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Damages of Buildings on Expansive Soils: Diagnosis and Avoidance

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Abstract

This paper aims to identify the factors that cause damages to buildings constructed on expansive soils and suggests practical solutions to avoid swelling problems. Literature of buildings failures associated with expansive soils and techniques experienced to prevent the swelling damages were intensively reviewed. Three regions in Khartoum state, famous expansive soil areas were selected for this study. Ten cases of damaged buildings were randomly selected for investigation. A field survey of damages was conducted to diagnosis and point out the causes, extent and type of damage that was observed in the buildings. It was observed that eight lightweight buildings suffered heavy damages and only two other buildings were slightly damaged. Common failures observed were cracks in walls and floors, foundation movements, column buckling, sagging of beams and slabs in typical damage cases. It was found that poor surface drainage, gardens watering close to buildings, source of water leakage and improper design of foundation contribute to most failures and damages in buildings. Based on the causes of failure and other factors, practical measures are suggested for the damaged buildings. Finally, conclusions are drawn from the study findings.

Keywords: *Damages; diagnosis; expansive soil; buildings.*

1. Introduction

Expansive soils pose a significant hazard to foundations of buildings founded in them. Such soils can exert uplift pressures which cause considerable damage to lightly loaded structures. The annual cycle of wetting and drying causes the soil to swell and shrink. Thus, the arid and semi-arid regions are much susceptible to damage from expansive soils throughout the year. In Sudan, the climate is semi arid and over one-third of the country land covered with expansive soils. Unfortunately, this area includes most of the nation's population cities and development projects. Many houses in central and eastern regions of Sudan were damaged due to soil heave, [1].

The presence of expansive soils in Khartoum has contributed to light buildings damages and subsequently causing increased annual repair expenditure, [2]. Many structures constructed on swelling clays have met with widespread problems associated with serviceability performance mainly in form of cracks or permanent deformation. There are many cases of residential buildings have experienced significant cracking and damages, [2].
Engineering problems due to expansive soils have been reported in many countries, costing millions of dollars due to severe damages of structures. Maintenance and repair cost can exceed the original cost of the foundation and creates financial burden to the owner, [1].Generally, the damage will result in economic loss for building owners and the country at large scale. Although the accusing finger is mainly pointed at the expansive soils, other contributing factors such as poor design, poor construction, inadequate supervision of the construction processes, poor drainage, gardens and big trees close to the building, and climatic factors have contributed to the problem.

The object of this research work is to identify the factors that cause failures to buildings constructed on expansive soil areas in Khartoum state. Some existing residential buildings suffered from damages by expansive soils were taken as a case study. Building sites were visited to inspect and ascertain some practices on site likely to cause damage or even collapse of buildings in order to recommend appropriate remedial measures.

2. Literature Review

2.1 Expansive Soil

Expansive soils are clay soils containing considerable amount of montmorillonite mineral which has a potential for swelling or shrinking due to changes in its moisture content. Expansive soil can be classified into two main groups with respect to the parent rock. The first group comprises the basic igneous rocks such as the basalts in India and South Africa. In this group, 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. Examples of this type of rock are bedrock shale found in North America and the shale in South Africa, [3]. The three most important minerals of expansive clay are montmorillonite, illite and kaolinite. The montmorillonite is considered as a highly expansion and the most effective one for swelling behavior, [4].

Potentially swelling clays can be recognized in the laboratory by their plastic and swelling properties. Generally, clays of high plasticity usually have high swelling potential. Expansive soils are characterized by plasticity index over 30%, liquid limit exceeding 50% and have high swelling potential, [3]. In the field, expansive clays can be recognized in the dry season by the deep cracks of roughly polygonal patterns, [5]. Three ingredients that are necessary for soil to swell, clay rich of montmorillonite mineral; when the natural water content is around the plastic limit of the soil; and there is a source of water leakage.

