctuates. In a country like Ethiopia, where there are distinct dry and wet seasons, the fluctuation of ground water table during these periods is large. In addition to the fluctuation of the ground water one should also consider free water which may seep under foundations, or the effect of evaporation which would cause moisture migration.

Hence a satisfactory solution to the problem would be to devise an economical way of stabilizing the soil moisture under and around buildings. It doesn't matter whether the moisture content is high or low, as long as it can be maintained constant throughout the year. This moisture fluctuation can be controlled by using the following methods:

Horizontal moisture barriers

Horizontal moisture barriers can be installed around a building in the form of membranes, rigid paving, or flexible paving. The purpose of the horizontal barriers is to prevent excessive intake of surface moisture [4]. Widely used horizontal membranes are polyethylene membrane, concrete aprons and asphalt membrane, extending beyond the limits of backfill [2].

Vertical moisture barriers

Vertical moisture barriers function in much the same way as horizontal barriers in terms of slowing the rate of heave and causing the water content distribution to be more uniform below the structure. However, vertical barriers are more effective than horizontal barriers in retarding lateral moisture migration. Consequently, edge effects are minimized [3]. To serve as a barrier in this category, one may use polyethylene membrane, concrete, or other durable impervious material. As shown in figure 2.9 below depth of the barriers should be equal to or greater than the depth of moisture fluctuation. Backfill materials may be used as vertical moisture barriers provided they are well compacted [2].

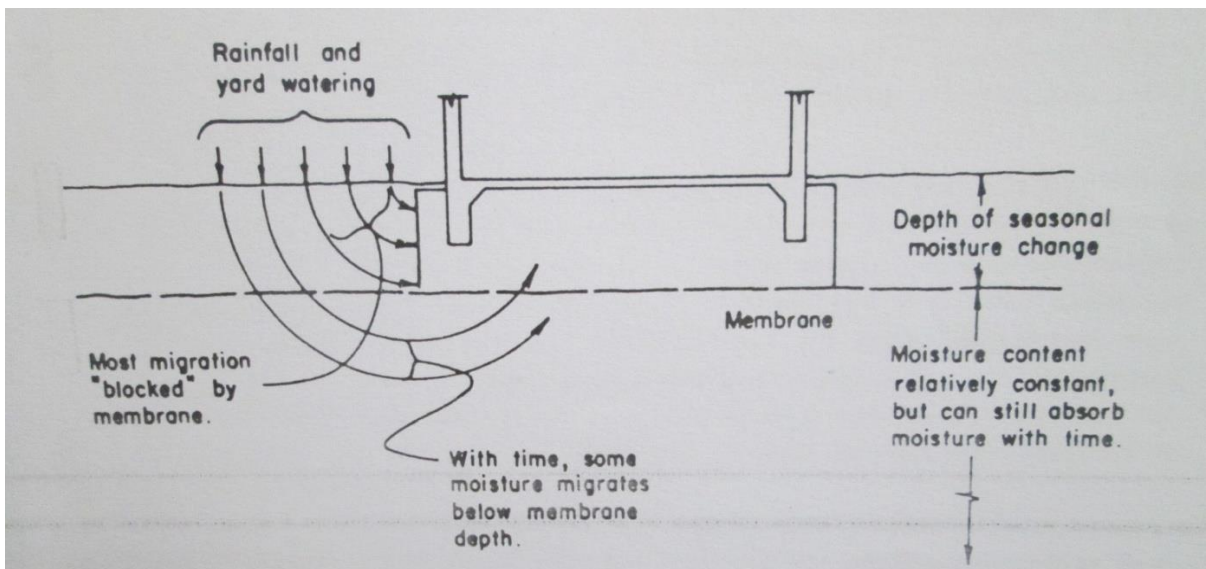


Figure 2.9 Path of moisture migration blocked by vertical barrier [4]

Subsurface drainage

The purposes of a subsurface drainage system are as follows:

1. Intercept the gravity flow of free water,
2. Lower the ground water or perched water, and
3. Arrest the capillary moisture movement and movement of moisture in the vapor state

The following are the major sub surface drainage system.

a) Intercepting drains

Intercepting drains are effective in minimizing the wetting of the foundation soils where the wetting is due to the gravity flow of free water in a subsurface pervious layer such as a layer of gravel or fissured clay. This is shown in figure 2.10. To insure the interception of free water, the drain must be completely filled with gravel and trench should be deep enough to reach the water-bearing layer.

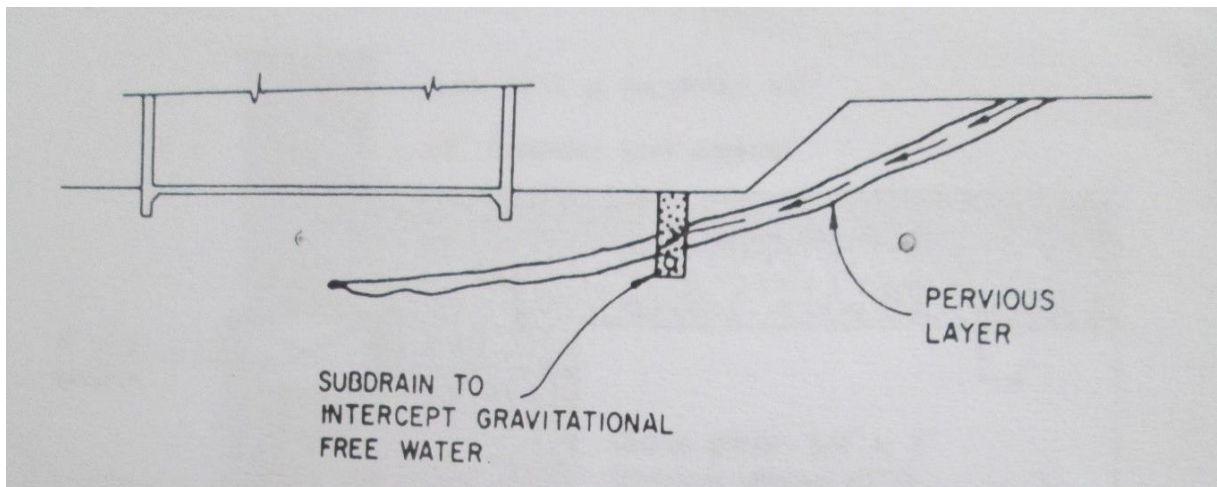


Figure 2.10 Typical function of intercepting drain ^[4]

b) Peripheral drains

Peripheral drains can be installed around either the interior or exterior of the building. The subsurface drainage system is effective in minimizing general wetting of foundation soils, which occur not only because of gravitational flow of free water, but also because of moisture migration. Figure 2.11 below indicates the suggested location of peripheral drains.

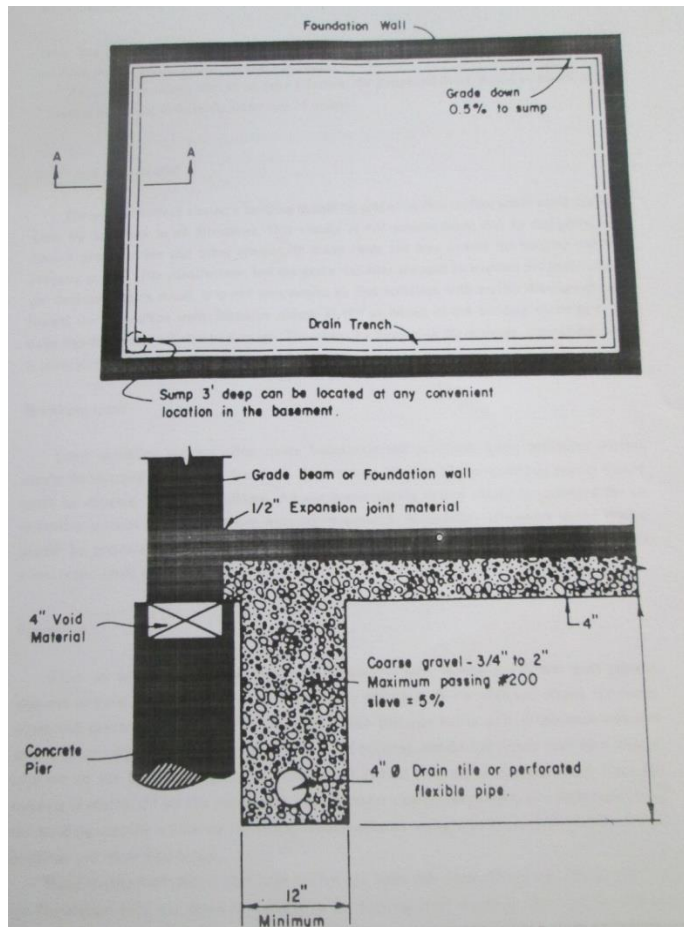


Figure 2.11 Typical sub-drain detail ^[4]

Surface drainage

The ground surface around a building should be graded so that surface water will drain away from the surface in all directions. This usually is not accomplished due to negligence, cost, limited property size and other reasons. As a result, it is not uncommon to find buildings with surface drainage directed towards the foundation walls. Moisture change at the perimeter of the building appears to be the most significant contributor to damage. Therefore, by improving the drainage, a beneficial effect is inevitable ^[4].

2.10.2 Soil stabilization

The successful application of soil stabilization procedures require considerable experience and judgment regarding the soil on-site, consideration of limitations of the methods to be chosen, and correct implementation procedures.

Treatment procedures that are available for stabilizing expansive soils before and after construction of structures and highways include the following:

Soil replacement

Soil replacement is the simplest and easiest solutions for slabs and footings founded on expansive soil. The expansive foundation soils are replaced by non-heaving materials. The strength of the method lies in the selection of the replacement material and depth of replacement.

If the active zone is very deep, it is not desirable that moisture migrate to the underlying expansive soil. For such condition material selected for replacement should be impervious non-expansive soil. Engineering judgment should be used in deciding on the thickness of the replacement. It should always be remembered that the replaced soil serves as a cushion, and even if the deep-seated soil swells, the movement due to heave will be regulated ^[2].

Prewetting or flooding

Prewetting is an old established concept among engineers and contractors as well as laymen in dealing with swelling soils. Prewetting or ponding/flooding/ is based on the theory that increasing the moisture content in the expansive foundation soil will cause heave to occur prior to construction and thereby eliminate problems afterward. It is assumed that if the high moisture content is maintained, there will be no appreciable increase in soil volume to damage the structure ^[3].

This procedure may have serious drawbacks that limit its application. Expansive soils typically exhibit low hydraulic conductivity and the time required for adequate wetting can be up to several years. Furthermore, after the water has been applied for long period of time serious loose of soil strength can result causing reduction in bearing capacity and slope instability. Another major drawback to the use of this procedure is that after a prolonged period of surface ponding the wetting front of the infiltrating water will have advanced to only to a depth much less than of the active zone. Redistribution of water throughout the active zone can continue after construction due to high water content in the zone above the wetting front. The continued migration of water into lower layer can result in continued heave after construction ^[3].

Prewetting shall be used for stabilizing soil beneath floor slabs, pavement or canal linings. However, its application for building foundations is still questionable and risky ^[2].

Chemical stabilization

By chemical stabilization is meant the process of mixing additives like lime, cement, organic and inorganic chemicals to expansive soils, so as to retard their potential expansiveness [2].

Lime stabilization has been used successfully on many projects to minimize swelling and improve soil plasticity and workability [3]. The addition of lime reduces the plasticity of the soil and hence its swelling potential [2]. Generally, from 3 to 8% by weight hydrated lime is added to the top of several centimeters of the soil. The strength characteristics of a lime-treated soil depend primarily on soil type, lime type. Lime percentage, and curing conditions (time-temperature) [3].

Some organic and inorganic chemicals have also been tested for their effectiveness in stabilizing expansive soils. Most of the chemicals were tested in laboratories. Their economic use in the field has not yet been reported [2].

2.10.3 Compaction control

The amount of swelling that occurs when a structural fill is exposed to additional moisture depends majorly upon the compacted dry density and the moisture content.

Gizenski and Lee show that expansive clays expand very little when compacted at low densities and high moisture but expand greatly when compacted at high densities and low moisture. For instance, researchers shows that, by decreasing the dry density of typical expansive clay soil from 17.17kn/m^3 to 15.7kn/m^3 , the swelling pressure decreased from 622.6Kpa to 239.5Kpa and the swelling potential decreases from 6.7 to 4.2 percent. All of this can be accomplished without changing the moisture content. The main advantage of using this approach is that the swelling potential can be reduced without the adverse effects caused by introducing excessive moisture into the soil.

The shortcoming of prewetting methods mentioned in the preceding section can be eliminated by compaction control. Excess water will not be present in the soil; therefore, there will not be migration of moisture to the underlying moisture-deficient soils and long waiting periods, prior to construction, will be unnecessary. A reasonably good bearing capacity can be assigned to the low density soil [4].

2.10.4 Structural measures

The structural measures that should be undertaken in order to minimize or, if possible, to eliminate damages of structures due to heaving are dependent on the design of the structures. The types of foundations commonly used worldwide to support structural loads in expansive soil environment are: shallow individual or continuous footings, rigid or stiffened raft and bored concrete piles.

The performance and selection of a technically viable foundation type for a certain structure founded on expansive soil will depend on:

- The swelling characteristics of the encountered soils; i.e., the swelling potential of the expansive clay layer(s), depth and layering sequence of the encountered deposits within the influence range of the foundation system.
- The environmental conditions; these include the moisture content of the swelling soil layers, depth of water table, rainfall intensity, temperature and vegetation cover. These factors affect and control the depth of the active clay zone.
- The type of the structure, its shape, rigidity/flexibility and tolerance to movements
- Constructional considerations such as availability of certain construction tools (e.g. piling rigs) and the experience of local contractors and home owners.

