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ASSESSMENT OF DAMAGE OF BUILDINGS CONSTRUCTED
IN EXPANSIVE SOIL AREAS OF ADDIS ABABA

A thesis submitted to
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ABSTRACT

The amount of damages caused by expansive soil is tremendously high and alarming. These damages are mainly dominated in light weight-engineering structures founded in expansive soils. These structures include lightweight buildings, roads, runways and buried utilities. The problem associated with expansive soils is not yet properly solved. It is important to assess buildings constructed in expansive soil areas in order to know the cause of failure. This helps in providing solutions for newly constructed buildings and to get remedial measures for those already damaged.

Therefore, in this study an attempt was made to assess the damage that occurred on buildings that are constructed on expansive soil areas by taking ninety six randomly selected houses in the city of Addis Ababa. The houses are located in Bole, Olympia, Nifasilk, Lafto, Old Airport, Mekanisa, Gergi and Bole bulbula localities of the city. The study showed that 64 % of the houses suffered heavy damage, 8 % of the houses were slightly damaged and 28% of the houses showed no damage.

Analysis was made to understand the cause, extent and type of damage that was observed in the houses. The damages that are observed are mainly caused by poor design, construction and non-controlled drainage.

Detailed investigation was made for the Ethiopian Airlines maintenance hangar building which has shown pronounced failure in both the sub structure and the super structure

Finally, conclusion and recommendations are made.

Chapter one

Introduction

1.1 General

Expansive soil is a clay soil that changes its volume when the water content of the soil changes. Usually, the soil will shrink when water (or moisture) content is reduced and will swell when the water content increases. The degree of expansiveness depends on the content of the active clay mineral called Montmorillonite

The stress caused by alternate heaving and shrinkage of the foundation soil creates stress on the structures. Usually, structures are not designed to withstand this stress or it is difficult to account quantitatively. As a result, the structures are damaged due to the additional stress.

Damage due to expansive soils could occur on any type of buildings, road and other civil engineering constructions that are not properly designed and/or constructed. However light structures like one or two story buildings, warehouses retaining walls and buried facilities are more vulnerable to damages because these structures couldn't exert a heavy pressure to counteract the uplift pressure from the expansive soils. There fore, in this study more emphasis is given to lightweight buildings founded on expansive soil. This avoids the possibility of confusing damages caused by structural faulty design and settlement, which are encounter in heavy weight buildings.

The damages due to alternate heave and shrinkage or differential heave of the foundation soil are 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 the 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 homeowner. Generally, the damage will create economic loss for building owners and the country at large.

Ethiopia is one of the nations where expansive soil is a critical problem. In Addis Ababa, recent construction areas are extensively covered with expansive soil. Most of the residents of Addis Ababa are low-income people. They usually construct lightweight building, which couldn't counteract the uplift pressure caused by the expansive soil. As a result cracks are bound to occur. Cracks don't only affect the structural safety and beauty of the building but also creates financial burden to the owners.

1.2 Objective of the study

The general objective of this research is to assess various randomly selected lightweight buildings founded on expansive soil of Addis Ababa and to investigate if there are damages, and to study the extent, cause of failure. The result of the study will be basis for findings remedial measures for already cracked buildings and helps in establishing good design and construction procedure for new constructions

1.3 Scope of the research

The research addresses the general objectives and tries to investigate the cause of building failure based on the existing theories and principles. The study includes assessment of ninety-six randomly selected lightweight buildings founded on expansive soils of Addis Ababa. Simple random sampling method is adopted. Detailed study of one selected building damaged by the expansive soil will be discussed

1.4 Organization of the thesis

The thesis consists of five chapters. The first chapter is the introduction part and it discusses briefly structures susceptible to expansive soil damage, the objective and the scope of the thesis. The second chapter is literature review of expansive soil mineralogy, its distribution, soil moisture relationship of expansive soil, effects of foundation movements, methods of preventing building damages and remedial measures. The third chapter comprises data collection and method of sampling, discussion on the observed buildings and possible causes of failure. The fourth chapter discusses detail investigation of Ethiopian Airlines maintenance hangar building in respect to the cause of damage and remedial measures to be taken. The fifth chapter consists of the conclusion and recommendation of the thesis.

Chapter two

Literature Review

2.1 Expansive soil mineralogy

The predominant mineral in expansive soil is montmorillonite. Its basic structure is the aluminum octahedral sheet sandwiched between two silica tetrahedral sheets. Experience shows that swelling problem arises when a soil contains more than 20% montmorillonite or mixed layer montmorillonite, illite vermiculite

2.2 Physical properties of expansive Soils

a. Moisture content

There will be no volume change if the moisture content of the clay element is unchanged. When the moisture content of the clay is changed, volume expansion in the vertical and the horizontal direction will take place. Complete saturation is not necessary to initiate swelling. Slight change in moisture content in the magnitude of 1 to 2% is sufficient to cause detrimental swelling. Soils with moisture content below 15% indicates danger because it easily absorb moisture but moisture content above 30% indicates that most expansion has take place and further expansion will be small. In the dry season the soil shrinks excessively and shrinkage crack as deep as two or three meter is common occurrence [6]

b. Dry density

The dry density of the clay is another index of expansive soils. Soils with higher dry density will show high swelling potential than lower density soils. Soils whose dry densities in excess of 110 pcf generally exhibit high swelling potential [6]

c. Index property

i) Atterberg Limit

Plasticity index and the liquid limit are useful indices for determining the swelling characteristic of most clay. Liquid limit and swelling clay both depend on the amount of water absorbed; High swelling soils will manifest high index properties

ii) Linear shrinkage

The shrinkage characteristic of clay should be a consistent and reliable index to the swelling potential. A soil having higher linear shrinkage limit is critical as compared to soils of lower linear shrinkage limit

iii) Free swell

Free swell is the maximum volume change expressed as percent of initial volume. Expansive soils have generally higher free swell value

iv) Colloidal content

The grain size characteristic of clay appears to have a bearing on its swelling potential, particularly the colloid content. For a given clay type, the amount of swell will increase with the amount of clay present in the soil

For any given remolded clay type, the relationship between the swelling potential and percentage of clay size can be expressed by the equation [6]

$$S = K C^x \dots\dots\dots 2.1$$

S= Swelling potential, expressed as percentage of swell under 1 psi surcharge for a Sample compacted at optimum moisture content to maximum density in standard AASHO compacted test.

C= Percentage of clay size finer than 0.002mm

X= an exponent depending on the type of clay and

K= Coefficient depending on the type of clay

d / Fatigue of swelling

There is a drastic reduction of swelling tendencies as the drying and the wetting cycle continues. This is due to a gradual decrease in dry density. After certain cycle, the soil reached a critical density where shrinkage and swelling equalize. At the critical density swelling, shrinkage and dry density became stable and no further change take place. [6]

2.3 Soil – Moisture relationship of expansive soils

For swelling to take place, the environment of the expansive soil has to be changed. Environmental change can consist of pressure release due to excavation, desiccation caused by temperature increase, and volume increase because of the introduction of moisture. It is the effect of water on expansive soil that plays the major role

2.3.1 Effect of moisture content

Moisture migration depends on the geological formation, climatic condition, topographic features, soil type and ground water level. The most common method of moisture transfer is by gravity. The seepage of surface water, precipitation and snow melting in to the soil are common examples [6]

Moisture migration can occur in all directions. In stiff clays and in shale bedrock, the flow occurs in the bedding plane or follows continuous fractures and fissures. In fine-grained soils, a capillary force is a significant means of water transfer. Thermal gradient are also a cause for moisture migration through the liquid phase of the soils. Vapor and liquid moisture transfer under thermal gradient can be an important cause of the swelling of moisture –deficient soils [6]

Moisture in the soil varies due to seasonal climatic changes, change of surface conditions and external influences. Climatic change consists of a change in atmospheric temperature, precipitation, evaporation, transpiration and relative humidity. Surface condition(changing of paved area in to garden) and External influence which is

resettlement of new houses around the existing building will disturb the moisture content of the foundation soil resulting variation of moisture content which in turn results in the swelling and shrinkage of the soil . This alternate shrinkage and swelling of the foundation soil creates stress on the structures as a result, the structures be faced to additional stress which is not yet considered during the design

2.3.2 Factor affecting volume change

Swelling pressure is the pressure, which prevents the specimens from swelling. i.e., It is the pressure required to return the specimens back to its original state after swelling (Void ratio, height).

Swell is influenced by initial moisture content, initial dry density, surcharge pressure, time allowed for swell, size and stratum thickness and degree of saturation

i) Initial moisture content

As the initial moisture content increases, the change in volume decreases but the absolute value of the swelling pressure does not depend on the initial moisture content. It is a constant at any initial moisture content

ii)Initial dry density

As the initial dry density increases, the swelling potential increase and the swelling pressure also increases. Therefore, compaction of expansive soil to a higher density is not good during construction

iii) Surcharge pressure

As the initial surcharge pressure increases, the volume change of expansive soil decreases but the swelling pressure remains constant

iv) Time allowed for swell

The time required for the soil to reach its maximum swelling potential may vary considerably depending on the initial density, Permeability and the thickness of the sample

v) Size and thickness

Sample thickness affects the time required for total saturation. The change in volume is proportional to the sample thickness but the swelling pressure remains constant.

vi) Degree of saturation

As the sample is subjected to moisture, the degree of saturation increases as a result swelling potential increases but the swelling pressure is unchanged [6]

2.4 Effects of foundation movement

The magnitude and intensity of structural damage is influenced by the intensity of contact pressure, the type of foundation and the relative stiffness of the super structure. In lightweight structures, the contact pressure is normally much smaller than the swelling pressure of the expansive soil. As a result, the whole building will be lifted differentially and creates stresses, which are not accounted on the design. This stress creates cracks.