Expansive soils experience volume changes as a result of moisture changes leading to differential movements below a building's foundation. When a structure builds on such a soil, it applies an upward pressure on the foundation. If the foundation transfers a downward stress which is smaller than the swelling pressure, the foundation 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 storey buildings, pavements, etc. which generally transmit smaller stresses to the soil than the swell pressure are greatly suffered the damage, [6].

2.2 Damages in Buildings

Different Buildings experience various levels of damages during their life time. Damages may occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occurs to disturb the soil moisture, [7]. The probability of damages increases for structures on swelling foundation soils if the climate and other field environment, effects of construction, and effects of occupancy tend to promote moisture changes in the soil. The differential movement caused by swell or shrinkage of expansive soils can increase the probability of damage to the foundation and superstructure. Differential rather than total movements of the foundation soils are generally responsible for the major structural damage. Differential movements redistribute the structural loads causing concentration of loads on portions of the foundation and large changes in moments and shear forces in the structure not previously accounted for in standard design practice, [6]. The damages are due to design faults, cheap construction materials, poor workmanship, poor drainage, climatic condition and swelling behaviour of expansive soils.

The volume change behavior of expansive soil generates serious damage to civil infrastructures in Sudan and many countries over the world. In general, the annual damage in Sudan exceeds $6million and most of the annual damage reported occurs in residential and commercial buildings, [1]. Previous studies indicated a continual increase in annual damage caused by expansive soil as the population continues to grow due to the need of new developments to the expanding residential buildings and commercial markets,[7][8]. Rosenbalm and Zapata [9] stated that in the United States alone, the cost to repair structures damaged by expansive soils has been estimated to be twice the combined damages of natural disasters. Expansive soils have reportedly inflicted billions of dollars in damages and repairs annually to structures, [10].

Evaluation of damages has to base on experience and knowledge of the history of the building, construction materials details, crack patterns, and existing physical condition. This is possible by means of walk through inspection to identify and categorize both distinct and hidden damages. For all damages, the professional inspector must predict a complete set of causes and effects. The correlation between causes and effects require experimental and analytical investigation. This is used to identify, localize and quantify the damages for structural performance evaluation. Damage evaluation based on different deterministic criteria in relation with angular distortion, [11][12].

The most obvious identifications of damage to buildings are doors and windows that get jammed, uneven floors, and cracked foundations, floors, masonry walls and ceilings. Moreover, different crack patterns mean different causes for different foundation materials. In most cases, cracks due to shrinkage and expansive clay usually run from corner towards adjacent opening and are uniform in width or v-shaped, wider at the top than the foundation wall, [13][14]. This pattern of cracks happens when the moisture movement is from the perimeter to the centre of the house. In some cases, the cracks are wider at the bottom than the top due to dishing effect as opposed to dooming effect. This happens when the moisture moves from centre to the perimeter resulting into the saucer effect. In the dishing effect, the cracks are wider bottom than top because of the inwards tilt, [15]. Cracks due to structural failure 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. Crack due to foundation movement are usually associated with expansive soil, which can exert a pressure which moves the structure. The pattern of the cracks depends on whether it is a doming heave or a dish shaped lift heave. Figure 1 schematically illustrates some commonly observed exterior cracks in brick walls from doming or edge down patterns of heave. The pattern of heave generally causes the external walls in the superstructure to lean outward, resulting in horizontal, vertical, and diagonal fractures with larger cracks near the top, [16].

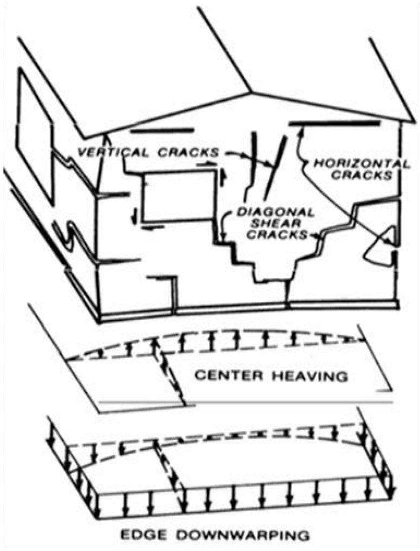

Figure 1 Cracks patterns on exterior wall resulting from dome heave of foundation soil, [16]

The classification of the damage is very important to assess whether the building calls for strengthening, repair, renovation or demolition. Various researchers ([17],[18], [11]) put forward many definitions, specifications, classification and effect of damage in structures as given in Table 1.

