UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

INVESTIGATION INTO THE CAUSES OF CRACKS IN BUILDINGS IN THE BOLGATANGA MUNICIPALITY

A CASE STUDY OF SABON ZONGO AND DAGMEW AREA OF THE UPPER EAST REGION OF GHANA

RUDOLPH KWAO TETTEHTSU

7101190008

2016

UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

INVESTIGATION INTO THE CAUSES OF CRACKS IN BUILDINGS IN THE BOLGATANGA MUNICIPALITY

A CASE STUDY OF SABON ZONGO AND DAGMEW AREA OF THE UPPER EAST REGION OF GHANA

RUDOLPH KWAO TETTEHTSU

(1NDEX NO: 7101190008)

A DISSERTATION IN THE DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, FACULTY OF TECHNICAL EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, UNIVERSITY OF EDUCATION, WINNEBA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF TECNOLOGY EDUCATION (CONSTRUCTION) DEGREE

JULY, 2016

DECLARATION

I Rudolph Kwao Tettehtsu, declare that this Dissertation, with the exception of quotations and references contained in the published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for any another degree elsewhere.

…………………………...   ………………….………

SIGNATURE   DATE

DECLARATION BY SUPERVISOR:

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

SUPERVISOR: DR. PETER PAA KOFI YALEY

…..………………..……….   …………..……………

SIGNATURE   DATE

ACKNOWLEDGEMENT

I first and foremost wish to express my heartfelt gratitude to the Almighty whose protection and guidance has brought me this far.

I also, owe a continuing debt of thanks to my supervisor; Dr. Peter Paa Kofi Yaley, whose numerous supports, criticisms, guidance and encouragement has brought this work to a reality.

Again, my profound gratitude goes to all the lecturers of the Department Of Design And Technology Education for their diverse inputs that has led to the successful running of this programme.

The author will like to seize this same opportunity to express his appreciation to Mr. Nyarko Daniel Osei; a Laboratory Technician of Ghana Highway Authority, Bolgatanga for his unflinching assistance in carrying out the field and laboratory test enabled me to have my research conducted at the two project sites.

Finally, my thanks go to all my colleagues for the high sense of cooperation they have exercised throughout the duration of this course.

DEDICATION

This dissertation is dedicated to my son; Abednego Tettey Kwao for him to grow to become a very responsible person in life. May he live longer to see the beauty of God"s love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1. ACI 503R: America concrete institute
2. BRE: Buildings RESEARCH ESTABLISHMENT
3. B.S: British Standard 2028 (1968)
4. DAS: District Assemblies
5. DCPT: Dynamic Cone Penetrometer Test
6. EWC: Elastomeric Wall Coatings
7. GREDA: Ghana Real Estate Developers Association
8. MPA: Municipal Planning Authority
9. QA: Quality Assurance
10. Q.C Quality Control/Circle

ABSTRACT

The real world is not static, coupled with movements in building, there is a potential for cracks to occur in building. It is essential that all building have adequate capacity to enable the foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement. It was against this background that the study investigated into the various causes of cracks in the buildings at Dagmew and Sabon Zongo Residetial areas of the Upper East Region of Ghana. Soil investigations coupled with several laboratory analyses were performed. The soil testing includes the DCPT while laboratory testing includes organic content testing and clay compatibility. Soil samples for the selected project sites were also obtained for the laboratory testing program. The study revealed that the causes of cracks in buildings in the study area are due to a combination of factors including incorrect design, poorly prepared foundation footings among others are the crucial factors that cause cracks in the buildings of the study area. There is also evidence that the cracks are caused by the expansion of clay dominated soils when they get wet. While the causes of cracks at Sabon-Zongo are more of structural issues that of Dagmew are more of soil conditions such as the expansive and compatibility nature of the soil characteristics. The results of the study support the conclusion that that faulty and poor quality work is the critical factors causing failure of building in the study area. The study recommend that building owners should identify the symptoms, understand the possible causes of the defects and carry out timely repair and maintenance works to keep their buildings in good structural condition. The Municipal Assembly through the Committee on Environment is also encouraged to enforce and implement policies on building regulations in the community.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Buildings play a very significant role in all aspects of human endeavor and it is against this background that shelter becomes one of the basic amenities in life. They are made up of a wide range of materials and could therefore be regarded as composite structures. Buildings are also classified into different categories and/or uses. Thus they could be classified according to the type of occupancy for example residential, mercantile, educational, assembly, factory, storage, business etc. as well as the type of materials and fire resistance of their elements or constituents. However, buildings in general, irrespective of the type or classification, render the following basic services to mankind: they provide security to the occupants, a place of rest/relaxation, recreation, protection against the elements of the weather such as solar radiant, wind, rain, winter, snow, and probably for aesthetic purposes.

In the vein of this, due consideration must always be given to everything that goes into the construction of buildings in terms of the design, quality of materials, the construction technology/method, workmanship, the effect of natural disasters and unusual loads if they are to have what is called structural integrity to stand the test of time as the importance of buildings cannot be overemphasized and which also means that their stability cannot be compromised.

Unfortunately, as technical characteristics of facilities and industrial processes have become increasingly complex, the potential for human error has not decreased (Feld & Carper , 1996). Thus as technology increases, construction deficiencies abound, leaving buildings with one defect or the other including serious or major cracks that put the stability of such structures at stake and consequently threats to lives. In fact, the issue of cracking in walls of buildings is a global phenomenon noticed many decades ago. Currently, the trend has become more alarming as this is associated with the proliferation of buildings in an attempt to accommodate the continuously increasing population growth. In attending to the problems of cracks, many authors and researchers have done a lot in identifying the various causes and the remedial measures as indicated in the chapter two of this report.

However, there is still much to be done in this regard since day in, day out we are confronted with diverse challenges in the construction industry in terms of cracks and their causal agents and effects. Hence, new lessons to be learnt every departing day once each challenge comes with its own consequences. Cracks in a building are like ailments in human body. The building gets weaker and weaker if the cracks are not treated properly. The cracks give an impression of faulty and poor quality work. Moisture penetrates through the cracks and deteriorates the external facade as well as the internal facade (Classification and Treatment of cracks in a building, 2010).

If the built environments are to serve their intended purposes, then the National Building Regulations, 1996 L.I.1360 and Quality Assurance and Control strategies must be seriously enforced to avert the various cracking defects that befall our buildings in service. This is a shared responsibility since an error made by one person can have immense devastating catastrophic implications (Feld & Carper , 1996).

1.1 Statement of the Problem

The popularity of sandcrete blocks and their extensive application as walling material in Ghana and other developing countries cannot be overemphasized. Sandcrete blocks, when properly produced, meet BS 2028 (1968) recommendations for density and compressive strength of structural masonry. Sandcrete block walls are usually not designed to support loads other than their own weight. However, one of the earliest warning signs of failure is often manifested by the formation of serious critical structural cracks long before the actual incident. Sometimes, there seems to be a single simple explanation for a failure, but failure usually results from a combination of conditions, mistakes, oversights, misunderstandings, ignorance and incompetence, or even dishonest performance (Feld & Carper, 1996)The recent structural collapses in Ghana at Achimota (Melcom shop), Kumasi (O.A Travels & Tours Terminal) and other places all over the world, have raised serious concerns that led to intensive and exhaustive studies into the resistance of all components of structures by many professional bodies and other individuals.

However, while significant research efforts have been devoted to steel and reinforced concrete, concrete framework and concrete masonry walls by Lyall and Colin (1991), Duncan, Derek and Roger (2003) and Lee (1987), there have not been much studies on sandcrete blocks walls and soil tests or investigations and thus leaving them to their fates. Not all, most at times, these blocks are molded by ordinary artisans without supervision by those with the technical know-how. Meanwhile, sandcrete block molding and laying form integral part of the built environment hence a technical activity/process which needs a lot of attention with regards to the type of sand, water, batching of materials, mixing, loading the machine, compaction, curing and the bonding. This phenomenon has left a lot of buildings with many pronounced cracks that are detrimental to their stability and human lives.

1.2 Research Objectives

The main objective of the study is to investigate into the various causes of cracks in the buildings at Dagmew and Sabon Zongo Residetial Areas of the Upper East Region of Ghana. Principally, the study seeks to:

1. Investigate the types of cracks predominant in the building at Dagmew and Sabon Zongo Residetial
2. Evaluate the various causes of cracks in the buildings at Dagmew and Sabon Zongo Residential
3. Examine whether there is any differences with regards to the cracks in Dagmew and Sabon Zongo residential areas
4. Examine the effects of cracks on the buildings, owners and the occupants
5. Suggest appropriate technical preventive and corrective measures that would aid in curbing the situation.

1.3 Research Questions

With reference to the objectives of the study, the following research questions were developed to guide the study:

1. What types of cracks are predominant in the buildings at Dagmew and Sabon Zongo Residential
2. What are the causes of cracks in the buildings at Dagmew and Sabon Zongo residential areas of the Bolgatanga Municipality?
3. What are the effects of these cracks on the buildings, owners and the occupants?

1.4 Significance of the Study

In general, the study would draw attention to some key causes of cracks in buildings which would be vital to all practitioners in the construction industry. Thus the report would enable the general populace to appreciate the various causes of cracks in buildings. The identification of the major causes of cracks in building in this study would help to develop a suitable repair guideline which would present design and performance evaluation concepts of both public and private building structures of regular configuration since Allen (2014) indicates that a suitable repair strategy can only be determined once the cause of the problem has been identified.

Thus findings from this study will provide firsthand information to major players in the construction industry including the Ghana Association of Building, Ghana Real Estate Developers Association (GREDA), the Ghana Institution of Builders, Ghana Institution of Engineers, Ghana Institution of Architects, Ghana Institution of Surveyors, Building and Civil Engineering Contractors Association, and the Government (Ministry of Works and Housing and Water Resources) to review and adjust policies on the construction of building projects. This is to ensure that the necessary management and execution practices are adopted in construction processes in order to ensure efficiency in the construction of projects to minimize the occurrences of cracks.

In the academia, the study would add up to knowledge as it would serve as source of information/literature for further researches in the area of cracks in building in the future. In other words, the study would significantly advance the frontier of knowledge in the construction industry by identifying the major causes of cracks in building. Specifically, this study would have implications for theory and practices. In relation to theory, the study would expand the theoretical arguments in relation to structural engineering by demonstrating how to bring science to engineering design in order to minimize structural defects in buildings. In relation to practice, the study would provide practical guideline as indicated to address cracks in buildings.

1.6 Scope of the Study

There are many different types of projects within the construction industry and these projects include building, civil, and industrial. Generally, this study focuses on the building construction industry in Ghana. Furthermore, Amevordzie (1997) notes that there are many different kinds of buildings and that each type is built to serve a specific purpose. Buildings are therefore classified into various types according to their use and the purpose they serve hence they are either domestic or public broadly. This study focused on the causes of cracks on both domestic and some public buildings such as school blocks, churches, shops/stores etc. in the Dagmew and Sabon Zongo residential areas of the Bolgatanga Municipality of the Upper East Region of Ghana.

Walls of buildings can be made of stone, clay and mud, timber, burnt clay bricks, concrete blocks, solid and hollow sandcrete blocks etc. but this study focused on only sandcrete blocks walls in the Dagmew and Sabon Zongo residential areas of the Bolgatanga Municipality of the Upper East Region of Ghana.

1.8 Limitations of the Study

Buildings are made of many components namely the foundations, floors, walls, lintels/beams, columns and roofs. Roofs can also be constructed from different types of material like concrete, tiles, sheets, etc. likewise the walls where they could be made of mud, adobe, wood, concrete, sandcrete etc. but attention was given to sandcrete block walls only because of time constraint. Also, the researcher would have preferred to cover a wider area other than only the Bolgatanga Municipality but due to the same time factor, the researcher could not go beyond.

1.9 Organization of Chapters

The dissertation is structured into six chapters. Chapter One is the introductory chapter. Chapter Two reviews related literature from the conceptual, empirical and theoretical perspectives. In this chapter, related literature on the causes of cracks in buildings as well as the best interventions in addressing cracks in buildings are reviewed.

The third chapter provides an in-depth explanation of the methodology of the study. It describes the study design, study population indicating the units of analysis, sample and sampling technique (methods of sampling), research instruments (data collection instruments including experiments, soil tests and investigations, site observations) and methods of data analysis (plan for analyzing the data obtained from the field). This chapter also gives a brief description of the tools used in undertaking the data collection.

Chapter Four presents the results while Chapter five gives focuses on the discussion of the findings. The discussion involves the possible implications of the findings using logical deductions in relation to the pertinent concepts discussed in the review of literature. Chapter six focuses on the summary, conclusions and recommendations. The major findings from the study are presented in this chapter as well as the management implications of the study, recommendations for management, and directions for further academic research. The recommendations would be based on the major findings arising from the study.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURE

2.1 Introduction

In this chapter, effort has been made to review the relevant literature related to the study. Thus the chapter critically presents the relevant literature on cracks in building. In reviewing the relevant literature for the study, the chapter draws on the previous work of structural researchers and building engineers, and practitioners to help enhance a unified conceptual and theoretical structural management framework suitable for the management of cracks in building in the construction industry. The literature is reviewed both from the conceptual, empirical and theoretical perspectives. Based on the research objectives of the study, the following themes are reviewed and discussed in this chapter:

i. Theoretical Frameworks
ii. Conceptualisation of Cracks in Building
iii. Types of Cracks in Buildings
iv. Causes of Cracks in Buildings
v. Technical Preventive and Corrective Measures that would Aid in Curbing Cracks in Buildings

2.2 Theoretical Frameworks

This section presents the theoretical analysis of the theories which are critical in addressing cracks in the building and construction industry. Thus this section discussed the theoretical assumptions and proponents under which this study was conducted. The structural contingency theory and the Terzaghi bearing capacity theory were used as the theoretical bases for the study.

2.2.1 Structural Contingency Theory

As structural designs and analysis techniques evolve, there is a need to more rationally assess uncertainties associated with building structures. In other words, it is necessary to gain a greater understanding of structural reliability within the building and construction industry as it relates to the safety and serviceability of building structures.

The structural contingency theory was coined by Lawrence and Lorsch in 1967 who argued that the amount of uncertainty and rate of change in an environment impacts the development of internal features in organizations. The structural contingency theory postulate that there is no a single best way to manage processes of organising while decision-making in different environments provide different antecedents (Luthans, 1976). In other words, the basic assumption of the structural contingency theory is that no single structure or structural type is optimal for all organizations. Instead, the structure that is most effective is the structure that fits certain factors, called contingencies. This Lex (2015) explains that the effectiveness of a structure depends on the degree to which it fits the contingencies.

Fundamentally, the application of the theory in this study is concerned with the rational treatment of uncertainties in structural engineering and with the methods for assessing the safety and serviceability of civil engineering and other structures. Beck, Chan, Irfanoglu and Papadimitriou (2009) argued that uncertainties exist in most areas of civil and structural engineering while rational design decisions cannot be made without modelling them and taking them into account. Many structural engineers are shielded from having to think about such problems, at least when designing simple structures, because of the prescriptive and essentially deterministic nature of most codes of practice. This is an undesirable situation.

Thoft-Cristensen and **Baker** (2014) supported the argument of Beck et al. (2009) by indicating that most loads and other structural design parameters are rarely known with certainty and should be regarded as random variables or stochastic processes, even if in design calculations, they are eventually treated as deterministic.

Therefore, in highly volatile industries including the building and construction industry, the importance of giving project site managers at all levels the authority to make decisions over their domain while managers are made free to make decisions contingent on the current situation is paramount in enhancing project efficiency.