The first sign of foundation movement for structures founded on expansive soil is the cracking of the floor slab, door binding, window sticking and cracks appearing in the exterior and interior walls and even in the ceilings.

2.4.1 Cause of cracks in buildings constructed in expansive soil areas

Cracks caused by swelling soil are wide at the top and narrow at the bottom. The cause of foundation movement is moisture fluctuation of the foundation soil. Normally, the first sign of foundation movement for a structure founded on expansive soil is the cracking of the floor slab, door binding, window stacking and cracks appearing in the exterior and in the interior walls and even in the ceiling . It is important to differentiate the different types of cracks and their causes in order to know cracks caused by expansive soil heave. It is difficult or costs a lot to make an absolute crack free building. The types and their causes are different. Some of cracks types and their causes are as follows

i. Crack due to shrinkage and expansion of the plaster work

Such cracks are hairline cracks, insignificant tilt of floors or change in levels and can be easily maintained. It mainly affects the aesthetic of the building .This type of cracks usually occurs and it is due to the stress induced by shrinkage or expansion of the mortar during drying. [8].

ii. Crack due to structural failure

Theses cracks are significant cracks and caused due to improper design and / or quality control failure. Besides functions and cost such cracks have psychological impact on the owners and can be encountered in high-rise building and in non-expansive soil areas. Such cracks occur very rarely.

iii. Crack due to foundation movement

These type of cracks are usually associated with expansive soil, which can exert a pressure which moves the structure. It is commonly observed in lightweight buildings founded on expansive soil areas. Such cracks are abundant.

2.4.2 Identification of cracks on buildings due to soil moisture

Change in expansive soil areas

Cracks are more readily noticed on buildings constructed in expansive soil areas .It is a rare case that cracks are caused on light weight buildings due to settlement. Settlement and shrinkage or heave crack can be distinguished by observing the width of the crack as the climate changes from season to season .If the crack width changes from season to season, the crack is the result of shrinkage and heave not settlement. [2]

Houses with slab foundation are affected by the climate change and its is influenced by changes in soil water. If the soil beneath the slab is wetter than the soil outside the slab, the moisture moves from under the slab towards the slab perimeter .The opposite happens if the soil beneath the slab is drier than the soil out side the slab. In the latter situation, water moves from the wetter soil out side the perimeter of the slab to the slab beneath the interior of the slab .Two principal of slab distortion occur as a result of this soil moisture movement [. 2]

1. Center lift distortion

The distortion takes the shape of a plate bent with the edge down and the middle up. This type of distortion occurs as a result of the soil around the edge of the slab drying out and shrinking, or the soil beneath the center of the slab wetting up and heaving or a

combination of both. Sometimes, the combination is produced by the soil beneath the slabs center wetting up and heaving while a tree or other vegetation is removing water from beneath the slab edge during a drought. This distortion mode is distinguished by floor being distorted in a concave down ward mode and exterior slab being wider at the top than at the bottom [2]

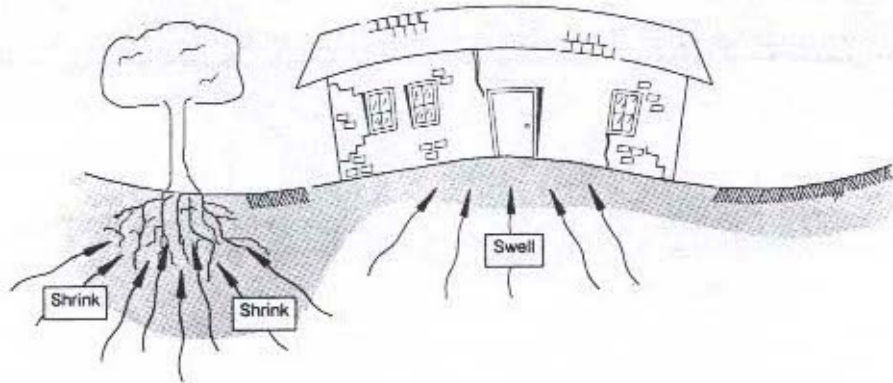


Fig 2.1 Center lift distortion which is typically caused by heaving beneath the interior of the building, shrinking around of the perimeter of the building

2. Edge lift distortion

Edge lift distortion takes the shape of plate bent with the edges up and the middle down, dishing type of distortion. This type of distortion occurs because of the soil around the edge of the slab wetting up and heaving. Although it could also be caused by the soil beneath the center of the slab drying out and shrinking, this situation seldom happens. This type of distortion mode is recognized by exterior crack being wider at the bottom than at the top

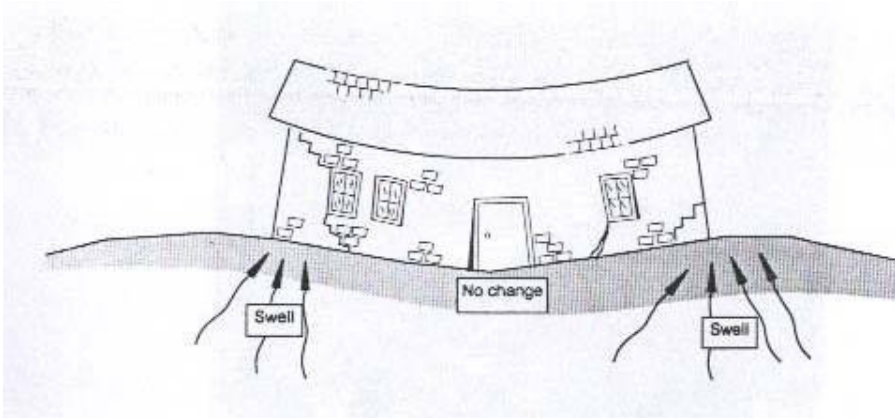


Fig 2.2 Edge lift distortion which is typically caused by heaving around the perimeter of the building

2.5 Methods of preventing building damages

Methods that have commonly been used to prevent building damages due to heave are moisture control, soil stabilization and structural measures. [16]

2.5.1 Moisture control

Generally, expansive soil will not be a problem if the moisture content is constant throughout the soil. Moisture fluctuation can be controlled by using horizontal barriers, vertical moisture barriers, subsurface and surface drainage.

Horizontal moisture barriers can be installed around a building in the form membrane, rigid paving or flexible paving. Polyethylene membrane, concrete aprons and asphalt membrane can be used as a horizontal moisture barrier.

Vertical moisture barriers are used around the perimeter of the building to cut off the source of water that may enter the under slab soils. Vertical barrier is more effective than

horizontal barriers in minimizing drying and shrinkage of the perimeter of the foundation soil as well as maintaining long-term uniform moisture conditions beneath the covered areas. Polyethylene membrane and concrete can be used as a vertical moisture barrier. When such materials are used as a barrier, this depth should be equal to or greater than the depth of moisture fluctuation.

A subsurface drainage system should intercept the gravity flow of free water, lower the ground water or perched water and arrest the capillary moisture movement and movement of moisture in the vapor state

Intercepting and peripherals drains are used, as a subsurface drainage. Intercepting drains are used in minimizing the wetting of the foundation soil. To ensure the interception of free water, the drains must be completely filled with gravel and the trench should be deep enough to reach the water-bearing layer. Intercepting drains are most effective when located along the toe of a slope where ground water leaves the deep strata and where it may merge to the surface peripheral drains can be installed around the interior or exterior of the building. It is effective in minimizing the general wetting of the foundation soils, which will occur. For proper surface drainage the ground surface around a building should be graded so that surface water will drain away from the structure in all direction

[6]

2.5.2 Soil Stabilization

The swelling potential of expansive soil can be minimized or completely eliminated by flooding or pre wetting, compacting to a lower density, by replacing the expansive soil with non expansive soil, by stabilizing the expansive soil with chemicals and by isolating the soil so that no moisture change will exist in the foundation soil. [6]

Prewetting or flooding the soil is done by allowing the soils to swell before construction. The moisture content of the soil after prewetting should be kept constant after construction.

Experimental investigations have revealed that expansive soils expand very little when compacted at low densities and high moisture. Hence, by controlling the compaction effort, it is possible to arrive at a density that lies well below the optimum, but does not cause settlement that endangers the structures. In such method, excess water will not be present in the soil. Therefore, there will not be migration of moisture to the underlying moisture- deficient soil and long wetting periods, prior to construction as in the case for pre wetting, will not be necessary. [6]

Soil replacement is the simplest method for preventing building damages. The most important requirements for soil replacement are the type of the material for replacement, the depth of replacement and the extent to which the replacement is needed.

The material replaced should be non-expansive and impermeable .If the replacing material is highly permeable (coarse sand, gravels), it transmits the surface moisture

directly on the expansive clay layer. This would bring about differential movement the same as the surface. Hence, use of sand, gravel as replacing materials is dangerous.

The depth at which the soil to be replaced depends on the depth of the active zone. Active zone is the depth at which the soil does not affected by dry weather.

Organic and inorganic chemicals can be used to stabilize the expansive soil. The most common chemicals used are lime, cement, sodium chloride and sodium silicate.