2.3. Practical Solutions for Swelling

In order to minimize or eliminate the danger of damage of buildings because of heave and shrinkage, the methods commonly have been used are moisture control, soil stabilization and structural measures.

2.3.1 Moisture Control Barriers

The main cause of heave and shrinkage is the fluctuation of moisture under and around the structure. In general, the natural ground water fluctuates depending on land topography, geological and weathering conditions. In a country like Sudan, where there are distinct dry and wet seasons, the fluctuation of ground water table during these periods is large.

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, [19].

Table 1 Classification and effect of damages in buildings, [11]-[17]

Degree of Damage	Description of damage	Effect of damage on building	Crack width (mm)
Insignificant	Hairline cracks	None	< 0.1
Very slight	Fine cracks	None	0.1 to 0.3
Slight	Cracks are visible and easily filled. Several slight fractures may appear inside of the building. Doors and windows may stick	Aesthetic only	0.3 to 2
Moderate	Cracks that require opening up and patching. Possible replacement of a small amount of brickwork. Doors and windows stick, service pipes may fracture.	May affect serviceability and stability of the building	2 to 5
Severe	Large cracks require extensive repair work involving breaking-out and replacing sections of walls. Windows and door frames distort and floor slopes are noticeable. Leaning or bulging walls. Beams lose some bearing. Utility service disrupted	Serviceability and stability of the building at risk.	5 to 25
Very severe	Major repair involving partial or complete rebuilding. Beams lose bearing, walls lean badly and require shoring and windows are broken with distortion.	There is a danger of structural instability	>25

Horizontal moisture barriers can be installed around a building in the form membranes, rigid paving or flexible paving. Widely used horizontal barriers are polyethylene membrane, concrete aprons and asphalts membrane. The purpose of the horizontal barriers is to prevent excessive intake of surface moisture, [10].

Vertical moisture barriers are used around the perimeter of the building to cut off the source of lateral water migration. Vertical barriers are more effective than horizontal barriers in terms of slowing the rate of heave and causing the water content distribution to be more uniform below the structure. Polyethylene membrane and concrete can be used as vertical barriers. When such materials are used as a barrier, this depth should be equal to or greater than the depth of moisture fluctuation [4].

2.3.2 Adequate Drainage

To control water fluctuation, adequate drainage system for surface and subsurface water is essential. Drainage is provided by surface grading and subsurface drains. The most commonly used technique is grading of a positive slope away from the structure. The slope should be adequate to promote rapid runoff and to avoid collecting near the structure, pond water which could migrate down the foundation soil. These slopes should be greater than 1% and preferably 5%. Covered drains can be provided to discharge away the surface runoff water. Subsurface drains may be used to control a rising water table, groundwater and underground streams and surface water penetrating through pervious soil. Subsurface drains or perforated pipes 15 cm diameter can help to control the water table before it rises but may not be successful in lowering the water table in expansive soil, [3]. This usually is not accomplished due to negligence, cost, limited property size and other reasons.

2.3.3 Chemical Stabilization

Many chemical admixtures can be used to stabilize expansive soils but lime has proven to be the most effective for highly expansive clays. The use of lime to prevent or minimize soil expansion has been increasing in favor during the last few decades because it significantly reduces swelling characteristics and increases soil strength. Generally the amount of lime required to stabilize expansive soils ranges from 5 to 8% by weight. The addition of lime to clay soil provides an abundance of calcium ions (Ca+2) and magnesium ions (Mg+2). These ions tend to displace other common cations such as sodium (Na+) and potassium (K+), in a process known as cation exchange. Replacement of sodium and potassium ions by calcium significantly reduces the plasticity of the expansive clay, [20]. A reduction in plasticity is usually accompanied by reduced potential for swelling. The addition of lime increases the soil pH, which also increases the cation exchange capacity. A change of soil texture takes place when lime is mixed with clay. Fly ash and fiber reinforcement in foundation also takes a vital role for stabilization of expansive soils, [4].