Some of the structural measures are discussed below:

Shallow individual or continuous footings

Shallow spread footings typically are not used in expansive soil applications. Where shallow footings are used techniques usually are applied in an attempt to increase the bearing pressure so as to minimize heave. Some modifications that have been used include ^[17]:

- narrowing the width of the footing base
- placing the foundation wall directly on grade without a footing
- providing void spaces within the supporting beam or wall to concentrate loads at isolated points
- increasing the reinforcement around the perimeter and into the floor slab to stiffen the foundation

Shallow footings are preferred where the expansive soil stratum is relatively thin to allow placing the footing on a low expansive or low swelling stratum.

Strip footings are used for load bearing structures but lack the three dimensional rigidity needed to resist small movements. Isolated or pad footings offer some structural rigidity needed to resist small movements therefore perform better than strip footings ^[14].

Rigid or stiffened mat foundation

Stiffened raft foundation consists of thin concrete slab stiffened with cross beams to provide additional stiffness of the slab. They are applicable with good performance in areas where soils possess large amounts of movements ^[14].

Pile Foundation

Piles are favored in expansive soils mainly because of their ability to resist uplift forces when properly installed. Piles in expansive soils are designed to act as anchors against uplift forces generated by these soils. They should develop sufficient capacity to carry structural loads and the movement of piles due to the net effect of uplift forces and structural loads should be less than a prescribed limit. The ultimate bearing capacity Q_u is the summation of the ultimate skin friction Q_s and ultimate base resistance Q_b . For a circular pile Q_u is obtained using the following equation:

$$Q_u = Q_s + Q_b \dots \dots \dots (1)$$

$$Q_s = \pi d L \alpha C_u \dots \dots \dots (2)$$

Where:

d: is the pile diameter

C_u : is the undrained shear strength of the soil along the pile shaft

L: is the pile length, and

α : is the adhesion factor

The undrained strength of the soil around the pile shaft is often obtained through laboratory testing of representative soil samples around the pile, whereas the adhesion factor varies

according to the soil type, pile type and method of pile installation. The ultimate base resistance is obtained using the following equation:

$$Q_b = A_b N_c C_{ub} \dots \dots \dots (3)$$

Where:

A_b : is the pile base area

N_c : is end bearing capacity factor, and

C_{ub} : is the undrained shear strength of the soil below the pile base

The end bearing capacity factor is a function of the soil type and its friction angle.

The design for uplift generally follows the simplified Chen (1975) method. Figure 1.12 shows the uplift forces within the active zone and the withholding (resisting) forces within the anchorage zone. For a safe pile the withholding forces will resist the uplift forces. The method assumes that uplift force is a function of the soil swelling pressure within the active zone. The uplift pressure F_u is the soil swelling pressure (SP) multiplied by an uplift factor (β). The uplift force along the active zone is obtained using the following equation:

$$F_u = \pi d Z_a \beta SP \dots \dots \dots (4)$$

Here Z_a is the depth of active zone. Therefore, to compute the uplift force, the designer needs to know the uplift factor, soil swelling pressure within the active zone depth and active zone depth.

The resistance to uplift (W) is offered by the adhesion resistance of the withholding part of the pile ($L-Z_a$) in Figure 2.12 and by the allowable load from the superstructure (Q_d). It is given by the following equation:

$$W = \pi d \alpha C_u (L - Z_a) + Q_d \dots \dots \dots (5)$$

A safe design requires that the uplift force (F_u) should be less than or equal to the withholding force or resistance (W). Equations (4) and (5) are equated and solved for the safe pile length.

From the above equations, parameters needed for the design of piles in expansive soils are: the adhesion factor α , bearing capacity factor N_c , uplift factor β & active zone depth Z_a ^[14].

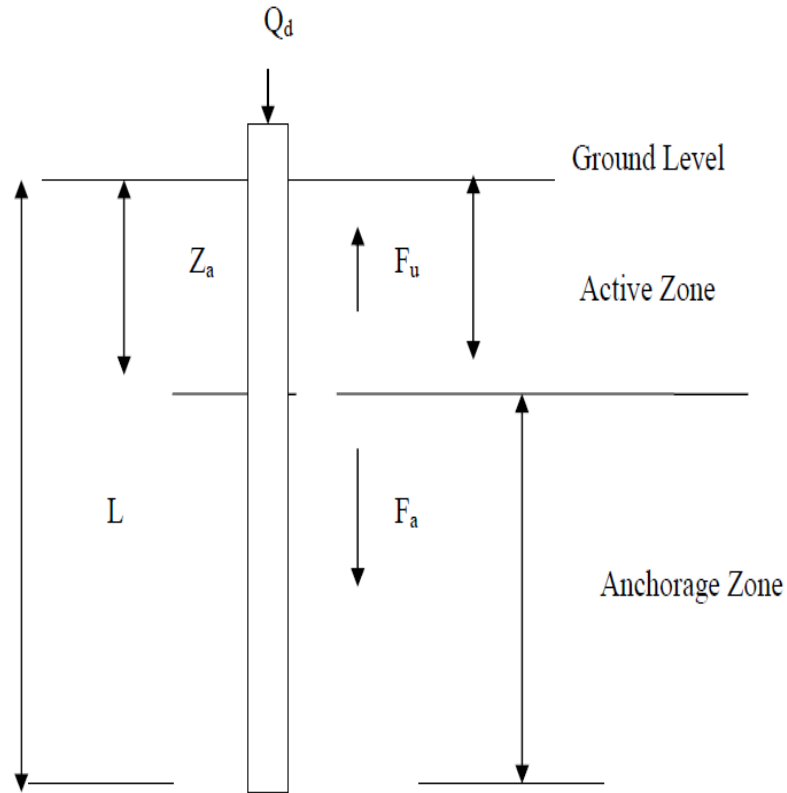


Figure 2.12 Forces acting on a pile in expansive soils ^[14]

2.11 Remedial measures

As indicated in previous sections, the building cracks were due to the cycle of heave and shrink during the wet and dry seasons. The theme of remedial work consist of two major parts: first, to prevent the cycle of heave and shrinkage by protecting the foundation of the building from water content changes; and second, to increase the stiffness of the building by increasing the cross-sectional area of structural elements (such as beams and columns) to account for increased bending moment and shear stress that would result due to the possible differential heave ^[6] and/or to increase the resistance of structure against the uplift force using different techniques like reducing footing area, providing space under continues footings and so on. Both methods are discussed in detail in the following sections.

2.11.1 Minimizing moisture fluctuation

To keep the moisture content constant by keeping the soil in dry state or saturated state is not practical due to environmental and practical reasons. The problem can, therefore, be best tackled by minimizing the moisture gradient between the edges and the center of the covered area ^[9].

To achieve this goal the following measures can be implemented;

- Cut trees and bushes located at a distance ranging from 1.0 to 1.5 times the height of the tree,
- Provide positive drainage around the building,
- Maintain damaged gutters, down pipes, sewerage pipes and water supply pipes that are creating local wetting,
- Extend the covered area around the building by providing an apron. An apron at the top of ground is not advisable because it is liable to damage by external forces or differential movement of the ground over which it rests. Therefore providing waterproof apron of about 2 m width at a depth of about 50 cm is more appropriate ^[9].
- As explained in detail in section 2.10.1, install horizontal barriers, vertical barriers, intercepting drains, peripheral drains or combination of them depending on source of water and surface drainage conditions ^[6].

2.11.2 Increasing stiffness of the structure and/or resistance against uplift

In addition to minimizing moisture fluctuation increasing the stiffness of the building and/or resistance against uplift pressure would also be a good solution for buildings damaged by cyclic heave and shrinkage of expansive soils. Such remedial measures various depending on the type of foundation system and extent of damages. Most commonly used structural remedial measures are presented below with respect to foundation systems ^[1].

For drilled pier foundation:

- Loosen soil around the pier to reduce the uplift pressure
- Reconstruct void space beneath the grade beams
- Eliminate the mushroom at the top of the pier

- Cut the top of the pier and adjust the pier by shims
- Remove all the back fill around the building and replace with compacted non-expansive clay to protect surface water entering through the foundation soil
- Improve the drainage condition around the building by providing adequate slope away from the building and paving with concrete

For continuous footing foundation

- Provide voids beneath the footings at calculated interval to increase the dead load pressure
- Post-tension the foundation to provide structural stability
- Reinforce existing foundation walls with new reinforced grade beam to tie the structure as in box construction
- Under pile the structure with piers drilled in to bed rock

For individual pad foundation:

- Decrease pad size to increase the dead load pressure
- Underpin the pad with piers drilled into bed rock

For basement

- Saw cut the slab along the foundation wall to allow free slab movement
- Adjust screw jack on top of pipe column to re-level interior I-beam
- Provide slip joints to all internal slab bearing partition walls, including door frames and staircase walls.

CHAPTER 3: RESEARCH METHODOLOGY AND ORGANIZATION

3.1 Introduction

Research is defined as processes of collecting, analyzing and interpreting information to provide solution for question or problem. With this background research methodology is therefore a means which ties up all the research processes jointly and guides the researcher to achieve the aim and objectives of the study. Hence, the purpose of this chapter is therefore to present research methodology/procedure which has been followed to achieve the ultimate goal of the research.

3.2 Data collection method

In order to achieve the objectives of the research stated in chapter one, two types of data are required. The methodologies implemented to collect the data are discussed below.

- a. Sampling of buildings constructed in expansive soil area:** The major type of data required for this research will be buildings constructed in expansive soil areas. Therefore; adequate numbers of representative sample buildings have to be carefully selected. Determination of sample size and distribution for each expansive soil area are presented in section 3.3 below.

The next step is collecting the required data. In order to do this a questioner (Annex A) was developed and data is collected by physical observation, interviewing building owners and people involved during construction period.

- b. Design data of selected buildings:** The design data has vital role in understanding the source of the problem, and in proposing the right solution. This data is collected by having discussion with engineers working in design offices and using questioner (Annex B).

As the number of design offices in Bahir Dar are not many the data is collected almost from all design offices working in Bahir Dar.

3.3 Method of sampling and sample size determination

Basically there are two types of sampling techniques. These are probability (random) and non-probability samplings. Probability sampling offers an equal opportunity or chance for each element (e.g. persons, households) being included in the sample. However; in nonprobability sampling, in contrast, population elements are selected on the basis of their availability or because of the researcher's personal judgment that they are representative ^[20].

In addition to this probability sampling is considered to be objective, empirical, scientific, quantitative and representative. Whereas; non-probability sampling is considered to be interpretive, subjective, not scientific, qualitative and unrepresentative. Therefore random sampling method is used for most scientific studies and implemented in this research too for sample size determination.

According to this method sample size has been determined as follows ^[21]:

$$n = \left[z^2 \times \frac{p \times q}{d^2} \right]$$

Where: n = sample size to be studied

z = standard normal value

p = expected prevalence (sample proportion which are damaged)

q = 1-p = expected non-prevalence (sample proportion which are not damaged)

d = relative desired precision

Assumptions for this study

z = 95% confidence interval is used for most studies. This means that we can be 95% sure that the true population value for our damage assessment is within the limits of the interval calculated. At 95% confidence the value of z=1.96.

p = Information to determine the estimated prevalence can be obtained from various sources such as previous studies, surveillance data or rapid assessment results ^[22].

Since there was no similar study in our county Afework Sisay (2004) ^[1] used p=0.5(50%) which gives the maximum sample size. From his research he found out that 72% of the buildings are damaged due to problems related to expansive soils. As compared to Bahir Dar many professionals have been working in Addis Ababa and participating in the design

& construction of buildings. In addition to this, due to various reasons, awareness of building owner about expansive soil is much better in Addis Ababa than Bahir Dar. Therefore; damage of buildings due to expansive soil in Bahir Dar is expected to be higher than that of Addis Ababa. This means if we take 0.72(72%) prevalence value from Sisay’s study we will get reasonably maximum number of sample buildings.

d = There is no standard precision to use when planning a survey. Desired precision depends on the objectives of the survey, estimated prevalence or rate, and resources (time and finance) available. Other things kept equal, the higher your desired precision, the larger is the sample size ^[22]. For our study +/-10% precision value is selected.

Hence our sample size will be:

$$n = \left[1.96^2 \times \frac{0.72 \times (1 - 0.72)}{0.1^2} \right] \approx 78 \text{bldgs}$$

These 78 buildings are distributed over every expansive soil locations in the study area based on area coverage and number of bldgs. constructed in the area as shown below in table 3.1.

Table 3.1 Distribution of sample buildings over expansive soil area

No.	Location	No of bldgs	Remark
1	Kebele 03	6.00	Tp7-1
2	Kebele 7	13.00	Pit 1 & 2
3	Kebele 8	6.00	Pit 1 & 2
4	Kebele 10	9.00	K10 & Tp5-1
5	Kebere 11(Abay Mado)	11.00	
6	Kebele 13	16.00	K13, Tp1-1 & Tp4-1
7	Kebele 14	6.00	Tp10-1
8	Kebele 15	5.00	
9	Kebele 16	6.00	
Total =		78.00	

3.4 Method of analysis

Data collected from sample buildings shall be presented statistically & in different categories and due to this quantitative analysis method has been followed. However; data collected from design offices are more of descriptive type and qualitative analysis method has been implemented.