Stabilization using lime reduces the plasticity and the swelling potential of the soil by replacing the weaker ion such as sodium on the surface of the clay particle by calcium ions of lime. Cement and other inorganic chemicals such as calcium hydroxide, Sodium chloride and sodium silicate reduces the swelling potential, plasticity index and liquid limit and increase the shear strength of the soil [6]

2.5.3 Structural measures

Building can be deigned as a rigid unit so that they can act as monolithic unit. This can be achieved by reinforcing the building adequately .The other alternative is to make the building flexible so that a certain amount of differential movement is allowed.

1) Footing Foundations

Footing foundation may be placed on expansive soil provided that one or more criteria are met.

- a/ Sufficient dead load pressure is exerted on the Foundation
- b/ The structure is rigid enough so that the differential heaving will not cause cracking.

2) Mat Foundation

Mat foundation is successful in moderate swelling soil areas. In the design of such foundation, the negatives bending moment produced by the swelling pressure of the soil should be considered and it is this that controls the design. Stiffened slab is the most common foundation system in expansive soil.

3) Drilled pier foundation

There are two kinds of drilled piers, one which has enlarged base, is called belled piers. The other is straight-shaft piers. The drilled piers foundation is a rational solution to combat the problem of expansive soils; however, the design and construction must be closely controlled. The piers should be placed well below the active zone where seasonal moisture fluctuation of the active soil is minimal. In dimensioning of the pier as shown in Fig 2.3, the uplifting force should balance with the withholding force. [6]

Total up –lifting force

$$U = 2 \pi r f p (D-d) \dots\dots\dots 2.2$$

Where r = radius of the pier

d = depth of the soil unaffected by wetting (m)

D = Total length of the pier (m)

P = the swelling pressure (m)

f = coefficient of up lift between concrete and soil

U = total uplifting force

Withholding force

$$W = \pi r^2 \sigma + 2 \pi r s d \dots\dots\dots 2.3$$

Where σ = unit dead load pressure (N/m²)

S= skin friction surrounding the pier (N/m²)

W= total with holding force (N)

d = depth of zone of the soil un affected by wetting (m)

r= radius of the pier

In designing the pier the withholding force must balance the up lifting force.

Figure 2.3 Grade beam and pier system foundation system

2.6 Remedial measures

The remedial measures to be taken for a cracked building is simpler once the cause of foundation movement has been determined .Remedial works to be taken differs in each case .The commonly used remedial measures are as follows : [6]

A) For distress caused by up lifting of 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

B) For distress caused by up lifting of footing foundation :-

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

C) For distress caused by heaving of Interior slab

- Allow free slab movement by providing space between the slab and the grade beam or the foundation wall in the case of basement
- Provide slip joints to all interior slab bearing partitions walls including door frames and stair case walls

- Replace the soil beneath the slab with non-expansive impervious compacted soils

D) Distress caused by heaving of a continuous footing foundation

- Provide voids beneath the continuous footing at calculated interval to increase the dead load pressure .This can be done by removing soil beneath the continuous footing
- Reinforce existing foundation walls with new reinforced grade beams to tie the structure as in box construction
- Post tension the foundation walls to provide structural stability by preventing unequal movement
- Under pine the foundation with piers drilled in to a stable zone

The general remedial measures applied to all types' foundation movements are the following:

- Provide positive drainage around the building
- Provide adequate outlet of all down spouts
- Remove and re-compact non expansive backfill
- Provide concrete aprons around the house
- Relocate all lawn sprinkler heads to a distance at least 10 feet from the building
- Remove all shrubs and flowers bed which are planted adjacent to the house

- Provide proper sub drain around the building below the lower floor slab
- Provide a positive out let for sub drains
- Maintain any leaking pipes around the building

Chapter three

Data collection and Analysis

3.1 General

It is known that most practical situation is represented by the normal or Gaussian distribution because most natural phenomena have similarities. It can be deduced from a sample data about the population from which a sample data is drawn [4]

Observation has shown that most of the residential buildings of Addis Ababa are lightweight buildings, which are susceptible to damage caused by expansive soil . These are mainly constructed from Hollow concrete block, brick or ‘checa’ wall. Only a few buildings are high rise or are constructed from corrugated iron sheet. Most of the dwellings of Addis Ababa, particularly in expansive soil area have similarities in size, construction material and construction method. Taking samples from the population inference can be made about the buildings those constructed in expansive soil areas. A normal distribution is applied for the determination of sample size.

3.2 Geotechnical characteristic of the study area

Expansive Soils are known to occur in many part of the world. Many countries in the world like Argentina, Australia, Burma, Canada, Cuba, Ethiopia, Ghana, India, Iran, Israel, Mexico, Morocco, Poland, South Africa, Spain, Turkey, U.S.A, U.S.S.R and Venezuela have been identified.

In Ethiopia, particularly Addis Ababa where recent constructions are carried out the eastern and southern part of a city are extensively covered with expansive soil The Study area in this work includes most parts of Addis Ababa where expansive soils are dominantly found. Theses are: Bole, Olympia, Lafto, old airport, Mekanisa, Gergi and Bole bulbula area shown in Fig 3.1

Samples were taken from different localities of the study area to a depth of 3m. The top 1.45 to 2 m depth is black in color and then the soil changes its color to grey. The laboratory test result showed both the black and the grey have similar properties.

3.2.1 Laboratory test results of Addis Ababa expansive soils

Various laboratory tests are carried out by various researchers to determine the range of values for the property of expansive soil of Addis Ababa. The test results obtained from different research works at different time are summarized in Table 3.1

Fig 3.1 The study area

Table 3.1 Range of values of laboratory test results of Addis Ababa expansive soils

Various researchers

| Researchers | LL (%) | PL (%) | PI (%) | Clay Con. .002mm (%) | Sand Con. .75mm (%) | Free Swell (%) | SP (Kpa) | Shrinkage Limit (%) | Specific Gravity |
|---|--------|--------|--------|-------------------------|------------------------|-------------------|----------|------------------------|---------------------|
| Morin and Parry [12] | 37-88 | | 11- 48 | 13-75 | | | 240-2000 | 7-28 | 2.62-2.94 |
| Yehaise. H [20] | 98-104 | 27-33 | 69-72 | 10-14 | | 70-110 | | | 2.63-2.85 |
| Tewold. E [19] | 91-106 | 24-29 | 64-80 | 55-68 | | 80-110 | 205-388 | 5-13 | 2.62-2.72 |
| Nebro. D [13] | 71-98 | 32-48 | 37-57 | | | 78-152 | | | |
| Yohanes. S[21] | 87-115 | 15-35 | | 40-70 | | 90-170 | 94-235 | | |
| Tefera. A and Leikun. M [17] | 80-120 | | 55-90 | 50-80 | | 23-90 | | | |
| Legesse .M and T.daniel (*)[11] , [18] | 96-109 | 24-28 | 55- 77 | 45-80 | 1-4 | 75-140 | 108-420 | 3-10 | 2.76-2.85 |

* Main reference for this thesis work

3.2.2 Classification of expansive soils of Addis Ababa

The expansive soils prevalent in Addis Ababa are either black or grey in color.

Based on different classification, degree of expansiveness is made. The plasticity chart developed by casagrande. A, [3]shows the expansive soil of Addis Ababa falls above the A-line and shows it is inorganic clay of high plasticity. According to Chen, [6] classification system relating the swelling potential with the plasticity index, it has very

high swelling potential. The activity chart, plasticity index versus clay fraction developed by De Bryn C. M. A/ [5] also shows the soil falls between activity 1 and 2 which means the soil is bad with regard to their effect on buildings erected on them

3.3 Method of sampling and sample size determination

It is often times difficult (if not impossible) to observe all the individual of the population because of the time and cost limitation. Based on this fact a sample, which is a sub group, or subset of the population, is taken. The sample is examined and observed and inference is made about the total population. In this study random sampling method has been used.

The buildings and dwellings are randomly selected, without previous knowledge about the actual conditions (Foundation type, construction method, construction material and damages due to expansive soils) .This approaches eliminates the possibility of either all the good portion or all the bad portions being sampled

The formula for the maximum sample size is obtained by solving the maximum error of the estimate formula for the population proportion for n . But since the sample hasn't been taken, there is no value for the sample proportion. p and q can be taken from a previous study, if it is available. If there is no previous study or estimate available, then use of 0.5 for p and q , as these are the values which will give the largest sample size, and it is better to have too large of a sample size and come under the maximum error of the estimate than to have too small of a sample size and exceed the maximum error of the estimate [9]

$$n = (Z_{\alpha/2}/E)^2 pq \dots\dots\dots 3.1$$

Where

n = sample size to be studied

E= maximum error

P= sample proportion which are damaged

q= sample proportion which are not damaged

$Z_{\alpha/2}$ = Standard normal value

The study has the following limitations

- 1/Some of the data are collected based on the information given by the owners
- 2/ Some of the buildings foundation depth is not well known
- 3/ Most of the buildings do not have drawings as a result it was difficult to get appropriate information about design and construction
- 4/ Knowledge of the expansive soil is limited and discussions were not convenient with owners during observation
- 5/ Lack of willingness of home owners to have their buildings observed
- 6/ Some owners were not involved in the construction, Therefore, they have little knowledge about details of their houses

Due to these limitations, 10% maximum error sampling is assumed. The sample size for 95% confidence interval for a maximum of 10% sampling error to represent the population is then calculated as 96

3.4 Observation and damage analysis

3.4.1 Data observations

The study considers ninety-six dwellings and buildings all of which are located within the region of the expansive soil area of Addis Ababa. Based on the area coverage and availability of buildings on different areas random houses are chosen. The classifications are listed in Table 3.2

Table 3.2 Number of samples studied in each locality of Addis Ababa

| Area | Number of samples |
|------------------------|-------------------|
| Bole | 22 |
| Olympia and Nifas silk | 24 |
| Lafto | 13 |
| Old airport | 10 |
| Mekanisa | 17 |
| Gergi | 7 |
| Bole bulbula | 3 |
| Total | 96 |

The observations are carried out with respect to many parameters such as Foundation type, Foundation depth, subsurface drainage condition, Surface drainage condition, Structural system and Building type. The observations are summarized and presented in tabular form in appendix -A

3.4.2 Damage analysis

The damages are related to the observational data and it is systematically analyzed as shown below.