The structural contingency theory provides a foundation on which to prepare for and to minimize the magnitude of structural disruptions in buildings. The theory is built on the premise that an outcome (in this case, cracks) is a "fit" or result of the application of multiple factors.

2.2.2 Terzaghi Bearing Capacity Theory

According to Prasad (2014), Karl von Terzaghi was the first to present a comprehensive theory for the evaluation of the ultimate bearing capacity of rough shallow foundations. Terzaghi bearing capacity theory states that a foundation is shallow if its depth is less than or equal to its width. However, according to Braja (2007), later investigations, have suggested that foundations with a depth, measured from the ground surface, equal to 3 to 4 times their width may be defined as shallow foundations.

Major assumptions in the theory according to Terzaghi (1943) include:

i. Depth of foundation is less than or equal to its width

ii. Base of the footing is rough.

iii. Soil above bottom of foundation has no shear strength; it is only a surcharge load against the overturning load

iv. Surcharge up to the base of footing is considered

v. Load applied is vertical and non-eccentric.

vi. The soil is homogenous and isotropic.

vii. L/B ratio is infinite

Prasad (2014) therefore critiqued Terzaghi bearing capacity theory on the following basis:

i. The theory is applicable to shallow foundations

ii. As the soil compresses, increases which is not considered. Hence fully plastic zone may not develop at the assumed

iii. All points need not experience limit equilibrium condition at different loads.

iv. Method of superstition is not acceptable in plastic conditions as the ground is near failure zone

In spite of the limitations, this study used the Terzaghi bearing capacity theory based on the fact that the theory takes into account the weight of spill and the effect of soil above the base of the foundation on the bearing capacity of soil. These attributes are very critical in investigating the cracks in buildings (Numan, 2015)

Conceptualisation of Cracks in Building

Whether at a macro or a micro level, materials respond to changes in their environment by trying to move. According to Lyall and Colin (1991), cracking is the result of the overstressing of materials due to one or more movements in the elements/components of the building as a result of externally applied loads, restraint of internal moments, vibrations, chemical changes, physical changes and moments in soils.

Roberts (2010) also noted that cracks are an indigenous, undesirable feature in buildings that results from wear and tear or construction defects. This defect may also result from expansion and contraction of soils, vibration, wind, snow loading and overloading and impacts. This Allen (2014) argued that **c**racking is an inevitable response to the inability of a structure to accommodate the movement to which it is subjected.

According to Maharajpur (2004), a building component develops cracks whenever the stress in the components exceeds its strength. Stress in the building component could be caused by externally applied forces, such as dead, live, wind or seismic loads; foundation settlement etc. or it could be induced internally due to thermal movements, moisture changes, elastic deformation, chemical action etc. Thus generally, cracks can occur due to chemical reactions in construction materials, changes in temperature and climate, foundation movements and settling of buildings, environmental stresses like nearby trains, earth quakes etc.

2.3 Types of Cracks in Buildings

According to Archicentre Technical Information Sheet (2012), cracking can be vertical, horizontal, cogged, stepped, or a combination. The form it takes is sometimes a clear indication of the problem. The cracking pattern is influenced by many factors, including the relative strength of the joints and the masonry units, the presence of openings or other points of weakness, the degree of wall restraint, and the cause of the cracking itself (Think Brick Australia, 2013).

2.3.1 Vertical crack

An equal width crack found at the corner of a building typically means there is pressure in the building where there is perhaps expansion or contraction from the outer wall causing a pushing movement and a vertical crack. There isn't a single reason for a vertical crack, it could also be in a building where there is a weakness between two large windows but it is not necessarily the only answer (1st Associated, 2010).

2.3.2 Diagonal cracks

Anand (2014) described diagonal cracking as an inclined crack that begins at the tension surface of a concrete member. Steep diagonal cracks appear in concrete foundation due to point loads that exceed the compressive strength of the concrete. This type of failure, known as settlement, can happen due to volume changes in clay soils due to fluctuation in their water content, increased pressure on a portion of the foundation, or long term consolidation of compressible clay under the foundation. If the soil under the footing cannot stand the compression force from the weight of the foundation and house/building, then the structure will sink and any adjacent walls that are adequately supported will resist this movement.

2.3.3 Stepped crack

This type of crack occurs in the mortar joints or separation along interface of mortar and unit. It rarely occurs in unit. Direction of crack alternates horizontally and vertically. Length of separation, condition (sagging or slippage) of structural supporting elements (Eschenasy, 2013).

2.3.4 Structural cracks

Structural cracks are those which result from incorrect design, faulty construction or overloading and these may endanger the safety of a building and their inmates (The Constructor, 2014). The Constructor (2014) further identified two types of cracks in buildings namely: Structural and non-structural cracks.

2.3.4.1 Nonstructural cracks*:*

They occur mostly due to internally induced stresses in building materials. These cracks normally do not endanger the safety but may look unsightly, create an impression of faulty work or give a feeling of instability (The Constructor, 2014).

2.3. 5 Shrinkage crack:

This type of horizontal cracks due to evaporation of moisture from the concrete surface in ambient air is created. And when the evaporation rate of the concrete surface is very high, high evaporation rate within the concrete and plastic shrinkage cracking of type is created. This type of concrete cracks depend on several factors including temperature, ambient temperature, relative humidity of air, sun and wind, steam velocity inside the concrete mix and water cement ratio (Kashyzadeh & Kesheh, 2012).

2.4 Causes of Cracks in Buildings

More often than not, most faults or failures in buildings first show in crack(s). Also, almost all failures or perceived failures generate extensive controversies and/ or arguments and in some cases litigations; all in an attempt to pin down the cause(s) and the culprit.

Sometimes, there is a single simple explanation to/for failure but usually, failure results from a combination of conditions, mistakes, oversights, misunderstandings, ignorance and incompetence or even dishonest performance (Feld & Carper, 1996).

2.4.1 Design Errors

Design errors have contributed to many of the failures that occur in buildings and these include: errors in design concept, lack of structural redundancy, failure to consider a load or a combination of loads, deficient connection details, calculation errors, misuse of computer software, detailing problems, including selection of incompatible materials or assemblies that are not constructible, failure to consider maintenance requirements or durability, inadequate or inconsistent specifications of materials or expected quality of work and unclear communication of design intent. Deficiency in the basic design of a structure such as amount of reinforcing steel at points of maximum moment or incorrect dimensions of concrete or steel sections to provide sufficient resistances for normal loading is a rare cause of failure (Feld & Carper, 1996)

2.4.2 Site Selection and Development Errors

Some failures often result from unwise land-use or site-selection errors. Certain sites are more vulnerable to failure than others. The most obvious examples are sites located in regions of significant seismic activity, in coastal regions, or in floodplains. Other sites pose problems related to specific soil conditions, such as expansive soils or permafrost in cold regions. Recognition of the characteristics of particular site conditions through appropriate geotechnical studies can lead to decisions about site selection and development that reduce the risk of failure. Unnecessary exposure to natural hazards is an unfortunate consequence of historic patterns of human settlement (Feld & Carper , 1996).

2.4.3 Construction Methods/Errors

The conditions under which construction takes place are often far from ideal and coupled with an emphasis on speedy completion, can result in careless and skimped work. Although the BRE study showed that only a small proportion of defects were attributable to faulty materials, it is apparent that some manufacturers of so-called high technology components have little awareness of the rigours of a building site or the standards of accuracy achievable under such conditions. Thus, whilst the materials may be perfect on leaving the factory, they can quite easily be damaged in transit, loading and unloading, unsuitable conditions of storage on site, hoisting and placing in position. Many of such defects could be avoided by ensuring greater care at all stages in the process, proper training of operatives and close supervision. To tackle this problem, the construction industry is beginning to introduce the quality assurance techniques developed in other industries such as Quality Assurance (QA) and circles (QC). Essentially, these techniques consist of setting down appropriate inspection procedures and specifying levels of acceptance and rejection together with methods of sampling testing the performance characteristics (Lee, 1987).

Failures can result from construction errors which may involve following: poor excavations, equipment failure, improper construction sequencing, inadequate temporary support, excessive construction loads, premature removal of shoring or formwork and nonconformance to design intent (Feld & Carper , 1996).

Duncan et al. (2003) also observe that, walls are sometimes constructed so poorly that they are inherently distorted. This can often be observed in older buildings but unfortunately, is found in some of recent constructions where walls can be seen to be out of plumb. Even though the wall may be distorted, it can still be stable and unless there is evidence of current progressive movement it is often acceptable to take no further action apart from monitoring at regular intervals.

2.2. 4 Soil Related Problems

Feld and Carper (1996) have it that, certain sites and specific soil conditions present extraordinary challenges. The more difficult sites include those with expansive soils, organic soils and contaminated soils. Fills frequently pose significant problems, requiring diligence during placement or construction. Numerous costly failure involve non-engineered fills, poorly engineered fills, fills containing organic materials and fills that are not carefully monitored during construction. Other challenging sites are those with permafrost conditions in cold regions and sites with large seasonal water content fluctuations or varying water table conditions.

2.2.4.1 Differential Settlement

This occurs where settlement takes place at differing rates under different parts or elements of a building or structure as a result of variations in loading and/or ground conditions. Alternatively, shallower foundations will be more susceptible to climate change, sub-soil shrinkage and the effect of trees or their removal. The effect is that the two parts of the building settle or move at different rates or even in opposite directions. Cracking will tend to occur at the interface between the two parts and these indicate that they are tending to slip or slide over each other (Duncan, Derek & Roger, 2003).

Poorer types of fill such as those containing organic matter or which were placed without control, are variable in their properties and are therefore liable to large differential settlements. They are also prone to large total settlements. Differential settlements are also likely to occur at the perimeter edges of filled areas and in places where the depth of fill changes rapidly (Lyall & Colin, 1991).

According to Obande (1985), uneven settlement of foundations may be due to traffic action or the nature of the subsoil. The soil may contain weak spots and when these are systematically compressed by the weight of the building, settlement occurs at these spots. This can lead to cracking of the blocks. Cracks of this nature emerge from below ground level and their remedy is often costly since it involves massive temporary structures i.e. supports to hold up the wall until the foundation is replaced.

Feld and Carper (1996) too reiterated that, all footings will settle when loaded and structural problems result when footings do not settle equally. Unequal settlement will occur unless soil resistances and load distributions are equal. Differential settlements can cause load transfer and tipping of the structure.

2.2.4.2 Settlement

This refers to the gradual downward movement of the ground or any structure on it due to the load applied by the structure (Duncan, Derek & Roger, 2003). In general, all soils will compact or consolidate i.e. settle in one way or the other on being loaded. The load on the soil, as applied through the foundation, increases both water and soil pressures. Water is squeezed from between the solid particles driven to areas where the water pressure is less. The soil particles, on the other hand, are forced closer together and consolidation continues until the water pressure has fallen to its original value and forces between the particles have increased by an amount that is equal to the newly applied load. Eventually the total settlement will be dependent on the type of soil and the load imposed upon it (Lyall & Colin, 1991).

Feld and Carper (1996) noted that the problem of settlement of a soil mass has two components: the initial settlement caused by deformation of the soil particles due to the weight of construction and consolidation settlement due to the expelling of fluid from the soil. Consolidation settlement is time dependent and for that matter can occur over considerable time in clay deposits of low permeability.

2.2.4.3 Subsidence

This is defined by Duncan et al (2003) as movement of the ground not caused by the imposition of building/foundation load.

Serious settlement may occur in those areas that suffer from mining subsidence. For this reason, local authorities and/or British Coal usually have records of areas where large settlements can be expected (Lyall & Colin, 1991).

Feld and Carper (1996) also documented that even without earthquake impulse, land masses are always rising or falling, usually at a very slow rate. Land subsidence is sometimes generated by human endeavors that change the natural conditions of the sub-soil.

2.2.4.4 Seasonal Movement

2.4.4.1 Introduction

A number of sub-soils are affected by seasonal change. This is due to seasonal variation between wet/cold and hot/dry weather. The extent to which a sub-soil is affected depends mainly on its water content. When a great amount of water is present normally in winter, the sub-soil will expand and conversely, it will contract when there is a reduction in water content normally in summer. The presence of trees and vegetation or their removal, can accelerate or exacerbate the effect of such changes (Duncan, Derek & Roger, 2003).

2.2.4.4.2 Frost Heave

This is a problem that can occur when the ground has a high water table or after a period of high rainfall. Water in the soil expands as it turns ice in cold weather. The effect upon the sub-soil is known as frost heave and it results in the ground expanding, primarily upwards. Sub-soils that can be adversely affected in this way include silts, fine sands and chalk (Duncan, Derek & Roger, 2003).

Lyall and Colin (1991) also confirm that expansion of soils can take place in any soil that is capable of holding water either within its particles or in voids between the particles. Soils mostly associated with frost heave are fine sands silts and chalks. Generally, it is not normal to anticipate expansion from freezing at a depth below 0.46m, although during severe winters in the UK frost may penetrate to a depth of 0.61m or so.

Frost action can increase the soil volume considerably. Ice lenses can continue to grow due to capillary action with the groundwater in soils with small pore space. When thawing occurs, large settlements may follow. Silt soils are more susceptible to frost heave than the other types of soil (Feld & Carper , 1996).

2.2.4.4.3 Shrinkable or Expansive Clay Soils

Clay soils are capable absorbing and releasing large amounts of water. However, not all clays do so. They range from firm clays with relatively low water content to shrinkable clays that contain high levels of water. The higher the water content of the clay, the more susceptible it is to climatic change and seasonal movement. Shrinkable clays can expand and/or contract by between 50mm and 75mm seasonally. They are also subject to greater initial settlement as water being squeezed out under a new building‟s load will cause the sub-soil to consolidate. In summer, shrinkable clay sub-soil will normally tend to contract due to reduction of water content and this is known as desiccation. This can be worse by presence of trees and shrubs that take up moisture through their roots. The resultant contraction of the sub-soil can lead to subsidence thus the building above will sag/move downwards. In such circumstances cracking will tend to be wider at the bottom rather than the top (Duncan, Derek & Roger, 2003).

Conversely, in winter and in periods of excessive rainfall, shrinkable clays will tend to expand as water content increases. The increase in volume of the clay leads to an effect known as heave and thus the building above will move upwards which is known as hogging. The effect is similar to frost heave as described previously but the cracks tend to be wider at the top and narrower at the bottom. The effects of seasonal changes in shrinkable clays can generally be avoided by ensuring that foundations are formed at a sufficient depth of at least 1200mm to avert the problems of subsidence and heave (Duncan, Derek & Roger, 2003).

2.2.4.4.4 Sub-soils Containing Organic Matter

The construction process requires the removal of all topsoil incorporating organic or vegetable matter. This is usually to a depth of 150-225mm across the whole area of the building. Normally, such removal will have disposed of all soil containing vegetable matter. However, certain deeper sub-soils, in particular peat that contains high levels of organic matter and water, may be unacceptable. Any applied load will compress such a material and result in movement of the building above. The effect of buildings on easily compressible sub-soil can be cracking within the walls and other elements of the structure as the inadequately supported foundations settle. Such settlement can be extensively and unevenly distributed around a building resulting in significant cracking with no discernible pattern (Duncan, Derek & Roger, 2003).

Feld and Carper, (1996) also affirm that the presence of organic deposits may be a significant problem in the sub-soil because they continually decay and thus construction of structures on these deposits is very risky.