CHAPTER 4: DATA COLLECTION, ANALYSIS AND RESULTS

In this chapter previous studies about damage caused by expansive soil in Ethiopia (in general) & in Bahir Dar (in particular), previous studies about property of expansive soil in Bahir Dar and damage assessment & analysis for randomly selected buildings have been thoroughly discussed.

4.1 Previous studies about damage caused by expansive soil

4.1.1 In Ethiopia

Regarding damage caused by expansive soil a research was conducted in Addis Abeba by Afewerk Sisay (2004). In this study ninety-six randomly selected lightweight buildings founded on expansive soils of Addis Ababa were examined and detail study of one selected building was also conducted.

The damages were related to the observational data and systematically analyzed and causes of damages were attributed to wall construction material, foundation system, drainage condition etc. Out of the observed ninety-six buildings, sixty-nines (72%) are affected by consequence of heave or shrinkage of the expansive soil. The problems observed on these 96 buildings vary from simple crack on walls to severe structural damages, which cause collapse of the whole building.

4.1.2 In Bahir Dar

So far no study has been done with regard to damage of building constructed on expansive soil of Bahir Dar. As shown in Table 4.1 below, all the 37 samples examined in the previous study show that the expansive soil in and around Bahir Dar is highly expansive^[18]. In addition to this Table 4.2 and Figures 4.3 show considerable numbers of buildings have been constructed in less than 50% of total expansive soil area of Bahir Dar.

Therefore; this research tried to identify the extent of damages caused by expansive soil in areas where buildings and others structures are already constructed.

4.2 Previous studies about property of expansive soil in Bahir Dar

4.2.1 Laboratory test results

In previous years few researches were conducted in Bahir Dar on determination of characteristics and soil type of the area. Especially researches done by Alemu D., Biru, G. and Negussie, D. ^[18] focused on determination of presence of expansive soils in the area, its index properties and engineering characteristics and investigating the relationships between index properties and swelling characteristics.

Negussie D. had covered large area in and around Bahir Dar. In this study 37 samples were collected from 20 locations and the following index properties and relationships have been identified:

The laboratory test results which were identified in the above study are summarized in Table 4.1 below.

Table 4.1 Range of values of laboratory test results of Bahir Dar expansive soils ^[18]

No.	Location	Depth (m)	LL (%)	PI (%)	Clay Cont. (%)	NMC w (%)	Volumetric Shrinkage (%)	Free Swell	CEC (Meq/100g)	Na ⁺ (Meq/100g)	Swelling pressure (Kpa)
1	Tikurit Mender	2.5	91.41	61.57	77	26.51	8.38	120	51.57	3.63	547.52
2	Zenzelma Abo	2.0	96.47	59.8	73	31.2	8.2	110	64.41	0.37	344.5
3	Gobame	2.0	99.51	65.98	87	46.88	13.95	150	57.35	0.92	111.82
4	Gordema	1.5	112.1	76.42	86	28.11	16.67	170	62.27	3.93	514.61
5	Gudadle	2.0	99.51	75	85	40.1	13.09	160	60.56	4.06	175.38
6	Baynes (Pit 2)	2.5	84.78	47.76	82	40.39	15.56	100	51.36	3.42	165.6
7	Baynes (Pit 1)	1.0	96.85	56	73	41.15	12.77	110	61.2	0.79	377.27
8	Kereza Mender	2.0	106.1	71.36	78	61.24	10.47	215	68.27	0.46	79.95
9	Chorka Mender	1.5	86.73	62.99	80	28.14	13.27	120	62.48	1.34	379.24
10	Sesa Beret (Pit 1)	2.5	88.11	66.7	82	31.1	13.78	80	49.86	1.25	538.33
11	Sesa Beret (Pit 2)	2.0	86.23	60.93	77	38.14	10.87	90	61.63	2.3	202.27

Table 4.1 Continued. . . .

No.	Location	Depth (m)	LL (%)	PI (%)	Clay Cont. (%)	NMC w (%)	Volumetric Shrinkage (%)	Free Swell	CEC (Meq/100g)	Na ⁺ (Meq/100g)	Swelling pressure (Kpa)
12	Lumame (Pit 1)	1.0	81.49	53.86	73	34.09	19.07	105	43.87	2.8	296.91
13	Lumame (Pit 2)	1.5	87.03	58.73	83.5	38.74	6.85	138	46.22	3.51	135.74
14	Mazoria	1.5	96.29	64.71	69	32.9	12.27	130	54.36	6.44	197.41
15	Sensela Bata	2.5	88.59	56.72	81	32.75	6.30	110	70.88	0.63	264.76
16	Kebele 16	1.5	93.93	59.53	80	40.99	12.86	200	50.08	1.58	114.37
17	Kebele 9	2.0	84.26	57.42	85	35.13	13.68	190	67.45	3.51	495.81
18	Kebele 7 (pit 1)	2.5	99.14	63.62	77	41.96	13.34	120	67.62	4.43	186.8
19	Kebele 10	1.5	93.49	56.33	80	40.8	16.40	170	57.57	1.63	298.11
20	Kebele 8 (pit 1)	2.5	90.66	58.66	80	37.19	11.74	200	67.41	0.42	210.22
21	Kebele 15	1.0	75	46.46	67	37.25	16.67	120	28.03	1.71	326.44
22	Kebele 13	1.0	82.19	50.01	81	48.61	10.63	130	48.36	8.11	140.64
23	Kebele 7 (pit 2)	1.5	78.5	50.23	66	59.45	15.18	150	52	1.71	92.12
24	Kebele 8 (pit 2)	2.0	89.39	44.55	83	34.2	15.18	180	77.51	3.88	128.09
25	Tp1-1	1.5	95.5	63.4	58.1		13.20	78			
26	Tp2-1	1.5	82	53.7	70.9		17.00	86			
27	Tp3-1	1.5	87.8	54.8	64.4		14.30	98			
28	Tp4-1	2.0	81.3	53.7	71.3		15.20	120			
29	Tp5-1	1.5	84.8	49.3	70.3		19.10	110			
30	Tp6-1	1.5	90	60.9	68.4		16.00	116			
31	Tp7-1	2.0	93.5	68.9	63.7		14.10	113			
32	Tp8-1	2.0	93	61.6	62		17.70	114			
33	Tp9-1	2.0	93.5	64.2	55.4		18.40	125			
34	Tp10-1	2.0	82.8	51.1	70.6		14.80	108			
35	Tp11-1	1.5	89.5	64	67.3		13.90	124			
36	Tp12-1	1.5	80	54.6	61.5		17.90	114			
37	Tp13-1	1.5	91	57.4	67.9		15.00	95			

From the above table degree of expansion of Bahir Dar expansive soil is summarize as follows^[4]:

- For all samples $LL > 60$ Very high degree of expansion.
- For all samples $PI > 35$ Very high degree of expansion.
- For all samples clay (colloid) content > 28 Very high degree of expansion.
- Free swell
 - ✓ 3 Pits $\geq 200\%$ Very high swelling potential.
 - ✓ 28 Pits $100\% - 200\%$ High swelling potential.
 - ✓ 6 Pits $50\% - 100\%$ Medium swelling potential.
- Swelling pressure varies from 79.95Kpa up to 547.52Kpa Medium to high Degree of Expansion.

Note: Index properties are parameters which can be used as a preliminary indicator of the swelling characteristics of a soil. However; it should be noted here that high index property doesn't necessarily mean high swelling potential while the converse may be true.

4.2.2 Classification of expansive soils

Classification of expansive soil of Bahir Dar area was also done by Nigussie and presented here under:

- According to USCS classification scheme most of the soil of the study area falls in CH or OH region, which shows that the soil is potentially expansive.

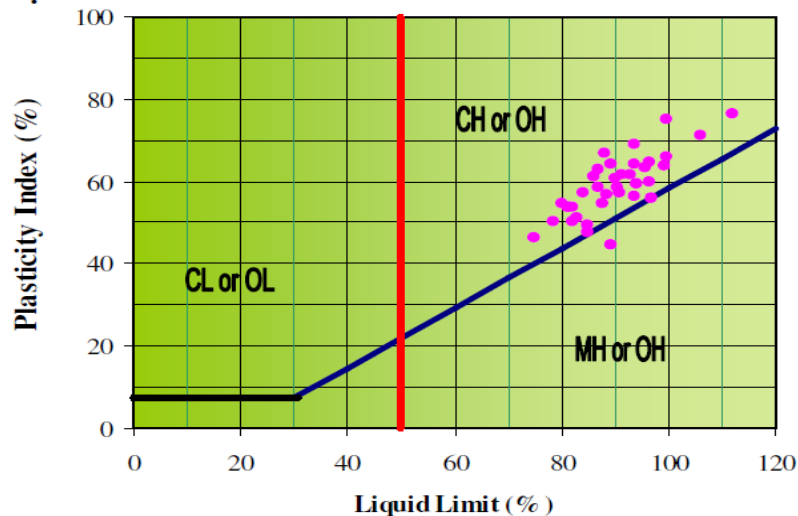


Figure 4.1 Plasticity chart of the study area soil, USCS System^[18]

- According to AASHTO classification system the soil of the study area falls in the region of A-2-7, A-7-5 and A-7-6. This means the soil under interest is plastic clay which has a high volume change capacity between wet and dry states.

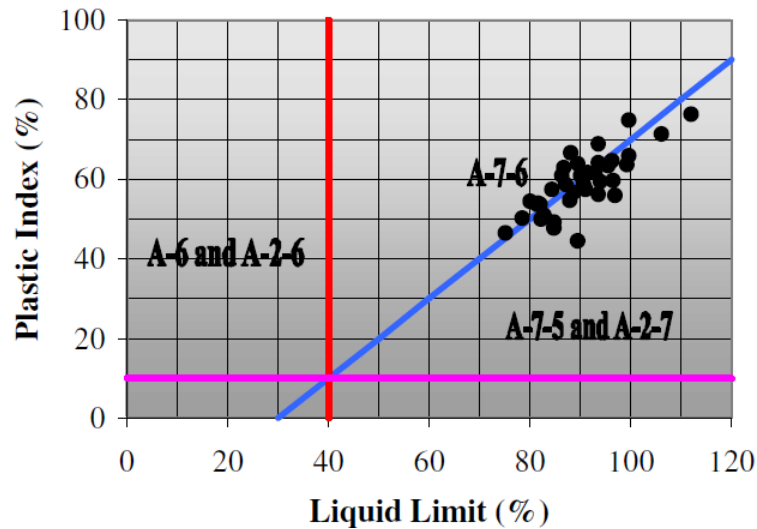


Figure 4.2 Soil classification for the study area according to AASHTO System ^[18]

Conclusion: The above laboratory test results and soils classifications showed that expansive soil of Bahir Dar have high to very high swelling potential!

4.2.3 Locations of expansive soil areas in Bahir Dar town

In addition to the laboratory tests and soil classifications, Nugussie has also provided coordinates for 30 test pits in 20 locations. For the purpose of this study these 20 locations are further described interims of distance from the center of the town and current construction activities in the area. The details are presented in Table 4.2 and Figures 4.3 below:

Table 4.2 Location of expansive soil area in Bahir Dar where samples are collected [18]

Location	Pit name	Northing (m)	Easting (m)	Elevation (m)	Distance from center of the town(Km)	Current construction status
Center of Bahir Dar		1281459	324236			
1	Tikurit Mender	1273834	325339	1768	7.70	Few Bldgs
2	Zenzelma Abo	1283804	332604	1903	8.69	No Bldgs
	Sesa Beret (Pit 1)	1284159	332526	1904	8.72	No Bldgs
	Sesa Beret (Pit 2)	1283945	332518	1901	8.65	No Bldgs
3	Gobame	1284753	314278	1811	10.49	No Bldgs
	Gudadle	1285037	314294	1812	10.57	No Bldgs
4	Gordema	1277529	324482	1797	3.94	Few Bldgs
5	Baynes (Pit 2)	1287231	332130	1903	9.78	Some Bldgs
	Baynes (Pit 1)	1287375	332072	1897	9.82	Some Bldgs
6	Kereza Mender	1275462	325155	1781	6.07	No Bldgs
7	Chorka Mender	1282045	330853	1897	6.64	No Bldgs
8	Lumame (Pit 1)	1286277	317032	1799	8.67	No Bldgs
	Lumame (Pit 2)	1286451	316926	1800	8.85	No Bldgs
9	Mazoria	1285613	332944	1917	9.65	Few Bldgs
10	Sensela Bata	1284203	322099	1787	3.48	No Bldgs
11	Kebele 16	1281637	322866	1795	1.38	Many Bldgs
	Tp7-1	1282221	322970		1.48	Many Bldgs
12	Kebele 9	1281175	325880	1801	1.67	Some Bldgs
13	Kebele 8 (pit 1)	1281330	325272	1803	1.04	Many Bldgs
	Kebele 8 (pit 2)	1281037	325445	1802	1.28	Many Bldgs
14	Kebele 7 (pit 1)	1280771	324579	1801	0.77	Many Bldgs
15	Kebele 10	1282627	325688	1796	1.86	Many Bldgs
	Tp5-1	1281952	325770		1.61	Many Bldgs
16	Kebele 15	1280636	323631	1806	1.02	Many Bldgs
	Tp10-1	1280808	323210		1.22	Many Bldgs
17	Kebele 13	1283340	321903	1794	3.00	Many Bldgs
	Tp4-1	1283326	322073		2.86	Many Bldgs
18	Kebele 7 (pit 2)	1279967	325305	1799	1.84	Many Bldgs
19	Tp1-1	1283352	321335		3.46	Many Bldgs
20	Tp13-1	1282037	323931		0.65	Many Bldgs

