Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 10, October - 2025

International Journal of Engineering Research &Technology Effect of Black Cotton Soil on Structures the Case Study of South Sudan

ABSTRACT
Effect of black cotton soil on structures has encounters several accusatory due to its unpredictability behaviours (swelling-shrinking) with moisture content variations on structures. The behaviours of engineering properties of black cotton soil, can cause instability and failure of structures built upon it. With the rapid growth in construction industry in South Sudan, there is need for proper understanding of effect and mitigation of black cotton soil on construction of structures. The study uses an interview-questionnaire form to gather data from relevant stakeholders, including civil engineers, and construction professionals. This study deliberated appropriate understandings into the challenges posed by black cotton soil on structures, as well as effective practices for mitigating these effects. Floating foundation such as Mat foundation, and Strip foundation and adopting use of Expanded Polystyrene (EPS) panel system on area of this soil. These are preferrable optimal for mitigating the effects of black cotton soil on structures. These will afford stability decrease the danger of differential settlement, and more suitable for supporting structures on black cotton soil.

Keywords: **Black cotton soil, Expanded Polystyrene (EPS) swelling-shrinking, mitigation measures.**

Philip Ahook Gai
Master of Geotechnical Engineering (Msc-GE) University of Juba, Bachelor Degree Honours in Civil Engineering (BSc-Hon) University of Juba, Managing Director for PEAK Engineering & Construction Co. Ltd

Prof. Gyavira Wani:
Professor University of Juba, School of Engineering

INTRODUCTION

Black cotton soil swells significantly when in contact with water and shrink when dry, forming characteristic cracks. Black cotton soil is very difficult for structures because of their low strength and tendency for significant volume variations. To lower the possibility of shrink-swell, alluvial soil is replaced with gravel and sand material, that improve drainage and aeration but potentially reducing water retention and affecting soil structure. This leads to ground movement, resulting in structural damage to buildings. These structural damages are cracks in walls, foundations, and floors as buildings experience unevenly settlement triggering structural failure.

Black cotton is predominantly distributed along River Nile banks and throughout the Upper Nile Region, covering areas in Jonglei, Unity, and Upper Nile States. These soils, known for their high clay content good for agricultural practices and upsetting, problematic and perilous to construction of structures due to its high tendency to shrinkage and swelling with present of moisture content. This soil common mineralogy, are montmorillonite, kaolinile and illile, their exhibitions significant stimulate its swelling behaviour depending on its moisture content, when dry, it shrinks and stabilizes, like stone with high bearing capacity, when saturated it swells, becoming moveable and losing its bearing capacity causing severe structural damage to foundation structures.

This study aims at addressing the effects of this soil on structures by finding the utmost techniques suitable for foundation to manage its bulk changeability with moistness variations and fanout appropriate materials favourably good with black cotton soil for building structures on it based-on its stability and load-bearing capacity to eradicate such problems. Black cotton soil has poor drainage characterises. This can exacerbate the swelling-shrinking cycle and can lead to increase hydrostatic pressure around foundation, retaining wall or basements.

BACKGROUND

South Sudan is predominantly featuring high clay soils that expand and contract in absorption of water levels. This oscillation can lead to shifts in the foundations of built-up structures, harmfully affecting resident inhabitants. In Regions of South Sudan, these soils present a serious threat to the stability of lightweight structures. The swelling clays, originating from residual soils, can generate upward pressures that may inflict significant destruction on lightly constructed structures.

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ISSN: 2278-0181
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Figure 1.1 A typically examples of structural damage on black cotton soil in Juba, South Sudan

BLACK COTTON SOIL (BCS)

Black cotton soil is worrying for the construction on account of its volumetric changes. Such tendency of soil is due to the presence of fine clay particles which swell, when they come in contact with water, resulting in alternate swelling and shrinking of soil causing differential settlement of structures.