2.2.4.4.5 Fills/Made-up Grounds

This type of fill usually contains a substantial amount of industrial, mining or domestic wastes. The constituents of the fill may vary considerably, as might the extent to which they have been compacted. In most cases, the fill is deep. In urban areas, relatively shallow fills occur where marshy lands have been reclaimed by raising the ground level and sites have been infilled with the ruble of demolished buildings or debris from construction sites. Nowadays, many existing docks are being filled. Fill that has large voids or materials liable to decay is especially hazardous. For example, refuse dumps may contain metal containers that rust and leave large voids and plastics containers which compress but do not decompose. Large settlement and for that matter, cracks may occur when organic matter breaks down (Lyall & Colin, 1991).

According to Feld and Carper (1996), soil is heterogeneous even under the most normal or favorable conditions hence, fills should be carefully examined for organic content. LePatner and Johnson (1982) noted that organic soils are potential sources of problems and for this reason, fills are potential sources of problems and also, fills with organic inclusions are double sources of problems that lead to serious cracks in structures.

2.2.5 Thermal Movement

The external walls are, by their nature, exposed to the elements and are therefore, subject to the effect of temperature changes. This often results in expansion and contraction of the wall. The exact amount of expansion experienced will depend on the materials used in the construction of the wall. In some cases, the excessive length of the wall or its detailing may influence the amount of movement. Usually, any expansion due to the effect of solar heat gain will be followed by contraction as the affected element cools down during subsequent climatic change. Unfortunately, the amount of contraction does not always equal the original expansion and the net result is permanent cracking. The cracking actually occurs during the cooling period of the cycle. It will also be found that the affected wall expands/contracts above any DPC – over which it tends to slide. This factor provides supporting evidence that the problem is caused by thermal movement. Thermal movement of other elements of construction can also cause problems due to the lateral pressures placed on adjoining walls as a result of expansion of roofs and floors (Duncan, Derek & Roger, 2003).

2.2. 5. Moisture Movement

Expansion and contraction of the fabric of a building can also occur because it is affected by moisture or subsequent drying out. The cause of the moisture may be weather-induced: rain, snow, dew, leakage, condensation or as result of the building process (Duncan et al., 2003).

2.2. 6 Natural Hazards and Unusual Loads

2.2. 6. 1 Seismic Events

Earthquakes are among the most terrifying natural hazards. The magnitude of natural forces associated with earthquakes, and the humanly limited ability to predict their occurrence, location and severity make them especially threatening to human life. Buildings that survive such tremors are left with one defect or the other including cracking. Much has been learned from experience with earthquakes and engineered buildings are now much better to cope with the effects of ground shaking than they were a few decades ago (Feld & Carper , 1996).

2.2. 6.2 Extreme Winds

According to Feld and Carper (1996), windstorms cause 350 deaths $4 billion to$5 billion damage to the built environment annually in the United States. Although the loss of life has been reduced by warning and evacuation planning, economic losses related to wind are escalating each year. Major damage is caused by the extreme winds associated with hurricanes and tornados. In addition, turbulent wind patterns in the dense urban environment, or in the vicinity of large buildings of complex configuration, hinder the use of public urban spaces and result in costly damage to the curtain walls of buildings. Structural damage resulting from storms of hurricane, tornados or typhoon intensity is to be expected, although these forces can be restricted by proper and well-known design procedures.

2.2. 6.3 Vibration and Blasting

Most people are familiar with natural causes attributed to foundation cracking such as earthquakes, wind, poor soil conditions, freezing and thawing cycles, tree roots, and moisture in the soil. Although vibrations caused by natural causes endanger structures, vibrations caused by man-made efforts may be troublesome as well. Common construction activities such as large equipment traffic, drilling, blasting and soil compaction produce ground vibrations which conceivably damage nearby buildings or homes. Demolition and new foundation work are common sources of vibrations that can cause an area effect. The tools and methods used in demolition and construction, such as pile drivers, jack hammers, wrecking balls, pavement breakers and rock blasting produce vibrations that may be transmitted to and can result in claims involving: exterior cracking of facades, interior cracking of walls, roof collapse / structural failure, pavement and foundation cracking (Sama, 2013)

Construction activities produce ground vibrations that can affect nearby structures and the soil that supports them. Construction activities such as pile driving, blasting, or breaking pavement can produce strong levels of vibration and are commonly cited as the cause of damage to nearby structures. Vibrations that are smaller in magnitude, such as those induced by traffic, equipment, and machines, may also cause damage under certain circumstances. Damage caused by construction vibrations is commonly architectural ("cosmetic") and results from non-uniform displacements imparted on the structure. Vibrations from construction activities can also be strong enough to cause settlement of the soil ("indirect" effect). Damage to existing structures resulting from excessive vibrations can range from cosmetic cracking in the walls to serious cracking that may compromise the structural integrity of the building (Sama, 2013)

The above agents of cracking in buildings have been tabulated by some of the authors as follows:

Generally, this chapter concludes that the two most important issues which must be considered in addressing the reasons for cracking are the nature and significance of the cause of movement as well as the ability of the structure to accommodate movement. The latter will depend on the nature of the material or, in the case of composite materials like masonry, the nature of the combination of materials used in the structure.

2.7 Technical Preventive and Corrective Measures that would Aid in Curbing Cracks in Buildings

The designer can try to prevent the occurrence and growth of cracks by allowing only moderate stress levels in the building. Proper design, selection and assembly of materials can eliminate most of the cracking problems report on job sites. Nonetheless, some cracking will still be reported (Cassidy, 2010).

2.7.1 Selection of materials

Stresses in building envelopes can be alleviated through proper selection and assembly of the building materials. Materials with low thermal expansion, low shrinkage and creep are preferred. Often, limiting the initial moisture content of lumber can prevent several future problems caused by shrinkage of the wood frame. Water vapor movement and water condensation can induce stresses and cause cracks, not only through shrinkage and expansion, but also via fatigue due to drying/wetting cycles. Proper design and location of the weather barrier and insulation can prevent occurrence of water condensation in critical areas for moisture cycling (Guru, 1997).

Usually cracks are brought to the attention of the architect after the homeowner complains to the builder, contractor or materials supplier. Often individual materials are first suspected as a cause of the cracking. This traditional attitude according to Guru (1997) is usually erroneous. In selecting the right materials, Dow Construction Chemical (2010) suggested that high-quality elastomeric wall coatings (EWC) applied at high film-build will bridge these inevitable concrete surface cracks and hide them from view. They also resist moisture, mildew, and dirt damage while maintaining an attractive, uniform appearance on the concrete surface.

2.7.2 Specifications for mortar and concrete: Gupta (2015) suggests that the ratio of the mortar and concrete should be according to the prescribed design. This meant that care should be taken so that the coarse and fine aggregates are free from silt suspended impurities while the mix should be homogeneous, well mixed and contain no excessive of water. Similarly to

Frew (2007), Gupta (2015) also suggested that characteristics of mortar should always be based on holistic evaluation of the building, which can then lead to the determination of performance requirements for the specific situation. Performance requirements cover a range of issues including the durability of the mortar, its ease of use and compatibility with original and/or other surviving historic materials.

2.7.3 Drawing and design of the building: While doing the construction work, care should be taken that foundation of the building should not be laid on loose /muddy soil. The mortar, M S steel reinforcement should be according to the design.

2.7.4 Good Construction practices: Cracks can sometimes be sealed, patched, or repaired by replacing the affected slab. These measures are useful options, but in many cases the cracking could have been prevented. Good pavement design and following best practices during construction will avoid a lot of problems. It is a lot easier to prevent crack problems in the first place, rather than trying to cure them once they are in your pavements (Pavement Interactive, 2012). This therefore means that it is necessary that work proceed uniformly in all part of building while the workmanship should be according to the prescribed norms and best practice in the building construction. Masonry work structure for example should be carried out in uniform levels at all parts of the structure to prevent differential settlement of foundation due to differential loading. This will prevent the cracking of masonry walls and also other structural elements (The Constructor, 2014).

2.7.5. Weather Effect: Weather is simply a reaction to changes in atmospheric pressure. These changes alter air movement, temperature, and humidity. Some changes are dramatic and produce violent storms. Other changes are subtle and have little effect on weather (Crissinger, 2005). The construction work should be avoided in very hot and dry weather and during very low temperature also. Weather conditions affect the design, construction, and performance of buildings.

2.7. 6 Injection of exposy: Cracks as narrow as 0.002 in. (0.05 mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures (ACI 503R). However, Thagunna (2014) argued that unless the cause of the cracking has been corrected, it will probably recur near the original crack. Epoxy injection requires a high degree of skill for satisfactory execution, and application of the technique may be limited by the ambient temperature.

2.7.8 Stitching: According to the Miller, Powers, and Taylor (1999), it involves drilling holes on both sides of the crack and grouting in U-shaped metal units with short legs (staples or stitching dogs) that span the crack. Stitching may be used when tensile strength must be reestablished across major cracks. The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non-shrink grout or an epoxy resin-based bonding system (Thagunna, 2014)

2.7.9 Overlay and surface treatments: Fine surface cracks in structural slabs and pavements may be repaired using either a bonded overlay or surface treatment if there will not be further significant movement across the cracks. Unbonded overlays may be used to cover, but not necessarily repair a slab. Overlays and surface treatments can be appropriate for cracks caused by one-time occurrences and which do not completely penetrate the slab. These techniques are not appropriate for repair of progressive cracking, such as that induced by reactive aggregates, and D-cracking

2.8 Conclusions

Generally, this chapter concludes by stating that cracks arise because the real world is not static. The two main reasons for movement in building are settlement and subsidence. Settlement occurs due to downward pressure while subsidence occurs due to the removal of earth beneath the foundations. Fundamentally, all building should have adequate capacity to enable the foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter provides an in-depth explanation of the methodology of the study. It describes the study design, study population indicating the unit of analysis, sample and sampling technique, research instruments (data collection instruments including experiments, soil tests and investigations, site observations) and methods of data analysis (plan for analyzing the data obtained from the field). The chapter also gives a brief description of the tools used in undertaking the data collection during the field and laboratory evaluations.

3.1 Background of the Study Area

3.1.1 Location of Project Site

Bolgatanga which was colloquially known as Bolga, is a Municipality located in the center of the Upper East Region and the Regional Capital. The Upper East Region, where Bolgatanga lies, is part of what was used to be known as the Upper Region. Between 1902 and 1960, the Northern Territory, which was then a British protectorate, has been separated into the Northern and Upper Region on 1st July, 1960. The Upper Region was further apportioned into Upper East and Upper West Region in 1983 during the PNDC Rule. The people of Bolga are called Gurene and they speak Gurene which later became “Frafra” when the Europeans who went to the place decided to call the people of Bolga “Frafra” (Ghana District Repository, 2006).

The Bolgatanga Municipality has a total land area of 729 km^2 and is bordered to the North by the Bongo District, to the East by Nabdam District, to the South by Talensi District and the Kassena-Nankana East Municipality to the west. There are about 213 communities in the Municipality. The major economic activity of the people is craftwork, which includes; straw baskets, hats, fan, leather works and smock, locally called "Fugu" (District Profile, the Planning Unit of the Bolga Municipal Assembly, 2009). Figure 3.1 shows the geographical location of the Municipality.

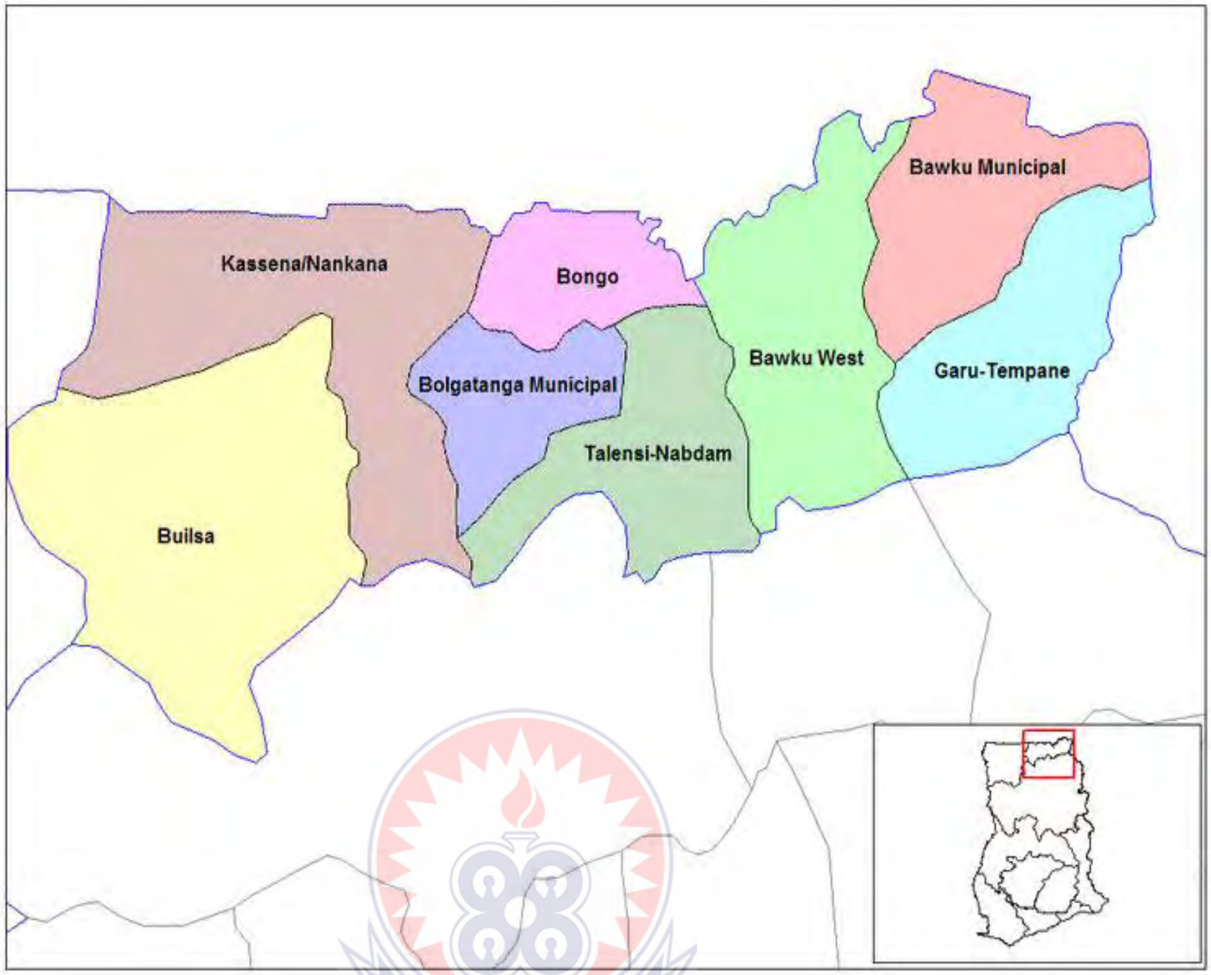


Figure 2: Map of the Upper East Region showing Bolgatanga Municipality

Source: Bolgatanga Municipal Assembly

3.1.2 Population

The Municipal in general has a population of 131,550. This according to the Ghana Statistical Service is made up of 62,783 males and 68,767 females (Ghana Statistical Service, 2010 Population and Housing Census).

3.1.3 The Site: Description of Buildings on Site

As indicated earlier, two sites were selected for the project, one in Sabon Zongo and the other in Dagmew community, all within the Bolgatanga Municipality.

Most of the structures in both Sabon Zongo and Dagmew communities are made up of sandcrete and a few mud houses. Majority of the houses have developed cracks in the walls.

3.1.4 Topography of the Area

3.1.4.1 Topography of Sabon Zongo

The Sabon Zongo site is on a gentle hill with undulating surface having some exposed rock outcrops. The site has poor drainage systems. The natural drainage condition of the site is generally poor but does not experience flooding when there is a heavy rainfall in the municipality.