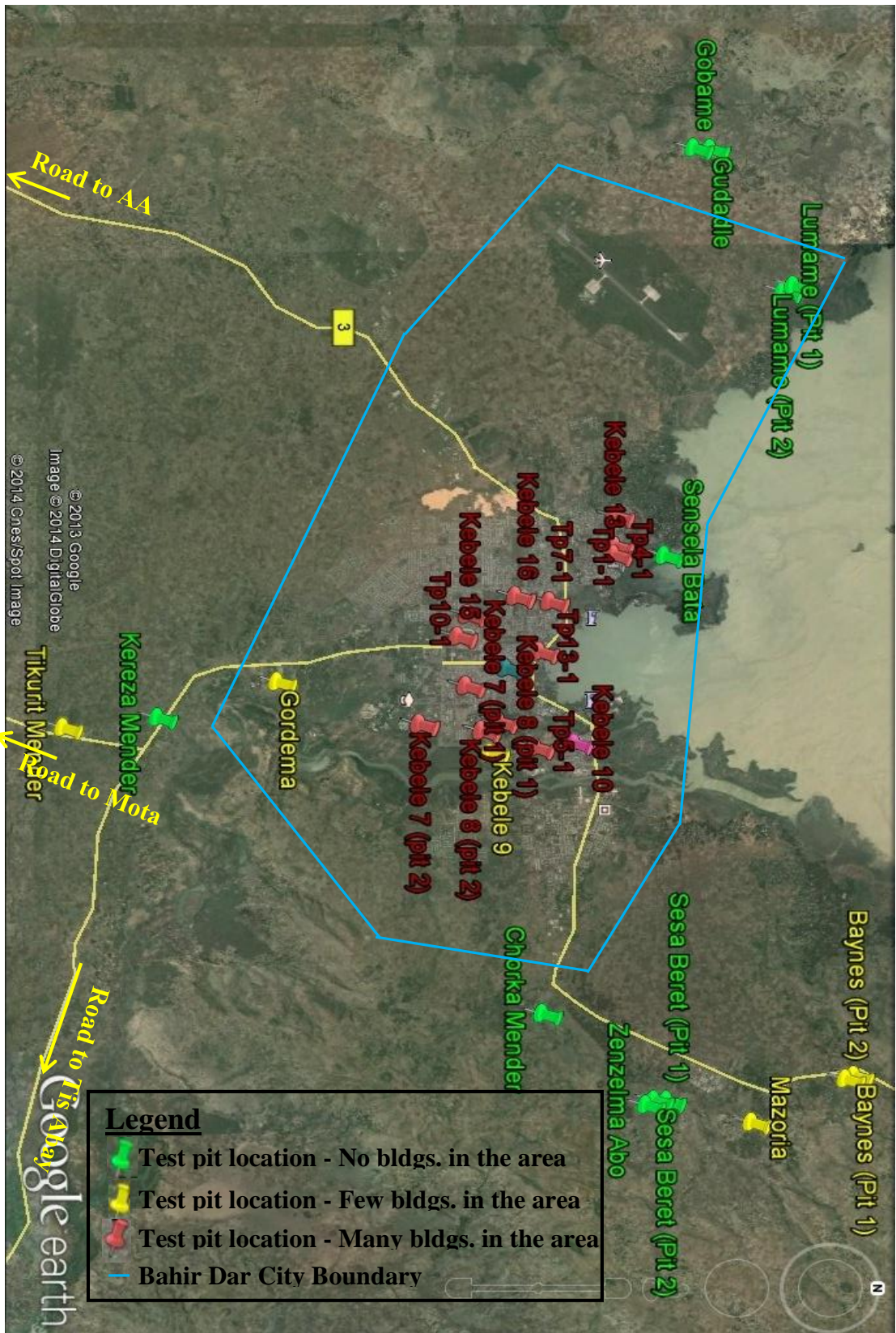


Figure 4.3 Test pit location in and around Bahir Dar - General over view

From Table 4.2 and Figure 4.3 we shall observe following 3 main points:

- ✓ Out of 20 locations, 10 of them are outside Bahir Dar town and there is almost no construction activity in these regions.
- ✓ Out of 20 locations, nothing has been built on 6 locations and in 5 locations only very few buildings have been constructed.
- ✓ The farthest test pit location is 10.53Km from the center of the city. Development activities are flourishing and the town is expanding in all directions (except towards Lake Tana). Hence those 10 locations which are currently outside of Bahir Dar are expected to be covered by buildings and infrastructures with in short period of time.

Bahir Dar doesn't have soil map. Due to this, it is difficult to estimate the area covered by expansive soils. However; we can roughly estimate the percentage of uncovered area using the number of expansive soil locations. Out of 20 expansive soil locations there are only few or no buildings at 11 locations. Hence roughly 55% ($11/20*100$) of expansive soil area of Bahir Dar isn't covered by buildings and other civil engineering structures.

4.2.4 Thickness of expansive soil and active zone

The amount of volume increases due to swelling of expansive soil is directly proportional to stratum thickness. The soil water content is considered to remain constant below active depth and foundations situated below this depth aren't subjected to distress from soil volume change. Hence; stratum thickness and active depth are vital factors that should be determined in order to understand problems related to expansive soils.

Ground water table

In order to get the ground water table depth of the study area the following three data sources were used:

- Studies conducted by Mengistu Y. ^[22] showed that the average ground water fluctuation depth ranges from 0.5m to 3.4m. He measured the water level of 11 water supply well of the town. Out of these 11 wells 4 of them are located at/or near expansive soil areas. The measurements of these four wells are presented below.

Table 4.3 Water well data around expansive soil area - from Mengistu [22]

Well Code	Location		Water level from ground elev.	Remark
	Northing	Easting		
BH-2	1281723	325569	3.1m	
BH-3	1280884	324639	3.4m	
BH-8	1280580	323650	1.8m	
BH-9	1283422	321705	0.5m	

- The second data was obtained from governmental organization, Amhara Water Well Drilling Enterprise (AWWDE). Borehole data of expansive soil areas obtained from this organization are tabulated in Table 4.4 below:

Table 4.4 Water well data around expansive soil area - from AWWDE

Well excavation date	Well owner	Location	Static water level	Remark
25/10/2004EC	B/Dar sanitary & sewage office	Addis Alem	2m	
11/02/2005EC	Bahir Dar University	BDU Peda well 1	3.25	
05/07/2005EC	Bahir Dar University	BDU Peda well 2	25	
29/02/2006EC	ANRS Sport	Bahir Dar Stadium	1.4m	

- In addition to the above two data, ground water table level readings were taken during three different periods of the year for an existing water well located at kebele 03 [1282324.8N & 322981.6E]. The reading are as follows:
 - ✓ April 07, 2014 1.9m
 - ✓ August 22, 2014. 0.0m (fully saturated to surface)
 - ✓ December 12, 2014. 1.05m

Except 1 data from Table 4.4 all the three data sources showed that the maximum ground water table doesn't exceed 3.4m. Hence we can conclude that the ground water table range indicated by Mengistu in 2003GC (0m to 3.4m) is valid.

Thickness of expansive soil

No study showing the thickness of expansive soil in the study area has been found. However; Nigussie ^[18] explained that the sample depth for all 37 pits ranges from 1.5m to 3m due to either presence of boulder or rising of ground water table. Stratum thickness might be greater than 3m, however; soil below 3.4m depth is under water and has no effect on the volume change. Therefore; we can conclude that the maximum effective stratum thickness which could contribute to the volume change is 3.4m.

4.3 Building damage assessment

In sections 4.1 and 4.2, previous studies about expansive soil of the study area have been summarized in such a way that could help in identifying the problems associated with expansive soil and propose proper remedial measures. The next steps will be examining the extent of damage, identifying possible causes and evaluate the design criteria and procedures followed by designer.

4.3.1 Observation and damage analysis for selected buildings

A questioner was prepared (Annex A) so that properly organized and consistent data could be collected during assessment of selected buildings. For each randomly selected building the required data was first collected by conducting physical observation. This stage has the following three major components:

- Identifying construction material of each component of the building
- Careful observation and analysis of extent of damage in each building element, if any
- Studying surface drainage and ground water table conditions

The second stage was interviewing house owners, elderly people in the area and skilled workers who had been participating in construction of buildings around that area or if possible people directly involved during the construction period.

The last step was interpretation of collected data. Hence; damage is analyzed and interpreted systematically with respect to type of foundation, wall, floor, pavement, door, window and fence. Detail results are presented below.

Table 4.5 Assessment of damage of buildings with respect to type of foundation system

Type	No. of visited bldgs.	No. of damaged foundations	Damaged foundations in %
Mat	0	0	0%
Isolated footing	10	7	70%
Masonry	47	17	36%
Wooden post (<i>Mud house foundation</i>)	9	9	100%
Wooden post with Masonry envelop	12	9	75%
Total	78	42	54%

Mud house are constructed from wooden skeleton and plastered by locally prepared mud which has cementitious characteristics. For such kind of houses the wooden skeleton extended down to the foundation soil and act as a foundation. For most buildings masonry around the building has been constructed to strengthen the wooden foundation. All visited houses with only wooden post foundations sink every rainy season. The same problem is observed almost on every building of wooden post foundation enveloped by masonry wall around the buildings.

Masonry foundation system is highly susceptible to damage due to expansive soil. Damage has been observed only on 36% building with masonry foundation. This is much less than expected damage. The main reason for this is that due to the flat terrain condition masonry foundations of most resident houses in the study area are totally buried in the ground (see pic 4.4e) and only grade beams are exposed. Hence even though there is foundation movement cracks are observed on floors and walls.

The type of foundation damage ranges from minor racks to total disintegration of masonry walls. Sample pictures are shown below.



a. Masonry foundation wall partially settled around the corner due to trees/vegetation close to the building



b. Building under construction and masonry started cracking.



c. Masonry crack extended to grade beam and HCB wall.



d. Seriously damaged masonry foundation, grade beam and floor slab.



e. Masonries of most residential houses are completely covered under the soil.

Figure 4.4 Sample pictures for foundation damages

Table 4.6 Assessment of damage of buildings with respect to wall type

Type	No. of visited bldgs.	No. of damaged walls	Damaged walls in %
HCB	51	38	75%
Masonry	1	1	100%
Brick	1	1	100%
Mud	19	16	84%
CIS	0	0	0%
Wooden post only	2	2	0%
Not Constructed	4	0	0%
Total - bldg. with wall	74	56	76%
Total	78	56	72%

Out of 78 building 51 of them are constructed from hollow concrete blocks and 19 are mud houses. Only one brick and one masonry wall types have been encountered during random assessment. The percentage of HCB and mud walls damages are 75% and 84% respectively.

The major type of damages observed in mud houses are minor cracks around corners of door/windows and reduction in wall height due to sinking of foundation. However; the extent of damage in HCB wall ranges from minor to severe cracks in different direction.



a. Seriously damaged elementary school class room. Students looking outside through the wall!



b. Cracks starting from door corner.



c. Wall cracks due to edge lift.



f. Diagonal cracks extended to glass from HCB wall

Figure 4.5 Sample pictures showing type of wall damages

Table 4.7 Assessment of damage of buildings with respect to type of floor system

Type	No. of visited bldgs.	No. of damaged floors	Damaged floors in %
Only concrete	13	9	69%
Concrete + Screed	39	29	74%
Concrete + PVC FF	3	2	67%
Concrete + Terrazzo	5	3	60%
Concrete + Ceramic	7	3	43%
Compacted soil	9	8	89%
Comp. soil + Screed	1	1	100%
Not Constructed	1	0	0%
Total - bldg. with floor	77	55	71%
Total	78	55	71%

Depending on their construction materials and response to movement, floors can be majorly categorized as concrete related and mud floor systems. Those floors in the first category are rigid structures and the types of damages they suffer are cracks in different direction, bulging

of some floor areas followed by cracks, settlement and total disintegration of the floor system. However; the mud floor system is flexible, as a result only bulging and some undulation are observed in response to seasonal moisture fluctuation.



a. Bulged floor



b. Cracks in different direction



c. Floor settlement – the floor system separated from skirting by 6.5cm



Figure 4.6 Floor damage sample pictures

Table 4.8 Assessment of damage of buildings with respect to types of walkways around the building

Type	No. of visited bldgs.	No. of damaged walkways	Damaged walkways in %
Concrete	24	21	88%
Stone	2	2	100%
Total - pavement around bldg.	26	23	88%
Total	78	23	29%

Walkways are light weight structures which can easily be affected by swelling and shrinkage cycle of expansive soils. Out of 78 assessed buildings 26 of them have walkways around the building. Except three walkways the rest are affected. These three buildings are constructed after removing the expansive soil from the building area and due to this none of their building components including their walkways are affected. The type of damage ranges from minor cracks to complete disintegration and removal from the area.



a. Cracks, vertical and horizontal movement



b. Walkway moved down by 47cm from its original position





c. Completely damaged walkway - the original position of the walkway was at 67cm from current NGL

d. Down pipes discharging to the foundation soil trough the crack created by horizontal & vertical movement of the walkway

Figure 4.7 Sample pictures of damaged walkways

Table 4.9 Assessment of damage to doors

Type	No. of visited bldgs.	No. of damaged doors	Damaged floors in %
Metal	57	24	42%
Wooden	12	7	58%
CIS	3	3	100%
Not Installed	2	0	0%
No door	4	0	0%
Total - bldg. with doors	72	34	47%
Total	78	34	44%