2.3.4 Soil replacement

Soil replacement is the simplest methods 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, [3]. 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, [2].

2.3.5 Structural Measures

The structural measures that should be undertaken in order to minimize or 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 are: spread footings, continuous footings, stiffened raft and bored concrete piles. The shallow foundations are modified to increase the bearing pressure so as to minimize heave. Some modifications have been provided include, [2]:

- 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, and
- increasing the reinforcement around the perimeter and into the floor slab to stiffen the foundation

3. Research Methodology

The research methodology which has been followed to achieve the ultimate goal of the study is conducted by field and laboratory investigation. Some cases of existing houses in Khartoum state were selected to assess their damages. The case study was carefully selected to provide rich information on expansive soils problems to lightweight buildings. The research focused on evaluating damages that occurred on some houses in Khartoum state in order to come out with the possible causes and practical remedies. Primarily the study based on recorded information, field investigation and laboratory tests.

3.1 Project Description

Khartoum is the capital and largest city of Sudan. Khartoum state is composed of three towns, Khartoum; Khartoum North; and Omdurman. The three towns are located around the river Nile and its two main branches, Blue Nile and White Nile in a triangle shape. Recently, construction developments are concentrated in areas extensively covered with expansive soils. The study area in this work includes most regions of Khartoum state where expansive soils are dominantly found, namely Almenshia in Khartoum (KH), Shambat and Alshabia in Khartoum North (KN) and Alarda in Omdurman (OM), shown in Figure 2.

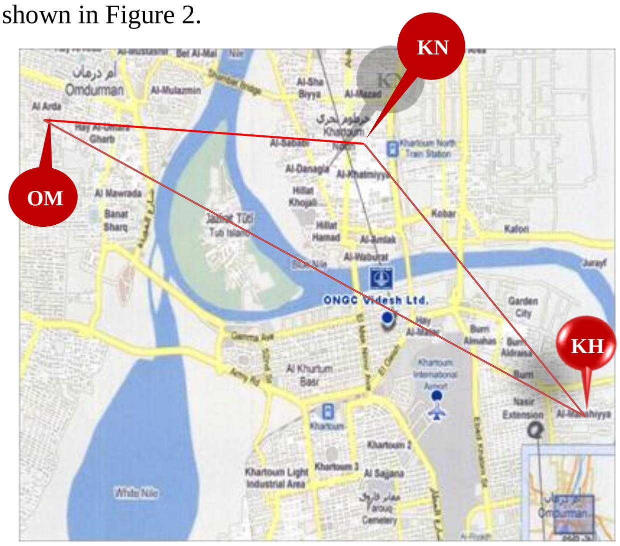

Figure 2 The project location in Khartoum state

In Khartoum state, most of the residential buildings are low rise buildings which are susceptible to damage caused by expansive soils. These buildings are mainly constructed from hollow concrete blocks, brick or masonry walls. Only few buildings are high rise or tall buildings. Most of the dwellings of Khartoum, particularly in expansive soil areas 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.

Ten randomly selected houses in the three towns of Khartoum state. The houses are located at Almanshia (three houses) in Khartoum; Shambat (three houses) and Alshabia (two houses) in Khartoum North; and Alarda (two houses) in Omdurman. The selected houses for the study were built in relatively small areas about 300 to 400 m2. Most of the studied houses (seven houses) are single storey buildings while the remaining are two-storey buildings. The houses are mostly built using masonry or hollow block concrete for load bearing walls or partition walls of reinforced concrete frame. The buildings are supported on reinforced concrete pad or strip foundations.