3.1.4.2 Topography of Dagmew

The investigative site is fairly flat and lying in a low land area. The site has poor drainage systems. The natural drainage condition of the site is generally bad and it floods anytime there is a heavy rainfall in the municipality

3.1.5 Geology of the Site

3.1.5.1 Geology of Sabon Zongo

The geology of the building site is made up of reddish brownish sandy decomposed sandstone interlaced with clayey silt. Some locations of the site have exposed sedimentary rocks. The general soil profile in the area varies with locations.

3.1.5.2 Geology of the Dagmew

The geology of the building site is made up of dark grey clayey overburden soil lying on clayey gravelly soil. The general soil profile in the area is more or less uniform.

3.2 Research Approach: Concurrent Triangulation Strategy

Research approach is a research framework around which data are collected and systematically organized in relation to the research questions and objectives. An assessment of the study"s research questions and objectives gives a clear indication that using a mixed design (combining both qualitative and quantitative approaches) was necessary because of the wide range of data needed to develop effective crack management frame work in the building and construction industry. In this study, the concurrent triangulation strategy which involves conducting qualitative and quantitative phases at the same time was used to reduce the amount of time required to the relevant collect data.

According to Jennifer and Mihas (2013), the term, "mixed methods" usually refers to contexts in which a researcher collects, analyses, and integrates both qualitative and quantitative data and methods within a single study. Thus mixed methods research is an approach to enquiry that combines or associates both qualitative and quantitative forms. Reviewing the philosophical foundation of the mixed research design, Creswell (2009) indicates that mixed methods research involves philosophical assumptions, the use of qualitative and quantitative approaches, and the mixing of both approaches in a study.

Specifically, integrating quantitative and qualitative research methods in this study was relevant to discover the multi-level mechanisms relevant for the management of cracks in buildings. The integration of the mixed research approach in this study further provided a trade-off between the breadth and depth of the field data. Figure 3.2 illustrates the topology of the research approach adopted in this study.

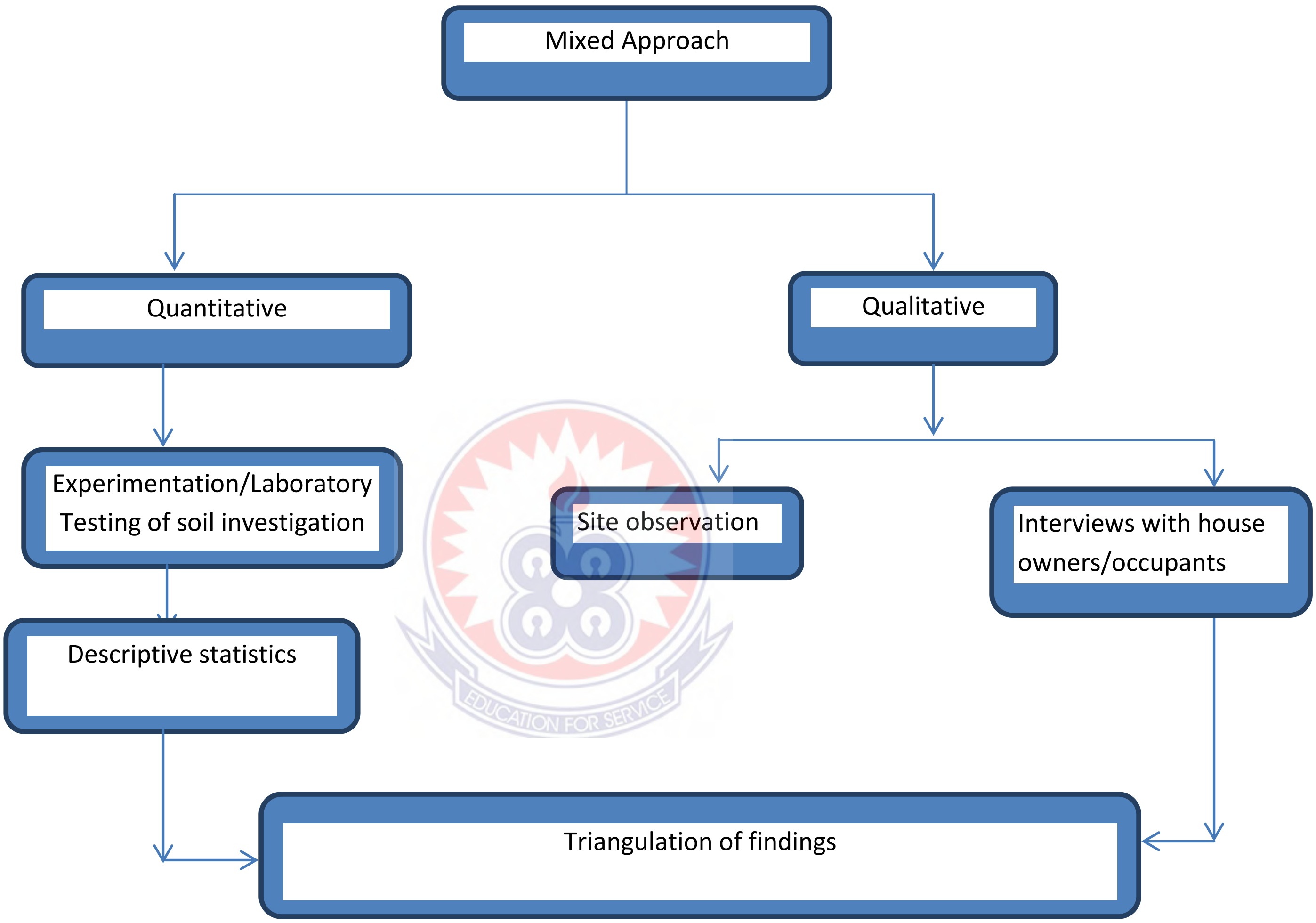


Figure 3.2: Detailed topology of the research approach

Source: Researcher Construct, 2014

Generally, employing both qualitative and quantitative approaches increased the comprehensiveness of the overall findings, by showing how the qualitative data provided explanations for the statistical data (experimental data) which is expected to increase the methodological rigour as findings in both phases were checked for consistency.

3.3 Study Design

The success of every research is dependent on the research design employed. Every component of the research methodology is informed by the design. A research design represents a blueprint of a research project, or a framework to guide data collection and analysis (Malhotra & Birks, 2003). Research design according to Kothari (2005) is a way to systematically solve the research problem. It comprises the various steps that are adopted in studying the problem.

Generally, the choice of a research design depends on the research problems and objectives. In this regard, a descriptive survey design was used. Descriptive survey is a research design that specifies the nature of a given phenomenon, by determining and reporting the way things are. According to Best and Khan (1998), descriptive design is concerned with the conditions or relationships that exist, such as determining the nature of prevailing conditions, practices and attitudes; opinions that are held; processes that are going on; or trends that are developed.

Descriptive survey is used as the research design for this study because it involves observation, description and documentation of aspects of a situation as it naturally occurs. To deeply study the causes of cracks in building involves fact-finding, observation and situation analysis in coming out with the key causes of cracks as well as the best techniques to control them. In other words, the survey design was deemed very appropriate because it helped probed into details the real situations on the ground to justify the adverse effects of the cracks on the functional and economic life of the buildings and the occupants within the case study area.

The use of the survey design also helped to generalise specific observations on the predominate cracks in buildings in the municipality as well as developed specific perditions from general principles regarding cracks in buildings in the municipality. Additionally, descriptive survey is considered the most appropriate for this study on the basis of its advantages of economy of design, the rapid turnaround in data collection and the ability to identify attributes of the population from a sample derived from that population.

3.3.1 Target Population

The study population involved different units of analysis such as the Engineer of the Bolgatanga Municipal Assembly and owners and occupants of cracked buildings. This involved key informants from the Works Department of the Municipal Assembly. To determine the effects of cracks on the buildings, owners and occupants of the selected buildings were also included in the study.

In relation to the buildings, this study included only buildings with various types of cracks. This meant that buildings without cracks were exempted from the study.

3.3.2 Sampling Techniques and Sample Size

Purposive sampling technique was adopted in the sampling of the key informants. The purposive sampling method was used to sample the Municipal Engineer as well as the occupants and owners of the selected buildings. In all hundred owners/occupants of selected buildings with cracks and the Municipal Engineer were sampled. According to Seidu (2006), purposive sampling helps to select only those variables that relate to the objectives of the study. In this study, the Municipal Engineer and the owners of the buildings were deemed the most appropriate to respond to the study because they have the knowledge/expertise of the phenomenon under consideration and for this reason; their views were deemed vital as far as this research was concerned.

The convenient sampling method was used for the selection of the buildings in identification of the types of cracks in the buildings. This meant that buildings which were conveniently located for assessment were included in the sample.

3.4 Data Collection

Data gathering is crucial in research, as the data is meant to contribute to a better understanding of the research (Bernard, 2002). Interview schedules and observational manual were used in the collection of the relevant qualitative data. Laboratory experiment of tested soils was the methods employed in the collection of quantitative data.

3.4.1 Sources of Data

Two main sources of data were used for the research report. They are the primary and the secondary data. The primary data included data gathered by the researcher through site surveys/visits, observations, situation photographs, interviews and laboratory testing. The primary data collection method provided original data directly from the study population and un-biased information; although the method was time consuming in gathering data.

Secondary data on the other hand was obtained through desk based research using library research of books, journals and other publications on causes of cracks in buildings. The used of secondary data in this study helped make the primary data collection more specific since with the help of secondary data, the researcher was able to make out what are the gaps and deficiencies and what additional information needed to be collected.

3.4.2 Data collection techniques

3.4.2.1 Site Surveys: Field Observation

Field observation is common methods for qualitative data collection, originating from ethnographic studies to sometimes check or confirm results obtained from sources such as interviews and questionnaires. As part of identifying the types and causes of cracks in buildings in the municipality, field observations were used. Specifically, the observation focused on the likely foundation constraints while analyzing the significance and impact of the constraints and making recommendations for design of foundation to support existing and new structures.

The method offered the researcher access to structural data that would have otherwise being difficult to collect. Additionally, the method served as a means of gathering data on constructional issues, as data can be collected first hand in a natural setting (Redmond & Griffith, 2003).

3.4.2.2 Interviews:

In this study, the researcher used semi-structured interviews to collect data from the Engineer of the Municipal Assembly, occupants and owners of the building survey.

Interview with the Engineer of the Municipal Assembly was to help determine the requirement for constructing buildings in the municipality in terms of eliminating structural cracks. Also, the interviews with the occupants was to gather data about the deforming condition of the structures in which the dwell. The effects of structural maintenance annually on owners in terms of cost were the focus of the interviews with house owners.

Semi-structured interviews are a data collection method that is usually conducted face to face between the interviewer and the participants allowing the researcher to control the process, and allowing freedom for respondents to express their thoughts (O'Leary, 2004). In this study, open-ended interview questions were used in order to acquire information related to the research topic. The researcher then probed using additional questions. These probes differed somewhat from participant to participant.

The interviews were tape-recorded with the permission of all the participants and supported with notes taken by the researcher. Each interview lasted average for 15 minutes. This eliminated the boredom often associated with long interviews such as interviewee fatigue.

3.4.2 Laboratory investigation

3.4.2.1 Soil Investigation

This mainly comprised of in-situ samples and sampling program, laboratory test on particle size distribution, Atterberg limits test determinations.

The foundation soils strength of the ground were investigated by probing with the German type dynamic cone penetrometer made to the specification of DIN 4094. Thus the soil investigation consisted of performing Dynamic Cone Penetrations Test (D.C.P.T). The purpose of the soil investigation was to assess the soil load bearing capacity and deformation characteristics which may impose restriction on the design and construction of new and existing buildings in the study areas. This enabled the variation of the soil strength with depth to be evaluated. In other words, the in-depth of the foundations of the buildings were tested using the DCPT for site investigation in support of analysis and design. During the exercise, a cone penetrometer was pushed quasi-statically into the ground.

The DCPT was performed by dropping a hammer from a certain fall height and measuring penetration depth per blow for each tested depth. The DCPT was used based on Wumharn and Johnson (1993) assertion that it is a quick test to set up, run, and evaluate on site. Due to its economy and simplicity, better understanding of DCPT results can reduce efforts and cost for evaluation of pavement and subgrade soils.

The following apparatus with specifications stated below were used in undertaking the soil investigation:

Weight of hammer	-	10kg
Height of fall of hammer	-	500mm
Cone diameter	-	24mm
Cone surface area	-	$6.4cm^2$
Cone apex angle	-	90^0

Specifically, the following tests were performed in undertaking the DCPT:

i. The first step of the test was to put the cone tip on the testing surface

ii. The lower shaft containing the cone was moved independently from the 5 reading rod sitting on the testing surface throughout the test

iii. The initial reading is not usually equal to 0 due to the disturbed loose state of the ground surface and the self-weight of the testing equipment. The value of the initial reading was counted as initial penetration corresponding to blow 0

iv. The hammer blows were repeated while the penetration depth was measured for each hammer drop

v. This process was continued until a desired penetration depth is reached. DCPT results consist of number of blow counts versus penetration depth

vi. A total of Ten (10) probes were sunk and in each test position, the number required to penetrate 10cm rod was noted and recorded for various depths and plotted as a function of depth

vii. Since the recorded blow counts are cumulative values, results of DCPT in general are given as incremental values defined as :

PI= (2.1)

where PI = DCP penetration index in units of length divided by blow count; ΔDp = penetration depth; BC = blow counts corresponding to penetration depth ΔDp.

As a result, values of the penetration index (PI) represent DCPT characteristics at certain depths

In order to run the DCPT, the researcher employed another operator since two operators are generally required. While the other person drops the hammer, the researcher records the measurements.

The dynamic cone penetrometer has been calibrated such that the ultimate bearing capacity (Q_{ult}) was obtained from the following relationship;

$$Q_{ult} = 30\,r \ (kPa)$$

Where;

Q_{ult} = Ultimate bearing capacity

r = the no. of blows required to advance the cone by 10cm

3.4.2.2 Experimentation: Lab Testing

For the purpose of soil classification, identification and quantification of clay in the soil, a number of laboratory tests were carried out. These tests include natural moisture content, particle size distribution and Atterberg limits. Some of the results from the tests were also used to determine the activity, plasticity, and the swell pressure of the clay arithmetically.

Samples recovered from the trial pitting were subjected to Gradation, Atterberg limit and natural moisture content test.