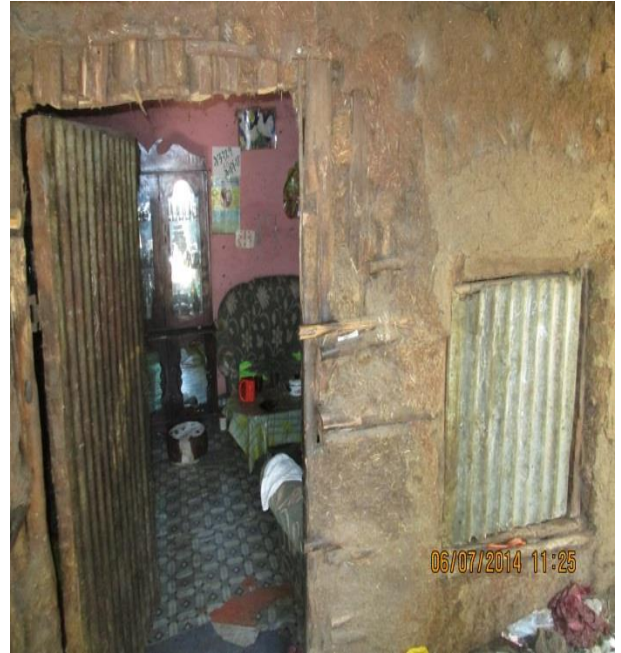
Table 4.10 Assessment of damage to windows

Type	No. of visited bldgs.	No. of damaged windows	Damaged windows in %
Metal	63	14	22%
Wooden	6	5	83%
CIS	3	3	100%
Not Installed	2	0	0%
No window	4	0	0%
Total - bldg. with windows	72	22	31%
Total	78	22	28%

Staked doors and windows are the major damages observed during the assessment. In few cases cracked and broken glasses are observed. Unlike floors and walls, the types of materials used don't have significant effect on the type of damages. Instead; it is dependent on the extent of wall and floors movements to which doors and windows are attached to. Sample damage types are shown below:



a. Doors not properly closable due to movement of wall and floor



b. House owner used to cut doors at the bottom or top to adjust the stacking problem



c. Some of affected metal and wooden windows

Figure 4.8 Windows and doors damage sample pictures

Table 4.11 Assessment of damage to fences

Type	No. of visited bldgs.	No. of damaged fences	Damaged fences in %
Masonry	6	3	50%
HCB	12	9	75%
Masonry + HCB	10	7	70%
Dry masonry	9	0	0%
CIS	6	0	0%
Wooden posts	9	0	0%
No fence	26	0	0%
Total - bldg. with fence	52	19	37%
Total	78	19	24%

Next to walkways around the buildings fences are highly susceptible to damage due to their light weights. Considerable damage observed on masonry and HCB fences while no damaged is observed on fences constructed from dry masonry, corrugated iron sheets (CIS) and wooden posts.

Voids in masonry fences are filled with mortar and it acts as a solid unit. However only joints between HCB blocks are filled with mortar and still cavities in each block are open. In addition to this, stones in masonry fence have a better interlock to each other as compared to predetermined joint lines in HCB walls. Due to these facts more HCB fence are damaged as compared to masonry fences.



Figure 4.9 Sample pictures of damaged fences

Table 4.12 Extent of damaged buildings with respect to building elements

Building Element	No. of visited bldgs.	No. of damaged bldg. elements	Damaged bldg. elements in %
Foundation	78	42	54%
Pavement around bldgs	26	23	88%
Floors	77	55	71%
Walls	74	56	76%
Doors	72	34	47%
Windows	72	22	31%
Fences	52	19	37%

As it can be seen from the above summary table the 1st building component which is highly susceptible to damage due to expansive soil is pavement around the building. The extent of damage decreases when we proceed to walls, floors, foundation in their respective orders.

Table 4.13 Extent of damaged with respect to building types

Building type	No. of visited bldgs.	No. of damaged bldg.	Damaged bldg. in %	Remark
G+4	1	1	100%	
G+2	2	2	100%	
G+1	1	1	100%	
G+0(HCB)	48	39	81%	
Mud house	20	19	95%	
Shed	2	2	100%	
Bldgs. Under construction	4	4	100%	
Total	78	68	87%	

Table 4.14 Number of damaged buildings - summary

Type	No. of visited bldgs.	No of damaged bldgs.	No of damaged bldgs. in %
All Bldgs	78	68	87%

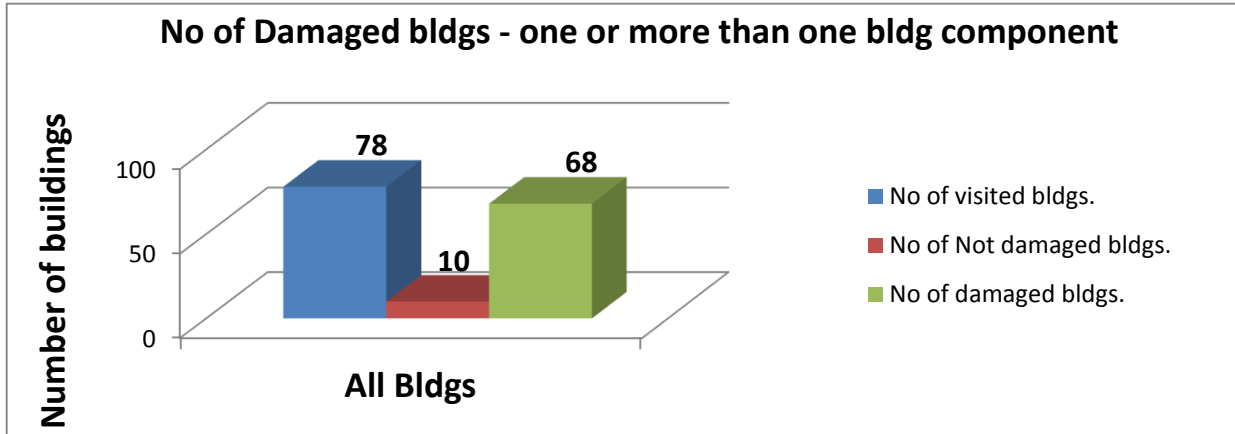


Figure 4.10 Damage summary

Conclusion: Out of randomly visited 78 buildings constructed on expansive soil areas 68 of them are damaged due to swelling and shrinkage cycle of the soil, which is 87%. In most cases more than one building components are affected.

4.3.2 Observations from design offices

As discussed in previous section, 87% of visited buildings are affected by heave and shrinkage of expansive soil. It is obvious that if these buildings had been properly designed and constructed taking the effect of expansive soils into consideration then the extent of damage wouldn't be as big as 87%. Therefore; it becomes necessary to evaluate the design methodologies and procedure implemented in design offices.

As per the data obtained from Bahir Dar town administration office there are one grade-1, two grade-3, one grade-4, eight grade-5 and nine grade-7 design offices which are working in Bahir Dar. Out of these 21 design offices 19 of them have been assessed, see annex B, and the major discussion points and findings are presented below.

Q: Do you know expansive soil area in/around Bahir Dar and their swelling potential and swelling pressure?

- Locations: Most of them don't know more than three areas.
- Swelling pressure: All offices don't have any data.

Q: Do you conduct geotechnical investigation before proceeding to design? If yes what kind of data you used to collect?

- All offices used to test the foundation soil for buildings having G+2 and above stories. The usual tests are direct shear, atterberg limits, sieve analysis and compaction.
- None of them know about swelling pressure test and its significance. Foundation dimensions are only determined from bearing capacity requirement. Nobody considers uplift.

Note: There are four soil laboratories in Bahir Dar. Two of them don't have consolidometer. In the other two laboratories the equipment are not used due to various reasons.

Q: Do you put soil investigation data on dwgs?

- 10 offices put allowable bearing capacity value and few notes like “use well graded selected fill and compact to 95% proctor test” and “provide apron around buildings & drain away water from the building”.
- Except 1 office all of them don't show soil profile where the building is going to be built.

Q: Do you have typical foundation design for expansive soil areas?

- The governmental authority only requested design documents for buildings with two stories and above. It is known that building with two stories and less are those highly affected by expansive soil. Hence, at least there should be standard foundation designs and proper details for building with G+2 and less stories. None of them have any typical foundation designs.

Q: Have you seen bldgs damaged by expansive soil in Bahir Dar? In your opinion, what percentage of bldg constructed on expansive soil area are damaged?

- Except three offices (managers) the rest at least have seen a building damaged by expansive soil.

Q: From your experience what do you encountered as the major causes of swelling and shrinkage of Bahir Dar expansive soils?

- Most of them mentioned the following reasons: Ground water fluctuation, presence of Lake Tana & Abay River around the town, stagnation of rain water in the area due to flat terrain condition.

Q: Do you have experience in investigating and proposing remedial measures for bldg damaged by expansive soil or by other reason? If yes how many? What kind of measures you have proposed?

- One consultant said that they did re-design for three buildings affected by expansive soil and another one consultant has also one experience. However the design documents for these four buildings were not accessible and due to this it wasn't possible to evaluate the implemented remedial measures.

Conclusion: It has been observed that all design offices in Bahir Dar don't consider the uplift pressure in their design. There are even some cases that samples were collected by the client from site in order to minimize laboratory costs. Sometimes, prior to getting test results from lab, footings have been designed with some estimated bearing capacity value and later on test results used to be simply attached as design documents. This shows that soil tests are usually conducted just to fulfill the requirements set by the regional government.

CHAPTER 5: DISCUSSION

5.1 Possible cause of failure and proposed remedial measures

In this study it is observed that except for few buildings the causes of failure are more than one. Due to this it is difficult to present the cause of failures in figurative way. Hence the major causes and related remedial measures are presented below qualitatively.

Ground water table fluctuation: The main cause of failure which takes the lion share in the study area is fluctuation of ground water table. As it has been discussion in section 4.2.4 the water table ranges from 0 to 3.4m. In most areas the ground water reaches natural ground level during rainy season. Hence the top 3.0m is active zone and foundations of most buildings are located within this depth. These buildings are constructed without taking any measures in response to volume change of the expansive soil. Therefore distress caused by heave and shrinkage cycles due to ground water fluctuation is the main causes for most damaged buildings.

Providing concrete or stone masonry aprons around the building increases the covered area and also will reduce the moisture fluctuation around the edge of building. This action will lead movement of more water towards the building. However; once the new soil moisture equilibrium has been set, the moisture fluctuation around the building will be considerably minimized and damage cause during seasonal moisture fluctuation will also be reduced.

It should be noted that while providing apron around the building the expansive soil underneath should be treated. Otherwise, it will easily be damaged and let water to move in to the foundation soil.

Poor surface drainage: Most of expansive soil areas in Bahir Dar have flat terrain which allows rain water to accumulate in the area. It isn't unusual to see resident compound at lower elevation than the road around the area; see figure 5.1 below. In addition to this road side ditches don't have proper slope and this leads to stagnation of rain and gray water in most of these ditches.

In order to minimize problems created by such conditions positive slope around house and proper outlets from the compound should be provided. In addition to this, road elevations, side

ditch and crossing structures should also be provided in such a way that the surrounding surface water can easily be drained away from the area.



Figure 5.1 Resident areas located below road levels



Figure 5.2 Gray water accumulated in road side ditch

Trees and vegetation: Considerable numbers of buildings are damaged due to trees/vegetation planted close to buildings (see Figure 4.4a). No house owner has awareness about such condition. Therefore; in addition to removing trees and other plants from the building area, awareness creation has to be done by the responsible governmental offices, design offices, contractors and academic institutions.

Damaged utility lines: Few buildings are affected due to local heave and shrinkage created by leaking water supply and sewerage pipes. Such condition can easily be solved by conducting regular inspection and maintenance of the referred pipes.



Figure 5.3 Leaking water supply pipe and damaged down pipe

Improper design: Assessment conducted in design offices showed that nobody is checking the safety of the building with respect to the uplift pressure. This indicates that there is either a knowledge gap or carelessness in design offices and/or designers. The authority who is in charge for approval of these designs also doesn't demand such requirements. Even design documents are not required for building below two stories which are vulnerable for damage due to their light weights.

Problems created by ground water fluctuation and poor surface drainage can be properly addressed by considering the situation during the design phase and providing detail drawings for house builders.

Academic institution around the area like Bahir Dar University are expected to do much works in collaboration with the responsible governmental authorities in filling knowledge gap and awareness creation.

5.2 Proposed design & construction methodologies

As it has been explained in chapter three structural analyses and proper provisions used to be done for G+2 and above buildings. Most resident buildings are G+0 buildings constructed from masonry foundation, HCB walls and concrete floors. There are also houses with Mud wall. However; most of these houses were constructed more than 10years ago. Currently the local government prohibited construction of mud houses. Therefore there is no need to propose proper foundation type for this kind of houses.

Considering design procedures followed in the study area, type of foundation used and amount of dead load imposed on foundation soil, design alternatives and detail drawings have been presented below by divided the building types in to two board categories:

5.2.1 Single story residential and other light weight buildings

Such type of buildings don't have sufficient load to counterbalance the uplift pressure induced by expansive soil. Hence, in order to minimize the damage;

- The foundation system should be isolated from the swelling effect of the soil,
- The foundation system should be rigid enough to avoid deferential movement
- Swelling potential of the foundation soil should be eliminated.

Tessema^[23] made the following foundation recommendations based on size of buildings and degree of expansiveness of the foundation soil.