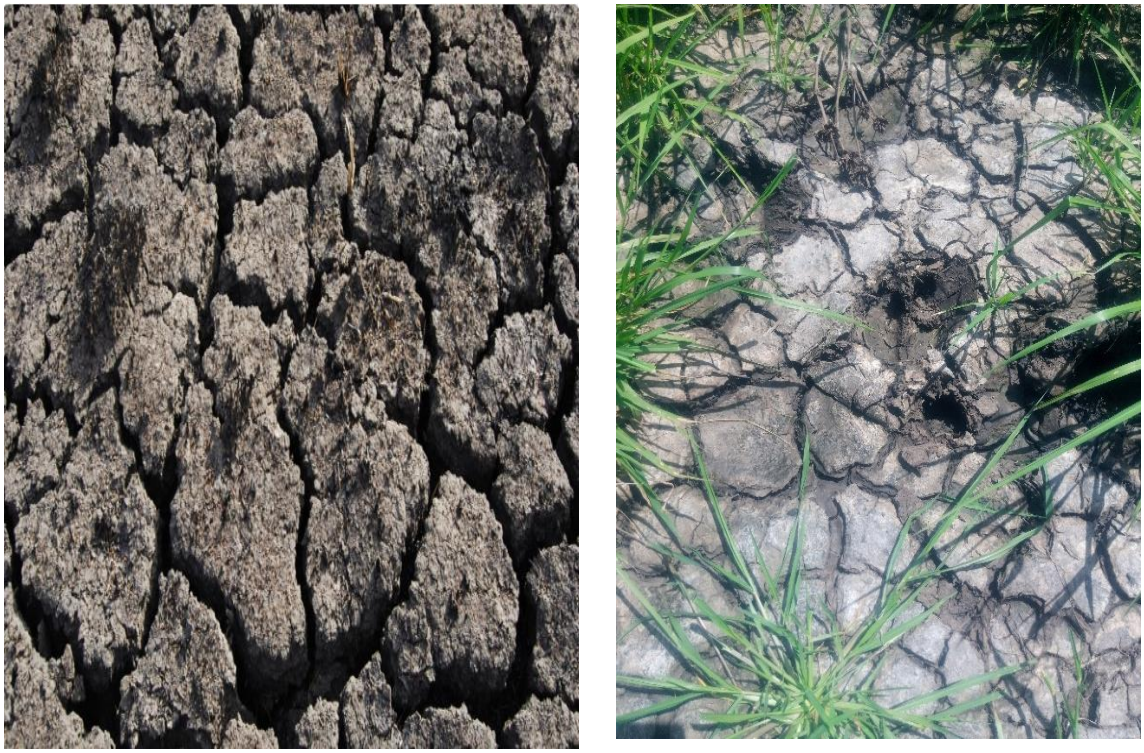

Fig 1.2 Black cotton soil nature

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Dispersal of black cotton soil in South Sudan, in areas along the River Nile banks and Upper Nile Region is occupied by black cotton soil. That means these soils are predominant in South Sudan trap plateau region, in most of South Sudan States.

BLACK COTTON SOIL IN SOUTH SUDAN

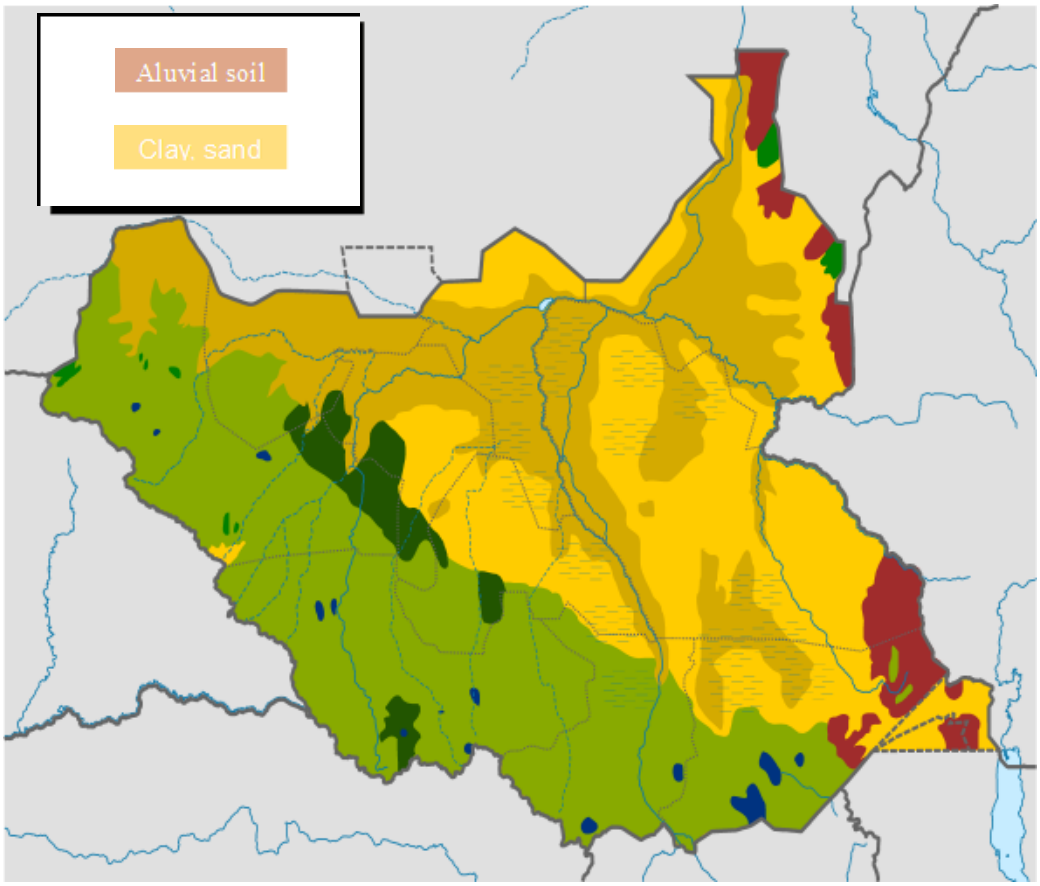

Fig 1.3 Areas of black cotton soil / Expansive soil (light brown & yellow)

EFFECTS OF BLACK COTTON SOIL ON STRUCTURES IN SOUTH SUDAN

Black cotton soil, can cause significant effects on structures built upon it due to its swelling and shrinking features when exposed to changing moisture levels; as show in the pictures below.