The laboratory tests were to determine various subsoil conditions in order to come out with specific findings and measures in relation to the causes of cracks in buildings. Specifically, the lab tests were undertaken to:

1. Determine the thickness and characteristics of the soils present at the site location and the influence of groundwater (if any) on substructure construction and post construction.
2. Describe the general support characteristics of the foundation soil
3. Determine the nature and conditions of the subsoil and assess its suitability to support the load of the existing structures.
4. Give recommendations for the purposes of evaluating suitable foundation type, depth, size among other measures in substructure

In summary, the following specific steps were undertaken during the soil investigation as well as the lab testing

- Planning the details and sequence of operations
- Collection of soil samples from the field
- Conducting all field tests for determining the strength and compressibility characteristics of the soil
- Study of ground water level conditions and collection of water samples for chemical analysis
- Testing in the laboratory of all samples of soil, rock, and water
- Preparation of drawings and charts
- Analysis of the results of the tests

3.4.2.3 Organic content analyses

This test was performed to determine the organic content of the soils in the two project sites. The organic content was determined as the ratio of the mass of organic matter in a given mass of soil to the mass of the dry soil solid expressed as a percentage. This test was so relevant to the study since organic matter influences many of the physical, chemical and biological properties of soils including the soil structure, soil compressibility and shear strength. In addition, it also affects the water holding capacity, nutrient contributions, biological activity, and water and air infiltration rates. The following equipment were used for the organic test

i. Muffle furnace
ii. Balance
iii. Porcelain dish
iv. Spatula
v. Tongs

Furthermore, the following procedures were performed in undertaking the organic test:

i. Determining and recording of the mass of an empty, clean, and dry porcelain dish (
ii. Placing a part of or the entire oven-dried test specimen in the porcelain dish, determining and recording the mass of the dish and soil specimen (MPDS).
iii. Placing the dish in a muffle furnace and leave the specimen in the furnace overnight
iv. Determining and recording the mass of the dish containing the ash (burned soil) (MPA)

In analysing the results from the organic test, the following were done:

i. Determining the mass of the dry soil from the site

ii. Determining the mass of the burned soil

iii. Determine the mass of organic matter

iv. Determine the organic matter (content)

3.5 Ethical Issues

Social research needs to pay attention to the main ethical issues of informed consent, intrusiveness, confidentiality and anonymity. As a consequence, a researcher needs to have high standards of personal and professional integrity (Tannor, 2014). Respondents for this study were ethically treated in two ways: Informing participants of their role in the study and maintaining confidentiality and anonymity during the research process.

To guarantee anonymity of responses and easy identification of house owners and occupants" identity numbers were randomly assigned to each building. Additionally, to obtain permission regarding ethical concerns from the heads of the buildings as well as the Municipal Engineer, an introductory letter from the University was obtained and sent to the respondents. This letter introduced the researchers as a student of the University on academic research assignment and should be given the needed assistance.

3. 6 Method of Data Analysis

After the field study, both written and recorded materials were immediately transcribed to English. The actual analysis of the qualitative data began with reading through the transcribed responses and listening to the audio records in order to have a good grasp of all the data. The key idea and emerging themes were identified from all the respondents. These themes were then pooled together and integrated into a common one. Thereafter, there was the generation of concepts for ease of organising the presentation of the study findings.

Generally, the qualitative analysis involved the categorisation of data from interviews and field notes into common themes. Specifically, the following steps were taken in analysing the qualitative data:

i. Read and review field notes;
ii. Writing of notes in reviewing of field notes and transcripts;
iii. Coding of the data: Identify common thematic area: The patterns and common themes that emerged in responses dealing with specific items;
iv. Coding of the data;
v. Check whether or not there are deviations from the patterns and common themes that emerged;
vi. Interpret the data by attaching significance to the themes and patterns observed;

The soil investigation data as well as the results of the laboratory tests were subjected to statistical analysis using Excel. Tables and graphs were used to present the results.

CHAPTER FOUR

RESULTS AND PRESENTATION

4.0 Introduction

The results of the data analysed and the discussion of the findings are presented in this chapter in accordance with the research objectives and questions. The results in this chapter are presented in two major headings including the qualitative and quantitative findings, while the next major section presents a discussion of both the qualitative and quantitative findings.

4.1 Qualitative Findings

This section presents the findings emanating from the qualitative data gathered during the field observations and interviews with the key informants. The qualitative analysis involved the categorisation of the data from field observation and interviews, and field notes into common themes.

4.1.1 Types of cracks

This section explored the types of cracks which are prevalent in the municipality. The section basically focused on the outcome of the observational data from the study.

The major type of cracks in the buildings observed from the two project sites was vertical cracks. Photocredit one to three shows the nature of the vertical cracks in the buildings studied.



Figure 4.1 **Figure 4.2** **Figure 4.3**

Source: Field survey

The cracks in these building foundation walls were visible as vertical hairline openings (less than 1.6mm wide) in the right hand foundation wall, above grade and inside the basement. Within a year, the owners reported several times that the cracks were becoming noticeably wider. In Figure 4.3, it is observed that the cracks have been patched/filled with concrete at some point. However, it looks like the filled concrete has been sanded down to smooth it out, so it"s really hard to tell how wide the cracks actually are. A careful inspection of the buildings" interior suggested that the front foundation wall and portions of the right foundation wall were settling. However, there were no corresponding cracks in the finished surfaces of the structure, probably because these were very stiffly-framed modular construction.

Further interviews with the owners of the building suggest that the cracks and foundation movement were probably due to a combination of:

i. Poorly prepared foundation footings

ii. Shallow placement of foundation/footings, and possibly

iii. Omission and improper fixing of steel reinforcement in walls, floors, beams and lintels.

In other words, the owners were basically attributing the cracks to errors in structural designs.

Although not significant, the horizontal types of cracks were also identified among a number of buildings in both project sites as illustrated in Figure 4.4 and 4.5.

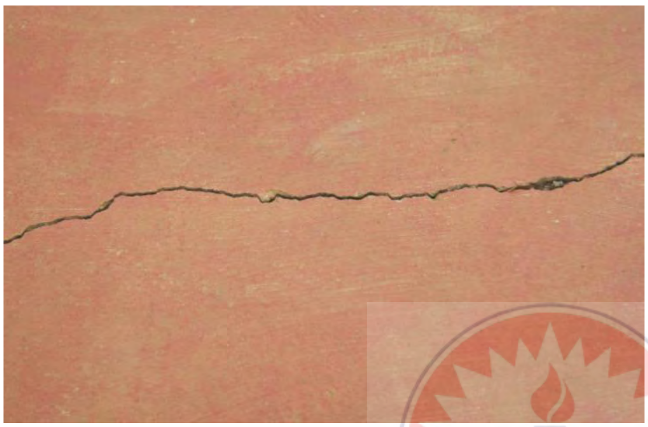


Figure 4.4: Horizontal cracks

Figure 4.5: Horizontal cracks

Source: Field survey

Figure 4.4 and 4.5 show horizontal cracks in walls about 5-15mm wide and 2 and 0.5m up the walls which span the entire length of the walls and which is an indication that they might be caused by frost or the expansion and contraction of clay based soils when get wet and dried. In other words, this is an indication that moisture and or/water pressure is causing inward deflection of the walls thereby causing failure. Further observation shows that, water drainage towards the foundation had caused an excessive hydraulic load while the lack of provision of drainage systems and aprons to the wall has increased the hydraulic load against the wall over time.

In Sabon Zongo, there were also few instances of diagonal cracks that begin at the tension surface of concrete members, most of which appeared above openings which is an indication of improper fixing or lack of steel reinforcement and inadequate beam/lintel bearing or clearance and in concrete foundation due to point loads that exceed the compressive strength of the concrete. According to (Duncan, Derek & Roger, 2003), any beam or plank lintel requires adequate support at each jamb and that lack of bearing will result in crushing of supporting structure by loads imposed.

4.1.2 Causes of Cracks in Buildings Expert point of view

This section tried to complement the experimental and soil investigation of the research question 2 which sought to explore the major causes of cracks in buildings from the perspective of the key experts.

Interviews with the Municipal Engineer shows that generally, the causes of the cracks in the buildings in the municipality are basically due to the lack of adherence to building regulations and legislation on the part of the various developers thereby resulting in structural design and operational errors**.** The Engineer complained:

> *"Although the building regulations demands that any prospective developer need to produce a geotechnical/soil investigation report duly signed by an engineer for a building of a three-storey size upwards and that an individual produce four copies of structural drawings duly signed by a qualified engineer, most of these persons ignored that and just get anybody at all to put up their building "*

Further analysis also shows that many people are not adhering to these regulations due to the lack of education and enforcement. An important point noticed from the Municipal Engineer is the fact that even in instances where there is approval for building structural designs; some house owners usually appeared to deviate from the original plan during construction.

The observation analysis also shows that most of the cracks in the Dagmew were more of as a result of the low land nature and the expansive nature of the clays. On the other hand, most of the causes of the cracks from the Sabon residential area were due to structural and operational errors. This one of the occupants mentioned:

"There are errors in most design concept resulting in the lack of structural redundancy"

4.1.3 Effects of cracks on the buildings, owners and the occupants

This section examined the resultant effects of cracked buildings among the key occupants, owners and on the building itself.

From the house owners interviewed, the major effect of cracks relates to the repair and maintenance cost. This meant that structural problems can cost tens of thousands of cedis to repair, as one of the house owners stated:

> Yes, you can spend several amount of money repairing the same position over and over. Sometimes I wonder whether the best alternative is to pull down the building

The interviews with the Engineer of the Municipal Assembly show that the rate of cracking in buildings in the municipality is alarming and that some house owners are not ready to invest in good structural constructions. The Municipal Engineer stated:

> Some of the cracks affect the structural safety or stability of the buildings while most of them are localized and non-structural in nature. Building owners or occupants should always be aware of the condition of their buildings.

A major effect of the cracks in buildings on the occupants is the constant fear and panic. From the interviews, it was gathered that sometimes especially during rainy seasons with turbulent storms when there are heavy movements of the buildings; occupants‟ safety is limited in the buildings with the cracks. One of the owners of the building narrated:

> Some few years ago, residents in my neighbor‟s building fled from their homes one Friday night after large cracks suddenly appeared in the structure, which have been widely attributed to some turbulent rain storms.

However, an interesting phenomenon observed was the fact that although some of the occupants lived in fear and panic in such cracked buildings, the difficulty of obtaining an alternative shelter constrained them thereby focusing to remain in them. One of the occupants of a vertically cracked building in the SABON ZONGO project site lamented**:**

> As I cradled my baby, I was always scared for our safety in this building but had nowhere else to go.

4.2 Quantitative Findings

The results of the quantitative data from the laboratory experiments and soil investigation are presented in these sections in relation to the research questions of the study. In other words, the section presents the results of the soil investigation including the compatibility and organic test as well as the allowable bearing capacity figures.

4.2.1 Soil investigation

This section presents the results of the various laboratory and soil tests conducted**:**

4.2.1.1 Compatibility test results

In relation to the soil sampling, ground water was not encountered at a depth of 2.0m during the field exercise. However, it is envisage that at a depth of 3.5m, ground water might be encountered at some locations.

The first trial pit sunk at the western part of the site revealed the following ground conditions;

Table 4.1: First trial pit at western site

Stratum	Thickness (m)	DCP 'N' estimation of Bearing Capacity
Loose to Dense reddish brown sandy decomposed sandstone	1.5	1362 KN/m^2

The second trial pit was sunk at the eastern part of the site and it revealed that, the ground has the following conditions

Table 4.2: Second trial pit at eastern site

Stratum	Thickness (m)	DCP 'N' estimation of Bearing Capacity
Firm to stiff brownish sandy clayey silt	2.0m	1656 KN/m^2

In relation to ground succession, the trial pit sunk at the site revealed the following

Table 4.3: Ground succession

Stratum	Thickness (m)	DCP 'N' estimation of Bearing Capacity
Soft to firm light grayish sandy silt clay	0.50	110 KN/m^2
Firm to stiff dark Grey silt Clayey	1.0	267KN/m^2

Test performed on disturbed soil samples taken proved that the overburden soil is fairly uniform and made up of expansive clayey silt. Ground water is expected to be encountered within 2.5 to 3m depth below ground level.

In actual fact, the field investigation proved that, beyond 3m depth of overburden soil would be competent. Also, considering the nature of the Dagmew area, coupled with the fact that the existing soils are capable of expanding and contracting, foundations are to be placed at a deeper depth other than the prototype depth of 0.6 to 0.9m being used. Again, the underlying soil exhibits medium to high plasticity properties.

4.2.1.2 Organic content analysis

Table 4.5 shows the calculation of the results of the organic content soil laboratory test and the respective analysis

Table 4.4: results of organic content test

Specimen	Units (grams) Sabon Zongo	Units (grams) Dagmew area
MP = Mass of empty, clean porcelain dish	23.20	23.20
MPDS = Mass of dish and dry soil	35.29	0.13
MPA = Mass of the dish and ash (Burned soil)	34.06	35.00
MD = Mass of the dry soil	12.09	1
MA = Mass of the ash (Burned soil)	10.86	11.80
MO = Mass of organic matter	1.23	5.13
OM = Organic matter, %	10.17	30.3

Calculations:

$$MP = 23.20g, MPDS = 35.29g, MPA = 34.06g$$

$$MD = 35.29 - 23.20 = 12.09g$$

$$MA = 34.06 - 23.20 = 10.86g$$

$$MO = 12.09 - 10.86 = 1.39g$$

$$O = \left(\frac{1.39}{12.09}\right) X100$$

$$O = 10.17\%$$

Generally, an organic content of 10.17 percent was obtained for the soil from Sabon Zongo project site.

Using the same calculation procedure as illustrated for the Sabon Zongo, an organic content of 30.3 percent was obtained for the Dagmew project site. This meant that the organic content of soil in the Dagmew site is 20.13 percent higher than that of the Sabon Zongo. The high organic content of soil from the Dagmew project site could be explained by the fact that the area is a low land area and with poor drainage systems which carry all manner of debris.

4.2.2 Allowable Bearing Capacity

This section presents the results from the DCP Test across the various depths. The section presented the descriptive statistical analysis for each of the depths including the average depths across the ten locations. In this section, attempts were also made to compare some elements of peculiarity of the developments (cracks) with respect to the case study areas i.e. Dagmew and Sabon Zongo Residential Areas of the Bolgatanga Municipality.

Table 4.6 shows the descriptive statistics on the allowable bearing capacity for soil samples of various depths for the Sabo Zongo site.