Table 5.1 Recommended foundation on expansive soil, Tessema, G. ^[23]

Type of Building	Degree of Expansiveness	Recommended foundation
Long store, workshop and similar buildings	Moderate to High	3.0m deep isolated footing foundation with 1.0m thick soil replacement under the ground slab and improved drainage system.
Compact: Light residential and single story office buildings	Moderate	3.0m deep isolated footing foundation with 1.0m thick soil replacement under the ground slab and improved drainage system.

Compact: Light residential and single story office buildings	High	Stiffened slab foundation, with split or flexible type of construction if the building is longer than 15m. Improved drainage system.
Multi-story and movement sensitive factory or other buildings	Moderate to High	Under-reamed pile foundation with suspended floor slab and grade beam, and increased rigidity of the building.

In addition to the above recommendations it is possible to considerably minimize the damage by providing certain provisions and modifications on the current construction practices.

In recent years house owners and people involved in house construction came to know that expansive soil creates problem on building directly constructed on it. Hence, it becomes usual practice to replace 60cm - 120cm of the expansive soil under masonry wall with non-expansive soil. It has been observed that this provision considerably reduced the type and extent of damage as compared to those building directly constructed on expansive soil.

However; the following cases in the current practice are still the major source of damage:

- Only few centimeters of soil under floor slab has been replaced or not replaced at all.
- Floor slabs are either monolithically casted with grade beam or there is no proper expansion joint between them.
- In most cases partition walls are usually constructed directly on floor slabs.
- External and internal walls are interlocked to each other at corners unless there is a column between them.

Due to this the uplift force from expansive soil beneath floor slab is transferred from the floor to grade beam, partition walls and external walls. Therefore, if we replace the soil under floor slab up to certain depth, allow the floor slab to float freely and let walls to act independently then the extent of damage will further be minimized or eliminated.

Based on recommendations stipulated in different literatures, observation during this research and experience in building construction the author proposes the following details for masonry foundations constructed in expansive soils.

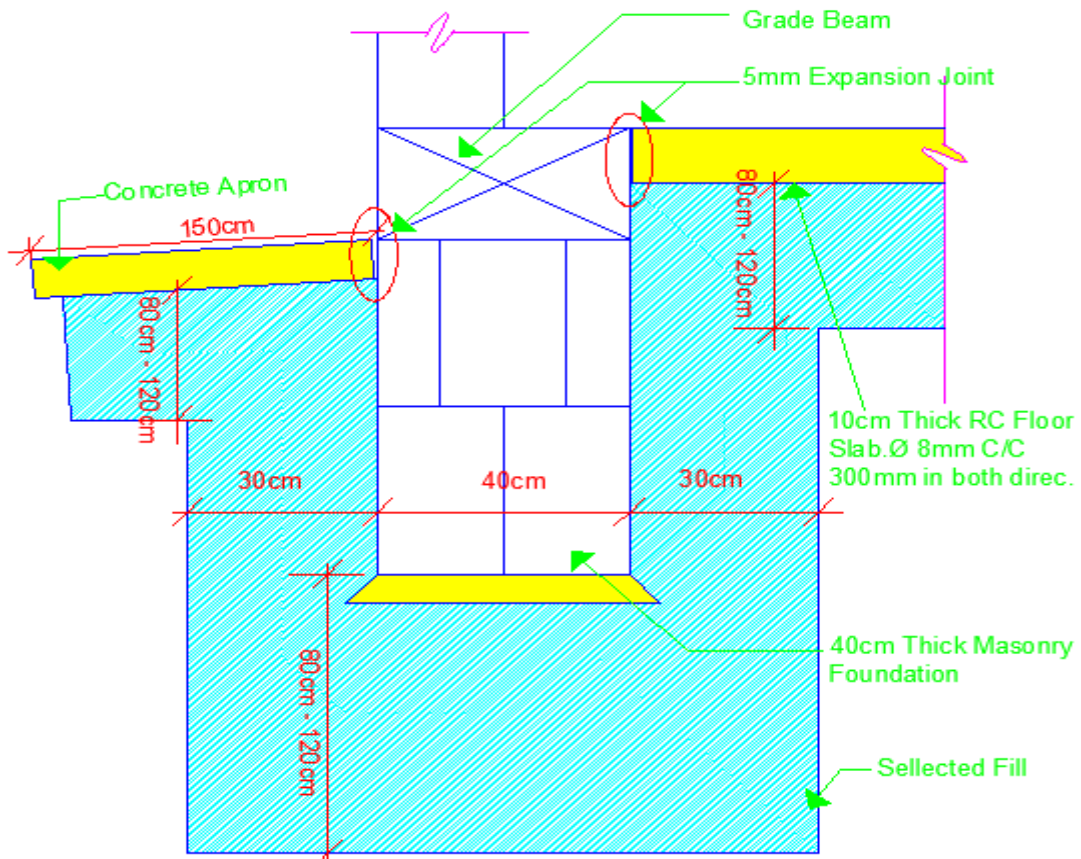


Figure 5.4 Proposed peripheral masonry foundation detail for the study area

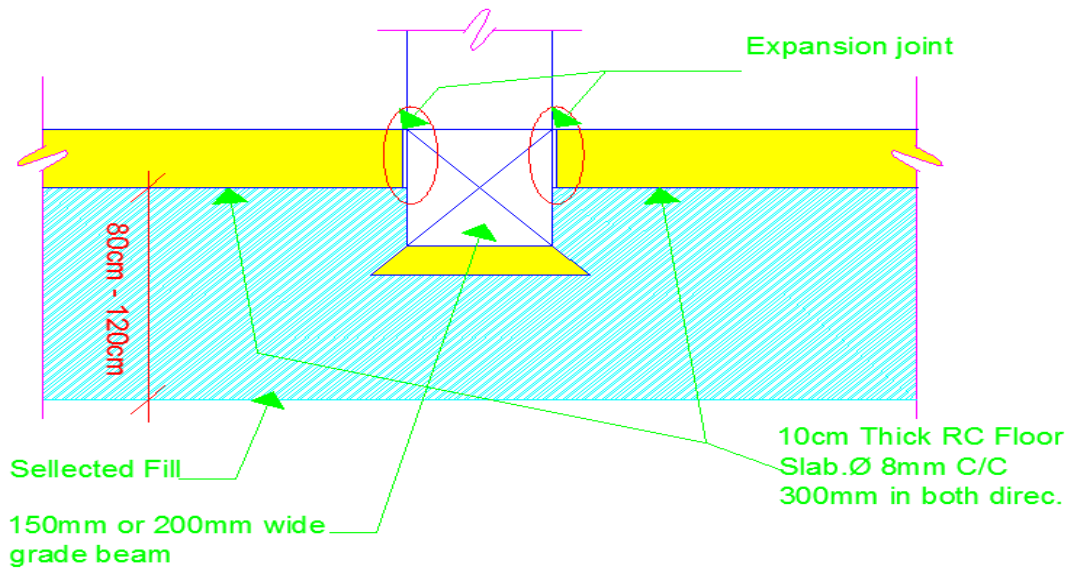


Figure 5.5 Proposed foundation detail for internal parts of buildings

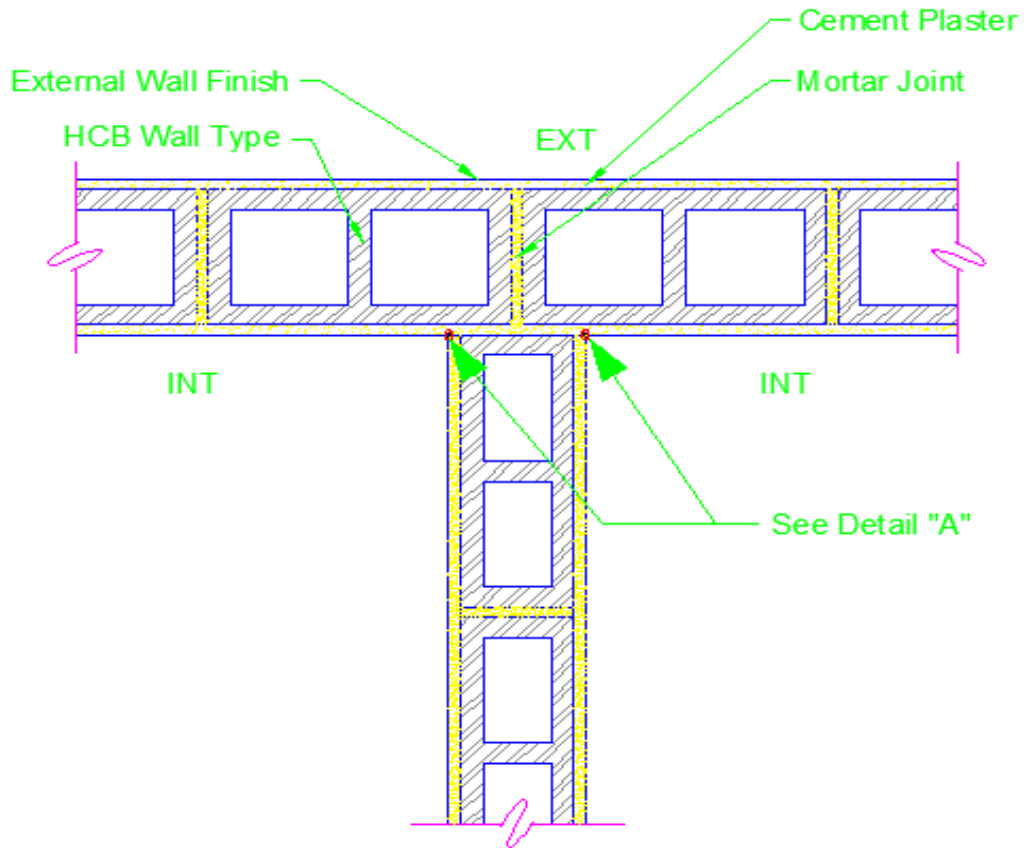


Figure 5.6 Proposed internal and external wall connection

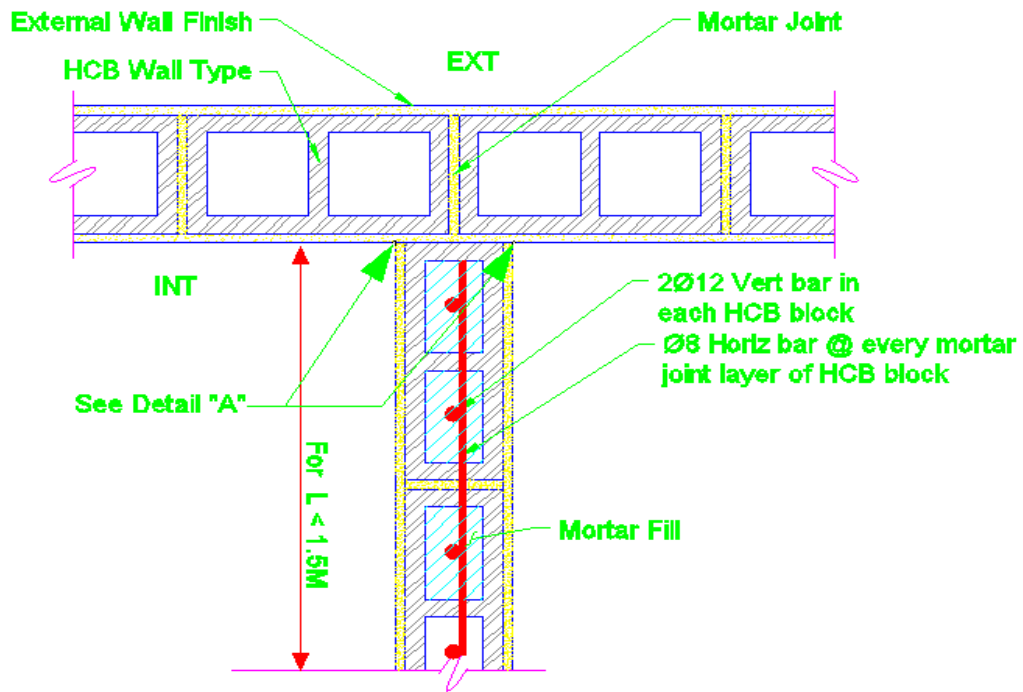


Figure 5.7 Proposed internal and external wall connection – short walls

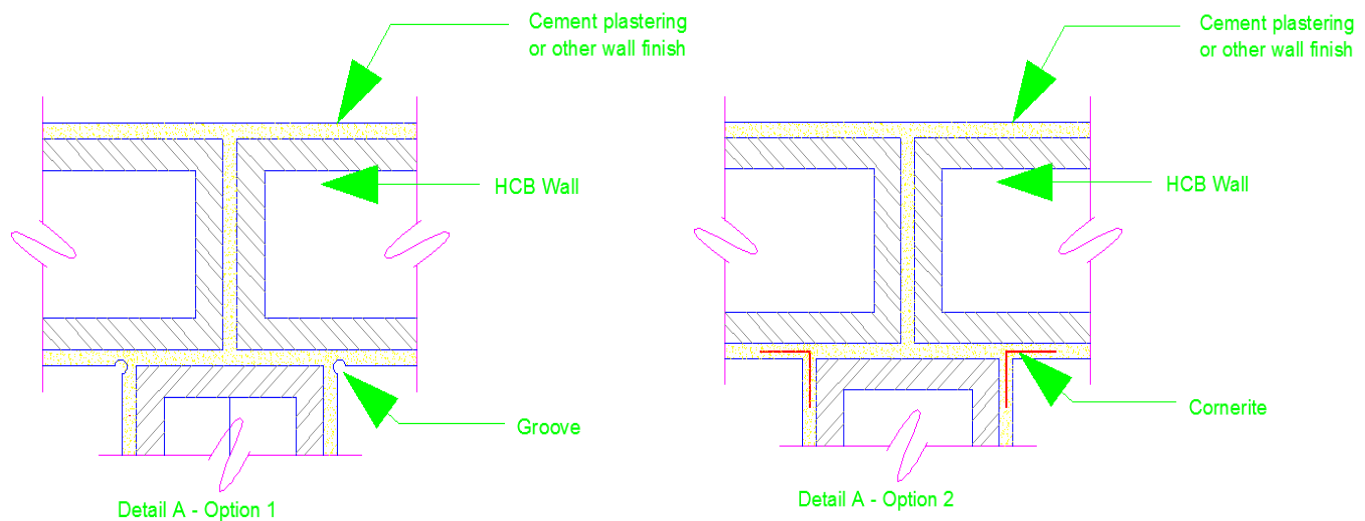


Figure 5.8 Detail A - Wall connection details

5.2.2 Multiple story buildings

It is a common practice, as also proposed by buildings Girma Tessema, to use under-reamed pile foundation with suspended floor slab and grade beam. In addition to this, isolated footings and stiffened mat can also be used.