Table 3.3 Number of damaged buildings. Wall are constructed from hollow concrete block, Brick and “Checa”

| Wall construction material | Number of buildings taken | Number of buildings with damaged walls | % of damage |
|----------------------------|---------------------------|--|-------------|
| Hollow concrete block | 54 | 36 | 67 |
| Brick | 15 | 6 | 40 |
| “Checa” and plastered | 23 | 9 | 39 |
| Other (Asbestos) | 2 | 1 | - |
| Not yet constructed | 2 | 0 | - |

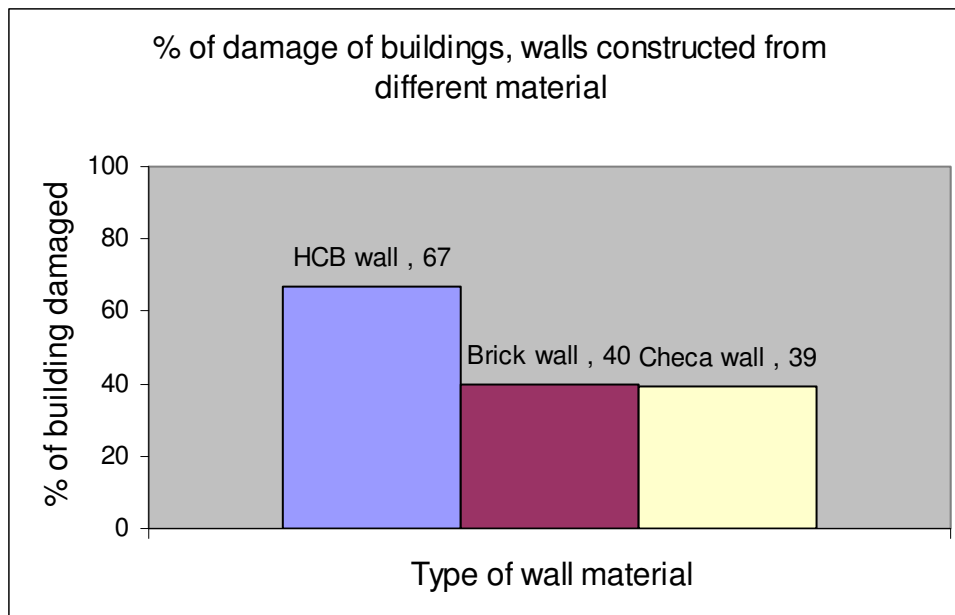


Fig 3.2 Chart showing % of building damages related with wall material

From the result of the observation data, Buildings walls constructed from hollow concrete block wall showed more damages than those walls constructed from brick and ‘checa’ wall.

Out of the observed ninety-six buildings, sixty-nines are damaged .The type of damages occurred on the buildings are different. The damages occurred on walls are more than that occurred on floors and ceilings. A comparison is made between type of damage and percentage of damaged buildings

Table 3.4 Number of damaged buildings and type of damages

| Type of damages in buildings | Number of damaged buildings |
|------------------------------|-----------------------------|
| Walls only damaged | 37 |
| Floors only damaged | 16 |
| Walls and floors damaged | 15 |
| Ceiling damaged | 1 |
| No observed damages | 27 |

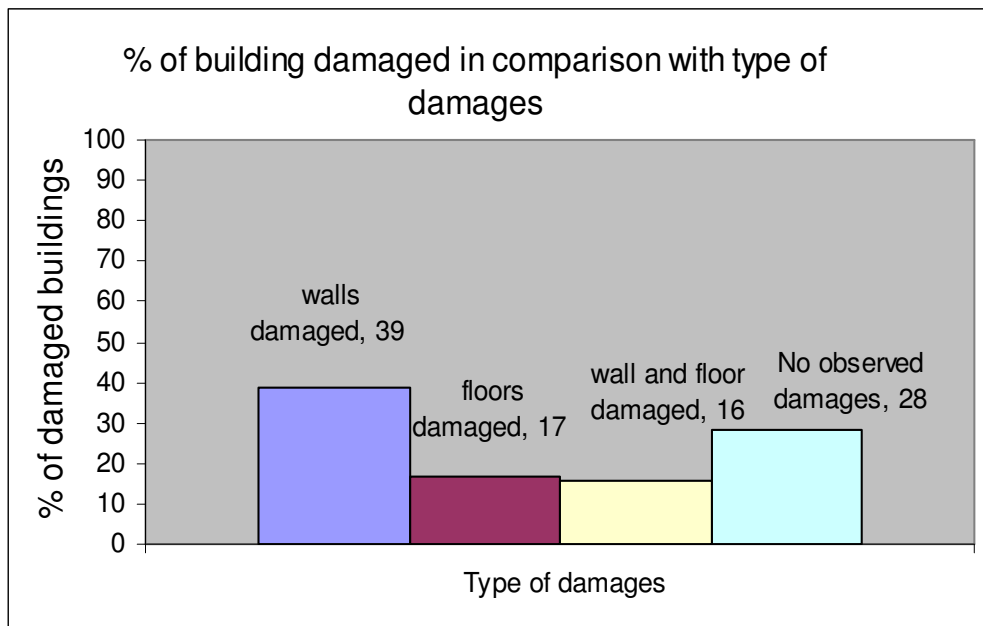


Fig 3.3 Chart showing % of building damages related with type of damages

Most of the foundations of the observed buildings are masonry foundation. 88 % of the buildings with masonry foundations are damaged. A comparison is made for the performance of foundations system on expansive soil.

Table 3.5 Number of damaged buildings in comparison with type of foundation system

| Type of foundations | Number of buildings | Number of damaged buildings |
|---------------------|---------------------|-----------------------------|
| Stiffened mat | 7 | 1 |
| Footing foundation | 26 | 13 |
| Masonry foundation | 57 | 50 |
| Pile foundation | 3 | 2 |
| Unknown | 3 | 3 |

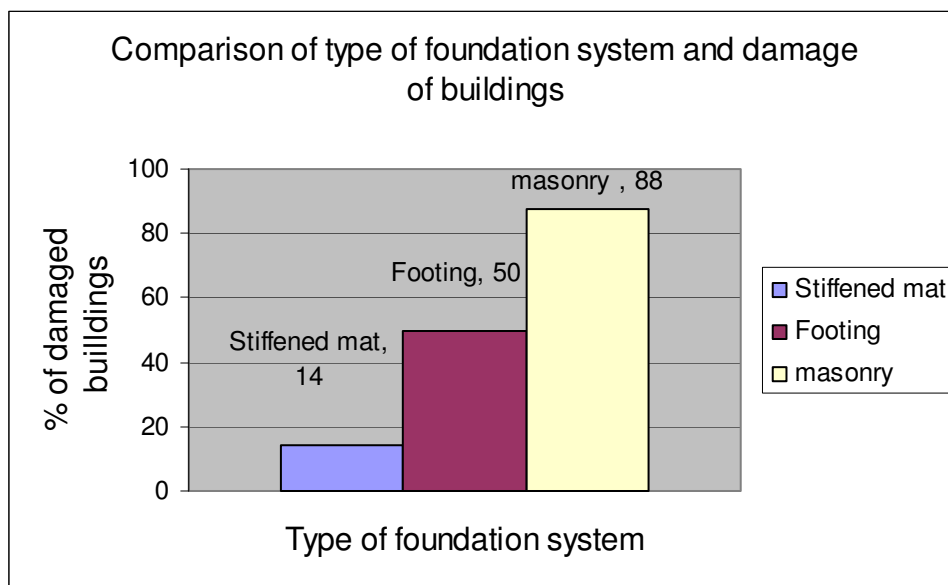


Fig 3.4 Chart showing % of building damaged related to foundation type

Most of the observed buildings lack proper drainage system and the surface water easily percolates to the foundation and hence disturbs the soils equilibrium moisture. A comparison is made among the observed buildings between failure of building caused by poor drainage system and caused by other factors

Table 3.6 Number of damaged buildings and cause of damages

| Cause of damages | Number of damaged buildings |
|------------------------------------|-----------------------------|
| Damage due to poor drainage system | 58 |
| Damage due to other factors | 11 |