Foundation Damage: black cotton soils on account of bulk causing heaving in foundations by uplift forces as they swell with moisture increases as a result ground movement causes foundations cracks affecting walls, and other structural elements.

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Fig 1.4 Sample of structures build on black cotton soil due to foundations failure.

The foundation is the fundamental element in every structure built on the grounds, once it damages the whole structure collapsed.

Differential Settlement: as a results of shrink-swell behaviour of soil under the structure can lead to settlement of structure, where different parts of building settle at different rates. These consequences result in several cracks on building and doors and windows and compromising architectural integrity.

Fig 1.5 *Several cracks on building resulting from uneven settlement*

Buildings Tilting: uneven settlement occurs as the ground movement from its characteristic's behaviours causing buildings to tilt making it insecure. This unexpected geological faults or fissures in the ground can also cause a building to sink. Changes in groundwater levels under the foundation can affect soil stability lead to building, to tilting.

Structural Damage: the periodic expansion and contraction can lead to observable cracking in the walls, floors, and ceiling of buildings. With time this can compromise the structural integrity, leading to significant repairs or need for demolition and reconstruction.

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Fig 1.6 Typical black cotton soils structural damage, school buildings in Bor Town

Road Pavements and Damage: the swelling and shrinking of black cotton soil can cause potholes, cracks, and other damage to roads and pavements. Due to very low CBR values of black cotton soil, excessive pavement thickness is required for designing for flexible pavement. The constant stress and strain from loaded transport vehicles are most liable to damage as a result of the volume changes in the soil.

Increased Maintenance costs: there are incurring expenses on buildings built on black cotton soil as may incur higher costs due to the need for regular monitoring and repairs resulting from soil movement and structural damage. Houseowners face momentous financial implications due to these continuing issues.

PROBLEM STATEMENT

The problem with expansive nature of black cotton soil is: insufficient understanding of the soil's behaviour causing insufficient foundation support, leading to complete structural failure. There is a lack of standardized construction practices that account for the unique challenges posed by this type of soil. Despite widespread recognition of these challenges, there remains a critical gap in understanding the specific impacts of black cotton soil on building performance, particularly in regions where it is prevalent. Current construction practices often fail to adequately account for the unpredictable behavior of this soil type, with many structures suffering from avoidable damage due to inadequate foundation support and design modifications.

JUSTIFICATION

The justification for the studies is rooted in a strong understanding of soil properties, innovative engineering solutions, and environmental considerations. Enduring research continues to provide insights that can lead to safer, more efficient, and workable construction practices. By effectively addressing the challenges that black cotton soil poses on buildings, it is possible to successfully develop structures that contribute positively to the community.

Research focus on evolving techniques to stabilize black cotton soil on improving construction challenges of its strength and reduce swelling and shrinkage and also explore methods of enhance poor drainage.

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OBJECTIVES

In this study, the specific objectives were to:

Specific objectives:

- Identify Mitigation Strategies: Propose engineering solutions and construction practices that effectively mitigate the risks associated with black cotton soil, including foundation design modifications and soil treatment techniques.
- Promote Sustainable Practices: Investigate sustainable techniques for managing black cotton soil in construction, aiming to minimize environmental impact while ensuring structural safety and durability.

Inconsequential Objectives:

- Identifying appropriate construction materials that interact favorably with black cotton soil.
- Improving soil bearing capacity of black cotton soil for medium and large buildings.

HYPOTHESIS

The study postulates significant solutions for steadying of changeability of Black Cotton soil. An excellent approach on shrinkage and swelling behavior control in achieving high strength for block cotton soil.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Despite widespread recognition of these challenges, there remains a critical gap in understanding the specific impacts of black cotton soil on building performance, particularly in regions where it is prevalent. Current construction practices often fail to adequately account for the unpredictable behavior of this soil type, with many structures suffering from avoidable damage due to inadequate foundation support and design modifications.

Broadly speaking soil stabilization encompasses every physical, physio-chemical and chemical method developed and used to make a soil perform better its desired engineering purpose. black cotton is unsuited soil which need careful understanding and appropriate method of construction of structures on it.

(V.N.S Murthy) Swelling soils, which are clayey soils, are also called expansive soils. When these soils are partially saturated, they increase in volume with the addition of water. They shrink greatly on drying and develop cracks on the surface. These soils possess a high plasticity index. Black cotton soils found in many parts of India belong to this category. Their colour varies from dark grey to black. It is easy to recognize these soils in the field during either dry or wet seasons. Shrinkage cracks are visible on the ground surface during dry seasons. The maximum width of these cracks may be up to 20 mm or more and they travel deep into the ground. A lump of dry black cotton soil requires a hammer to break. During rainy seasons, these soils become very sticky and very difficult to traverse.