Table 4.5: Descriptive statistics in DCP Test (Sabon Zongo)

Depth (cm)	Allowable Bearing (kN/m^2)			
	Mean	Minimum	Maximum	Standard Deviation
10	678	570	870	106
20	627	480	810	98
30	558	390	660	94
40	492	360	660	100
50	573	450	780	98
60	667	540	810	112
70	768	570	1020	153
80	828	540	1110	172
90	858	720	1110	151
100	853	100	1140	309
110	993	720	1170	132
120	987	240	1350	311
130	1113	780	1380	192
140	1233	1080	1410	108
150	1263	1050	1440	127
160	1365	1230	1500	96
170	1473	1350	1650	90
180	1569	1500	1680	84

Source: Computed from DCP Test Results

Table 4.6 shows that the largest allowable bearing was noted for the largest depth (Depth 180, allowable bearing= 1569.00) with a standard deviation of 106 and 83.74 respectively. On the other hand, the least allowable bearing was noted for depth of 40 cm (allowable bearing = 492.00). Generally, penetration depth of 70 cm and beyond consistently had their corresponding allowable bearing capacities being increased. An assessment of the standard deviation also shows that the variability in allowable bearing seemed to reduce after a depth of 140 cm. Figure 4.5 further shows the graphical view of the various allowable bearing across the various depths at the Sabon Zongo project site

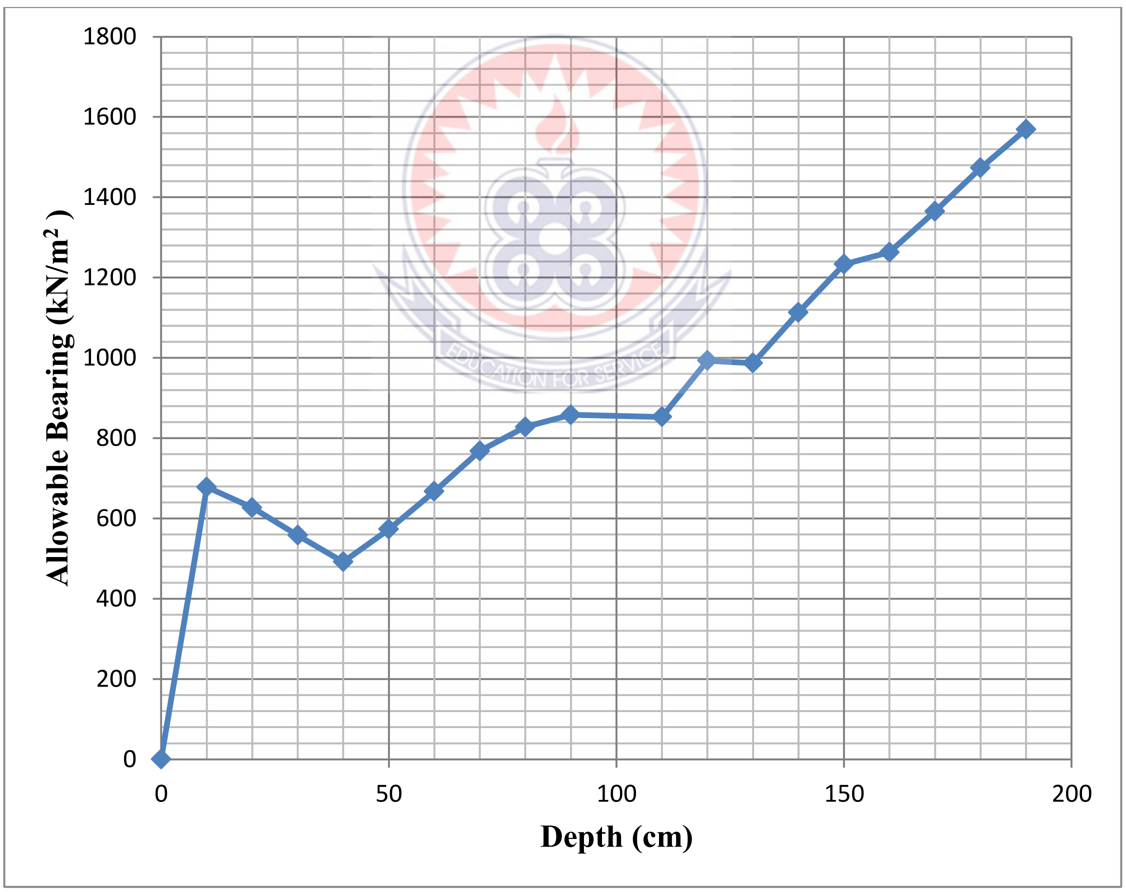


Figure 4.6: Allowable bearing at Sabon Zongo project site

Source: Computed from DCP Test Results

Figure 4.5 shows a positive correlational link between the depth of penetration and the corresponding allowable bearing, although there are some marginal reductions along the line. The allowable bearing capacity of Dagmew project site was also analyzed with the descriptive results shown in Table 4.6

Table 4.6: Descriptive statistics in DCP Test (Dagmew project site)

Depth (cm)	**Allowable Bearing (kN/m^2)**			
	Mean	**Minimum**	**Maximum**	**Standard Deviation.**
10	60	30	120	21
20	54	30	90	36
30	72	30	120	30
40	75	30	120	36
50	111	60	180	46
60	156	60	240	62
70	183	90	240	73
80	195	90	330	86
90	243	120	360	85
100	267	180	420	86
110	276	180	480	116
120	333	270	540	104

130	354	210	420	116
140	390	300	600	107
150	402	300	540	106
160	456	330	540	114
170	522	360	690	223
180	572	330	840	138

Source: Computed from DCT Test Results

The allowable bearing capacity for Dagmew project site is smaller at the smallest depth while the opposite is seen for the largest depths. For example, the allowable bearing capacity at a depth of 180 cm (Allowable bearing capacity = 57260) was 512 larger than the allowable bearing capacity at a depth of 10 cm (Allowable bearing capacity = 60). Figure 4.6 gives a clear picture of the result in Table 4.6

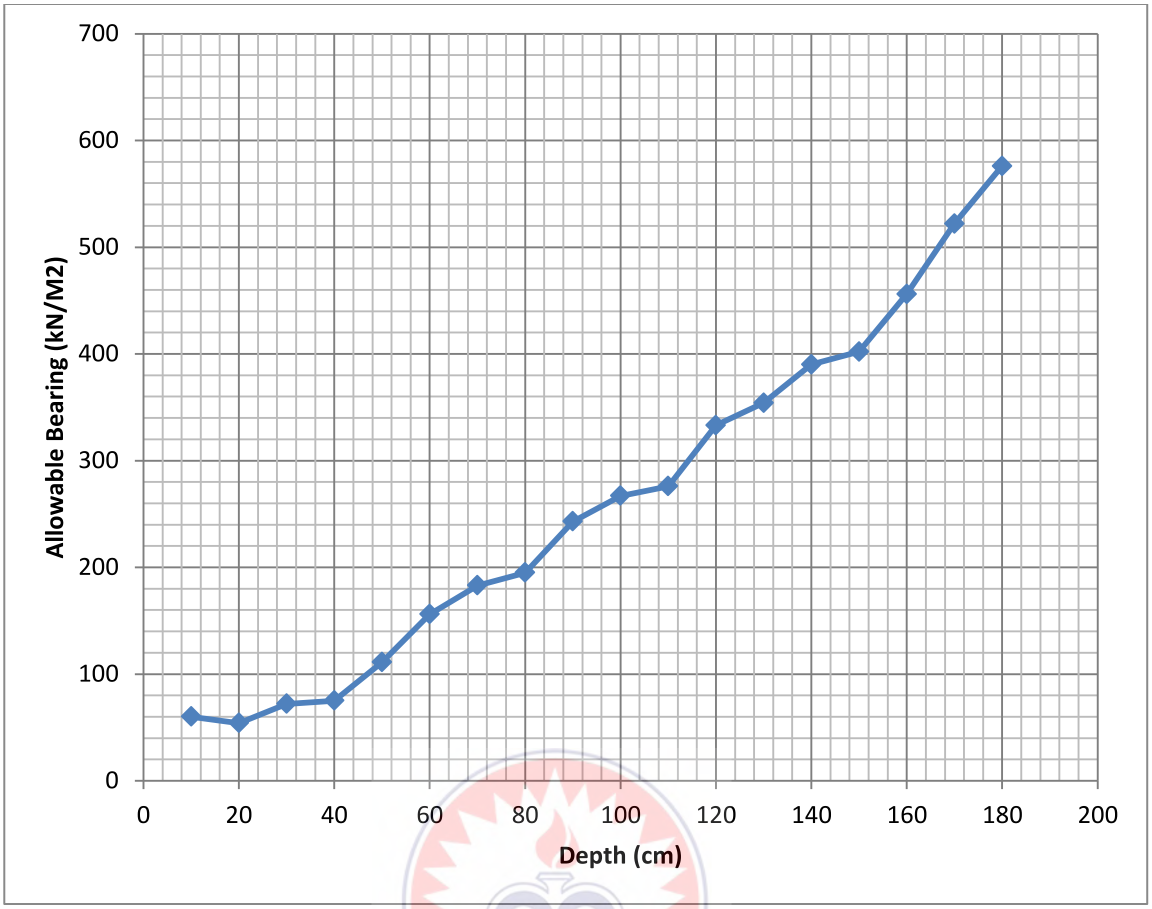


Figure 4.7: Allowable bearing capacity across various depths at Dagmew and Sabon Zongo project sites

Source: Computed from DCP Test Results

A trend analysis of Figure 4.6 shows that the allowable bearing capacity tends to move in a positive direction with the depth of penetration.

4.2.2.1 Comparative analysis of Allowable Bearing across two sites: Sabon Zongo and Dagmew Residential Areas.

This section compared the allowable bearing capacity for the two residential sites for the study. In this regard, the average allowable bearing capacity was noted for each of the sites across the various depths

Table 4.7: Descriptive statistics in DCP Test (Sabon Zongo and Dagmew)

Depth (cm)	Average Allowable Bearing	
	Zongo	Dagmew
10	678	60
20	627	54
30	558	72
40	492	75
50	573	111
60	667	156
70	768	183
80	828	195
90	858	243
100	853	267
110	993	276

120	987	333
130	1113	354
140	1233	390
150	1263	402
160	1365	456
170	1473	522
180	1569	572

Source: Computed from DCP Test Results

Generally, it is noted that the bearing allowance for all the depths in Sabon Zongo far outweighed that of the bearing allowance for Dagmew. For example, at a 10 cm depth, an allowable bearing capacity of 678 was recorded for Sabon Zongo while at the same depth, only 60 allowable capacity was noted for Dagmew. In other words, at a 10 cm depth, the bearing capacity at Sabon Zongo was 616 kN/cm more than the bearing capacity at Dagmew. In a similar vein, at 180 cm, an allowable bearing capacity of 1569 kN/cm was recorded at Sabon Zongo as against allowable bearing of 572 at the same 180 depth for Dagmew. Figure 4.7 illustrates the graphical view of the allowable bearing capacity across the two sites of study.

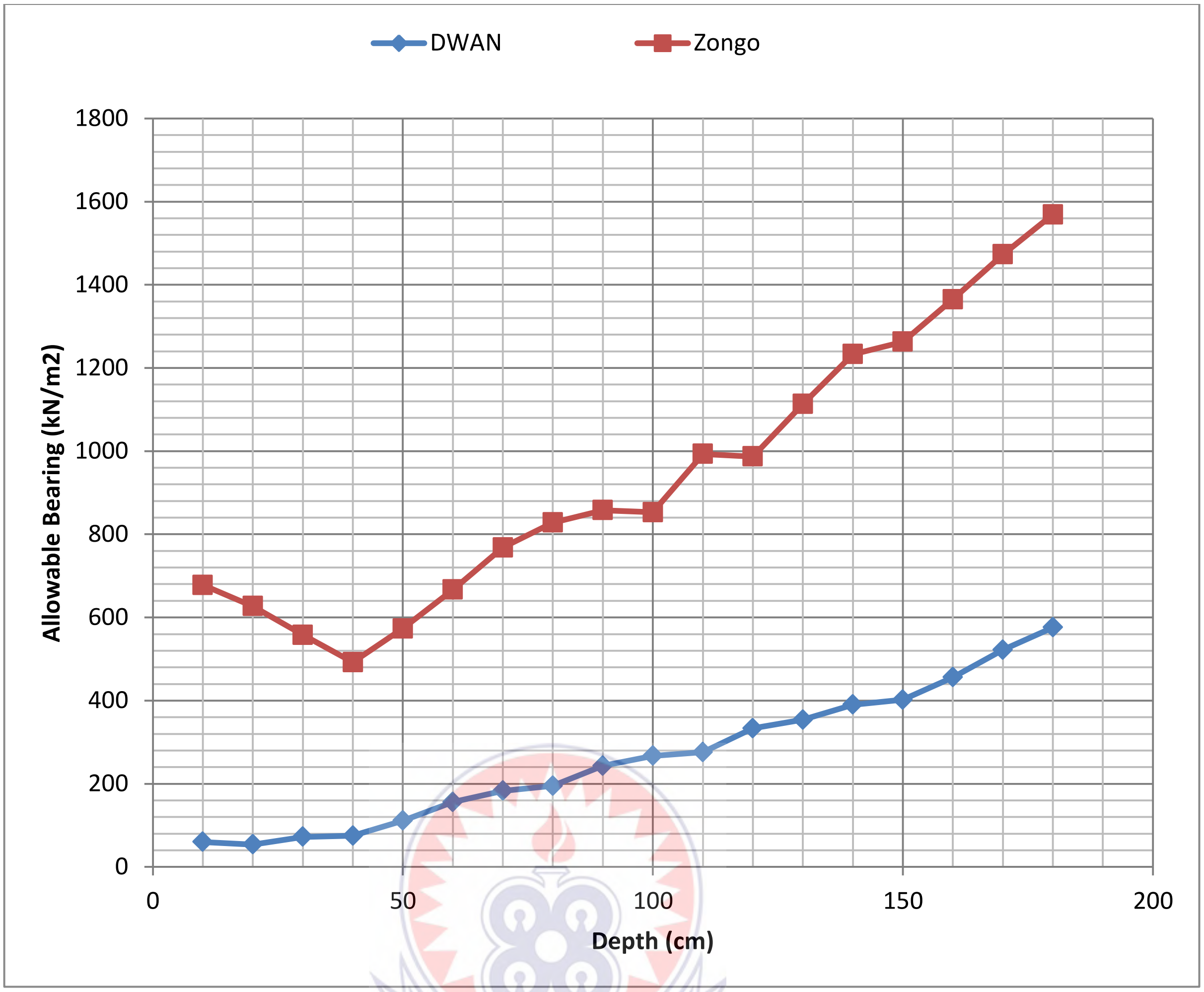


Figure 4.7: Allowable bearing across Sabob Zongo and Dagmew

Source: Computed from DCP Test Results

Figure 4.7 shows that the allowable bearing for Sabon Zongo reduces from 10 cm depth to 40 cm depth. However, there has been a consistent increase in allowable bearing from a depth of 50 cm to 90 cm depth. In relation to the allowable bearing for Dagmew, almost similar trend is noted in terms of the allowable bearing increasing with the depth. However, a major observation in the allowable bearing of Dagmew is that although the figures are not very large, the variations across the depths seemed to be marginal.

Attempts were also made to compare some elements of peculiarity of the developments (cracks) with respect to the case study areas i.e. Dagmew and Sabon Zongo Residential Areas of the Bolgatanga Municipality. The comparative analysis was performed using the One-Way ANOVA. In other words, the One Way ANOVA was used to examine the variability in the allowable bearing capacity across the two project sites

Table 4.8: Differences in allowable bearing

	Sum of Square	Mean Square	F-value	Significance (p)
Between Groups	2.813E7	1480492.648	77.308	0.000

The results above show that there is actually a significant difference in the mean allowable bearing across the two project sites, since a larger F value (77.308) is obtained with a very small significance „p-value" ($p \leq .05$). Since the study observed a significant difference in the variability of the bearing capacity of the soil foundation across the two project sites, further post-hoc analysis was done to determine which of the sites contributed significantly to the variability. The results show the Sabon Zongo project site

4.3 Discussions of Findings

The discussion of the findings involves the possible implications as well as the interpretation of the findings using logical deduction. However, in discussing the findings, attempts were also made to relate the findings of the study to the pertinent concepts and theories discussed in the literature review.

Structural and operational errors being the major causes of cracks in Sabon Zongo meant that the potential for human errors in technical and industrial process of building could be increasing as noted by (Feld & Carper , 1996). However, proper structural designs and construction practices can eliminate most of the cracking problems. But this cannot be achieved without proper compliance with the building regulations among many building developers, contractors and consultants.

The low allowable bearing capacity at Dagmew project site could be explained by the high volume changes in clay soils as a result of the fluctuation in their moisture content and the long term consolidation of compressible clay under most of the foundations. However, this area experiencing low allowable bearing was expected considering Feld and Carper (1996) assertion that the more difficult sites include those with expansive soils, organic soils and contaminated soils. Therefore, the volumetric changes in clayey soils make them dangerous to foundation of buildings based on Praveen (2014) assertion that clays swells extensively when wet and shrinks extensively when dry resulting in terrible cracks in soil without any warning. In this regard, foundations in this area are to be placed at a deeper depth.

The cracks in Dagmew are mostly related to specific sub-soil conditions, such as expansive soils hence the need for appropriate geotechnical studies in the area. This according to Feld and Carper (1996) can lead to decisions about site selection and development that reduce the risk of failure. Sabon Zongo‟s allowable bearing being higher than that of Dagmew suggests that the foundations at Sabon Zongo are more likely to be stable as compared to those in Dagmew.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the major findings from the study, the conclusions and recommendations as well as directions for future research. Thus, the chapter focuses on the implications of the findings from the study for policy formulation and future research.