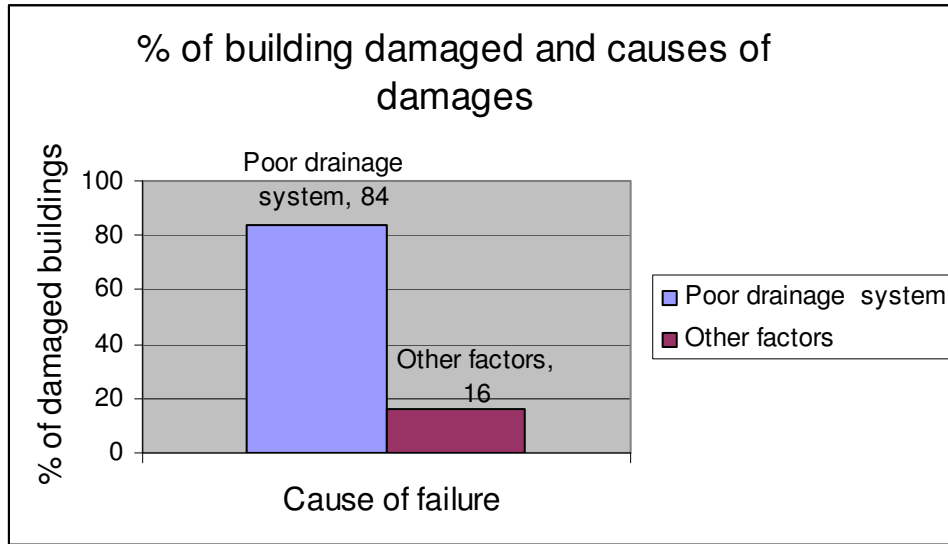


Fig 3.5 Chart showing % of building damaged and causes of damage

From the 69 buildings, that shows crack 84% lack adequate and appropriate surface and sub surface drainage system, which prevents equilibrium moisture disturbance. The other factors that cause damage are vegetations around the building, leaking of pipes, splashing of down pipes to the foundation soil and new adjacent construction.

3.5 Discussion on the observed buildings

Based on different classification system, expansive soil of Addis Ababa is highly expansive and exerts powerful uplift force. The swelling pressure ranges from 108-420 Kpa [18]. Out of the observed ninety-six buildings, sixty-nines are affected by the consequence of expansive soils. The detail observations of the ninety-six buildings are presented on appendix-A. 72 % of the buildings are affected by the consequence of heave or shrinkage of the expansive soil.

The problem observed on buildings varies from simple crack on walls to severe structural damages, which cause collapse of the whole building. Some of the problems observed are discussed below

1. Sever structural damage

The design of structural element is usually based on an idealized loading scheme resulting from the weight of the super structure .When the support move differentially resulting in yield of structural element due to overstressing under the redistribution of forces and moments. The moments and the shear stresses introduced are not usually accounted for in the usual design [1]

Shear of tie beams in Addis Ababa city Administration car maintenance hangar, buckling of steel column and failure of truss member in Ethiopian Airlines maintenance hangar is caused by the movement of the supporting structural element .The movement decreases the load carrying capacity of the structural element and ultimately may lead to collapse of the whole structure. Some of the observed buildings of which sever structural damages are observed are shown in Fig 3.6a and in Fig 3.6b.



Fig 3.6a Shear of tie beam in Addis Ababa city car maintenance hangar



Fig 3.6 b Detachment of tie beam and column in bole senior secondary school

2. Losses of proper service of the building / Psychological impact /

The staircase of the Ethiopian airlines main office building cracks excessively. As a result, at the time of observation, it doesn't give service and people there were also afraid of using it. They were using another stair. A level difference on floors, which is not less than 4%, is also observed. To avoid tilted or sloped surface, they were using a temporary wooden false floors on top of the concrete floor to make an apparent level surface. Sticking of doors and windows are observed in most of the observed buildings. Generally, the consequence of expansive soil decreases aesthetic and quality of the building by creating psychological impact on the users.

3. Creating additional financial burden for maintenance

The Bole senior secondary school fence was constructed twice and at present, more than half of the fence is totally damaged. Yearly maintenance of crack was also reported by the owners. This is due to lack of knowledge of the behavior of expansive soil. Building constructed on expansive soil area creates additional financial burden for maintenance on the owners which results in economic losses on the owners in general unless maintenance work is done with proper knowledge of expansive soil.

3.6 Possible cause of failure

The main cause of failure or damage of the buildings observed are due to poor drainage system, which easily disturbs the equilibrium moisture content of the foundation soil resulting in differential heave. The following factors aggravate the situation severely

3.6.1 Faulty Design

Design of structure while unaware of the existence and behavior of expansive soil can worsen a readily manageable situation. Due to low level of knowledge of understanding of the mechanics of heaving and wrong concept of safety associated with conservative design, aggravate the situation. It is observed that bearing capacity of expansive soil is taken to be 75kPa for the design of footing on expansive soil by one of the local consultant which results in bigger footing size as it is shown in Fig 3.7a and Fig 3.7b .As the footing size increases, the up lift force increases and creates foundation movement. But bearing capacity depends on two criteria which are shear failure and settlement. As the footing size increases, the heave increases resulting in additional up lift pressure on the structures. It is not practiced by many engineers to design foundation by comparing the dead load pressure with the up lift force induced by the swelling pressure. Lack of doing this worsens the situation. Problems associated with faulty design also include improper foundation loading, improper foundation depth and insufficient reinforcing steel and insufficient attention to surface and sub surface drainage. Settlement of masonry wall below grade beam is also observed in Bole bulbula area .This is due to improper foundation depth consideration. The masonry wall is placed near the surface believing that it is not structural. However, the footings were placed in a stable soil layer below 3m, and then during the summer the soil near surface shrinks and the masonry wall placed on surface or in shallow depth settles. This result in detachment of the masonry wall and the grade beam as it is shown in Fig 3.8 Therefore; the designers should be aware of the behavior and nature of expansive soil and take the proper measures during design stage

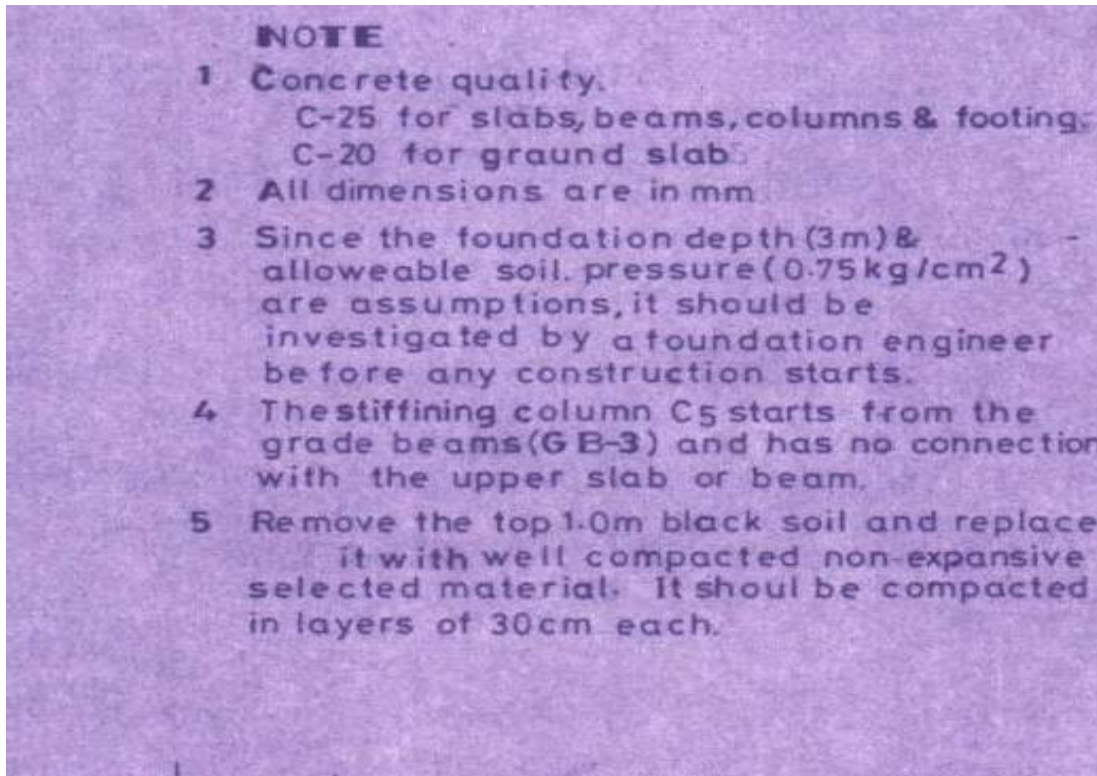


Fig 3.7a Bearing Capacity assumption by one of the local consultant for a building constructed in expansive soil area of Addis ababa

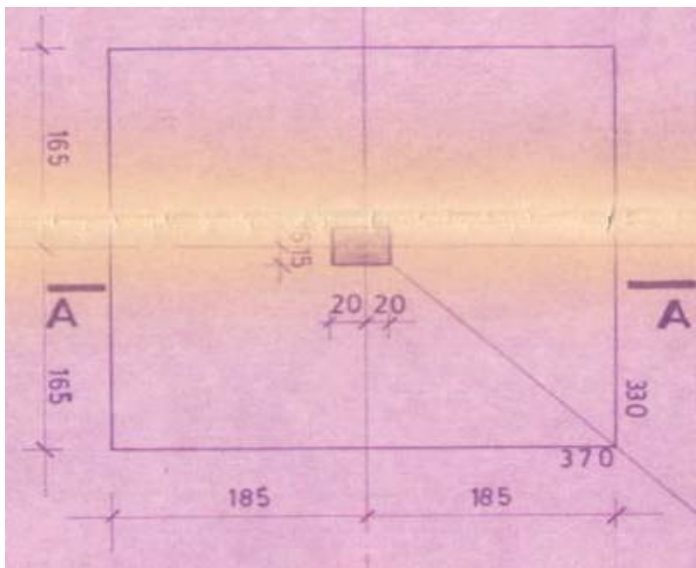


Fig 3.7b Footing size for G+1 office building in expansive soil area of Addis Ababa for the same building for which the note is shown above