The depths of these soils in some regions may be up to 6 m or more. Normally the water table is met at great depths in these regions. As such the soils become wet only during rainy seasons and are dry or partially saturated during the dry seasons. In regions which have well-defined, alternately wet and dry seasons, these soils swell and shrink in regular cycles. Since moisture change in the soils bring about severe movements of the mass, any structure built on such soil experiences recurring cracking and progressive damage. (Principles and practices of Soil Mechanistic and Foundation Engineering).

(Moles, et al 2006). Building effect on the soil behaviour: The construction of a building changes both the temperature and the evaporation condition of the soil beneath the area it occupied. This will change moisture movement as well as moisture contents in the concerned zones. The building will act as an impermeable membrane on the soil. The water under the building cannot escape anymore and will increase the moisture contents of the soil at this particular place. As a result, the soil will expand. It may happen that some part of this beneath soil will be in touch with water (for example at the side of the building) and start to expand while some other part will remain dried and so keep its original volume (at the centre of the building). This will definitely create some differential movement within the building structure. (HAL Science, 2006).

To dig trenches to build the foundation will allow the water to penetrate faster (between the existing soil and the substructure) to the base of the foundation. As a consequence, the soil between 90 and 100 cm beneath the base of the foundation will be subject to expansion and shrinkage movement. (HAL Science, 2006).

Soil behaviour effect on the building: Building erected in such soils without any particular precaution invariably develops cracks that can put its stability in danger. If it is possible to guarantee that the soil beneath the building

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will keep constant moisture content after the building has been erected, most of the problems will be solved. Unfortunately, moisture can come in touch to the soil beneath the building due to various factors: From the water table, rain, and through the tree's roots (the soil affected by expansion shrinkage can be up to five meter deep from the ground level). Through badly achieved technical details during the building construction (bad water drainage...) or failure of technical details during the building life (breakage of water pipe...), and from evaporation. (HAL Science, 2006).

(Kochi, 2022) supplement that, "Working on reinforcing black cotton soil to check its ability to serve as subgrade material but enhancement of drainage characteristics of black cotton soil requires more attention''. (IGC, 2022) (Jyothi, 2024) Assessment "One of the most significant challenges that geotechnical engineers encounter is building any form of foundation over weak or soft soil. Because high-rise buildings could suffer severe damage, it is imperative to enhance the load bearing capacity of black cotton soils by addition of layered stone Dust.'' SVSNDL Prasanna E3S Web of Conferences (04002ICSTCE, page 559).

(Terzaghi, 1951) writing, the Influence of Modern Soil Studies on the Design and Construction of foundations commented on foundations as "foundations can appropriately be described as a necessary evil. If a building is to be constructed on an outcrop of sound rock, no foundation is required. Hence, in contrast to the building itself, which satisfies specific needs, appeals to the aesthetic sense, and fills its matters with pride, the foundations merely serve as a remedy for the deficiencies of whatever whimsical nature has provided for the support of the structure at the site which has been selected. On account of the fact that there is no glory attached to the foundations, and that the sources of success or failures are hidden deep in the ground, building foundations have always been treated as step children; and their acts of revenge for the lack of attention can be very embarrassing''.

(ACNT, 1984), Foundation movements are a major cause of distress to established buildings. The main cause of such movements in Australia is the swelling and shrinking of expansive clays resulting from soil moisture changes. There are two aspects to this problem. Firstly, buildings must be managed in a manner that reduces the possibility of damage. Secondly, if foundation movements do occur, the damage should be repaired and measure taken to stabilize the footing system. (Damage to Buildings on Clay Soil, Technical Bulletin).

Mustapha Mohammed Alhajia and Musa Alhassan; Black cotton soil is one of those problematic clay soils found in many parts of the world. Large deposits of black cotton soil exist in the north-eastern part of Nigeria and also have the problem of causing serious damages to road pavement structures and light building structures founded on them. These soils cannot also be borrowed for use in any component of road pavement structure or fill of any sort because of their soft and swelling characteristics. A lot of researches have been carried out to evaluate the swelling characteristics of clays including black cotton soil. Other similar researches attempted to correlate swelling characteristics with consistency limits to ease the process of evaluating swelling properties and reduce the time required to conduct the real swelling tests. The cost of damages that have been caused by black cotton soil in various parts of the world as reported by various researchers was recorded by Gidigasu and Gawu.

In order to avert these damages, a lot of research has been conducted to modify or stabilize black cotton soil using various additives to improve its swelling-shrinkage characteristics, physical, and geotechnical properties. (Free Swelling and Modulus of Elasticity of Compacted Black Cotton Soil Treated with Reclaimed Asphalt Pavement, The Egyptian International Journal of Engineering Sciences and Technology, P 60–61, Vol. 25 2018).