The study examined the various causes of cracks in the buildings at Dagmew and Sabon Zongo Residetial Areas in the Bolgatanga Municipality of the Upper East Region of Ghana.

Soil investigations coupled with several laboratory analyses were performed. The soil testing includes the DCPT while laboratory testing includes organic content testing and clay compatibility. Soil samples from the selected project sites were also obtained for the laboratory testing program.

5.2 Summary of main findings

The major types of cracks among the buildings in the study area were studied in the first objective with the following key findings emerging:

i. Vertical cracks seems to be the most prevalent type of cracks in the two project sites

ii. In Sabon Zongo, there were also few instances of diagonal cracks that begin at the tension surface of a concrete member

With regards to the second objective which investigated the major cause of the cracks in the study area, the following major findings were noted:

i. There are a multi-faceted of factors that cause cracking of the buildings in the study areas

ii. Generally, while structural and operational errors were noted as the predominant causes of the cracks in the buildings across the two project sites, these causes were most prevalent in Sabon-Zongo

Objective three examined the differences with regards to the cracks in Dagmew and Sabon Zongo residential areas. The following key findings were noted/ noticed:

i. The soil conditions in Dagmew are more expansive and organic as compared to that of Sabon Zongo

ii. There were significant differences in the allowable bearing capacity of the soils across both project sites

iii. Sabon Zongo‟s soil had the largest capacity to support the loads applied to the ground

In the fourth objective, the effect of the cracks on the buildings, owners and occupants were analysed. The findings include:

i. From the house owners perspective, the major effect of cracks relates to the repairing and maintenance cost

ii. Safety, and panic were the major effects noted to be associated with the cracks in buildings from the perspective of the occupants in terms of structural failure, reptiles and other creatures‟ attacks.

Conclusions

The study concludes that the causes of cracks in buildings in the study area are due to a combination of factors and that faulty and poor quality work are not the only causes, although the significant factors. Thus while incorrect design, faulty construction, overloading, poorly prepared foundation footings among others are the crucial factors that cause cracks in the buildings of the study area, there are also evidence that the cracks are caused by the expansion and contraction of clay based sub-soils when get wet and dried.

The study also found significant differences in the causes of cracks across the two project sites. While the causes of cracks at Sabon-Zongo are more of structural issues, that of Dagmew are more of soil conditions such as the expansive and compatibility nature of the soil characteristics. The cost of serviceability and maintenance as well as the safety of occupants are the key resultant effects associated with cracks in buildings.

5.4. Recommendations

Based on the key findings emanating from the study, the following key recommendations are made for policy formulation and direction for further research

5.4.1 Education and Enforcement of the National Building Regulations, 1996 L.I.1360, Local Government Act, 1993 (Act 462) and Quality Assurance and Control

The National Building Regulations, 1996 L.I.1360 have not been largely enforced by the Municipal Assembly despite the fact that the Local Government Act, 1993 (Act 462) which replaced the Local Government Law 1988 (PNDC Law 207) accords DAs a central role in the implementation of building regulations. In this regard, the Municipal Assembly through the Municipal Planning Authority, Development Planning Sub-Committee and the Works Sub-Committee, is encouraged to enforce and implement policies on building regulations in the

Municipality. As part of the enforcement, it is also recommended that much education for the residents in understanding the laws in general and building regulations in particular by the public should be done to help enhance the knowledge of the public on the consequences of violation of building regulations on the owner, the building and the occupants. This education can be done by circulating leaflets, organizing stakeholders‟ briefing meetings on physical development bylaws and control, clubs‟/societal meetings, providing explanation of the development bylaws, and showing them the preparation of dossiers and other required procedures for filing complaints.

5.4.2 Compilation of a crack diary

House owners are advised to start a crack diary which would collect and record the following relevant information:

- **i.** where are the cracks i.e. the location
- **ii.** how long are the cracks
- **iii.** how wide are the cracks

The collection of this information is relevant in helping undertake an effective repair and maintenance.

In the compilation of the cracks dairy, there is also the need to undertake an evaluation of the cracks. This could be done by looking at the shape, pattern, frequency of occurrence, relationship to wall discontinuities and angles, placement of wall penetrations, correlation with cracks in floors, and location in the wall (corners, center), as well as length, width, continuity, age of wall, relation to site conditions (depth of backfill, blasting, rock).

(Duncan, Derek & Roger, 2003) also outlined similar procedure for investigating visible cracks in a wall.

5.4.3 Constant maintenance and repair

To avoid unnecessary panic, building owners should identify the symptoms, understand the possible causes of the defects and carry out timely repair and maintenance works to keep their buildings in good structural condition.

5.4. 4 Minimising the growth of large trees in Dagmew

Considering the fact that the soil in the community is shrinkable clay, the growing of large trees in the vicinity of buildings could cause damage in all type of soil conditions. Hence some precautionary radius should be taken around any present vegetation, as non- buildable area.

5.4.5 Directions for further studies

In the future, other researchers could consider other parts of Ghana for the investigation into the causes of cracks in buildings

REFERENCES

Archicentre Technical information Sheet (2012). *Cracking in brickwork*. Sydney Area: Archicentre PTY Ltd.

Amevordzie, V. B., (1997). *Building construction for senior secondary school* (2nd Edition) Longman Group U.K. Limited

Beck, J.L., Chan, E., Irfanoglu, A., & Papadimitriou, C. (1999). Multi-criteria optimal structural design under uncertainty. *Earthquake Engineering, Structural, Dynamics. 28, 741-761*.

Bernard, H. R. (2002). Research *methods in anthropology: Qualitative and quantitative methods*, (3rd ed.). Walnut Creek, C.A: Altamira Press.

Best, J. W. & Khan, J. V. (1998). *Research in education*. (7th ed.). Boston: Allyn and Bacon.

Bolga Municipal Assembly (2009). Medium term development plan: Bolgatanga:

Braja, D. (2007). *Principles of foundation engineering* (6th ed.), Stamford, CT: Cengage Publisher

Classification and Treatment of cracks in a building (2010). *Civil engineering projects*. Brighton: University of Brighton

Creswell, J. W.(2009) *Research design: Qualitative, quantitative, and mixed methods* *approaches*. (3rd Ed). Los Angeles: Sage Publications, Inc

Crissinger, L.S. (2005). *Design and construction vs weather*. Mexico: RCI Inc

Duncan, Derek & Roger, (2003). *Understanding housing defects.* London: Bell & Bain Ltd, Glasgow

Drew, J. C., Hardman, L. M. & Hosp, L. J. (2008). *Designing and conducting research in education*. Thousands Oaks, CA: Sage.

Dow Construction Chemical (2010). *Preventing cracks in walls*. Washington, DC: Hanley Wood Media

Feld, J., & Carper, K.L. (1996), *Construction failure*. New Jersey: John Wiley & Sons, Inc.

Fiedler, F. E. (1967) *A theory of leadership effectiveness.* New York: McGraw-Hill.

Ghana Statistical Service (2010). *2000 national population and housing census*. Accra: GSS

Gupta, R. (2015). *Concrete works*: New Delhi: Wapcos Ltd

Jennifer, W & Mihas, P. (2013). *Mixed methods: approaches for combining qualitative and quantitative research strategies.* North Carolina: ICPSR

Kashyzadeh, K.R. & Kesheh, N.A. (2012). Study types of cracks in building in construction and its controlling. *Advanced Engineering*, 2 (8), 528-531

Kothari, C. R. (2005). *Research methodology: Methods and techniques*. New Delhi: Wiley Eastern Limited.

Lee, R. (1987). *Building maintenance management*. London: William Collins Sons & Co. Ltd

Lex, D., (2015). *Structural contingency theory/information processing theory*. UK: Oxford University Press.

Lyall, A. & Colin, R. (1991). *Performance of materials in buildings*. Great Britain: Ipswich Book Co. Ltd., Ipswich, Suffolk.

Luthans, F. (1976). *Introduction to management: A contingency approach.* New York: McGraw

Hill p. 28.

Obande, M.O (1985). *Blocklaying and Concreting*. Singapore: Longman Singapore Publishers Pte Ltd

O'Leary, Z., (2004). *The essential guide to doing research*: *Facilitating change through research, London*: Sage publications

Prasad, S.K. (2014). *Bearing capacity of soil.* Mysore: S. J. College of Engineering

Malhotra, N. K. & Birks, D. F. (2003). *Marketing research: An applied approach*. London: Pearson Education Limited.

Maharajpur, W. (2004). *Cracks in building: Causes and prevention*. Gwalior : Centre for Advanced Maintenance Technology,

Redmond, E.C & Griffith, C.J. (2003). Consumer food handling in the home: a review of food safety studies, *J. Food Prot*, 66(1):130-61

Seidu, A. (2006). *Modern approaches to research in educational administration for research students Kumasi,* Accra: Payless Publication Ltd.

Tannor, L. L. (2014). *A guide to writing dissertations*. Revised Edition. Accra: Blessed Publications

Terzaghi, K.P. (1943). Rock defects and loads on tunnel supports. *Youngstown*, 17–99

Think Brick Australia (2013). *Design of clay masonry for serviceability.* Australia: SPL Consulting Pty Ltd

Thoft-Cristensen, P., & Baker, M. J. (1982). *Structural reliability theory and its applications*. Berlin: Springer-Verlag Berlin Heidelberg

APPENDICES

Appendix A: An abstract of some of the causes of cracks in buildings by some authors

Table1. The principal causes and effects of movements responsible for cracking in buildings

Cause	**Effect**	**Duration, frequency**	**Examples. of materials or components affected**
1. Externally applied loads a) Dead and live loading: Elastic deformation under service	Normally insignificant in vertical members but horizontal members may deflect	Continuous or intermittent under live loads; long term under dead loads	Suspended floor and roof slabs, beams, edge beams or spandrels and claddings; all other elements that support or contain the cladding
b) Creep	Contraction of vertical and deflection of horizontal members	Long term	Reinforced and pre-stressed concrete components as above
c) wind loading on cladding	Deflection (bowing or hogging)	Intermittent- frequency important	Lightweight cladding including opening glazing; sheet siding
2. Restraint of internal movements a) Temperature changes	Expansion and contraction	Intermittent, diurnal, seasonal	all
b) Moisture content changes: i. initial moisture absorption	Irreversible expansion	Relatively short term due to moist. absorption after manuf.	Brick and other ceramic products

Source: (Lyall A. and Colin R., 1991).

Table1. The principal causes and effects of movements responsible for cracking in buildings (continued)

Cause	**Effect**	**Duration, frequency**	**Examples. of materials or components affected**
ii. initial moisture release	Irreversible contraction	Relatively short term	Mortar, concrete, sand-lime bricks; unseasoned timber. Ceramic products.
iii. Alternate absorption release or moisture in service	Expansion and contraction	Periodic – e.g. seasonal	Most porous building materials, including cement-based and wood or wood-based products Shrinkable clay soil
3. vibrations (from traffic, machinery, wind forces	Possible loosening of fixings, disturbance of glazing areas	Intermittent and at high frequency	Lightweight cladding, glazing, sheet siding
4. Chemical changes a) Corrosion	Expansion permanent	Continuous over months to years	Iron and other ferrous metals in masonry (ties, lintels) or externally exposed reinforced concrete
b) Sulphate attack	Expansion permanent	Continuous over months to years	Porland cement products in constructions where soluble sulphates (e.g. high sulphate bricks, fill or hardcore) and persistent dampness present

Source: (Lyall A. and Colin R., 1991).

Table1. The principal causes and effects of movements responsible for cracking in buildings (continued)

Cause	**Effect**	**Duration, frequency**	**Examples. of materials or components affected**
c) Carbonation	Contraction permanent	Continuous over months to years	Porous porland cement products such as dense and lightweight concrete, asbestos-cement, reinforced fibre products (i.e. asbestos substitutes)
d) Akali silica reaction	Expansion irreversible	Over many years	Concretes containing reactive aggregates and sufficient alkali
e) moisture expansion of ceramics	Expansion permanent	Over many years	Fired clay bricks and ties
5. Physical changes a) Ice or crystalline salt formation	Expansion in building materials Frost heave in soils	Intermittent, dependent on weather conditions and moisture content of materials/soils	Porous natural stones, very exposed brickwork
b) Loss of volatiles	Contraction, loss of plasticity	Short or long term, depending on material, exposure	Some sealants, some plastics

Source: (Lyall A. and Colin R., 1991).

Table1. The principal causes and effects of movements responsible for cracking in buildings (continued)

Cause	**Effect**	**Duration, frequency**	**Examples. of materials or components affected**
c) Crypto efflorescence	Expansion; internal damage; spalling. Salt staining	Intermittent related to the weather	Porous materials notably fired clay bricks, tiles and natural stones which contain salts inherently or from contamination
6. Movement in soils a) Loading	settlement	1. Soils: varies with season; 2. Fill: loading/compaction dependent	1. Soils: silt and peaty ground (clay) particularly susceptible; 2. Fill: ground-floor slabs
b) Mining subsidence, swallow holes, landslips, soil creep, earth tremors	Expansion permanent	Over many years	Fired clay bricks and ties

Source: (Lyall A. and Colin R., 1991).

Table2. Common structural defects of foundations at construction stage

Potential Problem Areas	Implications	Typical Defects
Insufficient depth of foundation especially in shrinkable clay sub-soils.	Seasonal movement due to changes in water content of sub-soil. Movement due to trees and shrubs.	Cracks in walls especially at "natural" line of structural weakness, e.g. Windows, doors, junctions with extensions and bays.
Insufficient width of foundation	Load insufficiently spread over sub-soil. Tendency for settlement to occur.	Cracking in walls above ground level.
Soft spots in sub-soils.	Foundation is inadequately supported by the sub-soil leading to settlement	Cracking in walls above the affected section(s) of foundation.
Insufficient steps in strip foundation on sloping ground/site.	Tendency for building to slide or creep especially if there is soil erosion.	Displacement movement of building or section of building. Cracking in walls.
Trees and large shrubs in close proximity in shrinkable clay sub-soils.	Sub-soil subject to changes in water content due to desiccation (lack of moisture) and heave (excess moisture).	Cracking in walls especially along natural lines of structural weakness.
Recent removal of trees or large shrubs especially in shrinkable clay sub-soils.	Sub-soil subject to a period of heave over several years.	Cracking in walls especially along natural lines of structural weakness.
No provision of compressible material to pile and ground beams in shrinkable clay sub-soils to allow for heave.	Any expansion or heave of the sub-soil will lead to structural movement.	Upward movement with cracks along lines of weakness in structure.

Source: (Duncan, Derek and Roger, 2003).

Table2. Common structural defects of foundations at construction stage (continued)

Clay sub-soil with high sulfate content.	Sulfates attack concrete foundations and below- ground cement mortar jointing.	Movement in above-ground walls. Expansion and deterioration of below-ground cement mortar and concrete.
Inadequacy of structural support from land fill i.e. made-up ground.	Excessive settlement over a prolonged (often indeterminate) period of time.	Cracking of walls. Complete collapse of building.
Close proximity of drain runs which are deeper than foundations and/or lacking of concrete cover	Inadequate support to the foundations.	Cracking of walls above ground level. Walls out of plumb due to lateral displacement.

Source: (Duncan, Derek and Roger, 2003).