Isolated footing: In the study area the common foundation type for G+1 and higher buildings is isolated footing. These footings are usually placed between 2m to 3m depth below NGL. In these buildings, damages are usually observed on ground floor slab, walls constructed directly on ground floor slab, pavement around the buildings, masonry under grade beam and/or paved walkways. As explained in chapter four the maximum active zone depth for the study area is 3.4m. Hence; already practiced footing depth is acceptable. However; expansive soil under ground floor slab, pavement and masonry wall has to be replaced by non-expansive material up to 1.2m depth as recommended in section 5.2.1.

Rigid mat foundation^[2]: The other type of foundation practiced in Ethiopia is rigid mat. A heavily reinforced rigid mat is placed on leveled soil. The walls and columns are then built on the foundation. The rationale in this design is that the rigid mat will eliminate any differential heave, and the structure will “ride on” without suffering any internal distress.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Out of randomly visited 78 building 68 of them are damaged due to swelling and shrinkage cycle of the soil, which is 87%. In most cases more than one building components are affected.
2. Building component which is highly susceptible to damage due to expansive soil is walkway around the building. The extent of damage decreases as we proceed to walls, floors, foundation in their respective orders.
3. Out of 78 assessed building 26 of them have walkway around the buildings and except 3 the rest are damaged. The type of damage ranges from minor cracks to complete disintegration and removal from the area.
4. The percentage of HCB and mud walls damages are 75% and 84% respectively. The major type of damages observed in mud houses are minor cracks around corners of door/windows and sinking of foundation during rainy season. However; the extent of damage in HCB wall ranges from minor to severe cracks in different direction.
5. Concrete floors exhibit cracks in different direction, bulging of some areas followed by cracks, settlement and total disintegration of the floor system. Mud floor system is flexible and due to this only bulging and some undulation are observed.
6. It has been observed that all design office in Bahir Dar don't consider the uplift pressure in their design.
7. The study showed that the main cause of failure is fluctuation of ground water table. In addition to this poor surface drainage, presence of tress & vegetation close to buildings, damaged utility lines and improper design are also great contributors.

6.2 Recommendations

- The main cause of failure which takes the lion share in the study area is fluctuation of ground water table. Therefore the following measures should be taken.
 - i. Existing buildings: covered area around the building should be increased by providing concrete/masonry aprons or impervious membrane around the building. This action will considerably reduce the seasonal moisture fluctuation which in turn reduce the ground movement.
 - ii. New buildings: If the uplift induced by the expansive soil couldn't be counterbalanced by dead load of the structure then the soil below the foundation level shall be replaced by non-expansive material.
- Proper remedial measures like providing concrete aprons and positive drainage around buildings, removing tress and other plants around building and maintenance and regular inspection for utility lines should be implemented.
- Design offices should consider the swelling and shrinkage effect of expansive soil and provide appropriate design and details.
- The government authority is responsible for approval of building design and they only request design documents for building above two stories. It is known that building with two stories and less are those highly affected by expansive soil. Hence, at least there should be standard foundation designs and proper detail drawings for buildings which have one or two stories.
- Academic institutions like Bahir Dar University are expected to do much works in collaboration with the responsible governmental authority in filling knowledge gap and awareness creation.
- Bahir Dar doesn't have soil map. Those responsible institutions like Bahir Dar city administration office, Amhara region industrial and urban development office and Bahir Dar University are expected to produces soil map of the town.

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Appendix A: Standard format used to collect data from representative buildings

Inspection Date: _____

General Data

Building location Kebele: __ Northing: _____ Easting: _____

Building owner name (optional): _____

Master plan zoning of the area: _____

Soil Data (*from previous studies and observation*)

Color of the soil: _____

Swelling pressure: _____

Liquid Limit(LL): _____

Free swell: _____

Plasticity Index(PI): _____

Clay Content: _____

Building Data

Type of building (no. of story): _____

Building function: _____

Size of building: _____

Construction start date: _____

Foundation type: _____

Construction completion date: _____

Foundation depth: _____

Construction Materials

Bldg element	Construction Materials	Remark
Foundation		
Pavement around the bldg		
Floor		
Wall		
Ceiling		
Doors		
Windows		
Fence		

Bldg element	Construction Materials	Remark
Paved walkway		
Other structures (Septic tank, water wale, swimming pool . . . etc.)		

Surface Drainage Condition

Inside the compound: _____

Outside the compound: _____

Extent of Damage:

Bldg Element	Damage Description & Its Cause
Foundation	
Pavement around the bldg	
Floor	
Wall	
Ceiling	
Doors	

Bldg Element	Damage Description and Its Cause
Windows	
Fence	
Paved walkway	
Other structures	

Possible damaged causes: _____

Over all evaluation of the structure: _____

Others: _____

Appendix B: Standard format used to collect data from design offices

Date: _____

Name of consultant (optional): _____ Grade: _____

Do you know expansive soil area in/around Bahir Dar and their swelling potential and swelling pressure? /for e.g. /

Do you conduct geotechnical investigation before proceeding to design? If yes what kind of data you used to collect?

Do you put soil investigation data on dwgs? /see sample dwg/

- Soil type/profile
- Allowable bearing capacity
- Swelling pressure
- Ground water table depth

Do you have typical foundation design for expansive soil areas? /see sample dwg/

- Per soil type/area/
- Per structure

Is there a geotechnical engineer in your team?

Have you seen bldgs damaged by expansive soil in Bahir Dar? In your opinion, what percentage of bldgs constructed on expansive soil area are damaged?

From your experience what do you encountered as the major causes of swelling and shrinkage of Bahir Dar expansive soils?

Do you have experience in investigating and proposing remedial measures for bldgs damaged by expansive soil or by other reason? If yes how many? What kind of measures you have proposed?

Have you so far meet a client requesting for remedial measure for bdlgs damaged by expansive soil? If yes how many?

Appendix C: Summary data of all inspected buildings

Bldg. ID	Bldg. type	Construction Material									Type of Damage									Possible cause of damage
		Foundati on	Pavement around bldg.	Floor	Wall	Ceiling	Door	Window	Fence	Paved Walkway	Foundatio n	Pavement around bldg.	Floor	Wall	Ceiling	Door	Window	Fence	Paved Walkway	
Bldg 1	G+1	Isolated footing	Concrete	Concrete + PVC FF	HCB	Concrete	Wooden	Metal	No fence	No Walkway	Foun. movement	Both V&H Separation	Cracks in diff direc.	Cracks in diff direc.	No Damage	No Damage	Few affected	NA	NA	Water table fluctuation, trees close to bldgs., poor site drainage, design problem.
Bldg 2	G+0	Masonry	Concrete	Concrete + Screed	HCB	Chip wood	Metal	Metal	No fence	No Walkway	Cracked Masonry+ BG	Both V&H Separation	Central Heave	Cracks in diff direc.	No Damage	Few affected	Few affec.+ Brok. Glass	NA	NA	Water table fluctuation, trees close to bldgs., poor site drainage, garden tap close to bldg.
Bldg 3	G+0	Isolated footing	Concrete	Concrete + PVC FF	Brick	Concrete	Wooden	Metal	No fence	No Walkway	Foun. movement	Both V&H Separation	Cracks in diff direc.	Cracks in diff direc.	Cracked slab	No Damage	No Damage	NA	NA	Water table fluctuation, foundation construction in rainy season, poor site drainage, vegetation.
Bldg 4	G+0	Isolated footing	Concrete	Concrete + Terazzo	HCB	Chip wood	Metal	Metal	No fence	Concrete	Foun. movement	Both V&H Separation	Slab settlement	Cracks in diff direc.	No Damage	Many affected	Few affec.+ Brok. Glass	NA	Cracked walkway	Water table fluctuation, trees close to bldgs., poor site drainage.
Bldg 5	G+2	Isolated footing	Concrete	Concrete + Terazzo	HCB	Concrete	Wooden	Metal	No fence	Concrete	Foun. movement	Cracks in diff. direc.	No Damage	Cracks in diff direc.	No Damage	No Damage	No Damage	NA	No Damage	Unknown! Needs further investigation!
Bldg 6	G+2	Isolated footing	Concrete	Concrete + Terazzo	HCB	Concrete	Wooden	Metal	No fence	Cement tiles	No Damage	Vertical separation	No Damage	No Damage	No Damage	No Damage	No Damage	NA	No Damage	Water table fluctuation, trees close to bldgs.
Bldg 7	G+0	Isolated footing	Concrete	Concrete + PVC FF	HCB	Concrete	Wooden	Metal	No fence	No Walkway	No Damage	Both V&H Separation	No Damage	No Damage	No Damage	No Damage	No Damage	NA	NA	Water table fluctuation, water tap on pavement, vegetation close to bldg.
Bldg 8	Mud	Wooden p. + Masn.	No Pav.	Comp. soil + Screed	Mud	Abujedie	Wooden	Wooden	Masonry + HCB	No Walkway	Cracked Masonry	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	Cracked M.+HCB	NA	Water table fluctuation, presence of big trees, poor drainage. These 2 bldgs. are in one compound!
Bldg 9	G+0	Masonry	Concrete	Concrete + Screed	HCB	Chip wood	Metal	Metal	Masonry + HCB	Concrete	No Damage	Cracks in diff. direc.	No Damage	Cracks in diff direc.	No Damage	No Damage	No Damage	Cracked M.+HCB	Vertical separation	

Bldg 10	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	Masonry	Stone	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	NA	No Damage
Bldg 11	Under Const.	Masonry	No Pav.	Not Constructed	Not Constructed	No ceiling	No door	No window	No fence	No Walkway	Cracked Masonry	NA	NA	NA	NA	NA	NA	NA	NA	Water table fluctuation and poor drainage.
Bldg 12	Shed	Wooden post	No Pav.	Compact ed soil	Wooden post only	No ceiling	Metal	Metal	No fence	No Walkway	Wooden posts settle.	NA	Central Heave	No Damage	NA	No Damage	No Damage	NA	NA	Ground water fluctuation.
Bldg 13	Shed	Wooden p. + Masn.	No Pav.	Compact ed soil	Wooden post only	No ceiling	Metal	Metal	No fence	No Walkway	Cracked Masonry	NA	Central Heave	No Damage	NA	Few affected	No Damage	NA	NA	Ground water fluctuation.
Bldg 14	G+4	Isolated footing	Concrete	Concrete + Terazzo	HCB	Concrete	Metal	Metal	No fence	Cement tiles	Foun. movement	Both V&H Separation	Cracks in diff direc.	Cracks in diff direc.	No Damage	No Damage	No Damage	NA	Cracked walkway	Ground water fluctuation.
Bldg 15	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	CIS	No Walkway	Cracked Masonry+ BG	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	Water table fluctuation and poor drainage. These 2 bldgs. are in one compound!
Bldg 16	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	CIS	No Walkway	Cracked Masonry+ BG	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	
Bldg 17	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	No fence	No Walkway	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	NA	NA	No damage.
Bldg 18	G+0	Masonry	Concrete	Concrete + Screed	HCB	Chip wood	Metal	Metal	Masonry + HCB	No Walkway	Cracked Masonry	Cracks in diff. direc.	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	Cracked M.+HCB	NA	Water table fluctuation and poor site drainage.
Bldg 19	G+0	Masonry	Concrete	Concrete + Screed	HCB	No ceiling	Metal	Metal	No fence	No Walkway	No Damage	Cracks in diff. direc.	No Damage	No Damage	NA	No Damage	No Damage	NA	NA	Water table fluctuation, presence of trees and poor site drainage.
Bldg 20	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Plastic	Metal	Metal	Wooden posts	No Walkway	No Damage	NA	No Damage	Vertical crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation.
Bldg 21	G+0	Masonry	No Pav.	Only concrete	HCB	No ceiling	Metal	Metal	Wooden posts	No Walkway	No Damage	NA	No Damage	No Damage	NA	No Damage	No Damage	No Damage	NA	No damage.
Bldg 22	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	Masonry + HCB	Cement tiles	No Damage	NA	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	Cracked HCB	No Damage	Ground water fluctuation.
Bldg 23	Mud	Masonry	No Pav.	Concrete + Screed	HCB	Plastic	Metal	Metal	Wooden posts	No Walkway	Edge Heave	NA	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	No Damage	NA	Ground water fluctuation.
Bldg 24	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Wooden posts	No Walkway	No Damage	NA	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.