Fig 3.8 Settlement of masonry wall below grade beam in bole bulbula area

3.6.2 Improper Construction

Construction problems associated with expansive soil are mainly lack of reinforcing steel or insufficient or improperly placed reinforcing steel, mushroom-topped drilled pier, inadequate void space between the soils and grade beam, walls and tie beams [19]. Most of the observed buildings have shown bulged and cracked floors due to lack of void space between the slab and the grade beam as shown in Fig 3.9a and in Fig 3.9b. It is also a common practice to compact foundation soil believing that it will have a higher bearing capacity. However, Compacting of expansive soil during construction increases the density and results in a higher swelling pressure. Allowing clays to dry excessively

before pouring of concrete and permitting pond water near a foundation during and after construction also disturbs the initial moisture content and swelling pressure develops .There fore, concrete pouring should be done immediately after excavation without disturbing the soil moisture content excessively. New construction near a building on expansive soil also disturbs the moisture equilibrium of the existing building and results in problem



Fig 3.9a Heave of verandah floor in Olympia area due to lack of void between slab and grade beam



Fig 3.9b Crack of walk way in bole senior secondary school due to lack of void space between the walk way and the concrete curb stone .The source of moisture fluctuation is the surrounding vegetation

3.6.3 Maintenance failure

Surface water, leaking pipe and subsurface drainage are the main source of moisture disturbance of the foundation soil. Pipes around the building should not leak or assessment should be made of the monthly expense of water supply to know if there is water loss due to broken pipes. Breaking of down pipe and splashing of water to the foundation is commonly observed (see Fig 3.10a and 3.10b) results moisture disturbance and as a result swelling pressure develops.

The building in Fig 3.10a built in bole area cracked at the corner of windows in the vicinity of down pipe spout. The crack appeared due to failure in maintaining the down pipe spout, which splashes to the foundation soil. It is a good practice to observe any change around the building if crack happens and to make early maintenance before the condition worsens.



Fig 3.10a Splashing of water to the foundation soil



Fig 3.10b leaking of pipe around building and failure of maintaining the down pipe spout

3.6.4 Construction interruption related failure

It is a common trend to do foundation or substructure part in one phase and super structure in the next phase due to financial problem of homeowners. Buildings are designed to the final stage or condition. Construction interruption results in failure even if the foundation is designed properly with the precautions to be taken for expansive soil. Due to construction interruption, the dead load pressure which counter balance the uplift force gets lower resulting in foundation movement. It is also a common practice to pave the surrounding area after the construction is completed.

The building will be more susceptible to foundation movement if it is not paved during rainy seasons. There fore, it is recommended to complete the construction in one season by at the same time making all the precaution to be taken in expansive soil like, proper surface and subsurface drainage system, etc

3.6.5 Landscaping

Proper foundation design and construction may not be enough to solve the problem associated with swelling soil. The owner should also be careful on the landscaping of the area or the garden plot by

- i. avoiding grass and shrubs around the building
- ii. avoiding sprinkler system around the building
- iii. avoiding tree plantation around the building
- iv. giving appropriate slope so that the water drained away from the building

It is common to make garden in the compound. But shrubs and grass around building disturbs the moisture equilibrium of the soil. Most of the owners have garden in front of their homes and in the periphery of their fence as shown in Fig 3.11a and in Fig 3.11b. Garden watering disturbs the soil moisture and swelling pressures develops and results in crack.



Fig 3.11a Sever vertical crack of fence wall in Mekanisa area .Source of water is from garden watering



Fig 3.11b Sever diagonal crack of Nesanet public school .The building is surrounded with Shrubs and grasses

Chapter four

Detailed investigation of Ethiopian Airlines maintenance hangar building

Ethiopian airlines maintenance hangar is one of the ninety-six observed buildings, which has a sever problem due to foundation movement. It is huge and most of the information on the design and the soil information is available. There fore the hangar building is selected for detailed investigation.

4.1 General

The Ethiopian Airlines maintenance hangar building was constructed in 1960. The Ammann & Whitney-Husted Architects and Engineers (an American consultant) was the designer of the building .It is located in bole sub-city kebele 01 in the compound of Ethiopian Airlines and it is placed on a total of 7200m² area. The hanger looks like a canopy structure, which the trusses freely spanning 42 m. To counter balance the cantilevered freely span truss there is a two-story composite framed section office building. It is fully placed on the expansive soil. The foundations are piles of different diameter .The cladding and the clad supporting structure rested on a deep continuous beam. The partition walls are brick and they are load bearing .The surface condition during observation was at front (western part) is fully paved with concrete structural slab. The southern and the eastern parts are paved with asphalt. But the northern wing is exposed to surface water and most of the surface runoff water percolates to the ground and collected under the building

4.2 Foundation Information and soil data

The actual soil data, with which the design is carried out, was not available, but the foundation, all structural as built drawings and the soil data for the new maintenance hangar near by the former hangar, now under construction by CATIC, Chinese company are available. All soil tests are carried by Construction Design share Corporation, Material testing department in December 1984 E.C.

4.2.1 Bore hole and laboratory test data's

Subsurface soil exploration was carried up to 15m from the natural ground level. The field and laboratory tests reveals that the soil profile is composed of grayish brown , fine ,stiff clay with some black spots up to a depth of 8meter and then fine gritty loose silt to hard basaltic fragment to a depth of 15m. The test data obtained from laboratory has the following range of values for soil layers to a depth of 8m on average. A typical bore hole log data of Ethiopian airlines maintenance hangar is shown in Fig 4.1

Table 4.1 Range of values for laboratory test for Ethiopian Airlines maintenance hangar to a depth of 8m on average

| LL (%) | PL (%) | PI (%) | Clay Content 002mm (%). | Natural moisture Content (%). | Free Swell (%) | Shrinkage Limit (%) | Specific Gravity |
|----------|--------|--------|----------------------------|----------------------------------|-------------------|------------------------|---------------------|
| 102- 116 | 42-62 | 46-71 | 60 | 32-58 | 60- 120 | 7-28 | 2.37-2.75 |

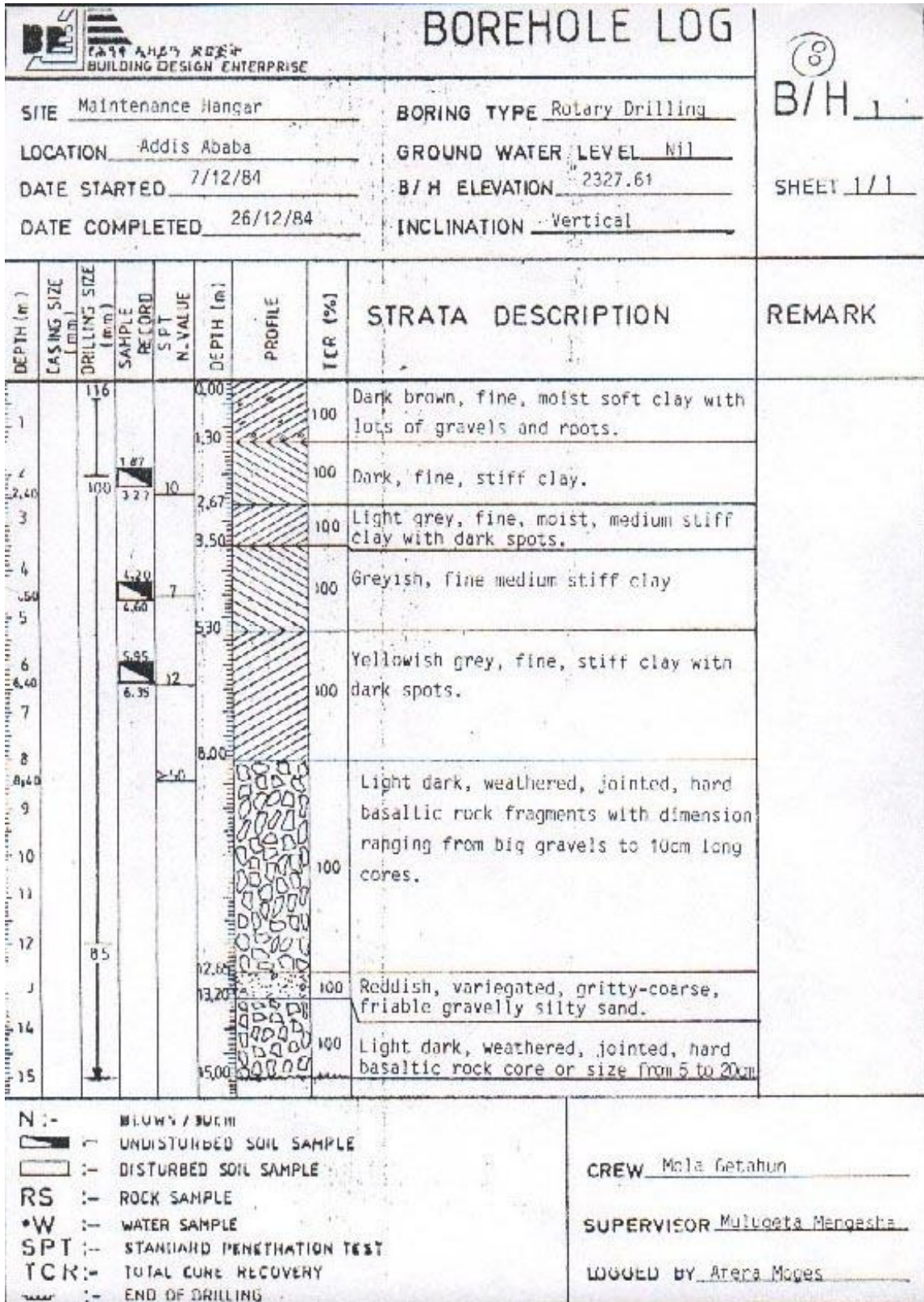


Fig 4.1 Typical borehole log data of Ethiopian Airlines maintenance hangar

4.2.2 Foundation information

Pile foundations were adopted and the hangar building rests on 53 single piles of different pile length and pile diameter as shown in the foundation plan in Fig.4.2a and in Fig.4.2b.