Table3. Common structural defects of walls at construction stage

Potential Problem Areas	Implications	Typical Defects
Below-ground brickwork or blockwork in sulfate-bearing clay sub-soil.	Sulfates in sub-soil will attack cement mortar.	Expansion and cracking of mortar below ground and movement in wall below and above.
Lack of adequate movement joints.	Excessive thermal expansion in long lengths of wall.	Vertical cracking at regular intervals in long sections of wall and at short returns. Horizontal movement above the line of dpc.
Inadequate restraint provided to walls from floors and roof.	Walls will tend to move horizontally.	Bulging and bowing of walls.
Lack of lintel over openings: small and large both above ground level.	Unsupported masonry.	Movement cracking above opening. Dropped head of opening.
Lintels with insufficient end-bearing.	Crushing of supporting brickwork or blockwork due to excessive point-loading.	Lintel drops at one end. Vertical cracking above end of lintel.
Incorrect mortar mix.	Inherent weakness in the structural capability of the wall.	Disintegration of mortar jointing. Bulging and bowing and/or buckling of walls.

Source: (Duncan, Derek and Roger, 2003).

Table4. Defects and the causes

FOUNDATIONS AND BASEMENTS		
Element	**Defect**	**Cause**
Foundations.	Settlement causing cracks in supporting walls.	1. Overloading through: a. Inadequate design e.g. width or depth insufficient in relation to bearing capacity of subsoil. b. Building used for a purpose different from that for which it was designed c. Structural alterations, e.g. formation of large openings in supported wall concentrating load on adjacent foundations. d. Building additional storey without strengthening existing foundations. 2. Shrinkage of clay subsoils through withdrawal of ground water by prolonged drought, nearby fast growing trees such as poplars, site drainage, or tunneling. 3. Undermining of foundations as a result of finer particles of sandy soils being washed out by underground streams, flooding or leaky drains. 4. Long-term settlement of peat and made-up ground. 5. Downhill creep of clay soils. 6. Swallow holes and mine workings under foundations. 7. New excavations immediately adjacent to building to greater depth than old foundations.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

FOUNDATIONS AND BASEMENTS		
Element	**Defect**	**Cause**
Foundations (contd).	Settlement causing cracks in supporting walls.	8. Foundations of extensions, bays, screen walls, etc., with shallower foundations than those to the main building. 9. Vibrations from heavy traffic, machinery, piling operations, tunneling, etc.
	Heave causing lifting and cracking of ground slabs.	1. Freezing of water in upper layers of soil. 2. expansion of clay soils on absorbing moisture during prolonged wet weather or as a result of felling large mature trees close to the building.
	Disintegration of concrete.	Sulphate attack i.e. reaction between tricalcium aluminates in cement and Soluble sulphates in soil.
Basements	Dampness	1. Defective tanking through: a. deterioration with age b. lack of continuity e.g.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

FOUNDATIONS AND BASEMENTS		
Element	**Defect**	**Cause**
Basements	Dampness	1. Defective tanking through: a. deterioration with age b. lack of continuity e.g. not carried under stanchions and other structural members which penetrate the tanking. c. damage occurring during construction. 2. Opening up of construction joints due to shrinkage of concrete where dense is used instead of tanking. 3. External pressure caused by rising of water table adjacent to building.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

WALLS AND FACINGS		
Element	**Defect**	**Cause**
External walls.	Diagonal cracks following horizontal and vertical joints.	Settlement of foundations.
	Horizontal and vertical cracks.	Thermal movement due to omission expansion joints in long lengths of walling. Moisture movement due to expansion of blocks used too soon after molding. i.e. not adequately cured.
	Outward bulging of wall between ground level and eaves with gap internally between wall and end of upper floors.	Displacement of wall through one or more of the following: a. low slenderness ratio i.e. insufficient wall thickness in relation to height. b. inadequate lateral support e.g. cross walls or floors not built into wall to restrain movement. c. overloading of structure. d. vibrations from heavy traffic or machines.
	Outward bulging of wall at top.	Spreading of untied rafter feet exerting horizontal thrust on supporting walls.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

WALLS AND FACINGS		
Element	**Defect**	**Cause**
External walls (contd).	Horizontal cracking of inner leaf of cavity wall.	Sulphate attack causing expansion of mortar joints in out leaf.
Openings	Crack in soffit.	Faulty lintel: a. inadequate size. b. concrete lintel upside down with reinforcement at top instead of bottom.
Partitions	Crack at head and sides.	Drying shrinkage of lightweight concrete blocks.
	General cracks.	Inadequate support at base: a. settlement of foundations of ground floor partitions. b. deflection of upper floor joists under load. c. new partition built on old floor of insufficient strength. Creep of concrete floors. Differential movement between partition and surrounding structure.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

FRAMES AND CLADDINGS		
Element	**Defect**	**Cause**
Frame:		
a). Steel	Wave distortion of frame.	Unequal settlement of columns, excessive loading or thermal movement.
	Cracking and rust staining of concrete cover.	Corrosion of steel; cover concrete of inferior quality or inadequate thickness, mechanical damage of exposed angles.
b). Concrete	Cracking and disintegration of concrete.	Weak concrete due to improper mix design, unsuitable aggregates or cement, wrong water/cement ratio, inadequate compaction and curing. Secondary effect of freezing of water which enters cracks causing spalling of surface layers of concrete. Use of calcium chloride as an additive to accelerate setting of concrete. Insufficient cover to reinforcement-increased loss of alkalinity caused by carbonation of concrete causes steel to rust and build up sufficient pressure to crack thin concrete cover. Overstressing caused by compressive, tensile or shearing forces.
	Vertical cracks in beams and walls.	Inadequate/improper lapping (lap length) of reinforcement.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

FRAMES AND CLADDINGS		
Element	**Defect**	**Cause**
b). Concrete (contd.)	Sagging and cracking of beams.	Inadequate design and/or workmanship. Overloading. Use of high alumina cement.
ROOFS AND COVERINGS		
Concrete	Cracks along top of supporting walls.	Thermal expansion of concrete.
WALL AND CEILING		
Plaster	Crazing of surface.	Drying shrinkage.
	Larger cracks.	Differential movement of structural members. Shrinkage of lightweight concrete partitions. Settlement of foundations. Vibration from external causes, e.g. heavy traffic.
	Continuous crack at junction of ceiling and wall.	Shrinkage.

Source: (Lee, 1987).

Table4. Defects and causes (continued)

WALL AND CEILING		
Element	**Defect**	**Cause**
Plaster (contd.)	Cracking in plaster at head of window frame.	Differential shrinkage of wall and lintel when dry out.
	Vertical crack in wall plaster.	Differential shrinkage at point where application of plaster was stopped for a period or where a brick wall is finished flush against a concrete column.
	Continuous straight cracks across ceiling.	Deflection of weak, springy floor joist or joints between sheets of plasterboard which have not been scrimmed.

Source: (Lee, 1987).

Appendix B: Photographs of some cracked buildings within the two project sites and other suburbs of the Municipality.

A volt chamber toilet facility which suffered all manner of cracks at Anglican JHS premises due to expansible nature of the sub-soil of the Dagmew Residential Area.

A 10-seater KVIP toilet facility which developed terrible cracks suspected to occur as a result of the clayey nature of the sub-soil at the same Anglican JHS premises, Dagmew.

A pictorial topography of the Dagmew Residential Area.

A building that cracked through a lintel which is an indication of operational error emerging from the lintel construction in the Sabon Zongo Residential Area.

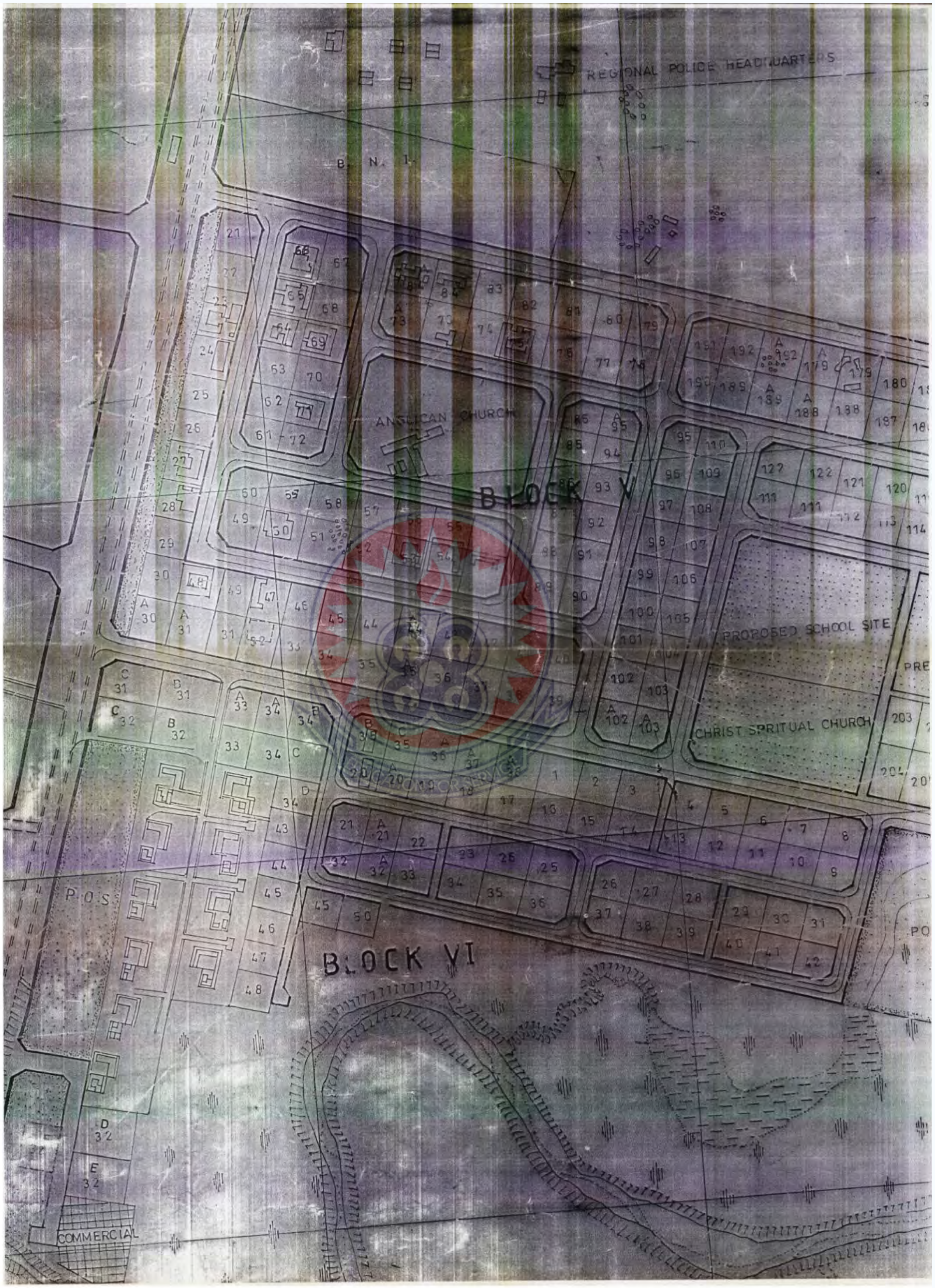
Another building that developed crack from floor level to gable, clearly showing that there is no lintel in the wall at Sabon Zongo Residential Area.

Another building that developed several cracks at various locations at Sabon Zongo. Photograph taken inside the building as the landlord expressed his frustrations about the development and took the researcher in for a technical advice.

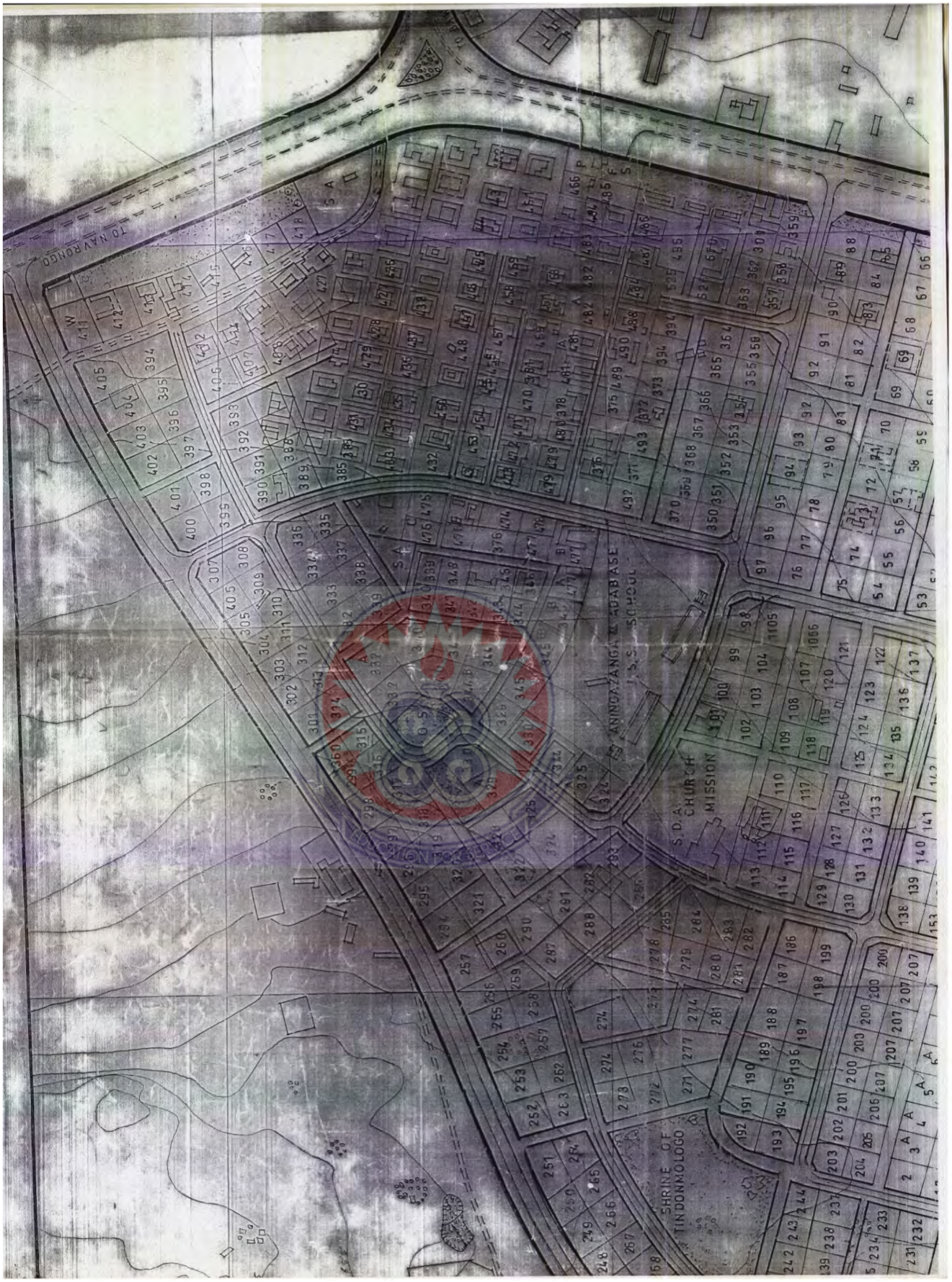
A 3-Unit apartment teachers' quarters at Ananteem in the Bolgatanga Municipality that has been abandoned due to several terrible structural cracks.

A building under construction that suffered serious structural cracks due to operational and/or constructional error at Sumbrungu in the Bolgatanga Municipality.

Appendix C: The scheme/layout of the two residential areas.



The scheme/layout of the Dagmew residential area. Note: not fully captured/covered.



The scheme/layout of the Sabon Zongo residential area, not fully covered/captured.

Appendix D: Field and laboratory tests.

Trial pits and Dynamic Cone Penetrometer Tests at the project sites.

Sieve, plasticity and sedimentation tests/analysis.

Sieve, plasticity and sedimentation tests/analysis.

Appendix E: Sample questionnaires