(Guru, et al, 2020), Black cotton soil is highly expansive in nature when gets in contact with water, thus making it unsuitable for construction. The unsuitability of black cotton soil can be changed by making the soil water repellent and exhibiting high bond strength. This can be achieved by application of Terrasil and Zycobond (A Zydex product) when added to soil mixed with water. It improves the bond strength between the soil particles and creates a protective layer by permanently changing the soil properties. It increases the California Bearing ratio of the soil mass exponentially over a period of time thus, making it suitable for infrastructure projects and high chances to be used as non-expansive BC soil in infrastructure development. The structures on black cotton soil bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. The physical properties of black cotton soil vary from place to place, 40 % to 60% of the BC soil has particle size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 % to 300% and results in swelling pressure as high as 8 kg/cm2 to 10 kg/cm2[1]. laboratory soaked CBR values of black cotton soils are generally found in the range of 2 to 4%. Due to very low CBR values of black cotton soil excessive pavement thickness is required for designing flexible pavement. Research & Development (R&D) efforts have been made to improve the strength characteristics of black cotton soil with new technologies. (Helix, 2020)

(Melese,et al, 2023); Black cotton soil is a porous soil that is not a good material to use when building roads. The key characteristics of this soil type are high swelling-shrinkage capacity, weak bearing capacity, and high levels of plastic clay. The expansive property of the soil is mostly caused by the clay mineral montmorillonite (Altmeyer, 1955). The expansive soils are also known as swelling soils or soils of black cotton. The black cotton soil is highly strong when dry but entirely weakens when wet (Yilmaz, 2004).

(Kavish, et al, 2014) also write that; The expansive soils occur all over the world. India has large tracks of expansive soil known as Black Cotton soil (BC soil), covering an area of 0.8 million square kilometre, which is about 20% of total land area. The major areas of their occurrence are states of Maharashtra, Gujarat, southern

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parts of Uttar Pradesh, eastern parts of Madhya Pradesh, parts of Andhra Pradesh and Karnataka. This type of soil is available up to a depth of 3.7 meters on an average in the above parts of India. Expansive soils occurring above water table undergo volumetric changes with change in moisture content. Increase in water content causes the swelling of the soils and loss of strength and decrease in moisture content brings about soil shrinkage. Swelling and shrinkage of expansive soil cause differential settlements resulting in severe damage to the foundations, buildings, roads, retaining structures, canal linings, etc. The construction of foundation for structure on black cotton soils poses a challenge to the civil engineers.

(Gaikwad, et al, 2024) statement; In the construction industry, black cotton soil is a troublesome soil because of its expansive nature and shrink-swell behaviour. This tendency causes cracking and differential settling in buildings and roads, which can be problematic. Stabilizing black cotton soil is necessary to improve its engineering properties and suitability. Construction on expansive soils, such as highways and railways, faces difficulties and suitable materials may not be readily available. Increases in strength and durability, as well as reductions in consistency limitations and shrinking-swelling behaviour, are all essential components of the expansion of expansive soils. With their susceptibility to moisture-induced volume fluctuations, expansive soils provide issues in the field of geotechnical applications and civil engineering. (Improving Shear Strength and Microstructural Behavior of Black Cotton Soil Treated with Construction Demolished Waste, Gaikwad, et al 2024)

(Jain et al, 2016) Black Cotton Soils are residual deposits formed from basalt rocks. They contain significant amount of montmorillonite mineral. It swells and shrinks excessively with change of water content. Such tendency of soil is due to the presence of fine clay particles which swell, when they come in contact with water, resulting in alternate swelling and shrinking of soil due to which differential settlement of structure takes place, (IRJET, 2016)

(Braja et al, 2021) Soft clay soils have high compressibility and low strength. The risks associated with design and construction over these deposits are significant, and consequently they are the materials most frequently subjected to ground improvement. Therefore, engineering geological models over areas of soft clay and other recently deposited materials must be detailed and robust if they are to provide the geotechnical engineer with an adequate understanding of the extents of the different material units and their behaviour. Soft clay deposits are often seen, and therefore considered, as a continuum with characteristics that can be defined by field or laboratory tests, and performance, in terms of strength and compressibility that can be defined by those tests. However, variability in strength and compressibility throughout any specific soft clay deposit is likely to be significant. This variability is a consequence of the geological setting, ongoing geological processes and stress history of the clay. An understanding of the geological origins of the deposit is essential to assess its physical extents and properties, and the potential variability of both. (CRC Press, 2021)