3.2. Records Review

A detailed record Review was conducted to obtain some information about the design and construction of the project. The documents contain information data about the building history, structural design, construction materials information and specifications, previous maintenance records, and other relevant information such as soil investigation reports, and temperature, weather or rainfall data. These collected data are very important for both the field survey task and the evaluation of building failures.

3.3 Field Investigation

The field investigation program includes site visits to the ten houses locations, interviews and structured questionnaire to have more information. A considerable amount of time was devoted to an arranged number of site visits in the case study sites to ascertain the visible prevailing conditions. To back up the site visits, visual inspections and studies of construction details of the buildings were carried out. The aim of visual inspections was to observe different factors affecting the foundation structures, identify construction type and materials, defects and signs of movement. Indicators of soil movement such as diagonal cracks in the walls, sticking doors and windows and cracks in the floors were identified. In addition, representative soil samples were collected from pitholes that excavated in each site.

3.3.1 Site Reconnaissance

The field investigation started with the site reconnaissance in order to collect information about the house construction and how the failure occurred from the owners to assess in investigating the source and reasons of failures. For each selected house the required data was first collected by conducting physical observation. This task has the following three major components: (i) Identifying construction material of each component of the building, (ii) Careful observation and analysis of extent of damage in each building element, and (iii) Studying surface drainage and ground water table conditions. The second task was interviewing house owners or contractors who had been participating in construction of buildings or people directly involved during the construction period.

3.3.2 Inspection of Distresses

A visual inspection was conducted for each house in order to examine the extent of damage, identify possible causes and evaluate the structural defects in the superstructure members. A questioner was prepared so that properly organized and consistent data could be collected during assessment of the selected houses.

It was observed that most of the surveyed houses of single storey buildings of masonry or hollow block concrete load bearing walls and supported on strip foundation, suffered much damages than the two-story buildings that supported on reinforced concrete pad foundations. One possible explanation for this could lie in the fact that the single storey buildings which exert downward pressures lower than the amount of upward ground pressure exerted by the swell soils.

The most common exterior damage was to the fence walls. Most of the surveyed houses, the fence walls are supported on strip foundation at a shallow depth. It was clearly observed that the walls nearby gardens are much suffered serious cracks due to the adverse effect of garden watering, shown in Figures 3 and 4. Cracks were vertical, horizontal or diagonal, and almost always through the mortar joints between bricks. Cracking were from hairline to more than 20 mm in width. In some cases the whole wall was separated, as shown in Figure 4.

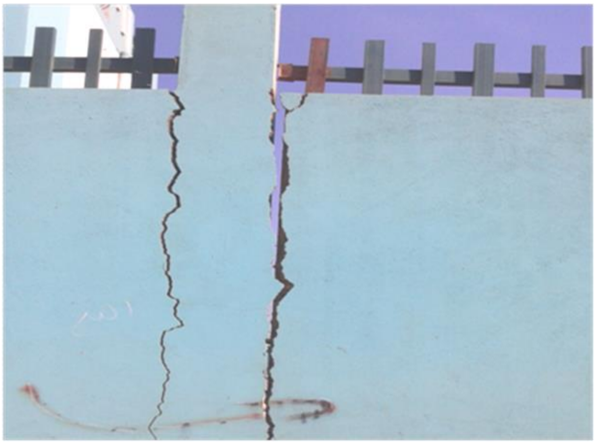

Figure 3 Sever vertical cracks appeared at the joint between column and masonry wall of the fence

Figure 4 Severe and deep cracks appear in the exterior walls of the building

The roots of big trees grown adjacent to the building resulted in settlement of the foundation wall around the corner of the building as shown in Figure 5. Also severe cracks and damages were seen in the exterior walls of the building due to water leakage in wastewater pipes occurred at the front part of the building and near bath rooms.