Bldg 25	G+0	Masonry	No Pav.	Only concrete	HCB	Plastic	Metal	Metal	Wooden posts	Concrete	Edge Heave	NA	Central Heave	Vertical crack	No Damage	No Damage	No Damage	No Damage	Vertical separation	Water table fluctuation, poor site drainage and vegetation around the bldg.
Bldg 26	G+0	Masonry	Stone	Concrete + Screed	HCB	Chip wood	Metal	Metal	No fence	Concrete	Edge Heave	Disintegrated pave.	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affec + Brok. Glass	NA	Vertical separation	Water table fluctuation and poor site drainage.
Bldg 27	G+0	Masonry	Stone	Concrete + Screed	HCB	No ceiling	Metal	Metal	No fence	No Walkway	Edge Shrink	Both V&H Separation	Cracks in diff direc.	Cracks in diff direc.	NA	Few affected	No Damage	NA	NA	Water table fluctuation and poor site drainage.
Bldg 28	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Chip wood	Metal	Metal	Dry masonry	No Walkway	Masonry Settle.	NA	Central Heave	Horizontal crack	No Damage	Many affected	No Damage	No Damage	NA	Water table fluctuation, poor site drainage and vegetation around the bldg.
Bldg 29	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	HCB	No Walkway	No Damage	NA	Central Heave	Cracks in diff direc.	No Damage	No Damage	No Damage	Cracked HCB	NA	Water table fluctuation and poor site drainage.
Bldg 30	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	Dry masonry	Concrete	No Damage	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Few affected	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 31	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Abujedie	Metal	Metal	Wooden posts	No Walkway	Wooden posts settle.	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 32	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Masonry + HCB	Concrete	No Damage	NA	Central Heave	Diagonal crack	No Damage	No Damage	No Damage	Cracked HCB	No Damage	Ground water fluctuation.
Bldg 33	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Wooden posts	No Walkway	Edge Heave	NA	Central Heave	Vertical crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 34	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	CIS	No Walkway	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	NA	No damage.
Bldg 35	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Abujedie	Metal	Metal	Masonry	Concrete	Wooden posts settle.	NA	Cracks in diff direc.	No Damage	No Damage	Many affected	Many affected	Cracked masonry	Disintegrated pave.	Water table fluctuation, poor site drainage & presence of big three.
Bldg 36	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Abujedie	Metal	Metal	HCB	Concrete	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No damage.
Bldg 37	G+0	Masonry	Concrete	Concrete + Screed	HCB	Abujedie	Metal	Metal	Wooden posts	No Walkway	No Damage	Cracks in diff. direc.	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 38	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	CIS	No Walkway	No Damage	NA	No Damage	Vertical crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.

Bldg 39	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Dry masonry	No Walkway	No Damage	NA	Cracks in diff direc.	Vertical crack	No Damage	No Damage	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 40	G+0	Masonry	No Pav.	Only concrete	HCB	No ceiling	Metal	Metal	No fence	No Walkway	No Damage	NA	No Damage	Diagonal crack	NA	No Damage	No Damage	NA	NA	Water table fluctuation and poor site drainage.
Bldg 41	G+0	Masonry	No Pav.	Only concrete	HCB	No ceiling	Metal	Metal	No fence	No Walkway	No Damage	NA	Cracks in diff direc.	Cracks in diff direc.	NA	No Damage	No Damage	NA	NA	Water table fluctuation and poor site drainage.
Bldg 42	G+0	Isolated footing	Concrete	Concrete + Terazzo	Masonry	Chip wood	Wooden	Metal	HCB	No Walkway	Foun. movement	Both V&H Separation	Slab settlement	Diagonal crack	No Damage	Few affected	No Damage	Cracked HCB	NA	Poor sub surface drainage.
Bldg 43	G+0	Isolated footing	Concrete	Concrete + Ceramic	HCB	Chip wood	Metal	Metal	HCB	Cement tiles	No. Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	Cracked HCB	No Damage	No damage.
Bldg 44	G+0	Masonry	Concrete	Concrete + Ceramic	HCB	Chip wood	Metal	Metal	HCB	Concrete	No Damage	Vertical separation	No Damage	No Damage	No Damage	No Damage	No Damage	Cracked HCB	No Damage	Ground water fluctuation.
Bldg 45	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	CIS	Cement tiles	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No damage.
Bldg 46	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Masonry + HCB	Concrete	No Damage	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Few affected	No Damage	No Damage	Cracked walkway	Poor sub surface drainage.
Bldg 47	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Masonry + HCB	Concrete	No Damage	NA	Cracks in diff direc.	No Damage	No Damage	Few affected	No Damage	No Damage	Cracked walkway	Poor sub surface drainage.
Bldg 48	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Abujedie	Metal	Metal	Masonry + HCB	No Walkway	No Damage	NA	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	No Damage	NA	Poor sub surface drainage.
Bldg 49	Under Const.	Masonry	No Pav.	Only concrete	Not Constructed	No ceiling	No door	No window	No fence	No Walkway	No Damage	NA	Cracks in diff direc.	NA	NA	NA	NA	NA	NA	Ground water fluctuation.
Bldg 50	Mud	Wooden p. + Masn.	Concrete	Concrete + Screed	Mud	Abujedie	Wooden	Wooden	Dry masonry	No Walkway	Wooden posts settle.	Cracks in diff. direc.	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	Water table fluctuation and poor site drainage.
Bldg 51	Mud	Wooden post	No Pav.	Compact ed soil	Mud	Abujedie	CIS	CIS	No fence	No Walkway	Wooden posts settle.	NA	No Damage	Cracks in diff direc.	No Damage	Many affected	Many affected	NA	NA	Ground water fluctuation.
Bldg 52	G+0	Masonry	No Pav.	Concrete + Screed	HCB	No ceiling	Metal	Metal	HCB	No Walkway	No Damage	NA	Cracks in diff direc.	Cracks in diff direc.	NA	No Damage	No Damage	Cracked HCB	NA	Water table fluctuation and poor site drainage.
Bldg 53	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Abujedie	Metal	Metal	Masonry	No Walkway	No Damage	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Few affected	No Damage	Cracked masonry	NA	Water table fluctuation and poor site drainage.

Bldg 54	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Chip wood	Metal	Metal	HCB	No Walkway	No Damage	NA	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	NA	No damage.	
Bldg 55	G+0	Masonry	Concrete	Concrete + Ceramic	HCB	Abujedie	Metal	Metal	HCB	No Walkway	No Damage	Horizontal separation	Central Heave	Diagonal crack	No Damage	Few affected	No Damage	Cracked HCB	NA	Ground water fluctuation.	
Bldg 56	Mud	Wooden p. + Masn.	Concrete	Concrete + Ceramic	Mud	Abujedie	Metal	Metal	Masonry	Concrete	No Damage	Cracks in diff. direc.	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	Cracked masonry	Cracked walkway	Ground water fluctuation.	
Bldg 57	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Chip wood	Wooden	Wooden	Dry masonry	No Walkway	Wooden posts settle.	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Few affected	No Damage	No Damage	NA	Water table fluctuation and poor site drainage.	
Bldg 58	Mud	Wooden post	Concrete	Concrete + Screed	Mud	Abujedie	CIS	CIS	Dry masonry	No Walkway	Wooden posts settle.	Cracks in diff. direc.	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	Water table fluctuation and poor site drainage.	
Bldg 59	G+0	Masonry	Concrete	Concrete + Ceramic	HCB	Chip wood	Metal	Metal	CIS	Concrete	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No Damage	No damage.
Bldg 60	Mud	Wooden post	No Pav.	Compact ed soil	Mud	Abujedie	Wooden	Wooden	Wooden posts	No Walkway	Wooden posts settle.	NA	Central Heave	Cracks in diff direc.	No Damage	Many affected	Many affected	No Damage	NA	Ground water fluctuation.	
Bldg 61	Mud	Wooden post	No Pav.	Compact ed soil	Mud	Abujedie	Wooden	Wooden	Dry masonry	No Walkway	Wooden posts settle.	NA	Central Heave	Cracks in diff direc.	No Damage	Many affected	Few affected	No Damage	NA	Water table fluctuation and poor site drainage.	
Bldg 62	Mud	Wooden post	No Pav.	Compact ed soil	Mud	No ceiling	Wooden	Wooden	Dry masonry	No Walkway	Wooden posts settle.	NA	Central Heave	Cracks in diff direc.	NA	Many affected	Few affected	No Damage	NA	Poor sub surface drainage.	
Bldg 63	Mud	Wooden post	No Pav.	Compact ed soil	Mud	Abujedie	CIS	CIS	No fence	No Walkway	Wooden posts settle.	NA	Central Heave	Cracks in diff direc.	No Damage	Many affected	Few affected	NA	NA	Poor sub surface drainage.	
Bldg 64	Mud	Wooden post	No Pav.	Compact ed soil	Mud	Abujedie	Metal	Metal	Dry masonry	No Walkway	Wooden posts settle.	NA	Central Heave	Cracks in diff direc.	No Damage	Many affected	Few affected	No Damage	NA	Poor sub surface drainage.	
Bldg 65	Under Const.	Masonry	No Pav.	Only concrete	Not Constructed	No ceiling	No door	No window	No fence	Cement tiles	Masonry Settle.	NA	No Damage	NA	NA	NA	NA	NA	NA	Water table fluctuation and poor site drainage.	
Bldg 66	G+0	Masonry	No Pav.	Only concrete	HCB	Not Constructed	Not Installed	Not Installed	Masonry	No Walkway	No Damage	NA	No Damage	Cracks in diff direc.	NA	NA	NA	No Damage	NA	Water table fluctuation and poor site drainage.	
Bldg 67	G+0	Masonry	Concrete	Concrete + Ceramic	HCB	Chip wood	Metal	Metal	HCB	Concrete	Masonry Settle.	Cracks in diff. direc.	Cracks in diff direc.	Cracks in diff direc.	No Damage	Few affected	No Damage	Cracked HCB	Cracked walkway	Ground water fluctuation.	
Bldg 68	Mud	Wooden p. + Masn.	No Pav.	Concrete + Screed	Mud	Abujedie	Metal	Metal	HCB	No Walkway	Wooden posts settle.	NA	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	Cracked HCB	NA	Ground water fluctuation.	

Bldg 69	G+0	Masonry	No Pav.	Only concrete	HCB	Not Constructed	Not Installed	Not Installed	No fence	Cement tiles	Masonry Settle.	NA	Cracks in diff direc.	Cracks in diff direc.	NA	NA	NA	NA	NA	Water table fluctuation and poor site drainage.
Bldg 70	G+0	Wooden post	No Pav.	Only concrete	HCB	No ceiling	Metal	Metal	No fence	No Walkway	Wooden posts settle.	NA	Cracks in diff direc.	Diagonal crack	NA	Many affected	No Damage	NA	NA	Water table fluctuation and poor site drainage.
Bldg 71	G+0	Masonry	No Pav.	Concrete + Screed	HCB	Plastic	Metal	Metal	Masonry + HCB	Concrete	Masonry Settle.	NA	Cracks in diff direc.	Cracks in diff direc.	No Damage	Many affected	Many affected	Cracked M.+HCB	Cracked walkway	Ground water fluctuation.
Bldg 72	G+0	Isolated footing	No Pav.	Only concrete	HCB	Not Constructed	Metal	Metal	Masonry + HCB	Concrete	Foun. movement	NA	Central Heave	Diagonal crack	NA	Few affected	No Damage	Cracked masonry	Cracked walkway	Ground water fluctuation.
Bldg 73	Mud	Wooden p. + Masn.	No Pav.	Compact ed soil	Mud	No ceiling	Metal	Metal	No fence	No Walkway	Wooden posts settle.	NA	Central Heave	No Damage	No Damage	Many affected	Many affected	NA	NA	Water table fluctuation and poor site drainage.
Bldg 74	Mud	Masonry	No Pav.	Only concrete	Mud	No ceiling	Metal	Metal	No fence	No Walkway	Cracked Masonry	NA	Cracks in diff direc.	Cracks in diff direc.	NA	Many affected	Many affected	NA	NA	Ground water fluctuation.
Bldg 75	Under Const.	Masonry	No Pav.	Only concrete	Not Constructed	No ceiling	No door	No window	No fence	No Walkway	Cracked Masonry	NA	Cracks in diff direc.	NA	NA	NA	NA	NA	NA	Ground water fluctuation.
Bldg 76	G+0	Masonry	Concrete	Concrete + Ceramic	HCB	Chip wood	Metal	Metal	Masonry	Concrete	Wooden posts settle.	No Damage	No Damage	Cracks in diff direc.	No Damage	No Damage	No Damage	No Damage	No Damage	No damage.
Bldg 77	G+0	Masonry	Concrete	Concrete + Screed	HCB	Chip wood	Metal	Metal	HCB	No Walkway	No Damage	Cracks in diff. direc.	Cracks in diff direc.	Diagonal crack	No Damage	No Damage	No Damage	No Damage	NA	Ground water fluctuation.
Bldg 78	G+0	Masonry	Concrete	Only concrete	HCB	Not Constructed	Metal	Metal	HCB	Concrete	No Damage	Cracks in diff. direc.	Cracks in diff direc.	Cracks in diff direc.	NA	Many affected	Many affected	Cracked HCB	Cracked walkway	Water table fluctuation and poor site drainage.