(HUSSAIN, 2019) In civil engineering works most problems occur when the sub-structure is found to be expansive clay. The low strength is the most critical situation of construction on expansive soil and this may also lead to poor construction of buildings over those soils, the tendency to enhance their volume when they come in contact with moisture and to shrink if moisture is eradicated from them. Those soils which possess more clay particles have the behavior of swelling when their moisture content is allowed to increase(Neeladharan et al., 2018). Volume change behaviors in swelling type of soils presence or absence of moisture are the origin of a lot of troubles in structures such as bridges, roads, building etc.; which are being constructed over those soils (Patel et al., 2015). Clay has the property of low strength and high compressibility. Many of the clayey soils are very sensitive, in the sense that their strength is reduced by mechanical disturbance. The problematic expansive clay material used for road and building construction needs its properties to be improved (stabilized) to avoid failure. The idea of soil replacement with good engineering properties by cut and fill is highly expensive and time consuming (Thomas et al 2016). (NICOSIA, 2019)

(Reddy, et al, 2023) Expansive soils have continued to attract the attention of the research fraternity for their inherent ability to undergo signi cant volume change due to drying and wetting cycles (Shahsavani et al. 2020). When lightweight and earthen structures such as single storey buildings, tunnels, buried pipelines, roads, embankments, etc., are built on/in these soils, they might experience non-uniform or differential settlements, eventually undergoing failure (Chen 1975; Uzundurukan et al. 2014; Sharma and Sivapullaiah 2016). Expansive soils are spread almost all over the world. It has been reported that the cost incurred for the damage caused by expansive soils exceeds that of natural hazards, oods, and re accidents (Shi et al. 2002; Zemenu et al. 2009). This inevitably elevates the necessity to enhance the knowledge on expansive soils to understand the different factors responsible for this behaviour both at micro-and macro-levels. Swelling behaviour is the major problem associated with the expansive soils upon hydration, which can be identi ed easily by the free swell index (FSI) test (Shi et al. 2002; Yao et al. 2005; Cheng et al. 2018; (RS, 2023)

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CHAPTER THREE
3.0 RESEARCH METHODOLOGY

3.1 Overview

The methodology uses descriptive qualitative study designed to assess the effect of black cotton soil on structures. This aim to understand the consequences of black cotton soil on structural integrity, foundation stability, buildings, roads, retaining structures, local huts and overall structures performance.

Fig 1.2 Black cotton soil nature

3.2 Research Design

This research adopts a descriptive qualitative design, with use of interviews and administrating questionnaires as the main tool for the collection of research data that can be qualified and analysed by quick impressionist summary. The choice of this design is entrenched in the need to obtain investigational evidence from the target population regarding the effects of black cotton soil on buildings and construction practices adopted in areas of this type of soil. Co-operating with all respondence in diverges sites.

3.3 Sampling Method

Sampling technique used to draw from twenty-four participants to ensure representation from different locations, occupations and knowledges. The population was divided based on occupation as four builders, eight technicians and twelve practising Civil Engineers to mitigate bias and achieve a comprehensive understanding of the subject. The structured questionnaire, which were developed to gather qualitative insights, focused on participants' knowledge and awareness, impact on buildings and mitigation strategies of black cotton soil properties, their past experiences with affected buildings (including observed structural damage and overall impact), the specific effects on the environment and structures, and current mitigation strategies, particularly foundation techniques used in this area of black cotton soil.

Interviews were conducted in person at construction sites and relevant institutions, with notes taken and recordings made with interviewee consent. A robust follow-up procedure was implemented to encourage participation and achieve a target sample size of 19-24 respondents, aligning with the Taro Yamane formula for sample size estimation.

CHAPTER FOUR
4.0 RESULTS AND DISCUSSION

4.1 Overview

Data collected from the interview questionnaires were analysed using statistical software, Spreadsheet and SPSS. In essence, data analysis provides the evidence, of research topic and problems.

Data analysis involves systematically applying procedures to sightsee and understand data, based on research objectives, revealing patterns, relationships, and insights. Discussion then builds upon this analysis, providing context, implications, and recommendations based on the findings.

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4.2 Results

To summarize demographic data and responses regarding knowledge and awareness with black cotton soil. The respondence base on analysis on their profound knowledge of black cotton soil is as;

Very knowledgeable	91%
Not very knowledgeable	9%

Tab 4. 1

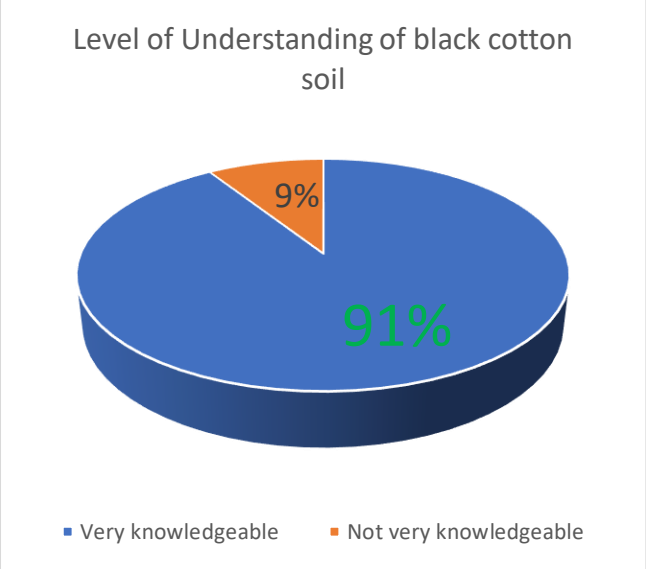

Fig 4.1

Respondent interviews are generally aware of black cotton and its problematic nature and have developed various methods for mitigating its negative effects, especially those involved in construction and agriculture. The soil's high clay content and tendency to swell and shrink with changing moisture levels cause significant issues.