Figure 5 Foundation wall partially settled around the corner due to trees nearby the building

The building internal walls as well as floors much suffered from serious cracks. It was observed that the cracks are generally diagonal at approximately 45° occurred above and below windows and above doorways. Movement of the walls had distorted door and window frames. The major type of damage observed in the houses is severe cracks around corners of doors and windows and reduction in wall height due to sinking of foundation. However; the extent of damage in the internal walls ranges from minor to severe cracks in different direction as shown in Figure 6.

Figure 6 Serious cracks around window in the interior wall

Floor damage caused by expansive soils is evident in most houses, shown in Figures 7 and 8. In these figures, it was observed that floor heave caused uneven level of the ceramic tiles and serious cracks appear on the slab. The floor heave resulted in difficulty in opening doors and windows as clearly seen in Figure 9.

Figure 7 Floor heave resulted in considerable difference in level about 5.5 cm

Figure 8 Heaving of interior floor causing cracking of slab

Figure 9 Doors not properly close or open due to movement of floor

Damage to concrete perimeter foundations caused by differential heave of the foundation soil ranged from minor hairline and 1 to 2mm cracking to much larger cracks with anywhere from 50-100 mm of separation and significant lateral offsets, as shown in Figure 10.

Figure 10 Severe cracking in concrete perimeter wall showing exposed reinforcing

3.4 Experimental Work

To investigate the causes of failures occurred in the studied houses, laboratory testing was carried out. For each building, an open pithole of 2m depth was excavated in the vicinity of the building. The pits were excavated manually using pick-axes and shovels. Disturbed soil samples were collected, packaged and transported to the laboratory of soil mechanics in university of Khartoum.

Physical and index properties, and swelling characteristics were determined on the soils by following relevant procedures. The test results are given in Table 2. The foundation soil is classified as high plastic clay of high expansiveness.

Table 2 Geotechnical properties of soils tested

Soil Property	Location of Soil Sample			
	Almanshya	Shambat	Elshabia	Alarda
Clay Content, % (<2μ)	65	69	58	46
Liquid limit, %	79	87	75	57
Plastic limit, %	20	24	28	19
Plasticity index, %	59	63	47	38
Free swell index, %	190	220	180	90
Swell Pressure, kPa	72	95	64	55
Degree of expansion	High	Very High	High	Moderate
Soil classification	CH	CH	CH	CH

4. Results and Discussion

Based on the field survey and soil investigation as well as thorough study of relevant documents such as working drawings and drainage patterns of the area, the following study findings were presented and discussed in the coming paragraphs.

4.1 Observations and Comments

The exterior walls of fences, masonry or hollow concrete blocks walls of 30 cm thick suffered extensive cracking due to differential heave. Most of these walls are located adjacent to gardens of big trees. The garden watering is the main cause of soil heave that created uplift pressures greater than the walls weights leading to wall movements and severe cracking.

The field work and laboratory tests have shown soil profiles of the studied houses. Tested soil samples from the project sites have been found to meet the diagnostic criteria for expansive soils. Laboratory tests of the clay-sized fraction, liquid limits, plasticity index, and swell reflect expansive potential due to the presence of clay minerals. From Table 2, the samples have liquid limits in the range 57% to 79%, plasticity index 38% to 59%, clay content (fracture >2μ) 46% to 69% and free swell 90% to 220%. It is observed that the soil obtained from Shambat has very high expansion while Alarda soil shows moderate expansion. The most expansive stratum is located at the depth of about 1 meter from the ground which is thought to be the active zone. The soils in Khartoum state can put forth upward swell pressure of about 45 kPa, which is greater than the average downward pressure of about 40kPa exerted by most of the single-storey buildings.

It was found that a considerable number of lightweight buildings are built so cheaply by low income urban dwellers with inadequate sources of finance, thus resulting into damages whose repair may be not possible or cost effective and replacement was the only viable option.