The piles are interconnected by deep continuous beams. The depth of the beam varies from 1.80meter to 2.05meter. The length and dimensions of different piles used are listed on Tables 4.2

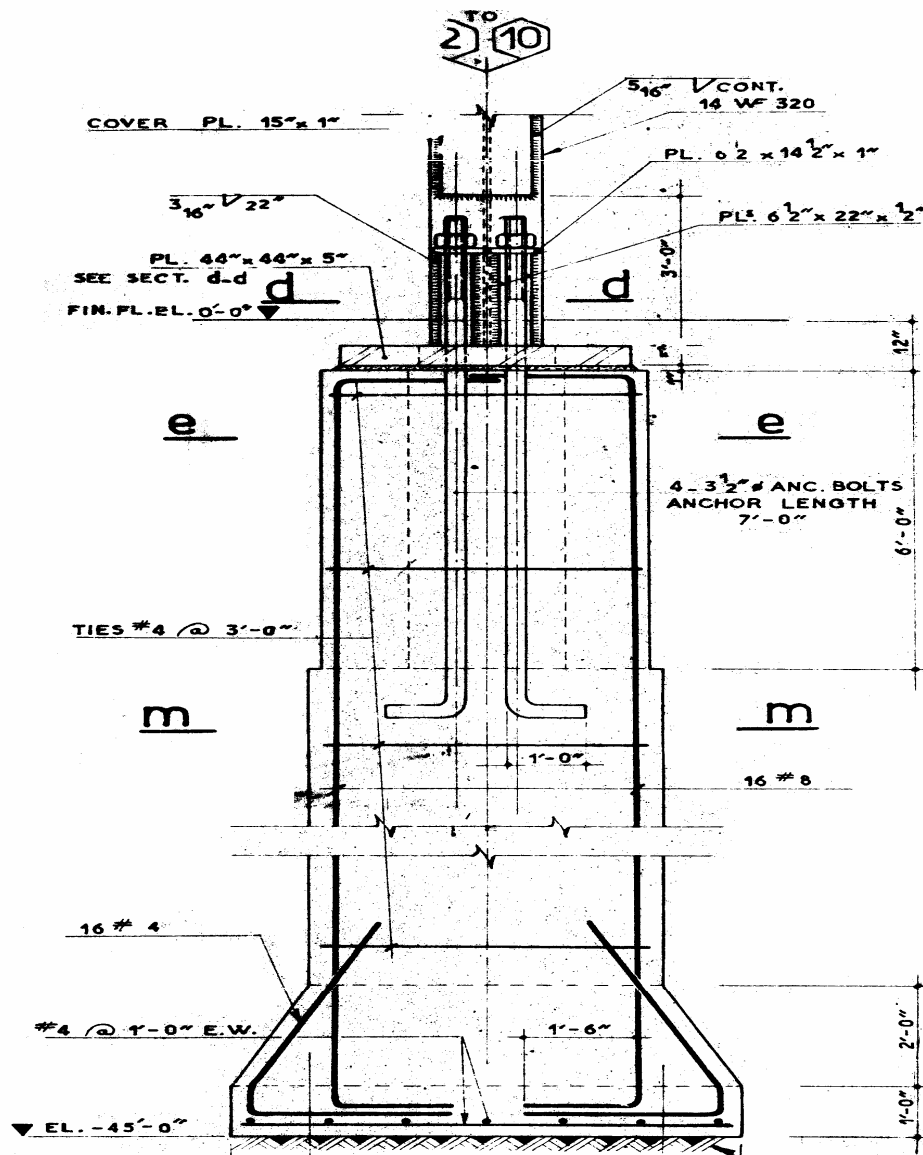


Fig 4.2a Typical pile foundation detail of Ethiopian Airlines maintenance hangar

Fig 4.2b Foundation plan of Ethiopian Airlines maintenance hangar building

Table 4.2, Foundation information of the Ethiopian Airlines maintenance hangar building.

| Pile type | Pile length (meter) | Pile size (Dimensions) (meter) |
|-----------|--------------------------|--------------------------------------|
| F-1 | 11.60 | Circular , diameter 2.15 |
| F-2 | 13.75 | Circular , diameter 1.40 |
| F-3 | 11.60 | Circular , diameter 2.15 |
| F-4 | 13.75 | Rectangular , 1.40 X 1.00 |
| F-5 | 11.60 | Circular, diameter 2.15 |
| F-6 | 13.75 | Rectangular , 0.96 X 0.96 |
| F-7 | ** | ** |
| F-8 | ** | ** |
| F-9 | ** | ** |
| F-10 | ** | ** |
| F-11 | ** | ** |
| F-12 | ** | ** |
| F-13 | ** | ** |

** These are foundations filled with 0.91-meter diameter cyclopean concrete to a depth Of 11m then 2.75 meter deep, reinforced concrete pile. F-14 and F-15 are Continuous footings with depth 2.05 meter and width 0.60m as shown in the Fig 4.3

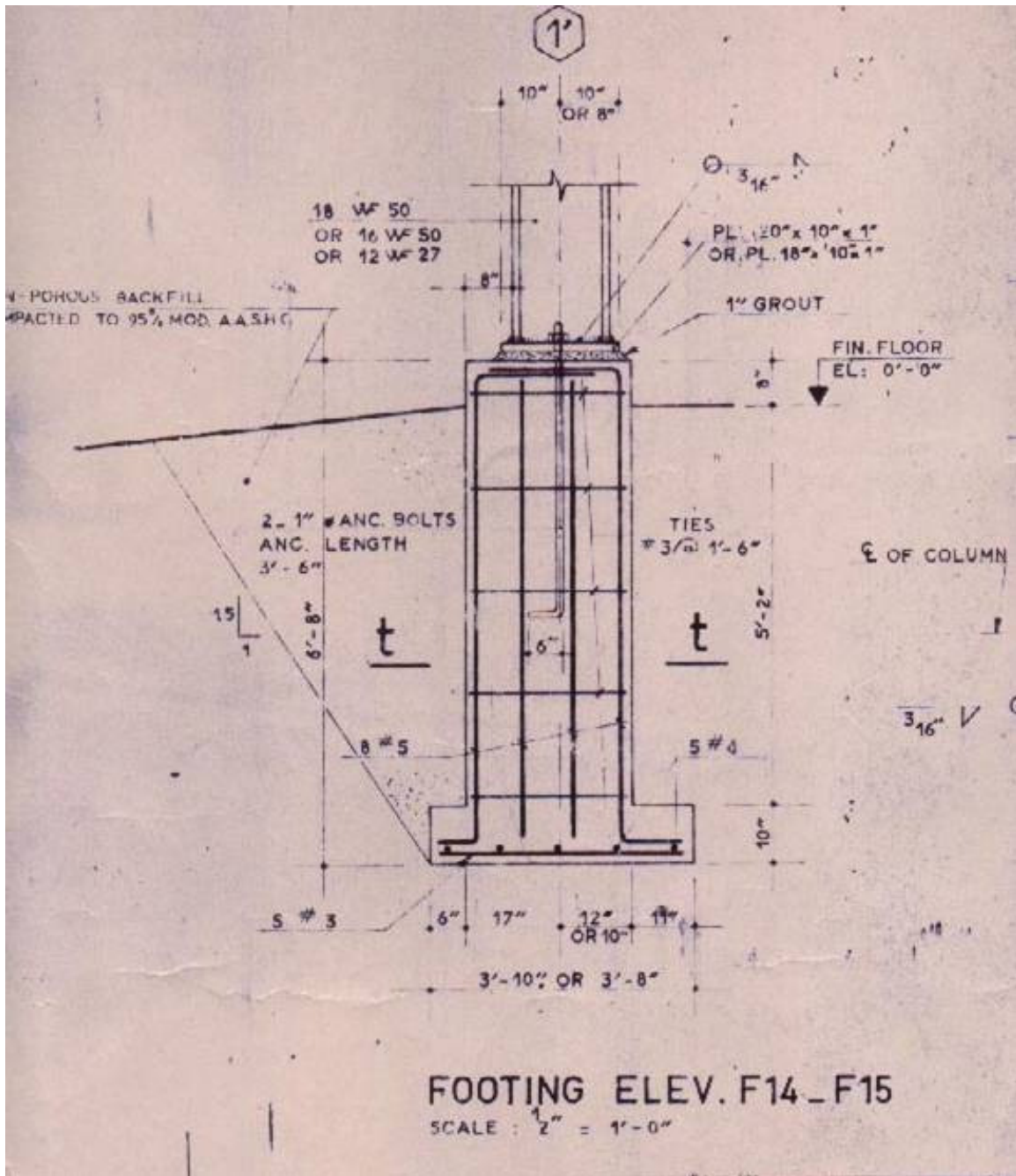


Fig 4.3 Cross section of the Continues Footing on Axis – 1 of the Ethiopian Airlines Maintenance Hangar building that support the cladding member

4.3 Survey of damage

Most of the damages are associated with the left wing of the building between Axes -1 and 5. As it is observed that the damages are clearly shown even in the suspended floors which are cracked. The following major damages are observed.