The percentage of buildings affected in Bor Town with inherent properties of black cotton soil is high, posing significant challenges to construction and can lead to foundation problems and structural damage if not addressed appropriately.

Assessing the degree of impact of black cotton soil on buildings and environment in the city according to interview with professionals and resident in the area gave us the following records with high rate of impacts.

Tab 4.2

Very positive	77%
Somewhat positive	23%

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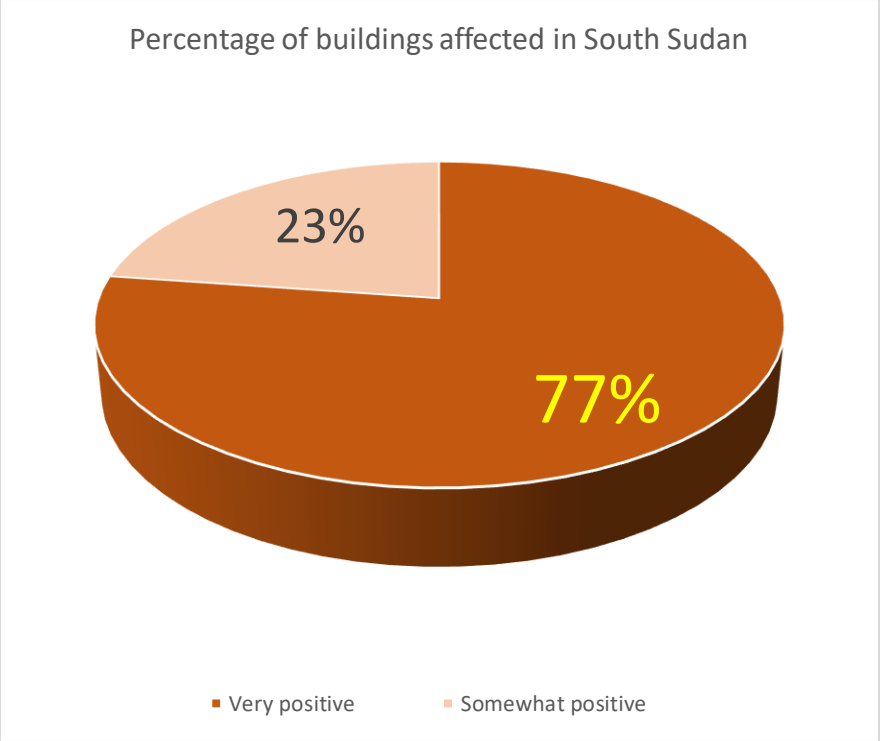

Fig 4.2

Inferential statistics is used to draw conclusions on analysed data collected in surveys. Making comparisons and predictions of foundation techniques used to mitigating the effects of black cotton soil. A Foundation is the most crucial component of any structure as it ensures the ground stability and transfers the building's load to the ground. There are various foundation types each serving a specific purpose. Understanding the alternative type of foundation for your project on black cotton soil that prevent settlement problems, and structural failure.
Factors like soil conditions, load requirements, and environmental challenges influence the selection of foundation type. With an understanding of different types of foundations & project requirements engineers can make informed decisions to ensure structural stability. They foundations practices from the occupations were quantify as below;

Tab 4.3

Strip Foundation	64%
Raft / Mat foundation	23%
Pile & Deep Foundation	14%

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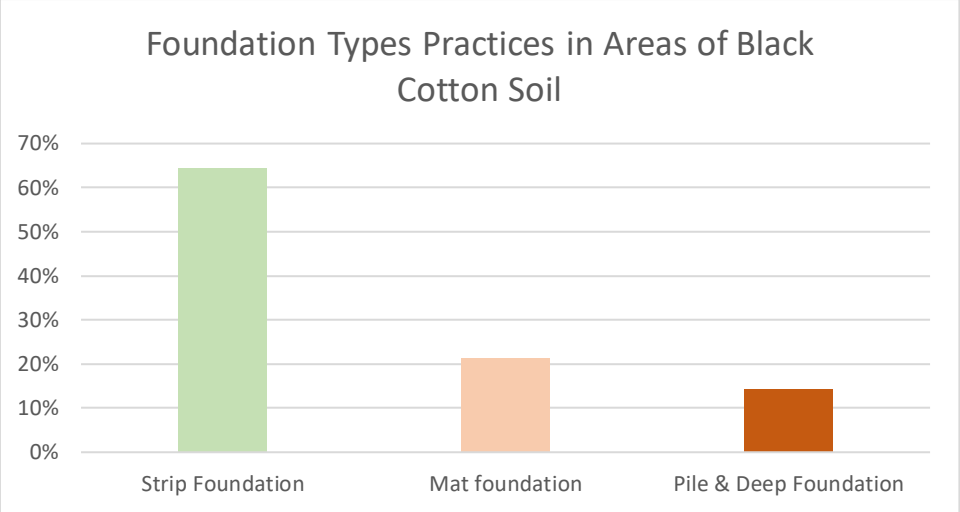