Many of the structural problems originate from improper design or construction, insufficient foundations and weak or inadequate materials triggered by the swelling soils. Other factors influencing the degree of damages include the climatic conditions, age, poor drainage and wet spots around the foundations, and neglected maintenance of the buildings. Taken together these factors underlying building damages are not mutually exclusive. The main challenge for any inspector is to investigate technically which one of these is predominant in any particular case.

4.2 Possible Causes of Damages

Based on the study results and available literature, the main causes of damages or failures in buildings founded on expansive soil areas are attributed to some factors such as climatic changes, poor drainage, presence of gardens nearby buildings, damaged water pipes and improper foundation design.

4.2.1 Climatic changes

Seasonal changes in rainfall were 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 study results and observations indicated 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.

4.2.2 Poor drainage

Improper drainage is probably the most important factor contributing to soil volume change and subsequent damage to buildings. If water is allowed to stand in drainage ditches close to buildings, it can penetrate down and amplify heave, [4]. The main causes of poor surface drainage can be considered include: 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; and slope of surrounding area.

4.2.3 Presence of gardens nearby buildings

Existence of lawns and gardens with fast growing trees in the vicinity of the building may cause cracks in walls due to expansive action of roots growing under the foundation. Roots of some trees generally spread horizontally on all sides in the effective zone of the foundation soil when trees are located close to a building, [19].

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 0.5 to 1 times their mature height from the structure. To minimize the effect of big trees roots, moisture barriers should be put in place to cover the effective zone of foundation soil, [19].

4.2.4 Damaged water pipes

Shallow water 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. 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 foundations could occur when excessive water is present due to site leakage at the edges of the structure, [1].

4.2.5 Improper foundation design

Assessment of foundation design sheets and reports showed that there no any consideration for checking the safety of building against uplift pressures. 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 expansive soil heave can be properly addressed by considering the situation during the design phase and providing detail drawings for house builders.

4.2.6 Construction with low quality materials

The use of low quality materials for construction adversely affects the performance of the building. This sometimes occurs in the form of the improper concrete mixture, and poor foundation of low bearing capacity. The use of substandard materials for building construction and wall plastering will affect structural performance. These materials may accelerate deterioration of the building and often result in cracking, low strength, shortened service life, or some combination of these problems. Designers have come to rely on modern structural materials. However, manufacturing or fabrication defects may exist in the most reliable structural materials, such as standard structural steel sections or centrally mixed concrete.

Conclusion

This study has been undertaken to investigate the causes of building damage. The findings and conclusions drawn as follows:

- The buildings in the case study area exhibit high variations in type and quality of construction ranging from cheap traditional materials to modern imported ones. While the effects of expansive soils predominate in the lightweight buildings. Light damages were observed in multi-storey buildings because they are to some extent constructed of sound materials heavy enough to prevent swelling pressures and their foundations are beyond the active zone.
- All the tested soils satisfied the expansive soil criteria and have potential expansion rating from 'moderate' to 'very high'. The soils contain swelling clay content more than 30%, have plasticity index exceeding 30%, free swell more than 90%, and swelling pressure in excess of 55kPa, which is greater than the pressure exerted by most of the lightweight footings almost 45kPa.
- The experience of constructing buildings in Khartoum state without appropriate measures or with underestimation of the design and construction on swelling soils has led to damages of the structures.
- This study has helped identify the expansive soils and associated problems in buildings. It provides some mitigation measures to prevent structural damages originating from the behaviour of expansive soils.
- It was pointed that understanding the causes of building damage will significantly contribute to the proper selection of effective repair technique results in prolonged service life of buildings and significant savings for the owners.
- The experience of the investigator is an important factor in correctly diagnosing the building failure causes and determining the best repair technique.
- The study has the potential to improve the safety of the communities by assisting homeowners in promoting proper design, positive construction and maintenance altitudes.

- Most of the damages caused by expansive soils are due to poor construction and lack of timely maintenance by the homeowners and are in most cases preventable, yet the communities have insufficient knowledge about the features and behaviour of the expansive soils.

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