- . Buckling of steel column on the junction of Axis-1 and Axis B
- . Heaving of floors at the upper floors .At the connection between loads bearing wall and slab makes ramp.
- . Walls cracked severely.
- . Staircase cracked severely.
- . Level difference of floors even in the suspended floor
- . Detachment of I-section beam with the brick wall

One of the truss members on axis-1 was also failed and now maintained as shown in Fig4. Generally, the problem is alarming and critical



Fig 4.4 Failed truss member of the Ethiopian Airlines maintenance hangar building on Axis-1

4.4 Failure analysis

The distress caused in the Ethiopian Airlines Maintenance hangar building is due to uplift of the continuous deep beam on axis 1. It is observed that most of the failure is seen between Axis 1 to Axis-5. The building is exposed to surface percolated water in the northern side due to poor subsurface drainage condition. It is clear that the percolated water disturbs the moisture equilibrium of the soil and creates swelling pressure which distresses the structural elements. Some of the damages and its causes are explained below.

1/ Failure of truss member and buckling of Steel –I column Fig 4.4)

The steel I-section columns on axis-1' rested on the continuous deep beam introduced in order to support the cladding, were designed to slide vertically along the vertical member of the truss element and the truss was designed as a cantilever element (Fig –4.5).

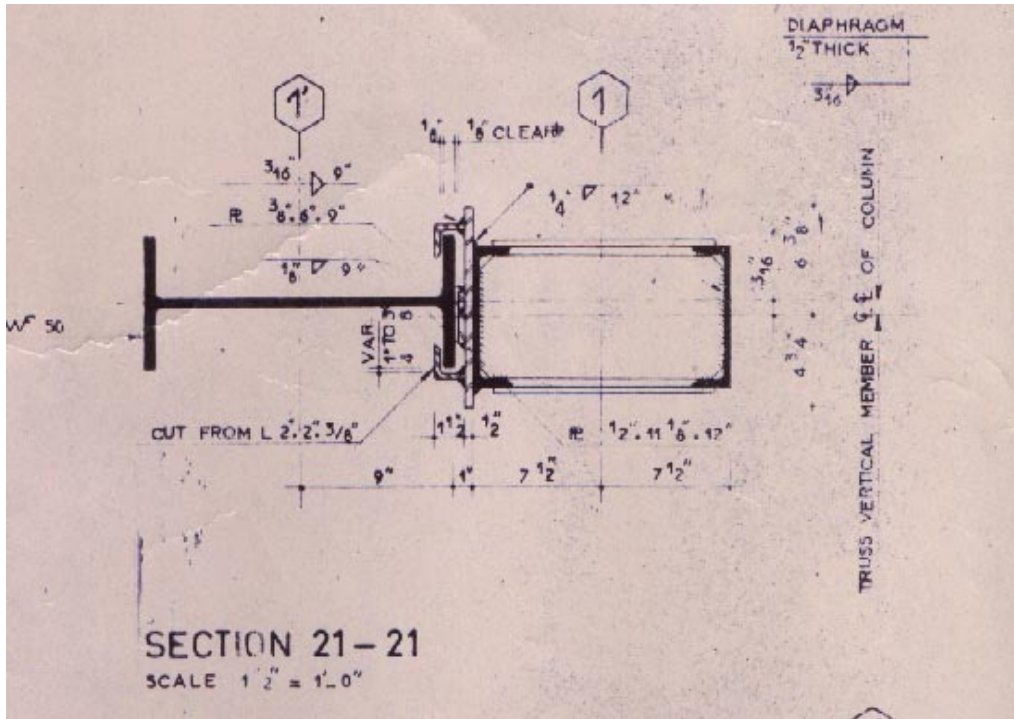
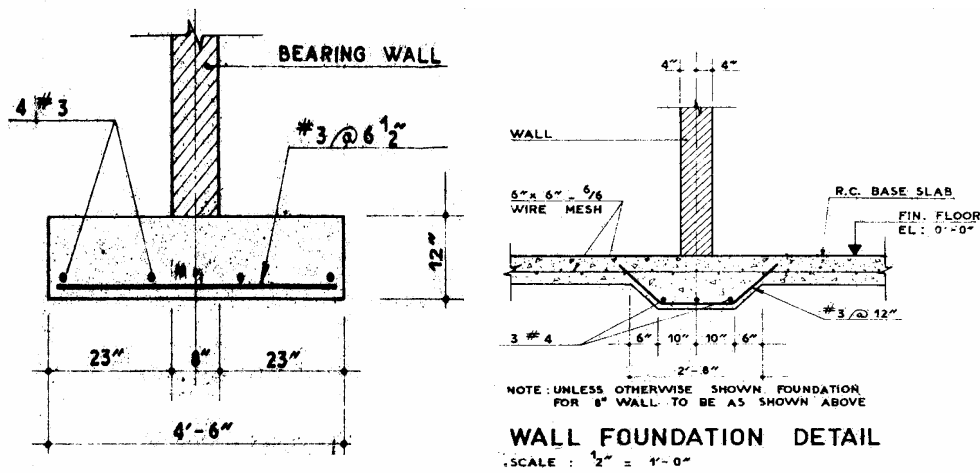


Fig4.5 Detail of truss vertical member and column connection for vertical movement of Ethiopian Airlines Maintenance Hangar building

Up lift of the continuous deep beam results in pushing of the truss member through Steel column, as a result one of the truss elements failed (Fig 4.4). In the other case the other steel –I section on axis -1 which supports the cantilever truss was initially in tension and designed for tension. Pushing of the truss through the Columns placed on the continuous footing due to imperfect connection forced the columns to be in compression and buckling of the column occurred.

2/ level difference of the upper floor and connection between load bearing wall and slab makes ramp

The partition walls were load bearing (Fig 4.6a and Fig 4.6b) and they rested on deep continuous beams and continuous footing. Most part of the beams is on the expansive soil. Similarly, uplift of the continuous deep beam has occurred and the load bearing brick walls between the deep beams and the first floor beams are in compression. The compressional force transmitted to the beams through the wall and the beam deflected and made slight ramp



a/ Load bearing brick wall

b/ Wall foundation detail

Fig 4.6 Load bearing brick wall and wall foundation for Ethiopian Airlines maintenance Hangar building

4.5 Cause of damage and remedial measures

The main cause of damage for the building is uplift of the continuous footing due to lack of proper sub surface drainage, leakage of utility lines around the building

The following remedial measures are recommended:-

- 1/ Provide proper sub surface drainage which intercepts the percolated water and drains a way from the building
- 2/ Provide void space between the walls and the beams to allow free movement
- 3/ Soil around the deep beams should be replaced by non expansive back fill to decrease the uplift
- 4/ Under pin the deep continuous footing to a stable zone
- 5/ Clean and make functional ditches around the building to drain water properly
- 6/ provide vertical moisture barrier
- 7/ Introduce void space between the grade beam and the expansive soil.

Chapter Five

Conclusion and recommendation

5.1 Conclusion

- 1/ Out of the surveyed buildings constructed in expansive soils of Addis Ababa 64 % are adversely affected. They showed cracks associated with expansive soils.
- 2/ Drainage is the most critical initiating factors for building damages. 84 % of the damaged buildings lack drainage system or the drainage system provided is inadequate
- 3/ Buildings for which the walls constructed from hollow concrete block showed to be more susceptible to crack compared to the once constructed of brick. 67 % of the buildings wall constructed from hollow concrete block showed crack and 40% of the buildings wall constructed from brick wall also showed crack
- 4/ 88% of the buildings with masonry foundations are damaged.
- 5/ The damages occurred on walls are more than the damaged that occurred on floors and ceilings
- 6 / Diagonal crack at the junction of openings and Corner wall crack are a typical crack pattern for the surveyed buildings
- 7/ Deep continuous footings on expansive soil with poor drainage system showed that they are not necessarily safe
- 8 / Non expansive impervious soil back fill below foundation and slab on ground decrease foundation movement
- 9 / Buildings with deep isolated footings and Stiffened mat foundations are not damaged or showed very minor damage

10/ Buildings which remained without crack for long time shows crack when the foundation soil is exposed to moisture

11/ The precautions to be taken in treating expansive soil using the available theories are not practiced in most buildings of Addis Ababa either at design or construction stages

12 / The adverse economic consequence of damages related to expansive soils in Addis Ababa is substantial

5.2 Recommendation

1/ It is recommended to apply all existing available theories and practices for the design and constructions of buildings located in expansive soil areas . Great emphasis should be made specially on moisture control measures

2/ A land use policy on expansive soil areas of Addis Ababa can be prepared by Professionals and city administration.

3/ Based on the field investigation, soil tests result and damage analysis of expansive soil, design guide or national building code for expansive Soil and need to be prepared

4/ Small bulletins can be prepared to educate home owners about building construction on expansive soil and the influence of expansive soil on buildings with out proper construction and design

5/ The result obtained may be used as a basis for further research in the area of expansive soil