Fig 4.3

The data analysis has shown that, effect of black cotton soil in studied area is really negative. There is lack of professional personnel, most of technicians and builders claim to be engineers and lack tactical engineering judgement of critical conditions of construction sites. The failure buildings in areas are result of lack of professional engineers and compromising the foundation for the interest of cost.
Construction on black cotton soil, required several tips can help mitigate the risks associated with its expansive nature. These include using lime or cement stabilization, replacing black cotton soil with suitable alternatives, and implementing measures to prevent water from reaching the soil foundation. Proper foundation design for selected type of foundation is crucial for successful construction on black cotton soil. Be mindful of the effects of dry and wet seasons on black cotton soil during design and construction is of great success.

4.3. Summary of The Main Findings
The findings from this research will provide valued insights into the challenges posed by black cotton soil and floodings on buildings, as well as effective practices for mitigating these impacts. The outcomes will subsidize to improved construction practices and inform stakeholders about possible risks related with black cotton soil.

- Strip foundations with stabilization of BC soil by replacement the top soil and blending with stabilizers such as sand and marram on foundation depth below the active zone of swelling and shrinking, to prevent damage.
- Ground improvement by backfilling and paving the site around buildings with marram, sand mix compacted in layers enhance the runoff.
- Building houses with Expanded Polystyrene (EPS) core Panel system in areas of BC soil. EPS is new technology recommended with its strength and durability - used extruded polystyrene virtually inert and does not absorb moisture, is durable and resistant to decay.
- Local house hut common materials used for huts in Bor particularly Jonglei state might comprise of, reeds, Tek, and Leng (Dink Language) as poles for structural elements poles and roofs. Foundation with burnt bricks good at drainage and powder acts as a stabilizer
- Some of factors are inadequate design or construction, unanticipated loads, deterioration of materials, compressibility of the supporting soils, landscaping practices, leaking plumbing, and slope instability, but most thought-provoking in the area is effect of black cotton soil.

4.4 Conclusions
Both strip foundations and mat foundations can be adapted to various buildings sizes and layouts, when properly designed and constructed, strip and mat foundations can provide the necessary structural integrity to withstand the challenges posed by black cotton soil. These foundation types (Strip foundation and Mat foundation) reduce the pressure exerted on the soil, by spreading the load minimizing the soil's tendency to swell or shrink under the foundation.

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Ground improvement techniques for black cotton soil helps to improve its engineering properties like strength, plasticity reduces swelling and shrinkage, improving overall durability. By mixing it with various additives to increase its strength and reduce its swelling potential, improving soil stabilization, moisture control, and strategic foundation design

A Damp Proofing Membrane (DPM) need to be applied under the foundation to acts as a barrier, avoiding upward movement of dampness from reaching the building's foundation and walls, which can lead to various problems like wall damage, damage to plaster and paint, and corrosion of steel.

RECOMMENDATIONS

Implementing the design of floating foundation by using expanded polystyrene (EPS) in construction on black cotton soil is its unique lightweight and compressible properties, which directly counteract the soil's destructive shrink-swell cycle. Rather than resisting the soil's movement, EPS provides a buffer that accommodates volume changes, significantly reducing stress on the foundation.

Adopting Strip foundation for low-rise buildings and Mat for midrise buildings while applying waterproof paint in substructure to prevent effect of moisture and ground improvement.

Excavation and Earthwork

Excavation depth should be carried out below the active zone, usually1.5 to 2.0 meters below the natural ground surface and the excavated soil should be properly managed to prevent moisture damage and carried away to avoid others issues. Backfilling with stable materials like gravel, redbrick dust and hardcore is recommended to avoid further issues with the foundation. Excavation before the rainy season, as the zone beneath the foundation may be affected by the soil's expansion/shrinkage and considering using moisture barriers and protective layers like gravel or sand to prevent direct contact between the soil and foundation walls during rainy seasons.

Deep Foundations: Deep foundation system, such as pier and grade beam support. The basic principle is to construct the piers such that they are below the depth of seasonal moisture change. The piers can be belled at the bottom in order to increase their uplift resistance. Grade beams and structural floor systems, that are free of the ground, are supported by the piers.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 10, October - 2025

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